Data Systems Relevant to JCOMM Activities

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Notification

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Part 1: Work Description

Introduction

The number of programmes making in-situ surface meteorological or oceanographic measurements are many. So many, that it can be hard to know where to look to obtain the data that they collect. Data are collected by large, international programmes and others arise from small, research driven endeavours. International programmes often have a coordination body to knit together the data collection efforts. Then there may be other groups who deal in assembling, processing, archiving and dissemination of the data collected. Someone interested in using the data should be able to find out information such as who collected the data, what procedures were used, what processing is done on the data and finally who to contact to get copies. Because of the many contributors involved, this is not an easy process.

What is more, data collection activities are often oriented around a suite of instruments. Different groups produce measurements of the same variable, such as sea surface temperature, but from different instruments with different operating characteristics. These data are often assembled, processed and archived in different places. If someone is interested is acquiring all of the sea surface temperature measurements, there are many programmes that need to be consulted. This is mitigated by activities undertaken such as in support of ICOADS or WOD which consolidate the variety of observations into single data sets.

Because of the myriad programmes collecting, assembling, processing archiving and disseminating measurements of in-situ variables, just knowing who to talk to can be a challenging or a frustrating experience. The GOOS Steering Committee in 2012 [1] identified in its work plan “the challenge of data interoperability…as a first step towards developing actions.” National and International data systems that support the work of JCOMM are not formally under JCOMM control. Rather JCOMM acts as a coordinating body. JCOMM agreed to commission a report that would describe access routes to in-situ data collections under ts purview. JCOMM-4 [2] asked the OPA, in cooperation with the DMPA, to "promote the establishment and publication of access routes to the authoritative data sets for the observing system elements under its coordination."

JCOMM and GOOS and their partners in sustained observation of the ocean seek a data system that will have:

1. well-defined tools for real-time data collection, calibration and transmission protocols and tools for monitoring network health, and
2. clearly defined and working data flow arrangements, with
    - defined responsibilities for managing real-time streams, quality control, metadata collection and flow to oceanographic services,
    - defined responsibilities for data (both in real-time and delayed mode) flow to climate quality archives,
    - defined responsibilities for making data discoverable and available in an interoperable way across observing networks.

Data collected through remote sensing systems (satellites, shore or ship radars, aircraft) are not within the scope of this report. At times, reference will be made to them, but that is all.

Report Preparation

The prime focus of this report is real-time data systems coordinated by the OPA of JCOMM and related programmes. However, since both real-time and delayed mode data contribute to climate archives, some consideration must be paid to contributions from other internationally governed as well as disparate ocean data collection programmes.

The JCOMM OPA [3] coordinates in-situ ocean observing networks from DBCP (surface drifters, tropical moorings, OceanSITES), SOT (volunteer ship observations, ships of opportunity and underway surface measurements), GLOSS (tide gauges); and cooperates with Argo (profiling floats), IOCCP (ocean carbon observations), and GO-SHIP (repeated hydrographic sections). Many of these data are contributed through real-time ocean data systems (those reporting in time frames of hours to days).

In addition, there are other collectors of in-situ data, such as researchers executing their own programmes, commercial operators of ships, etc. who contribute other kinds of data than those represented above (such as ADCP). Some are contributed in real-time and others in delayed mode. These data may appear in the data systems coordinated by IODE, a programme of IOC which is a co-sponsor of JCOMM.

The real-time data are used in service-oriented programmes, such as public weather services, assistance to maritime safety, search and rescue, and marine pollution response, recreational activities, disaster risk reduction (Tsunami, Tropical Cyclones, Storm Surge …), etc. These activities require the use of models of ocean and atmosphere processes, calibration/validation with satellite data, NWP, and other uses. Other scientists use both real-time and delayed mode data in their research. Beyond these communities, there are others, such as in the engineering industry, shipping, fisheries, insurance companies, and graduates and undergraduates at academic institutions who have uses for ocean data, but are either not aware of the data collected, or unable to access the data in convenient ways. All of these groups have different requirements for data quality, timeliness, delivery mechanisms, and perhaps others.

Sources and Definitions

The author of the report took the perspective of a potential data user in looking at on-line information for the observing systems noted above. When questions arose, he contacted some knowledgable individuals for further information. References and links are provided so that a reader can follow up if more details are wanted. Based on what was found, recommendations of actions to improve operations are made.

At OceanObs'09 [4] there were four keynote addresses on data management, and these have been used to develop a list of attributes against which data management practices of JCOMM observing systems are weighed. There was also much useful information reported there on observing systems. But because 5 years have passed since those documents were written, this report has not relied on the information contained in them.

The terms “real-time” and “delayed mode” are used in this report. In the meteorological domain, real-time means that data must reach a processing centre in time to be assimilated into the next weather forecast. Typically, this is a matter of minutes to hours from data collection. Real-time meteorological data are typically collected at what are termed synoptic hours, 0000, 0600, 1200 and 1800. Any data that arrive after this time are considered delayed mode. Thus, delayed mode data can arrive only a few hours, up to years after data collection.

In oceanography, real-time data are considered to be those that arrive in time for international distribution within 30 days of observation time. The difference compared to meteorology is due to the slower time scales of variability of equivalent “weather” in the ocean. As for meteorology, any data arriving after real-time is considered delayed mode and can be delayed up to years

Report Organization and Review

This report examines the data systems for each of the above mentioned Observing Systems of JCOMM. Part 2 of the report has a chapter about each. As an add on, it was requested that information be organized around an EOV perspective. Part 3 contains chapters on each.

Each of the chapters in Parts 2 and 3 conclude with a number of recommendations relevant to the chapter. The reader will be struck by many commonalities in recommendations across the chapters. In Part 4, these common recommendations are broadened from the specifics of the individual chapters and presented as overall recommendations.

Readers of more than one chapter of this report will be struck by a certain amount of repetition of content. This is particularly so in chapters of Part 3. This was done so that readers could pick up individual chapters to read and all relevant material is presented there.

The draft version of this report was delivered at the end of September, 2013. A review process was organized by the JCOMM Observations Programme Area Coordinator with responses from interested parties delivered in April, 2014. These responses were taken under review and changes made as deemed appropriate by the author. Because of the elapsed time between the submission of the draft report in 2013, and the responses, there have been changes in some of the web sites that cause some of the statements in the draft to be out-of-date. Such changes may be briefly noted in the final version.

Acronyms

ADCP: Acoustic Doppler Current Profiler
DBCP: Data Buoy Cooperation Panel
DMPA: Data Management Programme Area
GLOSS: Global Sea Level Observing System
GOOS: Global Ocean Observing System
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
ICOADS: International Comprehensive Ocean-Atmosphere Data Set
IOC: Intergovernmental Oceanographic Commission
IOCCP: International Ocean Carbon Coordination Project
IODE: International Data and information Exchange Committee
JCOMM: Joint Commission on Oceanography and Marine Meteorology
NWP: Numerical Weather Prediction
OPA: Observations Programme Area
SOT: Ship Observations Team
WOD: World Ocean Database

References

1. GOOS 2012 report (see Annex 1): http://hab.ioc-unesco.org/index.php?option=com_oe&task=viewDocumentRecord&docID=9957
2. JCOMM-4 Report: http://www.jcomm.info/index.php?option=com_oe&task=viewDocumentRecord&docID=9774
3. OPA Panels: http://www.jcomm.info/index.php?option=com_content&view=article&id=21&Itemid=38
4. OceanObs'09: http://www.oceanobs09.net/

Part 2: An Analysis by Observing System

Introduction

At OceanObs'09 [1] there were four keynote presentations on data management [2,3,4,5]. In these are found statements about the desirable attributes of a well constructed data system. In order to have a consistent treatment of each data system directly or associated with the JCOMM Observations Programme Area, a list of attributes was extracted from these presentations (see annex). Then, the availability of information about each of these attributes was investigated.

The data systems examined in this part of the report are those associated with the following observing systems:

SOT: Volunteer Observing Ships (VOS)
Ship of Opportunity Programme (SOOP)
Surface underway data
DBCP: drifting buoys
moored tropical and high seas buoys
OceanSITES
GLOSS
Argo
GO-SHIP
IOCCP

Content Organization

Each chapter in this part of the report begins with four sections dealing with data collection, data assembly, processing and archiving, and dissemination. For each of these, the attributes extracted from the OceanObs'09 data management presentations have been used as a guide. Although data dissemination received the attention of the GOOS Steering Committee, all of the other activities of bringing the data together and processing them have impacts on usability of the data.

While the operations of Member/Member States that support JCOMM are the main focus of this report, it is important to recognize that there are other activities in data collection, assembly, processing and archiving, and dissemination. In some instances, JCOMM related operations dominate, such as is the case for surface meteorological data. In the ocean domain, there are many contributors, and data systems which are not strictly tied to one observing system. A good example of this is the GTSPP. Its objectives are to consolidate all temperature and salinity profile data. As such it handles data from SOOP, from Argo, from GO-SHIP and data collected through programs at best loosely affiliated with JCOMM, such as profiles collected from instrumentation attached to marine mammals. Other projects, such as ICOADS, that consolidate data across more than one JCOMM observing system will be treated in a similar way as the GTSPP.

Within the oceanographic domain, the IODE coordinates the operation of more than 80 NODCs and ADUs around the world. Each of these operates archive services for ocean data of importance to their countries. As well, some of these operate regional or global archives. In the discussions on archiving and dissemination, references are made to only the NODCs that provide global services. But those wishing to find all data of a particular type may need to look to their national data centres as well.

In the section on data dissemination, a number of sources of the data are often identified. Besides the facilities available from the individual data systems, the WMO and IODE both are building information systems with components for data distribution. In IODE it is the ODP and for WMO it is the WIS. Some of the data from observing systems are available through either or both of these. At present, the diversity of marine meteorological and oceanographic observing system data from ODP and WIS is low, but this will increase as these systems are implemented.

A following section provides a concise summary of the important differences between the data to be found at the various sources. This cannot substitute for a more in depth examination by a potential user, but it is expected that this summary will be useful in deciding where to start.

There is a small section on user communities. This is not exhaustive, but it does give some indications of who are the routine, or not so routine users.

The next section deals with monitoring and performance metrics for the data system. For the purposes of this report, monitoring products are considered to be those whose primary use is internal to the observing programme under consideration to ensure that it is meeting its objectives and to allow for corrective action to be taken when needed. The different observing systems have a need for greater detail to monitor their performance so that corrective actions can be taken. For example, SOOP has targets for sampling along lines. These lines and sampling schemes are a tradeoff between available ships, available finances for XBT probes and science requirements. Monitoring of how well these lines are sampled is crucial to the programme.

There are many such monitoring products that are generated by individual observing systems and at JCOMMOPS. All of these are important, and what these are and how often they are reported should be a decision taken by each system.

This report provides links to some of the monitoring products that are available so that readers may look at them in greater detail as they may wish. The report will also discuss the metrics generated by each observing system that show how well the higher objectives are being met.

Performance metrics are those products primarily targeted at those outside the programme that demonstrate how well the broader objectives, as articulated by programmes such as GCOS or scientific panels of GOOS, are being met. It is expected that potential users can use this as a quick way to see what is collected and available, as well as to get further details, through the provided links, on how the data system assesses its own performance.

The GCOS-IP [6] has stated goals for the various observing systems. These are not all easily quantifiable since some refer to statements such as “all data to be archived”. Never-the-less, metrics need to be developed that address these objectives in a way that allows year to year (or whatever is the appropriate frequency) comparisons to be made to judge if observing systems are moving towards or receding from these goals. There is a section that provides a qualitative assessment of how well these goals are being met.

The chapter finishes with a set of recommendations, linked to text in the chapter, on what can be done to improve operations.

Acronyms

ADU: IODE Associate Data Unit
DBCP: Data Buoy Cooperation Panel
GCOS: Global Climate Observing System
GLOSS: Global Sea Level Observing System
GOOS: Global Ocean Observing System
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
GTSPP: Global Temperature Salinity Profile Project
ICOADS: International Comprehensive Ocean and Atmosphere Data Set
IOCCP: International Ocean Carbon Coordination Project
IODE: International Data and information Exchange Committee
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: JCOMM Observing Platform Support center
NODC: National Oceanographic Data Centre (of IODE)
ODP: Ocean Data Portal
SOOP: Ship Of Opportunity Programme
SOT: Ship Observations Team
VOS: Volunteer Observing Ship
WIS: WMO Information System
WMO: World Meteorological Organization
XBT: Expendable Bathythermograph

References

1. OceanObs'09: http://www.oceanobs09.net/
2. Pouliquen, S. & Co-authors (2011), "Argo Data Management", in Proceedings of the "OceanObs'09: Sustained Ocean Observations and Information for Society" Conference (Vol. 2), Venice, Italy, 21-25 September 2009, Hall, J, Harrison D.E. and Stammer, D., Eds., ESA Publication WPP-306.
3. Keeley R. & Co-Authors (2011). "Data Management System for Surface Drifters, , *in Proceedings of the "OceanObs'09: Sustained Ocean Observations and Information for Society" Conference (Vol. 2),* Venice, Italy, 21-25 September 2009, Hall, J., Harrison D.E. & Stammer, D., Eds., ESA Publication WPP-306.
4. Blower J. & Co-Authors (2011). "Ocean Data Dissemination: New Challenges for Data Integration", *in Proceedings of the "OceanObs'09: Sustained Ocean Observations and Information for Society" Conference (Vol. 1),* Venice, Italy, 21- 25 September 2009, Hall, J., Harrison D.E. & Stammer, D., Eds., ESA Publication WPP-306.
5. Hankin S. & Co-Authors (2011). "NetCDF-CF- OPeNDAP: Standards for Ocean Data Interoperability and Object Lessons for Community Data Standards Processes", *in Proceedings of the "OceanObs'09: Sustained Ocean Observations and Information for Society" Conference (Vol. 2)*, Venice, Italy, 21- 25 September 2009, Hall, J., Harrison D.E. &Stammer, D., Eds., ESA Publication WPP-306.
6. GCOS-IP (2010 update): http://www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf

Annex A: Data System Attributes

Each data system was evaluated in four categories with the attributes listed below. "Primary" information is that which is considered to be essential to know. "Secondary" is additional, desirable information to be reported as possible.

Collectors / Providers

Primary:

1. Who are they, where are they located, what programme are they operating under?
2. Is there a URL that describes the programme?
3. What variables do they collect and with what instruments?
4. What metadata is provided (minimum metadata: provenance, units, format, instrument information, sampling method, locations and times of samples)?
5. What processing on the data takes place before they are passed to an assembly centre?

Secondary:

6. How often are instruments calibrated?
7. Is information of precision and accuracy included in data files, in separate files, or inferred by knowing the instrument used?
8. Are other metadata about instrument characteristics, sampling, etc., included (manually, sensorML, some other method)?
9. Are the processes standard, commonly used or unique and is documentation describing these easily available?

Assembly

Primary:

1. Who does the assembly, where are they located, what is their affiliation? Do they have the staff for the job? How are they funded and is it secure?
2. Is there a URL that describes the assembly centre?
3. Does all of the metadata come embedded with the data, in separate files or is it missing (minimum metadata: provenance, when arrived, data types, units, format, instrument information, sampling method, locations and times of samples)?
4. Do they handle real-time data?
    - Who do the data come from and how do the data reach them?
    - What are the incoming data formats used? Is there documentation available?
    - Are copies of the incoming submissions saved?
5. Do they handle delayed mode data?
    - Who do the data come from and how do the data reach them?

- What are the incoming data formats used? Is there documentation available?
- Are copies of the incoming submissions saved?

6. What is the information feedback to providers?
7. Is the assembly centre closely linked to the collection programme(s)?

Secondary:

8. Do they handle real-time data?
    - Are the incoming formats the same from all providers?
    - Are the incoming formats standards, commonly used or unique?
9. Do they handle delayed mode data?
    - Are the incoming formats the same from all providers?
    - Are the incoming formats standards, commonly used or unique?
10. Is there a well used or common vocabulary for data and metadata description? If taxonomic, is WoRMS or other used?
11. Is there a data rescue component? Should there be?
12. Can in the incoming data be linked to a publication in any way?

<u>Processing and Archiving</u>

Primary:

1. Who does the processing, where are they located, what is their affiliation? Do they have the staff for the job? How are they funded and is it secure
2. Is there a URL that describes the processing centre?
3. Do they handle real-time data?
    - What are the processing steps (translation, unit conversions, QC, duplicates checks)?
    - Are there any limitations in the translation that degrades the resolution, precision, information content of the original data? Are some metadata lost in translation?
    - What happens at each step? Is this recorded and documented (e.g. QC performed, resulting assessment) with the data, separate from the data, or not at all?
    - During QC are original values preserved?
    - Is there any information feedback to providers?
    - What monitoring information is provided (data throughput, processing results, time to process, ...)? Are these easily available?
    - Do the data end up represented in JCOMM monitoring products (such as at OSMC or JCOMMOPS)?
    - Do the data from the same variables coming from different sources undergo uniform QC procedures?
4. Do they handle delayed mode data?
    - What are the processing steps (translation, unit conversions, QC, duplicates checks)?
    - Are there any limitations in the translation that degrades the resolution, precision, information content of the original data? Are some metadata lost in translation?
    - What happens at each step? Is this recorded and documented with the data, separate from the data, or not at all?
    - During QC are original values preserved?
    - Is there any information feedback to providers?
    - What monitoring information is provided (data throughput, processing results, time to process, ...)? Are these easily available?
5. Do the data end up in secure, long term archives (WDS, WOD)? Is there a disaster recovery plan in the long term archive? Is there a refresh cycle for media?
6. Are there products targeted at data providers / collection operators? How available are they?
7. Are there products targeted at data system managers? How available are they?

Secondary:

8. Do they handle real-time data?
    - Is the mapping from incoming to processing data structures recorded and documented for each data set?
    - Is the output data format robust to many types of data?
    - Are standards, common practices, unique procedures used?

- Is documentation available for each process?
- Are unique data identifiers used?

9. Do they handle delayed mode data?
   - Is the mapping from incoming to processing data structures recorded and documented for each data set?
   - Is the output data format robust to many types of data?
   - Is calibration, precision, accuracy, information on error estimates preserved?
   - Are standards, common practices, unique procedures used?
   - Is documentation available for each process?
   - Are unique data identifiers used?
   - Are delayed mode matched to real-time?
10. Is the archive strategy based on sampling geometry or some other organization?
11. What is the archiving technology used? Do all data of the same variable (different instruments, sources) end up together or at least in a common data structure?
12. Is there a way for the processing/archive centre to determine that the work they do is valued?
13. Is there version control on data, on processing steps? Is this well documented?

<u>Data Distribution</u>

Primary:

1. Who does the distribution, where are they located, what is their affiliation? How are they funded and is it secure?
2. Is there a URL that describes the distributing centre(s)?
3. Is there a clearly stated data sharing policy?
4. What products are offered?
5. Are there simple products available by ftp or as sophisticated as web services? (FTP, Twitter, RSS, OPeNDAP, DIGIR, WIS, ODP, GEOSS, WCS, WFS, WMS,...)
6. Are all variables received made available for distribution?
7. What data discovery (THREDDS, other), exploration, ordering services are available? Are they easy to use and understand? Is a geographic interface for displaying location used (such as Google Earth)?
8. What is the data sharing policy? Is there a fee attached to accessing the data?
9. What are the distribution formats for the data? Is documentation available?
10. What monitoring information is provided (data availability, use, ...)?
11. Do data of the same variable arrive in the same format? Do data from different variables arrive in the same format?
12. Is there an obvious way for users to provide feedback? Are there procedures to use this feedback?
13. How well does the data or product service work?

Secondary:

14. Are the products OGC compliant?
15. Is there documentation available to describe how products are made? Is this easily found and available?
16. Are the distribution formats for the data standard (CF or other), commonly used (ODV) or unique ones? Is documentation available?
17. Are the data easily merged with satellite records?
18. If the format is XML is it in a widely used or unique schema?
19. If distribution/access is distributed is a single logon needed or more than one?

2.1 Ship Observations Team (SOT)

Programme Objective

The SOT [1] is a Panel of the Observations Programme Area, OPA, of JCOMM. It consists of individual ship-based observing programmes that support research, climate forecasting, numerical weather prediction and maritime safety services amongst other applications. Variables measured include surface marine meteorological observations, plus sub-sets for upper air meteorological and underway surface and upper ocean physical ocean profile data. The sampling rationale for these variables has been set via the various scientific advisory groups and climate related panels with advice from operational services and users. Membership in SOT is open to any nation which operates ships or is interested in surface marine meteorological and oceanographic measurements.

Overview

There are three sub groups to the Panel, the Ship Of Opportunity Programme, SOOP [2], the Volunteer Observing Ship scheme, VOS, [3], and the Automated Shipboard Aerological Programme (ASAP). The ASAP programme will not be treated here because this report is focused on surface marine meteorological and ocean observations.

The SOOP web site describes the primary goal of the Implementation Panel (SOOPIP) as " to fulfill upper ocean data requirements which have been established by GOOS and GCOS, and which can be met at present by measurements from ships of opportunity. The SOOP is directed primarily towards the continued operational maintenance and co-ordination of the XBT ship of opportunity network but other types of measurements are being made (e.g. TSG, XCTD, CTD, ADCP, pCO_2, phytoplankton concentration)". Underway measurements fall under SOOPIP.

VOS describes itself as "... an international program comprising member countries of the World Meteorological Organization, WMO, that recruit ships to take, record and transmit weather observations whilst at sea.".

There are three chapters devoted to SOT activities. One describes VOS, one describes the subsurface portion of SOOP, the XBT, XCTD programme, and a third chapter describes surface underway data collected using TSGs and similar pumped sea water systems.

Acronyms

ADCP: Acoustic Doppler Current Profiler
CTD: Conductivity, Temperature, Depth instrument
GCOS: Global Climate Observing System
GCOS-IP: Global Climate Observing System – Implementation Plan
GOOS: Global Ocean Observing System
JCOMM: Joint Commission on Oceanography and Marine Meteorology
OPA: Observations Programme Area
pCO_2: partial pressure of CO_2
SOOP: Ship Of Opportunity Programme
SOOPIP: Ship Of Opportunity Programme Implementation Panel
SOT: Ship Observations Team
TSG: Thermosalinograph
VOS: Volunteer Observing Ship
WMO: World Meteorological Organization
XBT: Expendable Bathythermograph
XCTD: Expendable Conductivity, Temperature, Depth instrument

References

1. Ship Observations Team: http://www.jcommops.org/sot/

2. Ship Of Opportunity Programme: http://www.jcommops.org/sot/soop/
3. VOS home: http://www.bom.gov.au/jcomm/vos/

2.1a: SOT - SOOP XBT and XCTD

Introduction

Since its inception, even before JCOMM, the SOOPIP has focused on a global network of sampling the upper ocean from ships. At first, it used XBTs almost exclusively to measure water temperature profiles. As XCTDs were developed, these instruments were included although they are not a large part of the SOOP operations. Also, although the SOOP web site mentions the use of ADCPs as within their purview, these instruments and the data they collect are largely absent from meeting discussions (Rec 1).

The SOOPIP implements a set of standard transects mostly sampled using commercial vessels, and sometimes by research or military vessels.. After a review of operations and in conjunction with OceanObs'99 [1] and the advent of profiling floats, the low density component of the sampling network was abandoned to focus on frequently repeated and high density sampling. This continues to the present.

The focus of this chapter is on the data that are collected through the SOOP XBT/XCTD [2] operations. Members of the SOOP are provided at [3]. There are other programmes that provide data similar to that delivered by XBTs and XCTDs. Some of these other programmes are not well coordinated internationally, but some are important sources of data and so will be mentioned in passing. Greater detail will be provided in the sections that treat individual ECVs.

Data Providers

The workhorse instrument used in the SOOP is the XBT. It is manufactured by Sippican [4] and licensed for manufacture by TSK [5] in Asia. XBTs use a thermistor which is capable of accuracies of ±0.1℃ [6] or ±0.2℃ [7]. It computes depth by measuring the time of fall and a formula that converts time to depth. TSK also manufactures the XCTD probe [7] with a temperature accuracy of ±0.02℃ and conductivity with an accuracy of ±0.03mS/cm. The Australian IMOS provides documentation on instruments used [8] on their vessels.

Several experiments have been conducted since 1995 using inter-comparisons of XBT and CTD coincident profiles in order to assess the manufacturer's accuracy of depth and temperature. and differences on the order of 3% have been found. More recently, there are studies reporting a variation in differences based on when the XBT profiles have been collected. Readers are referred to a report from a Workshop held in 2010 [9].

XBT data are principally deployed from commercial vessels carrying goods across the world's oceans. The vessels are recruited to the program by national agencies participating in the SOOP and they are provided with XBT probes, launchers, and computer hardware and software to acquire, record, and transmit the observations . Very often the recruiters train the crews in the operation of taking XBT measurements. Ship's communications capabilities are used to move the data ashore in real-time (within 30 days of data collection and often within 24 hours). In the past, voice communication was used, but the most common route today is through satellite links such as Inmarsat [10], Argos [11] or Iridium [12]. Costs for SOOP operations are borne by the country operating the SOOP line.

In addition to commercial vessels, a significant fraction of XBTs is deployed from oceanographic research vessels [e.g. 13,14, 5]. These typically take responsibility for operating specific transects and usually place ship riders on board to do the XBT deployment. In doing so, the reliability of the data is improved, since the ship rider can take corrective actions immediately when needed. On commercial vessels, such quick action is not guaranteed. In addition, some ship riders perform routine calibration using high precision resistors (a test canister) to identify and correct problems anywhere from the Sippican MK21 data recorder to the autolauncher.

The number of XCTDs deployed is small, mostly because their cost is significantly greater than for an XBT. In 2012, for example, 290 XCTD profiles were collected and received from the GTS, compared to 18,600 profiles from XBTs [16].

Other types of profiles may be collected by ships performing SOOP activities. Generally these are not reported in real-time since formats (see later section) only permit water current profiles to be reported in addition to temperature and salinity. These additional types of profiles are collected by research vessels and may include dissolved oxygen, fluorescence, nutrients and others. These data are normally provided to archives through a delayed mode data stream. SOOP does not direct or coordinate what additional profile types are collected on research vessels. Rather, the research cruises contribute voluntarily to SOOP and the data are sent to national or international data centres.

Apart from SOOP, ocean profile data are also collected from moorings where there can be a suite of sensors suspended below a surface mooring such as those maintained by TIP [17]. The moorings of OceanSITES [18] also measure ocean profiles. These programmes are documented in other chapters of this report. As well, the Argo (see the Argo chapter in this report) collect profiles of temperature and salinity.

Although not formally part of SOOP, XBTs and SSXBTs (http://www.sippican.com/stuff/contentmgr/files/a704392149ca51dbe166f1b20bbf91c0/sheet/ssxbt92005.pdf) are also collected by national navies and by fisheries research vessels, operated by national agencies. In the case of naval operations, the release of the data is highly dependent on national rules with some navies being very open in contributing data immediately, and others being less open. Receipt of data from fisheries vessels is highly dependent on whether there are provisions in place in a country to acquire the data from the vessels and send the data in either real-time or delayed mode. Still many repeated XBT transects continue to be maintained by research and navy vessels providing critical data for analysis.

Other sources of ocean profile data include those collected from CTD sensors placed on marine mammals [19], on gliders [20], from cabled ocean observatories [21] and by hydrographic agencies e.g. [22,23]. None of these programmes are formally part of JCOMM, much less coordinated by SOT or SOOP. They are often run by research agencies and often are continually developing the technology (instrumentation, data processing and dissemination) to support their work. Some of the profiles collected by these programmes may enter the data systems, depending on how well these programmes are connected to the international data collection efforts or to national agencies that contribute to JCOMM. For example, most of the data from marine mammals are processed by SMRU, then forwarded to BODC for reformatting and through the UKMO for insertion onto the GTS.

For all of these programmes, there is some initial processing of the data and usually some data quality checking. Normally, this is performed by the data recording software running on board the collecting vessel. In some cases, there is checking done on the data with the initial processing before sending data to the GTS. Each data collection group carries out its own procedures.

The countries contributing the largest fractions of XBT data are Australia, France, Brazil, South Africa, and the United States.

Several types of acquisition systems that also conduct preliminary quality control tests are used on board ships before the data is transmitted. For example, Australia uses the Devil and Quoll data recorder [24] which conducts automated quality control on board before generating the BATHY message (see below). This includes spikes/gradient checks, climatology tests, constant profile tests, unreasonable inversions (as does occur in the southern ocean), and some others.

France uses Inmarsat to send emails from its research and naval vessels to a dedicated email box to receive data. The data undergo automatic quality control procedures and then are inserted on the GTS through Meteo France. Data collected by the vessel l'Astrolabe is managed and quality controlled by Australia. The vessel operates from Australia to Antarctica, uses the Australian Devil data recorders [24] and these are then sent directly to the GTS (see below). Data from French merchant vessels and related projects are transmitted to Argos [11] and inserted on the GTS by them.

XBT data is collected by AOML in high density mode along several transects in the Atlantic Ocean. The data are recorded and transmitted using Sippican MK21 recorders, Iridium and Inmarsat systems, as well as an automatic launcher that allows for the deployment of 6 to 8 probes of different types (Deep Blue, Fast Deep, etc). All these instruments are controlled and operated by the AMVERSEAS software. Most of the data collected by AOML is received onshore and submitted to the GTS and NODC in real-time. XBT data is also submitted to NODC in delayed-mode.

The AOML developed and maintains the AMVER/SEAS [25] software, which is also used for the acquisition and transmission of marine meteorological observations, for the US Coast Guard for search and rescue purposes, and for the Mandatory Ship Reporting of right whales in the US eastern coastal states. In addition, SIO uses a modified version of AMVER/SEAS2K [see poster at 13] which incorporates SIO's drop position plan (drop positions pre-programmed) and automated checking of each profile with previous profile to alert the ship rider to failures and unusual features for quick re-drops.

Data Assembly

The GTS [26] is the system operated by WMO to exchange meteorological data among WMO members. By agreement with IOC it is also the distribution network used to exchange ocean profile data in real-time. Data providers each have different avenues for getting data from at sea operations to a NMHS which are the only agencies with direct access to the GTS. Data inserted on the GTS must be in either Traditional Alphanumeric Code forms (TACs), or in a Table Driven Code form (TDC) called BUFR [Parts A and B respectively at [27]). TACs are ASCII code forms and three, known as BATHY, TESAC, and BUOY, are used to deliver ocean profile data. SOOP employs only BATHY and TESAC. The data in BUFR format are sent most often using specified layouts called templates. As the transition to Table Driven Codes is taking place, Traditional Alphanumeric Codes are gradually being abandoned for the real-time distribution of data through the GTS. Information about these forms can be found on the WMO web site.

Real-time data assembly for SOOP is carried out by the Integrated Science Data Management, ISDM, group in Canada through the GTSPP [28], a joint JCOMM, IODE project. ISDM assembles all of the ocean profile data that are sent over the GTS, whether from SOOP vessels or others. Data arrive continuously at ISDM and they are processed 3 times a week. Incoming data files are preserved in case they need to be consulted.

Real-time data streams contain a minimum of metadata – ship call sign, location and time of the observation, some information about sampling procedures and instruments used. In addition, information on who inserted the data onto the GTS and at what time, as well as when the data were received is available.

The U.S. NODC [29] operates the Continuously Managed Database, CMD, for the GTSPP. Their responsibility is to assemble the real-time data delivered from ISDM, and to process whatever delayed mode data come to them. The CMD receives all of these data after processing is complete.

The delayed mode data stream may be much richer in metadata content. This depends on the data provider and the format they use when sending the information to the U.S. NODC. Readers need to consult the U.S. NODC for specific information. Incoming data files are preserved in case they need to be consulted.

Data rescue is not an objective of the GTSPP. Such activities have been undertaken by the GODAR [30] project.

Processing and Archiving

ISDM passes the data through a series of processing steps. A specialized format was created for the GTSPP [18] that holds the entire contents of the TACs and TDCs as well as information about the time of data insertion and by which GTS node. After conversion to this format the data undergo a variety of quality assessment steps [17]. Details are found in the GTSPP Quality Control Manual found at [18]. The entire processing detail is also provided. Processing includes a resolution of duplicates on the GTS. Quality flags are added to the data file and the results are sent on to the U.S. NODC. ISDM provides data dissemination services as described in a later section Data are passed to the U.S. NODC three times a week for incorporation into the CMD.

The U.S. NODC operates on each file received from ISDM. Its contents is compared against the existing contents of the CMD to check for duplications or if higher quality versions already have been received. If not, the data are inserted into the CMD. As delayed mode data are received they are also checked against the CMD contents, and if a lesser quality version exists, the higher quality, higher resolution (usually delayed mode) data are inserted and the lower quality version of the profile is flagged as having been replaced. Thus, at any time, a query against the CMD will result in a mix of real-time data profiles (normally of lesser quality) and delayed mode profiles (normally of higher quality). All profiles undergo identical processing by both data centres and a consistent flagging scheme is used.

Delayed mode data periodically are sent to or received from ocean research institutes who collaborate with GTSPP to undertake "scientific quality control". The data are scrutinized by scientists and flags on data quality are set appropriately. These higher quality versions then "replace" lesser versions in the CMD.

All participants in GTSPP use a common data format developed for the project. The format contains instrument metadata (e.g. the XBT probe type and fall rate coefficients), processing metadata (e.g. what software steps were conducted in processing the data), as well as quality flags and provides the ability to track any changes that may have been made in the data. All of this is documented at [29].

Both centres, ISDM and the U.S. NODC, have backup plans should communications be lost or hardware failures take place. If errors are detected in the data, originators are notified if possible so that they can advise on corrective actions to be taken. There is a form of version control of the data through the inclusion of metadata in the GTSPP format that describes the processing steps through which the data go.

Because not all profile data are inserted onto the GTS, the CMD contains profile data with no real-time counterpart. Likewise, sometimes the delayed mode version of a real-time profile does not reach the CMD. Hence, the CMD contains only real-time versions of some profiles even many years after data collection.

Part of the reason for the persistence of older real-time data can be attributed to the inability to match a delayed mode profile to its real-time counterpart. In the course of scrutinizing the real-time data, the collectors may encounter clock errors (date and time information were wrongly set) in the real-time data. These are corrected in the delayed mode version. In a similar fashion position errors reported for the real-time station may also be corrected. The GTSPP duplicates analysis system was heavily dependent on matching date and time, position and ship identifier allowing for some tolerance for inexact matches on position and time. In an effort to improve on this, GTSPP instituted another scheme that assigns unique identifiers to profiles based on the original data transmitted in real-time. Information about this scheme must come from contacting the chair of the GTSPP [31]. (Rec 2)

A more recent development is the masking of ship call signs (identifiers used on the GTS). This masking sometimes substitutes the generic call sign SHIP for all data. Use of this complicates processing the real-time data since checks on location and time are stymied. It also complicates delayed mode processing if the delayed mode data do not provide some way to match delayed mode stations to those delivered in real-time.

Data from the U.S. NODC contributes to the World Ocean Database project [32]. Data received by GTSPP at the U.S. NODC are incorporated into the WODB and appear in monthly updates. As delayed mode data replace real-time, these are incorporated into the updates. All data, described in [33] entering the WOD, not just data from SOOP, undergo the same quality checking procedures, as described in [34].

Others also process the GTS data for their own purposes. For example, the French, through the Coriolis Project [35] at IFREMER, have a sophisticated operation that captures a variety of marine data types from their weather service and through the ftp service from ISDM (see next section). They operate a Thematic Assembly Centre within the auspices of the MyOcean Project [36]. Documentation of the procedures they use to check the quality of the data is available [37]. They also provide data dissemination services as described later.

The Australians use software called Mquest [38] to apply full scientific QC to the data received on shore. Once the data are fully quality controlled, they are sent to the U.S. NODC and IMOS (see later). The quality control tests are fully described in [39] and also accessed through the references link at [38].

SIO applies scientific QC to the data, adhering to Australian QC procedures. Additional metadata (not contained in the real-time transmitted binary data) is added to QC'd data and submitted to U.S. NODC.

NOAA/AOML receive the XBT data transmitted from the transects they operate in real-time. The full resolution profiles are transmitted in SEAS binary format without any modification. The files transmitted contain all of the available metadata, including the unique identifier mentioned before. The profiles are submitted to real-time quality control automatic procedures and profiles that are approved during these tests are submitted to the GTS. These profiles are also submitted in real-time to the U.S. NODC. To further avoid losing useful data, profiles that are not approved during the automatic real-time quality control process are reviewed visually and distributed. For cruises where XBTs are deployed in high density by a scientific rider, a scientific quality control process is applied to the data. These profiles are submitted in delayed-mode to NODC and included on AOML's XBT web site (see note later and [62]).

Data Dissemination

GTSPP provides data free of charge to all users.

ISDM provides a service that allows users to receive the most recent data coming from the GTS. Users receive the same data content three times a week as is sent to the US NODC. They provide the ability for a user to specify a geographic region of interest. This runs automatically and either places a file on the ISDM ftp site, or pushes the file to a designated ftp site. This service is not advertised and must be negotiated with ISDM [40].

The U.S. NODC operates the main data distribution service for GTSPP [29]. It allows users to select data sets through a web based interface. A user can get monthly files of real-time data received from ISDM, monthly files of the contents of the CMD (both real-time and delayed mode - called the "best copy" file), or use an interface to qualify data of interest by a number of selection criteria. Data are available in both ASCII and netCDF file formats [41]. However, there is no way to select data based on the line it is sampling. (Rec 3)

The Ocean Data Portal, ODP [42], is a free data distribution system put in place by the IODE [43]. The ODP aims to provide seamless access to collections and inventories of marine data from the NODCs of the IODE network and allows for the discovery, evaluation, through visualization and metadata review, and access to data via web services. The system architecture use Web-oriented information technologies to access non-homogeneous and geographically distributed marine data and information. This is distribution system only, with data sets being provided by IODE members. Users need to consult the provider of the data set to learn what processing has been done.

The WOD provides a data selection service [44] (free of charge) as well as detailed tools and documentation on how to read the data and use the tools [45]. Data are provided in a WOD native format, a comma delimited file format and netCDF.

The MyOcean project [36] operates within the Global Monitoring for Environment and Security program, GMES, in Europe. The main objective of the MyOcean project is to deliver and operate a rigorous, robust and sustainable Ocean Monitoring and Forecasting system for all marine applications: maritime safety, marine resources, marine and coastal environment and climate, seasonal and weather forecasting. Coriolis provides access to real-time and delayed mode data through a data dissemination page [46] on their web site. This provides access, free of charge, to a wide variety of data types, not just data collections coordinated by SOOP.

The U.S. Integrated Ocean Observing System, IOOS [47], Program's mission is to "lead the integration of ocean, coastal, and Great Lakes observing capabilities, in collaboration with Federal and non-Federal partners, to maximize access to data and generation of information products, inform decision making, and promote economic, environmental, and social benefits to our nation and the world. The Program works closely with the eleven U.S. regional associations to establish core capabilities that meet both national requirements and regional user needs.

As part of the U.S. IOOS Data Management and Communication, DMAC [48], core services, the U.S. IOOS Program Office has initiated a sustainable, community-based project to establish authoritative procedures for quality assurance, QA, and quality control, QC, of real-time ocean sensor data collected for U.S. IOOS. This project is entitled QARTOD, Quality Assurance/Quality Control of Real Time Ocean Data [49]. All of the known QA/QC programs in existence today provide parts to the solution, but none consolidates the various parts. The result of this effort is to develop standards that can become formal U.S. IOOS data standards for data from the U.S. Regional Associations. The application of these standards is left in the hands of the data providers. Access to IOOS data is given in [50].

The Australian Integrated Marine Observing System, IMOS [51], is a fully-integrated, national system, observing at ocean-basin and regional scales, and covering physical, chemical and biological variables. IMOS facilities, operated by ten different institutions, are funded to deploy equipment and deliver data streams for use by the entire Australian marine and climate science community and its international collaborators. The IMOS Ocean Portal [52] allows users to discover and explore data streams coming from the contributing national facilities -

some in near-real time, and all as delayed-mode, quality-controlled data. Information about the quality control of XBT data are not available on-line. Data sets are searchable by area, time and types and are delivered through an OPeNDAP server [53] in netCDF [54]. IMOS is also responsible for coordinating the Australian Ocean Data Network, AODN [63], Data Portal. The AODN Portal is the primary access point for marine data published by Australian Commonwealth Agencies with responsibilities in the Australian marine jurisdiction and by a large number of other data contributors. The portal provides access to standardized data files, including XBT data, that are hosted and maintained by the custodian agencies.

Another avenue of data distribution are the global portals of the WIS [55] operated by WMO. Like the ODP, data availability is based on voluntary contributions of data descriptions and data sets that exist in a searchable interface.

Differences Between Distributed Data Sets

ISDM: delivers real-time temperature and salinity profile data after QC with some operator scrutiny. The data format allows for tracking any changes or reasons for flagging and lists tests performed and failed. Data can be delivered 3 times a week. The data format is ASCII or GTSPP binary.

NODC: delivers the best version (highest vertical resolution, highest quality) at the time of the request of a global temperature and salinity profile data set (other variables may also be present) with updates to the archive three times per week. Duplicates between real-time and delayed mode are resolved and there is consistent QC applied. Some of the data have received scientific scrutiny and these are so marked in the data set. The data formats are ASCII or netCDF.

WOD: delivers all types of profile data after quality control procedures that are different from those performed by the GTSPP. Objective analysis allows identification of bull's eyes. Interpolations are provided to standard levels. The data set includes more than temperature and salinity profiles. Data are available in a custom ASCII format, comma separated value format or netCDF.

Coriolis: delivers all types of profile data after quality control similar to that performed by the GTSPP but extended to use objective analysis and comparisons with climatology. Selection can be by instrument, cruise, date, time, etc. Data are available in netCDF or comma separated value format.

ODP: is a distribution system only. Data are provided by different NODCs with different processing & QC. Data sets come in separate files, often in netCDF.

IOOS: provides documented standards for QA/QC for a variety of data types. Relies on data providers to execute these. It is a portal to US data in real-time. Data are available in netCDF.

IMOS provides access to Australian collected data only. Processing and QC are not described except if you know where to look. Data are available in netCDF.

User Communities

The different data dissemination web sites describe their purposes and there is strong overlap in intentions. In many cases the data are offered in support of operational oceanography applications. This includes the modelling community in both oceanography and meteorology.

Data selection capabilities allow for users with other interests to examine both the current and historical data from a particular location. Sometimes this is used in preparation for a data collection activity, and sometimes in an examination of long term properties or changes in the area.

Temperature and salinity data have been used in conjunction with changing distributions of planktonic species to demonstrate possible shifts in oceanic regimes, or trends in climate.

Profile data in general are used in studies of upper ocean heat content. Through combination with altimetry data and using established temperature and salinity relationships, it is possible to carry out ocean current and transport calculations.

With the advent of measurements of temperature and salinity profiles by instruments on marine mammals, new studies are opening up. Research into the detailed behaviour of these mammals can be related to physical properties of the water in which they are swimming. Feeding studies, for example, can start to relate ocean properties to the food web on which these mammals depend.

Monitoring and Performance Metrics

JCOMMOPS [56] provides a variety of monitoring products to show the status of participation in SOOP. There are also a selection of statistics and maps available under the "Monitoring" tab. (Rec 4). Maps of monthly and yearly transect sampling are shown [57].

The ISDM provides data distribution maps [58] by month for real-time data received, and a list of data reported from each platform over the GTS in a selected month.

The U.S. NODC [29] provides a map of real-time data received through the GTSPP. Under the "Documents" tab, there are also a series of reports, some annual and more recently biannual, with a variety of graphs and charts showing information about various aspects of the data management component of GTSPP.

AOML [14] provides information about platforms sending real-time data on a daily basis, though there is no explanation for the content and so this is of use to the programme only. They also provide a useful display of repeated line sampling, but this is only for the Atlantic ocean. (Rec 5). (Note: since the report was produced, AOML now hosts a new website created with contributions from the international community, in particular the members of the XBT Science Team, with information about the global XBT network operation, data applications, data access, data products, applications and XBT bibliography [62]).

SIO [13] provides a useful display and data access for SIO's Pacific, Indian and Atlantic ocean repeated line sampling. It also includes several of CSIRO's Pacific and Indian ocean transects.

SOT publishes meeting reports [59] in which a report of the SOOP chair can be found. While informative, there are no graphics that describe how well the programme is operating. (Rec 6) (Note since the initial draft of this report, reference 59 no longer seems to point to meeting and annual reports. These can be found at http://www.jcommops.org/soopip/ and at http://www.wmo.int/pages/prog/amp/mmop/jcomm_reports.html. This leads to Rec 10).

Information about data distributions, receipts and so on are also available either for global data sets, such as from Coriolis, or nationally, such as from IMOS or IOOS.

The Unites States funded Observing System Monitoring Center, OSMC [60], provides a variety of tools to examine the status of observing systems. On the home page is found a composite map of all observations in the last three days, or another time period can be selected. It also provides some capability to display on Google Earth projections. Some additional comments follow (Based of examining the site in early June 2013).

- Under the "In Situ Monitoring tab, there are some deficiencies (such as using programme names that are not necessarily clear to all users – NWLON. There is also the inclusion of US programmes, though this site obviously has a dual purpose, and it is missing some JCOMM observing systems – SOOP, VOS. However, when "all programs" is selected and a particular parameter it seems quite good.
- Under the "Observing System Metric Reports" tab and after selecting "XBT" there is a useful listing of XBT drops along SOOP lines. This needs perhaps to include the other measurements included in SOOP, such as XCTDs, though these are few. When selecting this tab, the name on the tab changes to "OOPC status reports" which seems odd. Also, one of the selections is labeled "psbe" and what this is is not obvious to users.
- Selecting the "Observing System Metrics" tab has this name change to "Climate Services". I also note that the "OSMC Viewers" link results in an error. As noted previously, this is a bit confusing. (Changing tab names is a common thing and it is not obvious why this is useful).The displays here can be for selected parameters, which can be a nice presentation for an observing system. The presentation of time series is interesting, but difficult to read and it was not clear how to print this display rather than the associated map.
- Presentations based on all platforms for a selected parameter is approaching what is needed for an ECV perspective.

Information from this site would be a good addition to an annual report for the SOOP observing system (Rec 7). There are a few problems with this site (Rec 8).

GCOS-IP (2010) Performance Indicators

Within the GCOS-IP (2010 update) [61] the SOOP XBT operations are mentioned in Action 25, listed here.

Action O25 [IP-04 O26]
Action: Sustain the Ship-of-Opportunity XBT/XCTD transoceanic network of about 40 sections.
Who: Parties' national agencies, coordinated through the Ship Observations Team of JCOMM.
Time-Frame: Continuing.
Performance Indicator: Data submitted to archive. Percentage coverage of the sections.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

Report: The only reporting at present that discusses how successfully sections were sampled exists in a document prepared for the last SOT meeting (SOT-7, doc 8.2). In that it is reported that in 2011-12 there were 14 lines in the Atlantic Ocean, 9 in the Indian Ocean, and 15 in the Pacific Ocean that were active. This totals 38 lines roughly 40% being frequently repeated and 80% high density sampling (a few lines are sampled in both modes). In the past, SOOP had implemented a semestrial report on line sampling and this had been available from JCOMMOPS. This report has not been updated for some time. A report of this type is important for showing how well SOOP is meeting GCOS objectives (Rec 9).

Recommendations

Rec 1: The coordination of ADCP data collection activities is absent from SOOP meetings. If this is part of the mandate for this group, SOOP should include discussions of this activity in its meetings, and encourage agencies that operate archives for these data to attend meetings and report on their work.
Rec 2: Documentation on the CRC duplicates identification scheme used by GTSPP should be made available on the GTSPP web site.
Rec 3: Line sampling is an important focus of the SOOP. Data selection by SOOP lines should be supported at data dissemination sites, at the very least by GTSPP.
Rec 4: Not all of the monitoring reports at the JCOMMOPS site for SOOP were actually working when tested (May 2013). Sometimes data base queries failed, sometimes links appear to be broken, sometimes reports were not current, and sometimes they did work. It is recommended that the SOOP Technical Coordinator review the variety of reporting available and ensure that they work properly. .
Rec 5: The display of sampling of SOOP lines as used at AOML should be extended to other oceans,
Rec 6: SOOP annual reporting needs to provide graphics to illustrate how well it is meeting its objectives. Some relevant material can be found in bi-annual reports of GTSPP, and also scattered on web sites. However, an annual review with text and graphics that show performance against SOOP objectives and illustrates issues that may have arisen would be recommended.
Rec 7: Given recommendation 6, there are some displays provided at the OSMC site that may well be useful additions to an annual report from SOOP.
Rec 8: There are some aspects of OSMC that were noted above and should be corrected / addressed.
Rec 9: While there is reporting on line sampling available in SOT meeting documentation, this is not prominent. SOOP should ensure that a report that directly speaks to GCOS Action O25 is easily available at an appropriate web site.
Rec 10: In the course of reviewing comments, it was noted that some links previously found on SOOP pages appear to have been moved or removed. Now the meeting and annual reports are found buried at JCOMMOPS pages or at WMO pages devoted to JCOMM. It is confusing to have these multiple locations to look for information and it is recommended that a more obvious path for these pages would be to find them at the SOOP pages as found in [20.

Acronyms

ADCP: Acoustic Doppler Current Profiler
AMVER: Automated Mutual-assistance VEssel Rescue system
AODN: Australian Ocean Data Network
AOML: Atlantic Oceanographic and Meteorological Laboratory
BODC: British Oceanographic Data Centre
BUFR: Binary Universal Form for data Representation
CMD: Continuously Managed Database
CTD: Conductivity Temperature Depth

DMAC: Data Management and Communication
ECV: Essential Climate Variable
ftp: File Transfer Protocol
GCOS: Global Climate Observing System Implementation Plan
GMES: Global Monitoring for Environment and Security (European Union project)
GODAR: Global Ocean Data Archaeology and Rescue project
GTS: Global Telecommunications System
GTSPP: Global Temperature Salinity Profile Project
IFREMER: L'Institut Français de Recherche pour l'Exploitation de la Mer
IOC: International Oceanographic Commission
IODE: International Oceanographic Data and information Exchange
IOOS: Integrated Ocean Observing System
IMOS: Integrated Marine Observing System
ISDM: Integrated Science Data Management
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
netCDF: net Common Data Format
NMHS: National Meteorological and Hydrological Service
NODC: National Oceanographic Data Centre (of IODE)
ODP: Ocean Data Portal
OPeNDAP: Open-source Project for a Network Data Access Protocol
OSMC: Observing System Monitoring Center
QARTOD: Quality Assurance/Quality Control of Real Time Ocean Data
QA: Quality Assurance
QC: Quality Control
SEAS: Shipboard Environmental data Acquisition System
SIO: Scripps Institution of Oceanography
SMRU: Sea Marine Research Unit (St. Andrews University)
SOOP: Ship Of Opportunity Programme
SOOPIP: Ship Of Opportunity Programme Implementation Panel
SOT: Ship Observations Team
SSXBT: Submarine-launched XBT
TAC (WMO): Traditional Alphanumeric Code
TDC: Table Driven Code
TIP: Tropical Moored Buoy Implementation Panel
T.S.K.: The Tsurumi Seiko Company
UKMO: United Kingdom Meteorological Office
VOS: Volunteer Observing Ship
WIS: WMO Information System
WMO: World Meteorological Organization
WOD: World Ocean Data project
WODB: World Ocean DataBase
XBT: Expendable Bathythermograph
XCTD: Expendable Conductivity, Temperature, Depth instrument

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2.1b: SOT - SOOP Underway Data

Introduction

The focus of this chapter is on the data that are collected through the SOOP underway [1] operations. Several ships of the SOOP operate Thermosalinographs (TSGs) to collect sea surface temperature and sea surface salinity observations along the ship track. Frequently the TSG operation is conducted in support of other observational projects, such as the pCO_2 ocean inventory effort.There are other programmes that provide data similar to that delivered by SOOP TSGs. These other programmes are not well coordinated internationally, but some are important sources of data and so will be mentioned in this chapter.

Data Providers

The instrument used in this programme is the TSG. It measures temperature and salinity at the surface, through a pumped seawater system. Most often the instrument is fed seawater from an existing ship's engine cooling system. In some cases, other intakes are used. More recent ship installations include, as well, measurements of a variety of seawater properties including pH, oxygen, pCO_2, nutrients, fluorescence, particle counters, turbidity, etc. Under SOOP, the focus of underway measurements has been on simply temperature and salinity, and so that focus will be retained in this chapter. Other variables will be noted in appropriate chapters on ECVs.

There are a number of manufacturers of systems for measuring underway temperature and salinity (and other variables). Each of these has differing capabilities, with ranges of accuracy for temperature between 0.01 to 0.005 ℃ and for salinity between 0.03 and 0.001 PSU. It is uncommon that instrument names used in the measurements are provided with the data. It is perhaps never that instrument measurement characteristics are recorded or provided with the data. The Australian IMOS provides documentation on instruments used [3] on their vessels and TSGs are noted there. This is the only instance where such information can be found at a site that also provides data access.

The quality of measurements of temperature and salinity depend not only on the quality of the instruments used, but also strongly on the siting of the instruments (including what is the intake, where relative to the ship's engines) but also on routine calibration of the instruments since they are subject to contamination by fouling and particulates in the water. In 1999, an installation guide [4] was prepared by IRD staff in France based on experience gained in running a TSG programme in the Pacific. A very simple operations manual has been prepared by AOML as well [5] and searches on the Internet turn up a number of other specific instructions. The only general document appears to be that of [4] (Rec 1).

TSG data within the SOOP are provided from commercial vessels carrying goods across the world's oceans. The vessels are recruited to the program either by national agencies participating in the SOOP or by dedicated programs, and more recently with support from JCOMMOPS. They are often provided with computer hardware and software to record measurements. Ship's communications capabilities are used to get the data ashore in real-time (within 30 days of data collection and often much sooner). In the past voice communication was used, but the most common route today is through satellite links such as Inmarsat [6], Argos [7] or Iridium [8]. Costs for SOOP operations are borne by the country operating the SOOP line.

A significant fraction of TSG data are collected from oceanographic research vessels or other programmes [e.g. 9,10,11,12,13,14,15] some of which also are part of SOOP. Not all of these data become available in real-time, such as through the systems noted above. There are a number of stand-alone web sites that provide access to such data in data formats particular to the site.

Research vessels carrying out fish population surveys also collect TSG data. The data collected for these purposes may or may not be reported or reach national data archives, depending on national practices. These data come from continental shelves, but also possibly from deep ocean.

For all of these programmes, there is some basic processing of the data and usually some data quality checking. This may be performed by the data recording software running on board the collecting vessel and / or there is checking done on the data with the later processing by each data collection group. There are published procedures by some organizations of their procedures, but there is no common approach. Likewise, unless the data get to the GTS, there is no evident commonality of data formats.

It is evident that there are many groups involved in the collection of TSG (and more generally surface ocean data) but this is not well coordinated nor is it easy to either identify the group or find the data. Once found, the information about how the data were collected, processed and if they have been contributed to national or international archives is difficult to determine. (Rec 2).

There are other data collection programmes that collect surface temperature and salinity data. Almost every programme that collects profiles of temperature and salinity collect observations at or near the surface. As well, buoys, both moored and drifting, typically collect surface temperatures and some provide salinities as well. These programmes are not considered here. Rather, in the chapters on ECVs of sea surface temperature and sea surface salinity, the contributions of all of these various programmes will be brought together.

Data Assembly

As noted above, there are many TSG data collection activities, some that provide data to the international programmes and some that do not. This section will concentrate on the programme coordinated by JCOMM.

The GTS [16], is the system operated by WMO to exchange meteorological data among WMO members. By agreement with IOC it is also the distribution network used to exchange TSG data in real-time. Data providers each have different avenues for getting data from at sea operations to a NMHS which are the only agencies with direct access to the GTS. Data inserted on the GTS must be in either Traditional Alphanumeric Code forms (TACs), or in a Table Driven Code form (TDC) called BUFR. TACs are in ASCII and the, TRACKOB code form is used to deliver surface data. In BUFR, the data are sent in binary most often using specified layouts called templates. As the transition to Table Driven Codes is taking place, Traditional Alphanumeric Codes are gradually being abandoned for the real-time distribution of data through the GTS. Information about these forms can be found on the WMO web site [17].

Real-time data assembly for SOOP TSG is carried out by the Integrated Science Data Management (ISDM) group in Canada [18] in support of the GOSUD project [19,20], a joint JCOMM, IODE project (Recs 3,4). ISDM assembles all of the TSG data that are sent over the GTS, whether from SOOP vessels or others. Data arrive continuously at ISDM and they are processed daily. Incoming data files are preserved in case they need to be consulted. GOSUD operations in France also assemble real-time data taken from the GTS by Meteo-France.

Real-time data streams contain a minimum of metadata - ship call sign, location and time of the observation and some information about sampling procedures and instruments used. In addition, which NMHS inserted the data onto the GTS and when it was done is contained in the GTS messages. In some cases the near real-time data format holds additional information such as instrument serial numbers or calibration coefficients. Real-time data can be used for monitoring the ship acquisition system when there is no technical staff on board.

The French Coriolis centre [21] operates the primary global archive for the GOSUD project. Their responsibility is to assemble the real-time data delivered from ISDM and their own sources, and to process whatever delayed mode data come to them. They provide data checking services, translation of incoming data to a common format, and data dissemination services (described later). Their archive receives all of these data after processing is complete. Documentation is available on data formats and procedures [22].

The delayed mode data stream may be much richer in metadata content. This depends on the data provider and the format they use when sending the information to the GOSUD project. Data requesters need to consult GOSUD for specific information and details of the metadata contained in the archive. Judging by the proposed netCDF [23] data format at GOSUD [24], the metadata that can be archived is extensive. Incoming data files are preserved in case they need to be consulted.

There is no data rescue component to GOSUD. Historical data exist in other international archives, as will be described later.

The U.S. NODC [25] is associated with GOSUD and acts as a long-term archive for the project. This is a useful function providing some redundancy.

Processing and Archiving

ISDM receives daily updates of TSG data from the GTS and passes the data through processing and minimum quality checks, though these are not described (Rec 3). It is known that the format used for these data is the same as that used for data in the GTSPP [26]. Again while not described by ISDM, the author knows that should there be problems found in processing TRACKOB reports, notification is usually forwarded to the SOOP Technical Coordinator [27] for help in resolving the problem. Copies of these data are uploaded daily to the main GOSUD data centre in France.

TSG data are received from Denmark, France, Germany, Japan, United Kingdom and the United States on a regular basis. In addition, vessels in the International SeaKeepers Society [28] report observations.

The GOSUD web site in France provides few details on how the data are processed when they arrive (such as use of unique identifiers, details of the database technology used, data version control, etc.). There is some documentation on what procedures are executed to check the quality of the data. As noted earlier, there is no description of the fields in the archive for data or metadata (Rec 5), but based on the description of the netCDF format there are fields available to handle much more than the usual details provided with typical real-time data submissions.

Delayed mode data are submitted to the GOSUD archive on a regular basis from Denmark, France, Germany, and the United States (again ships that are part of the SOOP operations of the country). There are also contributions from some ferry operations, the SAMOS project [14], and from the Nippon Project in Japan (two ships). Little of the real-time data received are later replaced by delayed mode, and there is no description of how this is done. Other countries contribute lesser amounts of data and irregularly.

Due to resources constraints, quality control of the delayed mode data at GOSUD is restricted to data received from French vessels, and these are the only sources which receive feedback on problems identified. There are two major consequences of this. First, data held in the GOSUD archive are of varying quality, ranging from perhaps no checking to some checking having been done. Second, documentation about what the various data providers do in processing the data before they contribute to GOSUD archives takes on greater importance.

AOML provides good documentation of their processing and quality control procedures [29] that apply to data collected by NOAA vessels and those collected on SOOP vessels managed by them. SAMOS also provides documentation on how they process underway data [30]. France provides documentation about its processing as well [31,32]. Information on what is done in other countries is not apparent (Rec 6).

The GOSUD project must also deal with masking of ship call signs (identifiers used on the GTS). This masking sometimes substitutes a generic call sign for all of the data from a ship. In the case of TSG data, each ship has its own identifier and so although the owner of the vessel is not known, it is still possible to use quality control checks that rely on tracking a ship's progress. The main difficulty is that information about the on-board instrumentation is difficult to get, since certainly there is no place in the TRACKOB code form for this information. In receiving the delayed mode data, provision of the international call sign instead of the self generated masked identifier is not always done. This requires arrangements to be made with data providers to be sure such masking is removed before data are submitted in delayed mode in order that some chance of knowing the instrumentation used can be recorded with the data.(Rec 7).

GOSUD began in the early 1990's and looking at the GOSUD archives, the earliest records are from about that time when the TSG instrument came into use. It is difficult to know how much of the TSG data collected today in various programmes around the world actually end up in the GOSUD archive. Estimates from GOSUD put this number at perhaps 60%.

Other archives exist, but these will be treated in the next section on dissemination because their contents do not appear to have large overlaps with GOSUD. (A reviewer noted that when GOSUD was started, the historical SSS dataset acquired during the WOCE experiment was integrated into the GOSUD archive. A trial query for data from 1970-1980 returned no data.)

Data Dissemination

GOSUD provides free access to its data holdings through a web interface [33]. Users can choose ftp or web downloads. The ftp service, version 1 and as mirrored at the U.S. NODC, is organized by ships within yearly folders. Information is provided in a “readme” file and there is a simple text index to the data available. Version 2, available only from Coriolis, has separate netCDF files by ship and year. (Reviewers noted there is a version 3 of the format, that contains much more information. A check of GOSUD pages did not show a Version 3 available.)

The web access (only available from GOSUD) provides selection by date, area and data type and users can receive data in netCDF or a csv file format. Both of these are described on the documentation pages noted earlier [19]. Because the interface provides access to other kinds of data, there is a list of parameters other than temperature and salinity, but if these others are selected, with only TSG as the instrument, no result is found (Rec 8).

There are other sources of TSG (temperature and salinity) and other kinds of data collected through seawater sampling systems. Information about other variables collected, such as listed earlier, will be provided in chapters of particular ECVs. In this section, there is a short list of other sources of surface temperature and salinity data. (next section. Documentation at these sites, including information of sources, processing, quality control, etc., is referenced when such information is apparent. As can be seen, there is a wide disparity in what information is available (Rec 6, 9).

Before GOSUD began, surface measurements of temperature were collected through engine intakes and bucket sampling. A large archive of these historical data exist at ICES [34], but this archive is confined to the Atlantic Ocean. They publish guidelines on processing of many data types, including underway data [35], but there is no evident description of what processing they do once the data arrive at their site. They do offer online access to the data they hold They also support some web services [36].

ICOADS [37] contains only surface temperature data, mostly from the VOS fleet but also from much older records recovered through data rescue projects. The most recent update contains data from 1662 to 2007 [38]. As discussed in the chapter on VOS, documentation of the processing done by ICOADS is not easily found.

Historical data collected through U.S. researchers in programmes such as WOCE [39,40] and JGOFS [41] are available. Through the U.S. NODC Geoportal pages [42] data from the Hawaii Ocean Time-series (HOT) Program, from NOAA ships (mostly operating before the start of GOSUD), and from academic institutions in the U.S. are available. They provide a search interface allowing selection by area, time and data type. They provide documentation that outlines how data are handled [43].

In Germany the HZG provides restricted access to data [44] collected from a series of ferries that they operate. They provide technical information about the instrumentation and data logging.

There was a project called FerryBox that ran in Europe for a number of years. There is only a few near real-time data still available on-line [45] from this project. After an inquiry it seems that these data are not easily accessed (Rec 10) although some of the data may be represented on the EMODNet website [46]. The BODC holds the final archive of this project.

Among other activities, the European project MyOcean II gathers in situ data at the European level for operational oceanography purposes and integrates data from global observation networks such as Argo and GOSUD. Within the MyOcean project, NIVA (Norway) is responsible for gathering Surface Underway data (temperature, salinity and other parameters).

The WOD provides a data selection service [47] (free of charge) as well as detailed tools and documentation on how to read the data and use the tools [48]. Data are provided in a WOD native format, a comma delimited value format or netCDF and documentation is available that describes how the data are handled [49].

The Australian Integrated Marine Observing System, IMOS, is a fully-integrated, national system, observing at ocean-basin and regional scales, and covering physical, chemical and biological variables. IMOS Facilities, operated by ten different institutions, are funded to deploy equipment and deliver data streams for use by the entire Australian marine and climate science community and its international collaborators. The IMOS Ocean Portal [50] allows users to discover and explore data streams coming from the Facilities. Information about the quality control of TSG data are not available on-line. Data sets are searchable by area, time and types and are delivered through an OPeNDAP server in netCDF. TSG data collected by IMOS facilities are not available from the GOSUD data delivery portal.

The BODC [51] provides access to underway data collected by the Atlantic Meridional Transect project [52,53]. These are available in a BODC csv format. They also provide information on how their archives are organized. This is an example of one such source of underway data that may or may not overlap with what the GOSUD holds.

Differences Between Distributed Data Sets

ISDM: delivers real-time TSG data with little quality control. The data format allows for tracking any changes or reasons for flagging and lists tests performed and failed. Data can be delivered daily. The data format is ASCII or GTSPP binary.

GOSUD: provides ftp and a database query interface to select data by date, time, ship, area, variable, etc. Data are of variable quality. They provide data in csv or netCDF formats.

NODC: provides a mirror ftp site for GOSUD data in netCDF format only.

ICES: provides access to surface temperature data (1891 to present) from the Atlantic ocean and in csv format. It is possible that there is overlap with GOSUD archives.

ICOADS: provides surface temperature data (from 1662 to 2007) originating mostly from VOS ships. They undergo extensive quality checks, but these are not well described. Data are available in an ICOADS ASCII format or netCDF.

WOD: provides many types of surface data after quality control that they describe. Objective analysis allows identification of data bull's eyes. Interpolations are provided to standard levels. Data are available in a custom ASCII format or csv format.

IMOS provides access to Australian collected data only. Processing and quality control descriptions are not easily found. Data are available in netCDF.

User Communities

The different data dissemination web sites associated with particular programmes describe their purposes and there is strong overlap in intentions. In many cases the data are offered in support of operational oceanography applications. This includes the modelling community in both oceanography and meteorology.

Data selection capabilities allow for users with other interests to examine both the current and historical data from a particular ocean location. Sometimes this is used in preparation for a data collection activity, and sometimes in an examination of long term properties or changes in the area.

Temperature and salinity data, including surface values, have been used in conjunction with changing distributions of planktonic species to demonstrate possible shifts in oceanic regimes, or trends in climate.

The surface underway data are used by the modelling community mainly for validation purposes. It is not clearly stated that the underway surface data are assimilated.

Surface temperature measurements are often used as surface truth, or at least, in comparison with values collected from satellite mounted sensors. The GHRSST programme [54] is a good example of the union of in-situ and satellite derived sea surface temperatures as well as providing links to numerous sources of such data and products of many kinds.

There are two satellites now in orbit, SMOS [55] and Aquarius [56], that allow computations of sea surface salinity. In-situ surface measurements of salinity are validation points for satellite observations.

Monitoring and Performance Metrics

JCOMMOPS [57] provides maps of locations of monthly and yearly observations. There is no further information about the TSG component of SOOP beyond this. (A reviewer notes “Further products for underway data are under development. JCOMMOPS will shortly be hosted next door to Coriolis/GOSUD, which will facilitate the implementation. There is also demand from GO-SHIP to take more underway data into account now at JCOMMOPS.")

The ISDM provides data distribution maps [18] by month for real-time data received, and a list of data reported from each platform over the GTS in a selected month.

The web page that describes the GOSUD project [19] provides a composite map of the locations of all the data in its archive. It also provides annual reports (although the most recent is 2007) that contains a variety of displays and data management products to illustrate project operations (Rec 11). Finally, there are reports of meetings, some jointly held with the SAMOS project. From the data query interface, it is possible to construct maps of TSG measurements contained in the archives.

AOML [58] provides information about the platforms it manages that contribute TSG data. They provide composite cruise tracks for the ships as well as presentation of the data collected. They also provide links to other TSG programmes they are associated with. Finally, they also provide data location maps for NOAA and SOOP ships in the last 3 months and since 2001.

The Australian IMOS [50] provides maps of locations of TSG observations collected by that country's vessels.

The Unites States funded OSMC [59] provides no displays specific to TSG observations. However, it does provide the facility to display locations of sea surface temperature or salinity. This site is a useful addition to monitoring, but it has a mixed presentation. On one hand it allows a selection by programme but the present list is more of a sample than comprehensive of JCOMM programmes. On the other hand, it allows a selection by parameter and a number of ECVs are represented there. It was noticed that a selection of sea surface salinity from all programmes and all platforms for the most recent months resulted in no data being displayed. This suggests that the GOSUD archive, at least, is not yet connected (Rec 12).

GCOS-IP (2010) Performance Indicators

In the GCOS-IP (2010 update) [60] the TSG observations are implicated in Action 11, listed here.

Action O11 [IP-04 O15]
Action: Implement a programme to observe sea-surface salinity to include Argo profiling floats, surface drifting buoys, SOOP ships, tropical moorings, reference moorings, and research ships.
Who: Parties' national services and ocean research programmes, through IODE and JCOMM, in collaboration with CLIVAR.
Time-Frame: By 2014.
Performance Indicator: Data availability at International Data Centres.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

Report: Action O11 is a composite one shared with the other programmes listed. The single performance indicator, data availability, is certainly partially met. However, there is no one data centre that provides access to all surface salinity data even from TSGs. It is difficult to know, in fact, what fraction of the total are available much less from a single location. The OSMC in cooperation with GOSUD could improve this (Rec 13).

Recommendations

Rec 1: Considering the strong dependence of good quality measurements on careful installation and maintenance of TSGs, it is suggested that the IRD manual be reviewed to ensure it is up-to-date, and greater prominence on JCOMM should be given to it.
Rec 2: TSGs are installed on many ships and such data are routinely collected. There is little coordination among these groups, and no common practices in handling the data. Some of the data do reach international archives, but little is known of data quality, instrument calibrations, etc. JCOMM in collaboration with IODE should try to bring these groups together and harmonize the data collections, ideally through the GOSUD programme.
Rec 3: Documentation on what processing is done by ISDM on TRACKOB data should be available on its web pages.

Rec 4: There is no mention of the GOSUD project on the ISDM web site nor any explanation of ISDM's role for this project. Such information needs to be documented and closely associated with the information mentioned in recommendation 3.

Rec 5: A detailed description of the processing steps, and quality control procedures are needed at the home web site of GOSUD. A quality control manual is recommended so that users can be fully informed of exactly what is done to the data and why and how data quality flags are set.

Rec 6: The lack of readily available documentation about details of sampling methods, processing, etc. that TSG data undergo before they are presented to users is common. Different programmes provide different levels of detail. All data providers (and not just those collecting underway data) need to provide extensive details so that users can understand impacts on the data that they are using. It is recommended that SOOP and GOSUD should press data providers to this information with their data.

Rec 7: Masking ship identification for real-time data transmission is an inconvenient fact of life for data systems. However, those submitting data in delayed mode should ensure this masking is removed – real ship identifiers are attached – before the data are submitted to archives. JCOMM can make a point of emphasizing at JCOMM Commission and Panel meetings that this be done. Help from IODE should also be sought.

Rec 8: There are some deficiencies in the GOSUD data access interfaces. For example, when selecting TSG data, the map display shows the tracks, but there is no list of platforms provided (reviewer notes this has been resolved). Also, although the TSG archives contain no data other than temperature and salinity, if TSG data type is selected, the list of available parameters is unchanged, which may lead a user to think other kinds of data are present as well. GOSUD should seek an outside review of their web site and provide comments on its usability and suggestions for improvements.

Rec 9: In an ideal world, all groups collecting underway data, or even just underway temperature and salinity measurements would share these measurements in real-time and in delayed mode. However, the data collectors are so dispersed today, that GOSUD can only lay claim to being the largest such archive and dissemination point for these kinds of data. This presents a problem for users wishing all such data. JCOMM with help from IODE needs to identify and strive to recruit data provisions from these many groups.

Rec 10: The FerryBox pilot project was apparently successful, but it is not apparent that the data resulting from the project did get to the intended archives. As it stands now, locating the data on-line is not possible. As for all projects, it is important that the long term archives for the resulting be identified (a reviewer noted it is the BODC), that the data reach the archive, and that the data are readily visible and available. JCOMM and IODE (GOSUD) should pursue these data to have them submitted to their archives along with whatever documentation on collection methods, processing, etc., is still available.

Rec 11: GOSUD has not produced or perhaps simply has not made available annual reports since 2007 through its web site. This is a problem since there is no easy way for someone outside the project to judge how well the project is operating. GOSUD should ensure annual reports are produced regularly and made available through their web site.

Rec 12: The OSMC is a good start at presentations of the observations available for ECVs. It is less successful in showing what is available from JCOMM programmes. There is some overlap, perhaps confusion, in what are the respective monitoring roles between OSMC and JCOMMOPS. This should be resolved and both JCOMMOPS and OSMC should request an outside review of their web sites to provide comments on usability and suggestions for improvements.

Rec 13: It is believed that GOSUD contains the largest fraction of observations of surface salinity made by TSG instruments. At a minimum and as a primary goal, GOSUD should make greater efforts to bring together the groups collecting such data and as possible consolidate the data. In doing so it would make the job of OSMC much easier to display the present availability of such data. This could be done in stages, through a push to identify data sources and provide links from GOSUD web pages. A major contribution would be to coordinate documentation on how the various data sets differ in processing and to gauge the level of duplication between these data sets.

Acronyms

AOML: Atlantic Oceanographic and Meteorological Laboratory
BODC: British Oceanographic Data Centre
BUFR: Binary Universal Form for data Representation
CLIVAR: CLImate VARiability project
csv: comma separated value

ECV: Essential Climate Variable
EMODNET: European Marine Observation and Data Network
ftp: File Transfer Protocol
GCOP-IP: Global Climate Observing System – Implementation Plan
GHRSST: Global High Resolution Sea Surface Temperature
GOSUD: Global Ocean Surface Underway Data programme (of JCOMM and IODE)
GTS: Global Telecommunications System (operated by WMO)
GTSPP: Global Temperature, Salinity Profile Project
HOT: Hawaii Ocean Tine Series
HZG: Helmholtz-Zentrum Geesthacht
ICES: International Council for the Exploration of the Seas
ICOADS: International Comprehensive Ocean-Atmosphere Data Set
IMOS: Intergrated Marine Observing System (Australian)
IODE: International Oceanographic Data and information Exchange
IRD: Institut de Recherche pour le Developpement
ISDM: Integrated Science Data Management (Canadian)
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: JCOMM Observing Platform Support centre
JGOFS: Joint Global Ocean Flux Study
netCDF: network Common Data Format
NIVA: Norsk Institutt for Vannforskning
NMHS: National Meteorological and Hydrological Service
NOAA: National Oceanographic and Atmospheric Administration (United States)
NODC: National Oceanographic Data Centre
OPeNDAP: Open-source Project for a Network Data Access Protocol
OSMC: Observing System Monitoring Center
PSU: Practical Salinity Units
SAMOS: Shipboard Automated Meteorological and Oceanographic System
SMOS: Soil Moisture and Ocean Salinity
SOOP: Ship Of Opportunity Programme
TAC: Traditional Alphanumeric Code
TDC: Table Driven Code
TSG: Thermosalinograph
VOS: Voluntary Observing Ship
WOCE: World Ocean Circulation Experiment
WOD: World Ocean Database
WMO: World Meteorological Organization

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2.1c: SOT - VOS

Introduction

The focus of this chapter is on the data that are collected through the VOS [1] operations ([2] provides a very useful page with pointers to information about many of the resources used in VOS). Members of the VOS are provided at [3]. There are other at sea operations that provide data similar to that delivered by this programme. These other programmes are not well coordinated internationally, but some may be important sources of data and so will be mentioned here.

Data Providers

The VOS component of SOT collects a variety of types of surface marine meteorological data. The full suite of measurements that are considered part of this programme is represented by the variables that are allowed to be reported using the traditional code form, FM-13 SHIP [4] and BUFR [5]. Table 1 provides a list.

Table 1: Marine Meteorological Variables of the VOS

Variable	Variable	Variable
Air pressure	Air pressure change (3 hours)	Dew-point temperature
Dry-bulb temperature	Wet-bulb temperature	Minimum air temperature
Maximum air temperature	Sea surface temperature	Horizontal visibility
Total Cloud cover	Lower Cloud amount	Cloud types (low, middle, high)
Height of base of cloud	Wind speed	Wind direction
Maximum wind gust speed	Minimum wind gust speed	Relative humidity
Past weather	Height of waves and swell	Period of waves and swell
Direction of swell	Ice deposit (thickness)	Rate of ice accretion
Cause of ice accretion	Sea ice concentration	Amount and type of ice
Ice situation	Ice development	Bearing of ice edge

It should also be noted that the FM-13 code form as well as the BUFR template for these data allows for the reporting of a limited suite of metadata that describes the location and time of observations, motion of the ship, the location and the general types of some of the instruments used and so on. All of this information is valuable in particular for operational use, and quality monitoring.

As would be expected, there are a variety of instruments used for this suite of variables, and some of these include human observations, such as for cloud information. WMO has a manual [6] that specifies the required measurement capabilities of instruments to be used. There is a specific section on marine observations that can be consulted. It is not the practice to report the accuracies along with the data.

Measurements collected by the VOS programme are principally provided from commercial vessels carrying goods across the world's oceans. The vessels are recruited to the program by national agencies participating in the VOS. Instruments can be provided by the ship's operators but are checked as often as possible by Port Meteorological Officers, PMOs [7] and returned for recalibration when they drift outside defined tolerances. These individuals have an important role to play in ensuring the proper functioning of instruments on board ship, and providing metadata including the characteristics of the ship, siting and type of the meteorological instruments in use, and calibration dates of instruments. All of this information is to be collected and forwarded to WMO Pub 47 [8]. No information on instrument accuracies is apparent in this publication. Rather, details of the instrument type, make and model are maintained. While this is suitable for present day instrumentation, as an instrument goes out of use, information on its characteristics may be lost to the historical archive (Rec 1). The official version is maintained by WMO but is updated irregularly. A database version is maintained by

E-SURFMAR [9] on behalf of WMO and is available from [8]. This version is updated daily and records provided to WMO. Users can access the full file through [8] or conduct a database query through the link provided by [2] after registering with E-SURFMAR. This version also contains information (e.g. about offshore rigs and platforms) that is not maintained in Pub 47 (Rec 2).

Around 2001 there was the start of a new enhanced project, called VOSClim [10,11]. The main purpose of the VOSClim Project was to provide a high quality sub-set of marine meteorological observations in both real-time and delayed mode with associated information on instrumentation and siting. This started with a subset of VOS ships and was later upgraded by SOT to introduce a dedicated VOSClim class of observing ship and all qualifying ships in the VOS fleet were encouraged to upgrade to VOSClim standards .

It has long been the practice for national VOS programmes to place computer systems on board ships to record weather observations; these are known as electronic logbooks. Initially these were systems that relied on the manual input of data from the various instruments installed on the ship. Examples of such software are the SEAS system [12] developed and maintained by the U.S., the software called TurboWin [13] and TurboWeb developed and maintained by KNMI, and OBSJMA [14] developed and maintained by the JMA. Readers should consult the references for specific information about their functionalities.

In recent years, there has been the development of Automated Weather Stations (AWSs) that include instrumentation and automated measurement recording software. A number of nations are vigorously pursuing this path by equipping their VOS fleet exclusively with such systems. In addition to the increased frequency of observations generated by AWS systems the advantage is that there is a tight coupling of instrumentation to recording systems, and even preparation of the data for reporting using ship's communications channels or included satellite transmission channels. The VOS web pages [15] indicate that AWS systems should measure at least air pressure, pressure change, temperature and humidity. Optional sensors include wind speed and direction and sea temperature measurements. However, the suite of meteorological measurements that can be measured electronically is much smaller than present communications formats allow and have been traditionally reported manually. Some of these systems allow manual input of manual / visual observations if associated with an e-logbook, but this is rarely done at present although the long time series of manual / visual observations are critical to climate studies and applications.

Most of the VOS fleet report data ashore through satellite communications. Which channels are used by which vessel is part of the metadata that appears in Pub 47. At the latest SOT meeting (SOT-7, Apr 2013) it was reported that 25% (in 2012) of ships use Iridium SBD [16] and 15% use the Inmarsat Code 41 service [17] although this latter service accounted for 36% of the visual observations. Other ships use other means, such as those operating under E-SURFMAR. Once ashore the data are reported on the GTS [18] using either FM-13 SHIP or the appropriate BUFR template. The U.S. has detailed information specific to the software it supports on the various ways to get data ashore as well as some general “Frequently Asked Questions” that are useful [19].

In addition to commercial vessels, some fraction of marine weather observations is collected from oceanographic research or other non-commercial vessels most often using automated systems either built by the meteorological agency or by the institute, operating the vessel and some of these record with high frequency sampling rates. Most of these data reach the GTS, that is are received in real-time, as it is a longstanding practice for ships at sea to report meteorological observations. An example of such operations are those coordinated by SAMOS [20].

It is to be noted that sea surface temperature is included in VOS considerations as this is commonly considered a marine meteorological variable to be reported. Of course, this is also considered an oceanographic variable and as such is one of the more common oceanographic measurements made. An example of this cross over between meteorology and oceanography is evident in the SAMOS and the GOSUD [21] programmes. Both of these collect surface temperature and while both encourage real-time exchange in the GTS of these data, not all of the data meet this objective.

Although not formally part of VOS, marine meteorological data are also collected by national navies and by fisheries vessels, sometimes operated by a national agency and sometimes as a commercial fleet. In the case of naval operations, the release of the data is highly dependent on national rules. In most cases, navies are reluctant to release such data in real-time for security reasons. With commercial fishing fleets or individual vessels, the result is the same. Though they collect the data, they do not always provide them to the public because they wish to keep their fishing locations private to protect their commercial interests. For national fisheries agencies, it is rare that they report data in real-time. With respect to delayed mode data, it is known that certain navies will release logbooks, but only many years after. It is also true that fishing vessels have reported their data in delayed mode. That some data from these sources have reached public archives is shown in a report [22] from ICOADS [23].

All of the e-logbooks and AWS have extensive data checking routines built in [12,13,14]. This is typically done before the data are sent over the GTS.

Data Assembly

The GTS [18] operated by the WMO is the distribution network used to exchange marine meteorological data (among other types of data and information) in real-time. As noted above data providers have different avenues for getting data from at sea operations to a NMHS which are the only agencies with direct access to the GTS. Data inserted on the GTS must be in either Traditional Alphanumeric Code forms (TACs), or in a Table Driven Code form (TDC) called BUFR. TACs are in ASCII and the one used for surface marine meteorological data is FM-13 SHIP [4]. In BUFR [5], the data are sent in binary most often using specified layouts called templates. As transition to Table Driven Codes is taking place, Traditional Alphanumeric Codes are gradually being abandoned for the real-time distribution of data through the GTS.

Real-time data assembly is done by NMHSs [24] by accessing the data that come through the GTS. Each uses the data for their own purposes including weather forecasting for their country. Commonly the data are assimilated into atmospheric computer models for short, medium, or long range weather prediction forecasts. Receipt times are very stringent, usually within minutes to two hours of the observation time, so that the data may be assimilated in the next model run.

Delayed mode data are assembled in the IMMT format [25] through the work of the Global Collecting Centers in Germany [26] and the U.K [27]. In brief, these centres cooperate to assemble the observations through the assistance of regional centres under the Marine Climatological Summaries Scheme, MCSS. Data submissions are encouraged to arrive quarterly. More information about operations at the GCCs is provided in the section on processing and archiving.

Processing and Archiving

Real-time data processing and archiving happens at individual NMHSs. Each of these NMHS uses its own procedures to verify the reliability of the surface observations. Often this includes comparisons of the VOS data with NWP first guess fields and with analyses of satellite observations. Climatology is also often used. A simple review of data assimilation is provided by wikipedia [28]. Each NMHS also decides whether to archive the data as received, how to carry this out, and whether any quality flagging information is made available. Readers must contact each NMHS for more information about their operations [29].

Delayed mode data assembled through the MCSS are subject to a variety of operations at the GCCs. These centres employ minimum quality control standards, MQCS - the same are recommended to regional data assembly partners - to ensure uniformity in data quality. The GCCs also check for duplications in observations. Information about these procedures, and about data formats to use are available from the German GCC [30] and WMO [31]. Annual reporting by the GCCs describe data volumes received, quality statistics, formats, standards, etc. Reports dating back to 2001 are available from the German GCC and reports starting in 2003 from the WMO [31].. The web sites of the two GCCs have different information in that some appears at one, but not at the other. It would be better if these sites coordinated content (Rec 3).

A very difficult issue has arisen since the mid 2000's. At the time some commercial vessels wanted permission to hide their ship identifiers (call signs) over concerns of vulnerability to piracy, or in an effort to gain a commercial advantage, or they would withdraw from the VOS. The SOT in an effort to preserve the VOS proposed a scheme, that was agreed to by the WMO Executive Council that would allow the masking of ship identifiers under certain conditions [30]. Implementation of this scheme in real-time has begun, but all of the procedures to ensure that unmasked identifiers come to global archives, such as maintained by GCCs are not yet implemented. This complicates the task of checking data quality since it impedes ship tracking and consequently tests that rely on comparisons of adjacent observations from the same ship and connecting Pub

47 metadata to observations (Rec 4).

The data received at GCCs are then forwarded to ICOADS [23] for inclusion in their archives. At the ICOADS site, there is an extensive bibliography that discusses many aspects of the data contained in the ICOADS documentation but there is no evident single document that provides details of what is done presently to the data (although the processing is discussed in referenced, published papers) before they are incorporated into the ICOADS releases. There is a figure that shows the basic data flow in processing [32], a document that provides detailed translation discussions for each of the incoming data formats [33], and Information about the breadth of content and data characteristics of the latest release (2.5) is available [34]. The latest release has incorporated some metadata contained in Pub 47 and this is an important contribution. The data are available in IMMA format [35] which contains all of the information that can be reported in FM-13 SHIP, BUFR or the IMMT format [25] used for delayed mode exchange. But as none of these formats provides space for reporting instrument accuracies and precision, IMMA does not carry this in any consistent way. Instead, instrument names are used as a proxy for this. The site does note [36] that ASCII documents are being converted to pdf forms but that this is not complete. As it stands, the most complete document that describes the processing [37] is in ASCII form and is dated from 1993. There is no indication of feedback given to data providers or agencies as data are being processed, although from personal experience the author knows this does occur. ICOADS sponsors the CLIMAR series of workshops [38] where there is substantial interaction with the data providers and user community. Results are published in special editions of the International Journal of Climatology [39]. There is a wealth of information present, but it is difficult to sift through (Rec 5). ICOADS provides some products [40] including extensive sets of monthly statistics.

There is a project, called RECLAIM [41]. Its web site states that it is “A cooperative international project to locate and image historical ship logbooks and related marine data and metadata from archives across the globe, and to digitize the meteorological and oceanographic observations for merger into the ICOADS and for utilization for climate research.”. While the website includes a wealth of valuable (U.K. and U.S. primarily) scanned publications and documentation, and its Marine Data Rescue report [22] is updated periodically, it also shows a report from only one meeting almost ten years ago, and so it would seem that the project is struggling to continue.

There is another project, called Old Weather [42] whose objective is to “Help scientists recover Arctic and worldwide weather observations made by United States’ ships since the mid-19th century. “. It is an outreach arm of the ACRE project [43] that uses a “citizen science” model to invite the interested public to volunteer to digitize historical data. Other projects currently active in historical ship data rescue include ERA-CLIM [44] and Germany’s “HISTOR” project. The ACRE web site [43 under the “data tab”] provides links to other data rescue projects.

The WMO's CCI [45] also has a Task Team dealing with data rescue, but its main focus appears to be on land based records.

Data rescue of historical records also happens in different countries as records turn up and financial resources are found. There is also some discussion of developing a network of a small number of CMOCs within the JCOMM MCDS [46] to spearhead such efforts. It is not clear how well all of these data rescue efforts are coordinated (Rec 6).

An issue that arises when dealing with historical records is the format of the data. WMO manages the format for the real-time reporting of data. In the past, FM-13 SHIP was used and now BUFR is the required form. The manuals describing these formats are well maintained by WMO and documented in the Manual on Codes No. 306 [5]. However, over the many years these codes have been in use, there have been many changes made. Some earlier versions of the Manual on Codes still exist and a spreadsheet of who holds these is available [47] as well as what exists at WMO and provides access to some versions [48]. Ensuring these earlier versions are preserved is important because not only are formats described, but the manuals also specify the regulations about how to encode data into the formats (Rec 7) and this is needed to understand historical observing methods.

Data Dissemination

Real-time data can be obtained through the WIS [49] although it is unclear if all surface ship data can be found at any one site. Also, the most recent available file (search conducted in late May 2013) appeared to be from April 2013. If not all, then most of the files appear to be in BUFR format and contain data as extracted from the GTS. Also, since these are data as extracted from the GTS, they presumably have no additional data quality checking than is done before data are inserted onto the GTS. As of May 2013, WIS is still being implemented so that not all of the objectives that have been set are realized. Users wanting access to more timely data, or data with additional checks having been performed will need to contact their national NMHS.

ICOADS [40] provides another source of global data through the cooperating US organizations, primarily now NCAR and NCDC. NCAR provides both bulk observational and product access, or web-based subsetting capability into simple spreadsheet ready formats, for both the ICOADS observations, in IMMA format. and monthly summary products (a one-time free registration is required). NCDC also provides access to ICOADS and to some other marine data sets, some simply data as they are received, and some with additional processing and checking, including VOSClim data. Data are provided in their own ASCII format and in netCDF [50]. Documentation of each is provided. They also provide LAS access. It appears that surface marine data from the previous month is the most recent that can be accessed (a query conducted in late May 2013 for that month's data resulted in an error). Data from up to the previous week are available from NCEP that is linked from the ICOADS site.

ICOADS has also begun (under NOAA Climate Program Office funding 2011-13), development of an ICOADS Value-Added Database, IVAD [51] , with the aim to make the results of research activities available alongside the observations such as bias adjustments for different parameters, observational and platform metadata, and estimates of data uncertainty. IVAD will also provide a mechanism for researchers to exchange information. It has also been proposed to expand and formalize this activity internationally under ETMC.

In the U.S. many of data sets at the National Weather Service and NCDC are available in formats that are able to be imported directly into Geographic Information Systems, GIS. Data formats include downloadable shapefiles, web services and KML files [52, 53]. Other weather services may offer data and products in this way, but they are not readily apparent from their web sites (Rec 8).

Considering access to delayed mode data, there is no link to the data sets archived by the GCCs on their web sites. However, the data are available through the WIS [49] (Rec 9).

ICOADS is the most comprehensive data set although it is not updated on a regular schedule. It is, however, extended forward monthly in near-real-time in the form of “preliminary” GTS-based observations and products. It provides a relatively simple, but extensive, selection of gridded monthly products [40] and a link to some visualization tools for its statistical products. It needs to be noted here that the support of ICOADS remains uncertain, although operationalization of key components and personnel from NOAA Research to NCDC (and NCAR) has progressed substantially since budget problems arose in 2012. This is an international resource, albeit supported presently by a single nation (Rec 10). Recently efforts have been initiated, including support by Germany and UK, to strengthen ICOADS through international partnerships. This proposed partnership is also planned to facilitate possible future formalization of ICOADS as a CMOC under the MCDS.

Considering national programmes, the U.S. Integrated Ocean Observing System (IOOS [54]) Program's mission is to "lead the integration of ocean, coastal, and Great Lakes observing capabilities, in collaboration with Federal and non-Federal partners, to maximize access to data and generation of information products, inform decision making, and promote economic, environmental, and social benefits to our nation and the world. The Program works closely with the eleven regional associations to establish core capabilities that meet both national requirements and regional user needs”.

As part of the U.S. IOOS Data Management and Communication (DMAC [55]) core services, the U.S. IOOS Program Office has initiated a sustainable, community-based project to establish authoritative procedures for quality assurance, QA, and quality control, QC, of real-time ocean sensor data collected for U.S. IOOS”. The data availability at this site is focused on ocean data and a national perspective but certain atmospheric observations, such as air pressure) are available.

Differences Between Distributed Data Sets

IOOS: provides documented standards for QA/QC for a variety of data types. It relies on data providers to execute these. It is a portal to US data in real-time. Data are available in netCDF.

WIS: is a global information system for WMO. It includes the GTS in particular for the real-time distribution of time critical data. Real-time data as extracted from the GTS are available from the previous month and older. The data format is usually BUFR. Delayed mode VOS data are available through a link to the GCCs.

GCCs: The primary archive for delayed mode VOS data. Data are provided in the IMMT format and have all passed through minimum quality control standards.

ICOADS: Provides access to VOS data combined with data from other sources (e.g. surface drifters, moored buoys, etc.). There is extensive checking of the data and harmonization of formats and content from the various input sources. Data are packaged into releases after processing is completed. The most recent spans years from 1662 to 2007, plus preliminary GTS data extend the record forward in near-real-time in monthly updates.

NCDC: Provides access to the most recent GTS data that is one week or older. Data are as extracted from the GTS and are available in a either netCDF or an NCDC ASCII format.

User Communities

There are two distinct communities using the VOS data. The real-time data community are the national weather prediction groups in NMHSs [e.g. 56] who require very timely reporting of surface observations to be assimilated into numerical weather prediction models. VOS are an important component providing the in-situ data to complement the satellite derived observations which are also used. They carry out their own assembly, processing (data checking for errors and duplications) and archiving. Some NMHSs provide real-time data feeds to external groups needing such rapid access but this needs to be arranged with the NMHS.

Those external to the GTS and who do not require immediate access use the data in air-sea interaction studies. Historical data contained in ICOADS are used in constructing the surface flux data set provided by NOC [57] as well in reanalysis studies.

Monitoring and Performance Metrics

The GTS data distribution system is not perfect. The GTS is a “store and forward” system where data are routed in “bulletins” which identify the originating centre. Each receiving node on the GTS has a set of tables specifying which bulletins get routed to nodes connected to it. Because of errors in routing tables, a receiving node may not be sent all of the data that it wants. The WMO conducts regular monitoring to catch such problems [58]. ETMC has a 2011 report [59] discussing the advantages of using data from multiple GTS streams.

E-SURFMAR monitors the real-time data by comparing differences between observed values and model output [60]. A user can look at statistics for a single ship, can look at ships that have been flagged with systematic differences (errors), or simple reporting volume statistics. This is a useful service, open to anyone without the necessity of registering at the site.

The UKMO provides for the monitoring of surface marine data, and producing useful monitoring statistics (e.g. biannual report on the quality of marine surface observations, VOS monthly monitoring reports, VOS time of receipt statistics, and annual VOS ranking list) on its dedicated website [61].

JCOMMOPS [62] provides a variety of monitoring products to show the status of participation in VOS. Maps of monthly and yearly line sampling are shown. It is also possible to look up some information from Pub 47 through a link on this site. Another link provides query tools to look at reporting and quality performance of individual ship's measurements.

From the above site a link takes a reader to pages maintained by the BoM in Australia [63]. Here there are links to various products offered by the UKMO, the VOSClim DAC, and Météo France. Note that some of these require a username and password.

ICOADS via its home page [23] also updates monthly some basic data flow monitoring plots for the VOS plus other platform types included in ICOADS. Also, in the latest release of ICOADS, there is an important figure [64] showing the decline in VOS reporting in recent years.

SOT publishes meeting and annual reports [65] in which a report by the VOS chair and some monitoring information can be found. While informative, the SOT annual report could be improved to better show how performance metrics for the VOS are met, and how well the programme is operating against its objectives (Rec 11).

The Unites States funded Observing System Monitoring Center [66] provides a variety of tools to examine the status of observing systems. On the home page is found a composite map of all observations in the last three days, or more if desired. It also provides some capability to display on Google Earth projections. Some additional comments follow.

- Under the "In Situ Monitoring tab, there are some deficiencies (such as using programme names that are not necessarily clear to all users – NWLON. There is also the inclusion of US programmes, though this site obviously has a dual purpose, and it is missing some JCOMM observing systems – SOOP, VOS. However, when "all programs" is selected and a particular parameter it seems quite good.
- Under the "Observing System Metric Reports" tab and after selecting "XBT" there is a useful listing of XBT drops along SOOP lines. This needs perhaps to include the other measurements included in SOOP, such as XCTDs, though these are few. When selecting this tab, the name on the tab changes to "OOPC status reports" which seems odd. Also, one of the selections is labeled "psbe" and what this is not obvious to users.
- Selecting the "Observing System Metrics" tab has this name change to "Climate Services". I also note that the "OSMC Viewers" link results in an error. As noted previously, this is a bit confusing. (Changing tab names is a common thing and it is not obvious why this is useful).The displays here can be for selected parameters, which can be a nice presentation for an observing system. The presentation of time series is interesting, but difficult to read and it was not clear how to print this display rather than the associated map.
- Presentations based on all platforms for a selected parameter is approaching what is needed for an ECV perspective.

Information from this site would be a good addition to an annual report for the SOOP observing system (Rec 11). There are a few problems with this site (Rec 12).

GCOS-IP (2010) Performance Indicators [67]

Key Action 18: Parties need to provide global coverage of the surface network by implementing and sustaining: (a) the GCOS baseline network of tide gauges; (b) an enhanced drifting buoy array; (c) an enhanced Tropical Moored Buoy network; (d) an enhanced Voluntary Observing Ships Climatology (VOSClim) network; and (e) a globally-distributed reference mooring network.

Report: Documentation from the last SOT meeting (SOT-7, doc 7.2) notes that an evolution of the entire VOS fleet to VOSClim standards is underway. At present there are 430 vessels meeting these standards. These figures are based on statistics derived from the E-SURFMAR database. There are known to be inaccuracies in content of the database and these need to be addressed so that the progress of this evolution can be tracked from year to year with confidence. Such figures should be more prominent on the VOS web pages (Rec 13).

VOS is also noted in text of section 4.1.1 as important for surface air temperature, air pressure, and wind speed and direction at the ocean surface and later it is noted, in reference to AF2, as a contributor to improved observations of air temperature and water vapour over the oceans.

Report: There is no reporting on the volumes or spatial distributions of ECVs. This could be done from the real-time data stream, or by the GCCs (Rec 14).

Action O6 [OF3]

Action: Improve meta-data acquisition and management for a selected, expanding subset of VOS (VOSClim) together with improved measurement systems.
Who: Parties' national services and ocean research agencies through JCOMM VOSClim.
Time-Frame: VOSClim meta-database in place by 2006. Continuing improvement to data streams.
Performance Indicator: Greater use of VOS data in climate products. Successful completion of initial phase of VOSClim.
Cost Implications: Category II.

Report: SOT-7 documentation remarks on the importance of improved metadata for vessels in the VOS fleet. It instructs VOS Focal Points to pursue this (Rec 15).

Action O10 [OF5]

Action: Obtain global coverage, via an enhanced drifting buoy array (total array of 1250 drifting buoys equipped with atmospheric pressure sensors as well as ocean temperature sensors), a complete Tropical Moored Buoy network (~120 moorings) and the improved VOSClim ship fleet.

Who: Parties' national services and research programmes through JCOMM, Data Buoy Cooperation Panel, and Tropical Mooring Implementation Panel.

Time-Frame: Complete by 2009.

Performance Indicator: Data submitted to analysis centres and archives.

Cost Implications: Category III.

Report: The JCOMMOPS, ICOADS, and OSMC provide some roles in this. OMSC seems the best place to take this on since it requires combining observations from more than one observing system.

Section 5.1.2 notes "The ability to exploit historical and contemporary data sets (of SST) is affected by the limited amount of metadata typically available; this is especially true when dealing with the VOS data". VOS is noted as a contributor to observations of sea surface salinity, pCO2, and sea state. In section 5.2.1, VOS is noted as a contributor to observations of ocean currents and potential to contribute to observations of biogeochemical and ecosystem variables.

Recommendations

Rec 1: Pub 47 (and presumably the version at E-SURFMAR) contains names of instruments used for the various meteorological measurements. It does not contain the basic characteristics of the accuracy and precision, nor details about how the instrument functions. Such information is valuable to keep with the historical data so that differences in measurement capability over time, and their impacts on observation reliability can be known. Fact sheets on each instrument could be assembled from the manufacturers and preserved. Appropriate groups (perhaps WMO, E-SURFMAR, JCOMM, SOT, ETMC, ICOADS, CCl) should plan and implement the preservation of such information. The VOS Panel should lead this activity.

Rec 2: The version of Pub 47 maintained by E-SURFMAR contains more information, is more actively maintained, and more searchable than the version maintained at the WMO website. It is recommended that E-SURFMAR and WMO develop appropriate arrangements such that the more functional version at E-SURFMAR be considered the primary or sole version or the WMO version be upgraded. With this, certain functions and documentation of the contents of Pub 47 should be more readily available to the public. For example, a list of fields and a description of contents should be readily accessible.

Rec 3: As an example of differences, the German GCC has a data flow diagram that is absent from the UKMO site. It is recommended that these two sites harmonize content and presentation. As well, there is no link to the data sets archived by the GCCs, and no reference to the format of that data set (although a description of IMMT format implies this is the delivery format). The data are available through the WIS, but a direct link from the GCC web site is recommended.

Rec 4: Masked call signs are still being received at GCCs and this makes the task of quality control more difficult. SOT and partner groups need to accelerate the implementation of a widely acceptable unmasking scheme that allows for unmasked data to become available immediately to legitimate users, and in delayed mode (after some agreed upon delay) through publicly available archives such as those at the GCCs and the ICOADS.

Rec 5: ICOADS is an important data collection but the documentation that describes its preparation and processing procedures is difficult to find and information is scattered. There is a stated intention to convert the documentation to pdf forms. This needs to happen as soon as possible and a revision in the organization of information will be necessary so that all of the data management information is brought together.

Rec 6: Adequate international coordination of the rescue and digitization of surface marine data is not evident and this is noted in a recent MARCDAT report [68]. JCOMM can take steps to improve this by encouraging discussions and coordination. A single website that at least identifies all of the groups (and chairs) and their sphere of contribution would be a first step. The ACRE initiative is seeking to organize many of these activities internationally in support of reanalyses, including a broader scope of data types (e.g. land stations) for historical VOS data. A more coordinated effort similar to that undertaken by the IOC GODAR project [69] should be considered.

Rec 7: The WMO Manual on Codes 306 has been the official guiding document for how data should be encoded into formats for transmission on the GTS. Earlier versions of these Manuals and of similar manuals (e.g. the International Maritime Organization, predecessor to WMO), national observing instructions, and related Commission reports (e.g. CBS and CMM) should be preserved to ensure that past observing practices, coding tables, and code forms are well documented. These are important in supplementing data rescue activities. It is recommended that JCOMM strengthen collaboration with the CCl and CBS to achieve this.

Rec 8: A simple search on Google for meteorological web services turned up sites in the U.S. that provide data and other products in these forms. No other NMHSs turned up. If an NMHS provides such access, it should be easier to find with a simple web search. It is recommended that JCOMM through CBS request that all NMHSs that do provide web services provide web pages that explain this.

Rec 9: It would seem logical that GCCs should have access advertised on their web sites for the data sets that they compile. It is recommended that If they do provide access, that this is much clearer that at present. If they do not, this should be explained, and a link provided to where the data can be obtained.

Rec 10: Given the uncertain funding for ICOADS and the international importance of maintaining and even enhancing its maintenance, JCOMM should investigate what it can do to improve the funding, share the workload, or other measures that will stabilize ICOADS operations.

Rec 11: VOS annual reporting needs to provide graphics to illustrate how well it is meeting is objectives. Some relevant material can be found in scattered reports and on web sites (ICOADS as well). However, an improved annual review with text and graphics that show performance against objectives and illustrates issues that may have arisen would be appropriate.

Rec 12: The OSMC web site is an important contribution to monitoring the implementation of JCOMM programmes. The origins of the “Observing System Metrics” should be explained somewhere. For example, why the statistics, grid resolution, and what are the appropriate ones for the variables? The differences and complementary natures of OSMC and JCOMMOPS should be documented.

Rec 13: Figures showing the progression of the VOS fleet to VOSClim standards need to be generated, with appropriate corrections in the metadata held in Pub47. These figures need to be prominent on the VOS web site.

Rec 14: The GCOS-IP notes the importance of VOS in a number of ECVs. Reporting of the volumes and spatial distribution of sampling of ECVs observed from the VOS fleet should be developed and prominent on VOS web pages and appear in annual reporting.

Rec 15: Showing improvement in the metadata held on the VOS fleet is not a simple matter. Those managing the metadata (WMO, E-SURFMAR) should exchange ideas on how this might be done and try to implement some method that demonstrates progress.

Acronyms

ACRE: Atmospheric Circulation Reconstructions over the Earth
AWS: Automated Weather Systems
BoM: Bureau of Meteorology (Australia)
BUFR: Binary Universal Form for data Representation
CBS: Commission on Basic Systems (of WMO)
CCl: Commission for Climatology (of WMO)
CIMO: Commission for Instruments and Methods of Observations (of WMO)
CLIMAR: Workshop on Advances in Marine Climatology
CMM: Commission on Marine Meteorology (of WMO)
CMOC: Centres for Marine-Meteorological and Oceanographic Climate (data)
DAC: Data Assembly Center
DMAC: Data Management and Communications (a component of IOOS)
ECV: Essential Climate Variable
ERA-CLIM: European Reanalysis of Global Climate Observations
E-SURFMAR: European Union Surface Marine Programme
ETMC: Expert Team on Marine Climatology

GCC: Global Collecting Center (JCOMM)
GCOS-IP: Global Climate Observing System – Implementation Plan.
GODAR: Global Ocean Data Archaeology and Rescue
GOSUD: Global Ocean Surface Underway Data project
GTS: Global Telecommunications System
ICOADS: International Comprehensive Ocean and Atmosphere Data Set
IMMA: International Maritime Meteorological Archive format
IMMT: International Maritime Meteorological Tape format
IOOS: Integrated Ocean Observing System (U.S.)
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: JCOMM Operations Support Centre
JMA: Japan Meteorological Agency
KML: Keyhole Markup Language
KNMI: Royal Netherlands Meteorological Institute
LAS: Live Access Server
MARCDAT: MARine Climate DATa workshops
MCDS: Marine Climate Data System (of JCOMM)
MCSS: Marine Climatological Summaries Scheme (of JCOMM)
MQCS: Minimum Quality Control Standards (of the MCSS)
NCAR: National Center for Atmospheric Research
NCDC: National Climate Data Center (U.S.)
NCEP: National Centers for Environmental Prediction (U.S)
netCDF: network Common Data Format
NMHS: National Meteorological and Hydrological Service
NOAA: National Oceanic and Atmospheric Administration
NOC: National Oceanographic Centre (of the UK)
OSMC: Operation Support Monitoring Center
PMO: Port Meteorological Officer
QA: Quality Assurance
QC: Quality Control
RECLAIM: RECovery of Logbooks And International Marine data project
SAMOS: Shipboard Automated Meteorological and Oceanographic System
SBD: Short Burst Data (Iridium transmitter)
SEAS: Shipboard Environmental data Acquisition System
SOOP: Ship Of Opportunity Programme
SOT: Ship Observations Team (of JCOMM)
TAC: Traditional Alphanumeric Code
TDC: Table Driven Code
UKMO: United Kingdom Meteorology Office
VOS: Volunteer Observing Ship
VOCClim: VOS CLIMate ship
WIS: WMO Information System
WMO: World Meteorological Organization

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2.2: Data Buoy Cooperation Panel (DBCP)

Programme Objective

The Data Buoy Cooperation Panel, DBCP, [1] is a Team of the Observations Programme Area, OPA, of JCOMM. It describes itself as " an international program coordinating the use of autonomous data buoys to observe atmospheric and oceanographic conditions, over ocean areas where few other measurements are taken". It organizes its activities through a number of action groups [2] that for the purposes of this report will be divided into separate chapters dealing with surface drifters, with data from the Tropical Moored Buoy Implementation Panel, TIP, and with data from OceanSITES.

Programme Overview

The TIP and groups on surface drifters both existed prior to the creation of JCOMM. The surface drifter programme grew out of the FGGE [3] in the late 1970's. The TIP grew from the TOGA [4] programme in the mid 1980's. These both expanded their operations over time until they are what exists today. OceanSITES began in the late 1990's to provide a series of deep water reference stations collecting a broad suite of oceanographic and atmospheric observations.

There are some 286 people listed in the DBCP, representing more than 35 countries. A list of contacts for DBCP activities are available [5] from the web site.

Acronyms

DBCP: Data Buoy Cooperation Panel
FGGE: First GARP Global Experiment
GARP: Global Atmospheric Research Programme
JCOMM: Joint Commission on Oceanography and Marine Meteorology
OPA: Observations Programme Area
TIP: Tropical Moored Buoy Implementation Panel
TOGA: Tropical Ocean – Global Atmosphere programme

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2.2a: DBCP - Surface Drifters

Introduction

The focus of this chapter is on the data that are collected through the DBCP [1] surface drifter Action Groups [2]. The specific groups involved are the GDP, all of the Regional Groups and the Southern Ocean Buoy Program. Members of the DBCP are provided at [3]. There are other programmes that provide surface oceanographic and meteorological data like those delivered by the DBCP. The other programmes that are part of or associated with JCOMM are treated in other chapters of this report.

The following sections offer detail about the DBCP drifter programme. Much of this was derived from the DBCP web site which provides comprehensive documentation on all aspects of the programme. A reader of this report should go to this web site first.

Data Providers

The workhorse instrument used in the surface drifter programmes is the Lagrangian drifter, which is deployed in the open ocean, and described at the DBCP web site [4]. However, other types of drifters are also used for specific applications, in particular on ice and the web page provides a brief discussion of the drifters used in ocean water, and on ice. Greater detail on the open water drifters is given at [4 under the “platform types” tag] and at the GDP web site [5]. (A reviewer notes that there is a publication “WOCE Surface Velocity Programme Barometer Drifter Construction Manual, A.L. Sybrandy, et al.; WOCE Report No. 134/95, SIO Report No. 95/27, September 1995.” but it does not appear available from any web site.) There is also a detailed publication by Lumpkin and Pazos [6] that provides an interesting history (as of 2006) of the evolution of the current generation of the standard drifter. As part of this description, they discuss the drogue, an important part of the equipment, that ensures that the drifter responds to surface currents rather than the wind. It should be noted that drifter design is always evolving to take technology advances into consideration, lessons learned, as well as cost-effectiveness which means that the documents cited here may be dated.

The DBCP site has a wealth of information (under the “Platforms” tag on the left sidebar) covering all aspects of operations with surface drifters. This includes a number of documents describing best practices, on deployments, sensor calibrations, satellite telecommunications, and message formats. All drifters are equipped with a thermistor to measure sea surface temperature. It is common to equip the drifter with additional sensors, including a barometer for surface pressure, sensors for near-surface salinity, surface wind speed and direction, and subsurface temperatures. Pressure tendency is derived from the time history of pressure measurements. The documents on instruments and calibrations provides minimum specifications for each of the sensors.

The “Community > Standards / Best Practice” tag discusses telecommunications issues, including a review of satellite systems and more information under the “Platforms > Telecommunications” tag. Important information is also provided on message formats to get the data ashore.

The DBCP home web site is rich in the practical information that it provides to prospective participants and to document the operations of getting instruments into the water and reporting data (Rec 1).

Virtually all of the observations made by surface drifter operators fall under the coordination of the various Action Groups. These are organized with a single global program, the GDP, and regional groups for different oceans areas. There are usually a couple of hundred drifters deployed at any given time that do not meet the GDP specifications of a drogue centred at 15-m. One example of this, the IABP, concentrates on the deployment of drifters on Arctic sea ice, often deployed without a drogue. Each Action Group has web pages dedicated to their activities that list, among other information, the members of the Group, meeting reports, and practical operational information such as deployment plans. The layout of each Group's pages are different to reflect different foci and the more important elements for that area.

There are other, intermittent surface drifter operators, such as those used in at-sea search and rescue operations by some countries. Generally these are not in the deep ocean and operate only for the duration of the operation. These data may or may not enter the data systems for the DBCP, but because of their limited spatial and temporal operations, the loss of such data has little impact.

Data Assembly

Data are transmitted ashore from platforms in a few different ways. DBCP provides a “Buyers Guide” and a review [7] to assist participants. This document presents a detailed comparison of the capabilities of each of the satellite systems that are available to get data ashore. There is important information here, especially describing bandwidth issues that operators should consider, as well as estimates of costs.

The GTS operated by the WMO [8] is the distribution network used to exchange meteorological data, and in particular surface drifter data in real-time. Again, the DBCP provides useful information and links (see the “Data” -> “Sharing Your Data” tag) on how data gets onto the GTS and formatting issues.

Most of the data from surface drifters are inserted onto the GTS through Service Argos [9]. Their operations are highly automated with conversions for the data streams coming from individual buoys to the message formats used on the GTS. These conversions happen quickly, so that data from a single buoy received by two different satellites arriving some minutes apart will generate 2 different GTS messages. It is common for these to have different content and this can complicate subsequent data processing.

Automatic quality control procedures are applied to the data before GTS distribution. These are described in a DBCP publication [10]. Additional quality control procedures for salinity data are provided in another DBCP publication [11]. The DBCP has also developed quality information feedback mechanism from buoy data users to the buoy operators to allow corrective action to be made relatively rapidly when systematic errors are detected [12].

Real-time data assembly for the DBCP is carried out by the ISDM, group in Canada [13]. ISDM has been a part of the data system since the days of FGGE and took on responsibility as a global archive for managing these data for IODE in the mid 1980's. ISDM assembles all of the surface drifter data that are sent over the GTS. Data arrive at ISDM continuously in groups of messages called bulletins and are accumulated for processing once a month. Incoming data files are preserved in case they need to be consulted. A list of the bulletins carrying data is provides by JCOMMOPS [14].

Real-time data streams now appear on the GTS in two forms. Data are still encoded in the FM-18 BUOY code form, an ASCII form, and in a FM-94 BUFR template. Both of these are documented at WMO [15] (BUOY in Volume I.1 and BUFR in Volume I.2, but also consult the templates). ISDM also provides an unofficial description of the BUOY code form [16]. As transition to Table Driven Codes (e.g. FM-94 BUFR) is taking place, Traditional Alphanumeric Codes such as FM-18 BUOY are gradually being abandoned for the real-time distribution of data through the GTS. ISDM handles both BUOY and BUFR. As of 2013, the data arriving in BUOY and BUFR are not identical, but because of differences in how data move from buoys to the GTS by Service Argos or Iridium, it will take an in depth study to verify which data stream is the more complete. At present (2013), ISDM still uses the BUOY form for its archives, but the BUFR data are also preserved.

The BUOY code form contains some metadata but the BUFR template is much better at handling more information. In addition, the BUOY code form contains information about who inserted the data onto the GTS and when this was done in the information attached to each received bulletin. This is all stored in the ISDM archives.

Global data assembly also takes place at the GDP Data Assembly Center [17]. They provide documentation of the operations at the centre which has been in place for more than 10 years.

Processing and Archiving

The DBCP web pages provide lots of information about data processing [18] and archives for surface drifters. This provides a useful starting point for information about what agencies are involved. More attention is paid to the information available on the site in the section on dissemination and on monitoring.

As noted, each month, all of the data received (in 2013 more than a million messages each month) is passed through processing at ISDM. There is little detail on the ISDM website to explain what is done, but an outline of procedures is available [19]. The data from both BUOY and BUFR messages are assembled into a calendar month file, with more recent data being set aside for next month. Usually this is done a few days after the end of a month to ensure all of the data from the target month have arrived. The data are translated into an internal format and a comparison is made of the messages received in the two different message streams. Duplicates are removed. As remarked above, data are inserted on the GTS by Service Argos after each satellite pass, so that a drifter may report information on a few successive orbits or from different satellites in view. Depending on the time that the satellite and drifter are in view, different amounts of data may be received. This means that there can be multiple reports with varying content from the same buoy on the same satellite pass. These are identified and merged. It is also the case that some data are inserted on the GTS by more than one GTS insertion point, and these messages may have different content. ISDM maintains a ranking scheme based on the insertion point that eliminates messages from a lower ranked node if the content is identical or with less information. After this screening, data pass through a quality control procedure that uses automated techniques and technician intervention if needed to flag data that lie outside of expected values. After this, the data are updated to the local archives.

The GDP at AOML receives raw, non-GTS data from Service Argos daily and in monthly dispatches from programmes whose Principal Investigators have given permission for this. Their objective is to derive surface velocity estimates from analyzing drifter tracks, accompanied by high quality sea surface temperature measurements. They provide a series of documents on various aspects of this work including two that describe how the data are processed [20]. Their data files also carry along the surface pressure and other observations, but the GDP does not quality control barometric pressure observations; this is done by Météo France using their QC tools (see text in the Monitoring section). After careful editing, the GDP produces sea surface temperature and position interpolated to six hour values. A more detailed summary is provided in the “Drifter Quality Control Procedures Presentation” link on their web site [20]. All of these data are archived at AOML. They send their processed files, including interpolations, to ISDM for long term safekeeping and to provide a redundant archive.

A complication in processing the data encountered at both centres is related to the reuse of WMO and Argos number identifiers on drifters. Because of the many drifters deployed over the years, the set of five-digit identifiers is limited. Early in the development of the programme, it was realized that these identifiers would need to be reused after a drifter ceased transmitting. In most circumstances this does not cause a major problem. Sometimes the time between an older drifter ceasing operation and the reuse of the WMO number is so short that the data from the two different drifters appear in the same GTS data stream when carrying out data checking. But perhaps more importantly, users looking at portions of archives that cover many years, will need to be aware that the same identifier will occur more than once. The GDP uses the Argos number of a drifter as its key identifier and when the ID is reused, a two digit deployment year is concatenated to the front of the five-digit drifter identifier. ISDM keeps the deployment year in a separate field. In some cases using just the year does not separate out the data from two different deployments.

Both centres have backup plans in case communications are lost or hardware failures take place. If errors are detected in the data at ISDM, contact is made with the Technical Coordinator at JCOMMOPS [21] and that person notifies operators or takes other action as appropriate. The GDP notifies Service Argos of drifters that appear to have lost their drogues so that an indicator in the GTS message can be properly set in ongoing reports from the drifter.

The data held by ISDM and by the GDP exist in different formats. The ISDM archives store the data in the same data structures as used for GTSPP data [22]. At the GDP there is no description of how the data are stored in their archives, but there is a description [23] of the format used to distribute the data. (A reviewer provided this information: “Information on how the data are stored in GDP archives and quality control procedures can be found in http://www.aoml.noaa.gov/phod/dac/Training_CD.pdf (under “Delayed Mode Quality Control Procedures”, and there is a description [20] of the format used to distribute the data through the web and a published paper on processing procedures, QC and interpolations in the peer reviewed literature, by Hansen, D.V. and P.-Marie Poulain, 1996 (http://www.aoml.noaa.gov/phod/dac/Hansen-Poulain_QC.pdf)” The author was unable to find the link to the Training CD).

When ISDM receives the data files from the GDP, there is some work carried out to ensure a consistent naming of buoys between what exists in the ISDM GTS data files and those coming from the GDP so that if users want to compare, the task is easier.

ISDM routinely contributes the GTS data to the ICOADS project [24] so that some of the variables (e.g. sea surface temperature, air pressure) can be incorporated in their archives. Before inclusion, ICOADS also carry out tests on data quality. On first glance this appears redundant, but it provides a second set of checks, carried out independently that sometimes identifies problems that were missed. When this happened in the past, there was some reprocessing that took place at ISDM to respond to the problems identified.

There is an extensive bibliography that discusses many aspects of the data contained in the ICOADS documentation but there is no evident single document that provides details of what is done to the data before they are incorporated into the ICOADS releases. There is a figure that shows the basic data flow in processing [25], a document that provides detailed translation discussions for each of the incoming data formats [26], and Information about the breadth of content of the latest release (2.5) is available [27]. The data are available in IMMA format [28] which contains all of the information that can be reported in BUOY code form or BUFR. The most complete document that describes the processing [29] is in ASCII form and is dated from 1993. There is no indication of feedback given to data providers or agencies, although from personal experience the author knows this does occur. There is a wealth of information present, but it is difficult to find (Rec 2). ICOADS provides some products including monthly statistics.

Data from the ISDM contributes to the World Ocean Database [30] and appear in monthly updates. As delayed mode data replace real-time, these are incorporated into the updates. All data, described in [31] entering the WOD, not just data from the surface drifter programme, undergo the same quality checking procedures, as described in [32].

Data Dissemination

The DBCP site provides a page [18] that references the major data access points for drifter data. For users needing near real-time data and interpolations to six hour intervals, it points to ISDM and the GDP, both providing data free of charge to all users. The paragraphs below provide brief information about these two sites.

At ISDM there is a simple data selection interface [33] for ASCII copies of the most recently processed data (normally some days after the end of a calendar month) (Rec 3). The data are available in a number of different formats [34]. ISDM provides a separate access to the data processed by the GDP [35]. They also provide a good description of this data product [36]. Data are available up to the end of 2012. In addition to this, ISDM sends all BUOY data transmitted on the GTS from buoys with sensors reporting subsurface measurements at more than one depth to the GTSPP CMD, three times a week. Such data may include measurements of temperature, salinity and horizontal current velocity.

Additionally, ISDM provides a service that allows users to receive the most recent data coming from the GTS. This is designed for those users who lack ready access to the GTS, or lack the processing needed to deal with the message formats used on the GTS. These data are available with a selection of area, and every day although there is little to no quality checking done. This service is not advertised and must be negotiated with ISDM [37].

The GDP provides access [38] to data and metadata for their interpolated data (all in ASCII files with data structures defined by them). Metadata (e.g. drifter identifier, type, type of drogue and operation period) are available through an ftp interface (see [20] and follow the "Details of all drifters..." tag). It is also possible to subset the metadata by area of drifter operation and time frame. Similar capabilities are provided for accessing the data files and a description of the data format. In this case, a selection process for one particular drifter is also provided. If any of the selection processes is chosen, the files are prepared offline and an email notification sent when the files are ready. The GDP also provides a map interface to recent GTS data for the selection of drifters [39].

The DBCP references the U.S. NODC [40] that provides a subset of surface drifter data [41]. Some of these data go back to before ISDM and the GDP started operations (ISDM in 1985, GDP during WOCE) although the GDP includes all data with holey-sock drogues centred at 15m going back to 1979. Users wanting complete archives to data from other drifter designs as far back as data exist, will need to consult them

The French Coriolis programme [42] also provides access to real-time data extracted from the GTS. The data from the current day and earlier in time are available there. Users should note that for the most recent data, there may be errors still present. Documentation about their quality control procedures are also provided [43].

The ICOADS [44] provides access to their holdings which are a compilation of data from a variety of sources, not just surface drifters. They provide data in the international IMMA format [45] or their own ASCII form. They provide access through three connections, one through NCAR that has restrictions, one through NOAA/NCDC that has data in yearly files, and one through NOAA/ESRL/PSD that contains only more recent ICOADS data.

WOD [30] provides access to their holdings, which like ICOADS, is a compilation of data from all kinds of oceanographic instruments. The WOD provides a data selection service (free of charge) as well as detailed tools and documentation on how to read the data and use the tools. Data are provided in a WOD format or a comma separated file format.

The Ocean Data Portal, ODP [46], is a free data distribution system put in place by the IODE [47]. The ODP aims to provide seamless access to collections and inventories of marine data from the NODCs of the IODE network and allows for the discovery, evaluation (through visualization and metadata review) and access to data via web services. The system architecture uses Web-oriented information technologies to access non-homogeneous and geographically distributed marine data and information. Data sets are provided on a volunteer basis by participating NODCs. Users need to consult the provider of the data set to learn what processing has been done. In the case of surface drifter data, the ODP provides access to the data received at ISDM from the GDP and available in netCDF [48] format.

Differences Between Distributed Data Sets

ISDM: provides near real-time data taken from the GTS after quality control with some operator scrutiny on a monthly basis, plus data from buoys with sensors at more than one depth, three times a week. The data format allows for tracking any changes or reasons for flagging and lists tests performed and failed. Data can be delivered daily, though with little to no data checking. The data format is ASCII. It also provides access to interpolated data from the GDP.

GDP: provides access to metadata and data delivered from Service Argos interpolated to values every six hours. This product is created after extensive quality checking procedures. The data are available in ASCII.

U.S. NODC: provides access to historical data that precedes operations of ISDM or the GDP as well as more recent data. Data are delivered in netCDF through an on-line interface.

WOD: provides all types of ocean data after quality control. Objective analysis allows identification of bull's eyes. Interpolations are provided to standard levels. The data set includes more than surface drifter data. Data are available in a custom ASCII format or comma separated value format.

Coriolis: provides drifter data taken directly from the GTS and data are available within hours of transmission. The most recent data may still have errors but data made available within days to weeks of observation will have been checked. Data are available in netCDF.

ODP: is a distribution system only. Data are provided by different NODCs with different processing and quality control. For surface drifter data, ODP provides access to a copy of the data from the GDP provided to ISDM and in netCDF.

User Communities

The DBCP site lists a number of uses of buoy data [49]. These include uses in conjunction with other data by both meteorological and oceanographic operational services. Commonly, the drifter data received from the GTS are assimilated into Numerical Weather Prediction models for short, medium, or longer range weather forecasts. and forecast products. This reference also provides links to some impact studies that discuss the contribution of surface data on observing systems.

The data are used in operational conditions for emergency response. Example incidents include oil spills and search and rescue operations.

The academic community also uses the data. Hundreds of peer-reviewed publications analyzing ocean currents and surface dispersion using the drifter data are documented in a GDP bibliography (see [20] and follow the "Information" > "Bibliography" tags)). One recent example (see Ryan et al., 2014) used the drifter data in concert with other data to analyze the connectivity of regions of the Gulf of Mexico during the Deepwater Horizon oil spill.

Monitoring and Performance Metrics

Global monitoring products are available from the various archives noted above. ISDM provides monthly maps [34] of the locations of surface drifter data reported on the GTS.

Upon data assimilation of drifter data into the models, the UK MetOffice provides for the monitoring of surface marine data, and it producing useful monitoring statistics (e.g. biannual report on the quality of marine surface observations [50]). Buoy monitoring statistics are also produced by ECMWF, Météo France, and NCEP. In addition, E-SURFMAR offers a number of quality monitoring tools on the web [51].

The GDP provides a chart of the content of the GDP archive [52]. They provide a series of products [20] including status maps from the equatorial Pacific and other ocean basins, population maps (number of drifters) with various properties, trajectory maps and some other presentations. They have a series of mean velocity estimates, animations and other products that can prove useful.

The DBCP data access page [18] references maps available from Météo France that shows information about the last 10 days of data returned from active buoys. Displays are provided one buoy at a time.

DBCP references a quality control Relay tool [53] that allows reporting by authorized persons of apparent problems seen in data from actively reporting drifters. The information is routed to the drifter operator to take appropriate action.

The DBCP references “Monthly Monitoring Statistics”, provided by analysis centres that also provide feedback on the quality of the data delivered by all drifters. Documentation on how these statistics are produced is also provided.

The DBCP pages on “Data – Quality Control” links to monthly monitoring statistics provided by Météo France. These are maps [54] showing statistics by 10° squares for surface pressure, air temperature sea surface temperature and winds derived from ship and buoy observations.

The “Network Status and Maps” tab [55] shows a variety of displays including a series of monthly maps showing a selection of location maps for buoys with different operating characteristics including platforms by country, barometer drifters and moorings, barometer upgrades by country, satcom type, GTS delays, number of drifter deployments and density maps. The DBCP website also has a Google Earth file and an interactive ArcIMS Map that is updated on daily locations. When selecting a platform, detailed metadata on the operator and contact information is made available (Rec 4).

JCOMMOPS provides a series of displays on the performance of drifters over time [56]. Part of the selection allows by type of drifter although this uses abbreviations that may be unrecognizable to a user. Also, the most recent data appears to be from August 2010 (Rec 5). (A reviewer notes this product is no longer available and will be replaced when new web pages are finished). There are other monitoring products (select the “monitoring” tab and one of the items that shows up). Some of these point to products already discussed and some are unique to JCOMMOPS (Rec 6).

There is also a variety of other useful information at JCOMMOPS including information about instrumentation, deployment opportunities, national focal points, etc. But this information is buried and difficult to find.

The Unites States funded Observing System Monitoring Center [57] provides a variety of tools to examine the status of observing systems. On the home page is found a composite map of all observations in the last three days although other time periods may be selected. There does not appear to be any documentation that describes the origins of the data used for these displays, or other information that would help a user to know how these are derived (Rec 7). It also provides some capability to display on Google Earth projections. Some additional comments follow.

- Under the “In Situ Monitoring tab, there are some deficiencies (such as using programme names that are not necessarily clear to all users – NWLON. There is also the inclusion of US programmes, though this site obviously has a dual purpose, and it is missing some JCOMM observing systems – SOOP, VOS. However,

when “all programs” is selected and a particular parameter it seems quite good.
- Under the “Observing System Metric Reports” tab and after selecting “Drifting Buoys” there is a useful listing of statistics on drifters operating in total and by country. There were some small differences in counts of drifters between the “In Situ Monitoring” and this one when a count is made for the first quarter of 2013. There was also a difference in counts for March 2013 between here and the DBCP monthly maps. In this latter case, the difference is more than 10% (Rec 8).
- Selecting the “Observing System Metrics” tab has this name change to “Climate Services”. It was also noted that the “OSMC Viewers” link results in an error. As noted previously, this is a bit confusing (changing tab names is common on this site and it is not obvious why this is useful). The displays here can be for selected parameters, which can be a nice presentation for an observing system. The presentation of gridded statistics is good.
- Presentations based on all platforms for a selected parameter is approaching what is needed for an ECV perspective.

The DBCP web pages do not have an obvious link to annual reports. A search using these keywords produced a reference to a report from 2003 only. While it is not necessary to produce such a report, these can be helpful reports to give to outside agencies seeking some overview of operations, such as GCOS (Rec 9). (A reviewer notes that Annual Reports, etc are maintained on the WMO web site and a link is available from [1] by following “Community” > “Documents”. When the author prepared the original draft report, this link was not present or missed).

GCOS-IP (2010) Performance Indicators

Within the GCOS-IP (2010 update) [58] the DBCP operations are mentioned in Action 8, listed here.
Action O8 [IP-04 O10]
Action: Sustain global coverage of the drifting buoy array (total array of 1250 drifting buoys equipped with ocean temperature sensors), obtain global coverage of atmospheric pressure sensors on the drifting buoys, and obtain improved ocean temperature from an enhanced VOS effort.
Who: Parties’ national services and research programmes through JCOMM, Data Buoy Cooperation Panel (DBCP), and the Ship Observations Team (SOT).
Time-Frame: Continuing (sustain drifting buoy array and enhance VOS by 2014).
Performance Indicator: Data submitted to analysis centres and archives.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

Report: Both the DBCP and OSMC sites provide counts of operating buoys in the total array, although there are some differences in this number (see comments earlier and Rec 8). Both of these sites currently report fewer than the target 1250. Between these two sites there is sufficient capability to determine how well the target is being met.

Recommendations

Rec 1: There is no recommendation on what else could be provided on the DBCP pages related to observing system instrument operations. The recommendation here is that the other observing systems look at what DBCP has done and emulate their information content.
Rec 2: As noted as well in recommendations in the VOS chapter, it is recommended that ICOADS assemble their documentation of processing into a more complete document and give it greater prominence on their web site.
Rec 3: The data access pages at ISDM allow for requesting data only as recent as 2010. But on a different page, users can see there are data available from as recently as 2013. It appears that not all pages are up-to-date in providing access to data. This needs to be corrected.
Rec 4: The monthly maps displayed in the 'Network Status” area on the DBCP web pages were maps from March 2013 when viewed in mid June, 2013. It should be expected that at least April would have been available, and more likely May. These maps should be kept current.
Rec 5: The drifter performance displays at JCOMMOPS use perhaps obscure abbreviations for the type of buoy (e.g. MB = moored buoy?). These should be spelled out. Also the most recent data is from 2010 and this product should be kept up to date.
Rec 6: The JCOMMOPS monitoring interface is at times obscure in that sometimes abbreviations are used (see Rec 5) and sometimes not. As a whole, there is no simple description of what a particular monitoring

product is and so a user is left to try them out to see what results. The interface lacks explanations and this should be remedied. The DBCP pages provide a better model in explaining what a person gets by clicking on a link.

Rec 7: The OSMC site is quite a good start towards having a comprehensive view of the state of observing systems both system by system and by ECV. What is presently missing is documentation that explains the origins of the data used in these displays and what processing, if any, is done.

Rec 8: The differences in counts of operating buoys between that shown on the DBCP site and at OSMC should not be as large as it apparently is. An effort should be made to compare how these counts are derived and to settle on one. If this is not sensible for some reason, explanations about how the counts are arrived at should be provided.

Rec 9: DBCP should consider if an annual report should be prepared chiefly for audiences outside of the DBCP wanting an overview of operations. There is much material available already for such a report such that the work to assemble such a report should be relatively easy.

Acronyms

AOML: Atlantic Oceanographic and Meteorological Laboratory
BUFR: Binary Universal Form for data Representation
DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate Variable
FGGE: First GARP Global Experiment
GARP" Global Atmospheric Research Programme
GCOS-IP: Global Climate Observing System – Implementation Panel
GDP: Global Drifter Programme
GTS: Global Telecommunications System
IABP: International Arctic Buoy Programme
ICOADS: International Comprehensive Ocean-Atmosphere Data Set
IMMA: International Maritime Meteorological Archive format
IODE: International Oceanographic Data and information Exchange
ISDM: Integrated Science Data Management
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: JCOMM Observing Platform Support center
NCAR: National Center for Atmospheric Research
netCDF: net Common Data Format
NOAA/NCDC: National Oceanic and Atmospheric Administration / National Climatic Data Center
NOAA/ESRL/PSD: National Oceanic and Atmospheric Administration / Earth System Research Laboratory / Physical Sciences Division
NODC: National Oceanographic Data Centre
ODP: Ocean Data Portal
OSMC: Observing System Monitoring Center
WOCE: World Ocean Circulation Experiment
WOD: World Ocean Data project
WMO: World Meteorological Organization

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2.2b: DBCP - Tropical Moorings (TIP)

Introduction

The focus of this chapter is on the data that are collected through the DBCP Tropical Moored Buoy Implementation Panel [1]. The DBCP is part of the JCOMM OPA. The specific groups involved are the TAO [2], TRITON [2] (Rec 1), PIRATA [3] and RAMA [4] groups. More information presented by the NDBC is also available [5] (Rec 2). Overview of the activities, terms of reference [6] and members of the TIP are provided at [7,8] (Rec 3). Countries and agencies presently providing support include the United States (NOAA / PMEL, NDBC, AOML), Japan (JAMSTEC), France (IRD), Brazil (INPE. DHN), India (INCOIS, NIO, NIOT), Indonesia (KKP, BPPT), China (FIO), and Australia (UTAS, CSIRO, BOM),

The other programme that provides surface oceanographic and meteorological data from moored platforms is OceanSITES and is described in another chapter. There are a few moorings (linked through the map of mooring locations) considered part of RAMA that are overseen by the ASCLME Project [9]. Only the meteorological or physical oceanographic data are treated in this chapter. There are other programmes that provide at-sea measurements (that are part of or associated with JCOMM) and these are treated in other chapters of this report.

Though not part of a question of access to data, where this report is focused, it is worthwhile to note that cruises to service moorings, also deploy instruments and make other marine observations. As well, the moorings can provide platforms for other observations. Examples of how cruises and platforms are used include the deployment of drifting buoys and Argo floats, placement on moorings of CO_2, O2 and other biogeochemical measurements, data collection on cruises of CTD profiles, acoustic measurements and atmospheric aerosols. These cruises are an important resource to the global marine community.

The following sections offer detail about the DBCP moored buoy programme. Much of this was derived from the DBCP home [7] and moored buoy action group web sites [2,3,4,5].

Data Providers

A nice description of the history, development and other information of the TAO / TRITON array is available [10] (and mirrored at [NDBC). It began after the large 1982-83 El Nino event. In 1984 a prototype ATLAS buoy was tested and deployments began under the TOGA programme. The full array was completed in 1994 at the end of TOGA. The importance of the array has been recognized by CLIVAR, GOOS and GCOS. In 2000, a partnership with JAMSTEC resulted in the joint support of the TAO / TRITON array.

The PIRATA web site provides a very brief history [3] as does RAMA [4] (Rec 4).

The DBCP web page on “Standards / Best Practices” [11] provides information on deployment techniques, sensors, manufacturers, satellite communications, among other information.

Additional information for the different groups is also available. Technical details of the buoys and instruments for TAO [12] and TRITON [13,14] are available, though the information provided for TAO is much more extensive (Rec 5, Rec 6). Technical information on PIRATA moorings [15] s is similar to the information provided for TAO moorings since the same technology is used in both programmes. RAMA technical information [16] references that for TAO / TRITON (Rec 7). (A reviewer noted there is a new set of web pages (http://tao.ndbc.noaa.gov/proj_overview/mooring_ndbc.shtml with updated information. This is not yet connected to the DBCP links.)

Information is available on sensors deployed on the TAO [12], TRITON [14], PIRATA [12] and RAMA [16] moorings. Information is also provided on calibrations, and operations of the different instruments by some of these. (Rec 8).

The TAO subgroup lists sensor information [17] for measurements of wind velocity, air temperature and pressure, relative humidity, rainfall, downwelling short and long wave radiation, surface and subsurface water pressure, temperature, salinity and currents. The same information also applies to PIRATA moorings since they use the same ATLAS buoys. The TRITON site [18] lists similar details for its suite of measurements: wind velocity, air temperature and pressure, relative humidity, rainfall, downwelling short wave radiation, surface and subsurface water pressure, temperature, salinity and currents. RAMA [19], using TRITON and ATLAS buoy measures the same suite of variables.

The PMEL web site [20] provides information on current and past cruises, as well as other useful field operation information. NDBC [21] provides recent, on-going and future cruise information for TAO. The PIRATA site [3] also provides lists of cruises conducted (Rec 9). (A reviewer noted that PIRATA and RAMA information cruise information is also available but see later text).

Data Assembly

Data can come ashore from platforms in a few different ways. The DBCP web page [22] describes how data generally get ashore from moorings. This reference provides a link to detailed information comparing the capabilities of each of the satellite systems that are available to get data ashore. There is important information here, especially describing bandwidth issues that operators should consider, and estimates of costs. More precise information for TAO and PIRATA [23] is available separately (Rec 10).

The GTS operated by the WMO [24, and links at 22] is the distribution network used to exchange meteorological data and information and in particular mooring data in real-time. Again, the DBCP [7] provides useful information and links (see the "Data -> Sharing Your Data" tab) on how data onto the GTS and formatting issues. TAO meteorological data and daily ocean profile data are available in SHIP (FM-13) and BUOY (FM-18) formats.

The data from the TRITON buoys (those operating in the Pacific Ocean – part of TAO / TRITON – and those in the Indian Ocean – part of RAMA) are collected from the buoys by Service Argos which then undertakes data processing, automatic data quality control, and encoding, and inserts the data onto the GTS in BUOY code and BUFR in hourly reports. Each report contains information from all variables measured. The data coming from ATLAS buoys (those operating in the Pacific Ocean – part of TAO / TRITON - those in the Indian Ocean – part of RAMA – and those in the Atlantic Ocean - PIRATA) are formatted in buoy and BUFR as well.

(A reviewer noted that the automatic quality control procedures applied to the data before GTS distribution are described in a DBCP publication (DBCP Technical Document no. 37, Guide to buoy data quality control tests to perform in real-time by a GTS data processing centre: ftp://ftp.wmo.int/Documents/PublicWeb/amp/mmop/documents/dbcp/Dbcp37-QC/DBCP37-QC-Guide-v1.pdf). The reviewer also noted that additional quality control procedures for salinity data are provided in another DBCP publication (DBCP Technical Document no. 42, Sea Surface Salinity Quality Control processes for potential use on Data Buoy observations: ftp://ftp.wmo.int/Documents/PublicWeb/amp/mmop/documents/dbcp/DBCP42-Salinity-QC/DBCP42-Salinity-QC.pdf). In fact reference to draft versions of both of these documents can be found on the DBCP web pages [11] under "Community" > "Standards"). The DBCP reference should be updated).

Real-time data streams now appear on the GTS in two forms. Data are encoded in the BUOY code form (an ASCII form) and in a BUFR template. Both of these are documented at WMO [25] (BUOY in Volume I.1 and BUFR in Volume I.2 but also consult the templates). ISDM also provides an unofficial description of the BUOY code form [26]. As transition to Table Driven Codes (e.g. FM-94 BUFR) is taking place, Traditional Alphanumeric Codes such as FM-18 BUOY are gradually abandoned for the real-time distribution of data through the GTS. At present ISDM handles both BUOY and BUFR. At present, the data arriving in BUOY and BUFR are not identical, but because of differences in how data move from the buoys to the GTS by Service Argos [27] or Iridium [28], it will take an in depth study to verify which data stream is the more complete. At present, ISDM still uses the BUOY form for its archives, but the BUFR data are also preserved.

The BUOY code form contains some metadata but the BUFR template is capable of holding more information. In addition, information about who inserted the data onto the GTS and when they did so is available in the information attached to each received bulletin.

Each action group assembles data from their moorings. Real time data from ATLAS moorings in TAO, PIRATA and RAMA are telemetered to shore and are distributed to the GTS by CLS America, Real time and delayed mode ATLAS data from TAO/PIRATA/RAMA are processed at PMEL [23] and distributed through web pages. TAO ATLAS data are also processed at NDBC and distributed via the web. TAO Refresh data (this term has appeared since the draft report was prepared and appears to reference more modern equipment) are telemetered to shore via Iridium to NDBC, where they are processed and distributed to the GTS and via the web. TRITON [29] uses Service Argos to receive the data and formats them to insert onto the GTS. JAMSTEC distributes TRITON data via the web. PMEL and NDBC collect TRITON data from JAMSTEC for distribution on their respective web sites. PMEL collects TAO refresh data from NDBC for distribution on PMEL's web site. Data from FIO's ATLAS equivalent mooring (known as Bai-Long) is telemetered ashore via Iridium and processed by FIO. PMEL collects these data from FIO for inclusion in their RAMA web site 30] (Rec 11). FIO does not distribute their data on the GTS, though this is planned.

Global real-time data assembly from moored buoys is also carried out by the Integrated Science Data Management (ISDM) group in Canada [31]. This includes capturing, processing and archiving of whatever moored buoy information is transmitted over the GTS in BUOY or BUFR templates. In addition to this, ISDM sends all BUOY data transmitted on the GTS from buoys with sensors reporting at more than one depth to the GTSPP CMD, three times a week, including variables such as temperature, salinity and horizontal current velocity.

Processing and Archiving

The DBCP web pages [11] provide general information about data processing and archives for data from moored buoys. Each subgroup provides details.

The TAO web site [32] describes in detail the tests that are performed on the data sent daily in real-time, then on weekly and monthly files. Data are also recovered in delayed mode from the buoys when they are serviced and the quality control procedures are also well described. The same procedures are used for PIRATA and RAMA measurements. NDBC performs comparable procedures on TAO data. (A reviewer provides this link: http://tao.ndbc.noaa.gov/proj_overview/qc_ndbc.shtml for more information about the QC. This does not seem to be connected to DBCP, or NOAA pages).

The TRITON web site provides pages describing their procedures (see the "data information section at [33]) separated into documents by the type of measurement or sensor. They don't provide the level of detail that is seen on the TAO site, but they state that the "quality control procedure and quality indices basically follow those performed by PMEL ..." (Rec 12). They also describe sensor drift tests based on pre and post deployment calibrations.

Because RAMA deployments mostly make use of ATLAS and TRITON buoys, the data processing follows procedures as described for these moorings.

There is no available information about archiving procedures, though all of the data from the four subgroups flow to PMEL (Rec 13). (A reviewer noted that NODC archives TAO, PIRATA and RAMA data from PMEL and TAO data from NDBC. There should be some easily found statement of this. Also, there was a comment regarding the degree of fragmentation in archiving data in the past, and some question if this was being addressed. Attention was drawn to
http://www.jcomm.info/index.phpoption=com_oe&task=viewDocumentRecord&docID=13061).

PMEL routinely contributes the data to the ICOADS project [34] so that some of the variables (e.g. sea surface temperature, air pressure) can be included there. ICOADS also perform a series of checks on the data. On first glance this appears redundant, but it provides a second set of checks, carried out independently that sometimes identify problems that were missed.

Data from moored buoys captured by ISDM undergo simple, automated quality control procedures only.

Data from the TIP are incorporated into the World Ocean Database [35] and appear in monthly updates. As delayed mode data replace real-time, these are incorporated into the updates. All data, described in [36] entering the WOD, not just data from the mooring programme, undergo the same quality checking procedures, as described in [37].

Data Dissemination

The DBCP site provides a link to data access but this only provides references for drifting buoys (Rec 14).

PMEL provides a variety of data display tools [38] (and see also the "Display and Delivery Page" link at the bottom of this page). These include summary plots of data from each buoy, horizontal geographic plots of values measured, time series plots, section plots, a variety of other plots and animations. These are quite useful in exploring the data to see how much is available and to look for interesting features in the data.

NDBC [5] provides a different set of displays of variables in ten-day intervals (Rec 15). Plots of variable time series, horizontal geographic plots, depth section plots and time-longitude displays. These are also useful to examine what data are available and what features may be present in the data.

A primary data access site for all moored data is available from PMEL [39 and the extra link noted at 38]. It provides data searches by ocean, time frame, variable with different averaging periods and delivery formats in ASCII or netCDF [40]. FTP access is also provided (accessed by the "Display and Delivery Page" link on [38]). An interface not requiring the use of java is also provided. NDBC [5] mirrors the same interface as PMEL, but only for Pacific Ocean moorings (TAO / TRITON). The delivery through ftp as netCDF files supporting OpeNDAP [41] access is provided.

At the ICOADS site, there is an extensive bibliography that discusses many aspects of the data contained in the ICOADS releases but there is no evident single document that provides details of what is done to the data before they are incorporated into the ICOADS releases. There is a figure that shows the basic data flow in processing [42], a document that provides detailed translation discussions for each of the incoming data formats [43], and Information about the breadth of content of the latest release (2.5) is available [44].

The ICOADS holdings are a compilation of data from a variety of sources, not just moored buoys. They provide data in their own form and in the international IMMA format [45] (both of these are in ASCII) which contains all of the information that can be reported in BUOY code form or BUFR. The most complete document that describes the processing [46] is in ASCII form and is dated from 1993. They provide access through three connections, one through NCAR that requires user registration, one through NOAA/NCDC that has data in yearly files, and one through NOAA/ESRL/PSD that contains monthly summaries and only more recent GTS data. There is no indication of feedback given to data providers or agencies, although from personal experience the author knows this does occur. There is a wealth of information present, but it is difficult to sift through it all. ICOADS provides some products including monthly statistics.

WOD [47] provides access to their holdings, which like ICOADS, is a compilation of data from all kinds of oceanographic instruments. The WOD provides a data selection service (free of charge) as well as detailed tools and documentation on how to read the data and use the tools. Data are provided in a WOD format or a comma separated file format.

As noted above ISDM captures, processes and archives the data from moored instruments that report their data in BUOY code or in the buoy BUFR template. Except for the data from buoys with sensors at more than one depth, these are not routinely distributed to users. They are sent yearly to NOAA/NODC and can be requested from ISDM.

Differences Between Distributed Data Sets

ICOADS: Provides access to moored buoy data combined with data from other sources (e.g. VOS, surface drifters, etc.). There is extensive checking of the data and harmonization of formats and content. Data are packaged into releases after processing is completed. The most recent spans years from 1662 to 2007, plus preliminary GTS data extend the record to near-real-time monthly.

ISDM: Provides near real-time data taken from the GTS in BUOY code on a monthly basis, plus data from buoys with sensors at more than on depth, three times a week. Data received in BUFR template are stored but not merged with the BUOY code form data. Data pass through simple, automated quality control and are archived. The data format allows for tracking any changes or reasons for flagging and lists tests performed and failed. Data can be delivered daily. The data format is ASCII. Access to the data is provided upon request.

PMEL: Provides access to all equatorial moored buoy data from TAO/TRITON, PIRATA, and RAMA. Data undergo extensive quality checking. Real-time data are replaced by delayed mode data as they are processed. There are useful displays of data availability and values of measurements made. Data access is on-line in a variety of formats. PMEL mirrors data held at NDBC.

NDBC: Provides access to moored buoy data from TAO/TRITON. There are useful displays (different from those available at PMEL) of data availability and values of measurements made. Data access is on-line in a variety of formats.

WOD: Provides all types of ocean data after quality control. Objective analysis allows identification of bull's eyes. Interpolations are provided to standard levels. The data set includes more than surface drifter data. Data are available in a custom ASCII format or comma separated value format.

User Communities

The impetus for equatorial mooring in the Pacific was the large El Nino of 1982/83. This remains a primary focus and supports the interested user community. PMEL [48] provides an extensive presentation on this. There is also an extensive list of publications [49] treating scientific contributions not only to El Nino studies, but broader ocean circulation, heat content, surface fluxes, hurricane forecasting, monsoons, the Indian Ocean Dipole, the Madden-Julian Oscillation, etc. A bibliography of RAMA publications is available from [50]. (A reviewer noted that AOML contains a bibliography related to PIRATA at http://www.aoml.noaa.gov/phod/pne/publications.php. The author could find no link to this from PIRATA pages).

The moored buoy data received from the GTS are assimilated into Numerical Weather Prediction models for short, medium, or longer range weather forecasts.

Because the data are on the GTS and used in operational atmosphere-ocean modelling, they also contribute to emergency response. Example incidents include oil spills and search and rescue operations.

The academic community also uses the data for basic research. A perusal of the publication lists noted above show the diversity of uses of the data.

Monitoring and Performance Metrics

The DBCP “Network Status & Maps” page [51] (pointing to displays from JCOMMOPS) shows maps about the last month of data returned from active buoys. Moored buoy locations (in the context or all other measurements), those measuring air pressure and the sensor complement by platform are shown. Past months are also available. The presentation, despite being global, is a useful and readable summary of what data have arrived in real-time (Rec 16).

DBCP also provides an ASCII formatted list of all active platforms which, when imported to a spreadsheet, can be sorted by platform type to highlight information from moored buoys. While the list appears quite clumsy, it is not and there is much useful, operationally important information there.

The DBCP has also developed quality information feedback mechanism from buoy data users to the buoy operators to allow corrective action to be made relatively rapidly when systematic errors are detected [52].

The JCOMMOPS monitoring tab [53] provides access to a variety of information on buoy platforms. In a number of cases, drifting and moored buoys are not separated early on in the query which makes it less useful. (Rec 17).

Upon data assimilation of drifter data into the models, the UKMO provides for the monitoring of surface marine data, and it producing useful monitoring statistics (e.g. biannual report on the quality of marine surface observations [54]. Buoy monitoring statistics are also produced by ECMWF and NCEP.

E-SURFMAR, part of Météo France, offers a number of quality monitoring tools on the web [55].

(A reviewer provided a link to a status page at PMEL: http://www.pmel.noaa.gov/tao/global/status/. There does not appear to be any connection to this page from [2] through the “Project Overview” tab or any other).

The Unites States funded OSMC [56] provides a variety of very nice tools to examine the status of observing systems. On the home page is found a composite map of all observations in the last three days though other periods may also be selected. There does not appear to be any documentation that describes the sources of the data used for these displays, or other information that would help a user to know how these are derived (Rec 18). It also provides some capability to display on Google Earth projections. Some additional comments follow.

- Under the "In Situ Monitoring" tab, there are some deficiencies (such as using programme names that are not necessarily clear to all users – NWLON, inclusion of U.S. programmes, though this site obviously has a dual purpose, missing some JCOMM observing systems – SOOP, VOS). However, when "all programs" is selected and a particular parameter it seems quite good.
- Under the "In Situ Monitoring" tab and after selecting "Tropical Moored Buoys" and "Refresh Map" I get a nice display of only the equatorial buoys. Then further qualifying by "Sea Level Pressure" the application cannot finish the request. This behaviour is not consistent from one attempt to another, so perhaps it is a question of system loads.
- Presentations based on all platforms for a selected parameters is approaching what is needed for an ECV perspective and will be dealt with in that chapter.

The DBCP web pages do not have an obvious link to annual reports. A search using these keywords produced a reference to a report from 2003 only. While it is not necessary to produce such a report, these can be helpful reports to give to outside agencies seeking some overview of operations, such as GCOS (Rec 19). (A reviewer notes that Annual Reports, etc are maintained on the WMO web site and a link is available from [7] by following "Community" > "Documents". When the author prepared the original draft report, this link was not present or missed).

GCOS-IP (2010) Performance Indicators

Within the GCOS-IP (2010 update) [57] the DBCP TIP operations are mentioned in two Key Needs and in Actions 11 and 27 listed here.

Key Need 21: Parties need to provide global coverage of the surface network by implementing and sustaining: (a) an enhanced network of tide gauges; (b) an enhanced surface drifting buoy array; (c) an enhanced tropical moored buoy network; (d) an enhanced voluntary observing ship network including salinity measurements; (e) the surface reference mooring network, (f) a globally-distributed plankton survey network; and (g) international coordination of coral reef monitoring.

Key Need 22: Parties need to provide global coverage of the sub-surface network by implementing and sustaining: (a) the Argo profiling float array; (b) the systematic sampling of the global ocean full-depth water column; (c) ship of opportunity trans-oceanic temperature sections; and (d) the tropical moored buoy and reference mooring networks referred to in Key Need 21 above.

Action O11 [IP-04 O15]
Action: Implement a programme to observe sea-surface salinity to include Argo profiling floats, surface drifting buoys, SOOP ships, tropical moorings, reference moorings, and research ships.
Who: Parties' national services and ocean research programmes, through IODE and JCOMM, in collaboration with CLIVAR.
Time-Frame: By 2014.
Performance Indicator: Data availability at International Data Centres.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

Report: Surface salinity in the equatorial buoy networks is being measured consistently at all buoys in the Pacific and Indian Oceans, albeit with some outages at times. In the Atlantic, 17 of 20 buoys measure sea surface salinity consistently.

Action O27 [IP-04 O28]
Action: Complete implementation of the current Tropical Moored Buoy, a total network of about 120 moorings.
Who: Parties national agencies, coordinated through the Tropical Mooring Panel of JCOMM.

Time-Frame: Array complete by 2011.
Performance Indicator: Data acquisition at International Data Centres. Annual Cost Implications: 30-100M US$84 (20% in non-Annex-I Parties).

Report: As of July, 2013 there are 113 moorings operating as part of the TAO / TRITON, PIRATA and RAMA arrays. There are additional sites along the equator in the Pacific Ocean, that are inactive. There are a few sites in the Atlantic and Indian Oceans that are also inactive.

Recommendations

Rec 1: The URL provided to TRITON on the DBCP Action Groups page does not function at all. This needs to be fixed.
Rec 2: There are two URLs for TAO/TRITON. The link on DBCP pages for TAO goes to http://www.tao.noaa.gov/ (an NDBC page) while the URL accessed through the RAMA page points to http://www.pmel.noaa.gov/tao/. This latter looks to be the more comprehensive page, but there is no obvious link to the NDBC page. These differences need to be reconciled.
Rec 3: The JCOMM pages describing members of the action groups related to moored buoys (which is the link provided from the DBCP pages) only points to TIP and it only lists 3 members. Is this really true? No links exist for TRITON, PIRATA or RAMA. Members of these should be provided. (The “Contacts” list from DBCP for the evaluation subgroup lists Bill Burnett which, I believe, is out of date).
Rec 4 : A more extensive history of objectives and progress would be welcome for PIRATA and RAMA.
Rec 5: The URL in [12] points to a “TRITON moorings” link (under “Related Links”) which does not load. This needs to be fixed. Also, almost all of the information provided from [12] applies to TAO moorings. A correct link to the TRITON information limited to moorings is provided in [13] although a better one is [14] (see Rec 6, 7 as well). If TAO / TRITON are a unified programme, the web pages describing the moorings of TAO and TRITON need to provide the same breadth of information for both. The present situation is inadequate.
Rec 6: A link to TRITON is provided by [14] that appears nowhere on the DBCP, TAO / TRITON pages (only indirectly through the RAMA page). This is indicative of the dispersed aspect of information about the TRITON moorings. This needs to be pulled together, with the DBCP pages providing the unifying aspects of the mooring programmes, and each being as well documented as TAO.
Rec 7: The technical information on “moorings” for RAMA points to “ATLAS, TRITON” links. The TRITON link goes to a page where there is another link to TRITON which when followed is probably the best for describing TRITON (see Rec 5). As well, the RAMA page notes “equivalent moorings”. Though it seems RAMA is in a state of being built, the technology and characteristics of these other buoys needs to be properly described.
Rec 8: Information about the four programmes (TAO, TRITON, PIRATA, RAMA) should be standardized across them all. For example, the TRITON pages (reference 14) provide a link to calibration and sampling information that is not apparently available from the other sites, or described differently. This means that someone looking to get a unified view of the tropical mooring programme needs to “fish around” to do so. A better coordination of information presentation is needed or if there are reasons for different information, this needs to be explained
Rec 9: TAO / TRITON, PIRATA and RAMA sites provide lists of past cruises and some cruise reports from these. NDBC and TRITON provide no such information. The most recent cruises listed at PMEL are from 2006 which seems unlikely. Links at PMEL point to NDBC pages for future cruises (though none are listed). Presenting such information appears to be a good idea, but the implementation is inconsistent across the various relevant sites. If this information is useful, some updating and consistent presentation should be maintained. (A reviewer noted that there are future cruises to be found at NDBC pages and this is true. This seems to have changed since the draft report was prepared.)
Rec 10: There is no information on how data get ashore from the TRITON moorings. It is assumed that ATLAS moorings of RAMA use the same methods as for TAO, though this should be stated. The stubs for appropriate links for such information exist at the DBCP “Community – Standards / Best Practices” link (http://www.jcommops.org/dbcp/community/standards.html) but they have no associated URLs
Rec 11: RAMA does not discuss how data get ashore from their moorings, but since they use TAO and TRITON buoys, it appears the data come to these latter two groups. What happens to the data from “equivalent moorings” is not explained at all. This information needs to be provided. Since there is some commonality to how data get ashore, perhaps the DBCP site is the best place to describe this.
Rec 12: The presentation of information at the TRITON web site is good, but it uses a small area which results in

much scrolling up and down. The authors should consider expanding the area for information presentation.

Rec 13: Some details about the data archiving procedures, such as system used, backup and recovery procedures, internal formats, etc., would be welcome.

Rec 14: The data access links on the DBCP site only points to sites providing surface drifter data. This should be extended to include links to sites providing moored buoy data (presumably PMEL, NDBC, and others?).

Rec 15: The data displays at NDBC are nice, but it is unclear how the time period selection impacts the display. It would appear that for a query, 5 plots are produced of 10 day periods counting back 5 days from the most recent date selected. So, choosing data for Jul 6-11 results in 5 plots starting with Jun 30-Jul 10, and ending with Jun 26-Jul 6. This is not bad, just a bit different from what is expected – displays for the time period selected.

Rec 16: It is noted that the link, http://www.jcommops.org/dbcp/doc/DBCP_Impl_Strategy.pdf, results in an error. This needs to be fixed. (A reviewer noted this link from the "Community" > "Documents" tag provides the correct document. This is correct.)

Rec 17: The Monitoring – GTS tab of the JCOMMOPS website [52] presents a table of selection criteria. One of the mandatory fields is "GTS code". This is not something that a general user would know what to fill in. Other such forms at JCOMMOPS should be reviewed and explanatory information provided when mandatory specifications are required.
As well, many pages reference "buoys" when the predominant information is about drifting buoys. If someone is searching for information about moored buoys, this is a frustration. Consideration should be given to further subdividing the moored buoy class into equatorial moorings, coastal moorings, OceanSITES moorings. These all serve different purposes which argues for separate treatment.
The interactive display has some nice features, but it is frustrating to have to toggle the "list icon (top left icon) to see the layers or the legend. It should be automatic that a legend is shown for the active layer.
The link under "Monitoring – Reports – Climate System Monitoring (NOAA/OCO)" produces an error. This should be changed to point to OSMC.

Rec 18: The OSMC site is quite a good start towards having a comprehensive view of the state of observing systems both system by system, and by ECV. What is presently missing is documentation that explains the origins of the data used in these displays and what processing, if any, is done.

Rec 19: DBCP should consider if an annual report should be prepared chiefly for audiences outside of the DBCP wanting an overview of operations. There is much material available already for such a report that the work to assemble such a report should be relatively simple. Sections separated between drifting buoys, and classes of moored buoys, as OSMC does, could be considered.

Acronyms

AOML: Atlantic Oceanographic and Meteorological Laboratory
ASCLME: Agulhas and Somali Current Large Marine Ecosystems
ATLAS: Autonomous Temperature Line Acquisition System
BOM: Bureau of Meteorology
BPPT: Agency for the Assessment and Application of Technology
BUFR: Binary Universal Form for data Representation
CLIVAR: Climate Variability and Predictability
CSIRO: Commonwealth Science and Industrial Research Organization
DBCP: Data Buoy Cooperation Panel
DHN: Diretoria De Hidrografia E Navegacao
ECV: Essential Climate Variable
ESRL/PSD: Earth System Research Laboratory / Physical Sciences Division
FIO: First Institute of Oceanography
FTP: File Transfer Protocol
GCOS: Global Climate Observing System
GCOS-IP: Global Climate Observing System – Implementation Panel
GOOS: Global Ocean Observing System
GTS: Global Telecommunications System
GTSPP: Global Temperature Salinity Profile Project
ICOADS: International Comprehensive Ocean-Atmosphere Data Set
IMMA: International Maritime Meteorological Archive format

INCOIS: Indian National Centre For Ocean Information Services
INPE: Instituto Nacional De Pesquisas Espaciris
IODE: International Oceanographic Data and information Exchange
IRD: L'institut de recherche pour le developpement
ISDM: Integrated Science Data Management
JAMSTEC: Japan Agency for Marine-Earth Science and Technology
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: JCOMM Observing Platform Support center
KKP: Ministry of Marine Affairs and Fisheries
NCDC:National Climatic Data Center
NDBC: National Data Buoy Center
netCDF: network Common Data Format
NIO: National Institute of Oceanography
NIOT: National Institute of Ocean Technology
NOAA: National Oceanic and Atmospheric Administration
OPA: Observations Programme Area
OpeNDAP: Open-source Project for a Network Data Access Protocol
OSMC: Observing System Monitoring Center
PIRATA: Prediction and Research Moored Array in the Atlantic
PMEL: Pacific Marine Environmental Laboratory
RAMA: Research Moored Array for African-Asian Monsoon Analysis and Prediction.
TAO: Tropical Atmosphere – Ocean project
TIP: Tropical moored buoy Implementation Panel
TOGA: Tropical Ocean Global Atmosphere
TRITON: Triangle Trans-Ocean Buoy Network
SOOP: Ship Of Opportunity Programme
UTAS: University of Tasmania
VOS: Volunteer Observing Ship
WOD: World Ocean Data project
WMO: World Meteorological Organization

References

1. DBCP TIP Action Groups: http://www.jcommops.org/dbcp/overview/actiongroups.html
2. TAO / TRITON home: http://www.pmel.noaa.gov/tao/
3. PIRATA home: http://www.pmel.noaa.gov/pirata/
4. RAMA home: http://www.pmel.noaa.gov/tao/rama/
5. TAO information at NDBC: http://www.tao.noaa.gov/
6. TIP information: http://www.pmel.noaa.gov/tao/proj_over/tip/newpanel.html
7. DBCP home: http://www.jcommops.org/dbcp/
8. TAO members: http://www.pmel.noaa.gov/tao/proj_over/tao_group.html
9. ASCLME home: http://www.asclme.org/
10. TAO history: http://www.pmel.noaa.gov/tao/proj_over/taohis.html
11. DBCP standards: http://www.jcommops.org/dbcp/community/standards.html
12. TAO mooring technical information: http://www.pmel.noaa.gov/tao/proj_over/mooring.shtml
13. TRITON buoy information: http://www.jamstec.go.jp/jamstec-e/kansoku/observ/triton/
14. TRITON information: http://www.jamstec.go.jp/jamstec/TRITON/real_time/php/top.php
15. PIRATA mooring technical information: http://www.pmel.noaa.gov/pirata/pir_technical.html
16. RAMA technical information: http://www.pmel.noaa.gov/tao/rama/technical.html
17. TAO sensor information: http://www.pmel.noaa.gov/tao/proj_over/sensors.shtml
18. TRITON sensor information: http://www.jamstec.go.jp/jamstec/TRITON/real_time/overview.php/po-t3.php
19. RAMA sensor information: http://www.pmel.noaa.gov/tao/rama/bams_appendix.pdf
20. TAO field operations: http://www.pmel.noaa.gov/tao/proj_over/proj_over.html
21. Cruise information at NDBC: http://www.tao.noaa.gov/refreshed/taoCruiseInfo.php
22. General telecommunications information: http://www.jcommops.org/dbcp/platforms/telecomms.html
23. TAO data telemetry: http://www.pmel.noaa.gov/tao/proj_over/tel.html
24. WMO home: http://www.wmo.int/pages/prog/www/TEM/index_en.html

25. BUOY and BUFR at WMO: http://www.wmo.int/pages/prog/www/WMOCodes.html
26. BUOY code description: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/gts-smt/codes/18-xii-eng.htm
27. Service Argos: http://www.argos-system.org/
28. Iridium home: http://www.iridium.com/default.aspx
29. TRITON telemetry: http://www.jamstec.go.jp/jamstec/TRITON/real_time/overview.php/po-o3.php
30. RAMA data telemetry: http://www.pmel.noaa.gov/tao/rama/data.html
31. ISDM home: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/index-eng.htm
32. TAO quality control: http://www.pmel.noaa.gov/tao/proj_over/qc.html
33: TRITON quality control: http://www.jamstec.go.jp/jamstec/TRITON/real_time/overview.php/po.php
34. ICOADS home: http://icoads.noaa.gov/
35. WOD home: http://www.nodc.noaa.gov/OC5/WOD/pr_wod.html
36. WOD introduction to data: ftp://ftp.nodc.noaa.gov/pub/WOD09/DOC/wod09_intro.pdf
37. WOD quality control: ftp://ftp.nodc.noaa.gov/pub/WOD09/DOC/wod09readme.pdf
38. Data display from PMEL: http://www.pmel.noaa.gov/tao/jsdisplay/
39. Moored buoy data from PMEL: http://www.pmel.noaa.gov/tao/data_deliv/deliv.html
40. netCFD home: http://www.unidata.ucar.edu/software/netcdf/
41. OpeNDAP home: http://www.opendap.org/
42. ICOADS processing schematic: http://icoads.noaa.gov/images/r2.5_fig6.gif
43. ICOADS translations: http://icoads.noaa.gov/translation.html
44. ICOADS release 2.5: http://icoads.noaa.gov/r2.5.html
45. IMMA format description: http://icoads.noaa.gov/e-doc/imma/R2.5-imma.pdf
46. ICOADS processing: http://icoads.noaa.gov/e-doc/other/esm_sep93
47. WOD data selection: http://www.nodc.noaa.gov/OC5/SELECT/dbsearch/dbsearch.html
48. El Nino presentation: http://www.pmel.noaa.gov/tao/elnino/nino-home.html
49. Equatorial moored buoy publications list: http://www.pmel.noaa.gov/tao/proj_over/pubs.html#bib
50. RAMA publications: http://www.pmel.noaa.gov/tao/rama/ramapubs.html
51. DBCP network status: http://www.jcommops.org/dbcp/network/status.html
52. DBCP Quality Information Feedback mechanism: http://www.jcommops.org/dbcp/support/feedback.html
53. JCOMMOPS monitoring: http://wo.jcommops.org/cgi-bin/WebObjects/JCOMMOPS
54. UKMO monitoring of surface marine data: http://research.metoffice.gov.uk/research/nwp/observations/monitoring/index.html
55. E-SURFMAR quality monitoring tools: http://www.meteo2.shom.fr/qctools/rechstat_surfmar.htm
56. OSMC home: http://www.osmc.noaa.gov/
57. GCOS-IP (2010 update): http://www.wmo.int/pages/prog/gcos/Publications/gcos-138.pdf

2.2c: DBCP – OceanSITES

Introduction

The focus of this chapter is on the data that are collected through the DBCP [1] Action Group [2] for the OceanSITES programme [3]. As described on the site, “OceanSITES is a worldwide system of long-term, deepwater reference stations measuring dozens of variables and monitoring the full depth of the ocean, from air-sea interactions down to 5,000 meters.” Organization of this programme is through an executive committee, a Science Team (21 countries represented) and a Data Management team (9 countries represented). Membership is shown on the site [4,5] (Rec 1).

The objective of the OceanSITES programme is to be found on its home page [3] with more detail on the “About” page. The User Manual [7] describes OceanSITES as “the global network of open ocean sustained time series sites”. The variation in wording describing the programme and the breadth of types of measurements of the platforms that fall under OceanSITES, makes its objectives confusing (Rec 2). (The wording on the “Home” and “About” pages has changed since they were originally viewed. Consequently part of the suggestion found in Rec 2 appears to be now met).

There are other programmes that provide surface oceanographic and meteorological data like those delivered by OceanSITES. The other programmes that are part of or associated with JCOMM are treated in other chapters of this report.

The following sections offer detail about the DBCP OceanSITES programme. Much of this was derived from the DBCP and OceanSITES web sites. As for other programmes of DBCP, its home web site provides a wealth of general information. Unlike the other DBCP programmes, almost all of the detailed information on OceanSITES is delivered through OceanSITES web pages.

Because OceanSITES is a collection of various programmes, the terminology used here is to refer to these diverse programmes as “components” of OceanSITES.

Data Providers

OceanSITES is a collection of individual projects (components), with different instrumentation, including surface and subsurface moorings, ship based full depth profiling activities and instrumentation installed on the bottom, such as cabled observatories. The OceanSITES programme itself exists as a coordinating body of these various programmes to develop a strategy for the global array, attracting users, sharing platforms, for capacity building, for development and sharing of best practices, and for data management and sharing (Rec 3,4).

Because there is such a variety of components, getting a grasp of the full suite of variables measured is not easy. The spreadsheet of summary information [8] (under the “About” heading) is the best summary short of following links to data from each project. However, the data collected is classified in broad categories with no indication what are the variables in each class (Rec 5,6). As an alternative, the User Manual [7] lists the full suite of variable names accommodated within the data format in Reference Table 3.

Details of what data are available from each site can be found by looking at the “oceansites_index.txt file [9] available from the GDAC ftp sites. This comes in a form that can be imported to a spreadsheet (Rec 7). Each record of this file represents a data file and there are multiple files from each mooring. Scanning the listing of variables measured, it is clear that a number of the ECVs that are of interest in this report are routinely sampled.

The details about the type and configuration of instruments, sampling, reporting, etc., is only found by going to the individual projects listed using the “Data” link [10] on the OceanSITES home page. A quick review shows there is a diversity of instruments used, with subsequent differences in performance.

The index file noted above [9] also indicates which data arrive in real-time. Of the total number of records, about 14% appear available in real-time. It is expected that where either ASCII code forms or BUFR templates exist that can carry the data in real-time, that these vehicles are used and data are reported on the GTS. There is insufficient information to verify this (Rec 8). (A reviewer noted that some platforms do transmit via Argos, but request that their data not be available via GTS in order to ensure that the data are withheld and not used to initialize models. This is not explained on the web pages.)

It is a challenge to get an overview of who are the data providers (this information is contained in the data files), what instruments they use, how the data are sent ashore, what is done to the data before they are sent on to the DAC or GTS. Some information about sites by ocean is available from 2010 white paper documents [11] but the content is not consistent from one site to another, the papers are from 2010 and so may be dated, and some of the files are quite large. (Rec 9). (A reviewer noted these papers are outdates and have been removed,)

Data Assembly

A description of the data policy for OceanSITES, “OceanSITES Data Policy”, and an overview of data flow, “OceanSITES Data Access”, are available [9] (Rec 10). The data access document provides the barest detail about data flow, processing and timeliness. The text states “Documentation of automated real-time quality control procedures will be available ...”. Such a document was not found, presumably it is not yet ready (Rec 11).

An overview of the data management structure is found the in the “OceanSITES User Manual” [7]. There is not much information to describe the details of how data get from the data providers to the two GDACs mentioned on OceanSITES home page. We are told the data come from the PI to a DAC then to the GDACs. The list of DACs is to be found in section 4.4 of the Manual. GDAC organization is described in Section 5 of the Manual. The two GDACS, in Coriolis and in NDBC, synchronize their contents daily. Apart from this, there is no further information on responsibilities, or actions that are performed by PIs, DACS or GDACs (Rec 12).

Processing and Archiving

Data management functions are described in the User Manual [7]. As noted in the last section, DACs serve as assembly centres for the various components that comprise OceanSITES, and GDACs for the main archive and dissemination agencies.

Documentation of processing and archiving operations at the DACs and GDACs is very sparse. The Data Access document [7] describes the responsibilities of the DACs to be “applying automated real-time quality control tests to identify and flag grossly bad data.” and also it appears that they have the responsibility to ensure the data get out to the GTS within 24 hours of observation time whenever real-time data transmission is possible. They are also responsible for relaying “All data, with flags ... to Global Data Assembly Centers” and in the case of real-time, the target is to have these data available from the GDACs within a few hours of GTS transmission”. They further state “Documentation of automated real-time quality control procedures will be available through the web portal ...” (Rec 12). The User Manual [7] lists which agencies perform DAC functions in Reference Table 4, though it is not stated which components each supports.

GDACs are operated by Coriolis, in France [12] and NDBC [13] in the U.S. The same Data Access document describes the responsibilities of the GDACs to “maintain complete (mirror) datasets, and make all data available from one place in a unified format, initially via ftp directories, later through user-friendly interfaces.”. GDACs also handle delayed mode data which contains post-calibration, PI inspected, flagged data with both original and corrected measurements. Such delayed mode data are to be available within 12 months of instrument retrieval.

Both DACs and GDACs have standardized on netCDF [14] with CF conventions [15] for a data format. There are four different file types, for metadata, profile data, time-series data, and trajectory data. (A reviewer noted that not all file types exist) The User Manual [7] is very informative in describing the format and contents with all relevant code/reference tables fully described. It also provides links to a data format checker application, and converters from two commonly used formats to OceanSITES netCDF. Additionally, a sample data file and cdl file are available [10].

The GDACs synchronize their data holdings once a day. It should be noted, though, that whereas Coriolis contains a subdirectory of “aggregated data”, NDBC does not. There is no explanation of what the differences are between the data files and aggregated data files (Rec 13).

Apart from this, there is little additional information on processing and archiving except what can be found by going to the individual component sites [10]. There are no details that describe the quality control that is done either at DACs or GDACs. There are no web links provided to the DACs so that these may be explored to see if they individually describe their procedures (the “links” page on the OceanSITES home page does provide links to member institutions, but identifying which operate DACs is not always clear. But there is much good information at these sites.). Details of the other processing that is carried out by DACs and GDACs is absent. Such information is useful to potential users because they can use it to judge what additional processing they need do when they access the data. It also tells them if there is consistent processing between DACs handling common variables (see Rec 12).

Data Dissemination

Data dissemination is handled by the GDACs. They provide a common data format for all of the data across the OceanSITES components. They also provide a consistency of processing (though, see Rec 12) which should be valuable when trying to combine data from the different sources.

At this point in time (July ,2013) data are available through ftp services only. The User Manual describes the file naming conventions, and an index file. The User Manual notes that part of the name convention is a unique platform code, a mandatory field in the data format, and described in a “catalogue” available at the ftp root. This catalogue is not available (Rec 14).

The ftp site is functional in that it allows an automated way to routinely download files of interest. Clearly, a non-routine user is not as well served by this sort of web site, though with a little study, they can figure out which are the files of interest. OceanSITES has stated that a more human oriented interface is an objective and this is to be encouraged to arrive as soon as possible.

Some of the component programmes also permit separate data access. These provide a query interface that is more sophisticated than the simple ftp access provided by GDACs at this time (July, 2013). It is not clear what are the differences between the data downloaded from the individual component sites and those data available from the GDACs (Rec 15).

Some of the meteorological centres and some of the oceanographic data centres of IODE [16] are receiving data in real-time or delayed mode from components of the OceanSITES programme. Without reviewing the web pages from each such site, it is not possible to know what information about OceanSITES is provided, nor if the data in the archives are identified as a contribution to OceanSITES, and therefore the data are also represented at the GDACs. This will be a source of confusion to a potential user who wishes to assemble data from a particular ocean area and time, since downloading from OceanSITES and from one or more NODCs is likely to result in duplicates. This is not a problem confined to OceanSITES, but since OceanSITES is relatively new, there is an opportunity to address this duplication (Rec 16).

In looking at existing consolidated data collections, such as ICOADS [17] and WOD [18], there is no information that suggests that any of the OceanSITES data are used routinely. Both ICOADS and WOD indicate that data from moored platforms are used, and WOD also indicates that some glider data are incorporated. But there is no indication that either of these routinely download and incorporate OceanSITES data into their products. Since these two consolidations are important to the meteorological and oceanographic communities, there should be some resolution of what each will do with OceanSITES data (Rec 17).

Differences Between Distributed Data Sets

The only consolidated source of OceanSITES data is the GDACs at Coriolis and NDBC and these are routinely synchronized. However, web sites from components of the OceanSITES programme offer data download facilities, and the differences between these various sources are not described (see Rec 15).

User Communities

The communities interested in data deriving from OceanSITES is broad reflecting the wide range of measurements made.

The operational oceanography and weather prediction community will appreciate the high quality of the data coming in real-time, but these data are few.

The research community is the largest benefactor of these data. This covers the spectrum of air-sea flux, biogeochemistry, physical oceanography, waves, and meteorology. The data re of research quality and will have broad appeal. Because of the data access policy, the data will be widely available, and if the programme attains its objective of releasing data within 12 months of instrument retrieval, this will be an important result.

As these sites build up longer time series at their locations, the data collected will be increasingly valuable in looking at environmental trends. The data are also useful to examine extreme events.

Monitoring and Performance Metrics

The OceanSITES web site points to only a few monitoring products. On the site itself, the “news” section displays a map from November 2012 that shows existing, installed and planned sites. There is also a graphic that indicates where the programme is relative to its objectives on platform installations. This is quite a high level summary but an effective way to explain the present status (Rec 18).

The various meeting reports [19] (and see the most recent from 2011) are a good source of information about where the programme is currently. In particular, the need to identify ways to assess the progress of OceanSITES towards objectives shows that the Steering Committee recognizes that this sort of reporting needs to be improved (Rec 19). It is noted that there are no evident monitoring products from the data management system (Rec 20).

Each of the components of OceanSITES has a web site and many of these show what data are collected and what the measurements look like. Data are shown from 2013 for some and older years for others. These are all interesting, but needing to go to each web site of the components is not a good way to demonstrate how well the programme coordinates activities (see Rec 19).

One of the purposes of JCOMMOPS is to provide reporting on the programmes under JCOMM sponsorship. Some displays relevant to OceanSITES are available under the “map room – Platforms” tab [20]. Selecting the OceanSITES directory references three map display, two dated from 2009 and the “Monthly Map” resulting in a “bad URL”. This is not the only problem noted. Generally, OceanSITES is not well represented at JCOMMOPS (Rec 21,22)..

The Unites States funded OSMC[21] provides a variety of tools to examine the status of observing systems. This largely is focused on real-time data, and since most OceanSITES platforms do not deliver data in real-time, there is little to show, except those data from the tropical moored buoy network. In choosing a time period from 2010 when there are delayed mode data available at the OceanSITES GDACs, the same display results. Since the OSMC “About OSMC” page states “The OSMC system displays current and historical status of globally distributed meteorological and oceanographic data ...”, there is a clear lack in meeting its goal (Rec 23).

GCOS-IP (2010) Performance Indicators

Within the GCOS-IP (2010 update) [22] the OceanSITES (surface reference network) operations are mentioned in two Key Needs and in Actions 11 and 27, listed here.

Key Need 21: Parties need to provide global coverage of the surface network by implementing and sustaining: (a) an enhanced network of tide gauges; (b) an enhanced surface drifting buoy array; (c) an enhanced tropical moored buoy network; (d) an enhanced voluntary observing ship network including salinity measurements; (e) the surface reference mooring network, (f) a globally-distributed plankton survey network; and (g) international coordination of coral reef monitoring.

Key Need 22: Parties need to provide global coverage of the sub-surface network by implementing and sustaining: (a) the Argo profiling float array; (b) the systematic sampling of the global ocean full-depth water column; (c) ship of opportunity trans-oceanic temperature sections; and (d) the tropical moored buoy and reference mooring networks referred to in Key Need 21 above.

Action O5 [IP-04 O8]
Action: Complete and maintain a globally-distributed network of 30-40 surface moorings as part of the OceanSITES Reference Mooring Network.
Who: Parties' national services and ocean research agencies responding to the OceanSITES plan.
Time-Frame: Network complete by 2014.
Performance Indicator: Moorings operational and reporting to archives.
Annual Cost Implications: 30-100M US$ (10% in non-Annex-I Parties).

Report: If the tropical moored buoy network is considered within the scope of OceanSITES, then it has met this objective. If these are not counted, there are more than 40 platforms, including transport sections and so again the objective is met. Most of these latter platforms are in operation, but do not report in operational time frames (that is within the definition of real-time – within 30 days of observation).

Action A9 *[IP-04 A8]*
Action: Equip all buoys in the Ocean Reference Mooring Network with precipitation-measuring instruments.
Who: Parties deploying moorings, in cooperation with JCOMM and OOPC.
Time-Frame: Complete by 2014.
Performance Indicator: Number of instruments deployed and data submitted to International Data Centres.
Annual Cost Implications: <1M US$ (Mainly by Annex-I Parties).

Report: This is difficult to assess because at present there is only the data index files to consult. There is no product generated from this file to demonstrate if this is met (Rec 24). From a scan of the index file, it appears this is not met.

Action O11 [IP-04 O15]
Action: Implement a programme to observe sea-surface salinity to include Argo profiling floats, surface drifting buoys, SOOP ships, tropical moorings, reference moorings, and research ships.
Who: Parties' national services and ocean research programmes, through IODE and JCOMM, in collaboration with CLIVAR.
Time-Frame: By 2014. Performance Indicator: Data availability at International Data Centres.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

Report: To the extent that many OceanSITES components measure sea surface salinity, this objective is being fulfilled by OceanSITES. A metric to show how many of the components measure surface salinity would be more quantitative (see Rec 24).

Action O16 [IP-04 O19]
Action: Implement a wave measurement component as part of the Surface Reference Mooring Network.
Who: Parties operating moorings, coordinated through the JCOMM Expert Team on Waves and Surges.
Time-Frame: Deployed by 2014.
Performance Indicator: Sea state measurement in the International Data Centres.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

Report: Some of the components of OceanSITES have wave measurement instruments installed. To this extent, OceanSITES has net the objective. However, a metric of showing how many are installed would be better (see Rec 24).

Action O29 [IP-04 O30]
Action: Work with research programmes to develop autonomous capability for biogeochemical and ecological variables, for deployment on OceanSITES and in other pilot project reference sites.
Who: Parties' national ocean research programmes, in cooperation with the Integrated Marine Biogeochemistry and Ecosystem Research, Surface Ocean – Lower Atmosphere Study, and Land- Oceans Interactions in the Coastal Zone of IGBP.
Time-Frame: Continuing.

Performance Indicators: Systems available for measuring pCO2, ocean acidity, oxygen, nutrients, phytoplankton, marine biodiversity, habitats, with other ecosystem parameters available for use in reference network applications.
Annual Cost Implications: 1-10M US$ (50% in non-Annex-I Parties).

Report: Reading the material available from OceanSITES and scanning the web sites of components, it appears that this activity is being addressed. Certainly biogeochemical measurements are being made at some locations (See Rec 24).

Recommendations

Rec 1: The link to the executive team at "http://www.oceansites.org/team/index.html" simply references the same page. This needs to be fixed.
Rec 2: The "news" page of OceanSITES identifies the "Deep T/S Sensor Challenge" of a deep ocean observing strategy as the objective. However, OceanSITES has "adopted" many existing emplacements, with many more sensors that just for T and S. These other measurements appear to be considered a component of OceanSITES as they appear in the index files to the data. This causes some confusion as to what is part of the OceanSITES programme, and so adheres to the data policy and access objectives, and what is ancillary. One way to clarify this would be an itemized set of objectives for OceanSITES and some words that explain the relationship of these other measurements to the objectives.
Rec 3: The "About" page (http://www.oceansites.org/about.html) is too brief in describing what OceanSITES is. Simple explanations about the types of installations that constitute member status would help a first time reader to grasp the programme. In particular, OceanSITES is a coordinating body of the component members but this is not clearly stated. I assume actions are determined by consensus, What, for example, is gained by the coordination? A more long-winded description would be welcome something along the lines of the text (and pictures?) included in the brochure.
Rec 4: On page "http://www.oceansites.org/network/index.html" the text refers readers to "... links at the left (grouped by ocean) ...". I was unable to see such a link, and following the available links did not result in a presentation that seemed grouped by ocean. There is "bulk" information below, so is this what is referenced? The idea of grouping by ocean is good, but clarity in how to find the links is needed. (A reviewer noted that this has changed so that now a user can click on the sites on the map to get additional information. This change was made after the production of the draft report.)
Rec 5: Finding out which components of OceanSITES collect which variables is hard. I note the brochure lists variables in categories that are similar to, but not the same as the spreadsheet. As a last resort, I needed to look at the index files on the ftp site as was described in the netCDF manual. A simple table with column 1 being variable and column 2 being projects that collect such measurements, even without links to web pages, would be a great help.
Rec 6: The "summary information on sites" (available from the "Global Network" page) spreadsheet is quite informative although some of the headings need explanation. A simple key to column headings would be helpful. For example, in the status column there are 0, 1, 2. I assume 0 means no such data, 1 means there are such data, but what does 2 mean? What are the variables included in the data categories? Can the very many blanks in the metadata URL column be more filled? Does the many blanks in the DAC column imply there is no organization of these data?
Rec 7: The index file is good and there is some explanations of column headings, but a definition for each column could be provided. I note that an explanation is provided in the User Manual but this is not an obvious place to look, nor the most convenient. In separating out the list of parameters I noted that in a few cases, JKEO for example, underscores are missing, replaced by spaces, which means the separate words in the parameter name causes them to be interpreted as separate parameter names. There were other layout problems noted, such as information in the wrong column as well. This should be corrected perhaps by using a different delimiter for parameters (rather than a space). This would allow each parameter to be placed in a unique column headed by that parameter name. This makes for many more columns, but would allow someone to compare what is available from which location. This hearkens back to the first comments in recommendation 3.
Rec 8: Even though much of the data collected do not travel in real-time, there is no information about which data from which components do and in what formats. There does not need to be a lot of detail, but at least this minimal information would be helpful in linking the data that arrive in real-time to OceanSITES.
Rec 9: The diversity of the various projects that contribute to OceanSITES makes for a difficult time for someone to grasp the scope of the programme. For someone wishing to use the data, they will be

interested in the details of which components make the measurements, how and what they do to the data and where to find them. Only partial information of this sort is available. It is suggested that the programme spend some time thinking how to summarize such information across the components, or at least find a series of presentations (files, summaries, graphics, etc.) to help a user to identify the components of interest so that they need not visit each and every contributor's web site. Equivalent information such as on http://www.oceansites.org/news/2012_06_microcat.html but for other aspects of OceanSITES should be considered.

Rec 10: Upon accessing the Data Policy document, it immediately reads “CLIVAR Data Policy”. Nowhere in this document is OceanSITES mentioned. I assume that this is because the CLIVAR policy was adopted, but at least some words saying that this is the case are in order. At the very least, the title should read “OceanSITES Data Policy”. If OceanSITES has its own policy, that should appear.

Rec 11: A detailed description of how data are processed at the DAC is promised, but not obviously available. Given that discussions surrounding the organization of OceanSITES began a decade ago, and the coalescence into a formal programme took place somewhere around 2007, it is time such a document was produced.

Rec 12: Documentation of what happens to data from the various instruments from the time the data come ashore to the time the data are presented to the public at the GDAC site is not available. Is there a standardization so that the same variable is treated the same way by all DACs? It is assumed that PIs carry out quality control, but are there other checks by the DACs? A great deal of such information is lacking. It is recommended that documentation that provides information on some or all of the attributes that were used in compiling this report be prepared (see the first chapter of Part 2 of this report).

Rec 13: Coriolis offers a subdirectory of aggregated data files which NDBC does not. But there is no evident explanation of how the aggregated files differ from the data files, so a user is left to guess or figure out the differences. An explanation is needed.

Rec 14: Neither of the GDAC ftp root directories have a catalogue file of platform codes. This is an important document since it is also a mandatory field in the netCDF format. A user wanting to access particular data files needs to know this. The file must exist. The catalogue needs to be placed where the User Manual describes it to be.

Rec 15: It is important to a user to know if the data available from component web pages is more desirable for their use compared to the data from the GDACs. GDACs provide a level of standardization to data from the variety of components, but the GDAC data may have less desirable attributes compared to the processing done at the individual components. Some explanations is needed to inform potential users, what are the differences to help them decide which source is better suited to their purpose.

Rec 16: The Data Management Team from OceanSITES should consult with IODE, and an appropriate meteorological organization (perhaps starting with ICOADS), to address how OceanSITES data can be identified and marked in national archives so that duplications in data retrievals from OceanSITES and NODCs are clear.

Rec 17: OceanSITES is an important programme, because it coordinates the collection and archiving of reference times series from the open ocean. WOD and ICOADS have earned reputations as important consolidations of particular measurements from a variety of platforms. At present, neither seem to include data from OceanSITES except perhaps from selected components. It is recommended that WOD and ICOADS consider what their products should and can do with the data available from the OceanSITES programme.

Rec 18: The two figures on the “news” page on the OceanSITES web site are good. The date of November 2012 is recent enough that there is likely little missing between then and now (July, 2013). The figure at the bottom, labeled “Deep Ocean Observing Strategy”, and its associated tables are also good. There is no date on these figures, but I assume they also were produced in November, 2012. The first figure shows the geographic distribution of platforms in place and planned. The second focuses on portraying how well the target of 50 + 50 sensor target is being met (I note a discrepancy of the top showing a gap of 27 matching sensors, but the table indicates 28). These are good, but similar portrayals for the other sensor components of OceanSITES are recommended.

Rec 19: The development and production of reporting metrics is an important tool for showing potential funding agencies, contributors and international sponsors that OceanSITES is meeting its objectives, both scientific and for data access (see Rec 2). This was identified in 2011 and it is now 2013. A report on progress made is due to OCG.

Rec 20: There a no evident products showing how well the data management system is meeting its objectives (are these defined other than the target data turn-around times?). Such products are usual ways to gauge success and should be developed and shown on the web pages.

Rec 21: It is clear that the displays relevant to OceanSITES at JCOMMOPS are either out of date or not functioning. This reflects badly on both OceanSITES and JCOMMOPS and needs rapid attention. The "map room – query – search by programme" results in no maps for OceanSITES yet there are old ones noted above. This needs to be fixed.

Rec 22: The "map room – variables" results in an incomprehensible list of archived files that when opened result in sea level pressure statistics from Mėtėo France. A better description is needed for the user. The "monitoring – platforms" tab shows no radio buttons from OceanSITES. Considering that OceanSITES is quite a different programme within DBCP, it deserves a separate listing.

Rec 23: The OSMC pages list OceanSITES as one of the programmes for which information is available, but it seems clear that the delayed mode data component for OceanSITES is not yet implemented (see more general comments in Part 4). In looking at this site for other programmes, other deficiencies were noted. To manage expectations of OSMC, it should consider how to inform site visitors about what is operating and what is planned.

Rec 24: The GCOS-IP states a clear requirement for precipitation-measuring, sea surface salinity, wave measuring instruments on all buoys. OceanSITES could use the data index file to determine its success. This or some other metric should be produced. Because GCOS-IP O29 is vague on what is required, OceanSITES should develop its own, more clearly stated objective and then produce a quantitative measure of how well it is meeting this.

Acronyms

BUFR: Binary Universal Form for data Representation
CF: Climate and Forecast
CLIVAR: Climate Variability and Predictability project
DAC: Data Assembly Center
DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate Variable
FTP: file transfer protocol
GCOS-IP: Global Climate Observing System – Implementation Panel
GDAC: Global Data Assembly Center
GTS: Global Telecommunications System
ICOADS: International Comprehensive Ocean-Atmosphere Data Set
IGBP: International Geosphere-Biosphere Programme
IODE: International Oceanographic Data and information Exchange
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: JCOMM Observing Platform Support center
NDBC: National Data Buoy Center (of the U.S.)
netCDF: network Common Data Format
NODC: National Oceanographic Data Centre
OCG: Observations Coordination Group
OOPC: Ocean Observation Panel on Climate
OSMC: Observing System Monitoring Center
PI: Principle Investigator
T/S: Temperature / Salinity
URL: Uniform Resource Locator
WOD: World Ocean Data project

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2.3: GLOSS

Introduction

The focus of this chapter is on the sea level, and associated data that are collected through the GLOSS [1] programme of JCOMM [2]. Its objectives are "... the establishment of high quality global and regional sea level networks for application to climate, oceanographic and coastal sea level research.". Its main component, the "global core network, GCN" consists of 290 sea level stations distributed around the world. The present list of stations in the network [3] has more than 90 countries participating [4]. GLOSS includes a subset of mostly island stations that provide altimeter calibration data. Country contacts for GLOSS are also available [4] (Rec 1).

No other group in JCOMM is concerned with sea level, but there are many more installations of tide gauges around the world. These are operated by national agencies, as are the gauges in GLOSS, and a user interested in all data from a particular area or time frame would need to pursue these other sources. This will be discussed further in the section on data dissemination below.

The following sections offer detail about GLOSS. Much of this was derived from the GLOSS and associated web sites which provide documentation on all aspects of the programme.

Data Providers

GLOSS provides a link to basic information on sea level measurement in IOC Manual and Guide 14, Volumes 1-3 plus a 2006 update [5]. The different volumes have material updated from previous versions with some extensions. Not all of the material appearing in Vol 1, for example, is repeated in other volumes.

The Manual covers aspects such as types of gauges, siting, datum control and benchmarks, and communications from gauges in some detail providing valuable information for those wishing to set up a tide gauge. As well, it lists a number of technical experts relevant to the different topics covered that can be consulted. This Manual also lists in its appendix the GLOSS requirements for sea level measurements.
Sea level gauges are operated by national agencies. The requirements placed on contributors are described in the GLOSS Implementation Plan [6] last updated in 2012. It notes that "all GCN stations are required to report data in near-real time ..." and "continuous measurements of the Global Navigation Satellite System (GNSS) ... in the vicinity of the tide gauge benchmark (TGBM) are required for all GCN stations ...". The Implementation Plan defines the obligations of participation and there are 11 of them (Rec 2).

GLOSS divides the GCN into 4 categories [7] that separate out the timeliness of reporting from the stations. Based on the map, there are more than 40 stations that have provided no data after 1996 [Rec 3}.

The sea level gauges that operate within GLOSS are dependent on the country and so vary from analogue gauges to more modern ones that record digitally and can report through satellite telecommunications systems in real-time. The characteristics of each gauge are well described in the station handbook pages [8], one for each gauge (Rec 4,5). The Implementation Plan remarks that different accuracy is needed for different applications, but it did not state those requirements.

Under the "Technical forum" tag on the GLOSS home page, there are presentations provided from two meetings [9]. These are useful in describing operations, technology, etc., as function at various agencies. There is no general information that sets out how data get from gauges to GLOSS (Rec 6).

The University of Hawaii Sea Level Center, UHSLC, [10] assists countries in the installation and maintenance of a world wide network of tide gauges for the purposes that range from tsunami warning to global sea level rise. The PSMSL also is "... closely involved in the delivery of sea level hardware and technical support for a number of stations in Africa and the western Indian Ocean ...".

As noted before, there are many more sea level measurements made than those described on GLOSS pages (information is available from PSMSL and BODC). The series of deep ocean buoys put in place to monitor tsunamis is one example. These will be described briefly in the data dissemination section. Additional data reside in national archives. Sometimes the records are short and designed to acquire enough data to identify principle tidal constituent information, sometimes the gauges are placed for a few months or years and then discontinued. Such data may be of valuable to a user with another purpose. In addition, many modern sea level gauges also measure properties of the water such as temperature and salinity (Rec 7).

Data Assembly

Data from national gauges are assembled internationally in a number of places. The data assembly at each of these is described here.

The University of Hawaii Sea Level Center [10] serves multiple roles. It provides assembly facilities to make data available to a “Fast Delivery” (FD) system. Fast delivery data have minimal calibration and quality control applied (see next section for greater detail). The data are hourly or daily values released within 1-2 months of acquisition. In addition, UHSLC hosts the JASL [11], in collaboration with the U.S. NODC, acquiring hourly data from other countries and assembling these with the FD data to prepare a research quality data set after greater scrutiny. The 2011 Annual Report for JASL [12] provides more background information about its origins and holdings. As research data are produced they replace the data presented through the FD facilities. More information is provided in a later section of this report.

Data arrive at UHSLC in a variety of formats and either through telecommunications with the individual gauges operated by UHSLC or from agencies in the country where the gauges are located. The JASL accepts hourly data from individual countries in a variety of formats. It also encourages data contributors to provide whatever supplemental documents are available to describe the gauges, sites, data processing, etc.

BODC [13] operates the delayed mode sea level data assembly centre for CLIVAR and the GLOSS data archive centre. They carry out a series of processing steps [14] that are similar for all moored / fixed data sets such as data from tide gauges.

The PSMSL [15], in conjunction with the BODC, assembles sea level data collected at high sampling frequency (defined as hourly or higher) in delayed mode. The primary role of PSMSL (see [16] for a nice description of the service) is to manage and provide monthly mean sea level data to the scientific community. It also assembles data from countries operating their own gauges. The data arrive from individual countries in a variety of formats and at the highest sampling made by the gauges. Good instructions to potential data contributors are provided [17].

Some sea level data circulate in “national only” bulletins (an ASCII format) in the U.S. These are from gauges operated or supported by the U.S. Information about these gauges can be found at the IOC monitoring facility described later.

Processing and Archiving

Manual and Guides 14 Vol 2 and 3 [5] provide some detail about quality control, but not enough to allow a user to know what is actually done. Instead it refers to sources of software that might be used [18]. This approach encourages standardization of processing, but it does not help inform a data user about what detailed processing occurs.

UHSLC carries out format conversions on the data they receive either from the gauges they operate or from other countries. Other countries send data in a variety of formats and these are all converted to a JASL format. If data arrive at higher frequencies than hourly, they are reduced to hourly values. UHSLC have calibration information about the gauges that they operate and this is used to check for time drifts. In addition, they examine the data from all sources.

Operations of the JASL carry out the more extensive processing of data checking to produce the Research Quality Data Set (RQDS) of hourly and daily values. This processing is described in the README file [19] associated with the RQDS files. Further information is provided in a Quality Assessment Policy [20]. Checking includes looking for data spikes and time shifts. Gaps of less than 25 hours are interpolated. Problems noted in reference levels go back to the originator for resolution. If this is not possible, comparisons to adjacent stations are made, or an examination of residuals. Upon completion, the data replace the FD data available from the

UHSLC Station Data Handbook. The FD data files and RQDS files are archived separately.

The RQDS of hourly and daily values prepared by JASL are archived within the U.S. NODC and annually updated to the World Ocean Data Center [21] in Silver Spring and to the PSMSL.

The steps undertaken for processing and archiving sea level data at BODC [22] include format conversions, original data and metadata (as received) are archived, standardized parameter codes are assigned, data are visually screened and flagged, documentation compiled from originators and processing at BODC, quality checking and then archiving (Rec 8). BODC encourages providers to send data at the highest frequency sampled , although as yet they do not appear to deal in the 1 minute sampling that occurs at tsunami gauges. Data are standardized in format, and a standard set of parameter coding is used. BODC also manages other data that may come with the sea level measurements. Such data can include temperature, and air pressure. The descriptive article on PSMSL [16] references journal articles to describe its data checking procedures (Rec 9). It acquires data from the 850 or so operating tide gauges around the world, usually annually. Quality checking routines include “buddy checking against nearby stations, visual comparisons of rate changes between neighbouring stations and the data gaps within them, and interactive flagging of questionable data. Additionally, high-level quality control is done through the use of the data in scientific analyses by PSMSL staff”. Again, journal references with greater detail are provided (see Rec 9).

JASL, PSMSL and BODC have arrangements for exchanging data but these are not formalized. It is, therefore, not clear which of these two archives is the one to approach for the highest quality data. A clear difference is that BODC may have higher frequency sampled data and the additional measurements, such as air pressure or water temperature, that are sometimes collected coincidently with sea level. However, since BODC often only receives hourly values, the distinction is unclear (Rec 10).

JASL, PSMSL and BODC also collaborate on data archaeology and are eager to acquire historical records. They accept, digitize and inspect paper chart records. A recent survey has shown that there exists a large store of such records. The work to recover these is ongoing. Details are available [23] and listed by countries.

(A reviewer remarked that there seems to be little attention paid to the international preservation of information about tide gauge types, operations, siting, changes in operations, etc. These are the assorted metadata that are valuable in examining historical sea level records. There does not appear to be something like a checklist of the sort of information required to be preserved. ICES provides a document on this topic [24], last revised in 2006 that should perhaps be referenced by GLOSS if nothing else (see Rec 6).)

Data Dissemination

Data dissemination of sea level data is organized on the GLOSS website [25] where a potential user can select from monthly mean sea levels from PSMSL, high frequency, delayed mode data available through the GLOSS Station Handbook, and high frequency fast mode data from UHSLC. More detailed explanations are also provided [26]. Access is free.

Access to UHSLC fast mode data [27], provides a list of stations with data at hourly, daily, or monthly sampling. A README file provides a description of the contents of the files, and a format description. Data are delivered in a simple ASCII form (Rec 11). The “Data” link provides useful information on how to download the data and even a few pictures of stations.

Another way to the fast mode data is through the GLOSS Station Handbook [8]. In this case, a selection of a station displays the station information sheet and clicking on the “folder” icon opens up the ASCII data file. The “document” icon opens up the README file noted above.

Yet another link to UHSLC [28] is provided from the pages found on the PSMSL web site [26] that describe “High Frequency Data”. This lands the user on a different set of UHSLC pages described as “not an operational site” (Rec 12).

Access to UHSLC RQDS files is provided through the GLOSS Station Handbook pages [8]. Selecting a station provides a data sheet about the station that gives details about operation of the gauge. Again the document icon opens the README associated with these data, while the “folder” icon delivers the file in a zipped form. In addition a “book” icon provides some quality control information about this station. Data are available 1 to 5 years after observation. The JASL site [29] provides an additional link, “FTP”, that describes how a user can get data from the ftp site. This can be useful when the selection of stations is known and the user wants routine downloads.

All of the data at UHSLC are also available through a THREDDS server [30, 31]. The U.S. NODC maintains a web link that points to all of the UHSLC data as well [32].

Access at PSMSL is available [33] to monthly and annual mean sea level data. The “help file” available on this page explains that there are two files, the “Revised Local Reference”, RLR, (a research quality set that is related to a consistent set of locally defined benchmarks through time), and “Metric” files. There are additional links to pages that explain both of these, and the “notes page” link describes the format, ASCII, for each.

The “Map View” page shows a map of the world with station locations marked and colour coded based on the most recent RLR data received, or length of time series. Clicking on individual pins provides information about the length of the series, etc., as well as providing a link to the monthly or yearly mean file. The display is very nice, but if one wants data from more than one station, a user needs to select each individually.

The “Table view” data page provides a large table listing stations, positions country, etc. And the data in the table may be sorted by all of these. Two columns, titled “coastline” and “station”, seem to group data though the brief explanation is not clear in explaining the differences (Rec 13). Selecting a station ID links to a page showing location on a map, some basic information and plots of the monthly and annual means times series. Links beside each provide a download of the data. A link to the “Metric” version is also available but caution is advised (and reasons explained in the help file). This are additional links to station documentation (Rec 14).

PSMSL also provides a map of anomalies for selected stations since 1950, and trends since 1900 [34].

GLOSS “data” pages pay special attention to tide gauge data from Africa [35]. These data are not available from any other source. Files of 15 minute and 1 minute sampling data are available as is some documentation of data processing, tide gauge characteristics, etc.

BODC supports GLOSS by offering access to the high frequency delayed mode data through the GLOSS Station Handbook [8]. Data are available 1-5 years after collection, although some are available much sooner, All have undergone scrutiny. As noted above in describing the UHSLC fast mode data, the Station Handbook provides a list of GCN stations that a user selects one at a time. A “book” icon provides some quality control information about each station. Clicking on the folder icon downloads a compressed file. Data are divided up into yearly time series and each file is in ASCII with the format description appearing at the beginning of each (Rec 15). It is not clear how a user gains access to the other data types that may accompany sea level measurements (Rec 16).

There are additional services to sea level data offered by BODC through the PSMSL site [36] that goes beyond what is offered through GLOSS. The stations available here are both the GCN stations, plus all of the data for other tide gauges submitted from stations around the world in support of WOCE and CLIVAR and data from bottom mounted pressure gauges. These undergo the same processing as the GCN stations. The data are available in either ASCII or netCDF (WOCE format), both of which are explained in linked pages of the BODC web site. Gauges are subdivided into five ocean areas and the bottom gauges are separate from these. The user is presented with a list of stations that require separate downloads for each station. A map that supports clicking on a location to jump directly to the table entry is helpful. The same “book” and “folder” icons described earlier are used here to provide the information and data for each station.

Finally, PSMSL offers access to what are called “other long records”. These are described as “not available in the monthly and annual mean format used by the PSMSL, or because they are not true MSL or even MTL”. Depending on the user's purposes these may be of use. Each of these is in a different form of ASCII and would require some manipulation to be used.

A small amount of sea level data is available through the ODP [37]. This is a free data distribution system put in place by the IODE [38]. The ODP aims to provide seamless access to collections and inventories of marine data from the NODCs of the IODE network and allows for the discovery, evaluation (through visualization and metadata review) and access to data via web services. The system architecture uses Web-oriented information technologies to access non-homogeneous and geographically distributed marine data and information. This is a distribution system only, with data sets being provided by IODE members. Users need to consult the provider of the data set to learn what processing has been done.

The data collected by the tsunami monitoring buoys are available through the NDBC [39] and are distributed on the GTS. They provide access to recent and historical records from these buoys as well as information on their operations. These buoys are not part of the GLOSS network, nor do they appear at BODC or PSMSL.

Differences Between Distributed Data Sets

UHSLC fast mode: These data have undergone minimal quality control. Sea level is provided at hourly or lower frequency. The data are from GCN stations usually 1-2 months after the observation date. Data are available one station at a time, in ASCII format or through a THREDDS server.

UHSLC RQDS: These data have undergone calibration and other quality checking procedures. Sea levels are provided at hourly or lower frequency. All data are from GCN stations and available1-5 years after observation. Data are available one station at a time, in ASCII format. JASL links to these data and provides a simple ftp access as well as a THREDDS service. The U.S. NODC provides a link to these data, too.

PSMSL means: These data have undergone quality control procedures. Sea levels are reduced to monthly or yearly means. Data are of two classes, RLR or metric, with only the former being suitable for time series analyses. Data are available 1-5 years after collection although some much more recent than that are also present. A map interface aids data selection, though only one station at a time.

BODC GCN high frequency data: These data, for GLOSS GCN stations, have undergone quality control procedures. Sea levels are available at hourly or at the sampling frequency as provided (except 1 minute data). Data are available 1-5 years after collection although some much more recent than that are also present. A map interface aids data selection, though only one station at a time. Data are available in ASCII, different from the UHSLC format.

BODC high frequency data: These data, for more than but including GLOSS GCN stations, have undergone quality control procedures. Sea levels are available at the sampling frequency as submitted and so may be better than hourly. Data are available 1-5 years after collection although some much more recent than that are also present. A map interface aids data selection, though only one station at a time. Data are available in ASCII (different from UHSLC), or WOCE netCDF.

BODC long time series: These data are of historical interest but require significant work to be used.

ODP: Few sea level data are available here, though these are in near real-time as provided by national agencies.

User Communities

The sea level community has a variety of interests. The routine practice is to define tidal constituents to allow for predictions of the tides at selected locations, often ports. Basic information of this sort can be obtained from short records, as short as one month. Some gauges are maintained for much longer to monitor storm surge and provide warnings to low lying areas. Longer time series are used to study local sea level changes. With proper references to well surveyed benchmarks and in association with modern three axis GPS systems, altimeter data from satellites and Argo data these records can be used for studies of global sea level rise.

Monitoring and Performance Metrics

JCOMMOPS [40] offers a simple monitoring service on behalf of GLOSS. The interface shows all JCOMM types of data, so a user needs to turn off layers other than that showing tide gauges. It is not clear what time period this covers, though it is assumed it is the past month (Rec 17,18).

GLOSS publishes meeting reports [41] but does not appear to make available any annual reports. PSMSL makes available annual reports [42] and these have some information relevant to GLOSS, but the most recent report available is from 2007 (Rec 19)

The IODE offers a service for monitoring the operations of tide gauges [43]. At present there are reports available from more than 700 gauges around the world (as of August, 2013). The gauges are polled every 5 minutes and simple data displays are provided. The site provides a variety of views of different categories of gauges, for example GCN only, stations reporting on the GTS, stations supporting web services (Rec 20).

NDBC also provides a way to monitor the current operation of tsunami gauges. It does not appear that these are duplicated by the same gauges available through IODE (Rec 21).

The Unites States funded Observing System Monitoring Center [44] provides a variety of tools to examine the status of observing systems. The “Main Console” page allows selection of tide gauge stations and a time frame and displays locations of stations reporting during that time. The “Metrics” page shows statistics on real-time and GLOSS reporting by country and time frame. The “Observing System Metrics” tab allows a display by time frame and parameter. The criterion for inclusion of a tidal station can be regulated by setting the “Threshold for % calculation”. There is no facility to separate out GLOSS GCN stations from all others (Rec 22).

There does not appear to be any documentation that describes the origins of the data used for these displays, or other information that would help a user to know how these are derived. It also provides some capability to display on Google Earth projections. Some additional comments follow.

- Under the “In Situ Monitoring” tab, there are some deficiencies (such as using programme names that are not necessarily clear to all users – NWLON, inclusion of US programmes, though this site obviously has a dual purpose, missing some JCOMM observing systems – GLOSS and others). However, when “all programs” is selected and a particular parameter it seems quite good.
- Under the “Observing System Metric Reports” tab and after selecting “Tide Gauges” there is a useful listing of statistics on gauges operating in total and by country.
- Presentations based on all platforms for a selected parameters is approaching what is needed for an ECV perspective and will be dealt with in that chapter.

GCOS-IP (2010) Performance Indicators

Within the GCOS-IP (2010 update) [45] the GLOSS operations are mentioned in Action 9, listed here.

Action O9 [IP-04 O11]
Action: Implement the GLOSS Core Network of about 300 tide gauges, with geocentrically-located high-accuracy gauges; ensure continuous acquisition, real-time exchange and archiving of high- frequency data; put all regional and local tide gauge measurements within the same global geodetic reference system; ensure historical sea-level records are recovered and exchanged; include sea- level objectives in the capacity-building programmes of GOOS, JCOMM, WMO, other related bodies, and the GCOS system improvement programme.
Who: Parties’ national agencies, coordinated through GLOSS of JCOMM.
Time-Frame: Complete by 2014.
Performance Indicator: Data availability at International Data Centres, global coverage, number of capacity-building projects.
Annual Cost Implications: 1-10M US$ (70% in non-Annex-I Parties).

Report: It is not possible to evaluate how close GLOSS is to fully meeting the action. This is partly because there is no active (annual) reporting of which stations met GCN objectives over time. Looking at the network status map presented on the GLOSS site, and guessing based on the colour of the dots, it would seem that there are perhaps 25% that have not reported since 2005 (see Rec 19).

Recommendations

Rec 1: The Implementation Plan discusses the tsunami warning network as a component of GLOSS, and so this includes the many open ocean sea level gauges of this network. There are some references to the DART (tsunami) gauges on the DBCP as well. It is recommended that OCG working with DBCP and GLOSS decide on which of these programme's web pages to place the primary description of this system. This aspect is not discussed at all on the GLOSS web site nor really on DBCP and it should be somewhere. Perhaps the various subgroups of GLOSS, such as PSMSL, ITWS, should be treated as “action groups” the way DBCP operates, and space provided on web pages for each of these. This assumes that these activities fall under the general coordination of GLOSS, which the Implementation Plan suggests.

Rec 2: The obligations are clearly stated in the Implementation Plan. However, these are deep in the Plan, and it is recommended that these be placed on a separate page on the GLOSS web pages.
It is not totally clear what are the responsibilities of membership in the GCN. The text quoted came directly from the Implementation Plan, but the text on the home page, “Another component is the GLOSS Long Term Trends (LTT) set of gauge sites (some, but not all, of which are in the GCN) for monitoring long term trends and accelerations in global sea level. These will be priority sites for Global Positioning System (GPS) receiver installations.” The second quoted text in the body of this report seems to refer to the LTT stations. A clear statement on objectives and member responsibilities (are these different from those of GLOSS noted in the Implementation Plan?) should appear on the GLOSS home page.

Rec 3: The map of GCN identifies that it was last updated in 2010. While changes from year to year may be small, a more up-to-date map should be presented. Also,there is no easy way to know how many stations fall into each of the categories. Both of these should be easy to get (the 2012 Implementation Plan shows one such figure and count) and should appear on the basic GCN network status map.

Rec 4: It is recommended that another useful summary of the GLOSS network would be a map portraying the different basic gauge capabilities. A categorization of analogue gauges with strip chart, analogue with A to D converter, digital, digital with GPS, and so on should be considered. Perhaps such information should be added to the station information sheet that accompanies each gauge. The intent is to tell a reader the state of capability of instrumentation in a succinct way.

Rec 5: The accuracy of sea level measurement is unstated in the station information sheets. The data file descriptions describe data to millimetre precision. If there is any variation between gauges, this should be recorded on the individual station sheets. If there is not, such information on gauge characteristics could be included in a general description of gauge capabilities.

Rec 6: IOC M&G in its various volumes provides advice on getting data from gauges to national agencies and thence to assembly centres. This is buried too deeply in documentation and needs to be brought to the forefront on the GLOSS pages (with pointers to greater detail as does exist). Included in this should be basic information about obligations of data providers, with a pointer to the pages that do treat this but are more buried on the web site. The apparent lack of a checklist of metadata that should be preserved with each gauge could also be addressed in the same way.

Rec 7: Reading the GLOSS pages, it seems that the GCN is the focus. In the data sections, particularly the pointers to BODC and PSMSL, they describe accepting data from more than GCN gauges. While it is good that access is provided to these other gauges as well, it is a bit confusing to a potential data users. It is recommended that the GLOSS web pages provide some text that describes what is part of GLOSS and what additional information and data are available from the GLOSS gauges.

Rec 8: More detail about the BODC quality control procedures for sea level data is needed. The more detail provided, the better able a user will be to assess what additional work may be required before the data are usable. As well, BODC makes no statement about how they deal with data in the variety of sampling frequencies. In the past, hourly values were the norm, but many gauges now report at 15 minutes, 5 minutes, 1 minute, and the tsunami gauges can operate at 1 second sampling. It is recommended that BODC state if they have an upper limit to sampling frequency for their archives, and if so, what happens to the higher frequency sampled data when they are received and processed.

Rec 9: It is very good that the data processing procedures appear in journal articles. However, it is recommended that PSMSL describes the data processing steps on its own web site and in sufficient detail to allow a user to know if he will need to carry out further work to suit his objectives.

Rec 10: A user should be able to distinguish which of the JASL or BODC archives is the one to go to with a data request. Except that BODC holds higher frequency data than hourly intervals, it is unclear which is the one to choose. It is recommended that JASL and BODC provide commonly agreed text on both websites that explain the attributes of each other's archives so that a user can decide from where to acquire data.

Rec 11: Access to fast mode data is easy and the file format simple. Station positions, latitudes and longitudes, are provided for each station in the list. This is good enough if a user is only interested in a single station. There is no map interface and no easy way to download all data from an area. Nor is there any way to subset by time, though this may not be a issue. It is recommended that the interface be improved to allow for easier downloads of data from an area.

Rec 12: It is not clear why there are different ways to the fast mode data at UHSLC. There is a direct link, a link through the GLOSS Station Handbook, and the link as described here. There is a page on the JASL site that explains how to get data and it shows that this is an old site. However, this link has a map of station locations. It is confusing to have two different pages pointed to. It is recommended that unless there is a good argument for keeping the different links, that only one be supported.

Rec 13: At the PSMSL mean sea level data download page, the columns marked coastline and station are not adequately described. A map the shows what is coastline “10”, or any other number would be helpful. Likewise the station number is not unique, though apparently within a coastline it is. It is not immediately clear why this type of sort criterion is helpful. It is recommended that either the columns be removed, or their utility be better explained.

Rec 14: The additional information part of the page uses the acronym SONL which did not seem to be explained. This needs to be explained.

Rec 15: Similar to UHSLC fast mode data access, there is no map nor any way to download more than one station at a time. It is recommended that this capability be added to the data query interface.

Rec 16: It is known that BODC stores the other data that sometimes accompany sea level measurements (e.g. water temperatures). However, these variables are not mentioned anywhere. It is recommended that BODC provide some text on their web site to explain that these other variables are welcome, that these data are also archived, and that explains how these other data may be accessed by a user.

Rec 17: The monitoring product from GLOSS does not state what is the time frame for display of the interactive map. It is assumed to be data received within the last calendar month, or perhaps last 30 days. For tide gauges, if a gauge reports one hourly value, is it displayed? It is recommended that some explanatory information relevant to tide gauges be provided. The data reporting criteria are weak. Clearly a single hourly value is inadequate for any purpose. It is recommended that a more sensible criterion be used.

Rec 18: The monitoring facility of JCOMMOPS is very limited. The services offered by IODE is much better. It is recommended that JCOMMOPS provide references to the IODE site from the GLOSS pages. Likewise, assuming the tsunami network is a component of GLOSS, a link to the NDBC site for monitoring the performance of these buoys is recommended.

Rec 19: There does not appear to be any annual reporting from GLOSS. At the very least, there should be some reckoning of how well stations in the GCN performed, and perhaps how well GLOSS is meeting GCOS-IP actions. It is recommended that OCG discuss reporting and monitoring requirements with GLOSS to better explain how well the program is meeting its objectives.

Rec 20: Although the IODE monitoring facilities are not evidently a part of GLOSS, they are very good. What is lacking, though, are explanations of the short form text that is used. For example, what does “pr1” or “rad” mean? It is recommended that OCG approach IODE and suggest such explanations be provided and that discussions with JCOMMOPS begin to decide what capabilities JCOMMOPS should be providing that do not overlap the IODE facility.

Rec 21: Monitoring of the operation of tsunami gauges is available through the NDBC. These do not appear to be the same gauges available through the IODE, but this is not clear. It is recommended that NDBC and IODE be approached to request that their sites make clear what overlap there is (or is not) and perhaps point to each other as available monitoring sites.

Rec 22: It is unclear which of the tidal stations represented at OSMC are GCN stations of GLOSS. This could be taken care of by specifying GCN as one of the available programs to be selected. However, the IODE site looks to do a much better job than OSMC, and so the discussions recommended in recommendation 21 should be followed up with OSMC as well.

Acronyms

BODC: British Oceanographic Data Centre
CLIVAR: Climate Variability and Predictability
DART: Deep-ocean Assessment and Reporting of Tsunamis
DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate Variable
FD: Fast Delivery
FTP: File Transfer Protocol
GCN: GLOSS Core Network
GCOS-IP: Global Climate Observing System – Implementation Panel
GLOSS: Global Sea Level Observing System
GNSS Global Navigation Satellite System
GOOS: Global Ocean Observing System
GPS: Global Positioning System
ICES: International Council for the Exploration of the Seas
IOC: Intergovernmental Oceanographic Commission

IODE: International Oceanographic Data and information Exchange committee
ITWS: International Tsunami Warning System
JASL: Joint Archive for Sea Level
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: JCOMM Observing Platform Support centre
MSL: Mean Sea Level
MTL: Mean Tide Level
netCDF: network Common Data Format
NODC: National Oceanographic Data Centre
OCG: Observations Coordination Group
ODP: Ocean Data Portal
OSMC: Observing System Monitoring Center
PSMSL: Permanent Service for Mean Sea Level
RLR: Revised Local Reference
RQDS: Research Quality Data Set
TGBM: Tide Gauge Benchmark
THREDDS: Thematic Realtime Environmental Distributed Data Services
UHSLC: University of Hawaii Sea Level Center
WMO: World Meteorological Organization
WOCE: World Ocean Circulation Experiment

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2.4: Argo

Introduction

The focus of this chapter is on the data that are collected through the Argo operations. Argo is not a formal observing system within JCOMM, but it works in close association with JCOMM. Argo maintains a Project Office, Regional Centers, and supports a Technical Coordinator at the JCOMMOPS, besides supporting its own data management components. All of this is described on the Argo website [1]. There are two teams that work within Argo; there is the Argo Steering Team [2] and the Argo Data Management Team [3]. There are other programmes that provide data similar to that delivered by Argo, but not as geographically spread, not in such volume, and not to such oceanic depths. These other programmes, SOOP and GO-SHIP, are treated in other chapters of this report. Other programmes delivering similar data, such as from research cruises, will be mentioned in passing.

Data Providers

Argo operations rely on collaboration among more than 30 countries. The Argo programme, with strong support from the Technical Coordinator, manages cooperation in float deployments, exchange of experiences with float operations, directs all aspects of data management, etc. When Argo was first organizing, an important criterion for operation was the agreement of participants to provide free and timely dissemination of data. The Argo Data Handbook [4] provides the responsibilities of participants. Still, it would be good to have a brief statement of the responsibilities of members, more readily available (Rec 1).

The instrument used by the Argo programme is the profiling float. It comes in several models from different manufacturers, but they all operate in basically the same way . All of this is well described [5]. Typically, floats operate on a ten day cycle spending most of that time drifting at their parking depth, usually about 1000m. During its observing part of the cycle, floats sink to 2000m, then rise to the surface sampling temperature and salinity at roughly 70 pressures levels. At the surface they transmit sensor and engineering observations at the end of the cycle. After this, they begin a new cycle with a descent back to their parking depth. All floats have a conductivity and a temperature sensor. Conductivity is measured through a conductivity cell and temperature is measured by a thermistor. Both are located on the top of the float.

A number of Argo floats have been instrumented with oxygen and other biogeochemical sensors as well. A recent meeting was held [6] of people interested in mounting oxygen and other biogeochemical sensors on the profiling float platform. Through the deployment of oxygen sensors on some floats there has been very useful at-sea trials such that there is confidence in the sensor's performance. A Bio-Argo group [7] has formed to organize this activity.

There are good reasons to initiate another group to deal with biogeochemical observations. First, each additional sensor mounted on a float requires power and this shortens the mission life of a float. Second, the community dealing in biogeochemical data is different from the physical oceanographic community from which Argo grew. Third, the design of Argo is based on objectives to routinely measure the temperature and salinity of the upper ocean to provide a quantitative description of the changing state of the upper ocean from months to decades, to complement satellite altimeter measurements, and initialize coupled ocean-atmosphere forecast models. Any diversion of float operations to support biogeochemical measurements, can impact the ability to meet these objectives. Hence, it was determined that additional floats would be required for these additional types of observations with their own set of objectives appropriate for a biogeochemical observing system.

As a consequence, though there are oxygen sensors presently operating successfully on Argo floats, discussion of this aspect of Argo will not be treated in depth in this chapter.

Temperature and salinity sensors on Argo floats have typical capabilities to measure temperatures to 0.002 ℃ and salinity to 0.002 PSU from 0-2000m (there are some variations depending on the CTD model used). A useful FAQ [8] provides more details on this and other aspects of Argo. A link to descriptions of float capabilities is available [5].

Argo data report ashore through satellite communications facilities of either Argos, or Iridium [5, 9, 10]. Among other functionality, the Argos system, operated by CLS, uses Doppler properties of the signals transmitted from floats to determine the float location. This permits low power transmitters with the obvious power savings. But, up until recently, there was more limited bandwidth for messages. Iridium, operated through multiple telecommunications providers, relies on a GPS system on the float to provide location, and a Doppler calculation when this fails. This uses more power but the bandwidth is larger as well. A larger bandwidth means the float does not need to remain at the surface as long to complete the transmission and so is exposed for a much shorter time to the more extreme conditions at the surface as well as biofouling, wind driven flow and grounding.

Other programmes collecting ocean profile data include the SOOP, GO-SHIP, and IOCCP. Each of these are treated in other chapters in this report. In addition there is the ocean research community making CTD measurements. But these do not routinely sample to 2000m (some go much deeper) nor are nearly as comprehensive in coverage. As well, these data often take months to years to become available, which is in sharp contrast to the data collected by Argo.

There is a developing community of glider operators. These operations are not well coordinated yet and so a search on the Internet turns up many pages dealing with gliders, but no coordinating body. Interested readers can look to pages on Wikipedia as a starting point [11]. Up to this time, management of the data coming from gliders is an issue for the operating agency. Some of these data reach national archives, and some do not. However, at the most recent OOPC meeting (September 2013) a representative of the glider community expressed strong interest in joining the JCOMM OPA. This is a positive development (Rec 2).

Ocean profile data are also collected from moorings where there can be thermistor chains suspended below a surface mooring such as those maintained by TAO [12]. The moorings of OceanSITES [13] also can report ocean profiles. These programmes are documented in other chapters of this report.

Profiles are also collected by national navies and by some fisheries vessels, usually operated by a national agency doing fisheries research or stock assessments. In the case of naval operations, the release of the data is highly dependent on national rules with some navies being very open in contributing data immediately, and others being less open. Receipt of data from fisheries vessels is highly dependent on whether there are provisions in place in a country to acquire the data from the vessels and send the data in either real-time or delayed mode (Rec 3).

Other sources of ocean profile data include those collected from CTD sensors placed on marine mammals [14], from cabled ocean observatories [15] and by hydrographic agencies [e.g. 16]. None of these programmes are formally part of or associated with JCOMM. They are often run by research agencies and often are continually developing the technology (instrumentation, data processing and dissemination). Some of the profiles collected by these programmes may enter international data systems, depending on how well these programmes are connected to national agencies that contribute to JCOMM or IODE. For example, most of the data from marine mammals are processed by SMRU [14], then forwarded to BODC for reformatting and pass through the UKMO for insertion onto the GTS. Because of programmes such as the GTSPP, these data are readily available.

For all of these programmes, there is some initial processing of the data and usually some data quality checking. Often, this is performed by the data recording software running on board the collecting vessel. In some cases, there is checking done of the data with the initial processing done on shore before sending data to the GTS. Each data collection group carries out its own procedures.

Data Assembly

The responsibilities for the complete data assembly process are well described in the Argo Data Management Handbook [4]. As well, all of the quality control procedures are described in a document [17]. The information presented here is a brief summary. Readers should consult these documents for all details.

Each contributing nation is responsible for organizing how the data from their floats are initially processed prior to real-time distribution. Processing involves acquiring data from the telecommunications providers for the floats and passing the data through a basic set of quality control tests that are standardized across all participants. Each participant is also responsible for maintaining all metadata about the float, its components, operations, etc. To accomplish this, some countries set up their own facilities for this purpose, while others have the work handled by the NODC. This operation is handled through a DAC.

The GTS, operated by the WMO, is one of the distribution networks used to exchange Argo data in real-time. The last step in processing is to convert the data stream to appropriate GTS message structures. At present, Argo data are all sent in the TESAC code form, and nearly all of the data also are sent in a particular BUFR template [18]. Once converted to these forms, the data are then uploaded to an organization that inserts the data onto the GTS. For some countries this is done through their NMHS. Some other countries take advantage of a facility offered by Argos to do this preliminary work and insert the data onto the GTS on their behalf.

After real-time processing, the data are also converted to the standard netCDF data format [19] for Argo data and at the same time as the data are sent for GTS distribution, the netCDF files are sent by ftp to both Argo Global Data Assembly Centers (GDACs). Principal investigators, PIs, responsible for the floats are also recipients of the real-time data. All of these responsibilities are described in the Argo Data Management Handbook [4].

Because all of the data circulate on the GTS in the TESAC or BUFR form, ISDM in Canada, operating the real-time component of the GTSPP (see the chapter on SOOP) assembles all of these real-time data and after processing for duplicates and quality control, forwards copies to the Coriolis centre, and the U.S. NODC. This function is outside of the formal Argo processing system, but provides a way to combine all profile data exchanged in real-time (from XBTs, Argo floats, research CTDs, etc.) into a single format after having undergone standard processing. The same is also true for other profile types that accompany T and S data on the GTS, but as yet there are no global designs nor consensus on how to sample and manage these other types.

The operations of dealing with delayed mode data, as well as other aspects are discussed in the next section.

Processing and Archiving

The responsibilities for the complete data assembly process are described in the Argo Data Management Handbook [4]. As well, all of the quality control procedures are described in a document [17]. The information presented here is a brief summary. Readers should consult these documents for more details.

For delayed mode data, the PIs are responsible for carrying out (sometimes delegating this to another organization) scientific quality control, again using standardized procedures. Whether done themselves, or delegated to others,the PIs are responsible for answering any questions about the. data if they arise. This work is targeted to be completed within 12 months of the data arriving from the float. After completion, the data, again in netCDF, is sent to both GDACS for retention and dissemination.

There are two GDACs for Argo, one in the U.S. at the USGODAE operations in Monterey [20], and the other at the Coriolis center in Brest, France [21]. Their responsibilities are to act as the central coordination and clearing house for all Argo data. They provide ftp and web access to the data, and mirror the contents of the other GDAC to provide redundancy and therefore security of access to the data. Coriolis provides monthly snapshots of their archives with DOIs.

Argo operates Regional Centers [22] whose responsibilities are to validate the float data for particular ocean areas by comparing the data to other data types, such as CTDs, inter-comparing data from floats in the ocean area operated by different countries, and preparing products. More information on the operations for these centres is available from [22] and from the Data Management Handbook [4].

The Argo Information Center, AIC, [23], operating as part of the JCOMMOPS, provides a valuable service in coordinating technical issues for Argo. It is responsible for resolving “any issues arising between float operators, manufacturers, data telecommunication providers, data assimilation centres, quality control and archiving agencies, WMO and IOC, encourages the participation of new countries, and assists as appropriate in the implementation of a global network”. It also operates a web site with various products, that will be described later.

Finally, the U.S. NODC operates the long term archive for Argo data [24]. Its purpose is to “maintain the authoritative reference version of original operational oceanographic data and information and to provide high quality data to a wide variety of users in a timely and useful manner".

An important part of managing the Argo programme has been the great attention paid to metadata management. The range of metadata that is captured and retained with the data is much more extensive than has ever been done before. There are different netCDF formats used in Argo. One is for the trajectory information, one for profile information, one for metadata and one for technical information. The trajectory and profile formats hold observations derived from the times when the float is drifting, either at the surface or at depth, or the observations collected when profiling on ascent. Both of these files contain metadata including who was responsible for operating the float, creation and modification dates of the file, PI name, positioning system, etc. In addition, they retain quality control flags resulting from the standardized tests, original versions of the observations as well as adjusted versions, calibration information, etc. Files contain a record of the processing history of the data which describes things such as what actions were performed on the data, when and by whom. All of this provides much richer information that any other ocean data set up to the time Argo started.

The metadata file records information such as the telecommunications system used and characteristics of operations and hardware used, battery, controller board, sampling operations, deployment, sensors, and calibration information.

The technical information file contains an open ended set of additional information that float operators and processors may want to retain. This is accomplished by storing information in a keyword, value pair. The keywords form a controlled vocabulary coordinated by the Data Management Team, but to which any Argo participant can submit additions.

All of this may seem like overkill, but storing all of this metadata allowed recovery of data with the discovered failure of a pressure sensor used in certain models of floats. The problem was not discovered until well after deployment, but because the details of which floats had which sensors, the suspect data could be identified, and reprocessing was able to recover much of what might have otherwise been lost. The Argo bibliography pages [25] reference this issue in papers by Barker, et. al., and by Kobayashi, et. al. (Rec 4).

Most countries operate their own web sites to explain their Argo program. Such sites are available through the "International collaboration" link found on the Argo home site [1]. By agreement, however, although countries are responsible for managing their Argo data, and for responding to questions about the data from the floats they operate, all potential users of Argo data are directed to the GDACs.

Data Dissemination

All Argo data are available free of charge and as soon as they appear either on the GTS or from the GDACS. As noted earlier, they are available from the GDAC in Monterey [20] or in Brest, [21]. The real-time data are available usually within 24 hours of the float transmitting to shore. The target for making delayed mode data available at the GDAC is 12 months after reception by the PI, but this is sometimes harder to achieve.

Data are all delivered in netCDF [19] with CF conventions used [27]. They are available from both ftp sites and www selections. The data on the ftp site is organized in three different ways to help users get just what they want. In the first form, the data are organized by the originating DAC, with directories by float and by individual profile. In the second form, the data are organized by ocean, with directories by year, then month, then day, and float profile. In the third form, the data are organized by the latest version of data, with directories by year, then month, then day and then float profile. There is a strict naming convention for files which helps users automatically know how to identify files of interest.

The www interface at Coriolis provides a map interface, with capabilities to select the kinds of data, profiles or trajectories, date ranges, area selection, and variables. Users can download in netCDF or a csv file format. At the USGODAE server there is a selection by area, time, and profile types, but without a map interface. It also provides a link to Argo data on a Live Access Server, however, the list of data presented there does not seem to have one dedicated to Argo. Making data available through a LAS is a nice feature, but this implementation is confusing (Rec 5).

The U.S. NODC operates the long term archive for Argo [24] with the data having undergone NODC quality control routines. These routines are not described (Rec 6). NODC provides ftp, http and OPeNDAP access [28] to data. The data are provided in netCDF, with descriptions provided, but no information that states whether or not this is the same as the netCDF provided from the GDACs. It is inferred that it is not, since the page describes the data being in “NODC versions” (Rec 7).

The ftp and http access takes a user to long lists of directories, and html files that display information about the floats and it is only by digging deeper and deeper does one find the netCDF or csv files. Likewise, selecting the http link takes a user to directories of files, some being html and some csv files. This is a confusing layout (Rec 8).

The OpeNDAP interface is more easily understood in that it shows waterfall plots for floats and allows users to select by floats, and then cycle number.

On the left margin of the “Access Argo Data” page is found other ways to access the data. These are briefly explained on the main access page and this is enough for a user to know what each way will provide (Rec 9).

Argo data have been incorporated in the WOD [29] with the variety of other data types that deliver profile data. All data, including Argo, undergo a WOD quality control treatment [30]. WOD provides a data selection service [31] (free of charge) as well as detailed tools and documentation on how to read the data and use the tools [32]. Data are provided in a WOD format or a comma separated file format.

NetCDF is a common format used for distribution of Argo data. But because this is not always easy for users, there is information provided on the Argo data guide page [33] that provides guidance and links to a Matlab program that can read netCDF.

The Argo home site also provides access to a data viewer [34]. This is produced and supported by Scripps.

The AIC provides a float and data discovery tool for Google Earth. The AIC acquires, checks and maintains a wide variety of metadata which are also available to interested parties through different services including text files, GIS and Google Earth applications. These are also used for monitoring performance (see text under Monitoring).

Differences Between Distributed Data Sets

DACs: deliver Argo data (profile, trajectory, metadata, technical information) after standardized Argo quality control (the level depends on whether data are real-time or delayed). Each may have a different data format.

GDACs: deliver the best versions of real-time and delayed mode Argo data (profile, trajectory, metadata, technical information) in the project agreed netCDF format. This is the first and best source that users should exploit for Argo data. All metadata are also available here and with a variety of ways to access data.

NODC: delivers the Argo profile data and metadata (see Rec 9) in a local netCDF format, after NODC quality control.

WOD: delivers all types of profile data, including Argo profiles, after quality control. Objective analysis allows identification of bull's eyes. Interpolations are provided to standard levels. The data set includes more than temperature and salinity profiles. Data are available in a custom ASCII format or csv format.

User Communities

The Argo home web pages [1] have an extensive section describing the uses of Argo data. In addition they also have a long list of published results where Argo data have been used.

Clearly the rapid availability of the data, the global extent of the observations, and their frequency mean Argo produces a data set that truly enables operational oceanography. This means that more realistic short and long time scale predictions of the ocean state are now possible. Of equal importance is that it allows for a better coupling of oceanic and atmospheric processes that makes computer modelling much more realistic.

Operational oceanographic capabilities have a wide range of other uses such as oil spill monitoring and prediction, search and rescue, and real-time ground truth for satellite systems.

Having estimates of the state of the ocean circulation provides background data that might be exploited in studies of species distributions and movements, commercial operations at sea, and others. The volume and detail of the data set opens up broad possibilities.

Monitoring and Performance Metrics

The Argo program produces a variety of monitoring products. Those available from the AIC [23 under the "monitoring tab"], a component of JCOMMOPS, include current and past maps of float distributions, statistics on deployments by year and oceans, statistics on float lifetimes as a function of year deployed, depth and spatial distribution of sampling, reporting delays, numbers of real-time and delayed mode profiles at GDACs and so on. In addition the AIC provides the ability to monitor floats individually, including the ability to look for deployment plans and possible opportunities. The AIC and the Argo Project Office maintain a support activity that can be accessed through support@argo.net and that can assist in gaining access to information about the project. There is much useful material at the AIC, but at times the response times for presenting pages is not good (Rec 10).

The ISDM provides a number of graphs showing the performance of Argo floats [35], including how well the project meets its target to get data to the GTS within 24 hours of observation.

Coriolis, as a GDAC, provides graphs [36] showing information about the locations, and performance of the different models of floats (including those making oxygen measurements). The Argo data guide page [33] states that a grey list of suspect floats is maintained on the GDACs. But there is no link provided and no such list could be found on the GDAC sites (Rec 11).

The Regional Centers of Argo [available from 33] all provide a variety of different monitoring products. Some are very detailed, such as showing the calibration information on a float by float basis for floats operating in the region.

Some national sites, linked from the Argo home site [1], provide details of battery performance for individual floats or other engineering properties.

The Unites States funded Observing System Monitoring Center, (OSMC) [37] provides a variety of tools to examine the status of observing systems. On the home page is found a composite map of all observations in the last 3 days. The information is composed of data and metadata taken from the US GTS node and from the AIC. The OSMC also provides some capability to display on Google Earth projections. Some additional comments follow.

- Under the "In Situ Monitoring tab, there are some deficiencies (such as using programme names that are not necessarily clear to all users (e.g.NWLON), inclusion of US programmes, though this site obviously has a dual purpose, missing some JCOMM observing systems (e.g. SOOP, VOS). However, when "all programs" is selected and then a particular parameter it seems quite good.
- Under the "Observing System Metric Reports" tab and after selecting "Argo Profiling Floats" there is a useful listing of operating floats, with numbers by countries. When selecting this tab, the name on the tab changes to "OOPC status reports" which seems odd. Also, one of the selections is labeled "psbe" and what this is is not obvious to users.
- Selecting the "Observing System Metrics" tab has this name change to "OOPC Status Reports". It was also noted that the "OSMC Viewers" link results in an error. As noted previously, this is a bit confusing. (Changing tab names is a common "feature" at OSMC and it is not obvious why this is useful).The displays here can be for selected parameters, which can be a nice presentation for an observing system. The presentation of time series is interesting, but difficult to read and it was not clear how to print this display rather than the associated map.
- Presentations based on all platforms for a selected parameter is approaching what is needed for an ECV perspective and will be dealt with in that chapter.

Reports of Argo data management meetings are available [38] from the beginning of the project. These are also available from the Argo home pages [1]. There is a great deal of information in these reports on the status of Argo implementation, on problems, and ongoing work. For example, the latest document (ADMT-13) states that 21% of delayed mode data are still undelivered to the GDACs after 12 months. National reports are included as well which give a very good, and very detailed, picture of the state of data management implementation. Likewise, the Argo home page [1] points to Argo Steering Team meeting reports. Again these are filled with good information about the project.

GCOS-IP (2010) Performance Indicators

Within the GCOS-IP (2010 update) [39] Argo operations are mentioned in 3 Actions, listed here. Information on how the project is meeting performance indicators was obtained from web pages cited in this report. (Note that these Performance Indicators cite an array of 3000 floats, but that has been changed by Argo to an array of 3600).

Action O11 [IP-04 O15]
Action: Implement a programme to observe sea-surface salinity to include Argo profiling floats, surface drifting buoys, SOOP ships, tropical moorings, reference moorings, and research ships.
Who: Parties' national services and ocean research programmes, through IODE and JCOMM, in collaboration with CLIVAR.
Time-Frame: By 2014.
Performance Indicator: Data availability at International Data Centres.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

Report: Argo is operating at its original target of 3000 reporting floats. More than 1 million temperature and salinity profiles are available from the GDACs.

Action 26 [IP-04 O27]
Action: Sustain the network of about 3000 Argo global profiling floats, reseeding the network with replacement floats to fill gaps, and maintain density (about 800 per year).
Who: Parties participating in the Argo Project and in cooperation with the Observations Coordination Group of JCOMM.
Time-Frame: Continuous.
Performance Indicator: Number of reporting floats. Percentage of network deployed.
Annual Cost Implications: 30-100M US$ (10% in non-Annex-I Parties).

Report: Argo achieved the target of 3000 floats operating in 2008 and has sustained it since then. At present (Jun 2013) there are more than 3500 floats operating to address expansions to the global design into marginal seas, high latitudes, equatorial and Western Boundary Current regions).

Action O30
Action: Deploy a global pilot project of oxygen sensors on profiling floats.
Who: Parties, in cooperation with the Argo Project and the Observations Coordination Group of JCOMM.
Time-Frame: Continuous.
Performance Indicator: Number of floats reporting oxygen.
Annual Cost Implications: 1-10M US$ (10% in non-Annex-I Parties).

Report: At present there are 118 floats that are or have been measuring oxygen and have reported more than 12,000 profiles. About 45% are currently active.

Recommendations

Rec 1: The data policy of Argo is embedded in the Data Management Handbook. However, the rapid and free access given to Argo data is a prerequisite of participation and so it is recommended that this receive greater prominence on the Argo home website, perhaps placed on the page discussing "International Collaboration".

Rec 2: All three Programme Areas of JCOMM should have a conversation with representatives of the global glider community as soon as practical. OPA interests are in the coordination of the data collections with other programmes. DMPA is impacted to help ensure that data reporting protocols (formats, timeliness, glider identification, etc.) conform to international requirements. SFSPA has interests in ensuring the data from gliders are properly identified and reach the services interested in using them.

Rec 3: Every country should encourage all organizations that collect ocean data to contribute these as soon as possible to international data systems. Promotion of this is best handled administratively at the IOC and WMO levels, but individuals can sometimes make a difference in getting results.

Rec 4: The experience of Argo and the faulty pressure sensor is in contrast to the well known XBT fall-rate problem [26]. Had there been information stored on probe types as the data were collected, the strategies for correction would have been much simplified. It is recommended that JCOMM and IODE encourage all data collection programmes to capture and archive instrument metadata with the data that they collect or receive.

Rec 5: The link provided on the USGODAE page indicates LAS access to Argo data. The LAS implementation at USGODAE needs the specification of a data set to begin. The list provided uses terms that are not familiar to an infrequent user, and there is no entry in the list that allows viewing Argo data separately from other contents available on the LAS. It is recommended that this implementation be modified to ensure access to Argo data is obvious.

Rec 6: It is hoped that the NODC describes its quality control processing somewhere on its web site. On the page that provides access to Argo data, there should be a link to describe what is done. There might also be an explanation of the value added by this additional processing. It is recommended that NODC make this information more easily found.

Rec 7: It is assumed that the NODC netCDF and the GDAC netCDF are different. Rather than call their version an "NODC version" it would be far better to state that this is different from that of the GDACs (if it is). And if it is different, some description of what are the differences and why would be helpful. What is gained by this difference?

Rec 8: Using the http or ftp links to access Argo data takes a user to a confusing list of files and directories. Explanation is needed to help a user interpret what he is seeing.

Rec 9: In one case, looking at the "Argo Floats Data" tag, the descriptive text says the profile, metadata and technical files are available, but on downloading a sample, only profile files seemed to be present. It would appear that the metadata information is not available from NODC. This needs to be verified and the descriptive text changed to reflect what is there, or a change to what is downloaded.

Rec 10: There is much useful monitoring information on the AIC, but response times are not always good. Some flaws were found in closing products as well. The AIC should ask someone outside to review their pages looking for weaknesses and make recommendations for changes.

Rec 11: Since the grey list is apparently unavailable, this should be stated. Some users may be interested in the reasons why some floats are listed there. There is no explanations about how the data from these floats are handled, except that the data do not do out on the GTS. Further explanation would be appropriate.

Acronyms

AIC: Argo Information Center
BODC: British Oceanographic Data Centre
BUFR: Binary Universal Form for data Representation
CF: Climate and Forecast conventions
CLIVAR: Climate Variability and Predictability project
CLS: Collecte Localisation Satellites
csv: Comma Separated Value
CTD: Conductivity, Temperature, Depth instrument
DAC: Data Assembly Center
DMPA: Data Management Programme Area
DOI: Digital Object Identifier
ECV: Essential Climate Variable
FAQ: Frequently Asked Questions
ftp: File Transfer Protocol
GCOS-IP: Global Climate Observing System – Implementation Panel
GDAC: Global Data Assembly Center
GO-SHIP: Global Ocean Ship-based Hydrographic Investigations Programme
GPS: Global Positioning System
GTS: Global Telecommunications System
GTSPP: Global Temperature Salinity Profile Project
IOC: Intergovernmental Oceanographic Commission

IOCCP: International Ocean Carbon Coordination Project
IODE: International Oceanographic Data and information Exchange
ISDM: Integrated Science Data Management
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: JCOMM Observing Platform Support centre
LAS: Live Access Server
netCDF: network Common Data Format
NMHS: National Meteorological and Hydrological Service
NODC: National Oceanographic Data Centre
OPA: Observations Programme Area
OPeNDAP: Open-source Project for a Network Data Access Protocol
OOPC: Ocean Observations Panel for Climate
OSMC: Observing System Monitoring Center
PI: Principal Investigator
PSU: Practical Salinity Unit
SFSPA: Services and Forecasting Systems Programme Area
SMRU: Sea Marine Research Unit (St. Andrews University)
SOOP: Ship Of Opportunity Programme
TAO: Tropical Atmosphere Ocean project
UKMO: United Kingdom Meteorology Office
USGODAE: US Global Ocean Data Assimilation Experiment
WOD: World Ocean Data project
WMO: World Meteorological Organization
XBT: Expendable Bathythermograph

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5. Float operations and instrument: http://www.argo.ucsd.edu/How_Argo_floats.html
6. Argo and biogeochemical sensors: http://www.argo.ucsd.edu/BGC1report.pdf
7. Bio-Argo information: http://www.ioccg.org/groups/argo.html
8. Argo FAQ: http://www.argo.ucsd.edu/FAQ.html
9. Service Argos: http://www.argos-system.org/
10. Iridium: http://www.iridium.com/
11. Wikipedia pages on gliders: http://en.wikipedia.org/wiki/Underwater_glider
12. TAO: http://www.pmel.noaa.gov/tao/
13. OceanSITES: http://www.oceansites.org/
14. Profiles from marine mammals: http://www.smru.st-andrews.ac.uk/
15. A sample programme: http://www.neptunecanada.com/about-neptune-canada/infrastructure/cabled-ocean-observatory/
16. Example of a hydrographic agency: http://www.charts.gc.ca/data-gestion/hydrographic/sd-ld-eng.asp
17. Quality control procedures: http://www.argodatamgt.org/content/download/15699/102401/file/argo-quality-control-manual-version2.8.pdf
18. GTS code forms: http://www.wmo.int/pages/prog/www/WMOCodes.html
19. netCDF format description: http://www.argodatamgt.org/content/download/17799/115797/file/argo-dm-user-manual-v3.0.pdf
20. USGODAE home: http://www.usgodae.org/argo/argo.html
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25. Argo bibliography: http://www.argo.ucsd.edu/Bibliography.html
26. XBT Fall rate issues: http://www.marine.csiro.au/~cow074/quota/bias_AMS_accepted.pdf
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2.5: GO-SHIP

Introduction

The focus of this chapter is on the data that are collected through the GO-SHIP [1] operations. Members of the GO-SHIP committee are listed at [2]. The programme is built on technical developments and procedures formed during WOCE and developed in response to needs identified in OceanObs'09 [3]. Its general objective is "... to develop a Global Ocean Ship-based Hydrographic Investigations Program ... by bringing together ... scientists with interests in physical oceanography, the carbon cycle, marine biogeochemistry and ecosystems, and other users and collectors of ocean interior data to develop a sustained global network of hydrographic sections ..."

There are other programmes that provide data similar to that delivered by GO-SHIP. In particular there is complementarity with the SOOP, Argo, OceanSITES, and IOCCP programmes. There are also other national programmes that collect the data of interest to GO-SHIP, but these do not necessarily repeat sampling of sections or don't have GO-SHIP level 1 variables or do not follow GO-SHIP data policy. (A reviewer noted that both of these were formally endorsed at the GO-SHIP-4 meeting in Hawaii (Feb 2014). They also noted that GO-SHIP does not look after all ship-based measurements).

Data Providers

GO-SHIP is not a programme such as Argo, or SOOP, that has installed infrastructure to make routine observations. Instead, it is a coordinating body that sets out objectives for repeat measuring of climate quality sampling of particular variables. It relies on the international ocean research community to collaborate with the programme by volunteering ship time and staff to perform the sampling. The data and metadata collection standards are the most stringent set by any programme and so demand experienced staff to carry them out.

GO-SHIP committee members organize data collection activities through their national affiliations and through their contacts with like-minded research scientists. There is significant coordination with the IOCCP [4] since it is through sea water collections that the data of interest to both programmes are acquired.

There are no general statements about the suite of variables of concern to GO-SHIP, but there is a well constructed "GO-SHIP Repeat Hydrography Manual" [5] that contains a chapter that discusses standards for the variables to be measured [6]. The list includes temperature, salinity, pressure, oxygen, nitrate, phosphate, silicate, dissolved inorganic carbon, alkalinity, partial pressure carbon dioxide, pH, tritium, CFCs, sulphur hexafluoride, and carbon isotopes. There are also sections in a different chapter that discuss how to make underway measurements including measurements of currents with ADCPs (Rec 1) as well as meteorological and flux measurements, for a number of ECVs. The suite of variables goes well beyond the current list of ECVs, but it is expected that when the EOVs are set, that list will include many or all of the variables listed by GO-SHIP.

(A reviewer noted that the recent GO-SHIP-4 meeting endorsed the set of level 1, level 2 and level 3 measurements, and the design of reference sections, which are often WOCE lines. Level 1 must be completed once per decade on these sections and contains:

•Dissolved inorganic carbon (DIC)
•Total Alkalinity (TAlk)
•pH
•CTD pressure, temperature, salinity (calculated)
•CTD oxygen (sensor)
•Bottle salinity
•Nutrients by standard auto analyzer (NO3/NO2, PO4, SiO3)
•Dissolved oxygen
•Chlorofluorocarbons (CFC-11, -12, -113) and SF6
•Surface underway system (T, S, pCO2)
•ADCP shipboard
•ADCP lowered

•Underway navigation and bathymetry
•Meteorological data

The “GO-SHIP Repeat Hydrography Manual” [5] that contains a chapter that discusses standards for the variables to be measured [6], will shortly be updated accordingly.

This is all useful information, available after this draft report was completed, If not already done so, it should be fully incorporated into formal documentation available from the GO-SHIP web site.)

The document that lists variables also provides standards that need to be met what making the measurements. In other documents there are extensive discussions of practices, including the metadata that should be collected [7]. A series of other chapters discusses recommended best practices for additional variables. All of this is comprehensive, encourages standardized methodologies, and is welcome to see on the web site.

GO-SHIP maintains a list of the reference sections that repeat some that were sampled during WOCE. A table, organized by ocean basin, lists the most recent occupations and when the next might be planned. These are very helpful in coordinating activities amongst researchers to make best use of ship resources. (A reviewer noted that the GO-SHIP coordinator at JCOMMOPS maintains a list of planned cruises on the website and interacts with focal points in all countries participating in GO-SHIP, and all these nations coordinate to add the required measurement to each decadal sections. The author could find no reference to GO-SHIP on the current JCOMMOPS pages. This clearly needs attention and relates to Rec 17 in insuring recent and complete information about the program be placed as soon as possible on the web sites where a user should reasonably expect to find it.).

The GO-SHIP cruise page [8] includes references to other “non-reference” sections, as well as cruises conducted by other programmes, such as Argo, GEOTRACES, SOOP XBTs, and national programme information as well. Again, the purpose of these is to inform the GO-SHIP community about other activities that collect data that can be useful to supplement GO-SHIP.

Because GO-SHIP is only able to encourage and coordinate activities, those who willingly participate are not likely to measure all of the variables at every station on a single cruise.

Data Assembly, Processing and Archiving

In GO-SHIP, the data assembly function is not separated from the processing and archiving functions, as they sometimes are for other programmes. Management of the assembly, processing and archiving of the data collected is a distributed function based on the variable measured. A data directory [9] shows eight centres participating in the U.S. and Japan (Rec 2). The challenge at each of these centres is more than to deal with the measurements. The guidance material described earlier that specifies the metadata to be collected with the data is also of great importance to manage and have available for users.

Some of the data collected on GO-SHIP cruises can be sent in real-time. So, for example, the standard meteorological variables such as air pressure and temperature, as well as temperature and salinity profiles all have practices in place to allow their transmission to shore and insertion onto the GTS [10]. The provision of data in real-time is outside of the objectives of GO-SHIP, but never-the-less they are sent by some ships.

Because of the very high quality standards for the measurements, and because of the great variety of kinds of data collected, the delivery of the data from PIs to data centres of GO-SHIP can take months to years. There are no statements about targets for data delivery by type of data on the GO-SHIP pages. However, the community white paper [11] prepared for OceanObs'09 does have recommendations that state that a “preliminary dataset (should be) released within six weeks (e.g., all data measured on the ship), six months for final physical data, one year for final data of all other variables (except for isotopes or tracers with shoreside analysis.” (Rec 3,4).

The GO-SHIP web pages make no statements about responsibilities for data quality assessment. The Hydrographic Manual described earlier places expectations on activities that the individual PIs should carry out as part of their analyses. Most of the chapters discussing techniques for the different variables also discuss data quality assessment procedures. It is expected that PIs will also carry out these procedures. There are no statements on GO-SHIP pages that describe responsibilities and operations of the data centres involved, Visiting the various data centre web sites shows that in only a few cases is there any documentation of operations. In particular, there is seldom any information about whether or not data centres undertake any data checking when the data arrive. If they do such checking, the procedures used are not well enough described so that a potential data user is well informed about what has been done to the data (Rec 5).

Data from individual cruises may get spread over a number of archives supporting GO-SHIP, though the mechanism for this is not clear (Rec 6). The CCHDO and CDIAC archives both support the same identification scheme, known as EXPOCODE. This is a worthwhile implementation as it allows a user to identify more than one kind of data collected on a cruise and that get spread over different archive systems, and allows the data to be brought back together fairly easily. It was unclear if the use of the EXPOCODE or some other means allows easy reunification of the other kinds of data collected on cruises (Rec 7).

It was noted on CCHDO and IOCCP sites that the U.S. NODC is used for long term safekeeping of the data held at these archives. The same submission of data to the NODC is likely true, though unstated, for the other archives that operate in the U.S. The Japanese archive is established at an NODC as well, but there are no statements about where copies of their data reside, such as might be found in a disaster recovery plan (Rec 8).

The appropriate types of data received at the NODC contribute to the World Ocean Database [12] and appear in monthly updates. All data, described in [13] entering the WOD, not just data from GO-SHIP, undergo the same quality checking procedures, as described in [14].

The portion of data collected under the GO-SHIP programme, but that are reported in real-time is restricted by the capability of real-time data formats. Typically, these are water column temperature, salinity, and currents, as well as surface meteorological measurements. These data end up in the data streams of other JCOMM programmes, principally SOOP and VOS. Readers are referred to the chapters describing these programmes for greater detail.

Data Dissemination

Data management and policy documentation on the GO-SHIP site refer to documents that were constructed for other projects or programmes. The inference is that GO-SHIP has adopted the same (Rec 9).

After visiting the various data archives, searching for information about data accessibility, it was found that there was a mixture. At some sites, there was detailed information explaining that some data were publicly available, and some not. Other sites declared that all data coming to it was publicly available. Others had no obvious statements whether or not there are any restrictions (Rec 10).

Most of the archives make their data available in netCDF [15]. It was not possible to verify if the various forms used are mutually compatible, for example using CF conventions [16]. While it might be ideal to present all of the data in a common netCDF file structure, this is deemed unlikely to be possible due to the great diversity of data. However, it may be possible for some consolidation by treating all time series in one structure, vertical profiles in another, and so on, along the same lines that Argo uses (Rec 11).

Most of the archives also deliver data in ASCII forms. There are wide variations in these forms which is bound to cause some difficulty if a user wishes to assemble data from a variety of sources. It is unclear how much effort should be put into trying to standardize these ASCII forms but perhaps there are some improvements that should be pursued (Rec 12).

Data access interfaces vary widely across the GO-SHIP archives. No doubt this reflects the history of how GO-SHIP has brought together under its umbrella the different contributing agencies. The mutual cooperation of these different groups is a very important first step. It is time to consider what directions the programme should take to present a more unified perspective (Rec 13).

Some of the archives are very explicit in making associated metadata available with the data. Probably the most detailed record of processing is that delivered with the LADCP data. The GO-SHIP Repeat Hydrography Manual makes a strong point of the importance of metadata. Therefore, this should be very visible when data are accessed (Rec 14).

The archives that are represented on the data directory page at GO-SHIP have been in existence before GO-SHIP began. Consequently, their data holdings include data collected before GO-SHIP was organized, or from programmes, such as the underway CO_2 monitoring programme, that are not under the GO-SHIP umbrella. It is good that these data are held in the archives. But there is no apparent GO-SHIP affiliations, no text on web pages, at many of the archives that identifies their cooperation with GO-SHIP, nor the affiliation of the data collected under the GO-SHIP banner. This presents the view that GO-SHIP is an opportunistic assembly of partners who would be in operation on their own anyway (Rec 15).

The WOD provides a data selection service [17] (free of charge) as well as detailed tools and documentation on how to read the data and use the tools [18]. Data are provided in a WOD format or a comma separated file format.

Both SOOP and VOS programmes have data dissemination facilities from which some data that appears in GO-SHIP archives may also be found. Readers are referred to the chapters describing these programmes for greater detail.

Differences Between Distributed Data Sets

GO-SHIP archives: these deliver the highest quality, most recent data available. It often has metadata. Data types are quite varied, with archives specializing in different types. Data formats are varied with many providing a netCDF form and also ASCII, though there does not appear to be much commonality in this latter form.

WOD: delivers all types of profile data after quality control processing as described on their site. Objective analysis allows identification of bull's eyes. Interpolations are provided to standard levels. The data set includes some variety of data types, but not all that is collected within the GO-SHIP programme. Data are available in a custom ASCII format or comma separated value format.

SOOP and VOS: These data are a mix of real-time and delayed mode. The real-time data are available very soon after data collection, but are of lesser quality and resolution. The delayed mode components, such as water column data, replaces the real-time and will duplicate of some of the data held in GO-SHIP archives.

User Communities

The users of GO-SHIP data are predominantly in the research and climate community. They require the highest accuracy and precision in the data and the most care in processing. Data are available with delays dependent on the type of data.

The GO-SHIP data that are made available in real-time contribute to operational weather and ocean forecasting. They also contribute to surface truth for satellite observations.

A bibliography of results from projects that use the repeat hydrographic data is compiled at GO-SHIP [19]. These provide a cross section of the existing user community.

Monitoring and Performance Metrics

The GO-SHIP web pages show maps by basins that also list the most recent occupation of repeated sections and the next planned one(s). There is a section that provides news that includes opportunities for researchers on upcoming cruises. There are also reports from the various workshops held, though the last available is from 2010 (see Rec 17).. Beyond this, there is no information about the status of the programme.

From a data monitoring perspective, the CCHDO provides search tools for data, and information on recent updates to data holdings. Under the “Browse Data” tab, maps and lists of cruises, by basin, project or time series, that are held are also provided. Other archives referenced in the “Data Directory” tab usually have similar sorts of displays. Some of these also have documentation on meetings that address aspects of the programme.

It is difficult to identify what might be effective performance metrics of a coordination programme of research efforts. Essentially, the programme consists of activities volunteered by participants as they are able to secure ship time and resources. A starting point provided on the CCHDO site is the list of cruises conducted.

Starting with the stated objectives of GO-SHIP as found on the home page, “to develop a globally coordinated network of sustained hydrographic sections”, it is possible to suggest a way to measure the success of the program. It is suggested that the GO-SHIP web site have a table that lists all of the cruises conducted, as it now appears to do. For each cruise a link is provided to a cruise track map. Columns for time and a unique cruise identifier should be provided. Each data archive would be a column, and an indicator found there about whether such data were collected on the cruise, and if so, if the data have arrived at the archive. The cruise identifier could be linked to a simple metadata file, and/or perhaps a map that identifies where the stations of the different types were collected. Using the cruise identifier, a common reference across all of the archives, would provide a potential user with a nice summary in a single table of the status of data collection, assembly and location (Rec 16).

In other chapters of this report, it has been suggested that some kind of annual, or at least regular, reporting be undertaken for programmes. The table suggested above would be a useful contribution to such a report. It is possible that individual archives contributing to GO-SHIP would also have sections where they could provide updates on how their operations have progressed annually. Such a report can be used to demonstrate to sponsors that the GO-SHIP programme is working (Rec 17).

GCOS-IP (2010) Performance Indicators

Within the GCOS-IP (2010 update) [20] the GO-SHIP operations are mentioned in Action 24, listed here.

Action O24 [IP-04 O25]
Action: Development of a plan for systematic global full-depth water column sampling for ocean physical and carbon variables in the coming decade; implementation of that plan.
Who: National research programmes supported by the GO-SHIP project and IOCCP.
Time-Frame: Continuing.
Performance Indicator: Published internationally-agreed plan from the GO-SHIP process, implementation tracked via data submitted to archives. Percentage coverage of the sections.
Annual Cost Implications: 10-30M US$ (Mainly by Annex-I Parties).

Report: There is no plan in place nor anything to describe cooperation between national research programmes, CCHDO and IOCCP. Implementation is proceeding, though it is difficult to measure the success of the programme. (A reviewer noted that the addition of a program coordinator has provided a focal point for national GO-SHIP reporting and coordination. The GO-SHIP committee have had regular teleconference meetings since 2011 and these are now organized by the program coordinator. The author applauds this, but evidence of this needs to appear on appropriate GO-SHIP and JCOMMOPS web pages).

Recommendations

Rec 1: In describing itself, SOOP takes responsibility for ADCP measurements, and a recommendation in that chapter refers to the lack of attention paid to ADCP at SOOP meetings. GO-SHIP also speaks about ADCPs. The two committees should get together to decide how the data management activities for ADCP data should be handled so that it is clear to a potential user, which programme is leading the data management, and where the data can be found. At present, this appears to be lead by GO-SHIP.

Rec 2: In the Data Directory list, there is a small error for Underway Data. The reference to Robert Keeley needs to be removed, since he is now retired.

Rec 3: It is recommended that the targets set in the community white paper have greater prominence on the GO-SHIP web site. They could be associated with the data directory page or some other more suitable location. The publication of the targets gives the GO-SHIP committee another way to evaluate how well the programme is meeting objectives.

Rec 4: There are no targets stated on delivery of isotope or tracer data except to note that one year delivery is difficult. It is recommended that GO-SHIP set a target for these kinds of data that recognizes the difficulties of such analyses but informs potential users about what can be expected.

Rec 5: It is expected that GO-SHIP data centres do some checking of the information and data when they are received. At the very least, it is expected that they verify that all of the needed metadata accompanies the data, since this is an important component of the data collection procedures described. In most cases, the individual data centre web sites have no descriptions of what they do. It is recommended that each site prepare a document that explains what functions they perform as data and metadata are received, processed and inserted into archives.

Rec 6: It is not clear what instructions are given to potential data providers. Does GO-SHIP ask the individual researchers to send the data under their responsibility to the appropriate archives? Does one GO-SHIP archive that happens to receive data or a type managed by another archive forward those data on? It is recommended that GO-SHIP provide some text that advises on both the preferred way that data should be submitted and what occurs if data of all types arrives at the door of one of the archives.

Rec 7: It was not apparent how a potential user could easily assemble all of the data from the same cruise across the many archives that exist in GO-SHIP. In particular, it was not clear if there was a consistent cruise labelling scheme across archives, except the EXPOCODE used by CCHDO and CDIAC. It is recommended that the partners in GO-SHIP decide on and implement a common data labelling scheme. This should be explained on an information page on the main GO-SHIP web site and possibly in combination with other information on data operations that are common.

Rec 8: All archives should have copies of their data stored off site to guard against accidental loss. Some of the archives are explicit in stating how they ensure copies are safeguarded, though how often copies are secured is not clear. It is recommended that all of the archives explain their backup procedures on an appropriate information page.

Rec 9: It is recommended that GO-SHIP have data management and policy documentation that is labeled as its own. It is fine to adopt policies of other programme if they are appropriate. However, not having a clear statement of a GO-SHIP plan or policy leaves the impression that this has not been addressed seriously.

Rec 10 It is recommended that at the very least, each of the data archives that cooperate in GO-SHIP should have a document that explains if there are any restrictions on the data that they hold. If there are restrictions, there should be clear statements about how and when those restrictions are removed.

Rec 11: Not all archives appear to be able to disseminate data in netCDF. It is recommended that this be done. It was unclear if all of the existing forms of netCDF used common data description conventions, such as CF. Nor was it obvious that data sets with like geometric features use the same netCDF structure. For example, time series independent of the variable could all be delivered in the same netCDF structure. It is recommended that GO-SHIP partners discuss a way forward to achieve standardization and implement this.

Rec 12: There is no standardization on ASCII forms and none in the way data are described in these forms. It is recommended that some improvements in data descriptions, such as names of variables being common, should be implemented. If further standardization is possible between forms from different archives, this should also be pursued.

Rec 13: A very positive development would be a unified data access interface to the holdings in all archives. Such an interface would reside on the GO-SHIP web site, and would allow a user to both browse and download data from the variety of archives without having to visit each one separately. This is a significant amount of work, but it is recommended that GO-SHIP begin the planning to accomplish this and to set a target for its implementation.

Rec 14: It was not obvious when searching for and requesting a data download, that the metadata associated with the data were also available. Given the strong emphasis made on the importance of metadata, it is recommended that every GO-SHIP archive be very clear in making the metadata available at the time that the data are accessed.

Rec 15: This discussion speaks to the perception of GO-SHIP as being a convenient veneer to overlay existing programmes. At the start, this was likely the fact. However, it is recommended that GO-SHIP try to present a more coordinated view with individual archives having GO-SHIP recognition on their pages, coordination in formats, naming conventions – in fact a programme standardization so that it appears and really functions as a united programme.

Rec 16: The text provided here are suggestions only. But such a table would accomplish at least 2 things. First, it would provide an overview of the status of the programme, something that is now lacking. Second, and as important, it provides a demonstration of the coordination that the GO-SHIP programme undertakes. It is recommended that the GO-SHIP committee consider these suggestions, discuss other ways to achieve this overview, and implement their decisions as soon as possible.

Rec 17: Annual reports need not be onerous to do if content to include is carefully selected from what may already be produced for other purposes. Certainly archives need to justify their operations in some fashion to their management or sponsors. Using a GO-SHIP annual report to assemble reports (not necessarily all content) from the archive centres would be a way to demonstrate progress. It is recommended that the GO-SHIP committee discuss ways to communicate its success, and talk to sponsors or advocates, such as OOPC and JCOMM about what they would like to see. In addition, putting meeting reports up on-line as soon as possible after a meeting is a good way to provide detail on the project.

Acronyms

ADCP: Acoustic Doppler Current Profile
CCHDO: CLIVAR and Carbon Hydrographic Data Office
CDIAC: Carbon Dioxide Information Analysis Center
CF: Climate and Forecast
CFC: ChloroFluoroCarbon
CLIVAR: Climate Variability and Predictability
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
EXPOCODE: Expedition Code
GCOS-IP: Global Climate Observing System – Implementation Plan
GO-SHIP: Global Ocean Ship-based Hydrographic Investigations Program
GTS: Global Telecommunications System
IOCCP: International Ocean Carbon Coordination Project
JCOMM: Joint Commission on Oceanography and Marine Meteorology
LADCP: Lowered Acoustic Doppler Current Profile
netCDF: net Common Data Format
NODC: National Oceanographic Data Center
PI: Principle Investigator
SOOP: Ship Of Opportunity Programme
VOS: Volunteer Observing Ship
WOCE: World Ocean Circulation Experiment
WOD: World Ocean Data project
XBT: Expendable Bathythermograph

References

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3. OceanObs'09 home: http://www.oceanobs09.net/
4. IOCCP home: http://www.ioccp.org/
5. GO-SHIP Manual: http://www.go-ship.org/HydroMan.html
6. GO-SHIP variables: http://www.go-ship.org/Manual/IntroCollection.pdf
7. GO-SHIP practices: http://www.go-ship.org/Manual/Swift_DataEval.pdf
8. GO-SHIP cruise page: http://www.go-ship.org/CruisePlans.html
9. GO-SHIP data directory: http://www.go-ship.org/DataDirect.html
10. GTS home: http://www.wmo.int/pages/prog/www/TEM/index_en.html
11. GO-SHIP community white paper: http://www.go-ship.org/Docs/IOCTS89_GOSHIP.pdf
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2.6: IOCCP

Introduction

The focus of this chapter is on the data that are collected through the IOCCP [1] operations. Members of the IOCCP SSG are listed at [2]. A nice recounting of the history of ocean carbon research and the motivation for the establishment of the IOCCP is provided [3].

From its early beginnings and through evolution, the IOCCP became " ... a standing project, replacing the CO_2 Panel, with new terms of reference approved by the SCOR Executive Council and the 23rd Session of the IOC Assembly" in 2005. The IOCCP is "focused on implementing coordination actions ... with support from the sponsor organizations ... (and) to include communication and coordination services for the full range of ocean carbon variables (not only CO_2) and to assist the global, regional, and national research programs, as requested, with coordination of research activities ...".

The IOCCP has a strong relationship with GO-SHIP and the repeat hydrography programme. However, it also works to coordinate activities with other ocean interior observations outside of GO-SHIP, such as underway CO_2 observations, biogeochemical time series measurements, various ocean acidification projects, and measurements of nutrients and oxygen that occur on research cruises. The IOCCP, therefore covers a gamut of ocean variables, but relies on observation programmes often run by groups outside of IOCCP.

IOCCP works with the synthesis community to consolidate and standardize the various ocean carbon measurements to produce a global carbon product, discussed later.

Data Providers

IOCCP is not a programme such as Argo or SOOP that has installed infrastructure to make routine observations. Instead, it is a coordinating body that sets out to assemble ocean carbon and other associated data, to provide advice on processing standards of such data, to standardize and safeguard into the future the data that come to its archive, to disseminate the data to users, and to construct products, such as a global carbon atlas, that incorporate all sources of such data.

The IOCCP relies on the international ocean research community to collaborate in the programme by volunteering ship time and staff to perform the sampling. IOCCP has a strong collaboration with GO-SHIP and the repeat hydrography programme. Through contacts into the various groups making carbon measurements, as listed above, IOCCP encourages the standardization of measurements, and the provision of the data that are collected into a consolidated archive. They provide a comprehensive guide [4] for making CO_2 measurements and a directory of information about the instruments and sensors for carbon and related measurements [5].

There are no general statements about the suite of variables of interest to IOCCP but the information contained in the instruments and sensors page [5] suggests that IOCCP programme encompasses measurements of dissolved inorganic carbon, alkalinity, pCO_2, pH, and particulate carbon. The suite of variables goes beyond the current list of ECVs, but it is expected that when the EOVs are set, that list will include a number of the variables listed here.

Apart from GO-SHIP coordinated cruises, there are other providers discussed on the IOCCP pages. Underway CO_2 measurements are made on VOS and SOOP vessels that operate within the SOT. The instrumentation is automated, and since these mostly are mounted on commercial vessels, they sample along shipping routes.

Ocean interior observations are made by national programmes from research vessels with their own research interests. Often carbon measurements of various kinds are made. IOCCP encourages collaboration between these groups to improve methods of measuring carbon, and to share observations.

Time series of biogeochemical measurements are conducted at a number of sites, many now coordinated through the OceanSITES programme. Again, IOCCP encourages collaboration in these groups to improve methods of measuring carbon, and to share observations.

As stated on their web site “the IOCCP, in strong collaboration with the NOAA Ocean Acidification Program [6], the GOOS [7], the Ocean Acidification International Coordination Center [8] and other ... partners worldwide, works towards the development of a Global Ocean Acidification Observing Network (GOA-ON)”. This is envisioned as a network of fixed stations, VOS, and research cruises and floats measuring carbon in all oceans.

IOCCP is encouraging the development of standard research methods and certified research materials to allow ready comparison of nutrient measurements.

All of these coordination efforts rely on the acceptance of the wider community and their goodwill in developing and adopting the recommended methods, and in sharing the data they produce.

Data Assembly, Processing and Archiving

IOCCP has no independent data assembly or processing facilities. Instead it relies on activities of other programmes to compile data sets containing carbon measurements. Activities of each of the programmes are noted here.

SOCAT [9] is “a collection of underway ocean observations quality controlled by the science community”. The resulting archived data is global in extent. The procedures used are reported in literature. A QC Cookbook [see 10 at the bottom of the page] describes the flagging scheme for the data. This encodes not only the assessed quality of data, but also completeness of metadata and techniques, methods and accuracy of the instruments used. The cookbook does not describe the mechanics of quality assessment; instead it refers to a workshop report (Rec 1). Included in the archived data sets are non-carbon observed data extracted from WOD (2005) [11].

The second data set advertised is from CARINA [12]. This group has produced “a merged internally consistent data set of open ocean subsurface measurements for ... studies involving the carbon system. The ... geographic extent ... now includes data from the entire Atlantic, the Arctic Ocean, and the Southern Ocean.”. The data come from 188 cruises and include salinity, oxygen, nutrient, inorganic carbon system and CFC measurements. There is a good reference to a variety of publications that explain how the data included in CARINA are handled. An overview [13] speaks to the process of how data are handled, and another paper deals with details of the quality assessment process [14].

The third data set pointed to is assembled by the GLODAP programme [15]. This is a programme to coordinate global synthesis projects funded through US agencies (NOAA, DOE, NSF) as part of the JGOFS synthesis and modelling project. “The central objective of this project is to generate a unified data set to help determine the global distributions of both natural and anthropogenic inorganic carbon, including radiocarbon.”. Data were collected through WOCE, JGOFS and OACES sponsored cruises from 1990 to 1998. There is an extensive bibliography presented [16] discussing the scientific results, but also a number of these discuss how data from the various cruises were processed and checked. There are also four documents that specifically treat how the quality of inorganic carbon measurements is assessed [17].

The fourth data set pointed to is from the PACIFICA project [18]. The project “merged hydrographic and hydrochemical datasets from a total of 213 cruises” in the Pacific Ocean, “including those from cruises conducted between the late 1980's and 2000 but not stored in GLODAP as well as CLIVAR/CO2 Repeat Hydrography datasets from the 2000's”. Additionally, data from 59 Line P cruises from the west coast of Canada, and 34 cruises from the WOCE Hydrographic Program were merged. Adjustments were made “to account for the analytical offsets in the data of dissolved inorganic carbon, total alkalinity, salinity, oxygen, and nutrients (nitrate and nitrite, phosphate, and silicic acid) for each cruise as a result of secondary quality control procedures ...”. These procedures were “... based on the crossover analysis for the data from deep layers” are described in a publication by Tanhua et. al., in 2010 in ORNL/CDIAC-159, NDP-092 [18]. They also publish a table of adjustments made for each of the cruises and variables that informs a user of the specific results that apply [19].

A fifth referenced data set is the Takahashi global surface pCO_2 database (2012 version [20]). This is a global dataset compiled from data collected between 1957 and 2012. There are two documents [21, 22] that describe how the data were processed, what checks were performed, differences from earlier versions, and a comprehensive list of data sources that were used. The data set contains measurements of surface temperature and salinity, air pressure and various other measures relevant to pCO_2.

The final data set referenced is a global surface ocean alkalinity climatology [23]. The techniques used to process and analyze the data [24] are presented. The data derive from the WOA 2001 [25] and as such is a little dated.

Overall, these data sets comprise an important source of ocean carbon data and products. In some cases, the processes, computations, data sources, quality checking procedures, etc. are very well described but in others, this is not the case (Rec 2). An important point in all of the data sets is to be able to discern the degree of overlap in the data used. In some cases, EXPOCODEs have been used to reference individual cruises, and this is an efficient way to do a large scale comparison of sources. It is not clear for any particular cruise, if the data from this or that station have been used, modified or rejected (Rec 3).

All of these data sets are housed at CDIAC [26]. They have a good selection of publications [27] that explain the processes and computations to which data they receive are subjected. In particular, the "New Handbook" [28], describes much of this (see Rec 3). The descriptions of the processing of the various data sets noted above suggests that there are differences between what CDIAC does and what has been done to derive these data sets as products. Of particular note, is that all of the information in the Handbook is available in 2 languages, and some in a third as well.

Data Dissemination

Each of the data sets described above have a data download interface that is different. Most provide access to individual files of cruises in an ASCII spreadsheet format, while some of the gridded files are in netCDF [29] with CF conventions [30]. In many cases, metadata files are also available in a separate text file for each cruise. In many cases, data are presented in a format that can be read by ODV [31]. This latter capability is particularly helpful because ODV is a very capable display and analysis software package that is freely available. Also, ODV has some capability to identify duplications in data sets, which may help a user in dealing with overlaps in data sets as noted before.

Each of the ASCII spreadsheet formats are different. Considering that these represent different products, this may or may not pose a problem. In the instance where a user wishes to compare systematically the analyzed values of a particular station that appears in different data sets, there is first the necessity to harmonize formats, then identify the duplicated stations, then compare the results (Rec 4,5).

CDIAC operates a data dissemination service [32] for carbon data as well. Besides the interfaces to the data sets described above, they have one to query all of the ocean carbon data that they hold. Using the "Mercury" engine and the "Browse" tab, a user is presented with two choices of kinds (discrete and underway) and within these a variety of views of individual files that can be downloaded separately. The "Search" tabs allow text searches and in the advanced form qualification by area, time frame, variable, etc., is allowed. The final access is again by individual files and metadata files are all available.

There is another interface, WAVES, that allows searches through the GLODAP, CARINA and Takahashi data sets (Rec 6). Search criteria include time frames, data set, area, variable and more. Results are available in an ASCII spreadsheet compatible form. Just as in the Mercury interface, metadata files are all available. It is also possible to download all data from a section at once. Results are in ASCII spreadsheet format.

Finally there is a LAS page serving GLODAP data, but using this link resulted in an error (Rec 7).

Differences Between Distributed Data Sets

There are six identified data sets on the IOCCP pages (SOCAT, CARINA, GLODAP, PACIFICA, Takahashi (LDEO) and surface alkalinity). In addition, from the CDIAC pages, a user can search all ocean CO_2 data that they hold. Some contain surface data only, some full water column data, some from underway instruments only, some with perhaps all data, including surface, and many of these include other variables besides carbon. It is unclear if the CDIAC access to "all ocean carbon data" includes additional data to those in the other data sets (such as from VOS, or OceanSITES) or simply allows a search that spans all of the data sets accessible separately. Each data set appears to have different procedures employed in its production. And while many are well described individually, and in great detail, it is hard for someone wishing to use all of the carbon data to determine the differences. Finally, it appears that there is a greater or lesser degree of overlap in source data between the various data sets. Taking into consideration that because of the processing that has gone into the different data sets, these may be considered data “products” and not data as they arrived from the providers. In this respect, overlap is less of an issue. If a user is interested in the data as originally provided, for example, they may construct a new data set with all available data, but with different processing employed, it is not clear where these data can be found. As a result, a user is left with a number of questions (Rec 8).

User Communities

The users of IOCCP data are predominantly in the research and climate community. They require the highest accuracy and precision in the data and the most care in processing. Data become available with the type of data determining the delays.

The IOCCP website has a pointer to “IOCCP in Peer Reviewed Literature”. This is a very useful compilation. Unfortunately, at the moment (July 2013) it is “to be added” (Rec 14).

Monitoring and Performance Metrics

The IOCCP website contains meeting reports that provide information about the status of implementation of the programme. This is quite valuable, but the addition of graphs or displays showing the changes in, for example, underway reporting, would be a useful addition. This is true for the other sections of the report as well (Rec 10). It is noted that some of the actions identified in the report speak to this issue of graphic displays and that is encouraged. The list of data processing status as appears in the section on Data and Information Management is good but it is buried in a meeting report and not obvious to a potential user (Rec 11).

Each of the individual data set web sites has some information about the growth in their data set holdings and in updated scientific results based on the data. In most cases, there are maps of the individual cruises contributing to the data set. A few of the data sets provide some graphic displays illustrating the contents of the data sets, or samples of derivations from the data set. Good examples can be found in the Takahashi and alkalinity web pages. These serve as eye catching but also informative displays to help a potential user understand what each data set contains. A number of other possible displays are possible (Rec 12).

Just as it was for GO-SHIP, it is difficult to identify what might be effective performance metrics of a coordination programme of research efforts. Essentially, the programme consists of activities volunteered by participants as they are able to secure ship time and resources. A starting point is the list of cruises conducted and the processing status of data derived from these cruises (see Rec 11). From such a table, some quantifiable numbers could be compiled, such as volumes of data processed or received each year, trends in types of data collected, and so on. Such numbers will inform IOCCP and others on how effectively their coordination efforts are, and may show where more effort is required.

There is no “Project Plan” for IOCCP evident on its web pages such as appears for other observing systems reviewed by this report. Without this, there is no “standard” against which the effectiveness of IOCCP can be judged. A project plan typically has a series of bullets stating its objectives. From such a list, it would be possible to articulate measures that show how well the programme is meeting these objectives (Rec 13).

In looking at documents and reports related to IOCCP, it was noted that a project report was prepared in 2008, but since then, it appears that only presentation reports are available, and these not produced on a regular basis. Annual reports or at least regular reporting is a good way to inform the wider community about progress, and activities of a programme. It is a vehicle to show accomplishments and the range of activities being pursued. It is expected that individual data sets referenced by IOCCP would have sections where they could provide updates on how their operations have progressed annually. Such a report can be used to demonstrate to sponsors that the IOCCP programme is working (Rec 14).

GCOS-IP (2010) Performance Indicators

Within the GCOS-IP (2010 update) [33] the IOCCP operations are mentioned in Actions 13, 14 and 24, listed here.

Action O13 [IP-04 O17]
Action: Develop and implement an internationally-agreed strategy for measuring surface *p*CO2.
Who: IOCCP, in consultation with OOPC; implementation through national services and research programmes.
Time-Frame: Implementation strategy for end-2010; full implementation by 2014.
Performance Indicator: Flow of data into internationally-agreed data archives.
Annual Cost Implications: 1-10M US$ (Mainly Annex-I Parties).

Report: The IOCCP through CDIAC has published a Handbook describing best practices for oceanic CO_2 measurements. This appears to have fulfilled the first part of the action. As to the implementation part, it is uncertain how well along this is.

Action O14
Action: Develop instrumentation for the autonomous measurement of either DIC, Alk, or pH with high accuracy and precision.
Who: Parties' national research programmes, coordinated through IOCCP.
Time-Frame: Strategy: 2010; technology: 2012; pilot project: 2014.
Performance Indicator: Development of instrumentation and strategy, demonstration in pilot project.
Annual Cost Implications: 1-10M US$ (Mainly by Annex-I Parties).

Report: IOCCP publishes a list of instrumentation and sensors used. While this is not an endorsement of any item on the list, it goes partway to meeting this action (Rec 15).

Action O24 [IP-04 O25]
Action: Development of a plan for systematic global full-depth water column sampling for ocean physical and carbon variables in the coming decade; implementation of that plan.
Who: National research programmes supported by the GO-SHIP project and IOCCP.
Time-Frame: Continuing.
Performance Indicator: Published internationally-agreed plan from the GO-SHIP process, implementation tracked via data submitted to archives. Percentage coverage of the sections.
Annual Cost Implications: 10-30M US$ (Mainly by Annex-I Parties).

Report: There is a plan in place and cooperation between national research programmes, CCHDO and IOCCP. Implementation is proceeding, though it is difficult to measure the success of the programme.

Recommendations

Rec 1: Documentation of the details of what is done to assess the quality of the data used in the SOCAT atlas should be easily available on the web site. It is good that discussions of what is done is documented in journals, but someone investigating use of the data set should have information immediately at hand. It is recommended that an overview document be produced that provides a description of the mechanics of data assembly, processing, quality assessment and archiving. As needed, greater detail can be provided by reference to other documents available on the web site. In the preparation of this report it was noted that many of the references to meeting reports have broken links. This should be fixed.

Rec 2: The PACIFICA, GLODAP and Takahashi data sets are very well described. It is recommended that the other data sets provide the same level of information.

Rec 3: For a user to determine which of the presented data set they may wish to use, one of the factors may be the "completeness" of the data set. There is some degree of overlap between these different data sets and it is not clear how a user might be able to sort out this duplication. It is recommended that the IOCCP produce a document that explains how a user might approach this.

Rec 4: Following up on recommendation 3, a comparison of values at the same station of a duplicated cruise that is used in data sets, is complicated by the different ASCII formats. It is recommended that IOCCP consider whether a standardization of the ASCII spreadsheet forms across all of these data sets would be of value, would be in demand by users, and if so, undertake such a standardization. It was noted that using the WAVES interface, that the search results provide data in an ASCII spreadsheet form. This may, in fact, meet the spirit of this recommendation.

Rec 5: Many of the data are not (obviously) available in netCDF. As more and more interdisciplinary studies take place, it is likely that the demand for data in netCDF will grow. IOCCP should consult their user community and with groups such as OOPC and OPA to measure the utility of providing data in netCDF as well as existing forms. If the response is positive, action should be taken.

Rec 6: Access to the Takahashi data set is named as such on the IOCCP list of data sets, but identified as the LDEO data set when a user accesses the data page. On the CDIAC web site, the data set is identified as from LDEO. It is recommended that the data set be identified in a consistent way.

Rec 7: The link to the LAS for GLODAP found on page http://cdiac.ornl.gov/oceans/datmet.html resulted in an error. This should be fixed.

Rec 8: It is recommended that IOCCP produce a document that summarizes the important differences between the data sets, how content may be compared (i.e. overlap identified) and other factors of relevance.

Rec 9: It is good that there is a placeholder on IOCCP web pages for a bibliography. It is recommended that this be implemented as soon as possible and be kept up to date.

Rec 10: The meeting reports of the IOCCP contain valuable information on status and trends in data collection, processing and so on, These reports would be enhanced by graphs, plots, or other visual devices that summarize the points made in the text. It is recommended that future reports contain such graphics.

Rec 11: The table of processing status of all data received by CDIAC should be available on the CDIAC web pages. CCHDO has a “Recent Updates” column on it's pages. CARINA has a “cruise summary” table that might also be used to model a “cruise processing status” table. It is recommended that CDIAC implement an appropriate equivalent.

Rec 12: Visual displays of the contents of archives serve two purposes. They attract a potential user's eye initially, but more importantly can serve as a quick illustration of what kinds of data exist in what time frames and locations for a user. It is likely that there are results in the many scientific publications that could be used. It is recommended that IOCCP consider ways to graphically display the contents of the data sets to entice and inform potential users.

Rec 13: It was noted that the IOCCP started in about 2002, but a review of documents on IOCCP, IODE, and IOC could find no references to a documented project plan. It is recommended that the IOCCP Project Plan, assuming this exists, (if not this must be done as soon as possible) be given prominence on the IOCCP site. The Project Plan should contain a list of succinctly stated objectives. IOCCP should consider how to demonstrate that these objectives are being met.

Rec 14: Regular reporting in a published document is a way to inform sponsors, the broader ocean community, and participants how well a programme is meeting its objectives. With a careful choice of content, it is possible to assemble such a report with a small amount of work. It is recommended that IOCCP undertake to design a report that can be updated each year and that this report for 2013 be completed and placed on its web site by the middle of 2014 at the latest

Rec 15: It is recommended that IOCCP produce a document that describes the accuracy and precision requirements, subdivided by application area such as appears in OSCAR for ECVs [34], for the measurement of the suite of carbon and associated observations that are needed. This is, perhaps, implied by the listed instruments and sensors, but as more variables enter the list of EOVs, these specifications will be needed.

Acronyms

Alk: Alkalinity
CARINA: Carbon in the Atlantic Ocean
CCHDO: CLIVAR and Carbon Hydrographic Data Office
CDIAC: Carbon Dioxide Information Analysis Center
CF: Climate and Forecast
CFC: Chlorofluorocarbon
CLIVAR: Climate Variability and Predictability
DIC: Dissolved Inorganic Carbon
DOE: Department of the Environment
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
EXPOCODE: Expedition Code
GCOS-IP: Global Climate Observing System – Implementation Plan

GOA-ON: Global Ocean Acidification Observing Network
GOOS: Global Ocean Observing System
GO-SHIP: Global Ocean Ship-based Hydrographic Investigations Program
GLODAP: Global Ocean Data Analysis Project
IOC: Intergovernmental Oceanographic Commission
IOCCP: International Ocean Carbon Coordination Project
IODE: International Oceanographic Data and information Exchange committee
JGOFS: Joint Global Ocean Flux Study
LAS: Live Access Server
LDEO: Lamont-Doherty Earth Observatory
netCDF: net Common Data Format
NOAA: National Oceanic and Atmospheric Administration
NSF: National Science Foundation
OACES: Ocean-Atmosphere Exchange Study (of NOAA)
ODV: Ocean Data View
OOPC: Ocean Observations Panel on Climate
OPA: Observations Programme Area
OSCAR: Observing Systems Capability Analysis and Review
PACIFICA: Pacific Ocean Interior Carbon Database
QC: quality control
SCOR: Scientific Committee on Ocean Research
SOCAT: Surface Ocean CO2 Atlas
SOOP: Ship Of Opportunity Programme
SOT: Ship Observations Team
SSG: Scientific Steering Committee
VOS: Volunteer Observing Ship
WAVES: Web Accessible Visualization and Extraction System
WOCE: World Ocean Circulation Experiment
WOA: World Ocean Atlas
WOD: World Ocean Database

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Part 3: An analysis By ECV

Introduction

As an output of the OceanObs'09 meeting, a group was formed to develop a framework for ocean observations. They produced a report, Framework on Ocean Observations [1], that identifies the need to develop a list of Essential Ocean Variables, EOVs. As yet, this list has not been developed, and so as a starting point, this report reverts to the ocean ECVs identified by GCOS. This list is composed of sea level, carbon dioxide partial pressure (surface and sub-surface). sea state, sea ice, phytoplankton (surface), salinity (surface and column), temperature (surface and column), current (surface and sub-surface), ocean colour (surface), pH (surface and sub-surface), nutrients (sub-surface), oxygen (sub-surface), and tracers (sub-surface). It may well be that the list of EOVs will be longer, or more precisely defined than the ocean ECVs, but it seems entirely likely that many of the ECVs will be in the list of EOVs.

To develop a better precision on the ECVs and observing requirements, WMO has developed a Rolling Review of Requirements that identifies environmental variables to be measured and assigns spatial and temporal measurement precision in order to meet a variety of purposes. These are maintained in a data base known as OSCAR [2]. In the individual chapters on ECVs these requirements will be reproduced since it is these metrics against which observing systems are evaluated.

This report is restricted to the consideration of in-situ observing systems. But it is clear that the combination of in-situ with remotely sensed (e.g. satellites, shore or ship radars, acoustic systems) observations are complementary. In-situ systems provide the direct measurements that help calibrate those made remotely. But they lack spatial coverage, and frequently repeated measurements that is well filled by remote systems. Each ECV measured by in-situ systems are treated in subsequent chapters. Certainly for ocean surface atmosphere and aquatic measurements, and perhaps even for the subsurface ocean, remotely sensed data supplement the spatial and temporal coverage. What is presented as the current state of ECV observation is, therefore, a more pessimistic picture than would be derived if both in-situ and remotely sensed measurements were combined.

Content Organization

Each chapter opens with a quick review of the instrumentation that is currently used, or has been used (since data from these instruments sit in archives). A following section provides a short description of the operating characteristics of the relevant instruments.

JCOMM does not have a monopoly on all marine observations, and so it is necessary to consider other observation programmes that can and do contribute to the complete set of observations available. This draws in not only at-sea operations, but also international programmes outside of JCOMM, and data systems (including dissemination capabilities). A section describes each of the JCOMM and other programmes that are known to contribute or that likely contribute some data of the type under consideration.

There are three significant areas where the variety of observing systems has impacts. First, each system has its own set of temporal and spatial resolution needs. In some cases, such as Argo, it is relatively easy to enunciate these needs and this acts as a strong driver for deployments. In other cases, such as fisheries agencies, the resolution is driven by statistical sampling requirements to identify target species. These have no particular basis in physical processes except to the extent that target species respond in their own ways to their environment. In this case, the horizontal and vertical sampling likely results in an over or under sampling as needed by GCOS. Still these data may help to fill in observation gaps.

The second impact is strongly related to the instrumentation used. Specifically, the measurement accuracy and precision for a particular ECV can vary a great deal from one instrument to another. The result is that when data from these different sources are assembled together, they may not all carry the same weight of information. For example, when very high accuracy temperature measurements are required, the use of lower accuracy ones may obscure the signal being investigated. In other cases, such as global circulation modelling, it is possible to use lower accuracy data by suitable weighting schemes used for assimilation or analyses.

The third impact is on the timeliness of reporting and therefore for which purposes the data may be used. For operational models, data must arrive at the modelling centre in time for ingestion. Such timely delivery puts constraints on telecommunications channels that can be used. Of course, this has cost implications as well. With respect to temporal sampling, the frequency with which a variable is sampled is important. In time series measurements, the sampling frequency impacts the frequency resolution of the series, such as in wave measurements. In generating long times series, there are constraints on the low frequency changes and trends that can be extracted.

Part of the OceanObs'09 Framework on Ocean Observations Report examined a way to assess the "... activities of individuals and organizations within the Framework ... to gauge the readiness of requirements, observation elements, and data and information products. Those seeking to incorporate a new observation into the sustained global observing system will need first to mature the associated requirements for acceptance, mature their measurement technology for inclusion, and mature their data and information products for appropriate accessibility and application to a range of scientific and societal uses." A section in each chapter presents the elements of the "Readiness Levels" that pertain to data and information.

The next section of the report presents the contents of OSCAR that pertain to the ECV under consideration. This is followed by a section that reviews the simple targets for data acquisition by observing system that was set at the beginning of JCOMM. These were developed by the OPA coordinator at the time, and were meant to be used as rough targets until a more composite view could be developed.

This is followed by a qualitative assessment of how well the collection of observing systems meet OSCAR targets.Each chapter ends with a set of recommendations linked to the text that would improve how well the composite observing system could report its progress towards its goals.

Choice of ECVs

OSCAR contains many variables from land, atmosphere, and marine domains. Not all of these are relevant to this report. As a starting point to qualify ECVs of interest, the first pass through the database retained only those variables that were observed either at or below the ocean surface. This left a much smaller number.

Of the remaining, there are some for which observing systems lie outside JCOMM (bathymetry), those whose OSCAR sampling scales can only be met through remote sensing techniques (chlorophyll, suspended sediment concentration, sea ice, sea height anomaly), those that are derived from other measured variables (dynamic topography and mass flux) and those that are either extremely difficult to measure or have so few data collected, there is no hope at present to meet the OSCAR requirements (precipitation, heat flux). What remains are some 16 variables that are individually treated in their own chapters.

Wave measurements are treated in one chapter even though this is not a variable that figures strongly in the OPA. It is treated for 2 reasons. First, there are many countries making routine wave measurements from offshore buoys, and secondly, the DBCP has a pilot project to operate wave sensors on surface drifters. Should this latter be successful, it will mean a significant expansion in spatial coverage of in-situ wave measurements and this ECV will fall within the JCOMM sphere.

Acronyms

DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
GCOS: Global Climate Observing System
JCOMM: Joint Commission on Oceanography and Marine Meteorology
OPA: Observations Programme Area
OSCAR: Observing System Capability, Analysis and Review
WMO: World Meteorological Organization

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2. OSCAR: Observing Systems Capability Analysis and Review Tool at http://www.wmo-sat.info/oscar/observingrequirements

3.1: Air Pressure (at surface)

A Review of Instruments

Nearly all ships at sea carry barometers whether they are part of a formal observing programme or not. Many of them provide their observations to their national weather services, knowing that they are contributing to improved weather forecasts.

The WMO has long encouraged this participation and in an effort to standardize the measurement, both on land and sea, have a Commission devoted to Instrumentation and Methods of Observation, CIMO. This body has extensive documentation that describes the various instruments used for meteorological measurements, and sections in their Manual [1] that discuss observation practices at sea. The sections on at-sea observation have been developed closely with experts in IGOSS and CMM prior to the formation of JCOMM. The sections on marine observations have been reviewed and revised since JCOMM started in 2001, with contributions from SOT, DBCP and others.

Equally important to the actual observation is the physical location of the instruments on the ship. Instruments placed in locations sheltered from the elements provide data that is not representative of actual conditions. Siting of instruments is also treated in the Manual noted above.

With advances in technology, many countries are moving to completely automated meteorological measurement systems (AWS) installed on ships. There are a number of positive consequences of this. First, reporting can be completely standardized and data delivered to shore even if the ship's crew is busy at other tasks. Secondly, the consistency of measurement is less reliant on the diligence and care taken by ship's crew. There are negative consequences though. Present automated systems cannot make the range of measurements that were provided in the past and so weather services are seeing fewer types of observations. AWS are required to measure at least air pressure, pressure change, temperature and humidity. Optional sensors would include wind speed and direction and sea temperature measurement [2]. Although automated data logging systems make provision for manual input of other types of observations, this is seldom done with the consequence of a decline in their quantity in recent years.

It is fortunate that surface air pressure observations are easy to automate and so these continue to be collected routinely.

Calibration and maintenance of instrumentation is an important aspect of measuring marine properties. Even though modern, electronic instruments are now the norm, ensuring the stability of the measurements has a strong impact on the quality of the data. In the VOS programme, there has long been the practice of having PMOs [3] visit participating ships when they come into port. Among other duties, they check the meteorological instruments to be sure they were functioning properly. The number of PMOs that are working today is smaller than in the past, and their duties are more complex with advancements in ship's technology. Still this is a valuable service that deserves continued support.

In the DBCP programme, monitoring has been put in place to check the quality of the reported pressures and where there is suspicion of problems, the problematic observations are withdrawn from distribution.

Surface air pressure was originally measured by the height of mercury in a column, so units were inches of mercury. Later this was changed to millimetres and today it is recorded in hectoPascals. The CIMO Manual provides appropriate conversion factors for these.

Instrument Characteristics

WMO requires air pressure to be reported with an uncertainly of 0.1 hPa, with a sensor time constant of 20 seconds and averaged over 1 minute.

Each type of barometer (mercury, electronic, aneroid, Bourdon-tube, etc.) has characteristics and operating requirements to ensure reliable measurements. As for other aspects, such as proper siting, this is well described in the CIMO Manual.

Data Providers / Observing Systems

The table below provides a list of the sources of surface air pressure data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled "Typical Instruments" describes only one type: "WMO approved". This reflects the acceptance of national meteorological services to adhere to WMO requirements. That is not to say that other methods and higher accuracy ways of measuring surface air pressure are not under study, particularly within the research community. For formal reporting purposes to weather services, approved barometers are required.

The column "Typical Sampling" provides some information about the horizontal and temporal sampling of the system. These are approximate and are to be considered only as an indication of the usual characteristics. WMO also has suggestions for frequency of reporting, typically what is called synoptic times (every 6 hours). Reporting at intermediate times, every 3 hours, is encouraged. AWS systems often report data hourly.

Table 1. Instruments typically used in each observing system that contributes surface air pressure measurements.

Observing System	**Present JCOMM Targets**	**Comments**
DBCP drifters [4,5]	WMO approved	Barometers are starting to be deployed.
DBCP moorings [6]	WMO approved	Sample typically in tropics and hourly.
DBCP OceanSITES [7]	WMO approved	Not at all locations. Reference mooring stations sparsely distributed over the oceans. Report at main synoptic times or better.
SOT SOOP [8]	WMO approved	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation. Report at main synoptic times or better.
SOT VOS [9]	WMO approved	Sample along ships routes.
SOOP underway [10]	WMO approved	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation. Report at main synoptic times or better.
GO-SHIP [11]	WMO approved	Sample along sections, fewer than once a year. Stations are typically widely separated. Report at main synoptic times or better.
Navies	WMO approved	Varying distribution depending on purposes. Reporting is dependent on national defence policies but when available are at main synoptic times or better.
Fisheries	WMO approved	Often in random sampling patterns with sometimes 10's of km separation between stations. Typically sample on continental shelves. Report at main synoptic times or better.
National moorings	WMO approved	At nationally selected sites, usually on coastal shelves or slopes. Sampling can be hourly or better, but highly dependent on the programme.

National monitoring / research	WMO approved	Sampling is highly dependent on the programme but may report at main synoptic times or better.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [12]. The objective was " to develop an integrated framework for sustained ocean observing ..." to "... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...". They agreed that implementation of new systems for EOVs "... will be carried out according to their readiness levels ...". The table that describes this, extracted from that report, follows.

Table 2. FOO readiness levels.

Readiness Level	**Description**	**Data Management and Information Products**
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
Mature 8	Mission qualified	Data availability: globally available Evaluation of utility
Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan
Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance
Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
Concept 2	Documentation	Socialization of data: Interoperability strategy Expert review
Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [13], that is "... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.". OSCAR is

a complicated database in that it contains the spatial and temporal sampling requirements as needed by the varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:
uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
availability

Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The rows relevant to air pressure have been extracted from OSCAR, reformatted somewhat and are shown here.

Table 3. OSCAR entries for surface air pressure.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (2) Breakthrough Threshold**	**Vert. Res: Goal Breakthrough Threshold**	**Obs. Cycle: Goal (3) Breakthrough Threshold**	**Availability: Goal (3) Breakthrough Threshold**
Global NWP - - over sea	firm	0.5 hPa 1.0 1.0	15 km 100 500	Not applicable	1 h 6 12	6 m 1/2 h 12
Ocean Applications - marine safety - over sea	firm	0.5 hPa 1.0 1.0	10 km 25 100	Not applicable	1/2 h 2 12	1/2 h 1 2
Climate-AOPC - over sea	reasonable	0.5 hPa 0.65 1.0	200 km 300 500	Not applicable	3 h 6 24	3 h 6 12
High res NWP - - over sea	firm	0.5 hPa 0.6 1.0	1 km 5 20	Not applicable	1/2 h 1 6	1/4 h 1/2 2
Marine biology - - over sea	firm	10 hPa 12 15	50 km 75 100	Not applicable	24 h 36 2 d	3 h 4 7
Ocean Applications - ocean forecasting - over sea	firm	1 hPa 5 10	1 km 10 25	Not applicable	1 h 3 6	3 h 6 12

Notes:
1. Units: hPa is hectoPascals
2. Units: km is kilometres
3. Units: d is days
h is hours
m is minutes
No units are indicated when there is no difference from the units of the entry immediately above in the table.

It should be noted that programmes often carry out sampling by ships along lines. But there are many ships contributing and the more broadly distributed pressures coming from surface drifters. As a consequence, sampling in the Northern Hemisphere oceans, though still not uniformly distributed, is not bad. Southern Hemisphere sampling is less well distributed and sampling is even poorer in all high latitude regions.

Composite View

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The analysis by Kent et. al. [14] discussed in the overview of these chapters on ECVs shows a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to surface air pressure measurements.

Table 4. Present targets for JCOMM Observing Systems

Observing System	**Present JCOMM Targets**	**Comments**
DBCP drifters	1250 buoys deployed 5x5 degree global distribution 1250 with barometers 300 with salinity	Practical target for barometer buoys is 600.
DBCP moorings	131 moorings Topical oceans	Coastal moorings are deployed with national discretion. Tsunami buoys are in another IOC programme.
DBCP OceanSITES	29 reference moorings 58 others	At selected sites, 10 in Atlantic, 10 in Pacific, 5 in Indian Oceans.
SOT SOOP	37,000 XBTs deployed 26 High density lines (HDX) 25 Frequently repeated lines (FRX)	All carried out on selected lines to meet specific scientific objectives. HDX lines sampled 4 times a year, with 10-20 km between stations. FRX lines sampled 20 repeats a year with 50-100 km between stations.
SOT VOS	3000 active ships 500 AWS 250 VOSClim	Active ships provide more than 20 reports/month.
SOOP underway	No specified requirements	
GO-SHIP	Selected WOCE lines Repeated each decade (or better) Surface to bottom at 5m resolution or better	Network encompasses fewer lines than WOCE.

JCOMMOPS [15] generates a number of charts and graphs that provide a qualitative way to see if certain of the observing systems are meeting these simple targets. For example, DBCP pages provide maps showing the number of active surface drifters with barometers [16] and their latest reported positions. Similar displays are available for SOT. However, not all JCOMM programmes have displays that easily summarize the status of the programme (Rec 1).

The JCOMMOPS presentations reflect the individual observing system targets, but these are not a perspective that well represents an ECV perspective. A start towards this goal is provided at OSMC [17]. At this site and at the “Observing System Metrics tab, a user can select a parameter, a time frame and either one or all platforms. A further selection of gridding, and display presents a map that portrays the composite view, or individual platform view. There are some weaknesses to this display (Rec 2, 3), but it is working towards the right goal. One notable lack is that a user cannot plug in the OSCAR requirements for any particular application area, as shown in table 3. But considering the present state of in-situ sampling, this “lack” is sensible and pragmatic, as is discussed below.

The next table is a qualitative review of the OSCAR application requirements.

Table 5: A qualitative assessment of application area for surface air pressure measurements.

Application Area - Comment - Layer	**Uncertainty**	**Horiz. Res**	**Vert. Res**	**Obs.Cycle**	**Timeliness**	**Comments**
Global NWP - - over sea	G	T-	Not applicable	B+	T+	Global distributions do not meet spatial scales everywhere. Reporting times and timeliness reflect synoptic sampling or better.
Ocean Applications - marine safety - over sea	G	L	Not applicable	T+	L	Global distributions do not meet spatial scales everywhere. Reporting times and timeliness reflect synoptic sampling or better.
Climate-AOPC - over sea	G	T-	Not applicable	T+	B+	Global distributions do not meet spatial scales everywhere. Reporting times and timeliness reflect synoptic sampling or better.
High res NWP - - over sea	G	L	Not applicable	T	L	Global distributions do not meet spatial scales everywhere. Reporting times and timeliness reflect synoptic sampling or better.
Marine biology - - over sea	G	L	Not applicable	G	B+	Global distributions do not meet spatial scales everywhere. Reporting times and timeliness reflect synoptic sampling or better.
Ocean Applications - ocean forecasting - over sea	G	L	Not applicable	T+	B+	Global distributions do not meet spatial scales everywhere. Reporting times and timeliness reflect synoptic sampling or better.

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement. Plus and minus signs indicate if current sampling is greater than, or less than that requirement.

The assessment in Table 5 would suggest that for surface air pressure, the instrumentation required is available as long as maintenance is performed. The spatial sampling is near Threshold requirements for some parts of the oceans. Observing cycle and timeliness reflects synoptic sampling regimens of WMO.

Overall, the observing systems with the largest contributions to surface air pressure measurements are those from drifters, ships and tropical moorings. These data systems are at a FOO readiness level of Mature 8 or 9.

Recommendations

Rec 1: Each of the formal JCOMM programmes should provide simple displays on their home web pages that articulate as precisely as possible the observing targets, and show how well these targets are being met. Examples to emulate would be those provided by DBCP.

Rec 2: The displays allow a gridding in terms of latitude and longitude squares. The OSCAR requirements are set by units of meters (and kilometres). Also there are many different horizontal resolution requirements in OSCAR than are possible to specify at OSMC. Given the state of in-situ sampling, it is reasonable that all scales are not supported. However, a gridding based on meters / kilometres should be presented rather than degrees of latitude and longitude.

Rec 3: When trying to see a map of all platforms reporting sea level pressure the query (In-situ Monitoring) takes a fairly long time to execute (>1 minute in July, 2013). Conversely, the Observing System Metrics display is very quick. The slowness of the display causes concerns that it has stalled. Efforts should be made to try to either improve the performance or provide some informative display that assures the user the query is still executing.

Acronyms

AOPC: Atmospheric Observation Panel for Climate
AWS: Automated Weather (observing) System
CIMO: Commission on Instruments and Observations (of WMO)
CMM: Commission on Marine Meteorology
DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GDP: Global Drifter Program
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
hPa: hectoPascals
IGOSS: Integrated Global Ocean Station System
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
NWP: Numerical Weather Prediction
OCG: Observations Programme Coordinator
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
PMO: Port Meteorological Officer
SOOP: Ship Of Opportunity Programme
SOT: Ship Observations Team
VOS: Volunteer Observing Ship
WOCE: World Ocean Circulation Experiment
WMO: World Meteorological Organization
XBT: Expendable Bathythermograph

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3.2: Air Temperature (at surface)

A Review of Instruments

Nearly all ships at sea carry thermometers whether they are part of a formal observing programme or not. Many of them provide their observations to their national weather services, knowing that they are contributing to improved weather forecasts.

The WMO has long encouraged this participation and in an effort to standardize the measurement, both on land and sea, have a Commission devoted to Instrumentation and Methods of Observation, CIMO. This body has extensive documentation that describes the various instruments used for meteorological measurements, and sections in their Manual [1] that discuss observation practices at sea. The sections on at-sea observation have been developed closely with experts in IGOSS and CMM prior to the formation of JCOMM. The sections on marine observations have been reviewed and revised since JCOMM started in 2001, with contributions from SOT, DBCP and others.

Equally important to the actual observation is the physical location of the instruments on the ship. Instruments placed in locations sheltered from the elements provide data that is not representative of actual conditions. Siting of instruments is also treated in the Manual noted above.

With advances in technology, many countries are moving to completely automated meteorological measurement systems (AWS) installed on ships. There are a number of positive consequences of this. First, reporting can be completely standardized and data delivered to shore even if the ship's crew is busy at other tasks. Secondly, the consistency of measurement is less reliant on the diligence and care taken by ship's crew. There are negative consequences, though. Present day automated systems cannot make the range of measurements that were provided in the past and so weather services are seeing fewer types of observations. AWSs are required to measure at least air pressure, pressure change, temperature and humidity. Optional sensors would include wind speed and direction and sea temperature measurement [2]. Although automated data logging systems make provision for manual input of these other observations, the quantity of these other types has declined in recent years.

It is fortunate that surface air temperature observations are easy to automate and so these continue to be collected routinely.

Calibration and maintenance of instrumentation is an import aspect of measuring marine properties. Even though modern, electronic instruments are now the norm, ensuring the stability of the measurements has a strong impact on the quality of the data. In the VOS programme, there has long been the practice of having PMOs [3] visit participating ships when they come into port. Among other duties, they check the meteorological instruments to be sure they were functioning properly. The number of PMOs that are working today is smaller than in the past, and their duties are more complex with advancements in ship's technology. Still, this is a valuable service that deserves continued support.

Surface air temperature was originally measured by mercury thermometers measuring in degrees Fahrenheit, or degrees Celsius. The latter scale is most commonly used today but with reporting temperatures in degrees Kelvin. The CIMO Manual provides appropriate conversion factors for these.

Instrument Characteristics

WMO requires air temperature to be reported with a maximum uncertainly of 0.2º K, with a sensor time constant of 20 seconds.

Each type of thermometer (liquid in glass, mechanical, electrical) has characteristics and operating requirements to ensure reliable measurements. Of particular importance is a radiation shield, to screen the thermometer from direct exposure to the sun. As for other characteristics, this is well described in the CIMO Manual.

Data Providers / Observing Systems

The table below provides a list of the sources of surface air temperature data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled "Typical Instruments" describes only one type, "WMO approved". This reflects the acceptance of national meteorological services to adhere to WMO requirements. That is not to say that other methods and higher accuracy ways of measuring surface air temperature are not under study, particularly within the research community. For formal reporting purposes to weather services, approved thermometers are required.

The column "Typical Sampling" provides some information about the horizontal and temporal sampling of the system. These are approximate and are to be considered as only an indication of the usual characteristics. WMO also has suggestions for frequency of reporting, typically what is called synoptic times (every 6 hours). Reporting at intermediate times, every 3 hours, is encouraged. AWS systems often report data hourly.

Table 1. Instruments typically used in each observing system that contributes surface air temperature measurements.

Observing System	**Present JCOMM Targets**	**Comments**
DBCP drifters [4,5]	WMO approved	Widely dispersed in all oceans.
DBCP moorings [6]	WMO approved	Sample typically in tropics and hourly.
DBCP OceanSITES [7]	WMO approved	Not at all locations. Reference mooring stations sparsely distributed over the oceans. Report at main synoptic times or better.
SOT SOOP [8]	WMO approved	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation. Report at main synoptic times or better.
SOT VOS [9]	WMO approved	Sample along ships routes.
SOOP underway [10]	WMO approved	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation. Report at main synoptic times or better.
GO-SHIP [11]	WMO approved	Sample along sections, fewer than once a year. Stations are typically widely separated. Report at main synoptic times or better.
Navies	WMO approved	Varying distribution depending on purposes. Reporting is dependent on national defence policies but when available are at main synoptic times or better.
Fisheries	WMO approved	Often in random sampling patterns with sometimes 10's of km separation between stations. Typically sample on continental shelves. Report at main synoptic times or better.
National moorings	WMO approved	At nationally selected sites, usually on coastal shelves or slopes. Sampling can be hourly or better, but highly dependent on the programme.

National monitoring / research	WMO approved	Sampling is highly dependent on the programme but may report at main synoptic times or better.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [12]. The objective was " to develop an integrated framework for sustained ocean observing ..." to "... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...". They agreed that implementation of new systems for EOVs "... will be carried out according to their readiness levels ...". The table that describes this, extracted from that report, follows.

Table 2. FOO readiness levels.

Readiness Level	**Description**	**Data Management and Information Products**
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
Mature 8	Mission qualified	Data availability: globally available Evaluation of utility
Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan
Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance
Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
Concept 2	Documentation	Socialization of data: Interoperability strategy Expert review
Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [13], that is "... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.". OSCAR is a complicated database in that it contains the spatial and temporal sampling requirements as needed by the

varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:
uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
availability

Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The rows relevant to air temperature have been extracted from OSCAR, reformatted somewhat and are shown here.

Table 3. OSCAR entries for surface air temperature.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (2) Breakthrough Threshold**	**Vert. Res: Goal Breakthrough Threshold**	**Obs. Cycle: Goal (3) Breakthrough Threshold**	**Availability: Goal (3) Breakthrough Threshold**
CLIC - - surface	tentative	0.2 K 0.3 0.5	100 km 200 500	Not applicable	12 h 16 24	24 h 30 2 d
Climate-AOPC - temperature - air - surface	firm	0.1 K 0.15 0.3	25 km 50 100	Not applicable	3 h 6 12	24 h 36 2 d
Global NWP - - surface	reasonable	0.5 K 1 2	15 km 50 200	Not applicable	1 h 6 12	6 m 30 6 h
High Res NWP - - surface	firm	0.5 K 0.8 2	1 km 5 20	Not applicable	1/2 h 1 6	1/2 h 1 2
Nowcasting - - surface	reasonable	0.5 K 0.7 1.0	5 km 8 20	Not applicable	1/4 h 1/2 1	15 m 20 30
Ocean applications - maritime safety services - over sea	firm	0.1 K 0.5 1	1/2 km 1 10	Not applicable	1/2 h 1 3	4.8 m 60 6 h
Synoptic meteorology - - surface	firm	0.5 K 1 2	10 km 20 100	Not applicable	1 h 3 12	1 h 1.5 4

Notes:
1. Units: K is degrees Kelvin
2. Units: km is kilometres
3. Units: d is days
h is hours
m is minutes
No units are indicated when there is no difference from the units of the entry immediately above in the table.

It should be noted that some JCOMM programmes often carry out sampling by ships along lines. There are many more ships contributing more measurements than the more broadly distributed temperatures coming from surface drifters. As a consequence, sampling in the Northern Hemisphere oceans, though still not uniformly distributed, is not bad. Southern Hemisphere sampling is less well distributed and even poorer in all high latitude regions.

Composite View

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The partial analysis by Kent et. al. [14] discussed in the overview of these chapters on ECVs shows a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to surface air temperature measurements.

Table 4. Present targets for JCOMM Observing Systems

Observing System	**Present JCOMM Targets**	**Comments**
DBCP drifters	1250 buoys deployed 5x5 degree global distribution 1250 with barometers 300 with salinity	Very few report this variable.
DBCP moorings	131 moorings Topical oceans	Coastal moorings are deployed with national discretion. Tsunami buoys are in another IOC programme.
DBCP OceanSITES	29 reference moorings 58 others	At selected sites, 10 in Atlantic, 10 in Pacific, 5 in Indian Oceans.
SOT SOOP	37,000 XBTs deployed 26 High density lines (HDX) 25 Frequently repeated lines (FRX)	All carried out on selected lines to meet specific scientific objectives. HDX lines sampled 4 times a year, with 10-20 km between stations. FRX lines sampled 20 repeats a year with 50-100 km between stations.
SOT VOS	3000 active ships 500 AWS 250 VOSClim	Active ships provide more than 20 reports/month.
SOOP underway	No specified requirements	
GO-SHIP	Selected WOCE lines Repeated each decade (or better) Surface to bottom at 5m resolution or better	Network encompasses fewer lines than WOCE.

JCOMMOPS generates a number of charts and graphs that provide a qualitative way to see if certain of the observing systems are meeting these simple targets. For example, DBCP pages provide maps showing the number of active surface drifters measuring surface air temperature [15] and their latest reported positions.

Similar displays are available for SOT. However, not all JCOMM programmes have displays that easily summarize the status of the programme (Rec 1).

The JCOMMOPS presentations reflect the individual observing system targets, but these are not a perspective that well represents an ECV perspective. A start towards this goal is provided at OSMC [16]. At this site and at the “Observing System Metrics tab, a user can select a parameter, a time frame and either one or all platforms. A further selection of gridding, and display presents a map that portrays the composite view, or individual platform view. There are some weaknesses to this display (Rec 2), but it is working towards the right goal. One notable lack is that a user cannot plug in the OSCAR requirements for any particular application area, as shown in table 3. But considering the present state of in-situ sampling, this “lack” is sensible and pragmatic, as is discussed below.

The next table is a qualitative review of the OSCAR application requirements.

Table 5: A qualitative assessment of application area for surface air temperature measurements.

Application Area **- Comment** **- Layer**	**Uncertainty**	**Horiz. Res**	**Vert. Res**	**Obs.Cycle**	**Timeliness**	**Comments**
CLIC - - surface	G	T	Not applicable	G	G	
Climate-AOPC - temperature - air - surface	T+	L	Not applicable	B	G	
Global NWP - - surface	G	L	Not applicable	B	T+	
High Res NWP - - surface	G	L	Not applicable	T	L	
Nowcasting - - surface	G	L	Not applicable	L	L	
Ocean applications - maritime safety services - over sea	L	L	Not applicable	L+	T+	Many reports are collected within a Obs, Cycle of 3 hours but not enough.
Synoptic meteorology - - surface	T	L	Not applicable	T+	T-	

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement. Plus and minus signs indicate if current sampling is greater than, or less than that requirement.

The assessment in Table 5 would suggest that for surface air temperature, the instrumentation required is mostly available as long as maintenance is performed. The spatial sampling is mostly below requirements. Observing cycle and timeliness reflects synoptic sampling regimens of WMO.

Overall, the observing systems contributions to surface air temperature measurements are from drifters, ships and tropical moorings. The data systems are at a FOO readiness level of Mature 8 or 9, though lacking in the volume of data reported.

Recommendations

Rec 1: Each of the formal JCOMM programmes should provide simple displays on their home web pages that articulate as precisely as possible the observing targets, and show how well these targets are being met. Examples to emulate would be those provided by DBCP.

Rec 2: The displays allow a gridding in terms of latitude and longitude squares. The OSCAR requirements are set by units of meters (and kilometres). Also there are many different horizontal resolution requirements in OSCAR than are possible to specify at OSMC. Given the state of in-situ sampling, it is reasonable that all scales are not supported. However, a gridding based on meters / kilometres should be presented rather than degrees of latitude and longitude.

Acronyms

AOPC: Atmospheric Observation Panel for Climate
AWS: Automated Weather (observing) System
CIMO: Commission on Instruments and Observations (of WMO)
CliC: Climate and Cryosphere (project)
CMM: Commission on Marine Meteorology
DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GDP: Global Drifter Program
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
IGOSS: Integrated Global Ocean Station System
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
NWP: Numerical Weather Prediction
OCG: Observations Programme Coordinator
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
PMO: Port Meteorological Officer
SOOP: Ship Of Opportunity Programme
SOT: Ship Observations Team
VOS: Volunteer Observing Ship
WOCE: World Ocean Circulation Experiment
WMO: World Meteorological Organization
XBT: Expendable Bathythermograph

References

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2. AWS observations: http://www.bom.gov.au/jcomm/vos/vos.html
3. PMOs: http://www.bom.gov.au/jcomm/vos/pmo.html
4. DBCP drifters: http://www.jcommops.org/dbcp/platforms/types.html
5. DBCP GDP home: http://www.aoml.noaa.gov/phod/dac/index.php
6. DBCP moorings action groups: http://www.jcommops.org/dbcp/overview/actiongroups.html
7. DBCP OceanSITES home: http://www.oceansites.org/
8. SOT SOOP: http://www.jcommops.org/sot/soop/
9. SOT VOS: http://www.jcommops.org/sot/#VOS
10. SOT underway: http://www.gosud.org/
11. GO-SHIP home: http://www.go-ship.org/
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3.3: Colour of Dissolved Organic Matter - CDOM

A Review of Instruments

The colour of dissolved organic matter is an optical property resulting mostly from tannins from decaying material. CDOM absorbs light most strongly in the blue end of the spectrum. Through this absorption, the amount of light penetration through the water column is reduced with subsequent impact on growth of phytoplankton. An important property is that CDOM's impact the ability of satellite sensors to measure chlorophyll concentration and so adds to uncertainty in estimates of primary productivity from satellite.
A workshop report from 2007 for the Charlotte, N.C. Area provides a nice overall summary of information on CDOM [1]. CDOM can be measured with spectrophotometers or fluorometers measuring water properties of pumped water systems, or by an instrument lowered through the water column.

Calibration is an import aspect of measuring ocean properties. This is particularly true when small quantities and precise chemical treatments are involved. Attention to detail has a strong impact on the quality of the data.

Instrument Characteristics

Fluorescence instruments measure the amount of fluorescein present and convert this to a measure of CDOM. In contrast spectrophotometry measures absorption of specific wavelengths, or ranges, and converts to a measure of CDOM.

There is a great deal of literature describing methods used to estimate CDOM [see 2].

Data Providers / Observing Systems

There is no international data management initiatives to deal with CDOM data although it is known that fluorescence measurements are common. The table below provides a list of the potential sources of oceanic CDOM data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled “Typical Instruments” and “Typical Sampling” provide some information about the horizontal, vertical and temporal sampling of the system. These are approximate and are to be considered as only an indication of the usual characteristics.

Table 1. Instruments typically used in each observing system that contributes CDOM measurements.

Observing System	Typical instrument(s)	Typical Sampling
DBCP OceanSITES [3]	Fluorometer	Data are collected at time series stations such as HOTS and BATS. Samples are collected roughly monthly or better from the full water column.
GO-SHIP [4]	Fluorometer	Sample along sections, fewer than once a year. Stations are typically widely separated. Water samples are collected from top to bottom.
National monitoring / research	Varied	National research programmes may exist separate from OceanSITES. Sampling is highly dependent on the programme.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [5]. The objective was “ to develop an integrated framework for sustained ocean observing ...” to “... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...". They agreed that implementation of new systems for EOVs "... will be carried out according to their readiness levels ...". The table that describes this, extracted from that report, follows.

Table 2. FOO readiness levels.

Readiness Level	Description	Data Management and Information Products
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
Mature 8	Mission qualified	Data availability: globally available Evaluation of utility
Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan
Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance
Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
Concept 2	Documentation	Socialization of data: Interoperability strategy Expert review
Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [6], that is "... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.". OSCAR is a complicated database in that it contains the spatial and temporal sampling requirements as needed by the varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:
uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
availability

Each of these categories has three criteria as described here:

Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The rows relevant to CDOM have been extracted from OSCAR, reformatted somewhat and are shown here.

Table 3. OSCAR entries for CDOM.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (2) Breakthrough Threshold**	**Vert. Res: Goal Breakthrough Threshold**	**Obs. Cycle: Goal (3) Breakthrough Threshold**	**Availability: Goal (3) Breakthrough Threshold**
CLIVAR - - open ocean	speculative	5 m^{-1} 10 20	100 km 200 500	Not applicable	24 h 2 d 6	30 d 45 90
Marine biology - - open ocean	firm	5 m^{-1} 8 20	1 km 2 5	Not applicable	24 h 36 2 d	3 d 4 7
SIA - - coast	speculative	5 m^{-1} 10 20	100 km 200 500	Not applicable	24 h 2 d 6	30 d 45 90

Notes:
1. Units: m^{-1} is per metre
2. Units: km is kilometres
3. Units: d is days
h is hours

No units are indicated when there is no difference from the units of the entry immediately above in the table.

Composite View

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The analysis by Kent et. al. [7] discussed in the overview of these chapters on ECVs shows a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to CDOM measurements.

Table 4. Present targets for JCOMM Observing Systems

Observing System	Present JCOMM Targets	Comments
DBCP OceanSITES	29 reference moorings 58 others	At selected sites, 10 in Atlantic, 10 in Pacific, 5 in Indian Oceans.
GO-SHIP	Selected WOCE lines Repeated each decade (or better) Surface to bottom at 5m resolution or better	Network encompasses fewer lines than WOCE.

There is no monitoring of CDOM measurements undertaken either by JCOMMOPS nor by OSMC. The only way to assess the status of this ECV is through an analysis of the data that are available through OceanSITES and GO-SHIP archives. In addition it is known that there are many fluorescence measurements made by national agencies, and these data are held in the various national archives around the world. If there is to be any attempt to monitor in-situ CDOM measurements, data from these archive systems will need to be taken into consideration (Rec 1).

The next table is a qualitative review of the OSCAR application requirements. It seems that requirements are set with satellite observations in mind. In most cases the present state of in-situ sampling does not fall within OSCAR requirements. No assessment is given of whether or not uncertainty requirements can be met.

Table 5: A qualitative assessment of application area for CDOM measurements.

Application Area - Comment - Layer	Uncertainty	Horiz. Res	Vert. Res	Obs. Cycle	Timeliness	Comments
CLIVAR - - open ocean		B	Not applicable	L	L	Horiz. Res. is only met in-situ at limited locations or sections.
Marine biology - - open ocean		L	Not applicable	L	L	
SIA - - coast		B	Not applicable	L	L	Horiz. Res. is only met in-situ at limited locations or sections.

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement.

The assessment in Table 5 suggests that the horizontal spatial sampling is mostly inadequate unless this is considered to apply along sections. Not enough samples are collected even on sections or at moorings. An observing cycle of years is in-line with planned repeat GO-SHIP objectives. Turning the data around to make them available within 90 days might be possible if the effort was made.

Overall, the observing systems with contributions to CDOM measurements are at a FOO readiness level in the Concept category even considering those data collected by JCOMM programmes (Rec 2).

Recommendations

Rec 1: Data that can contribute to an estimate of this ECV are collected by a few JCOMM programmes, but also by many national agencies. Before any monitoring activity can begin, an identification of sources, reconciliation of data processing, formats, quality control procedures, etc., will be needed. It is recommended that OOPC work with JCOMM to determine what level of effort is needed.

Rec 2: Before CDOM can move to a “pilot level” as described by the FOO, there will need to be some international body that takes on board the development of a broad scale effort to collect these data. Part of this work will be to engage the many national collections of fluorescence and standardization of their procedures and protocols.

Acronyms

BATS: Bermuda Atlantic Time-series Study
CDOM: Colour Dissolved Organic Matter
CLIVAR: Climate Variability and Predictability
DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate VariableHOTS: Hawaii Ocean Time-Series
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
HOTS: Hawaii Ocean Time-Series
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
OCG: Observations Programme Coordinator
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
SIA: Seasonal and Inter-Annual Forecasts
WOCE: World Ocean Circulation Experiment
WMO: World Meteorological Organization
XBT: Expendable Bathythermograph

References

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3.4: Cloud Properties

A Review of Instruments

The WMO has long encouraged reporting attributes of clouds (coverage, type, heights, etc.) and in an effort to standardize the measurement, both on land and sea, have a Commission devoted to Instrumentation and Methods of Observation, CIMO. This body has extensive documentation that describes the various instruments used for meteorological measurements, and sections in their Manual [1] that discuss observation practices at sea. The sections on at-sea observation have been developed closely with experts in IGOSS and CMM prior to the formation of JCOMM. The sections on marine observations have been reviewed and revised since JCOMM started in 2001 with contributions from SOT, DBCP and others.

Nearly all ships at sea have made manual observations of the presence of clouds and their type. Documentation from WMO [2] provides not only descriptions but also pictures of the different types of clouds so that proper identification is possible.

With advances in technology, many countries are moving to completely automated meteorological measurement systems (AWS) installed on ships. There are a number of positive consequences of this. First, reporting can be completely standardized and data delivered to shore even if the ship's crew is busy at other tasks. Secondly, the consistency of measurement is less reliant on the diligence and care taken by ship's crew. There are negative consequences, though. Present day automated systems cannot perform the range of measurements that were provided in the past and so weather services are seeing fewer types of observations. AWS systems are required to measure at least air pressure, pressure change, temperature and humidity. Optional sensors would include wind speed and direction and sea temperature measurement [3].

Making estimates of cloud cover from automated instruments at sea is challenging. By far, most measurements are made visually. And although automated data logging systems make provision for manual input of these other observations, the quantity of these observations has declined in recent years.

In the case of manually observed variables such as cloud cover, it is important to have well trained ship's crew and consistency. In the VOS programme, there has long been the practice of having PMOs [4] visit participating ships when they come into port. Among other duties, they would check the meteorological instruments to be sure they were functioning properly. They also can help improve consistency of reporting and training of ship's crew so that measurements of cloud properties are made reliably and input to electronic logs. The number of PMOs that are working today is smaller than in the past, and their duties are more complex, given the advancements in ship's technology. Still this is a valuable service that deserves continued support.

Reports on clouds include the amount of sky covered and were reported in octas (eighths of the sky). Older code forms reported octas directly, whereas new BUFR tables makes a correspondence between octas and 10ths of the sky. Cloud types and heights of clouds are also reported by ships, sometimes distinguishing the type of low, medium and high cloud.

Instrument Characteristics

There are automated instruments that can be used to estimate cloud properties. These are typically land based systems that do not function well in the marine environment. The CIMO manual noted above describes these.

Data Providers / Observing Systems

The table below provides a list of the sources of cloud data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled “Typical Instruments” describes only one type, “Manual / visual” to signify there is no typical instrumentation used. That is not to say that automatic ways of measuring cloud properties are not under study.

The column “Typical Sampling” provides some information about the horizontal and temporal sampling of the system. These are approximate and are to be considered as only an indication of the usual characteristics. WMO also has suggestions for frequency of reporting, typically what is called synoptic times (every 6 hours). Reporting at intermediate times, every 3 hours, is encouraged. AWS systems, if equipped, often report data hourly.

Table 1. Observing systems that contribute cloud property measurements.

Observing System	**Present JCOMM Targets**	**Comments**
DBCP OceanSITES [5]	WMO approved	Not at all locations. Reference mooring stations sparsely distributed over the oceans. Report at main synoptic times or better.
SOT SOOP [6]	WMO approved	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation. Report at main synoptic times or better.
SOT VOS [7]	WMO approved	Sample along ships routes.
SOOP underway [8]	WMO approved	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation. Report at main synoptic times or better.
GO-SHIP [9]	WMO approved	Sample along sections, fewer than once a year. Stations are typically widely separated. Report at main synoptic times or better.
Navies	WMO approved	Varying distribution depending on purposes. Reporting is dependent on national defence policies but when available are at main synoptic times or better.
Fisheries	WMO approved	Often in random sampling patterns with sometimes 10's of km separation between stations. Typically sample on continental shelves. Report at main synoptic times or better.
National monitoring / research	WMO approved	Sampling is highly dependent on the programme but may report at main synoptic times or better.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [10]. The objective was “ to develop an integrated framework for sustained ocean observing ...” to “... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...”. They agreed that implementation of new systems for EOVs “... will be carried out according to their readiness levels ...”. The table that describes this, extracted from that report, follows.

Table 2. FOO readiness levels.

Readiness Level	**Description**	**Data Management and Information Products**
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted

Mature 8	Mission qualified	Data availability: globally available Evaluation of utility
Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan
Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance
Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
Concept 2	Documentation	Socialization of data: Interoperability strategy Expert review
Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [11], that is ”... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.”. OSCAR is a complicated database in that it contains the spatial and temporal sampling requirements as needed by the varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:
uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
availability

Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The rows relevant to clouds measurements have been extracted from OSCAR, reformatted somewhat and are shown here. Some values found in OSCAR would seem to be in error and are shown here in bold and italic (Rec 1).

Table 3. OSCAR entries for cloud properties.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (2) Breakthrough Threshold**	**Vert. Res: Goal Breakthrough Threshold**	**Obs. Cycle: Goal (3) Breakthrough Threshold**	**Availability: Goal (3) Breakthrough Threshold**
Climate-AOPC - Accuracies should apply to low and high clouds separately - total column	firm	10 % 15 20	***99 km*** 100 500	Not applicable	3 h 4 6	3 h 6 12
GEWEX - - total column	reasonable	5 % 10 20	50 km 100 250	Not applicable	3 h 6 12	30 d 45 60
Global NWP - - total column	reasonable	5 % 10 20	5 km 15 50	Not applicable	1 h 3 12	6 m 30 6 h
High Res NWP - - troposphere column	tentative	5 % 8 20	1/2 km 2 10	Not applicable	15 m 30 3 h	15 m 30 2 h
Nowcasting - - low troposphere	firm	5 % 10 20	1 km 5 20	Not applicable	30 s 3 m 60	1 m 3 30
Ocean applications - maritime safety services - low troposphere	firm	***0 %*** ***0*** ***0***	1/2 km 1 5	Not applicable	3 m 6.6 30	15 m 24 60
Base height: GEWEX - - 2-d field	tentative	0.5 km 1 2	50 km 100 250	Not applicable	3 h 6 12	30 d 45 60
Base height: Global NWP - - 2-d field	reasonable	0.2 km 0.5 1	5 km 15 50	Not applicable	1 h 3 12	6 m 30 6 h
Base height: High Res NWP - - 2-d field	reasonable	0.2 km 0.5 1	1/2 km 2 10	Not applicable	1/4 h 1 3	15 m 30 2 h
Top height: CliC - - 2-d field	reasonable	0.5 km 0.7 1	100 km 200 500	Not applicable	12 h 15 24	24 h 30 2 d
Top height: Climate-AOPC - accuracy should be 5 hPa (min 10) - 2-d field	firm	0.5 km 1 2	100 km 200 500	Not applicable	3 h 4 6	3 h 6 12
Top height: Global NWP - - 2-d field	firm	0.2 km 0.5 1	5 km 15 50	Not applicable	1 h 3 12	6 m 30 6 h
Top height: High Res NWP - - 2-d field	firm	0.2 km 0.5 1	1/2 km 2 10	Not applicable	15 m 30 3 h	15 m 30 2 h

Top height: Nowcasting - - 2-d field	firm	0.1 km 0.3 1	1 km 3 10	Not applicable	30 s 3 m 30	72 s 5 m 30
Top height: Synoptic meteorology - - 2-d field	firm	0.5 km 0.8 2	1 km 2.2 10	Not applicable	15 m 43.3 6 h	15 m 43.3 6 h

Notes:
1. Units: % is percent cloud cover
   km is kilometres
2. Units: km is kilometres
3. Units: d is days
   h is hours
   m is minutes
   s is seconds

No units are indicated when there is no difference from the units of the entry immediately above in the table.

It should be noted that in-situ programmes often carry out sampling by ships along lines. As a consequence, sampling in the Northern Hemisphere Atlantic Ocean, though still not uniformly distributed, is not bad. In other oceans the sampling is less well distributed and even poorer in high latitude regions.

Composite View

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The analysis by Kent et. al. [12] discussed in the overview of these chapters on ECVs shows a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to cloud measurements.

Table 4. Present targets for JCOMM Observing Systems

Observing System	**Present JCOMM Targets**	**Comments**
DBCP OceanSITES	29 reference moorings 58 others	At selected sites, 10 in Atlantic, 10 in Pacific, 5 in Indian Oceans.
SOT SOOP	37,000 XBTs deployed 26 High density lines (HDX) 25 Frequently repeated lines (FRX)	All carried out on selected lines to meet specific scientific objectives. HDX lines sampled 4 times a year, with 10-20 km between stations. FRX lines sampled 20 repeats a year with 50-100 km between stations..
SOT VOS	3000 active ships 500 AWS 250 VOSClim	Active ships provide more than 20 reports/month
SOOP underway	No specified requirements	

GO-SHIP	Selected WOCE lines Repeated each decade (or better) Surface to bottom at 5m resolution or better	Network encompasses fewer lines than WOCE.

JCOMMOPS [13] generates a number of charts and graphs that provide a qualitative way to see if certain of the observing systems are meeting these simple targets. SOT pages [6,7,8] provide maps showing the number of reports from ships in that programme but there is no qualification by which of these report cloud properties (Rec 2).

The JCOMMOPS presentations reflect the individual observing system targets, but these are not a perspective that well represents an ECV perspective. A beginning towards this goal is provided at OSMC [14]. At this site and at the “Observing System Metrics tab, a user can select a parameter, a time frame and either one or all platforms. A further selection of gridding, and display presents a map that portrays the composite view, or individual platform view. There are some weaknesses to this display (Rec 3), but it is working towards the right goal. One notable lack is that a user cannot plug in the OSCAR requirements for any particular application area, as shown in table 3. But considering the present state of in-situ sampling, this “lack” is sensible and pragmatic, as is discussed below.

The next table is a qualitative review of the OSCAR application requirements.

Table 5: A qualitative assessment of application area for cloud measurements.

Application Area - Comment - Layer	**Uncertainty**	**Horiz. Res**	**Vert. Res**	**Obs.Cycle**	**Timeliness**	**Comments**
Climate-AOPC - Accuracies should apply to low and high clouds separately - total column	B	T	Not applicable	T+	T+	
GEWEX - - total column	T+	L	Not applicable	B+	G	
Global NWP - - total column	T+	L	Not applicable	T+	T+	
High Res NWP - - troposphere column	T+	L	Not applicable	L	L	
Nowcasting - - low troposphere	T+	L	Not applicable	L	L	
Ocean applications - maritime safety services - low troposphere	-	L	Not applicable	L	L	
Base height: GEWEX - - 2-d field	T	L	Not applicable	B+	G	
Base height: Global NWP - - 2-d field	L	L	Not applicable	T+	T+	

Base height: High Res NWP - - 2-d field	L	L	Not applicable	L	L	
Top height: CLIC - - 2-d field	L	T	Not applicable	G	G	
Top height: Climate-AOPC - accuracy should be 5 hPa (min 10) - 2-d field	T	T	Not applicable	T+	B+	
Top height: Global NWP - - 2-d field	L	L	Not applicable	T+	T+	
Top height: High Res NWP - - 2-d field	L	L	Not applicable	L	L	
Top height: Nowcasting - - 2-d field	L	L	Not applicable	L	L	
Top height: Synoptic meteorology - - 2-d field	T	L	Not applicable	T+	T+	

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement. Plus and minus signs indicate if current sampling is greater than, or less than that requirement. The "-" is used where the requirements appear to be suspect.

Uncertainty is difficult to gauge with visual observations. However, character code forms used on the GTS report in octas, and it is assumed that an observer can reliably distinguish this. An octa is roughly 15% of the sky and so it is assumed that this represents the uncertainty (see [1]).

Cloud heights are assumed to have an uncertainty of 10m for clouds within 100m and 10% of the height for higher clouds. But the type of cloud observed can also provides clues to the heights (see [1]). For the sake of this table it is assumed height can be estimated to 2 km.

The assessment in Table 5 would suggest that for cloud properties in-situ, visual estimates could meet requirements for some application areas, but not others. The reporting cycles and observing cycles often fall within the synoptic observing times recommended by WMO and often met by observers. The spatial sampling is mostly below requirements.

Overall, the observing systems contributions to cloud measurements are mostly visual observations and from ships. Because these are visual, and countries are switching to AWSs, the number of cloud observations are limited and declining. Data systems to manage cloud data are at a FOO readiness level of Mature 8 or 9, though lacking in the volume of data reported. This estimate assumes that cloud property observations and reporting are consistently done by the various observing programmes.

Recommendations

Rec 1: The error in the OSCAR tables should be corrected.

Rec 2: Each of the formal JCOMM programmes should provide simple displays on their home web pages that articulate as precisely as possible the observing targets for ECVs, and show how well these targets are being met.

Rec 3: The displays allow a gridding in terms of latitude and longitude squares. The OSCAR requirements are set by units of meters (and kilometres). Also there are many different horizontal resolution requirements in OSCAR than are possible to specify at OSMC. Given the state of in-situ sampling, it is reasonable that all scales are not supported. However, a gridding based on meters / kilometres should be presented rather than degrees of latitude and longitude.

Acronyms

AOPC: Atmospheric Observation Panel for Climate
AWS: Automated Weather (observing) System
CIMO: Commission on Instruments and Observations (of WMO)
CliC: Climate and Cryosphere (project)
CMM: Commission on Marine Meteorology
DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GEWEX: Global Energy and Water Exchange Project
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
IGOSS: Integrated Global Ocean Station System
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
NWP: Numerical Weather Prediction
OCG: Observations Programme Coordinator
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
PMO: Port Meteorological Officer
SOOP: Ship Of Opportunity Programme
SOT: Ship Observations Team
VOS: Volunteer Observing Ship
WOCE: World Ocean Circulation Experiment
WMO: World Meteorological Organization
XBT: Expendable Bathythermograph

References

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2. WMO International Cloud Atlas: http://library.wmo.int/pmb_ged/wmo_407_en-v2.pdf
3. AWS observations: http://www.bom.gov.au/jcomm/vos/vos.html
4. PMOs: http://www.bom.gov.au/jcomm/vos/pmo.html
5. DBCP OceanSITES home: http://www.oceansites.org/
6. SOT SOOP: http://www.jcommops.org/sot/soop/
7. SOT VOS: http://www.jcommops.org/sot/#VOS
8. SOT underway: http://www.gosud.org/
9. GO-SHIP home: http://www.go-ship.org/
10. OceanObs'09 FOO: http://www.oceanobs09.net/foo/
11. OSCAR: http://www.wmo-sat.info/oscar/observingrequirements
12. Kent et. al. analysis: http://eprints.soton.ac.uk/50260/
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3.5: Dissolved Inorganic Carbon (DIC)

A Review of Instruments

Dissolved inorganic carbon is the sum of inorganic carbon as carbon dioxide, carbonic acid, carbonate and bicarbonate anions dissolved in seawater. The variable is important because anthropogenic CO_2 can change the DIC of the ocean. Values for DIC also change in the vertical water column due to uptake by phytoplankton. In deep waters the dissolution of sinking calcium carbonate shells from phytoplankton remineralize to DIC. References to instrumentation and characteristics is provided by IOCCP [1]. The same site provides a description of “standard operating procedures” [2] for measuring DIC in seawater. There are a number of different techniques used to measure DIC. A recent paper by Hansen et. al. [3] discusses these. In addition, DIC can be calculated from measurements of pH and total alkalinity.

Calibration is an import aspect of measuring ocean properties. This is particularly true when small quantities and precise chemical treatments are involved. Attention to detail has a strong impact on the quality of the data.

Instrument Characteristics

In the case of measuring DIC, the first step is the collection of a seawater sample. After this, there are some different techniques referred to in literature (see for example [3]), such as infrared methods, gas chromatography and IRMS. However, each of these requires very careful manipulation and treatment of the sample to ensure no contamination. The method recommended by IOCCP uses the coulometry and this is the only instrument and method presented. The OceanSITES HOTS programme [4] also provides information on how their measurements are made.

Table 1. Nominal instrument/method characteristics used to measure DIC.

Instrument	**Accuracy**	**Comments**
Coulometer	±1.5 microM/Kg	E.g. [5]

Data Providers / Observing Systems

The table below provides a list of the sources of oceanic DIC data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled “Typical Instruments” and “Typical Sampling” provide some information about the horizontal, vertical and temporal sampling of the system. These are approximate and are to be considered as only an indication of the usual characteristics.

Table 2. Instruments typically used in each observing system that contributes DIC measurements.

Observing System	**Typical instrument(s)**	**Typical Sampling**
DBCP OceanSITES [6]	Coulometer	Data are collected at time series stations such as HOTS and BATS. Samples are collected roughly monthly or better from the full water column.
GO-SHIP [7]	Coulometer	Sample along sections, fewer than once a year. Stations are typically widely separated. Water samples are collected from top to bottom.
IOCCP [8]	Coulometer	Same as GO-SHIP.
National monitoring / research	Varied	National research programmes may exist separate from OceanSITES. Sampling is highly dependent on the programme.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [9]. The objective was " to develop an integrated framework for sustained ocean observing ..." to "... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...". They agreed that implementation of new systems for EOVs "... will be carried out according to their readiness levels ...". The table that describes this, extracted from that report, follows.

Table 3. FOO readiness levels.

Readiness Level	**Description**	**Data Management and Information Products**
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
Mature 8	Mission qualified	Data availability: globally available Evaluation of utility
Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan
Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance
Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
Concept 2	Documentation	Socialization of data: Interoperability strategy Expert review
Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [10], that is "... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.". OSCAR is a complicated database in that it contains the spatial and temporal sampling requirements as needed by the varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:

uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
availability

Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The row relevant to dissolved inorganic carbon has been extracted from OSCAR, reformatted somewhat and is shown here. The entries in bold and italics would appear to be in error (Rec 1).

Table 4. OSCAR entries for dissolved inorganic carbon.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (2) Breakthrough Threshold**	**Vert. Res: Goal (2) Breakthrough Threshold**	**Obs. Cycle: Goal (3) Breakthrough Threshold**	**Availability: Goal (3) Breakthrough Threshold**
Climate-OOPC - -	reasonable	0.5 Mol/Kg 0.6 1	50 km 60 100	***10 km*** ***13*** ***20***	4.9 y 5.9 9.8	1 y 1.3 2

Notes:
1. Units: Mol/Kg is Moles per kilogram
2. Units: km is kilometres
3. Units: y is years
No units are indicated when there is no difference from the units of the entry immediately above in the table.

It should be noted that programmes sample either by ships along sections or at fixed locations. The requirements in the above table do not properly reflect this sampling strategy, except if the horizontal requirements are interpreted to apply to how data are collected along the section, or vertically at fixed stations and along sections. If the entries in the table are interpreted to be horizontal and vertical resolution over the whole ocean, OSCAR thresholds would not be achieved.

Composite View

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The analysis by Kent et. al. [11] discussed in the overview of these chapters on ECVs shows a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to DIC measurements.

Table 5. Present targets for JCOMM Observing Systems

Observing System	Present JCOMM Targets	Comments
DBCP OceanSITES	29 reference moorings 58 others	At selected sites, 10 in Atlantic, 10 in Pacific, 5 in Indian Oceans.
GO-SHIP	Selected WOCE lines Repeated each decade (or better) Surface to bottom at 5m resolution or better	Network encompasses fewer lines than WOCE.
IOCCP	37 carbon survey	A new group is forming as a Carbon SOOP. Otherwise, data are collected by GO-SHIP.

There is no monitoring of DIC measurements undertaken either by JCOMMOPS nor by OSMC. The only way to assess the status of this ECV is through an analysis of the data that are available through IOCCP. It is expected, though not known, if the DIC observations made through OceanSITES end up at IOCCP archives (Rec 2).

The next table is a qualitative review of the OSCAR application requirements. In most cases the present state of in-situ sampling does fall within OSCAR requirements.

Table 6: A qualitative assessment of application area for dissolved inorganic carbon measurements.

Application Area - Comment - Layer	Uncertainty	Horiz. Res	Vert. Res	Obs. Cycle	Timeliness	Comments
Climate-OOPC - -	G	T	L	G	T	Any rating other than L assumes sampling on sections or at a few fixed locations is to be considered.

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement. Plus and minus signs indicate if current sampling is greater than, or less than that requirement.

The assessment in Table 6 would suggest that for DIC, the instrumentation required is available. Beyond this, the horizontal spatial sampling is completely inadequate unless the criteria in OSCAR is considered to apply along sections. Assuming that the units for vertical resolution should be m, even then not enough samples are collected on sections or at moorings. An observing cycle of years is in-line with planned repeat GO-SHIP / IOCCP objectives. Turning the data around to make them available within 2 years would seem to be possible. Overall, the observing systems with contributions to DIC measurements are at a FOO readiness level of a Pilot. They are vulnerable because the present programmes are significantly dependent on research funding (Rec 3).

Recommendations

Rec 1: The error in the OSCAR tables should be corrected.

Rec 2: This ECV is a difficult one to make and the data become available only after careful analysis of water samples. For this reason, there is no real-time monitoring or assessment. It is not apparent that delayed mode assessment is anyone's responsibility. It is recommended that OOPC provide some guidance to JCOMM or others about what sort of monitoring or assessment is deemed necessary at this time.

Rec 3: The organization of the data system for DIC shows elements of maturity, but there are still some aspects, such as interoperability and availability, that need attention. It is recommended that IOCCP work with its partners, and perhaps strongly with CDIAC to make the data available as soon as possible and in addition to the products that are currently offered. Consideration of a netCDF structure [12] with CF conventions [13] should be given as one data delivery format.

Acronyms

BATS: Bermuda Atlantic Time-series Study
CF: Climate and Forecast
DBCP: Data Buoy Cooperation Panel
DIC: Dissolved Inorganic Carbon
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
HOTS: Hawaii Ocean Time-Series
IOCCP: International Ocean Carbon Coordination Project
IRMS: Isotope Ratio Mass Spectrometry
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
microM/Kg: microMoles per kilogram
netCDF: net Common Data Format
OCG: Observations Programme Coordinator
OOPC: Ocean Observations Panel for Climate
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
SOOP: Ship Of Opportunity Programme
WOCE: World Ocean Circulation Experiment
WMO: World Meteorological Organization

References

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3.6: Air Specific Humidity (at surface)

A Review of Instruments

Specific humidity is defined to be the ratio between the mass of water vapour and the mass of moist air. This is not something that is commonly measured at sea. However, the more usual measurements of either relative humidity or dew point temperatures can be converted to specific humidity through suitable conversion formulae [1].

Nearly all ships at sea carry instruments that can observe humidity whether they are part of a formal observing programme or not. Many of them provide their observations to their national weather services, knowing that they are contributing to improved weather forecasts.

The WMO has long encouraged this participation and in an effort to standardize the measurement, both on land and sea, have a Commission devoted to Instrumentation and Methods of Observation, CIMO. This body has extensive documentation that describes the various instruments used for meteorological measurements, and sections in their Manual [2] that discuss observation practices at sea. The sections on at-sea observation have been developed closely with experts in IGOSS and CMM prior to the formation of JCOMM. The sections on marine observations have been reviewed and revised since JCOMM started in 2001 with contributions from SOT, DBCP and others.

Equally important to the actual observation is the physical location of the instruments on the ship where the measurements are collected. Instruments placed in locations sheltered from the elements provide data that is not representative of actual conditions. Siting of instruments is also treated in the Manual noted above.

With advances in technology, many countries are moving to completely automated meteorological measurement systems (AWS) installed on ships. There are a number of positive consequences of this. First, reporting can be completely standardized and data delivered to shore even if the ship's crew is busy at other tasks. Secondly, the consistency of measurement is less reliant on the diligence and care taken by ship's crew. There are negative consequences, though. Present day automated systems cannot perform the range of measurements that were provided in the past and so weather services are seeing fewer types of observations. AWSs are required to measure at least air pressure, pressure change, temperature and humidity. Optional sensors would include wind speed and direction and sea temperature measurement [3]. Although automated data logging systems make provision for manual input of these other observations, the quantity of these other types has declined in recent years.

It is fortunate that surface humidity observations are easy to automate and so these continue to be collected routinely.

Calibration and maintenance of instrumentation is an import aspect of measuring marine properties. Even though modern, electronic instruments are now the norm, ensuring the stability of the measurements has a strong impact on the quality of the data. In the VOS programme, there has long been the practice of having PMOs [4] visit participating ships when they come into port. Among other duties, they would check the meteorological instruments to be sure they were functioning properly. The number of PMOs that are working today is smaller than in the past, and their duties are more complex, given the advancements in ship's technology. Still, this is a valuable service that deserves continued support.

Instrument Characteristics

WMO requires humidity to be reported with a maximum uncertainly of 1%, with a sensor time constant of 20 seconds averaged over 1 minute. If dew point temperature is measured, uncertainty must be 0.1 ºK with the same time constants and averaging periods [2].

There are many different methods to measure humidity. These include the condensation method, the psychrometer, sorption methods, and absorption hygrometers. Each has characteristics and operating requirements to ensure reliable measurements. Of particular importance is a protective filter to screen the humidity sensor from contaminants. As for other operational requirements, this is well described in the CIMO Manual.

Data Providers / Observing Systems

The table below provides a list of the sources of humidity data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled "Typical Instruments" describes only one type, "WMO approved". This reflects the acceptance of national meteorological services to adhere to WMO requirements. That is not to say that other methods and higher accuracy ways of measuring humidity are not under study, particularly within the research community. For formal reporting purposes to weather services, approved thermometers are required.

The column "Typical Sampling" provides some information about the horizontal and temporal sampling of the system. These are approximate and are to be considered as only an indication of the usual characteristics. WMO also has suggestions for frequency of reporting, typically what is called synoptic times (every 6 hours). Reporting at intermediate times, every 3 hours, is encouraged. AWS systems often report data hourly.

Table 1. Instruments typically used in each observing system that contributes humidity measurements.

Observing System	**Present JCOMM Targets**	**Comments**
DBCP moorings [5]	WMO approved	Sample typically in tropics and hourly.
DBCP OceanSITES [6]	WMO approved	Not at all locations. Reference mooring stations sparsely distributed over the oceans. Report at main synoptic times or better.
SOT SOOP [7]	WMO approved	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation. Report at main synoptic times or better.
SOT VOS [8]	WMO approved	Sample along ships routes.
SOOP underway [9]	WMO approved	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation. Report at main synoptic times or better.
GO-SHIP [10]	WMO approved	Sample along sections, fewer than once a year. Stations are typically widely separated. Report at main synoptic times or better.
Navies	WMO approved	Varying distribution depending on purposes. Reporting is dependent on national defence policies but when available are at main synoptic times or better.
Fisheries	WMO approved	Often in random sampling patterns with sometimes 10's of km separation between stations. Typically sample on continental shelves. Report at main synoptic times or better.
National moorings	WMO approved	At nationally selected sites, usually on coastal shelves or slopes. Sampling can be hourly or better, but highly dependent on the programme.

National monitoring / research	WMO approved	Sampling is highly dependent on the programme but may report at main synoptic times or better.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [11]. The objective was " to develop an integrated framework for sustained ocean observing ..." to "... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...". They agreed that implementation of new systems for EOVs "... will be carried out according to their readiness levels ...". The table that describes this, extracted from that report, follows.

Table 2. FOO readiness levels.

Readiness Level	**Description**	**Data Management and Information Products**
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
Mature 8	Mission qualified	Data availability: globally available Evaluation of utility
Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan
Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance
Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
Concept 2	Documentation	Socialization of data: Interoperability strategy Expert review
Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [12], that is "... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.". OSCAR is a complicated database in that it contains the spatial and temporal sampling requirements as needed by the

varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:
uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
availability

Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The rows relevant to humidity have been extracted from OSCAR, reformatted somewhat and are shown here.

Table 3. OSCAR entries for humidity.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (2) Breakthrough Threshold**	**Vert. Res: Goal Breakthrough Threshold**	**Obs. Cycle: Goal (3) Breakthrough Threshold**	**Availability: Goal (3) Breakthrough Threshold**
CLIC - - surface	tentative	10 % 12 20	100 km 200 500	Not applicable	12 h 18 24	24 h 36 2 d
Climate-AOPC - - surface	speculative	1 % 1.3 2	25 km 50 100	Not applicable	3 h 4 6	1 d 2 3
Global NWP - - surface	reasonable	2 % 5 10	15 km 50 250	Not applicable	1 h 3 12	6 m 30 6 h
High Res NWP - - surface	reasonable	2 % 5 10	1 km 5 20	Not applicable	1/2 h 1 6	15 m 30 2 h
Ocean applications - maritime safety services - over sea	firm	0.5 % 1 3	1 km 5 25	Not applicable	1/5 h 1 3	1/2 h 1 6

Notes:
1. Units: % is percent
2. Units: km is kilometres
3. Units: d is days
h is hours
m is minutes
No units are indicated when there is no difference from the units of the entry immediately above in the table.

It should be noted that programmes often carry out sampling by ships along lines. There are many ships contributing observations and as a consequence, sampling in the Northern Hemisphere oceans, though still not uniformly distributed, is not bad. Southern Hemisphere sampling is less well distributed and even poorer in high latitude regions.

Composite View

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The partial analysis by Kent et. al. [13] discussed in the overview of these chapters on ECVs showed a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to humidity measurements.

Table 4. Present targets for JCOMM Observing Systems

Observing System	**Present JCOMM Targets**	**Comments**
DBCP moorings	131 moorings Topical oceans	Coastal moorings are deployed with national discretion. Tsunami buoys are in another IOC programme.
DBCP OceanSITES	29 reference moorings 58 others	At selected sites, 10 in Atlantic, 10 in Pacific, 5 in Indian Oceans.
SOT SOOP	37,000 XBTs deployed 26 High density lines (HDX) 25 Frequently repeated lines (FRX)	All carried out on selected lines to meet specific scientific objectives. HDX lines sampled 4 times a year, with 10-20 km between stations. FRX lines sampled 20 repeats a year with 50-100 km between stations.
SOT VOS	3000 active ships 500 AWS 250 VOSClim	Active ships provide more than 20 reports/month.
SOOP underway	No specified requirements	
GO-SHIP	Selected WOCE lines Repeated each decade (or better) Surface to bottom at 5m resolution or better	Network encompasses fewer lines than WOCE.

JCOMMOPS only provides maps to locations of VOS reports [14] (Rec 1). There are no obvious tools that tell how many humidity observations are received and from where in a given time period (Rec 2).

The JCOMMOPS presentations reflect the individual observing system targets, but these are not a perspective that well represents an ECV perspective. A start towards this goal is provided at OSMC [12]. At this site at the “Observing System Metrics tab, a user can select a parameter, a time frame and either one or all platforms. A further selection of gridding, and display presents a map that portrays the composite view, or individual platform view. There are some weaknesses to this display (Rec 3, 4), but it is working towards the right goal. One notable lack is that a user cannot plug in the OSCAR requirements for any particular application area, as shown in table 3. But considering the present state of in-situ sampling, this “lack” is sensible and pragmatic, as is discussed below.

The next table is a qualitative review of the OSCAR application requirements.

Table 5: A qualitative assessment of application area for humidity measurements.

Application Area **- Comment** **- Layer**	**Uncertainty**	**Horiz. Res**	**Vert. Res**	**Obs.Cycle**	**Timeliness**	**Comments**
CLIC - - surface	G	T	Not applicable	G	G	
Climate-AOPC - - surface	G	L	Not applicable	T+	G	
Global NWP - - surface	G	T-	Not applicable	T+	T+	
High Res NWP - - surface	G	L	Not applicable	T+	L	
Ocean applications - maritime safety services - over sea	B	L	Not applicable	T-	T+	

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement. Plus and minus signs indicate if current sampling is greater than, or less than that requirement.

The assessment in Table 5 assumes that platforms that measure air temperature also measure humidity and do so within the uncertainties specified by WMO. It also assumes that such measurements are made and reported within at least the 4 synoptic times required by WMO or more frequently.

As long as instruments and measurements are made at or better than WMO requirements, it would appear that instruments are able to meet uncertainty requirements. As for other parameters, the spatial distribution of measurements can meet the minimum requirements in only a few application areas. Observing cycle and timeliness can in most circumstances meet or exceed the minimum requirements.

Overall, the observing systems contributions to humidity measurements come mostly from ships and tropical moorings. The data systems are at a FOO readiness level of Mature 8 or 9, though lacking in the volume of data reported.

Recommendations

Rec 1: The maps presently on the JCOMMOPS site showing VOS locations are from 2009. This was noted at a recent SOT meeting, but it is recommended that this be addressed as soon as possible so that up-to-date information is available.

Rec 2: Each of the formal JCOMM programmes should provide simple displays on their home web pages that articulate as precisely as possible the observing targets, and show how well these targets are being met. Examples to emulate would be those provided by DBCP showing buoys with barometers.

Rec 3: The “Observing System Metrics” tab does not allow the selection of humidity. It is recommended that all ECVs be available.

Rec 4: The displays allow a gridding in terms of latitude and longitude squares. The OSCAR requirements are set by units of meters (and kilometres). Also there are many different horizontal resolution requirements in OSCAR than are possible to specify at OSMC. Given the state of in-situ sampling, it is reasonable that all scales are not supported. However, a gridding based on meters / kilometres should be presented rather than degrees of latitude and longitude.

Acronyms

AOPC: Atmospheric Observation Panel for Climate
AWS: Automated Weather (observing) System
CIMO: Commission on Instruments and Observations (of WMO)
CliC: Climate and Cryosphere (project)

CMM: Commission on Marine Meteorology
DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
IGOSS: Integrated Global Ocean Station System
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
NWP: Numerical Weather Prediction
OCG: Observations Programme Coordinator
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
PMO: Port Meteorological Officer
SOOP: Ship Of Opportunity Programme
SOT: Ship Observations Team
VOS: Volunteer Observing Ship
WOCE: World Ocean Circulation Experiment
WMO: World Meteorological Organization
XBT: Expendable Bathythermograph

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12. OSCAR: http://www.wmo-sat.info/oscar/observingrequirements
13. Kent et. al. analysis: http://eprints.soton.ac.uk/50260/
14. JCOMMOPS home: http://wo.jcommops.org/cgi-bin/WebObjects/JCOMMOPS.woa/wa/map?type=GTSM_VOS
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3.7: Irradiance

A Review of Instruments

Measurement of irradiance is not common practice. Most of the JCOMM programmes are not equipped to provide data of this type in any routine fashion.

WMO, in an effort to standardize measurements both on land and sea, have a Commission devoted to Instrumentation and Methods of Observation, CIMO. This body has extensive documentation that describes the various instruments used for meteorological measurements, and sections in their Manual [1] that discuss observation practices at sea. The sections on at-sea observation have been developed closely with experts in IGOSS and CMM prior to the formation of JCOMM.

Equally important to the actual observation is the physical siting of the instruments on the platform where the measurements are collected. Siting of instruments is also treated in the Manual noted above.

With advances in technology, many countries are moving to completely automated meteorological measurement systems (AWS) installed on ships. There are a number of positive consequences of this. First, reporting can be completely standardized and data delivered to shore even if the ship's crew is busy at other tasks. Secondly, the consistency of measurement is less reliant on the diligence and care taken by ship's crew. There are negative consequences, though. Present day automated systems cannot perform the range of measurements that were provided in the past and so weather services are seeing fewer types of observations. AWS systems are required to measure at least air pressure, pressure change, temperature and humidity. Optional sensors would include wind speed and direction and sea temperature measurement [2]. Although automated data logging systems make provision for manual input of other observations such as irradiance, the quantity has declined in recent years.

Calibration and maintenance of instrumentation is an import aspect of measuring marine properties. Even though modern, electronic instruments are now the norm, ensuring the stability of the measurements has a strong impact on the quality of the data.

Irradiance is measured in Watts per square meter. Albedo is measured as a percent of incoming radiation.

Instrument Characteristics

The CIMO Manual states “There are no formally agreed statements of required uncertainty for most radiation quantities ... and best practice uncertainties are stated for the Global Climate Observing System’s Baseline Surface Radiation Network (see WMO, 1998).”. Unfortunately, this document does not appear to be available on-line from WMO (Rec 1). Uncertainties and calibration methods for the various types of instruments that can be used are discussed in the sections of the CIMO Manual.

Data Providers / Observing Systems

The table below provides a list of the sources of irradiance data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled “Typical Instruments” provides no detail since each installation has chosen an instrument appropriate for its purpose. Greater detail needs to be sought with the data.

The column “Typical Sampling” provides some information about the horizontal and temporal sampling of the system. These are approximate and are to be considered as only an indication of the usual characteristics.

Table 1. Instruments typically used in each observing system that contributes irradiance measurements.

Observing System	**Present JCOMM Targets**	**Comments**
DBCP moorings [3]	WMO approved	Sample typically in tropics and hourly.
DBCP OceanSITES [4]	WMO approved	Not at all locations. Reference mooring stations sparsely distributed over the oceans. Report at main synoptic times or better.
GO-SHIP [5]	WMO approved	Sample along sections, fewer than once a year. Stations are typically widely separated. Report at main synoptic times or better.
National moorings	WMO approved	At nationally selected sites, usually on coastal shelves or slopes. Sampling can be hourly or better, but highly dependent on the programme.
National monitoring / research	WMO approved	Sampling is highly dependent on the programme but may report at main synoptic times or better.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [6]. The objective was " to develop an integrated framework for sustained ocean observing ..." to "... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...". They agreed that implementation of new systems for EOVs "... will be carried out according to their readiness levels ...". The table that describes this, extracted from that report follows.

Table 2. FOO readiness levels.

Readiness Level	**Description**	**Data Management and Information Products**
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
Mature 8	Mission qualified	Data availability: globally available Evaluation of utility
Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan
Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance

Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
Concept 2	Documentation	Socialization of data: Interoperability strategy Expert review
Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [7], that is ”... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.”. OSCAR is a complicated database in that it contains the spatial and temporal sampling requirements as needed by the varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:
uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
availability

Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The rows relevant to humidity have been extracted from OSCAR, reformatted somewhat and are shown here.

Table 3. OSCAR entries for irradiance.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (2) Breakthrough Threshold**	**Vert. Res: Goal Breakthrough Threshold**	**Obs. Cycle: Goal (3) Breakthrough Threshold**	**Availability: Goal (3) Breakthrough Threshold**
Earth surface long-wave: Climate-AOPC - - surface	firm	5 W/m^2 6.5 10	25 km 50 100	Not applicable	3 h 4 6	1 d 2 5
Earth surface long-wave: Global NWP - - surface	reasonable	1 W/m^2 10 20	10 km 30 100	Not applicable	1 h 3 12	1 d 5 30
Earth surface short-wave: Climate-AOPC - - surface	firm	5 W/m^2 6.5 10	25 km 50 100	Not applicable	24 h 2 d 5	1 d 3 30

Earth surface short-wave: Global NWP - - surface	reasonable	1 W/m^2 10 20	10 km 30 100	Not applicable	1 h 3 12	1 d 5 30
Earth surface albedo: Climate-TOPC - - surface	reasonable	5 % 7 10	1 km 2 10	Not applicable	1 d 3 30	30 d 45 90
Earth surface short-wave bidirectional: Climate-AOPC - - surface	speculative	5 % 6.5 10	25 km 50 100	Not applicable	3 h 4 6	1 h 2 5
Earth surface short-wave bidirectional: Global NWP - - surface	reasonable	1 % 2 5	10 km 30 100	Not applicable	1 h 3 12	1 d 5 30
Fraction of absorbed PAR: marine biology - - coast	firm	5 % 10 20	1 km 2 5	Not applicable	1 h 3 24	3 d 4 7
Earth surface long-wave upward: Climate-AOPC - - surface	speculative	5 W/m^2 6.5 10	25 km 50 100	Not applicable	3 h 4 6	1 h 2 5
Earth surface long-wave upward: Global NWP - - surface	reasonable	1 W/m^2 10 20	10 km 30 100	Not applicable	1 h 3 12	1 h 5 30

Notes:
1. Units: W/m^2 is Watts per square metre
% is percent reflected
2. Units: km is kilometres
3. Units: d is days
h is hours
No units are indicated when there is no difference from the units of the entry immediately above in the table.

Composite View

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The partial analysis by Kent et. al. [8] discussed in the overview of these chapters on ECVs showed a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table). Because of the very few observations, it is unlikely that such an analysis is warranted based on in-situ observations. However, irradiance properties are derivable from remote sensing platforms. So, the in-situ measurements can act as ground truth for these measurements (Rec 2).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to surface irradiance measurements.

Table 4. Present targets for JCOMM Observing Systems

Observing System	**Present JCOMM Targets**	**Comments**
DBCP moorings	131 moorings Topical oceans	Coastal moorings are deployed with national discretion. Tsunami buoys are in another IOC programme.
DBCP OceanSITES	29 reference moorings 58 others	At selected sites, 10 in Atlantic, 10 in Pacific, 5 in Indian Oceans.
GO-SHIP	Selected WOCE lines Repeated each decade (or better) Surface to bottom at 5m resolution or better	Network encompasses fewer lines than WOCE.

Neither JCOMMOPS nor OSMC provide any tools to see where or what irradiance observations are available. Instead, users who are interested must go to the tropical moorings, OceanSITES and GO-SHIP websites to learn this (Rec 3).

No qualitative assessment review of the OSCAR application requirements is provided here as it is evident that the volume of in-situ data are completely insufficient.

Overall, the FOO readiness level is considered to be at the Concept level only.

Recommendations

Rec 1: It is recommended that WMO make available on-line the document “Baseline Surface Radiation Network (BSRN): Operations Manual. WMO/TD-No. 879” or if there is a more recent statement of requirements, this be made available.

Rec 2: In-situ observations by themselves cannot come close to fulfilling OSCAR requirements for this ECV. It is clear that an analysis such as Kent et. al. made is only sensible if both remotely sensed and in-situ data are combined. In-situ observing requirements need to be stated in terms of the number of observations, locations, reporting frequency and so on that are needed to constrain the uncertainties from satellite measurements. It is recommended that OOPC pursue this.

Rec 3: There is no simple way for a user to see what in-situ irradiance data are collected within JCOMM or outside for that matter. OCG in discussions with OOPC and appropriate observing systems should determine what basic monitoring tool in possible to implement. A first objective would be to show on a single web page what kind of irradiance data are collected, where, with what instruments and uncertainties.

Acronyms

AOPC: Atmospheric Observation Panel for Climate
AWS: Automated Weather (observing) System
CIMO: Commission on Instruments and Observations (of WMO)
CMM: Commission on Marine Meteorology
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
IGOSS: Integrated Global Ocean Station System

JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
NWP: Numerical Weather Prediction
OCG: Observations Programme Coordinator
OOPC: Ocean Observations Panel for Climate
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
PAR: Photosynthetically Active Radiation
TOPC: Terrestrial Observation Panel for Climate
WOCE: World Ocean Circulation Experiment
WMO: World Meteorological Organization

References

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2. AWS observations: http://www.bom.gov.au/jcomm/vos/vos.html
3. DBCP moorings action groups: http://www.jcommops.org/dbcp/overview/actiongroups.html
4. DBCP OceanSITES home: http://www.oceansites.org/
5. GO-SHIP home: http://www.go-ship.org/
6. OceanObs'09 FOO: http://www.oceanobs09.net/foo/
7. OSCAR: http://www.wmo-sat.info/oscar/observingrequirements
8. Kent et. al. analysis: http://eprints.soton.ac.uk/50260/

3.8: Surface and Subsurface Ocean Velocity

The ECVs of surface currents and ocean velocity are combined into a single treatment.

A Review of Instruments

Measuring ocean currents is a central component for only two JCOMM programmes. The DBCP surface drifters measure currents in the near surface layer only. OceanSITES moorings often include current meter deployments. Argo floats are also used to infer subsurface currents, but this is an adjunct to their main purpose. Ocean velocity measurements [1] have typically been made with current meters suspended on moorings. Early versions used simple vanes and counting methods, but instrumentation today is all electronic with data being stored on board for retrieval when the mooring is recovered.

ADCPs are also used for ocean current measurements (sometimes in conjunction with CTD measurements). These can operate in a ship mounted operation that in shallow waters can use the ocean bottom as a reference value to remove ship motion. ADCPs are also used in deeper water, where precise ship navigation is needed to remove ship motion from the computation of currents. ADCPs may also be placed on the ocean bottom and look towards the surface.

Ocean currents at depths below the surface can be measured with freely drifting floats. Surface drifting buoys usually have drogues attached so that their drift will represent the water motions at the depth of the drogue, typically at 15m. Argo profilers stay parked typically at 1000m and rise to the surface once every 10 days to report data and then return to their parking depth. The difference in location between successive times at the surface provides some indication of deep currents.

Acoustic tracking of SOFAR or RAFOS floats, maintaining their depth on fixed pressure or density surfaces below the surface can also indicate currents at the levels of operation.

Currents, integrated over the total water column can be measured by undersea cables [2]. Because seawater is an electrical conducting medium, moving sea water induces a small electrical signal in such cables, and by monitoring this, a measure of total integrated current velocity orthogonal to the cable can be measured. These are carried out by different nations, such as the one operated by the U.S.A. to monitor the Florida Current [3], and by Korea in the Korean Strait [4].

Surface currents can also be estimated by arrays of high frequency coastal radars, such as the arrays operating in the southeastern United States documented at http://secoora.org/data/recent_observation_maps/HFRadar.

Calibration is an import aspect of measuring ocean properties. Even though modern, electronic instruments are now the norm, ensuring the stability of the measurements has a strong impact on the quality of the data.

Instrument Characteristics

Current meters operate in a variety of ways. Some use rotors and vanes to measures velocities, others use acoustic techniques.

Monitoring volume transport with submarine cables, is not well documented nor are the data managed by any international archive data system.

The table below provides the nominal characteristics of the different instruments that can be used to measure ocean currents. The uses of data returned from instrumentation is tied to the capabilities of the instrument and methods used. This is a strong reason for data providers and archives to ensure the instrument and its operating characteristics are preserved with the measurements.

Table 1. Nominal instrument characteristics used to measure ocean velocity.

Instrument	Accuracy	Comments
Current meters	±1 cm/s, or 4% ± 0.15 cm/s	rotor and vane acoustic
ADCP	± 0.5 cm/s	
Submarine cables	± 3%	
Surface drifters	Analysis dependent	See [5]
RAFOS, SOFAR (1)	O(3km)	See [6]
Profiling floats	± 0.2 cm/s	See [7]
Coastal radars		

(1) The accuracy value quotes the uncertainty in determining the location of the float to about 3 km. The uncertainty in the estimate of the current depends further on differences in times between locations, and uncertainties in sound speed integrated between the receiver and transmitter.

Data Providers / Observing Systems

The table below provides a list of the sources of ocean velocity data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled “Typical Instruments” and “Typical Sampling” provide some information about the horizontal, vertical and temporal sampling of the system. These are approximate and are to be considered as only an indication of the usual characteristics.

Table 2. Instruments typically used in each observing system that contributes ocean velocity measurements.

Observing System	Typical instrument(s)	Typical Sampling
DBCP surface drifters [8,9]	Tracking trajectories	Positions typically reported 4 times a day widely dispersed in oceans. Rely on drogues to drift with surface currents rather than winds.
DBCP OceanSITES [10]	Current meters	Reference mooring stations sparsely distributed over the oceans. Sample frequently in time, at selected depths with data available only after mooring is recovered.
Argo [11]	Tracking trajectories	Widely distributed in all ice-free oceans with roughly 3x3 degrees (latitude and longitude) separation. Typically drift at 2000m for 10 days.
GO-SHIP [12]	ADCP	Sample along sections, fewer than once a year. Stations are typically widely separated.
National moorings	Current meters	At nationally selected sites. Sampling can be frequent in time, at selected depths with data available sometimes in real-time and sometimes after the mooring is recovered.
National monitoring / research	Current meters ADCP	Some nations maintain a programme of routine collections from traditional moorings or cabled networks or routine ADCP surveys. Volume transport measurements by telephone cable measurements can infer large scale current estimates. Sampling is highly dependent on the programme. Coastal radars also provide nearshore surface current estimates.

Fisheries	ADCP	Surveys are designed to measure fish populations or plankton density. Sampling is highly dependent on the programme.

ADCPs are often used as an adjunct to other measurements, such as XBT surveys near Japan. They are routinely deployed in fisheries research cruises both in coastal and open ocean. Researchers also collect such data for measuring ocean currents.

It is likely that the many ADCP measurements that are made could be combined for use in a comprehensive picture of ocean velocity but this assumes that the operations and data assembly of the ADCP are suitable. In addition, the data assembly, processing and archiving is not well coordinated on an international scale. There is an archive centre [13] but at present there is only some 1500 cruises represented there, and it is not certain how many of these observations could be used to derive sea surface currents.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [14]. The objective was " to develop an integrated framework for sustained ocean observing ..." to "... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...". They agreed that implementation of new systems for EOVs "... will be carried out according to their readiness levels ...". The table that describes this, extracted from that report, follows.

Table 3. FOO readiness levels.

Readiness Level	**Description**	**Data Management and Information Products**
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
Mature 8	Mission qualified	Data availability: globally available Evaluation of utility
Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan
Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance
Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
Concept 2	Documentation	Socialization of data: Interoperability strategy Expert review

Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [15], that is "... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.". OSCAR is a complicated database in that it contains the spatial and temporal sampling requirements as needed by the varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:
uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
availability

Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The rows relevant to ocean current measurements have been extracted from OSCAR, reformatted somewhat and are shown here.

Table 4. OSCAR entries for ocean velocity.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (2) Breakthrough Threshold**	**Vert. Res: Goal (2) Breakthrough Threshold**	**Obs. Cycle: Goal (3) Breakthrough Threshold**	**Availability: Goal (3) Breakthrough Threshold**
Ocean application - coastal applications - Upper ocean	firm	5 cm/s 10 20	1 km 5 20	1 m 10 100	30 m 50 3 h	15 m 60 6 h
Ocean application - offshore applications - Upper ocean	firm	10 cm/s 20 50	1 km 5 20	1 m 10 100	1 h 3 6	1 d 3 30
Ocean application - coastal ocean forecasting - Upper ocean	firm	5 cm/s 10 20	1 km 5 30	1 m 10 50	6 h 24 3 d	1 h 2 3
Ocean application - open ocean forecasting - Upper ocean	firm	10 cm/s 20 50	10 km 50 100	1 m 10 50	6 h 24 3 d	1 h 2 3
Nowcasting - - sea surface	firm	0.5 cm/s 0.6 1.0	10 km 17.1 50	Not applicable	6 h 17.3 6 d	6 h 15.1 4 d
Ocean applications - climate modelling - coast	firm	10 cm/s 20 50	50 km 100 1000	Not applicable	1 d 3 6	24 d 72 2 y

Ocean applications - ocean forecasting - coast	firm	5 cm/s 10 20	1 km 5 10	Not applicable	3 d 12 24	1 d 2 3
Ocean applications - coastal applications - sea surface	firm	5 cm/s 10 20	1 km 5 20	Not applicable	12 h 24 3 d	6 h 14 6 d
Ocean applications - open ocean applications - sea surface	firm	10 cm/s 20 50	50 km 100 1000	Not applicable	1 d 3 6	24 d 72 2 y
Ocean applications - ocean forecasting open ocean - sea surface	firm	10 cm/s 20 50	5 km 10 25	Not applicable	6 d 24 72	1 d 2 3

Notes:
1. Units: cm/s is centimetres per second
2. Units: km is kilometres
m is meters
3. Units: y is years
d is days
h is hours
m is minutes
No units are indicated when there is no difference from the units of the entry immediately above in the table.

Composite View

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The analysis by Kent et. al. [16] discussed in the overview of these chapters on ECVs shows a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to ocean current measurements.

Table 5. Present targets for JCOMM Observing Systems

Observing System	**Present JCOMM Targets**	**Comments**
DBCP surface drifters	1250 buoys deployed 5x5 degree global distribution 1250 with barometers 300 with salinity	Currents at 15m depth are inferred from buoys with drogues attached.
DBCP OceanSITES	29 reference moorings 58 others	At selected sites, 10 in Atlantic, 10 in Pacific, 5 in Indian Oceans.

Argo	3200 floats 3X3 degree sampling Surface to 2000m Report every 10 days	Subsurface trajectories are inferred by differences in times and positions when floats surface. Surface trajectories tracked while at the surface. These are useful additions to Argo but not the main driver in designed the sampling.

JCOMMOPS [17] generates a number of charts and graphs that provide a qualitative way to see if the DBCP surface drifter programme is meeting these simple targets. However, since other programmes do contribute ocean current measurements, a case could be made for assessing how well the other programmes also contribute.

The JCOMMOPS presentations reflect the individual observing system targets, but these are not a perspective that well represents an ECV perspective. This goal is not presently provided at OSMC [18] (Rec 1).

The next table is a qualitative review of the OSCAR application requirements. In most cases the present state of in-situ sampling does fall within OSCAR requirements.

Table 6: A qualitative assessment of application area for ocean velocity measurements.

Application Area **- Comment** **- Layer**	**Uncertainty**	**Horiz. Res**	**Vert. Res**	**Obs. Cycle**	**Timeliness**	**Comments**
Ocean application - coastal applications - Upper ocean	G	L	T-	L	L	It is uncommon to have such high vertical resolution on moorings, but ADCPs can provide such data in a few areas.
Ocean application - offshore applications - Upper ocean	G	L	T-	L	L	It is uncommon to have such high vertical resolution on moorings, but ADCPs can provide such data in a few areas.
Ocean application - coastal ocean forecasting - Upper ocean	G	L	L	L	L	
Ocean application - open ocean forecasting - Upper ocean	G	L	L	L	L	
Nowcasting - - sea surface	T-	L	Not applicable	L	L	Uncertainty targets are only at a moorings.
Ocean applications - climate modelling - coast	G	T	Not applicable	L	L	
Ocean applications - ocean forecasting - coast	G	L	Not applicable	L	L	
Ocean applications - coastal applications - sea surface	G	L	Not applicable	L	L	
Ocean applications - open ocean applications - sea surface	G	T	Not applicable	L	L	
Ocean applications - ocean forecasting open ocean - sea surface	G	L	Not applicable	L	L	

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement. Plus and minus signs indicate if sampling is greater than, or less than that requirement.

The assessment in Table 6 would suggest that for ocean currents, the instrumentation required is mostly available. However, targets are not met for spatial and temporal sampling nor data reporting.

Overall, the observing system with the largest contributions to ocean velocity measurements at the near surface is the surface drifter programme and it is at a FOO readiness level of Mature 8 or 9. However, overall in-situ programmes of this kind are not close to meeting OSCAR targets and there is much more data being collected than is readily available (Rec 2).

Recommendations

Rec 1: The status of the surface drifter programme is well represented at JCOMMOPS. A broader assessment of the state of ocean velocity measurements against ECV targets is provided at http://www.aoml.noaa.gov/phod/soto/gsc/index.php. JCOMMOPS or OSMC should improve their monitoring of surface ocean velocities.

Rec 2: ADCPs are used by many ships and most of these data do not reach international archives. In addition, there is no broadly accepted standards for processing and archiving such data. JCOMM in cooperation with IODE should discuss what can be done to bring these data into a comprehensive archiving system.

Acronyms

ADCP: Acoustic Doppler Current Profiler
DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
OCG: Observations Programme Coordinator
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
RAFOS: equivalent to SOFAR except the floats contain the receivers (hence the reversed letters in the acronym)
SOFAR: Sound Fixing And Ranging (floats)
WMO: World Meteorological Organization
XBT: Expendable Bathythermograph

References

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15. OSCAR: http://www.wmo-sat.info/oscar/observingrequirements
16. Kent et. al. Analysis: http://eprints.soton.ac.uk/50260/
17. JCOMMOPS home: http://wo.jcommops.org/cgi-bin/WebObjects/JCOMMOPS

18. OSMC home: http://www.osmc.noaa.gov/

3.9: pCO_2

A Review of Instruments

References to instrumentation and characteristics is provided by IOCCP [1]. There are different kinds of methods referenced there. The first employs a pumped seawater system with some pretreatment components and an Infrared CO_2 gas analyzer plus gas standards. Another type uses a reagent based colorimetry system. These add known reagents to a seawater sample to react with the CO_2 and then compare the colour detected against known standards. Another technique, built into CARIOCA buoys [2], use a spectrophotometer that determines the pH in a sample of seawater and relates that to pCO_2. Finally, there are NDIR systems that operate by pumping water through a membrane. Dissolved CO_2 molecules diffuse through the membrane into a chamber, where their volume is determined by means of IR absorption spectrometry.

The IOCCP web site provides a description of “standard operating procedures” [3] for measuring pCO_2 in seawater.

Calibration and instrument maintenance is an important aspect of measuring ocean properties. This is particularly true when measuring chemical properties in small quantities.

Instrument Characteristics

The Company LICOR provides an “Application note” [4] that provides a description of the complexities in making pCO_2 measurements at sea.

The table below provides the nominal characteristics of the different instruments that can be used to measure pCO_2 as extracted from instrument fact sheets of manufacturers. Different models have greater or less capabilities than what is recorded here. Because of this, the uses of data returned from instrumentation is at least partly tied to the capabilities of the instrument. This is a strong reason for data providers and archives to ensure the instrument and its operating characteristics are preserved with the measurements.

Table 1. Nominal instrument characteristics used to measure pCO_2.

Instrument	Accuracy	Comments
Infrared gas analyzer	±1 ppm	Care is needed in calibration and operation.
Colorimetry	± 3 ppm	
Spectrophotometer	± 3 ppm	Measures pH to convert to pCO_2
NDIR	~ 1 ppm	

Data Providers / Observing Systems

The table below provides a list of the sources of pCO_2 data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled “Typical Instruments” and “Typical Sampling” provide some information about the horizontal, vertical and temporal sampling of the system. These are approximate and are to be considered as only an indication of the usual characteristics.

Table 2. Instruments typically used in each observing system that contributes pCO_2 measurements.

Observing System	Typical instrument(s)	Typical Sampling
SOT SOOP [5]	WMO approved	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation. Report at main synoptic times or better.
SOT VOS [6]	WMO approved	Sample along ships routes
SOOP underway [7]	WMO approved	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation. Report at main synoptic times or better.
DBCP OceanSITES [8]	Varied	Reference mooring stations sparsely distributed over the oceans. Sample frequently in time and from surface to bottom.
GO-SHIP [9]	Varied	Sample along sections, fewer than once a year. Stations are typically widely separated. Sample from top to bottom.
IOCCP [10]	Varied	Same as GO-SHIP.
National monitoring / research	Varied	Nations conduct their own programmes [e.g. [11]). Sampling is highly dependent on the programme.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [12]. The objective was " to develop an integrated framework for sustained ocean observing ..." to "... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...". They agreed that implementation of new systems for EOVs "... will be carried out according to their readiness levels ...". The table that describes this, extracted from that report, follows.

Table 3. FOO readiness levels.

Readiness Level	Description	Data Management and Information Products
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
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Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan

Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance
Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
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Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [13], that is "... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.". OSCAR is a complicated database in that it contains the spatial and temporal sampling requirements as needed by the varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:
uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
availability

Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The row relevant to pCO_2 has been extracted from OSCAR, reformatted somewhat and are shown here.

Table 4. OSCAR entries for pCO_2

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal Breakthrough Threshold**	**Horiz. Res: Goal (1) Breakthrough Threshold**	**Vert. Res: Goal Breakthrough Threshold**	**Obs. Cycle: Goal (2) Breakthrough Threshold**	**Availability: Goal (2) Breakthrough Threshold**
Climate-OOPC - - sea surface	reasonable	1 microatom 1.5 3	5 km 10 50	Not applicable	1 h 3 30	30 d 70 360

Notes:
1. Units: km is kilometres
2. Units: d is days
h is hours
No units are indicated when there is no difference from the units of the entry immediately above in the table.

It should be noted that JCOMM and national programmes often carry out sampling with ships traversing sections or with moorings. The measurements may be contributed to JCOMM, though not always, but their purpose is to monitor processes. The requirements in the above table do not properly reflect this sampling strategy except if the requirements are interpreted to apply to how data are collected along a section. For example, GO-SHIP vessels sample at roughly 50 km station separation which meets the threshold for horizontal resolution. However, this is only true along the section. If the entries in the table are interpreted to be horizontal resolution over the whole ocean, GO-SHIP would not achieve even the threshold.

Composite View

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The analysis by Kent et. al. [14] discussed in the overview of these chapters on ECVs shows a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to pCO_2 measurements.

Table 5. Present targets for JCOMM Observing Systems

Observing System	**Present JCOMM Targets**	**Comments**
SOT SOOP	37,000 XBTs deployed 26 High density lines (HDX) 25 Frequently repeated lines (FRX)	All carried out on selected lines to meet specific scientific objectives. HDX lines sampled 4 times a year, with 10-20 km between stations. FRX lines sampled 20 repeats a year with 50-100 km between stations.
SOT VOS	3000 active ships 500 AWS 250 VOSClim	Active ships provide more than 20 reports/month.
SOOP underway	No specified requirements	
DBCP OceanSITES	29 reference moorings 58 others	At selected sites, 10 in Atlantic, 10 in Pacific, 5 in Indian Oceans.
GO-SHIP	Selected WOCE lines Repeated each decade (or better) Surface to bottom at 5m resolution or better	Network encompasses fewer lines than WOCE.
IOCCP	37 carbon survey	A new group is forming as a Carbon SOOP. Otherwise, data are collected by GO-SHIP.

There is no monitoring of pCO_2 measurements undertaken by JCOMMOPS. At OSMC [15] there is provision to view sampling of the fugacity of CO_2 in seawater, but no data appear when this parameter is selected on the Observing System Monitoring page. On the Observing System Monitoring page, there is no selection available for pCO_2. That no data appear on the page related to in-situ monitoring reflects the fact that such data are just not available in real-time (a query for data from the start of 2013 to mid August of that year also returned no data). However, there could be a presentation on the Monitoring page if connections were made to IOCCP (Rec 1).

The next table is a qualitative review of the OSCAR application requirements. The present state of in-situ sampling does fall within OSCAR requirements.

Table 6: A qualitative assessment of application area for pCO_2 measurements.

Application Area - Comment - Layer	Uncertainty	Horiz. Res	Vert. Res	Obs. Cycle	Timeliness	Comments
Climate-OOPC - - sea surface	T	T	Not applicable	G	L	

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement.

The assessment in Table 6 would suggest that the instrumentation required to meet the threshold and perhaps better is available. The spatial sampling is generally close to Threshold, but this is qualified with sampling being along selected sections and at moorings. The goal can be met for observing cycle, but again only if considered at selected sections and locations. The availability is below requirements, but this perhaps can be improved (Rec 2).

Overall, the observing systems with the largest contributions to pCO_2 measurements are SOOP, VOS and OceanSITES. These programmes are in the Mature level of FOO, but access to the data of this ECV is more in the Pilot range of readiness.

Recommendations

Rec 1: OSMC should make connections to the pCO_2 data available at IOCCP so that this ECV could be queried on the Observing System Monitoring page.

Rec 2: Making data available more quickly to the public is an objective that should be pursued. This would enhance monitoring (noted in Rec 1) and generally improve access to data.

Acronyms

CARIOCA: Carbon Interface Ocean Atmosphere
DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
IOCCP: International Ocean Carbon Coordination Project
IR: Infrared
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
NDIR: Non-dispersive, Infrared absorption spectrometry
OCG: Observations Programme Coordinator
OOPC: Ocean Observations Panel for Climate
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
pCO_2: partial pressure of CO_2
SOOP: Ship Of Opportunity Programme
VOS: Volunteer Observing Ship
WOCE: World Ocean Circulation Experiment
WMO: World Meteorological Organization
XBT: Expendable Bathythermograph

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3.10: Ocean Salinity

A Review of Instruments

Measurement of salinity profiles in the ocean in the early years was confined to capturing sea water samples in water bottles suspended from cables from ships. Salinity was determined through chemical analysis of the water samples. With the development of conductivity methods for measuring salinity it became not only faster but possible to acquire much more data at much higher vertical resolution than could ever be achieved using water bottles.

With the development of the CTD, it became routine to collect simultaneous measurements of temperature and salinity at 1 or 2 m intervals from the surface to depth. Acquisition is still constrained by the time it takes to lower and raise an instrument from the surface to the bottom, but this is much faster than collecting water samples and provides much higher vertical resolution.

Using a CTD to derive salinity operates by measuring conductivity, temperature and pressure. Conductivity is converted to salinity through a conversion formula. Pressure may be converted to depth through the hydrostatic equation. It is common to leave vertical units as pressure and so users find both pressure and depth in archives. Conductivity is measured through a resistance measurement as seawater passes through a conductivity cell. But another method, using inductance, has also be devised and is used in XCTDs. CTDs can now be lowered while a ship is stationary, or while moving, using what is known as a MVP. CTDs are also deployed on moorings sometimes with an instrument that crawls up a mooring line, making temperature and salinity measurements along the way.

Measurements of upper ocean (the upper 2000m) salinity profiles have increased hugely since WOCE. The WOCE saw the first broad scale use of profiling float technology. These are instruments that can be deployed from a ship, and operate autonomously until their batteries are exhausted. They adjust their buoyancy so that they can submerge, typically to 2000m, then regularly rise to the surface, sampling temperature and salinity with a CTD at roughly 70 depths (more near the surface, less at depth). Data are reported through satellite communications systems. The Argo programme was developed as an international effort to routinely sample the upper ocean with such technology and since its beginning in the early 2000's, more measurements of temperature and salinity in the upper ocean have been made than all previous observations in historical archives.

Undulating instruments, such as gliders, can also provide salinity measurements using CTDs. The accuracy of these are dependent on the model of CTD and some of the post processing. The same comments could be made of the CTDs mounted on marine mammals.

Upper ocean salinities can also be measured using conductivity cells mounted on wires suspended below a mooring, sometimes below a surface drifter, and these also report typically through satellite communications systems. Again these measurements are commonly associated with temperature measurements.

Measuring salinity in the deep ocean is still confined to lowering instruments from ships at sea. Typically, such measurements, say to 4000m, can take more than an hour to complete. Operating ships is expensive and this is one reason that the number of deep ocean measurements is relatively few. Companies are testing a deep ocean profiling float, one that can withstand the increased pressure needed to sample the full water column in mid ocean.

Calibration is an import aspect of measuring ocean properties. Even though modern, electronic instruments are now the norm, ensuring the stability of the measurements has a strong impact on the quality of the data. In particular, conductivity cells can become fouled with use and should be calibrated regularly. Usually this is done by collecting water samples at selected depths, and comparing salinities derived from a laboratory analysis of the water sample against the salinity measured by the CTD while in use. Laboratory equipment is usually calibrated against a standard seawater sample [1] to ensure stability over time.

A variety of salinity scales have been used over the years. In 1978 IOC adopted the Practical Salinity Scale, based on the recommendations of a joint UNESCO, ICES, SCOR and IAPSO panel report [2]. A more recent analysis has developed an absolute salinity scale based on the equation of state for seawater [3].

Instrument Characteristics

A very nice compendium of instrument operating characteristics is provided by Boyer et. al. [4] in discussing the data that appear in the WODB-2009. The table below provides the nominal characteristics of the different instruments that can be used to measure salinity as extracted from Boyer et. al. However, there is no discussion of how to estimate the accuracy of the early chemical determinations of salinity. A skilled technician could make highly accurate determinations of chlorosity and through a conversion formula (that did alter over time) could produce salinity measurements with accuracies that rival conductivity measurements of today. There is no easy way to estimate such an accuracy, so the values quoted for CTDs as used on profiling floats is used.

Different models or electronics have greater or lesser capabilities than what is recorded here. Because of this, the uses of data returned from instrumentation is at least partly tied to the capabilities of the instrument. This is a strong reason for data providers and archives to ensure the instrument and its operating characteristics are preserved with the measurements.

Table 1. Nominal instrument characteristics used to measure salinity.

Instrument	**Accuracy**	**Comments**
Chemical analysis	±0.002 PSU	Higher or lower accuracies are possible depending on the abilities of the technician doing the analysis.
CTD	±0.005 PSU	For profiling floats. Higher and lower accuracies exist depending on the CTD model.
XCTD	±0.05 PSU	

Data Providers / Observing Systems

The table below provides a list of the sources of salinity profile data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled “Typical Instruments” and “Typical Sampling” provide some information about the horizontal, vertical and temporal sampling of the system. These are approximate and are to be considered as only an indication of the usual characteristics.

Table 2. Instruments typically used in each observing system that contributes water temperature measurements.

Observing System	**Typical instrument(s)**	**Typical Sampling**
SOOP [5]	XCTD	Sample along sections but used much less frequently than XBTs.
DBCP moorings [6]	Conductivity cells on thermistor chains	Sample typically in tropics, once a day but some hourly. Some have sampled from surface to 500m with 5-10 measurements in a profile.
DBCP OceanSITES [7]	CTD Chemical analysis	Reference mooring stations sparsely distributed over the oceans. Sample frequently in time and from surface to bottom.
Argo [8]	CTD	Widely distributed in all ice-free oceans with roughly 3x3 degrees (latitude and longitude) separation. Typically sample to 2000m at 70+ levels every 10 days.

GO-SHIP [9]	CTD Chemical analysis	Sample along sections, fewer than once a year. Stations are typically widely separated. Sample fro top to bottom, at 1-2m intervals.
IOCCP [10]	CTD Chemical analysis	Same as GO-SHIP.
Marine mammals	CTD	Locations and times dependent on animals used. Typically sample in top 1000m at 20 levels.
Fisheries	CDT	Often in random sampling patterns with sometimes 10's of km separation between stations. Typically sample on continental shelves at 1m intervals. Often measure salinity at the openings of towed nets.
Gliders	CTD	Sparse sampling in oceans. Typically the deepest sample is from 100-1000m at 1m intervals.
National moorings	CTD	At nationally selected sites, usually on coastal shelves or slopes. Sampling can be hourly or better, but highly dependent on the programme.
National monitoring / research /hydrography	CTD Chemical analysis MVP	A few Ocean Weather Stations still exist, and nations maintain a few locations that are sampled routinely, usually on shelves. Sampling is highly dependent on the programme.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [11]. The objective was “ to develop an integrated framework for sustained ocean observing ...” to “... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...”. They agreed that implementation of new systems for EOVs “... will be carried out according to their readiness levels ...”. The table that describes this, extracted from that report, follows.

Table 3. FOO readiness levels.

Readiness Level	**Description**	**Data Management and Information Products**
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
Mature 8	Mission qualified	Data availability: globally available Evaluation of utility
Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan

Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance
Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
Concept 2	Documentation	Socialization of data: Interoperability strategy Expert review
Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [13], that is "... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.". OSCAR is a complicated database in that it contains the spatial and temporal sampling requirements as needed by the varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:

uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
availability

Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The rows relevant to salinity have been extracted from OSCAR, reformatted somewhat and are shown here.

Table 4. OSCAR entries for salinity.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (2) Breakthrough Threshold**	**Vert. Res: Goal (2) Breakthrough Threshold**	**Obs. Cycle: Goal (3) Breakthrough Threshold**	**Availability: Goal (3) Breakthrough Threshold**
Climate-OOPC - - deep ocean	reasonable	0.002 psu 0.003 0.005	50 km 60 100	2 m 2.5 4	30 d 70 360	4.8 d 110 360
Climate-OOPC - - upper ocean	reasonable	0.001 psu 0.002 0.01	15 km 40 300	1 m 2 10	1 d 2 10	30 m 36 60
Global NWP - - upper ocean	tentative	0.1 psu 0.2 0.3	5 km 100 250	1 m 2 10	1 d 30 60	3 h 24 5 d

Ocean applications - marine modelling - upper ocean	firm	0.05 psu 0.07 0.01	1 km 5 30	1 m 10 100	1 h 3 12	3 h 6 24
Ocean applications - climate modelling offshore - upper ocean	firm	0.05 psu 0.07 0.01	50 km 100 1000	1 m 10 100	1 h 3 12	1 d 3 30
Ocean applications - ocean forecasting coastal - upper ocean	firm	0.05 psu 0.07 0.01	1 km 5 30	1 m 10 50	6 h 24 3 d	2.5 d 5 7.5
Ocean applications - ocean forecasting open ocean - upper ocean	firm	0.05 psu 0.07 0.01	10 km 50 100	1 m 10 50	6 h 24 3 d	2.5 d 5 7.5

Notes:
1. Units: psu is Practical Salinity Unit
2. Units: km is kilometres
m is meters
3. Units: y is years
d is days
h is hours
m is minutes
No units are indicated when there is no difference from the units of the entry immediately above in the table.

It should be noted that national programmes often carry out sampling by ships along sections. The measurements may well be contributed to JCOMM, though not always, but their purpose is to monitor processes through these sections. Indeed the GO-SHIP programme, is focused on sampling along sections rather than broad scale for precisely this reason. The requirements in the above table do not properly reflect this focus, except if the requirements are interpreted to apply to how data are collected along the section. For example, GO-SHIP vessels sample at roughly 50 km station separation, and 1 m vertical resolution, which meets the goal for horizontal and vertical resolution. However, this is only true along the section. If the entries in the table are interpreted to be horizontal and vertical resolution over the whole ocean, GO-SHIP would not achieve even the threshold.

Composite View

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The analysis by Kent et. al. [13] discussed in the overview of these chapters on ECVs shows a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to salinity measurements.

Table 5. Present targets for JCOMM Observing Systems

Observing System	Present JCOMM Targets	Comments
SOOP	37,000 XBTs deployed 26 High density lines (HDX) 25 Frequently repeated lines (FRX)	All carried out on selected lines to meet specific scientific objectives. HDX lines sampled 4 times a year, with 10-20 km between stations. FRX lines sampled 20 repeats a year with 50-100 km between stations.
DBCP moorings	131 moorings Topical oceans	Coastal moorings are deployed with national discretion. Tsunami buoys are in another IOC programme.
DBCP OceanSITES	29 reference moorings 58 others	At selected sites, 10 in Atlantic, 10 in Pacific, 5 in Indian Oceans.
Argo	3200 floats 3X3 degree sampling Surface to 2000m Report every 10 days	Between 60N and 60S in open ocean. A new target design is being developed.
GO-SHIP	Selected WOCE lines Repeated each decade (or better) Surface to bottom at 5m resolution or better	Network encompasses fewer lines than WOCE.
IOCCP	37 carbon survey	A new group is forming as a Carbon SOOP. Otherwise, data are collected by GO-SHIP.

JCOMMOPS [14] generates a number of charts and graphs that provide a qualitative way to see if certain of the observing systems are meeting these simple targets. For example, Argo pages provide maps showing the number of active floats and their latest reported positions. Similar displays are available for SOT. However, not all JCOMM programmes have displays that easily summarize the status of the programme (Rec 1).

The JCOMMOPS presentations reflect the individual observing system targets, but these are not a perspective that well represents an ECV perspective. A start towards this goal is provided at OSMC [15]. At this site and at the “Observing System Metrics tab, a user can select a parameter, a time frame and either one or all platforms. A further selection of gridding, and display presents a map that portrays the composite view, or individual platform view. There are some weaknesses to this display (Rec 2), but it is working towards the right goal. One notable lack is that a user cannot plug in the OSCAR requirements for any particular application area, as shown in table 4. But considering the present state of in-situ sampling, this “lack” is sensible and pragmatic, as is discussed below.

The next table is a qualitative review of the OSCAR application requirements.

Table 6: A qualitative assessment of application area for salinity measurements.

Application Area - Comment - Layer	Uncertainty	Horiz. Res	Vert. Res	Obs. Cycle	Timeliness	Comments
Climate-OOPC - - deep ocean	G	G	G	L	T-	Along lines only. Observing cycle is at best 3 years. Timeliness often falls below.
Climate-OOPC - - upper ocean	G	T	T-	T	G	Vert. Res. better near surface, below in deeper waters.

Global NWP - - upper ocean	G	T-	T	B+	B	Vert. Res. better near surface, below in deeper waters.
Ocean applications - marine modelling - upper ocean	G	L	T+	L	T+	Vert. Res. is better than Threshold, less than Breakthrough
Ocean applications - climate modelling offshore - upper ocean	G	T+	T+	L	G	Horiz., Vert. Res. are better than Threshold, less than Breakthrough
Ocean applications - ocean forecasting coastal - upper ocean	G	L	T+	B	G	Vert. Res. is better than Threshold, less than Breakthrough
Ocean applications - ocean forecasting open ocean - upper ocean	G	L	T+	B	G	Vert. Res. is better than Threshold, less than Breakthrough

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement. Plus and minus signs indicate if current sampling is greater than, or less than that requirement.

The assessment in Table 6 would suggest that for salinity, the instrumentation required is available. The very high accuracy required for deep and upper ocean measurements are achievable now, but only on the sections. the same is true for the spatial sampling. The ranking here is based on what is achievable on GO-SHIP and IOCCP cruises. The spatial sampling is generally close to Threshold in the vertical, but weaker in the horizontal. Achieving even the Threshold targets for observing cycle is difficult. Timeliness is generally good.

Overall, the observing systems with the largest contributions to salinity measurements is Argo and is at a FOO readiness level of Mature 8. It might be considered at level 9 except that many of the present programmes are significantly dependent on research funding which means that funding is less secure than if a programme was on long term funding.

Recommendations

Rec 1: Each of the formal JCOMM programmes should provide simple displays on their home web pages that articulate as precisely as possible the observing targets, and show how well these targets are being met. Examples to emulate would be those provided by Argo and SOT.

Rec 2: The displays allow a gridding in terms of latitude and longitude squares. The OSCAR requirements are set by units of meters (and kilometers). Also there are many different horizontal resolution requirements in OSCAR than are possible to specify at OSMC. Given the state of in-situ sampling, it is reasonable that all scales are not supported. However, a gridding based on meters / kilometers should be presented rather than degrees of latitude and longitude.

Acronyms

CTD: Conductivity Temperature Depth
DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
IAPSO: International Association for the Physical Sciences of the Oceans
ICES: International Council for the Exploration of the Sea
IOC: Intergovernmental Oceanographic Commission
IOCCP: International Ocean Carbon Coordination Project
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
MVP: Moving Vessel Profiler
NWP: Numerical Weather Prediction

OCG: Observations Programme Coordinator
OOPC: Ocean Observations Panel for Climate
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
PSU or psu: Practical Salinity Scale
SCOR: Scientific Committee on Ocean Research
SOOP: Ship Of Opportunity Programme
SOT: Ship Observations Team
UNESCO: United Nations Educational, Scientific and Cultural Organization
WMO: World Meteorological Organization
WOCE: World Ocean Circulation Experiment
WODB: World Ocean Data Base
XBT: Expendable Bathythermograph
XCTD: Expendable Conductivity Temperature Depth

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15. OSMC home: http://www.osmc.noaa.gov/

3.11: Sea Level

A Review of Instruments

Early water level measurements were made by reading measurements at regular intervals from a calibrated pole stuck in the bottom [1]. Some such measurements exist in national archives from the late 19th century. Later, measurements were collected manually to record times and heights of high and low water. Measurement technology progressed to placing floats on a pulley mechanism, placed inside a well and secured to a dock. The well dampened wave action. Measurements were recorded mechanically by pen on a chart on a rotating drum and had to be digitized manually. Today, there is a wide variety of technologies used [2] to measure water levels including bottom pressure gauges, radar, acoustic as well as floats. Bubbler systems are of note since these allow the operation of gauges in cold conditions where ice formation would stop the gauges from reliable recording. All of these record data in digital form.

The sampling intervals for water level data has progressed from times and heights of high and low water, to every 6 hours, every 3 hours and now the international archives hold hourly values, typically. Modern digital gauges are capable of much higher sampling rates, such as 15 minutes, 6 minutes, 1 minute and better. The DART gauges used in the tsunami warning system, can adjust their sampling to continuous mode if a possible tsunami is detected.

National tide gauges are leveled into a national benchmark system that allows comparison of sea level readings from gauges adjacent to each other. In the past, these national systems were not referenced across borders, which made comparisons of data difficult. This has changed so that this issue is largely taken care of.

Modern gauges are often capable of recording measurements of other physical variables such as air pressure, and water temperature and salinity. In addition, some gauges have been sited near 3-D GPS instruments that measure movements of the earth which are relevant to studies of long term trends in sea level.

Instrument Characteristics

A quick review of manufacturers of water level instruments [2] provides the following operating characteristics for the different kinds of gauges. Different models or electronics have greater or less capabilities than what is recorded here. This is a strong reason for data providers and archives to ensure the instrument and its operating characteristics are preserved with the measurements.

Table 1. Nominal instrument characteristics used to measure water level.

Instrument	**Accuracy**	**Comments**
Floats	± 0.02 full scale	Higher or lower accuracies are possible depending on the instrument model.
Pressure gauges	± 0.02 full scale, ± 3cm	For open ocean deployments, such as DART buoys. Coastal deployments can have higher accuracy.
Bubblers	± 3cm	Depends on instrument model.
Radar	± 1cm	Depends on instrument model.
Acoustic	± 1cm	Depends on instrument model.

Data Providers / Observing Systems

The table below provides a list of the sources of water level data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled “Typical Instruments” and “Typical Sampling” provide some information about the observing system. These are approximate and are to be considered as only an indication of the usual characteristics.

Table 2. Instruments typically used in each observing system that contributes water level measurements.

Observing System	Typical instrument(s)	Typical Sampling
GLOSS [3]	Varied	Depends on national contributions.
DBCP moorings [4]	Pressure gauges	Sample typically in tropics, once a day but some hourly. Some sample from surface to 500m with 5-10 measurements in a profile.
DBCP OceanSITES [5]	Pressure gauges	Reference mooring stations sparsely distributed over the oceans.
National moorings	Varied	At nationally selected sites. Sampling can be hourly or better, but highly dependent on the programme.
National monitoring / research	Varied	Besides other research programmes, this would include pressure gauges operating as part of cabled networks such as the Ocean Observatories Initiative, or Neptune.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [6]. The objective was “ to develop an integrated framework for sustained ocean observing ...” to “... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...”. They agreed that implementation of new systems for EOVs “... will be carried out according to their readiness levels ...”. The table that describes this, extracted from that report, follows.

Table 3. FOO readiness levels.

Readiness Level	Description	Data Management and Information Products
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
Mature 8	Mission qualified	Data availability: globally available Evaluation of utility
Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan
Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance

Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
Concept 2	Documentation	Socialization of data: Interoperability strategy Expert review
Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [7], that is "... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.". OSCAR is a complicated database in that it contains the spatial and temporal sampling requirements as needed by the varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:
uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
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Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The row relevant to sea level measurements have been extracted from OSCAR, reformatted somewhat and is shown here.

Table 4. OSCAR entries for water level.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (1) Breakthrough Threshold**	**Vert. Res: Goal Breakthrough Threshold**	**Obs. Cycle: Goal (2) Breakthrough Threshold**	**Availability: Goal (2) Breakthrough Threshold**
Climate-OOPC - - coast	reasonable	1 cm 2 10	25 km 100 1000	Not applicable	1 d 2.1 10	1 h 3 h 24

Notes:
1. Units: km is kilometres
cm is centimetres
2. Units: d is days
h is hours
No units are indicated when there is no difference from the units of the entry immediately above in the table.

There is no capability at present at the GLOSS web site nor anywhere else to assess in any easy way the availability of data in terms of the OSCAR requirements (Rec 1).

Composite View

The principle observing system for water level is the GLOSS. They specify a Global Core Network of 290 stations. Of this set, though, data reporting requirements are "liberal" in that often very long delays are allowed.

At the UHSLC [8] can be found more than 280 stations for which data are available within 1 to 2 months of acquisition, although some appear much sooner than that. BODC [9] operates the international archive for sea level data that provides data with longer delays.

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The analysis by Kent et. al. [10] discussed in the overview of these chapters on ECVs shows a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to sea level measurements.

Table 5: A qualitative assessment of application area for salinity measurements.

Application Area **- Comment** **- Layer**	**Uncertainty**	**Horiz. Res**	**Vert. Res**	**Obs. Cycle**	**Timeliness**	**Comments**
Climate-OOPC - - coast	T+	T	Not applicable	G	L	While gauges sample fast enough to meet observing cycle needs, reporting is much too slow in almost all cases (though DART/TIP gauges do achieve G.

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement. Plus and minus signs indicate if current sampling is greater than, or less than that requirement.

The assessment in Table 5 would suggest that water level instrumentation is capable of meeting Threshold criteria, though data reporting is mostly too slow (Rec 1). Only the DART and TIP type moorings report data quickly enough to meet timeliness criteria.

The observing systems with the largest contributions to water level is GLOSS and these measurements are at a FOO readiness level of Mature 8.

With the combination of altimeter and gravity missions of satellites, in combination with sea level gauges co-located with 3-D GPS, and Argo floats, it is possible to arrive at very accurate global assessments of sea level.

Recommendations

Rec 1: It is recommended that either GLOSS or JCOMM OCG develop an automated way to allow the assessment of water level reporting in line with OSCAR requirements. It may be that the on-line reporting system of IODE (see the chapter in this report on GLOSS) can assist or provide inspiration.

Rec 2: Data coming from the GLOSS network, particularly to GCN gauges need to greatly improve their timeliness. It is recommended that this be a top priority for GLOSS.

Acronyms

BODC: British Oceanographic Data Centre
DART: Deep-ocean Assessment and Reporting of Tsunamis
DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing

GCN: GLOSS Core Network
GLOSS: Global Sea Level Observing System
GPS: Global Positioning System
IODE: International Data and information Exchange Committee
JCOMM: Joint Commission on Oceanography and Marine Meteorology
OCG: Observations Programme Coordinator
OOPC: Ocean Observations Panel for Climate
OSCAR: Observing Systems Capability Analysis and Review (tool)
TIP: Tropical Moored Buoy Implementation Panel
UHSLC: University of Hawaii Sea Level Center
WMO: World Meteorological Organization

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3.12: Sea Surface Salinity

A Review of Instruments

Measurement of sea surface salinity in the ocean in the early years was confined to capturing surface sea water samples in buckets or from water bottles suspended from cables from ships. Salinity was determined through chemical analysis of the water samples. With the development of conductivity methods for measuring salinity it became not only faster but possible to acquire much more data at much higher horizontal resolution than could ever be achieved otherwise.

With the development of the CTD, it became routine to collect simultaneous measurements of temperature and salinity in the water column. Surface measurements are usually collected whenever profiles are measured. Using a CTD to derive salinity operates by measuring conductivity, temperature and, typically, pressure. Conductivity is converted to salinity through a conversion formula. Pressure may be converted to depth through the hydrostatic equation. It is common to leave vertical units as pressure and so users can find both in archives. At first, conductivity was measured through a resistance measurement as seawater passed through a conductivity cell. This is still the most common way. But a method using inductance has also be devised and is used in XCTDs. CTDs can now be lowered while a ship is stationary, or while moving, using what is known as a MVP. CTDs are also deployed on moorings sometimes with an instrument that crawls up a mooring line, making temperature and salinity measurements along the way.

Measurements of upper ocean (the upper 2000m) profiles and surface salinity have increased hugely since WOCE. The WOCE saw the first broad scale use of profiling float technology. These are instruments that can be deployed from a ship, and operate autonomously until their batteries are exhausted. They adjust their buoyancy so that they can submerge, typically to 2000m, then regularly rise to the surface, sampling temperature and salinity, with a CTD, at roughly 70 depths (more near the surface, less at depth). Data are reported through satellite communications systems. The Argo programme was developed as an international effort to routinely sample the upper ocean with such technology and since its beginning in the early 2000's, more measurements of temperature and salinity in the upper ocean have been made than all previous data in historical archives. Surface salinity measurements from profiling floats have special considerations in that the water pump for the conductivity cell is often turned off close to the surface so that surface debris does not enter the cell and contaminate it. The assumption is that the cell flushes sufficiently from upward motion so that a surface reading is reliable.

Undulating instruments, such as gliders, can also provide salinity measurements using CTDs. The accuracy of these are dependent on the model of CTD and some of the post processing. The same comments could be made of the CTDs mounted on marine mammals.

Upper ocean and surface salinities can also be measured using conductivity cells mounted on wires suspended below a mooring, sometimes below a surface drifter, and these also report typically through satellite communications systems. Again these measurements are commonly associated with temperature measurements.

Since the 1990's, thermosalinographs, TSGs, have been used to measure surface salinity. These devices sample water pumped in through a seawater intake system that is afterwards used for ships cooling. Fouling concerns and bubbles are an important factor in such systems, and constant maintenance is needed to ensure reliable measurements.

Calibration is an import aspect of measuring ocean properties. Even though modern, electronic instruments are now the norm, ensuring the stability of the measurements has a strong impact on the quality of the data. In particular, conductivity cells can become fouled with use and should be calibrated regularly. Usually this is done by collecting water samples and comparing salinities derived from a laboratory analysis of the water sample against the salinity measured by the CTD while in use. Laboratory equipment is usually calibrated against a standard seawater sample [1] to ensure stability over time.

A variety of salinity scales have been used over the years. In 1978 IOC adopted the Practical Salinity Scale, based on the recommendations of a joint UNESCO, ICES, SCOR and IAPSO panel report [2]. A more recent analysis has developed an absolute salinity scale based on the equation of state for seawater [3].

Instrument Characteristics

A very nice compendium of instrument operating characteristics is provided by Boyer et. al. [4] in discussing the data that appear in the WODB-2009. The table below provides the nominal characteristics of the different instruments that can be used to measure salinity as extracted from Boyer et. al. However, there is no discussion of how to estimate the accuracy of the early chemical determinations of salinity. A skilled technician could make highly accurate determinations of chlorosity and through a conversion formula (that did alter over time) could produce salinity measurements with accuracies that rival conductivity measurements of today. There is no easy way to estimate such an accuracy, so the values quoted for CTDs as used on profiling floats is used.

Different models or electronics have greater or less capabilities than what is recorded here. Because of this, the uses of data returned from instrumentation is at least partly tied to the capabilities of the instrument. This is a strong reason for data providers and archives to ensure the instrument and its operating characteristics are preserved with the measurements.

Table 1. Nominal instrument characteristics used to measure salinity.

Instrument	**Accuracy**	**Comments**
Chemical analysis	±0.1 PSU	Higher or lower accuracies are possible depending on the abilities of the technician doing the analysis.
CTD	±0.005 PSU	For profiling floats. Higher and lower accuracies exist depending on the CTD model. TSG data often are not as accurate.
XCTD	±0.05 PSU	
TSG	±0.005 PSU	Instruments are capable of this, but maintenance and calibration are very important to ensure reliability. This value is likely unrealistic.

Data Providers / Observing Systems

The table below provides a list of the sources of surface salinity data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled “Typical Instruments” and “Typical Sampling” provide some information about the horizontal, vertical and temporal sampling of the system. These are approximate and are to be considered as only an indication of the usual characteristics.

Table 2. Instruments typically used in each observing system that contributes surface salinity measurements.

Observing System	**Typical instrument(s)**	**Typical Sampling**
SOT SOOP [5]	XCTD	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation. Report at main synoptic times or better.
SOT SOOP underway [6]	CTD (TSG)	Sample along sections, as often as bi-weekly, but more often quarterly. Samples collected at surface every 1 minute or better. Report at main synoptic times or better.

DBCP moorings [7]	Conductivity cells on thermistor chains	Sample typically in tropics, once a day but some hourly. Some sample from surface to 500m with 5-10 measurements in a profile. Salinity measurements are rare.
DBCP OceanSITES [8]	CTD Chemical analysis	Reference mooring stations sparsely distributed over the oceans. Sample frequently in time and from surface to bottom.
Argo [9]	CTD	Widely distributed in all ice-free oceans with roughly 3x3 degrees (latitude and longitude) separation. Typically sample to 2000m at 70+ levels every 10 days. Conductivity cell pump shuts off within 5m of surface.
GO-SHIP [10]	CTD Chemical analysis	Sample along sections, fewer than once a year. Stations are typically widely separated. Sample fro top to bottom, at 1-2m intervals.
IOCCP [11]	CTD Chemical analysis	Same as GO-SHIP
Marine mammals	CTD	Locations and times dependent on animals used. Typically sample in top 1000m at 20 levels.
Fisheries	CDT	Often in random sampling patterns with sometimes 10's of km separation between stations. Typically sample on continental shelves at 1m intervals. Often measure salinity at the openings of towed nets.
Gliders	CTD	Sparse sampling in oceans. Typically the deepest sample is from 100-1000m at 1m intervals.
National moorings	CTD	At nationally selected sites, usually on coastal shelves or slopes. Sampling can be hourly or better, but highly dependent on the programme.
National monitoring / research	CTD Chemical analysis	A few Ocean Weather Stations still exist, and nations maintain a few locations that are sampled routinely, usually on shelves. Sampling is highly dependent on the programme.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [12]. The objective was “ to develop an integrated framework for sustained ocean observing ...” to “... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...”. They agreed that implementation of new systems for EOVs “... will be carried out according to their readiness levels ...”. The table that describes this, extracted from that report follows.

Table 3. FOO readiness levels.

Readiness Level	**Description**	**Data Management and Information Products**
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
Mature 8	Mission qualified	Data availability: globally available Evaluation of utility

Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan
Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance
Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
Concept 2	Documentation	Socialization of data: Interoperability strategy Expert review
Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [12], that is ”... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.”. OSCAR is a complicated database in that it contains the spatial and temporal sampling requirements as needed by the varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:
uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
availability

Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The rows relevant to surface salinity have been extracted from OSCAR, reformatted somewhat and are shown here.

Table 4. OSCAR entries for surface salinity.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (2) Breakthrough Threshold**	**Vert. Res: Goal Breakthrough Threshold**	**Obs. Cycle: Goal (3) Breakthrough Threshold**	**Availability: Goal (3) Breakthrough Threshold**
Climate-GOOS - - sea surface	firm	0.1 psu 0.2 1	200 km 271.4 500	Not applicable	10 d 14.4 30	10 d 14.4 30
Climate-OOPC - - sea surface	firm	0.05 psu 0.1 0.3	100 km 170 500	Not applicable	7 d 11 30	10 d 15 30
CLIVAR - - sea surface	reasonable	0.1 psu 0.2 0.3	100 km 150 250	Not applicable	30 d 45 60	9 d 30 120
Global NWP - - sea surface	reasonable	0.1 psu 0.2 0.3	5 km 100 250	Not applicable	1 d 30 60	3 d 24 120
Ocean applications - marine modelling - sea surface	firm	0.05 psu 0.07 0.1	1 km 5 30	Not applicable	12 h 24 6 d	1 d 6 24
Ocean applications - ocean forecasting open ocean - sea surface	firm	0.05 psu 0.07 0.1	5 km 10 25	Not applicable	6 h 24 72	1 d 2 3
Ocean applications - climate modelling offshore -	firm	0.05 psu 0.07 0.1	1 km 5 30	Not applicable	12 h 24 6 d	3 d 3 2 y
Ocean applications - ocean forecasting coastal -	firm	0.05 psu 0.07 0.1	1 km 5 10	Not applicable	3 d 12 24	1 d 2 3
SIA - - sea surface	reasonable	0.1 psu 0.15 0.3	100 km 150 250	Not applicable	30 d 40 60	9 d 20 120

Notes:
1. Units: psu is Practical Salinity Unit
2. Units: km is kilometers
3. Units: y is years
d is days

No units are indicated when there is no difference from the units of the entry immediately above in the table.

It should be noted that national programmes often carry out sampling by ships along sections. The measurements may well be contributed to JCOMM, though not always, but their purpose is to monitor processes on these sections. Indeed the SOT programme, is focused on sampling along sections rather than broad scale for precisely this reason. The requirements in the above table do not properly reflect this focus, except if the requirements are interpreted to apply to how data are collected along the section. For example, SOT vessels sample at roughly 50 km station separation, and 1 m vertical resolution, which meets the goal for horizontal and vertical resolution. However, this is only true along the section. If the entries in the table are interpreted to be horizontal and vertical resolution over the whole ocean, SOT would not achieve even the threshold.

Composite View

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The analysis by

Kent et. al. [14] discussed in the overview of these chapters on ECVs shows a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to surface salinity measurements.

Table 5. Present targets for JCOMM Observing Systems

Observing System	**Present JCOMM Targets**	**Comments**
SOOP XBT	37,000 XBTs deployed 26 High density lines (HDX) 25 Frequently repeated lines (FRX)	All carried out on selected lines to meet specific scientific objectives. HDX lines sampled 4 times a year, with 10-20 km between stations. FRX lines sampled 20 repeats a year with 50-100 km between stations.
SOOP underway	No specified requirements	
DBCP moorings	131 moorings Topical oceans	Coastal moorings are deployed with national discretion. Tsunami buoys are in another IOC programme.
DBCP OceanSITES	29 reference moorings 58 others	At selected sites, 10 in Atlantic, 10 in Pacific, 5 in Indian Oceans.
Argo	3200 floats 3X3 degree sampling Surface to 2000m Report every 10 days	Between 60N and 60S in open ocean. A new target design is being developed.
GO-SHIP	Selected WOCE lines Repeated each decade (or better) Surface to bottom at 5m resolution or better	Network encompasses fewer lines than WOCE
IOCCP	37 carbon survey	A new group is forming as a Carbon SOOP. Otherwise, data are collected by GO-SHIP.

JCOMMOPS [15] generates a number of charts and graphs that provide a qualitative way to see if certain of the observing systems are meeting these simple targets. For example, displays are available for SOT but none of these portray data collected at surface by TSGs (Rec 1). However, not all JCOMM programmes have displays that easily summarize the status of the programme (Rec 1).

The JCOMMOPS presentations reflect the individual observing system targets, but these are not a perspective that well represents an ECV perspective. A start towards this goal is provided at OSMC [16]. At this site and at the “Observing System Metrics tab, a user can select a parameter, a time frame and either one or all platforms. A further selection of gridding, and display presents a map that portrays the composite view, or individual platform view. A selection of surface salinity shows no results on the “In-situ Monitoring tab” and there is no selection for surface salinity on the “Observing System Metrics” tab (Rec 2,3).

The next table is a qualitative review of the OSCAR application requirements.

Table 6: A qualitative assessment of application area for surface salinity measurements.

Application Area **- Comment** **- Layer**	**Uncertainty**	**Horiz. Res**	**Vert. Res**	**Obs. Cycle**	**Timeliness**	**Comments**
Climate-GOOS - - sea surface	G	T+	Not applicable	G	G	Only Argo provides broad coverage.
Climate-OOPC - - sea surface	G	T+	Not applicable	B	G	Only Argo provides broad coverage.
CLIVAR - - sea surface	G	T-	Not applicable	G	G	Only Argo provides broad coverage.
Global NWP - - sea surface	G	T-	Not applicable	B	G	Only Argo provides broad coverage.
Ocean applications - marine modelling - sea surface	G	L	Not applicable	L	G	TSG measurements can meet Horiz. Res. requirements, but only along sections
Ocean applications - ocean forecasting open ocean - sea surface	G	L	Not applicable	L	G	TSG measurements can meet Horiz. Res. requirements, but only along sections
Ocean applications - climate modelling offshore -	G	L	Not applicable	L	G	TSG measurements can meet Horiz. Res. requirements, but only along sections
Ocean applications - ocean forecasting coastal -	G	L	Not applicable	G	G	TSG measurements can meet Horiz. Res. requirements, but only along sections
SIA - - sea surface	G	T-	Not applicable	G	G	Only Argo provides broad coverage.

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement. Plus and minus signs indicate if current sampling is greater than, or less than that requirement.

The assessment in Table 6 would suggest that instrumentation for measuring surface salinity is adequate, though TSG measurements often need careful attention. Horizontal Resolution is only achieved through the Argo programme. Moorings provide fixed point values and data from ships provide data along sections only. Only TSG instruments provide high horizontal resolution data.

Surface salinity measurements come from a variety of programmes. The overall FOO readiness level is about Pilot 4-6 largely because quality control procedures are not universally applied.

Just as there are questions about what is a “sea surface temperature”, the same may be raised about a surface salinity. Salinities collected through pumped seawater systems sample anywhere from the first meter of water to a number of meters below the sea surface. Certainly data collected from profiling floats sample at or near the surface, but these may or may not be counted depending on the person and application (Rec 4).

Recommendations

Rec 1: JCOMMOPS has no apparent displays of surface salinity measurements from TSGs, even though these data circulate on the GTS and have their own code form, TRACKOB, and a BUFR template. TSG data should appear on JCOMMOPS maps.

Rec 2: OSMC appears to be able to show surface salinity measurements, but when this parameter is selected (if available) there are no results. Either the application removes measurements, such as from Argo, (which seems to be the case) because they are not marked as "surface", or is not connected to real-time measurements such as from TSGs. If there is some criterion used to define surface, this needs to be explained. TSGs certainly report as "surface" so this data stream should be connected.

Rec 3: The displays allow a gridding in terms of latitude and longitude squares. The OSCAR requirements are set by units of meters (and kilometers). Also there are many different horizontal resolution requirements in OSCAR than are possible to specify at OSMC. Given the state of in-situ sampling, it is reasonable that all scales are not supported. However, a gridding based on meters / kilometers should be presented rather than degrees of latitude and longitude.

Rec 4: The definition of what is a surface salinity needs the same consideration as is given to sea surface temperature. This latter was driven by comparisons of temperatures collected by satellites with "surface" temperatures from drifters, XBTs, buckets, etc. With the launch of the SMOS satellite [17] and the upcoming launch of the Aquarius satellite [18], the same questions will arise. It is suggested that OOPC encourage an analysis and definition of what is a sea surface salinity.

Acronyms

BUFR: Binary Universal Form for data Representation
CLIVAR: Climate Variability and Predictability
CTD: Conductivity Temperature Depth
DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GOOS: Global Ocean Observing System
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
IAPSO: International Association for the Physical Sciences of the Oceans
ICES: International Council for the Exploration of the Sea
IOC: Intergovernmental Oceanographic Commission
IOCCP: International Ocean Carbon Coordination Project
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
MVP: Moving Vessel Profiler
NWP: Numerical Weather Prediction
OCG: Observations Programme Coordinator
OOPC: Ocean Observations Panel for Climate
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
PSU or psu: Practical Salinity Scale
SCOR: Scientific Committee on Ocean Research
SIA: Seasonal and Inter-Annual Forecasts
SOOP: Ship Of Opportunity Programme
SOT: Ship Observations Team
TSG: Thermosalinograph
UNESCO: United Nations Educational, Scientific and Cultural Organization
WOCE: World Ocean Circulation Experiment
WODB: World Ocean Data Base
WMO: World Meteorological Organization
XBT: Expendable Bathythermograph
XCTD: Expendable Conductivity Temperature Depth

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3.13: Sea Surface Temperature

A Review of Instruments

At the beginnings of oceanography, measurement of sea surface temperature in the ocean was done using a bucket to capture a sample from the surface, and then a thermometer to measure the temperature. This was common practice even into the 1960's. Surface temperatures were and still are captured with reversing thermometers (there are now electronic versions) on profile measurements from ships. The MBT was developed in the late 1930's and soon a digital version, the DBT was developed. An expendable version, the XBT, followed. Many versions of these devices are available.

After the XBT came the CTD, an instrument that is lowered from a ship and measures conductivity, temperature and, typically, pressure. CTDs can be lowered while a ship is stationary, or while moving, using what is known as a MVP. There are also expendable versions, XCTDs. CTDs are also deployed on moorings sometimes with an instrument that crawls up a mooring line, making temperature and salinity measurements along the way.

Measurements of upper ocean (the upper 2000m) temperature profiles, and sea surface temperatures as well, have increased hugely since WOCE. The WOCE saw the first broad scale use of profiling float technology. These are instruments that can be deployed from a ship, and operate autonomously until their batteries are exhausted. They adjust their buoyancy so that they can submerge, typically to 2000m, then regularly rise to the surface, sampling temperature and salinity, with a CTD, at roughly 70 depths (more near the surface, less at depth). The upper-most measurement is considered to be at the sea surface (see comments later). Data are reported through satellite communications systems. The Argo programme was developed as an international effort to routinely sample the upper ocean with such technology and since its beginning in the early 2000's, more measurements of temperature and salinity in the upper ocean have been made than all previous data in historical archives.

Undulating instruments, such as gliders, can also provide sea surface temperature measurements using CTDs. The accuracy of these are dependent on the model of CTD and some of the post processing. The same comments could be made of the CTDs mounted on marine mammals.

Sea surface temperatures are also measured using thermistors, and this is the typical way they are returned from moorings. Typically, on a mooring or a drifting buoy, there is a hull mounted thermistor that is used to measure surface temperature and these report through satellite communications systems.

Since the 1990's, thermosalinographs, TSGs, have been used to measure surface temperature and salinity. These devices sample water pumped in through a seawater intake system that is afterwards used for ships cooling. Fouling and bubbles are of concern and an important factor in such systems. Constant maintenance is needed to ensure reliable measurements.

Calibration is an import aspect of measuring ocean properties. Even though modern, electronic instruments are now the norm, ensuring the stability of the measurements has a strong impact on the quality of the data.

A variety of temperature scales have been used over the years [1]. These are based on a precise measurement of the triple point of water. The current standard is called ITS-90 defined in 1990. A discussion of ITS-90 and its importance to the equation of state for seawater is provided in [2].

Instrument Characteristics

A very nice compendium of instrument operating characteristics is provided by Boyer et. al. [3] in discussing the data that appear in the WODB-2009. The table below provides the nominal characteristics of the different instruments that can be used to measure sea surface temperature as extracted from Boyer et. al. Different models or electronics have greater or less capabilities than what is recorded here. Because of this, the uses of data returned from instrumentation is at least partly tied to the capabilities of the instrument. This is a strong reason for data providers and archives to ensure the instrument and its operating characteristics are preserved with the measurements.

What is called sea surface temperature has been a subject of some debate. Ship's hull mounted sensors sample temperature a few metres or more below the air-sea interface, and where precisely depends on ship loading. Drifting buoys typically sample within 1 metre of the air-sea interface. Lowered instruments sample in the top 1-3 metres. The ability of XBTs to provide any useful temperature data in the upper 3 m has been under active discussion. TSGs sample at whatever depth the sea water intake is at, and such intake data are complicated by the stirring of water by the ship's passage. GHRSST has published a study [4] that offers definitions of “sea surface temperature” that takes these differences into consideration.

Table 1. Nominal instrument characteristics used to measure sea surface temperatures.

Instrument	**Accuracy**	**Comments**
Reversing thermometer	±0.001 ℃	Digital thermometers provide higher accuracy
MBT	±0.5 ℃	See [3]
DBT	±0.05 ℃	See [3]
XBT	±0.1 ℃	Typical for T7 probes
CTD	±0.002 ℃ (profiling floats)	For profiling floats. Higher and lower accuracies exist depending on the CTD model..
XCTD	±0.02 ℃	
Thermistor	±0.01 ℃	Varies by model used. Higher accuracy is available.

Data Providers / Observing Systems

The table below provides a list of the sources of sea surface temperature data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled “Typical Instruments” and “Typical Sampling” provide some information about the horizontal and temporal sampling of the system. These are approximate and are to be considered as only an indication of the usual characteristics.

Table 2. Instruments typically used in each observing system that contributes sea surface temperature measurements.

Observing System	**Typical instrument(s)**	**Typical Sampling**
SOT SOOP [5]	XBT XCTD	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation.
SOOP underway [6]	CTD	Sample along sections, as often as bi-weekly, but more often quarterly. Samples collected at surface every 1 minute or better.
SOT VOS [7]	Hull thermistors Pumped systems	A very broad spatial distribution, but with a northern hemisphere bias. Samples are at least hourly, or better.
DBCP moorings [8]	Thermistor chains	Sample typically in tropics and hourly.
DBCP surface drifters [9,10]	Hull thermistors	Sample in broad distributions usually reporting 4 times a day or better. Some data are available from ice covered regions.
DBCP OceanSITES [11]	CTD Hull thermistors	Reference mooring stations sparsely distributed over the oceans. Sample frequently in time.

Argo [12]	CTD	Widely distributed in all ice-free oceans with roughly 3x3 degrees (latitude and longitude) separation. Typically sample to 2000m at 70+ levels every 10 days.
GO-SHIP [13]	CTD Reversing thermometers Pumped systems	Sample along sections, fewer than once a year. Stations are typically widely separated.
IOCCP [14]	CTD Reversing thermometers Pumped systems	Same as GO-SHIP
Marine mammals	CTD	Locations and times dependent on animals used.
Navies	XBT	Varying distribution depending on purposes. Reporting is dependent on national defence policies.
Fisheries	XBT Hull thermistors Pumped systems	Often in random sampling patterns with sometimes 10's of km separation between stations. Typically sample on continental shelves. Often measure temperature at the openings of towed nets.
Gliders	CTD	Sparse sampling in oceans.
National moorings	CTD Hull thermistors	At nationally selected sites, usually on coastal shelves or slopes. Sampling can be hourly or better, but highly dependent on the programme.
National monitoring / research	CTD reversing thermometers XBT Hull thermistors Pumped systems	A few Ocean Weather Stations still exist, and nations maintain a few locations that are sampled routinely, usually on shelves. Sampling is highly dependent on the programme.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [15]. The objective was " to develop an integrated framework for sustained ocean observing ..." to "... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...". They agreed that implementation of new systems for EOVs "... will be carried out according to their readiness levels ...". The table that describes this, extracted from that report follows.

Table 3. FOO readiness levels.

Readiness Level	**Description**	**Data Management and Information Products**
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
Mature 8	Mission qualified	Data availability: globally available Evaluation of utility
Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability

Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan
Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance
Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
Concept 2	Documentation	Socialization of data: Interoperability strategy Expert review
Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [16], that is ”... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.”. OSCAR is a complicated database in that it contains the spatial and temporal sampling requirements as needed by the varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:
uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
availability

Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The rows relevant to sea surface temperature have been extracted from OSCAR, reformatted somewhat and are shown here.

Table 4. OSCAR entries for sea surface temperature.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (2) Breakthrough Threshold**	**Vert. Res: Goal Breakthrough Threshold**	**Obs. Cycle: Goal (3) Breakthrough Threshold**	**Availability: Goal (3) Breakthrough Threshold**
CliC - - sea surface	reasonable	0.5 K 0.8 2.0	25 km 39.7 100	Not applicable	3 h 5 12	30 d 37.8 60
Climate-GOOS - - sea surface	firm	0.1 K 0.2 1.0	10 km 31.1 300	Not applicable	6 h 29.6 30 d	6 h 29.6 30 d

Climate-AOPC - bulk - sea surface	firm	0.25 K 0.4 1.0	10 km 50 500	Not applicable	3 h 6 24	3 h 6 12
Climate-OOPC - - sea surface	reasonable	0.1 K 0.126 0.2	1 km 8 500	Not applicable	1 h 3 24	3 h 5 12
CLIVAR - - sea surface	reasonable	0.1 K 0.2 0.3	10 km 20 50	Not applicable	3 h 4 6	24 h 36 3 d
Global modelling - - sea surface	reasonable	0.5 K 1.0 2.0	50 km 100 250	Not applicable	1 h 3 12	30 d 45 60
Global NWP - - sea surface	firm	0.3 K 0.5 1.0	5 km 15 250	Not applicable	3 h 24 5 d	3 h 24 5 d
High Res NWP - - sea surface	firm	0.3 K 0.5 1.0	1 km 5 20	Not applicable	1 h 2 6	1/2 h 1 6
Marine biology - marine biology in coastal waters - coast	firm	0.1 K 0.2 0.5	1 km 2 5	Not applicable	24 h 36 2 d	2 h 3 4
Marine biology - - sea surface	firm	0.1 K 0.2 0.5	10 km 20 50	Not applicable	24 h 36 2 d	2 h 3 4
Nowcasting - - sea surface	firm	0.5 K 0.8 2.0	5 km 10.8 50	Not applicable	60 m 108 6 h	60 m 78 2 h
Ocean applications - atmospheric modelling - sea surface	reasonable	0.1 K 0.5 1.0	10 km 25 100	Not applicable	1 h 3 24	4.8 m 60 6 h
Ocean applications - marine modelling - sea surface	reasonable	0.1 K 0.5 1.0	1 km 10 25	Not applicable	1 h 3 24	4.8 m 60 6 h
Ocean applications - climate modelling - sea surface	reasonable	0.1 K 0.2 0.5	10 km 50 100	Not applicable	1 h 3 24	12 h 24 3 d
Ocean applications - ocean forecasting open ocean - sea surface	firm	0.1 K 0.2 0.5	5 km 10 25	Not applicable	6 h 24 3 d	1 h 2 3
Ocean applications - marine safety services - sea surface	firm	0.1 K 0.5 1.0	0.5 km 1 10	Not applicable	1/2 h 1 3	1/2 h 1 6
Ocean applications - ocean forecasting coastal - sea surface	firm	0.1 K 0.2 0.5	1 km 5 10	Not applicable	3 h 12 24	1 h 2 3
Ocean surface-GOOS - - sea surface	firm	0.1 K 0.271 2.0	1 km 2.2 10	Not applicable	6 h 7.6 12	2 h 2.5 4

SIA - tropical ocean - sea surface	firm	0.1 K 0.2 0.5	50 km 85.5 250	Not applicable	3 h 6 12	3 h 6 24
Synoptic meteorology - - sea surface	firm	0.5 K 0.8 2.0	5 km 10.8 50	Not applicable	3 h 6 24	1 h 2.9 24

Notes:
1. Units: K is ºKelvin
2. Units: km is kilometres
3. Units: d is days
h is hours
m is minutes

No units are indicated when there is no difference from the units of the entry immediately above in the table.

It should be noted that programmes often carry out sampling by ships along lines. The measurements may well be contributed to JCOMM, though not always. Indeed the SOOP programme, is focused on sampling along sections rather than broad scale to monitor processes along these lines. The requirements in the above table do not properly reflect this focus, except if the requirements are interpreted to apply to how data are collected along the section. For example, SOOP vessels sample at 50 km station separation, and 1 m vertical resolution, which meets the goal for horizontal and vertical resolution. However, this is only true along the section. If the entries in the table are interpreted to be horizontal and vertical resolution over the whole ocean, SOOP would not achieve even the threshold.

Composite View

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The analysis by Kent et. al. [17] discussed in the overview of these chapters on ECVs shows a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to surface temperature measurements.

Table 5. Present targets for JCOMM Observing Systems

Observing System	**Present JCOMM Targets**	**Comments**
SOT SOOP	37,000 XBTs deployed 26 High density lines (HDX) 25 Frequently repeated lines (FRX)	All carried out on selected lines to meet specific scientific objectives. HDX lines sampled 4 times a year, with 10-20 km between stations. FRX lines sampled 20 repeats a year with 50-100 km between stations.
SOT VOS	3000 active ships 500 AWS 250 VOSClim	Active ships provide more than 20 reports/month.
SOOP underway	No specified requirements	

DBCP drifters	1250 buoys deployed 5x5 degree global distribution 1250 with barometers 300 with salinity	Practical target for barometer buoys is 600.
DBCP moorings	131 moorings Topical oceans	Coastal moorings are deployed with national discretion. Tsunami buoys are in another IOC programme.
DBCP OceanSITES	29 reference moorings 58 others	At selected sites, 10 in Atlantic, 10 in Pacific, 5 in Indian Oceans.
Argo	3200 floats 3X3 degree sampling Surface to 2000m Report every 10 days	Between 60N and 60S in open ocean. A new target design is being developed.
GO-SHIP	Selected WOCE lines Repeated each decade (or better) Surface to bottom at 5m resolution or better	Network encompasses fewer lines than WOCE.
IOCCP	37 carbon survey	A new group is forming as a Carbon SOOP. Otherwise, data are collected by GO-SHIP.

JCOMMOPS [18] generates a number of charts and graphs that provide a qualitative way to see if certain of the observing systems are meeting these simple targets. For example, DBCP pages provide maps showing the number of active surface drifters and their latest reported positions. Similar displays are available for SOT. However, not all JCOMM programmes have displays that easily summarize the status of the programme (Rec 1).

The JCOMMOPS presentations reflect the individual observing system targets, but these are not a perspective that well represents an ECV perspective. A start towards this goal is provided at OSMC [19]. At this site and at the “Observing System Metrics tab, a user can select a parameter, a time frame and either one or all platforms. A further selection of gridding, and display presents a map that portrays the composite view, or individual platform view. There are some weaknesses to this display (Rec 2), but it is working towards the right goal. One notable lack is that a user cannot plug in the OSCAR requirements for any particular application area, as shown in table 4. But considering the present state of in-situ sampling, this “lack” is sensible and pragmatic, as is discussed below.

The displays at OSMC do not consider the shallowest temperatures from Argo profiles to be sea surface, nor are there any TSG measurements shown. Some explanation of what is considered to be “sea surface” is needed to alert a user (Rec 3,4).

The next table is a qualitative review of the OSCAR application requirements. In most cases the present state of in-situ sampling does fall within OSCAR requirements.

Table 6: A qualitative assessment of application area for water temperature measurements.

Application Area - Comment - Layer	**Uncertainty**	**Horiz. Res**	**Vert. Res**	**Obs. Cycle**	**Timeliness**	**Comments**
CliC - - sea surface	G	L	Not applicable	B+	G	

Climate-GOOS - - sea surface	G	T-	Not applicable	G	G	
Climate-AOPC - bulk - sea surface	G	T+	Not applicable	B+	G	
Climate-OOPC - - sea surface	G	T+	Not applicable	B	G	
CLIVAR - - sea surface	G	L	Not applicable	B	G	
Global modelling - - sea surface	G	T-	Not applicable	G	G	
Global NWP - - sea surface	G	T-	Not applicable	T+	G	
High Res NWP - - sea surface	G	L	Not applicable	G	T+	
Marine biology - marine biology in coastal waters - coast	G	L	Not applicable	G	B	
Marine biology - - sea surface	G	L	Not applicable	G	B	
Nowcasting - - sea surface	G	L	Not applicable	T+	L	
Ocean applications - atmospheric modelling - sea surface	G	L	Not applicable	B	T+	
Ocean applications - marine modelling - sea surface	G	L	Not applicable	B	T+	
Ocean applications - climate modelling - sea surface	G	L	Not applicable	B	G	
Ocean applications - ocean forecasting open ocean - sea surface	G	L	Not applicable	G	T	
Ocean applications - marine safety services - sea surface	G	L	Not applicable	T	T+	
Ocean applications - ocean forecasting coastal - sea surface	G	L	Not applicable	G	T	
Ocean surface-GOOS - - sea surface	G	L	Not applicable	G	T+	

SIA - tropical ocean - sea surface	G	T-	Not applicable	G	G	
Synoptic meteorology - - sea surface	G	L	Not applicable	G	B-	

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement. Plus and minus signs indicate if current sampling is greater than, or less than that requirement.

The assessment in Table 6 would suggest that for sea surface temperature, the instrumentation required is available. Care must be taken in processing and use of data from certain instruments. Also, consideration must be given to the vertical location of the sampling as to its representativeness of the sea surface. The spatial sampling is generally below Threshold requirements.

Overall, the observing systems with the largest contributions to sea surface temperature measurements with global spatial measurements are at a FOO readiness level of Mature 8 or 9.

Recommendations

Rec 1: Each of the formal JCOMM programmes should provide simple displays on their home web pages that articulate as precisely as possible the observing targets, and show how well these targets are being met. Examples to emulate would be those provided by Argo and SOT.

Rec 2: The displays allow a gridding in terms of latitude and longitude squares. The OSCAR requirements are set by units of meters (and kilometres). Also there are many different horizontal resolution requirements in OSCAR than are possible to specify at OSMC. Given the state of in-situ sampling, it is reasonable that all scales are not supported. However, a gridding based on meters / kilometres should be presented rather than degrees of latitude and longitude.

Rec 3: OCG in consultation with OOPC should clarify what definition of sea surface temperature, as defined by GHRSST, should be used to monitor the acquisition of this ECV.

Rec 4: The GHRSST analysis of different types of surface temperature should be employed by OSMC to qualify what is considered a sea surface temperature and this should be explained.

Acronyms

AOPC: Atmospheric Observation Panel for Climate
CLIVAR: Climate Variability and Predictability
CTD: Conductivity Temperature Depth
CliC: Climate and Cryosphere (project)
DBCP: Data Buoy Cooperation Panel
DBT: Digital Bathythermograph
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GHRSST: Global High Resolution Sea Surface Temperature
GOOS: Global Ocean Observing System
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
IOCCP: International Ocean Carbon Coordination Project
ITS-90: International Temperature Scale – 1990
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
MBT: Mechanical Bathythermograph
MVP: Moving Vessel Profiler
NWP: Numerical Weather Prediction
OCG: Observations Programme Coordinator
OOPC: Ocean Observations Panel for Climate
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
SIA: Seasonal and Inter-Annual Forecasts

SOOP: Ship Of Opportunity Programme
SOT: Ship Observations Team
TSG: Thermosalinograph
VOS: Volunteer Observing Ship
WMO: World Meteorological Organization
WOCE: World Ocean Circulation Experiment
WODB: World Ocean Data Base
XBT: Expendable Bathythermograph
XCTD: Expendable Conductivity Temperature Depth

References

1. International temperature scales: http://www.its-90.com/index.html
2. Seawater equation of state: http://www.teos-10.org/pubs/TEOS-10_Manual.pdf
3. Instrument characteristics: ftp://ftp.nodc.noaa.gov/pub/WOD/DOC/wod09_intro.pdf
4. GHRSST SST definitions: http://ghrsst-pp.metoffice.com/pages/sst_definitions/
5. SOT SOOP: http://www.jcommops.org/sot/soop/
6. SOT underway: http://www.gosud.org/
7. SOT VOS: http://www.jcommops.org/sot/#VOS
8. DBCP moorings action groups: http://www.jcommops.org/dbcp/overview/actiongroups.html
9. DBCP drifters: http://www.jcommops.org/dbcp/platforms/types.html
10. DBCP GDP home: http://www.aoml.noaa.gov/phod/dac/index.php
11. DBCP OceanSITES home: http://www.oceansites.org/
12. Argo Project Office: http://www.argo.ucsd.edu/
13. GO-SHIP home: http://www.go-ship.org/
14. IOCCP home: http://www.ioccp.org/
15. OceanObs'09 FOO: http://www.oceanobs09.net/foo/
16. OSCAR: http://www.wmo-sat.info/oscar/observingrequirements
17. Kent et. al. Analysis: http://eprints.soton.ac.uk/50260/
18. JCOMMOPS home: http://wo.jcommops.org/cgi-bin/WebObjects/JCOMMOPS
19. OSMC home: http://www.osmc.noaa.gov/

3.14: Ocean Temperature

A Review of Instruments

Since the beginnings of oceanography, measurement of temperature profiles in the ocean was confined largely to lowering reversing thermometers from ships (there are now electronic versions). The MBT was developed in the late 1930's and soon a digital version, the DBT was developed. An expendable version, the XBT, followed. Many versions of these devices are available but the most widely used XBT today samples temperature as a function of time of fall nominally to 760 m (though other models sample to lesser or greater depths). Time of fall is converted to depth through a fall rate equation and the coefficients of this equation have been found to be different from the original manufacturer's specifications and with some time dependency as well.

After the XBT came the CTD, an instrument that is lowered from a ship and measures conductivity, temperature and, typically, pressure. Temperatures are measured with a thermistor. Conductivity is converted to salinity through a conversion formula. Pressure may be converted to depth through the hydrostatic equation. It is common to leave vertical units as pressure and users can find both in archives. CTDs can be lowered while a ship is stationary, or while moving, using what is known as a MVP. CTDs are also deployed on moorings sometimes with an instrument that crawls up a mooring line, making temperature and salinity measurements along the way. There are expendable versions as well, called XCTDs.

Measurements of upper ocean (the upper 2000m) temperature profiles have increased hugely since WOCE. The WOCE saw the first broad scale use of profiling float technology. These are instruments that can be deployed from a ship, and operate autonomously until their batteries are exhausted. They adjust their buoyancy so that they can submerge, typically to 2000m, then regularly rise to the surface, sampling temperature and salinity with a CTD, at roughly 70 depths (more near the surface, less at depth). Data are reported through satellite communications systems. The Argo programme was developed as an international effort to routinely sample the upper ocean with such technology and since its beginning in the early 2000's, more measurements of temperature and salinity in the upper ocean have been made than all previous data in historical archives.

Undulating instruments, such as gliders, can also provide temperature measurements using CTDs. The accuracy of these are dependent on the model of CTD and some of the post processing. The same comments could be made of the CTDs mounted on marine mammals.

Upper ocean temperatures can also be measured using thermistors alone, and this is the typical way they are observed on moorings. Strings of thermistors are suspended below a mooring, sometimes below a surface drifter, and these also report typically through satellite communications systems.

Measuring temperature in the deep ocean is still confined to lowering instruments from ships at sea. Typically, such measurements, say to 4000m, can take more than an hour to complete. Operating ships is expensive and this is one reason that the number of deep ocean measurements is relatively few. Companies are currently testing a deep ocean profiling float, one that can withstand the increased pressure needed to sample the full water column in mid ocean.

Calibration is an import aspect of measuring ocean properties. Even though modern, electronic instruments are now the norm, ensuring the stability of the measurements has a strong impact on the quality of the data.

A variety of temperature scales have been used over the years [1]. These are based on a precise measurement of the triple point of water. The current standard is called ITS-90 defined in 1990. A discussion of ITS-90 and its importance to the equation of state for seawater is provided in [2].

Instrument Characteristics

A very nice compendium of instrument operating characteristics is provided by Boyer et. al. [3] in discussing the data that appear in the WODB-2009. The table below provides the nominal characteristics of the different instruments that can be used to measure water temperature as extracted from Boyer et. al. Different models or electronics have greater or less capabilities than what is recorded here. Because of this, the uses of data returned from instrumentation is at least partly tied to the capabilities of the instrument. This is a strong reason for data providers and archives to ensure the instrument and its operating characteristics are preserved with the measurements.

Table 1. Nominal instrument characteristics used to measure water temperatures.

Instrument	Accuracy	Comments
Reversing thermometer	±0.001 ℃	Digital thermometers provide higher accuracy
MBT	±0.5 ℃	See [3]
DBT	±0.05 ℃	See [3]
XBT	±0.1 ℃	Typical for T7 probes
CTD	±0.002 ℃ (profiling floats)	For profiling floats. Higher and lower accuracies exist depending on the CTD model..
XCTD	±0.02 ℃	
Thermistor	±0.01 ℃	Varies by model used. Higher accuracy is available.

Data Providers / Observing Systems

The table below provides a list of the sources of ocean temperature profile data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled “Typical Instruments” and “Typical Sampling” provide some information about the horizontal, vertical and temporal sampling of the system. These are approximate and are to be considered as only an indication of the usual characteristics.

Table 2. Instruments typically used in each observing system that contributes water temperature measurements.

Observing System	Typical instrument(s)	Typical Sampling
SOT SOOP [4]	XBT XCTD	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation. Typically sample to 760m at 1m intervals.
DBCP moorings [5]	Thermistor chains	Sample typically in tropics, once a day but some hourly. Some sample from surface to 500m with 5-10 measurements in a profile.
DBCP OceanSITES [6]	CTD	Reference mooring stations sparsely distributed over the oceans. Sample frequently in time and from surface to bottom.
Argo [7]	CTD	Widely distributed in all ice-free oceans with roughly 3x3 degrees (latitude and longitude) separation. Typically sample to 2000m at 70+ levels every 10 days.
GO-SHIP [8]	CTD Reversing thermometers	Sample along sections, fewer than once a year. Stations are typically widely separated. Sample from top to bottom, at 1-2m intervals.
IOCCP [9]	CTD Reversing thermometers	Same as GO-SHIP.

Marine mammals	CTD	A few animals are fitted with CTDs that report the temperature and salinity properties of a previous dive when the animal is at the surface and satellite systems are in view. Vertical sampling is sparse at times. Many reports come from polar regions.
Navies	XBT	Varying distribution depending on purposes. Typically in top 760m at 1 m intervals. Reporting is dependent on national defence policies
Fisheries	XBT CTD	Often in random sampling patterns with sometimes 10's of km separation between stations. Typically sample on continental shelves at 1m intervals. Often measure temperature at the openings of towed nets.
Gliders	CTD	Sparse sampling in oceans. Typically the deepest sample is from 100-1000m at 1m intervals.
National moorings	CTD Thermistor chains	At nationally selected sites, usually on coastal shelves or slopes. Sampling can be hourly or better, but highly dependent on the programme.
National monitoring / research	CTD reversing thermometers XBT	A few Ocean Weather Stations still exist, and nations maintain a few locations that are sampled routinely, usually on shelves. Sampling is highly dependent on the programme.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [10]. The objective was " to develop an integrated framework for sustained ocean observing ..." to "... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...". They agreed that implementation of new systems for EOVs "... will be carried out according to their readiness levels ...". The table that describes this, extracted from that report follows.

Table 3. FOO readiness levels.

Readiness Level	**Description**	**Data Management and Information Products**
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
Mature 8	Mission qualified	Data availability: globally available Evaluation of utility
Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan

Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance
Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
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Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

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uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
availability

Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The rows relevant to ocean temperature have been extracted from OSCAR, reformatted somewhat and are shown here. It should be noted that in rebuilding the table, certain of the entries in the databases appeared to be suspect. These are shown in bold and italic font (Rec 1).

Table 4. OSCAR entries for water temperature.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (2) Breakthrough Threshold**	**Vert. Res: Goal (2) Breakthrough Threshold**	**Obs. Cycle: Goal (3) Breakthrough Threshold**	**Timeliness: Goal (3) Breakthrough Threshold**
Climate-OOPC - - deep ocean	reasonable	0.002 K 0.003 0.005	50 km 60 100	2 m 2.5 4	2 y 9.9 236.7	60 d 110 360
Climate-OOPC - - upper ocean	reasonable	0.001 K 0.002 0.01	1 km 6 300	1 m 2 10	24 d 48 240	30 m 36 60
Global NWP - - upper ocean	reasonable	0.3 K 0.5 1.0	5 km 100 250	1 m 2 10	1 d 2 30	3 h 24 5 d

Ocean applications - atmospheric modelling - upper ocean	reasonable	0.1 K 0.5 1.0	10 km 20 100	***5 m*** ***0*** ***0***	1 d 3 24	12 h 24 3 d
Ocean applications - climate modelling offshore - upper ocean	reasonable	0.1 K 0.5 1.0	50 km 100 500	***1 m*** ***0*** ***0***	1 d 3 24	1 d 3 30
Ocean applications - marine modelling - upper ocean	reasonable	0.1 K 0.5 1.0	2 km 10 50	***1 m*** ***0*** ***0***	1 d 3 24	12 h 24 3 d
Ocean applications - ocean forecasting coastal - upper ocean	firm	0.1 K 0.5 1.0	1 km 5 10	***0 m*** ***0*** ***0***	3 d 12 24	1 d 2 3
Ocean applications - ocean forecasting open ocean - upper ocean	firm	0.1 K 0.5 1.0	5 km 10 25	***0 m*** ***0*** ***0***	6 d 24 72	1 d 2 3

Notes:
1. Units: K is ºKelvin
2. Units: km is kilometres
m is meters
3. Units: y is years
d is days
h is hours
m is minutes
No units are indicated when there is no difference from the units of the entry immediately above in the table.

It should be noted that national programmes often carry out sampling by ships along sections. The measurements may well be contributed to JCOMM, though not always, but their purpose is to monitor processes on these sections. Indeed the SOOP programme, is focused on sampling along sections rather than broad scale for precisely this reason. The requirements in the above table do not properly reflect this focus, except if the requirements are interpreted to apply to how data are collected along the section. For example, SOOP vessels sample at 50 km station separation, and 1 m vertical resolution, which meets the goal for horizontal and vertical resolution. However, this is only true along the section. If the entries in the table are interpreted to be horizontal and vertical resolution over the whole ocean, SOOP would not achieve even the threshold.

Composite View

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The analysis by Kent et. al. [12] discussed in the overview of these chapters on ECVs shows a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to water temperature measurements.

Table 5. Present targets for JCOMM Observing Systems

Observing System	Present JCOMM Targets	Comments
SOOP	37,000 XBTs deployed 26 High density lines (HDX) 25 Frequently repeated lines (FRX)	All carried out on selected lines to meet specific scientific objectives. HDX lines sampled 4 times a year, with 10-20 km between stations. FRX lines sampled 20 repeats a year with 50-100 km between stations.
DBCP moorings	131 moorings Topical oceans	Coastal moorings are deployed with national discretion. Tsunami buoys are in another IOC programme.
DBCP OceanSITES	29 reference moorings 58 others	At selected sites, 10 in Atlantic, 10 in Pacific, 5 in Indian Oceans.
Argo	3200 floats 3X3 degree sampling Surface to 2000m Report every 10 days	Between 60N and 60S in open ocean. A new target design is being developed.
GO-SHIP	Selected WOCE lines Repeated each decade (or better) Surface to bottom at 5m resolution or better	Network encompasses fewer lines than WOCE.
IOCCP	37 carbon survey	A new group is forming as a Carbon SOOP. Otherwise, data are collected by GO-SHIP.

JCOMMOPS [13] generates a number of charts and graphs that provide a qualitative way to see if certain of the observing systems are meeting these simple targets. For example, Argo pages provide maps showing the number of active floats and their latest reported positions. Similar displays are available for SOT. However, not all JCOMM programmes have displays that easily summarize the status of the programme (Rec 2).

The JCOMMOPS presentations reflect the individual observing system targets, but these are not a perspective that well represents an ECV perspective. A start towards this goal is provided at OSMC [14]. At this site and at the "Observing System Metrics tab, a user can select a parameter, a time frame and either one or all platforms. A further selection of gridding, and display presents a map that portrays the composite view, or individual platform view. There are some weaknesses to this display (Rec 3), but it is working towards the right goal. One notable lack is that a user cannot plug in the OSCAR requirements for any particular application area, as shown in table 4. But considering the present state of in-situ sampling, this "lack" is sensible and pragmatic, as is discussed below.

The next table is a qualitative review of the OSCAR application requirements. In most cases the present state of in-situ sampling does fall within OSCAR requirements.

Table 6: A qualitative assessment of application area for water temperature measurements.

Application Area **- Comment** **- Layer**	**Uncertainty**	**Horiz. Res**	**Vert. Res**	**Obs. Cycle**	**Timeliness**	**Comments**
Climate-OOPC - - deep ocean	G	B	G	B	T-	Along lines only. Timeliness often falls below.
Climate-OOPC - - upper ocean	B	T	T-	B	L	Vert. Res. better near surface, below in deeper waters.

Global NWP - - upper ocean	G	T-	T-	T	B	Vert .Res. better near surface, below in deeper waters.
Ocean applications - atmospheric modelling - upper ocean	G	L	T-	T	B	
Ocean applications - climate modelling offshore - upper ocean	G	T+	T-	T	B	Horiz. Res. is better than Threshold, less than Breakthrough
Ocean applications - marine modelling - upper ocean	G	T	T	B-	T-	Hor.iz Res. only along sections
Ocean applications - coastal ocean forecasting - upper ocean	G	T		B-	T-	Missing entry reflects uncertainty of values in OSCAR
Ocean applications - open ocean forecasting - upper ocean	G	L		G	T-	Missing entry reflects uncertainty of values in OSCAR

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement. Plus and minus signs indicate if current sampling is greater than, or less than that requirement.

The assessment in Table 6 would suggest that for water temperature, the instrumentation required is all available. The spatial sampling is generally close to Threshold, but this is qualified with some sampling being along selected sections only and in the upper ocean vertical sampling at depth is only just near Threshold.

Overall, the observing systems with the largest contributions to water temperature measurements are at a FOO readiness level of Mature 8. They might be considered at level 9 except that many of the present programmes are significantly dependent on research funding which is less secure perhaps than if a programme was on long term funding.

Recommendations

Rec 1: Experts, likely from OOPC, should review the identified OSCAR entries that appear to be suspect, to confirm the present entries or correct them as required.
Rec 2: Each of the formal JCOMM programmes should provide simple displays on their home web pages that articulate as precisely as possible the observing targets, and show how well these targets are being met. Examples to emulate would be those provided by Argo and SOT.
Rec 3: The displays allow a gridding in terms of latitude and longitude squares. The OSCAR requirements are set by units of meters (and kilometres). Also there are many different horizontal resolution requirements in OSCAR than are possible to specify at OSMC. Given the state of in-situ sampling, it is reasonable that all scales are not supported. However, a gridding based on meters / kilometres should be presented rather than degrees of latitude and longitude.

Acronyms

CTD: Conductivity Temperature Depth
DBCP: Data Buoy Cooperation Panel
DBT: Digital Bathythermograph
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
IOCCP: International Ocean Carbon Coordination Project
ITS-90: International Temperature Scale – 1990
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
MBT: Mechanical Bathythermograph

MVP: Moving Vessel Profiler
NWP: Numerical Weather Prediction
OCG: Observations Programme Coordinator
OOPC: Ocean Observations Panel for Climate
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
SOOP: Ship Of Opportunity Programme
SOT: Ship Observations Team
WMO: World Meteorological Organization
WOCE: World Ocean Circulation Experiment
WODB: World Ocean Data Base
XBT: Expendable Bathythermograph
XCTD: Expendable Conductivity Temperature Depth

References

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3. Instrument characteristics: ftp://ftp.nodc.noaa.gov/pub/WOD/DOC/wod09_intro.pdf
4. SOT SOOP: http://www.jcommops.org/sot/soop/
5. DBCP moorings action groups: http://www.jcommops.org/dbcp/overview/actiongroups.html
6. DBCP OceanSITES home: http://www.oceansites.org/
7. Argo Project Office: http://www.argo.ucsd.edu/
8. GO-SHIP home: http://www.go-ship.org/
9. IOCCP home: http://www.ioccp.org/
10. OceanObs'09 FOO: http://www.oceanobs09.net/foo/
11. OSCAR: http://www.wmo-sat.info/oscar/observingrequirements
12. Kent et. al. Analysis: http://eprints.soton.ac.uk/50260/
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14. OSMC home: http://www.osmc.noaa.gov/

3.15: Waves

A Review of Instruments

Early wave measurements were made visually, and indeed, this is often still true for most ship observations. Instrumentation to measure waves was developed and deployed in about the 1960's with the use of accelerometers, either gimballed or strapped down. These were placed on buoys and moored on ocean shelves or sometimes in deeper water. At first, only line-of-sight communications was possible, so this restricted these operations to either on-board storage, or transmission to close platforms, such as oil rigs. With the advent of satellite communications systems, it is possible for buoys to report data as soon as collected and from anywhere in the ocean.

The first routinely deployed buoys were able to measure only non-directional spectra. Typically, surface heave measurements are recorded at about 0.5 sec intervals for about 20 minutes, amassing 2048 points. These are passed through an instrument response function, some shaping of the time series is done, and then through a Fourier analysis. Different averaging schemes are used to increase the confidence in the spectral energy that is computed. At first buoys had power or on-board computing restrictions, but these are less of a concern today. It is not uncommon for data to be acquired, processed to 1-D spectra and these transmitted to shore every hour. Many nations support a series of moorings along their coasts making such measurements, in conjunction with water properties and meteorological variables.

In the recent past, buoys capable of measuring wave motions in three dimensions have come more into use. These record pitch, roll and heave motions on 3 orthogonal axes and when passed through a Fourier analysis can produce directional spectra.

Other wave measurement technology has been explored, such as lasers, or acoustics for wave staffs, or coastal radars, but so far these are confined to near shore operations and will not be considered further. Of note, though, is ship's X band radars that are capable of local wave measurements as the ship is in operation. It is not known how much data from this type of measurement is entering the data streams of wave information coming from ships (Rec 1).

Maintenance of a mooring and calibration of instrumentation is an import aspect of measuring wave properties. Buoys accumulate biological growth and this can impact the response characteristics of the buoy to the waves, or reduce power through fouling of solar panels. Routine maintenance is necessary to ensure proper functioning. Checking the calibration of accelerometers when a buoy is serviced is also important. Maintaining records of all of this can help resolve problems that turn up when data are analysed.

New technologies are in development that are reducing the size of the accelerometers and improving their sensitivity so that it is becoming feasible to consider making wave measurements from expendable platforms such as surface drifters.

Instrument Characteristics

A recent report from MARINET [1] provides a convenient summary of instruments and their operation. Different models or electronics have greater or less capabilities but most buoys can deliver accuracies of better than 2% full scale.

Data Providers / Observing Systems

The table below provides a list of the sources of wave data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled “Typical Instruments” and “Typical Sampling” provide some information about the horizontal, vertical and temporal sampling of the system. These are approximate and are to be considered as only an indication of the usual characteristics.

Table 1. Instruments typically used in each observing system that contributes wave measurements.

Observing System	**Typical instrument(s)**	**Typical Sampling**
SOT VOS [2]	Visual Radar	Samples are along shipping routes. Observations may be every 6 hours or better. It is not known how much radar data are present.
DBCP moorings [3]	Heave, pitch, roll	Sample typically in tropics and hourly. The dominant instrumentation is simple heave sensors.
DBCP OceanSITES [4]		Sampling is done at some sites. There are questions about the size of the platform affecting wave measurements.
National moorings	Heave Heave, pitch, roll	At nationally selected sites, usually on coastal shelves or slopes. Sampling can be hourly or better, but highly dependent on the programme. The dominant instrumentation is simple heave sensors.
National monitoring / research	Heave Heave, pitch, roll Coastal radars Wave staffs Others	At nationally selected sites, usually on coastal shelves or slopes. Sampling can be hourly or better, but highly dependent on the programme.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [5]. The objective was " to develop an integrated framework for sustained ocean observing ..." to "... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...". They agreed that implementation of new systems for EOVs "... will be carried out according to their readiness levels ...". The table that describes this, extracted from that report follows.

Table 2. FOO readiness levels.

Readiness Level	**Description**	**Data Management and Information Products**
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
Mature 8	Mission qualified	Data availability: globally available Evaluation of utility
Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan

Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance
Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
Concept 2	Documentation	Socialization of data: Interoperability strategy Expert review
Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [6], that is ”... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.”. OSCAR is a complicated database in that it contains the spatial and temporal sampling requirements as needed by the varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:
uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;
horizontal resolution;
vertical resolution;
observing cycle;
availability

Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The rows relevant to wave measurements have been extracted from OSCAR, reformatted somewhat and are shown here. Some values found in OSCAR would seem to be in error (they appear to be reversed). The entries in the table, in bold and italic, have been reversed from what is in OSCAR (Rec 2).

Table 3. OSCAR entries for waves.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (2) Breakthrough Threshold**	**Vert. Res: Goal Breakthrough Threshold**	**Obs. Cycle: Goal (3) Breakthrough Threshold**	**Availability: Goal (3) Breakthrough Threshold**
Dominant direction: Global NWP - - sea surface	firm	10 deg 15 30	15 km 50 250	Not applicable	1 h 3 12	6 m 30 6 h
Dominant direction: High Res NWP - - sea surface	firm	10 deg 15 30	5 km 10 40	Not applicable	1/2 h 3 6	6 m 30 3 h

Dominant direction: Ocean surface-GOOS - - sea surface	firm	10 deg 13 20	10 km 14.4 30	Not applicable	60 m 108 6 h	2 h 2.5 4
Dominant direction: Synoptic meteorology - - sea surface	firm	20 deg 22.9 30	50 km 79.4 200	Not applicable	3 h 4.8 12	60 m 84 3 h
Dominant period: Global NWP - - sea surface	firm	0.25 s 0.5 1.0	15 km 50 250	Not applicable	1 h 3 12	6 m 30 6 h
Dominant period: High Res NWP - - sea surface	firm	0.25 s 0.5 1.0	5 km 10 40	Not applicable	1/2 h 3 6	6 m 30 3 h
Dominant period: Ocean applications - global assimilation / validation - sea surface	reasonable	0.1 s 0.5 1.0	5 km 10 60	Not applicable	6 m 3 h 24	4.8 m 60 6 h
Dominant period: Ocean applications - delayed mode validation - sea surface	firm	0.1 s 0.5 1.0	50 km 300 1000	Not applicable	6 h 24 10 d	1 d 3 30
Dominant period: Ocean applications - satellite cal / val - sea surface	reasonable	0.1 s 0.5 1.0	10 km 200 1000	Not applicable	1 h 3 24	1 d 3 30
Dominant period: Ocean applications - ocean wave climate - sea surface	firm	0.1 s 0.5 1.0	100 km 500 1000	Not applicable	3 h 6 24	1 d 3 30
Dominant period: Ocean applications - wave coupling - sea surface	reasonable	0.1 s 0.5 1.0	10 km 200 1000	Not applicable	1/2 h 1 6	1 d 3 30
Dominant period: Ocean applications - regional assimilation / validation -	firm	0.1 s 0.5 1.0	0.1 km 5 20	Not applicable	6 m 24 h 24	4.8 m 60 6 h
Dominant period: Ocean surface-GOOS - - sea surface	firm	0.5 s 0.6 1	10 km 14.4 30	Not applicable	60 m 108 6 h	2 h 2.5 4
Dominant period; Synoptic meteorology - - sea surface	firm	0.5 s 0.6 1	50 km 79.4 200	Not applicable	3 h 4.8 12	60 m 84 3 h
Significant wave height: Climate-AOPC - - sea surface	firm	0.1 m 0.3 2.0	25 km 50 250	Not applicable	3 h 4 6	3 h 6 12

Significant wave height: Global modelling - - sea surface	reasonable	0.5 m 0.7 1.0	100 km 150 250	Not applicable	12 h 18 24	30 d 45 60
Significant wave height: Global NWP - - sea surface	firm	0.1 m 0.3 0.5	15 km 50 250	Not applicable	1 h 3 12	6 m 30 6 h
Significant wave height: High Res NWP - - sea surface	firm	0.1 m 0.3 0.5	5 km 10 40	Not applicable	1/2 h 3 6	10 m 30 3 h
Significant wave height: Ocean applications - global assimilation / validation - sea surface	reasonable	0.1 m 0.25 0.25	5 km 10 60	Not applicable	6 m 3 h 24	4.8 m 60 6 h
Significant wave height: Ocean applications - delayed mode validation - sea surface	firm	0.05 m 0.25 0.25	50 km 300 1000	Not applicable	6 h 24 10 d	1 d 3 30
Significant wave height: Ocean applications - satellite cal / val - sea surface	reasonable	0.05 m 0.25 0.25	10 km 200 1000	Not applicable	1 h 3 24	1 d 3 30
Significant wave height: Ocean applications - ocean wave climate - sea surface	firm	0.05 m 0.25 0.25	100 km 500 1000	Not applicable	***3 h*** ***6*** 24	1 d 3 30
Significant wave height: Ocean applications - wave coupling - sea surface	reasonable	0.05 m 0.25 0.25	10 km 200 1000	Not applicable	1/2 h 1 6	1 d 3 30
Significant wave height: Ocean applications - regional assimilation / validation - sea surface	firm	0.1 m 0.25 0.25	0.1 km 5 20	Not applicable	6 m 1 h 24	4.8 m 60 6 h
1-D energy spectrum: Ocean applications - regional assimilation - coast	firm	0.1 m^2/Hz 0.15 0.2	1 km 20 100	Not applicable	6 m 10 h 24	4.8 m 60 6 h
1-D energy spectrum: Ocean applications - - sea surface	reasonable	0.1 m^2/Hz 0.15 0.2	25 km 50 300	Not applicable	6 m 3 h 24	4.8 m 60 6 h
1-D energy spectrum: Ocean applications - - sea surface	firm	0.1 m^2/Hz 0.15 0.2	50 km 300 1000	Not applicable	6 h 24 10 d	1 d 3 30
1-D energy spectrum: Ocean applications - - sea surface	reasonable	0.1 m^2/Hz 0.15 0.2	100 km 500 1000	Not applicable	1 h 3 24	1 d 3 30

1-D energy spectrum: Ocean applications - - sea surface	firm	0.1 m²/Hz 0.15 0.2	100 km 500 1000	Not applicable	***3 h*** ***6*** 24	1 d 3 30
1-D energy spectrum: Ocean applications - - sea surface	reasonable	0.1 m²/Hz 0.15 0.2	10 km 200 1000	Not applicable	1/2 h 1 6	1 d 3 30
Directional energy spectrum: Ocean applications - regional assimilation - coast	firm	0.1 m²/Hz 0.15 0.2	1 km 20 100	Not applicable	6 m 10 h 24	4.8 m 60 6 h
Directional energy spectrum: Ocean applications - - sea surface	reasonable	0.1 m²/Hz 0.15 0.2	25 km 50 300	Not applicable	6 m 3 h 24	4.8 m 60 6 h
Directional energy spectrum: Ocean applications - - sea surface	firm	0.1 m²/Hz 0.15 0.2	50 km 300 1000	Not applicable	6 h 24 10 d	1 d 3 30
Directional energy spectrum: Ocean applications - - sea surface	reasonable	0.1 m²/Hz 0.15 0.2	100 km 500 1000	Not applicable	1 h 3 24	1 d 3 30
Directional energy spectrum: Ocean applications - - sea surface	firm	0.1 m²/Hz 0.15 0.2	100 km 500 1000	Not applicable	***3 h*** ***6*** 24	1 d 3 30
Directional energy spectrum: Ocean applications - - sea surface	reasonable	0.1 m²/Hz 0.15 0.2	10 km 200 1000	Not applicable	1/2 h 1 6	1 d 3 30

Notes:
1. Units: deg is compass degrees
   s is seconds
   m is metres
   m²/Hz is metres squared per Hertz
2. Units: km is kilometres
3. Units: d is days
   h is hours
   m is minutes

No units are indicated when there is no difference from the units of the entry immediately above in the table.

Composite View

As noted above, a wave measurement observing system is not a component of JCOMM OPA but such measurements are made from moorings and from ships. There are no JCOMM targets at present for these data. However, the DBCP programme has a pilot project [7] to test the feasibility of wave measurements from surface drifters. Depending on the success, it should be expected that some targets will be set for the number of drifters with such sensors (Rec 3).

Just as in other chapters dealing with individual ECVs, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The partial analysis by Kent et. al. [8] discussed in the overview of these chapters on ECVs showed a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

There are no international monitoring efforts to deal with wave measurements. Nor is there any global archive for such data. All of the existing measurements, and there are substantial numbers and over many years, are held in national data systems. Efforts within JCOMM are progressing to develop an archive of extreme wave events. The intention has been to compile in-situ wave data on wave events that can be used as test cases for wave modelling groups. This has been slow to develop (Rec 4). If sensors are successful in providing useful wave measurements from surface drifters, then JCOMM will need to be more aggressive in identifying a suitable global archive for such data and in developing appropriate monitoring capabilities (Rec 5).

The next table is a qualitative review of the OSCAR application requirements. In most cases the present state of in-situ sampling does fall within OSCAR requirements.

Table 4: A qualitative assessment of application area for salinity measurements.

Application Area - Comment - Layer	**Uncertainty**	**Horiz. Res**	**Vert. Res**	**Obs. Cycle**	**Timeliness**	**Comments**
Dominant direction: Global NWP - - sea surface	B	L	Not applicable	B+	T+	Moorings along coasts may sometimes achieve threshold Horiz. Res. Many wave instruments measure and report hourly.
Dominant direction: High Res NWP - - sea surface	B	L	Not applicable	B+	T+	Many wave instruments measure and report hourly.
Dominant direction: Ocean surface-GOOS - - sea surface	B	L	Not applicable	B+	T+	Many wave instruments measure and report hourly.
Dominant direction: Synoptic meteorology - - sea surface	B	L	Not applicable	G	T+	Moorings along coasts may sometimes achieve threshold Horiz. Res. Many wave instruments measure and report hourly.
Dominant period: Global NWP - - sea surface	G	L	Not applicable	B+	T+	Instruments are good at determining periods. Same comments as above for Horiz. Res. and timeliness.
Dominant period: High Res NWP - - sea surface	G	L	Not applicable	B+	T	Instruments are good at determining periods. Same comments as above for Horiz. Res. and timeliness.
Dominant period: Ocean applications - global assimilation / validation - sea surface	G	L	Not applicable	B+	T+	Instruments are good at determining periods. Same comments as above for Horiz. Res. and timeliness.
Dominant period: Ocean applications - delayed mode validation - sea surface	G	T	Not applicable	G	L	Instruments are good at determining periods. Same comments as above for Horiz. Res. and timeliness.

Dominant period: Ocean applications - satellite cal / val - sea surface	G	T	Not applicable	B+	L	Instruments are good at determining periods. Same comments as above for Horiz. Res. and timeliness.
Dominant period: Ocean applications - ocean wave climate - sea surface	G	T	Not applicable	G	L	Instruments are good at determining periods. Same comments as above for Horiz. Res. and timeliness.
Dominant period: Ocean applications - wave coupling - sea surface	G	T	Not applicable	T	L	Instruments are good at determining periods. Same comments as above for Horiz. Res. and timeliness.
Dominant period: Ocean applications - regional assimilation / validation -	G	L	Not applicable	G	T+	Instruments are good at determining periods. Same comments as above for Horiz. Res. and timeliness.
Dominant period: Ocean surface-GOOS - - sea surface	G	L	Not applicable	T+	T+	Instruments are good at determining periods. Same comments as above for Horiz. Res. and timeliness.
Dominant period; Synoptic meteorology - - sea surface	G	L	Not applicable	G	T	Instruments are good at determining periods. Same comments as above for Horiz. Res. and timeliness.
Significant wave height: Climate-AOPC - - sea surface	G	L	Not applicable	B+	G	Instruments are good at determining SWH. Same comments as above for Horiz. Res. and timeliness.
Significant wave height: Global modelling - - sea surface	G	L	Not applicable	G	G	Instruments are good at determining SWH. Same comments as above for Horiz. Res. and timeliness.
Significant wave height: Global NWP - - sea surface	G	L	Not applicable	B	T+	Instruments are good at determining SWH. Same comments as above for Horiz. Res. and timeliness.
Significant wave height: High Res NWP - - sea surface	G	L	Not applicable	B	T	Instruments are good at determining SWH. Same comments as above for Horiz. Res. and timeliness.
Significant wave height: Ocean applications - global assimilation / validation - sea surface	G	L	Not applicable	B	T+	See comments for other SWH rows.
Significant wave height: Ocean applications - delayed mode validation - sea surface	G	T	Not applicable	G	G	See comments for other SWH rows.
Significant wave height: Ocean applications - satellite cal / val - sea surface	G	T	Not applicable	B	G	See comments for other SWH rows.

Significant wave height: Ocean applications - ocean wave climate - sea surface	G	T	Not applicable	G	G	See comments for other SWH rows.
Significant wave height: Ocean applications - wave coupling - sea surface	G	T	Not applicable	T+	G	See comments for other SWH rows.
Significant wave height: Ocean applications - regional assimilation / validation - sea surface	G	L	Not applicable	T+	T+	See comments for other SWH rows.
1-D energy spectrum: Ocean applications - regional assimilation - coast	G	L	Not applicable	B+	T+	See comments for SWH rows.
1-D energy spectrum: Ocean applications - - sea surface	G	L	Not applicable	B	T+	See comments for SWH rows.
1-D energy spectrum: Ocean applications - - sea surface	G	T	Not applicable	G	G	See comments for SWH rows.
1-D energy spectrum: Ocean applications - - sea surface	G	T	Not applicable	B	G	See comments for SWH rows.
1-D energy spectrum: Ocean applications - - sea surface	G	T	Not applicable	G	G	See comments for SWH rows.
1-D energy spectrum: Ocean applications - - sea surface	G	T	Not applicable	T+	G	See comments for SWH rows.
Directional energy spectrum: Ocean applications - regional assimilation - coast	G	L	Not applicable	B+	T+	See comments for SWH rows.
Directional energy spectrum: Ocean applications - - sea surface	G	L	Not applicable	B	T+	See comments for SWH rows.
Directional energy spectrum: Ocean applications - - sea surface	G	L	Not applicable	G	G	See comments for SWH rows.
Directional energy spectrum: Ocean applications - - sea surface	G	L	Not applicable	B	G	See comments for SWH rows.

Directional energy spectrum: Ocean applications - - sea surface	G	L	Not applicable	G	G	See comments for SWH rows.
Directional energy spectrum: Ocean applications - - sea surface	G	L	Not applicable	T+	G	See comments for SWH rows.

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement. Plus and minus signs indicate if current sampling is greater than, or less than that requirement.

The assessment in Table 4 shows that overall, the instruments are able to make the measurements needed with the required uncertainties. However, the spatial distribution of wave measurements is clearly lacking for the very large scales; the requirements are met only for regions adjacent to coasts. Finally, there are not nearly enough directional wave measurements to satisfy OSCAR requirements.

Recommendations

Rec 1: It is recommended that OPA in conjunction with DMPA undertake a study to determine how much wave data from ship's radar observations or coastal facilities and with different instrumentation is entering the real-time data streams and to take necessary steps to be sure appropriate metadata are also collected and reported with the data.

Rec 2: The apparent error in the OSCAR tables should be addressed.

Rec 3: Up until now, in-situ wave measurements are confined to coastal regions and a few locations of moorings. Global coverage is possible from satellites, but suitable surface truth comparisons are hard to find and it is difficult to reconcile the horizontal averaging inherent in a satellite image compared to the point time series from a mooring. Should the surface drifter programme prove successful, OOPC should consider how to set appropriate targets in OSCAR for wave measurements.

Rec 4: JCOMM has been working with national agencies interested in wave measurements to put an extreme wave archive in place. It has been slow to develop, perhaps because it has not found the right group to lead this. JCOMM OPA and DMPA should look inside its existing data systems and with IODE to identify the most suitable agency with a strong interest for assembling extreme wave data so that this activity can move more quickly.

Rec 5: There is no global archive for wave data at present nor any coordinated monitoring program. There will be greater urgency for this, if wave measurements from surface drifters proves successful. JCOMM should partner with IODE or perhaps an appropriate World Data System centre to encourage the development of a global archive for wave measurements and appropriate monitoring capabilities.

Acronyms

AOPC: Atmospheric Observation Panel for Climate
DBCP: Data Buoy Cooperation Panel
DMPA: Data Management Programme Area
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GOOS: Global Ocean Observing System
IODE: International Data and information Exchange Committee
JCOMM: Joint Commission on Oceanography and Marine Meteorology
MARINET: Marine Renewables Infrastructure Network
NWP: Numerical Weather Prediction
OPA: Observations Programme Area
OSCAR: Observing Systems Capability Analysis and Review (tool)
SOT: Ship Observations Team
SWH: Significant Wave Height
VOS: Volunteer Observing Ship

WMO: World Meteorological Organization

References

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6. OSCAR: http://www.wmo-sat.info/oscar/observingrequirements
7. DBCP Pilot: http://www.jcomm.info/index.php?option=com_content&view=article&id=58&Itemid=38
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3.16: Winds

A Review of Instruments

Nearly all ships at sea carry anemometers whether they are part of a formal observing programme or not. And many of them provide their observations to their national weather services, knowing that they are contributing to improved weather forecasts.

The WMO has long encouraged this participation and in an effort to standardize the measurement, both on land and sea, have a Commission devoted to Instrumentation and Methods of Observation, CIMO. This body has extensive documentation that describes the various instruments used for meteorological measurements, and sections in their Manual [1] that discuss observation practices at sea. The sections on at-sea observation have been developed closely with experts in IGOSS and CMM prior to the formation of JCOMM from these two groups. The sections on marine observations have been reviewed and revised since JCOMM started in 2001, with contributions from SOT, DBCP and others.

Equally important to the actual observation is the physical location of the instruments on the ship. Instruments placed in locations sheltered from the elements provide data that is not representative of actual conditions. This is particularly important for wind measurements as air flow around the ship and its heading relative to the prevailing wind direction can have significant impacts on recorded winds. Siting of instruments is also treated in the Manual noted above.

With advances in technology, many countries are moving to completely automate meteorological measurement systems (AWS) installed on ships. There are a number of positive consequences of this. First, reporting can be completely standardized and data delivered to shore even if the ship's crew is busy at other tasks. Secondly, the consistency of measurement is less reliant on the diligence and care taken by ship's crew. There are negative consequences, though. Present day automated systems cannot perform the range of measurements that were provided in the past and so weather services are seeing fewer types of observations. AWSs are required to measure at least air pressure, pressure change, temperature and humidity. Optional sensors would include wind speed and direction and sea temperature measurement [2]. Although automated data logging systems make provision for manual input of these other observations, the quantity of these other types has declined in recent years.

It is fortunate that even though wind measurements are optional, these observations are easy to automate and so these continue to be collected routinely.

Calibration and maintenance of instrumentation is an import aspect of measuring marine properties. Even though modern, electronic instruments are now the norm, ensuring the stability of the measurements has a strong impact on the quality of the data. In the VOS programme, there has long been the practice of having PMOs [3] visit participating ships when they come into port. Among other duties, they would check the meteorological instruments to be sure they were functioning properly. The number of PMOs that are working today is smaller than in the past, and their duties are more complex, given the advancements in ship's technology. Still, this is a valuable service that deserves continued support.

Standardized reporting of surface winds at sea began with the Beaufort wind scale. Later speeds were reported in knots, but this has changed to m/s. Directions are reported in compass degrees clockwise relative to true north and as the direction the wind is coming from.

Instrument Characteristics

WMO requires air pressure to be reported with an uncertainly of 0.5 m/s for speeds less than 5 m/s and 10% for greater speeds, with a sensor time constant of 2 to 5 minutes and averaged over 2 or 10 minutes.
Wind sensors are typically a vane to measure direction and a cup-rotor or propeller to measure speed. A number of other techniques have been developed, such as sonic anemometers. The CIMO Manual [2] discusses these.

Data Providers / Observing Systems

The table below provides a list of the sources of wind data. Entries that are in normal font, are observing systems included in, or associated with JCOMM. More detailed information about these systems can be found in other chapters of this report on JCOMM Observing Systems. Entries in italics, are other sources which may be contributing to JCOMM data streams, but may have no formal connections.

The columns titled “Typical Instruments” describes only one type, “WMO approved”. This reflects the acceptance of national meteorological services to adhere to WMO requirements. That is not to say that other methods and higher accuracy ways of measuring winds are not under study, particularly within the research community. For formal reporting purposes to weather services, approved instruments are required.

The column “Typical Sampling” provides some information about the horizontal and temporal sampling of the system. These are approximate and are to be considered as only an indication of the usual characteristics. WMO also has suggestions for frequency of reporting, typically what is called synoptic times (every 6 hours). Reporting at intermediate times, every 3 hours, is encouraged. AWSs often report data hourly.

Table 1. Instruments typically used in each observing system that contributes wind measurements.

Observing System	**Present JCOMM Targets**	**Comments**
DBCP moorings [4]	WMO approved	Sample typically in tropics and hourly.
DBCP OceanSITES [5]	WMO approved	Not at all locations. Reference mooring stations sparsely distributed over the oceans. Report at main synoptic times or better.
SOT SOOP [6]	WMO approved	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation. Report at main synoptic times or better.
SOT VOS [7]	WMO approved	Sample along ships routes.
SOOP underway [8]	WMO approved	Sample along sections, as often as bi-weekly, but more often quarterly. Stations have about 50 km separation. Report at main synoptic times or better.
GO-SHIP [9]	WMO approved	Sample along sections, fewer than once a year. Stations are typically widely separated. Report at main synoptic times or better.
Navies	WMO approved	Varying distribution depending on purposes. Reporting is dependent on national defence policies but when available are at main synoptic times or better.
Fisheries	WMO approved	Often in random sampling patterns with sometimes 10's of km separation between stations. Typically sample on continental shelves. Report at main synoptic times or better.
National moorings	WMO approved	At nationally selected sites, usually on coastal shelves or slopes. Sampling can be hourly or better, but highly dependent on the programme.
National monitoring / research	WMO approved	Sampling is highly dependent on the programme but may report at main synoptic times or better.

System Readiness

As a result of the OceanObs'09 Conference held in Venice in 2009, a task team was organized to prepare a document called a Framework for Ocean Observing [10]. The objective was " to develop an integrated framework for sustained ocean observing ..." to "... guide the ocean observing community as a whole to establish an integrated and sustained global observing system ... organized around essential ocean variables (EOVs), rather than by specific observing system ...". They agreed that implementation of new systems for EOVs "... will be carried out according to their readiness levels ...". The table that describes this, extracted from that report follows.

Table 2. FOO readiness levels.

Readiness Level	Description	Data Management and Information Products
Mature 9	Sustained	Information Products Routinely Available: Product generation standardized User groups routinely consulted
Mature 8	Mission qualified	Data availability: globally available Evaluation of utility
Mature 7	Fitness for purpose	Validation of data policy: Management Distribution
Pilot 6	Operational	Demonstrate: System-wide availability System-wide use Interoperability
Pilot 5	Verification	Verify and validate management practices: Draft data policy Archival plan
Pilot 4	Trial	Agree to management practices: Quality control Quality assurance Calibration Provenance
Concept 3	Proof of concept	Verification of Data Model with Actual Observational Unit
Concept 2	Documentation	Socialization of data: Interoperability strategy Expert review
Concept 1	Idea	Specify data model: Entities, standards Delivery latency Processing flow

ECV Requirements

The WMO has compiled a database, called OSCAR [11], that is "... the official repository of requirements for observation of physical variables in support of WMO Programmes and Co-sponsored Programmes.". OSCAR is a complicated database in that it contains the spatial and temporal sampling requirements as needed by the varied application areas. Clearly, the requirements are varied and these are reflected in the targets recorded. Confidence in the criteria is captured in another column. OSCAR uses 5 criteria to categorize the EOVs. These are:

uncertainty - the estimated range of observation errors on the given variable, with a 68% confidence interval;

horizontal resolution;

vertical resolution;

observing cycle;
availability

Each of these categories has three criteria as described here:
Threshold - is the minimum requirement to be met to ensure that data are useful;
Breakthrough - an intermediate level between "threshold" and "goal" which, if achieved, would result in a significant improvement for the targeted application. The breakthrough level may be considered as an optimum, from a cost-benefit point of view, when planning or designing observing systems and timeliness.
Goal - an ideal requirement above which further improvements are not necessary;

The rows relevant to winds (wind stress has not been included) have been extracted from OSCAR, reformatted somewhat and are shown here. Some values, indicated in bold and italic, found in OSCAR would seem to be in error (Rec 1).

Table 3. OSCAR entries for winds.

Application Area - Comment - Layer	**Confidence Level**	**Uncertainty: Goal (1) Breakthrough Threshold**	**Horiz. Res: Goal (2) Breakthrough Threshold**	**Vert. Res: Goal Breakthrough Threshold**	**Obs. Cycle: Goal (3) Breakthrough Threshold**	**Availability: Goal (3) Breakthrough Threshold**
Horizontal surface speed: Climate-GOOS - - over sea	firm	1.0 m/s 1.3 2.0	25 km 39.7 100	Not applicable	24 h 45.9 7 d	24 h 45.9 7 d
Horizontal surface speed: Climate-OOPC - - over sea	reasonable	0.5 m/s 0.6 1.0	10 km 40 500	Not applicable	1 h 3 24	1 h 2 12
Horizontal surface speed: Global NWP - - over sea	firm	0.5 m/s 1.5 2.0	15 km 100 250	Not applicable	1 h 6 12	6 m 30 6 h
Horizontal surface speed: High Res NWP - - over sea	firm	0.5 m/s 1.0 3.0	0.5 km 5 20	Not applicable	1/2 h 3 12	15 m 30 120
Horizontal surface speed: Nowcasting - - over sea	firm	1.0 m/s 1.7 5.0	5 km 10.8 50	Not applicable	15 m 34.3 3 h	15 m ***0 y*** 60 m
Horizontal surface speed: Synoptic meteorology - - over sea	firm	2.0 m/s 2.7 5.0	20 km 43.1 200	Not applicable	1 h 2.3 12	60 m 84.4 3 h
Horizontal surface vector: CLIC - - over sea	unstated	1.0 m/s 1.7 5.0	25 km 39.7 100	Not applicable	12 h 15.1 24	30 d 37.8 60

Horizontal surface vector: Climate-GOOS - - over sea	firm	1.0 m/s 1.3 2.0	25 km 39.7 100	Not applicable	24 h 45.9 7 d	24 h 45.9 7 d
Horizontal surface vector: Climate-AOPC - trend - over sea	firm	0.5 m/s 1.0 5.0	10 km 50 500	Not applicable	1 h 3 6	3 h 6 12
Horizontal surface vector: Climate-OOPC - - over sea	firm	0.5 m/s 1.0 5.0	10 km 20 100	Not applicable	1 h 3 24	3 h 5 12
Horizontal surface vector: CLIVAR - - over sea	reasonable	1.0 m/s 2.0 5.0	50 km 100 250	Not applicable	12 h 18 24	3 d 4 7
Horizontal surface vector: Global modelling - - over sea	reasonable	1.0 m/s 2.0 5.0	50 km 100 250	Not applicable	12 h 18 24	30 d 45 60
Horizontal surface vector: Global NWP - - over sea	firm	0.5 m/s 2.0 3.0	15 km 100 250	Not applicable	1 h 6 12	6 m 30 6 h
Horizontal surface vector: High Res NWP - - over sea	firm	0.5 m/s 1.077 5.0	2 km 10 40	Not applicable	1/2 h 3 12	15 m 30 2 h
Horizontal surface vector: Marine biology - - over sea	firm	2.0 m/s 2.7 5.0	4 km 9.3 50	Not applicable	24 h 30.2 48	3 h 4 7
Horizontal surface vector: Nowcasting - - over sea	firm	1.0 m/s 1.7 5.0	5 km 10.8 50	Not applicable	15 m 34.3 180	15 m 23.8 60
Horizontal surface vector: Ocean applications - ocean forecasting open ocean - over sea	firm	0.5 m/s 2.0 5.0	10 km 25 50	Not applicable	1 h 3 6	12 h 24 48
Horizontal surface vector: Ocean applications - marine modelling - over sea	reasonable	0.5 m/s 2.0 5.0	5 km 10 60	Not applicable	6 m 3 h 24	4.8 m 60 6 h

Horizontal surface vector: Ocean applications - maritime safety services - over sea	firm	0.5 m/s 2.0 5.0	0.1 km 5 20	Not applicable	6 m 3 h 24	4.8 m 60 6 h
Horizontal surface vector: Ocean applications - ocean forecasting coastal -	firm	0.5 m/s 2.0 5.0	1 km 10 25	Not applicable	1 h 3 6	3 h 6 12
Horizontal surface vector: Ocean applications - atmospheric modelling coastal -	reasonable	0.5 m/s 2.0 5.0	1 km 5 25	Not applicable	6 m 3 h 24	4.8 m 60 6 h
Horizontal surface vector: Synoptic meteorology - - over sea	firm	2.0 m/s 2.7 5.0	20 km 43.1 200	Not applicable	1.0 h 2.3 12	60 m 84 180

Notes:
1. Units: m/s is metres per second
2. Units: km is kilometres
3. Units: y is years
d is days
h is hours
m is minutes

No units are indicated when there is no difference from the units of the entry immediately above in the table.

It should be noted that programmes often carry out sampling by ships along lines. As a consequence, sampling in the Northern Hemisphere Atlantic ocean, though still not uniformly distributed, is not bad. In other oceans sampling is less well distributed and even poorer in high latitude regions.

Composite View

It is possible to review each of the observing systems separately considering the requirements as stated in OSCAR and the readiness level as stated in the FOO. However, this chapter strives to provide a composite view of how well the observing systems are able to meet requirements. This is not a simple task. The analysis by Kent et. al. [12] discussed in the overview of these chapters on ECVs shows a way for a quantitative evaluation. As noted, this would need to be done for each ECV and each application area (each row in the above table).

At the start of JCOMM, it was recognized that a way was needed to describe objectives for the observing system that was easy to understand and provided meaningful targets to work towards. At the time, the chair of the OCG, Mike Johnson, used targets that already existed and were articulated by individual observing systems, such as by Argo, or set values that he considered to be realistic. Typically these translated to putting into operation a certain number of instruments, or making a certain number of observations. These have been used ever since as a way to gauge how well JCOMM is performing. These are very pragmatic goals, easy to articulate to funding agencies and fairly simple to measure. Such goals have been updated more recently. The table below reproduces these targets for those JCOMM observing systems that contribute to wind measurements.

Table 4. Present targets for JCOMM Observing Systems

Observing System	Present JCOMM Targets	Comments
DBCP moorings	131 moorings Topical oceans	Coastal moorings are deployed with national discretion. Tsunami buoys are in another IOC programme.
DBCP OceanSITES	29 reference moorings 58 others	At selected sites, 10 in Atlantic, 10 in Pacific, 5 in Indian Oceans.
SOT SOOP	37,000 XBTs deployed 26 High density lines (HDX) 25 Frequently repeated lines (FRX)	All carried out on selected lines to meet specific scientific objectives. HDX lines sampled 4 times a year, with 10-20 km between stations. FRX lines sampled 20 repeats a year with 50-100 km between stations.
SOT VOS	3000 active ships 500 AWS 250 VOSClim	Active ships provide more than 20 reports/month.
SOOP underway	No specified requirements	
GO-SHIP	Selected WOCE lines Repeated each decade (or better) Surface to bottom at 5m resolution or better	Network encompasses fewer lines than WOCE.

JCOMMOPS only provides maps to locations of VOS, or moorings reports [13] (Rec 2). There are no obvious tools that tell how many wind observations are received and from where in a given time period (Rec 3).

The JCOMMOPS presentations reflect the individual observing system targets, but these are not a perspective that well represents an ECV perspective. A start towards this goal is provided at OSMC [14]. At this site and at the “Observing System Metrics tab, a user can select a parameter, a time frame and either one or all platforms. A further selection of gridding, and display presents a map that portrays the composite view, or individual platform view. There are some weaknesses to this display (Rec 4), but it is working towards the right goal. One notable lack is that a user cannot plug in the OSCAR requirements for any particular application area, as shown in table 3. But considering the present state of in-situ sampling, this “lack” is sensible and pragmatic, as is discussed below.

The next table is a qualitative review of the OSCAR application requirements.

Table 5: A qualitative assessment of application area for surface wind measurements.

Application Area **- Comment** **- Layer**	Uncertainty	Horiz. Res	Vert. Res	Obs.Cycle	Timeliness	Comments
Horizontal surface speed: Climate-GOOS - - over sea	G	L	Not applicable	G	G	
Horizontal surface speed: Climate-OOPC - - over sea	G	T	Not applicable	T+	T+	

Horizontal surface speed: Global NWP - - over sea	G	T-	Not applicable	B+	T+	
Horizontal surface speed: High Res NWP - - over sea	G	L	Not applicable	T+	L	
Horizontal surface speed: Nowcasting - - over sea	G	L	Not applicable	L	L	
Horizontal surface speed: Synoptic meteorology - - over sea	G	L	Not applicable	T+	L	
Horizontal surface vector: CLIC - - over sea	G	L	Not applicable	G	G	
Horizontal surface vector: Climate-GOOS - - over sea	G	L	Not applicable	G	G	
Horizontal surface vector: Climate-AOPC - trend - over sea	G	T	Not applicable	T+	T+	
Horizontal surface vector: Climate-OOPC - - over sea	G	L	Not applicable	T+	B+	
Horizontal surface vector: CLIVAR - - over sea	G	T-	Not applicable	G	B-	
Horizontal surface vector: Global modelling - - over sea	G	T-	Not applicable	G	G	
Horizontal surface vector: Global NWP - - over sea	G	T-	Not applicable	B+	T+	
Horizontal surface vector: High Res NWP - - over sea	G	L	Not applicable	T+	L	
Horizontal surface vector: Marine biology - - over sea	G	L	Not applicable	G	T+	

Horizontal surface vector: Nowcasting - - over sea	G	L	Not applicable	L	L	
Horizontal surface vector: Ocean applications - ocean forecasting open ocean - over sea	G	L	Not applicable	T+	G	
Horizontal surface vector: Ocean applications - marine modelling - over sea	G	L	Not applicable	T+	T+	
Horizontal surface vector: Ocean applications - maritime safety services - over sea	G	L	Not applicable	T+	T+	
Horizontal surface vector: Ocean applications - ocean forecasting coastal -	G	L	Not applicable	T+	B+	
Horizontal surface vector: Ocean applications - atmospheric modelling coastal -	G	L	Not applicable	T+	T+	
Horizontal surface vector: Synoptic meteorology - - over sea	G	L	Not applicable	T+	L	

Notes: G = goal, B = breakthrough, T = threshold, L = less than requirement. Plus and minus signs indicate if current sampling is greater than, or less than that requirement.

The assessment in Table 5 assumes that platforms that measure pressures also measure winds and do so within the uncertainties specified by WMO. It also assumes that such measurements are made and reported within at least the 4 synoptic times required by WMO or more frequently.

As long as instruments and measurements are made at or better than WMO requirements, it would appear that instruments are able to meet uncertainty requirements. As for other parameters, the spatial distribution of measurements can meet the minimum requirements in many application areas. Observing cycle and timeliness can in most circumstances meet or exceed the minimum requirements.

Overall, the observing systems contributions to surface wind measurements are from ships and moorings. Data systems for these are at a FOO readiness level of Mature 8 or 9, though lacking in the volume of data reported.

Recommendations

Rec 1: The error in the OSCAR tables should be corrected.

Rec 2: The maps presently on the JCOMMOPS site showing VOS locations are from 2009. This was noted at a recent SOT meeting, but it is recommended that this be addressed as soon as possible so that up-to-date information is available.

Rec 3: Each of the formal JCOMM programmes should provide simple displays on their home web pages that articulate as precisely as possible the observing targets, and show how well these targets are being met. Examples to emulate would be those provided by DBCP showing buoys with barometers.

Rec 4: The displays allow a gridding in terms of latitude and longitude squares. The OSCAR requirements are set by units of meters (and kilometres). Also there are many different horizontal resolution requirements in OSCAR than are possible to specify at OSMC. Given the state of in-situ sampling, it is reasonable that all scales are not supported. However, a gridding based on meters / kilometres should be presented rather than degrees of latitude and longitude.

Acronyms

AOPC: Atmospheric Observation Panel for Climate
AWS: Automated Weather (observing) System
CIMO: Commission on Instruments and Observations (of WMO)
CliC: Climate and Cryosphere (project)
CLIVAR: Climate Variability and Predictability
CMM: Commission on Marine Meteorology
DBCP: Data Buoy Cooperation Panel
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GOOS: Global Ocean Observing System
GO-SHIP: Global Oceans Sustained Hydrographic Investigations Program
IGOSS: Integrated Global Ocean Station System
JCOMM: Joint Commission on Oceanography and Marine Meteorology
JCOMMOPS: Joint Commission on Oceanography and Marine Meteorology Observations Support Centre
NWP: Numerical Weather Prediction
OCG: Observations Programme Coordinator
OOPC: Ocean Observations Panel for Climate
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
PMO: Port Meteorological Officer
SOOP: Ship Of Opportunity Programme
SOT: Ship Observations Team
VOS: Volunteer Observing Ship
WOCE: World Ocean Circulation Experiment
WMO: World Meteorological Organization
XBT: Expendable Bathythermograph

References

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Part 4: Concluding Remarks and Recommendations

Report Summary

The impetus for the preparation of this report came from JCOMM and the desire of the co-Presidents to improve access to marine data. The assembly of data is not well understood outside of the individual data systems, and potential users are frustrated by not being able to gain easy access to the data that they know is being collected.

This first part of this report is focused on a review of the data systems of observing programmes that either are under the umbrella of JCOMM or closely associated with it. There are other data collection activities taking place, some of which might be exploited in the JCOMM effort to assemble as many of the marine observations as possible, particularly those that report in real-time. Data systems associated with JCOMM have strong overlaps to IODE systems and activities and so these have been discussed as well, though not with the same degree of detail. This broader view was employed because ignoring these other activities is too restrictive.
In preparing the review, criteria of what constitute important attributes of a data system were extracted from presentations made at the OceanObs'09 [1] meeting. Information about the observing systems that was available from their on-line presence was used to weigh how well each met the attributes. From this assessment a number of recommendations pertaining to each was generated and are available in the observing system chapters.

A second objective was to take a “variable based” perspective. In this view, information about what data are collected for each variable individually was assembled. Combining data from a variety of sources and often different instruments, poses challenges. For example, very high accuracy water temperature profiles can be collected with CTDs, but water temperature profiles are also widely collected with poorer accuracy XBTs. Combining these effectively depends on weighing the instrument characteristics and choosing the appropriate application areas in which these combinations can contribute knowledge.

In choosing what variables were to be assessed, and how to weigh the present state of data availability, information from the WMO OSCAR database [2] was used. This database contains targets on measurement uncertainties, horizontal and vertical scales of observing, repeat cycles of those measurements, and required timeliness of reporting the data. The variables in OSCAR are GCOS's Essential Climate Variables, ECVs. An output of OceanObs'09 was a Framework for Ocean Observing, FOO [3], that identified the need to develop a list of essential ocean variables, EOVs. This list does not yet exist, though no doubt, there will be overlaps with the ECVs. This report uses the ECV list in OSCAR.

The FOO also developed a chart of “Framework Processes by Readiness Levels”. There are three columns in this chart, one being “Data Management and Information Products”. It is this particular column that was used to provide an qualitative assessment of the readiness state of data systems for each ECV. It is based on a simple perception by the author of how well observing system in total meet the marine variable's sampling targets by each application area in OSCAR.

In the course of assembling information on individual observing systems and ECVs, certain recommendations occur over and over. More general restatements of these follow as recommendations 1 through 10.

Data System Considerations

Information about the actual, at-sea operating characteristics of instruments is difficult to find in general (Rec 11).

There are a number of consequences of the variety of programmes making ocean observations for each ECV. For example, at present each of the observing systems that provide ocean temperature profiles has its own data system. This is true whether or not the system is associated with JCOMM or not. There are good reasons for this including the different times that systems have been built, the requirements on timeliness of reporting, technological developments, data and metadata content, and processing, archive and dissemination needs. In some cases, newer systems have been built taking into account lessons learned from older systems. An example of this is the Argo data system, built considering the experience gained from GTSPP and WOCE. That this experience was used is more a reflection of the experience of the initial co-chairs of the ADMT rather than a conscious effort by Argo. It would be best if each new system built on the experience of older systems, but at present there is no documented “history” of how data systems are built and so those responsible for new systems must rely on the experience of the people tasked with getting the latest system built (Rec 12).

The FOO provides a classification system for the maturity level of an observing and data management system for an EOV. As part of this, the sampling need and strategy needs to be clear. For some instruments or observing systems, such as ADCPs for ocean velocity and TSGs for underway data, strategies are not clear. One consequence is that where there are observing programmes using these instruments, the connections to the scientific requirements, and the observing strategies are weak. This results in inadequate attention to these ECVs within JCOMM, and elsewhere (Rec 13).

Data Format Issues

Data and metadata characteristics of a data stream have important impacts on choices for transport, archive and dissemination formats. Transport formats in real-time typically have been restricted by bandwidth either from the instrument to communications system, or instrument to ship recorder to communications system. Global distribution formats in real-time have been restricted in content by old ASCII forms, though this is being overtaken by the table driven format called BUFR [4]. The transition from ASCII forms to BUFR is exploiting the facility in BUFR to construct templates, a formatting aid that makes encoding and decoding simpler. However, such templates curtail the main advantage of BUFR in changing the message content based on only what information is available. Present BUFR templates are as inflexible as the old character code forms (Rec 14).

A strength of BUFR is also a weakness. BUFR allows a data encoder to provide only the data and metadata that is available. While this makes it highly efficient, and therefore minimally taxing on communications bandwidth, it highlights an important problem. The different observing systems that collect ocean profile data all report different metadata. Some provide none to minimal information on what instruments were used and how, about instrument precision and accuracy, about platforms, about data collection procedures, and so on. There are quite sensible explanations about why this is so. There are historical lessons (e.g the Druck pressure sensor problem in Argo, XBT fall rate questions in SOOP) that argue for recording much more information about instrumentation than is customary at present. Experience in developing climate time series and data sets, such as ICOADS, inform us that the interpretation of historical data can be confounded by a lack of metadata. This lesson is clear, but efforts to improve current practices are uncoordinated.

JCOMM in collaboration with IODE and other groups could take the lead in examining instrument by instrument what is known to be the important metadata to store in archives with measurements made by that instrument. Technology may well be of help here with the increased capabilities of Sensor ML. This can feed into specifications for observing practices, for data reporting, processing, archiving and dissemination systems. This could standardize metadata content and improve what is going into real-time ocean modelling, into long term archives and the historical record (Rec 15).

Within formats, terminology is used that have clear definitions within a programme, but may be ambiguous to users outside the programme. This argues for more formal language for describing content in formats. A step towards this is the use of CF conventions [5] in netCDF files. But looking at this web site shows there are a number of conventions that currently exist (there are more than documented here). The MMI [6] is an initiative to try to converge these, or at least develop a mapping from one to another . Newer technologies, such as SensorML, may have a role to play here. There is work underway in SeaDataNet2 [7], a European Union project to build a standardized system for managing the large and diverse data sets collected by the oceanographic fleets and automated observation systems. JCOMM and IODE have the ODSBP [8] which has a similar objective of converging standards for use in oceanography. There is much work yet to do (Rec 16).

Data processing includes the various steps including format conversion, error and duplication checking, and archiving strategies. In some data systems, there is metadata provided in the data format to document errors found, corrections taken, processing steps the data have passed through, data quality flagging and so on (e.g. see the GTSPP format description [9]). The inclusion of quality flags helps alert users to potential problems identified in the data. Documentation of testing performed and external detailed documentation of those tests informs users of how potential errors have been identified. Including information on processing informs both users and archive staff of details of what has been done to the data. All of this is valuable.

But not all programmes carry out the same procedures on data of the same type, they do not all document what is done, nor the results. Convergence to a single set of procedures is an ideal and should be encouraged, but in the meantime, thorough documentation should be encouraged [Rec 17]

Dissemination Considerations

Because there are often many data sources there is a strong likelihood of a user downloading duplicate or near duplicate data sets. There is no easy way to determine this level of duplication and so a user often has to rely on their own methods for discovering the degree of duplication in data from different sources. In some cases, duplication is not as serious a problem, such as in model assimilation where supersets of data are often formed before gridding of observations is done. But for other purposes, duplication is an issue and this is more significant as larger data sets are assembled.

Duplication is an issue that has not received the attention that is needed. There are different ways to attack the problem. The CRC method, discussed in the chapter on the SOOP observing system, works at a very deep level of detail. It has the potential to resolve duplications very efficiently and has the advantage of being a solution that can be implemented incrementally but still deliver positive impacts. Another approach is to devise a product specification for data sets such as is used by NASA [10]. Such a scheme requires a broad based agreement of how to subdivide products (such as data sets) in a way that makes clear data origins and degrees of screening for duplication. It is possible that more than one solution will be needed (Rec 18).

Assembly of data from the various sources will raise another set of issues. First, there is no single data format that is used exclusively. Within meteorology, BUFR is the format of choice for real-time data and it is also used for outputs of models. Within oceanography and meteorology, netCDF [11] is becoming one that is commonly used. Consolidations of data from various sources, such as ICOADS [12] represents, or other sources use data formats tuned to their requirements. The result is that anyone assembling data from the variety of sources will need to do some format translation, though if everything is in something like netCDF this may be a bit easier.

Using a Services Oriented Architecture, SOA, in data dissemination can help in dealing with data from a variety of sources. Readers can consult Wikipedia [13] and the references contained there for an overview or more in depth discussions of this technology. In essence, SOA puts a software layer between data and distribution that allows for machine / man to machine request-reply actions. In this way, data stored in different archive structures, with different content and even different locations can all respond to a standardized information query and reply with a standardized output. The output is usually files that are compliant with OGC web service standards [14,15] that users can process for themselves, or more likely can be used by the requesting application for a presentation to another process or a person. As example, a user may ask for a map display of the locations of all sea surface temperature data from all resources implementing an SOA. Each resource returns the information specified in the request and this is displayed. Such architecture is not always evident in the on-line resources cited here or presented elsewhere. But, for example, the presentations at the OSMC use this strategy to combine resources. Of course, when combining data acquired through web services, a user must be careful that the variables delivered are named in a common or compatible way. In some cases, the availability of web services is made known when people access a web site, and in this case, the option of exploiting this is evident (Rec 19).

Using the data in some analysis or other will also need to take into consideration at least the accuracies of the instrumentation used if not other characteristics of the sampling or observing methods. Data dissemination sites must be sure to provide documentation that can help a user discern the differences in the measurements included in the data (Rec 20).

Data Portals

There are two global data portals that are directly pertinent to JCOMM operations. There is the WIS [16], operated by WMO, and the ODP [17], operated by IODE. Both of these operate with a data discovery component that describes data sets that are accessible to them. Under the WIS, the data discovery records are located at Global Information System Centers, GISCs. There are a few national meteorological services that operate a GISC and, in principle, all such records are shared so that the data described is available through whatever GISC a user goes to. As the WIS operations are still being developed, it is not certain that this sharing is universally true.

The ODP has a single site operated through the IODE Project Office [18]. For this portal, various ocean data centres provide data discovery metadata and also provide access to data sets they agree to share through the portal. Some subsetting of data is possible through the portal. The suite of data available through this portal is still limited although IODE is striving to increase what is available. However, there is a link to the WIS through the data access tab on the ODP home page.

In both cases, the design and intention of these portals is to be completely interoperable. That is, a user should be able to see ocean data sets described at GISCs, and meteorological data sets referenced through the ODP. This is not yet fully in place (Rec 21).

Monitoring

In looking at the OSMC and JCOMMOPS web sites, there is noted to be some overlap in the sorts of displays that are provided, in particular the displays of locations of real-time data received by platform. While it may be sensible to provide this redundancy, it was noted that counts of platforms for the same time period are different at times between OSMC and JCOMMOPS. This may be a result of each getting data from different GTS data feeds, or a difference in counting or some other factor. Sometimes these differences are large enough to raise questions of why this is so (Rec 22).

At a recent OOPC/OCG joint meeting (Sep 2013), a presentation from JCOMMOPS showed progress towards a modernized web site. This was good to see and it is hoped that recommendations from this report will not be received too late to influence this work. It was noted that there was potentially even greater overlap in activities between JCOMMOPS and OSMC. Some degree of redundancy is acceptable, but it appears that what is being developed at JCOMMOPS and at OSMC are not coordinated (Rec 23).

In order to show the sorts of displays that appear at JCOMMOPS and OSMC, it is necessary for each to download real-time data streams. Both sites provide facilities to look at reports from previous time frames, and some quite old. It is important to provide such information, but is either JCOMMOPS or OSMC the most appropriate place for this? It may be that these sites should support real-time / operational activities and leave the display of past data and performance to an organization such as IODE (Rec 24,25).

Recommendations

Rec 1a: Each observing system currently decides what to monitor, how frequently this is done, how often reported and to whom; this is appropriate. The point of monitoring is to be able to gauge if the observing system / data system is performing to meet objectives. For some observing systems, the objectives are not clear and consequently the monitoring is weak. OCG should use this report to press observing / data systems to improve their monitoring.

Rec 1b: All observing systems need to be able to report how much data they collect, how much reaches data system archives and how much is distributed to users. This is not now the case, though some observing systems are better than others. This also needs to be done on an ECV by ECV basis. The “data units” to report need to be common across observing systems so that they can be combined in a reasonable way to assess how well each contributes to the collection of an ECV. It is recommended that OCG lead the definition of sensible “data units”. It should work with OOPC, DMCG and IODE and perhaps others as appropriate. It is recommended that the development start with a handful of ECVs, but that this list be reasonably diverse so that the individuality of measuring different ECVs is considered early on. Second, only a few and simple “data units” should be chosen at the start. Finally, designate agents or seek volunteers that will undertake to generate these results that can be compared across observing systems, and taken to GCOS and GOOS regularly. An annual reporting is suggested, but this needs to be decided as the reporting requirements become set.

Rec 2: A number of observing programmes exhibit some degree of fragility. This is not just in the data collection aspect. Data systems are funded through contributions of individual countries, and these may not have a stable funding base. If observations need to be collected and used routinely and consistently, funding needs to be routine and consistent. It is recommended that JCOMM co-Presidents and others with senior positions in international organizations continue to encourage countries to place their routine observing and data processing and dissemination system support on stable funding. At the same time, it is recommended that OCG encourage individual observing systems to develop concrete examples of the value (economic, scientific, other) of their observing systems and the data they produce. These examples should be widely advertised.

Rec 3: Much of the information compiled in this report has come from observing system web pages. There is a fairly wide diversity in the ease that was encountered in assessing how well the data system meets the list of attributes derived from OceanObs'09 presentations. Sometimes, the information is easily found, and at other times it is deeply buried. OCG should review the attributes used by this report (perhaps reduce the number or detail) and ask each observing system to present the information on their web sites. It is suggested that they use the same headings as in this report (assembly, archiving and processing, etc.) to provide consistency. The layout or presentation need not be identical, but the information should be easily found.

Rec 4: Web pages with very useful information can vanish. Information about the methods of data collection and processing are essential to carry forward into the future as these all have impacts on the usability of the data. Some of this information should be retained in close association with the data (such as instruments used, uncertainties). Other information (such as details on the quality control systems used) should be retained by the data system itself. But to secure this information from accidental loss, it is recommended that DMCG lead a project to secure the information for every JCOMM observing system. DMCG should collaborate with OCG to decide what information should be considered for this treatment, but it is suggested that the general descriptions, such as appear on web pages, are candidates to be considered. It is suggested that the IODE Digital Library be considered as the long term repository of the documentation, and a refresh cycle set. This activity should align with the activities to support the JCOMM Catalogue of Standards and Best Practices.

Rec 5a: Originally, it was planned to provide a data flow diagram for each observing system. For some this was easy as they already exist. But it was clear that for others this was much harder to do, too hard in fact. As well, each existing data flow diagram represents what was considered to be the more important functions, and these differ across systems. It is recommended, therefore, that OCG lead (with DMCG consultation) the development of a uniform way to describe data flow, and to have each observing system develop a succinct diagram that delivers the information. This should appear prominently on the web site of each observing system. It is recommended that the diagram take the perspective of a potential data user. In that respect the diagram needs to identify the main agencies that contribute particular functions to the movement of data from collectors to users. This might be considered an “address book” of who to contact if questions arise about how data are managed through the data system. A very important component of the diagram is to identify the institutional agencies that receive data from an observing system. This will aid in identifying different versions of the data. Linking to the information discussed in recommendation 3 should be considered.

Rec 5b: Some of the agencies involved in handling the data coming from JCOMM observing systems, also handle data from other sources. These data may be mixed with those from JCOMM sources. Any data flow diagram needs to identify these additions and where they occur in the data flow.

Rec 6: The web pages of some observing systems do a very good job of presenting the view of a well coordinated programme. Others send readers to multiple other web sites where information is not consistently presented and generally gives the impression of a lack of coordination at least in the data systems. It is recommended that OCG press the observing systems (those requiring it are identified in individual chapters) to improve their web presence.

Rec 7: Some observing systems collect data on only a few ECVs and some collect data on many. For some systems it was difficult to find a simple list of what variables are collected by the programme. It is recommended that every observing programme compile such a list and give it prominence on their web site. The information presented in such a list would be even more helpful if there is also a list of even the nominal instrumentation used to measure each ECV.

Rec 8: It was encouraging to see that many observing systems are using netCDF and CF conventions as one “data format” for distribution. Even though having data in netCDF does not guarantee identical data structures in the files, it does impose a level of standardization that is helpful. It is important to use CF (or some such) convention as well. It is recommended that every JCOMM observing system offer data in netCDF with CF conventions in addition to whatever other form(s) they wish to support.

Rec 9a: The development of the Observing System Monitoring Center, OSMC, is a positive development. There is still work to do and this is noted in individual chapters. OCG should continue to press for development of the capability at OSMC.

Rec 9b: OSMC only deals with the data that report in real or near real-time, and even then not all of it. While this may be the focus of JCOMM, the tools at OSMC only provide part of the “story” on the availability of data of any particular ECV. It is recommended that DMCG use its influence with IODE to present the complete picture of available data so that ECV targets can be readily assessed. OOPC should be consulted on how it would like to see ECV/EOV reporting.

Rec 10a: OSCAR has been created by WMO and its underlying premise is the requirement for a global observing system with sampling more or less uniformly distributed in space. This is valid when the measurement of variables is amenable to satellite remote sensing techniques. However, in-situ observing programmes frequently do not have the ability to measure on global scales and at the observing cycles that are typically expected for meteorological variables. Programmes such as SOT, for example, can measure at 10-100 km resolution, but only along a ship's track, and there are not enough ships operating to have a global distribution in any reasonable time frame. The consequence is that judging in-situ observing system performance by the tables presently in OSCAR is bound to result in failure to meet even the minimum targets. Perhaps where there is a viable satellite system to measure an ECV, the in-situ observing system needs to be judged on how well it provides the ground truth to validate satellite measurements. The requirements of the in-situ component may then be something like so many measurements at so many locations – something closely related to objectives of OceanSITES. For those variables that satellites cannot measure, another set of targets, not those of OSCAR, needs to be set. It is recommended that OOPC lead the restatement of requirements on measuring ECVs that recognizes when in-situ measurements contribute surface truth and when they are the sole source of data. This will provide a much better set of criteria against which the performance of in-situ observing systems can be measured.

Rec 10b: GCOS and GOOS have the very broad goals of building an observing system that meets the requirements of measurements for marine and other variables. The first quantification of this requirement is OSCAR. A complete assessment of the observing system as a whole to deliver the required measurements of any particular ECV needs to encompass both in-situ and remote sensing systems, those within the purview of JCOMM and those outside. Such a comprehensive assessment needs to include, for example, data sources such as coastal radars for waves and the many coastal moorings that fall outside of JCOMM. It needs to look at delayed mode data as well as real-time and take into consideration the uncertainties associated with the measurements coming from the different sources. This is not an easy or simple job. As a starting point, It is suggested that OOPC consider how to execute such an assessment for one or two ECVs using JCOMM and satellite sources only.

Rec 11: Each data collection programme that contributes data to the overall assembly of measurements of an ECV should be encouraged to provide documentation of the recommended instruments, or at least recommended measurement requirements in terms of accuracy and precision. Where JCOMM plays a coordination role, the OCG should insist on this.

Rec 12: Data system developers do not provide documentation that explains construction choices made when a data system is built. Consequently, those responsible for a new system have no history to draw on except that which resides with the immediate development team. It should be a requirement that documentation be provided, not simply of what was built, but that describes the reasons for development choices that were made. In this case, the technology is of lesser importance; it is the functionality that should be explained. JCOMM should encourage members of the data system teams to provide such documentation. Further, this documentation should be stored in the joint Ocean Data Standards and Best Practices library of JCOMM and IODE or an equivalent easily accessible repository.

Rec 13: ADCPs and TSGs are two good examples. For the first, the only place within JCOMM where these types of instruments are mentioned is on SOT and SOOP web pages. In the case of ADCP, it is unclear whether SOT takes responsibility for these measurements. In the case of TSGs, SOOP seems to take responsibility, but the discussions of collection and management of underway data gets little attention. JCOMM should review its observing system Panels, to ensure that it is clear what instrumentation/data are within their scope of operations, and review if those within are adequately managed.

Rec 14: BUFR templates hobble the efficient use of BUFR. The current set of marine data templates are little better that the older character code forms in having fields for all possible data and thereby requiring the use of “missing values” when such data do not exist. There are more efficient ways of encoding only the data that are available. The template idea being worked on by the JCOMM DMPA TT on Table Driven Codes is one possible solution. Their work should be strongly encouraged.

Rec 15: JCOMM and IODE should develop recommendations on instrument metadata and encourage their use in all programmes operating under or partnered with them (this is part of what the DMPA TT mentioned in recommendation 14 is working on). As a start, an idea to consider is to request JCOMMOPS to scan the metadata information on instruments it holds, and for each instrument, download a copy of the manufacturer's specifications. As new instruments are deployed, new specification sheets would be assembled. At some point, these copies could be provided to the IODE digital library for safe keeping and thereby would improve the historical information about data collection instruments. Consideration of a more sophisticated way to preserve metadata that provides a database and on-line access would go beyond the simple suggestions offered here.

Rec 16: JCOMM in conjunction with IODE has an important role in encouraging the adoption of standards for data, metadata, descriptions, formats, etc. At this point, JCOMM and IODE should be aggressive in pushing programmes operating under or partnered with them to converge to standards that allow ready mapping between them, if not adoption of the same standards.

Rec 17: JCOMM and IODE should strongly encourage global standards for processing data, and recording results and documentation of the processing. In particular, ensuring readily available documentation describing their operations by all organizations that process data is vital.

Rec 18: JCOMM, IODE and others need to address the problem of duplication in assembled data sets. This will need consultations with users that have different purposes for the data. Agreement on how to document such attributes as data origins and duplicates screening in data sets assembled from a variety of sources is needed.

Rec 19: Any programme web pages that provide access to data, metadata or other information (such as controlled vocabularies) should also be very clear in telling a user if web services are available and describe how these can be used. Good description of the content of what is delivered is very important.

Rec 20: Whenever data sets are provided to a user, the uncertainties in the measured values need to be stated clearly. If the data set includes an assembly of data from different instruments, this is even more important.

Rec 21: Even though both the GISCs of the WIS and the ODP of IOC are still under development, the interoperability of these systems is not very evident. ODP does provide a link to WIS data sets through a data access link, but a reciprocal link from the GISCs to ODP is not obvious. The ability to link from one portal to the other needs to be demonstrated in both directions and made more obvious to a user.

Rec 22: While it is acceptable for there to be small differences in counts between OSMC and JCOMMOPS, larger ones just cause users to doubt what is presented. If some redundancy such as exists is desired, then there should be some explanations about how differences arise. If they count different things, this should be explained on web pages.

Rec 23: It is recommended that a higher degree of cooperation in planning the developments and objectives of JCOMMOPS and OSMC be put in place. Where redundancy is desired, explanations should be provided so that users are aware of why this is so.

Rec 24: It is suggested that OCG consider limiting the data holding component of its monitoring to some recent time period, perhaps the last 5 years to improve on-line performance at OSMC and JCOMMOPS. To provide deeper looks into past data, it is suggested that OCG and DMCG open a discussion with IODE to see it agencies in that organization would be prepared to provide the complementary displays to the recent past available from JCOMMOPS and OSMC.

Rec 25: Limiting the time period of data holding at JCOMMOPS and OSMC would also help to link the JCOMM Observation programmes such as IOCCP, GO-SHIP and OceanSITES that largely assemble data in delayed mode. These programmes are not well represented on JCOMMOPS yet are important. There is a new category of member within IODE, called the Associate Data Unit, that need not be governmental in character, and yet can have formal representation at IODE. Perhaps these observation programmes dealing mostly in delayed mode could apply for such status in IODE. Discussions with IODE are recommended.

Acronyms

ADMT: Argo Data Management Team
BUFR: Binary Universal Form for data Representation
CF: Climate and Forecast
CRC: Cyclic Redundancy Check
CTD: Conductivity Temperature Depth
DMCG: Data Management Coordination Group
ECV: Essential Climate Variable
EOV: Essential Ocean Variable
FOO: Framework for Ocean Observing
GCOS: Global Climate Observing System
GOOS: Global Ocean Observing System

GISC: Global Information System Centers
GTSPP: Global Temperature, Salinity Profile Project
ICOADS: International Comprehensive Ocean-Atmosphere Data Set
IOC: Intergovernmental Oceanographic Commission
IODE: International Oceanographic Data and information Exchange (committee of IOC)
JCOMM: Joint Commission on Oceanography and Marine Meteorology
ML: Markup Language
MMI: Marine Metadata Interoperability (project)
NASA: National Aeronautics and Space Administration
netCDF: net Common Data Format
OCG: Observations Programme Coordinator
ODP: Ocean Data Portal
ODSBP: Ocean Data Standards and Best Practices
OGC: Open Geospatial Consortium
OOPC: Ocean Observations Panel for Climate
OSCAR: Observing Systems Capability Analysis and Review (tool)
OSMC: Observing System Monitoring Center
SOA: Service Oriented Architecture
SOOP: Ship of Opportunity Programme
SOT: Ship Observation Team
TT: Task Team
WIS: WMO Information System
WOCE: World Ocean Circulation Experiment
WMO: World Meteorological Organization
XBT: Expendable Bathythermograph

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5. CF conventions: http://www.unidata.ucar.edu/software/netcdf/conventions.html
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