Expansion to a Nationally Coordinated IOOS Passive Acoustic Monitoring Network

Lindsey Peavey Reeves, Xavier Mouy, Carrie Wall

NOAA FISHERIES

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Our Ocean. Our Planet. Our Future.®

NERACOOS

CIRES

A Three Part Talk

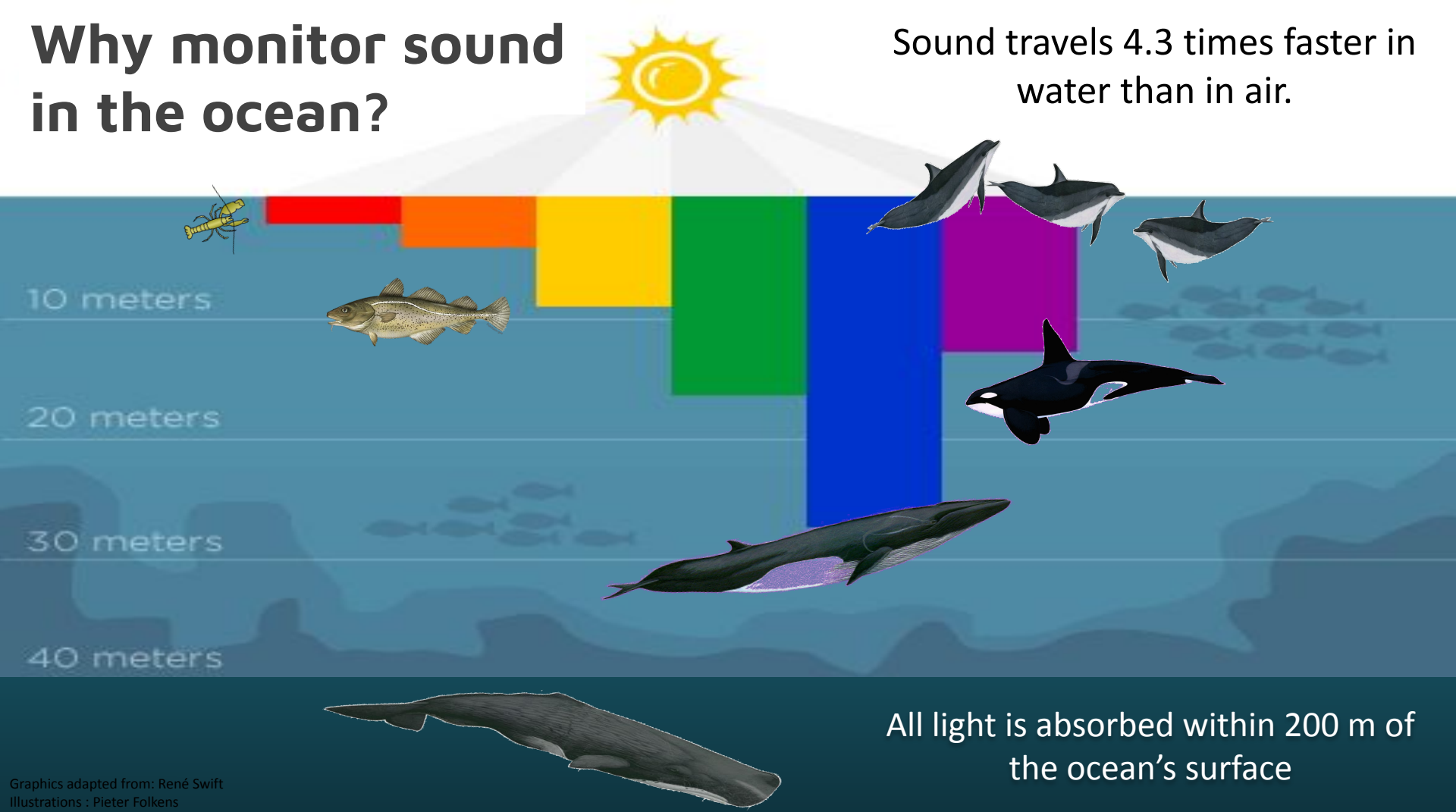
The Sound Cooperative (SoundCoop) Project: What we accomplished

The Ocean Sound Observing Network (OSON): Leveraging networked MPAs and SoundCoop best practices

Expanding the NOAA Fisheries Passive Acoustic Monitoring Strategic Initiative (PAM SI) to IOOS: How we're leveraging national collaborations

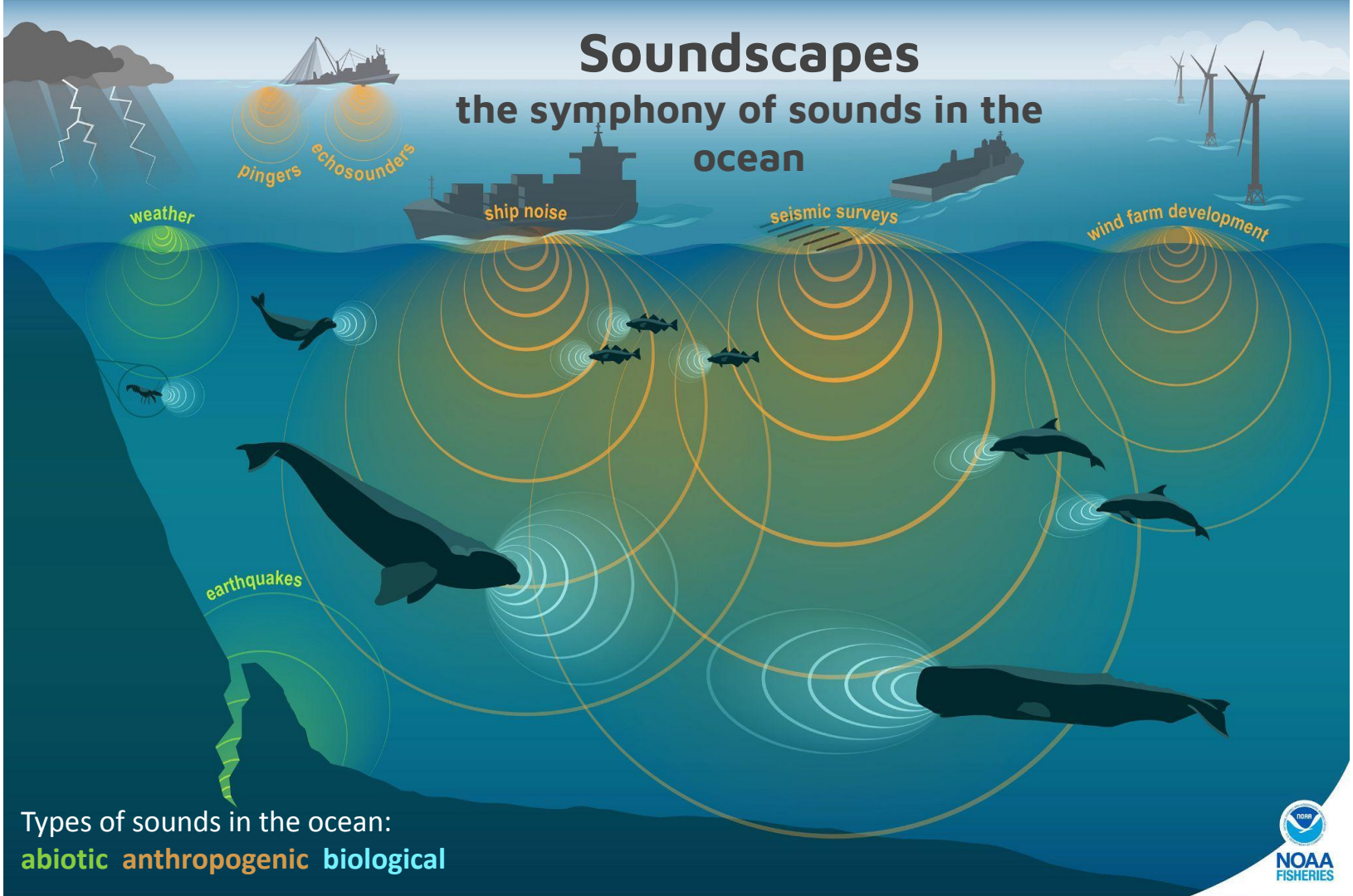
Why monitor sound in the ocean?

Sound travels 4.3 times faster in water than in air.



All light is absorbed within 200 m of the ocean's surface

Graphics adapted from: René Swift
Illustrations : Pieter Folkens


Soundscapes
the symphony of sounds in the ocean
pingers
echosounders
ship noise
seismic surveys
wind farm development
weather
earthquakes
Types of sounds in the ocean:
abiotic anthropogenic biological
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The Sound Cooperative (SoundCoop) Project

What we accomplished

SoundCoop

Develop a **community-focused**, national **cyberinfrastructure** capability for **passive acoustic monitoring data**, technology, and best practices to promote improved, scalable and sustainable accessibility and applications for management and science.

Co-funded by
NOAA IOOS*, BOEM,
US Navy LMR and ONR

*** FY21 IOOS DMAC Topic 2**

Endorsed by
UN Ocean Decade on the
Marine Acoustic Environment

SoundCoop

Develop a **community-focused**, national **cyberinfrastructure** capability for **passive acoustic monitoring data**, technology, and best practices to promote improved, scalable and sustainable accessibility and applications for management and science.

Objectives

1. **Create comparable, standardized sound level metrics using open source software for a variety of datasets**
2. **Develop a standardized file format for metric output**
3. **Establish workflows to access data from separate cloud repositories**
4. **Co-visualize sound levels and integrate with environmental data**

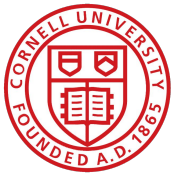
The SoundCoop Community

NOAA FISHERIES

IOOS
Integrated Ocean Observing System

BOEM
Bureau of Ocean Energy Management

Oregon State University



RWSC
Regional Wildlife Science Collaborative for Offshore Wind

Interreg
North Sea Region
Jomopans
European Regional Development Fund

EUROPEAN UNION

SoundCoop Datasets

12
Projects

- AEON
- AFSC-ALTIMA
- BOEM-Cornell
- ESONS
- FRAM
- JOMOPANS
- MBARI-MARS
- NEFSC
- NRS
- NYSDEC-Cornell
- SanctSound
- SWAL

10
Recording systems

- AMAR
- AUH
- AURAL
- DSG
- HARP
- icListen
- MARU
- SEH
- SoundTrap
- SonoVault

7
Geographic regions

- Arctic Ocean
- Central California Coast
- Fram Strait
- Gulf of Maine
- Mid Atlantic
- North Sea
- Southeast US Estuary

17
Year span of data

- First day processed: **Sep 26, 2006**
- Last day processed: **Apr 23, 2023**

2-256
kHz sample rate

- Duty cycles vary from 2 min per hour to continuous

Standardized file format for sound level metric output

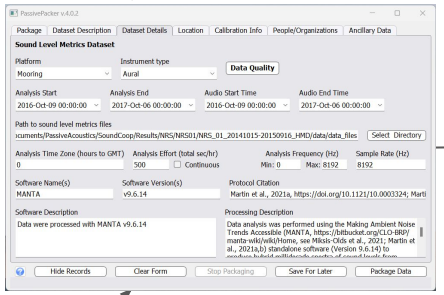
audio input & metadata

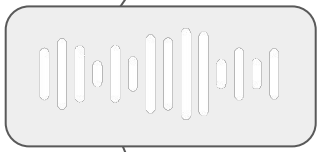
calibration

MANTA

MANTA output

Daily CSVs, netCDFs, pngs and dataset XLS





PyPAM output

Daily netCDFs

Community Standards

calibration

DOI

Data Quality Matrix

Community Standards

PassivePacker output

Metadata JSON, data files

SoundCoop output

Daily netCDFs

DOI

Visualize sound levels and integrate with environmental data

Tools for the Community

Published a suite of Jupyter Notebooks on our IOOS-hosted github repository, including documentation and guidance for running the notebooks

github.com/ioos/soundcoop/

README | Code of conduct | BSD-3-Clause license

SoundCoop

This repository contains Jupyter notebooks developed by the SoundCoop project team for the passive acoustic community.

- Key contributors: Danelle Cline, Trevor Golden, Karina Khazmutdinova, Clea Parcerisas, Carlos Rueda, John Ryan, and Brian Stone

Overview

The SoundCoop Project was a three-year effort funded by NOAA Integrated Ocean Observing System, Bureau for Ocean Energy Management, U.S. Navy Living Marine Resources, and the Office of Naval Research. The goal of the project was to develop technology in collaboration with the passive acoustic monitoring (PAM) community to enable scalable processing of comparable sound level metrics and to provide open access to centralized data for science and management applications.

U.S. and international scientists contributed PAM data spanning 12 separate long-term monitoring projects. Datasets from ten of these projects were used to calculate a specific sound level metric, hybrid millidecade (HMD) spectra, across a diversity of labs and instruments.

The collaborative effort of the SoundCoop led to several advances in data management, processing, dissemination, visualization, and knowledge sharing.

- Two open access software toolkits were produced/enhanced by project members to process SoundCoop datasets into one-minute HMD spectra, namely MANTA and PyPAM/PyPAM-Based Processing or PBP.
- SoundCoop Project members, along with the NCEI passive acoustic data archive team, established a standards-driven netCDF format, which greatly facilitated comparison and distribution of the HMD sound levels.
- The project developers at Axiom Data Science built an interactive data portal to visualize and explore the SoundCoop datasets alongside environmental data to show the benefits of connecting acoustic and non-acoustic information.

Jupyter notebooks were created to demonstrate how to access data from different open access cloud buckets (Step 0), process raw audio data collected from two different recording instruments into HMD spectra using PBP and output the result in the SoundCoop netCDF standard (Step 1), read, visualize and analyze HMD netCDFs using PyPAM (Step 2), and integrate and visualize the HMD netCDFs with enviornmental data just like the visualizations available in the SoundCoop portal (Step 3).

Jupyter Notebooks

Data notebooks

In `0_download_data/`

- download_ESONS_from_rw: This notebook shows how to access HMD netCDF files recorded at the ESONS listening site from the Axiom Data Science Research Workspace.

README | Code of conduct | BSD-3-Clause license

Jupyter Notebooks

Data notebooks

In `0_download_data/`

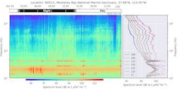
- download_ESONS_from_rw: This notebook shows how to access HMD netCDF files recorded at the ESONS listening site from the Axiom Data Science Research Workspace.
- download_JOMOPANS_from_rw: This notebook shows how to access one-third octave sound levels recorded at a listening site in the North Sea as part of the JOMOPANS project. Originally accessed from the ICES database, the HDF files were translated into netCDF and are hosted on the Axiom Data Science Research Workspace.
- use_minio_to_access_GCP This notebook shows how to download files from Google Cloud Platform, specifically SB03 HMD netCDFs from the NCEI SoundCoop bucket on GCP.

Processing notebooks

In `1_process_to_HMD_pbp/`

- In `MARS` gen_HMD_MARS_icListen.ipynb: Access data recorded from the Monterey Bay Aquarium Research Institute (MBARI) Monterey Accelerated Research System (MARS) undersea cabled observatory from the Amazon Web Services (AWS) Registry of Open Data, read in processing metadata, create calibrated one-minute HMD spectra for one day and output the results as as a netCDF.
- In `MB05` gen_HMD_MB05_SoundTrap.ipynb: Access data recorded in the Monterey Bay National Marine Sanctuary from the Amazon Web Services (AWS) Registry of Open Data, read in processing metadata, create calibrated one-minute HMD spectra for one day and output the results as as a netCDF.
- In `NRS11` gen_HMD_NRS11_Haruphone.ipynb: Access data recorded from the NOAA-National Park Service Ocean Noise Reference Station Network (NRS) from the NCEI Passive Acoustic Data Archive Google Cloud Platform (GCP) bucket available through the NOAA NODD Program, read in processing metadata, create calibrated one-minute HMD spectra for one day and output the results as as a netCDF.

Example summary plot of HMD from NRS11 (click on the image for a larger view):



Analysis notebooks

In `2_analysis_of_HMD_pypam/`

- data_analysis_with_pypam: Access one year of one-minute HMD recorded in the Cordell Bank National Marine Sanctuary as part of the NRS project (NRS11) on GCP and one month of MBARI-MARS one-minute HMD from AWS, read in and plot LTSA and SPD where data quality tags are set to 'Good', extract and plot the blue and fin whale call index (CI), co-plots PSD for both listenting stations, and reprocess and plot as broadband and decidecade sound levels.
- dimension_reduction_and_clustering: Using one year of NRS11 and MBARI-MARS HMD data, this notebook conducts dimension reduction using UMAP.

In `3_HMD_environmental_data/`

- plot_sound_environmental_and_climatology_data: Access two months of HMD recorded at Monhegan Island site in the Gulf of Maine from the GCP bucket, access associated wind speed and wave height recorded at the 44007 environmental sensor station located ~72 km from the listening site from October 23, 2021 to November 17,

Tools for the Community

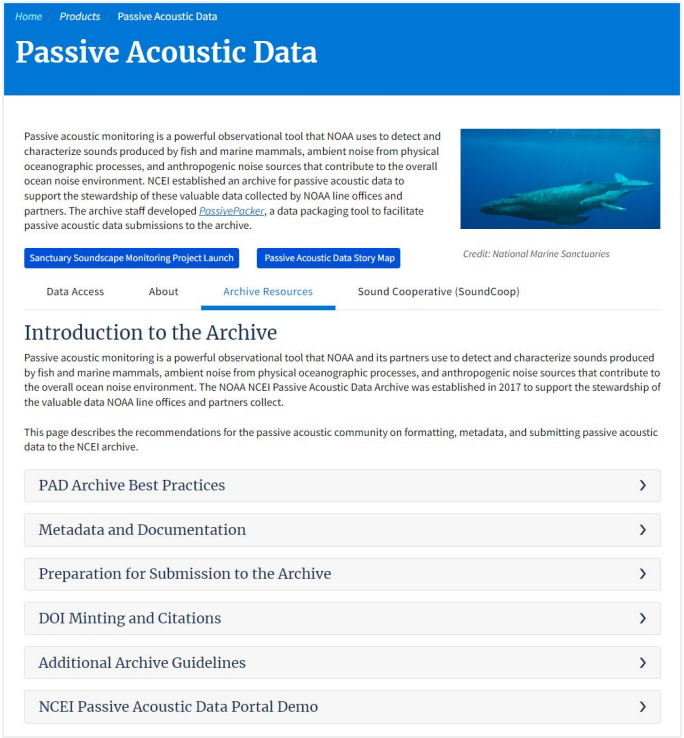
Published a suite of Jupyter Notebooks on our IOOS-hosted github repository, including documentation and guidance for running the notebooks

Published guidance on formatting, metadata, and submitting passive acoustic data to the NCEI archive

Published a website on SoundCoop describing goals, partners, accomplishments, and best practices

SoundCoop manuscript in prep

www.ncei.noaa.gov/products/passive-acoustic-data



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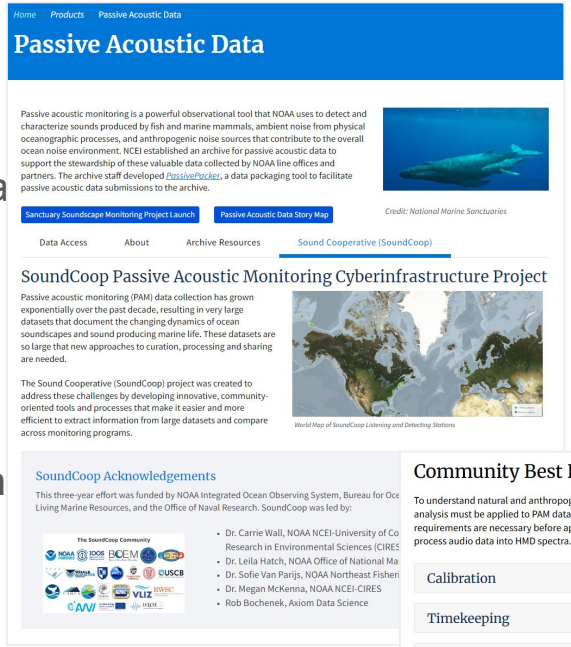

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SoundCoop manuscript in prep

Big Data, Sound Science, Lasting Impact: a framework for passive acoustic monitoring

Carrie C. Wall[1,2] *, Megan McKenna[1,2], Leila T. Hatch[3], Sofie M. Van Parijs[4], Rob Bochenek[5], Peter Dugan[6,7], Clea Parcerisas[8,9], John Ryan[10], Charles D. Anderson[1,2], Kyle Becker[11], Catherine Berchok[12], Mathew Biddle[13], Olaf Boebel[14], Adrienne Canino[5], Gabrielle Canonico[13], Danelle Cline[10], Genevieve E. Davis[4], Kaitlin Frasier[15], Jason Gedamke[16], Samara M. Haver[17,18], Karina Khazmutdinova[5], Niels Kinneging[19], Anurag Kumar[20], Alyssa Marian[21], Jennifer Miksis-Olds[22], Eric W. Montie[21], Dimitri Ponirakis[7], Aaron N. Rice[7], Timothy J. Rowell[4,23], Carlos Rueda[10], Emily Shumchenia[24], Thomas Shyka[25], Erica Staaterman[26], Karolin Thomisch[14]

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5. Axiom Data Science, LLC, Anchorage, AK, USA
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8. Flanders Marine Institute, Ostend, Belgium
9. Department of Information Technology, Ghent University, Ghent, Belgium
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11. Office of Naval Research, Arlington, VA, USA
12. NOAA Alaska Fisheries Science Center, Seattle, WA, USA
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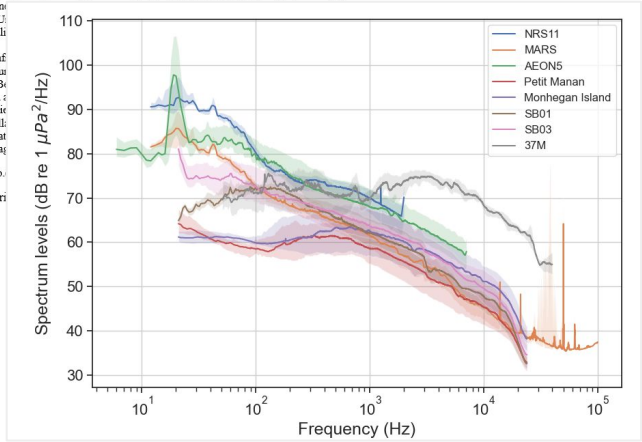
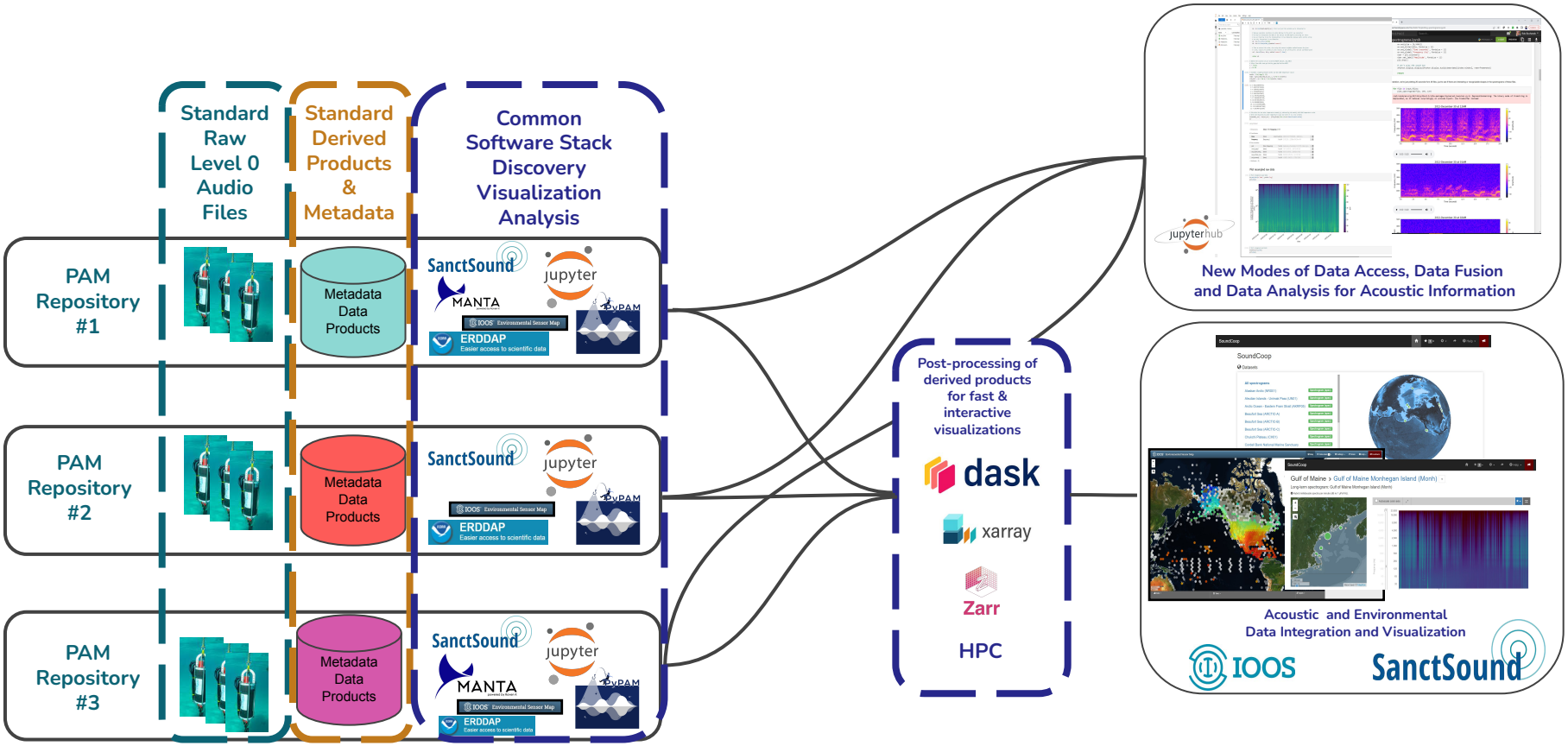
17. Cooperative Institute for Marin
Laboratory and Oregon State U
18. Department of Fisheries, Wildli
USA
19. Rijkswaterstaat, Ministry of Inf
20. US Navy Living Marine Resou
21. University of South Carolina Be
22. Center for Acoustics Research
23. NOAA Southeast Fisheries Scie
24. Regional Wildlife Science Coll
25. Northeastern Regional Associat
26. Bureau of Ocean Energy Manag

*Correspondence: carrie.bell@colorado.

Keywords: Passive acoustic monitori



Putting the Pieces Together



SoundCoop End Products

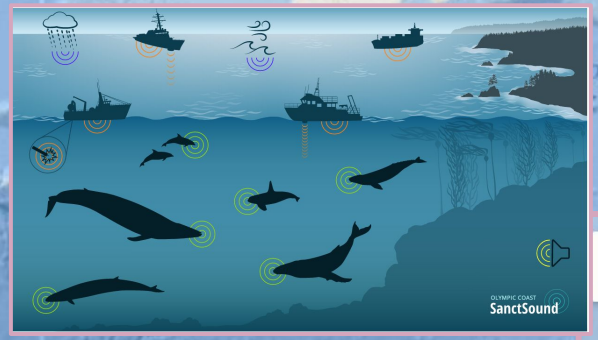
Data	Comparable 1-min hybrid millidecade spectra in netCDF standard
Access	Interactive portal to visualize acoustic data with env data
Software	Community-ready versions of Manta and PyPAM
Knowledge	Best practices guidance, tutorials and notebooks

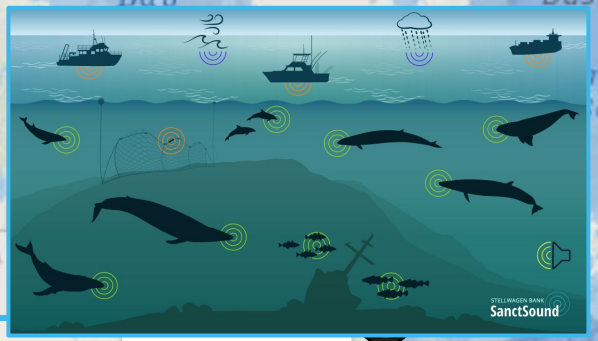
The Ocean Sound Observation Network:

Leveraging networked MPAs and SoundCoop best practices

Opportunities for coordination: national marine sanctuaries

Many ways to record sound & track animals and vessels





Olympic Coast

West Coast Region

Monterey Bay

Chumash Heritage

Channel Islands

Stellwagen Bank

Eastern Region

Flower Garden Banks

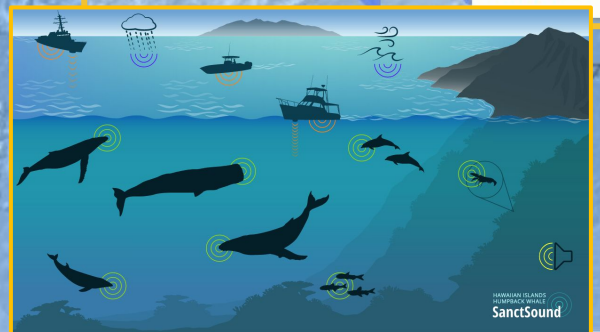
Gray's Reef

Florida Keys

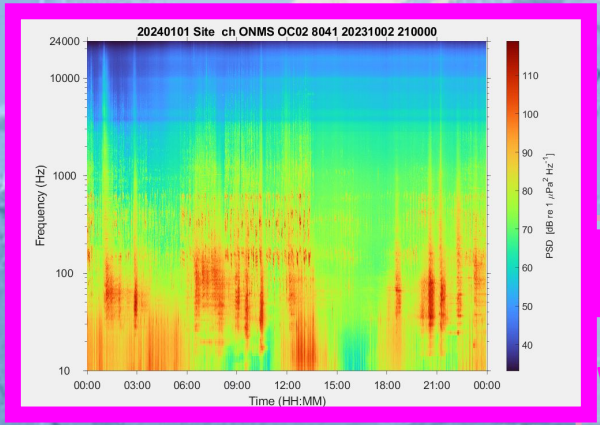
Papahānaumokuākea

Pacific Island Region

Hawaiian Islands Humpback Whale



SanctSound



MANTA powered by Raven-X

CIRES

NORTH AMERICA

Olympic Coast

West Coast Region

Chumash Heritage

Channel Islands

Stellwagen Bank

Eastern Region

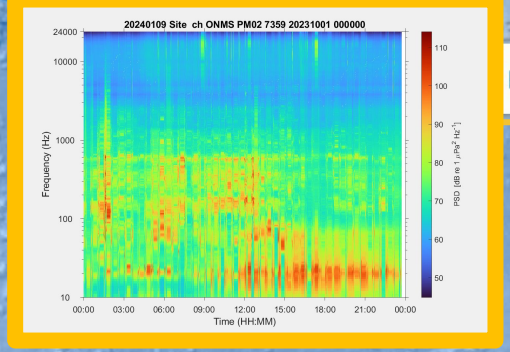
Flower Garden Banks

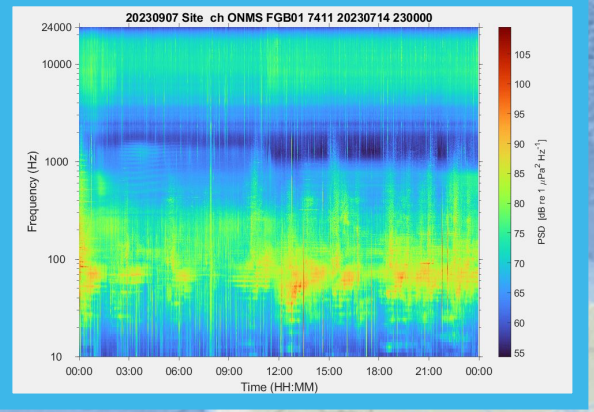
Gray's Reef

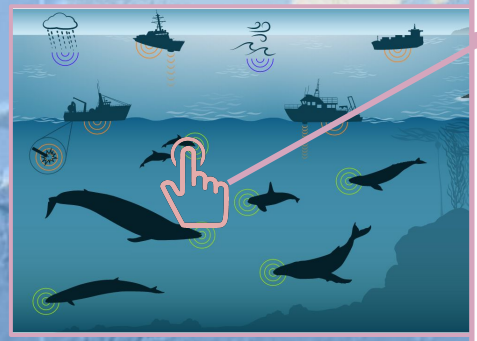
Papahānaumokuākea

Pacific Island Region

Hawaiian Islands Humpback Whale

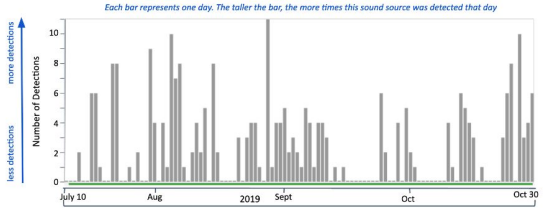






Dolphins

Sights & Sounds | **Time series** | Monthly Patterns | Hourly Patterns



Of the four time periods of analyzed data at the shipping lanes listening station on the northern end of Olympic Coast sanctuary, only one recorded dolphins acoustically active: July through October 2019.

West Coast Region

Chumash Heritage

Channel Islands

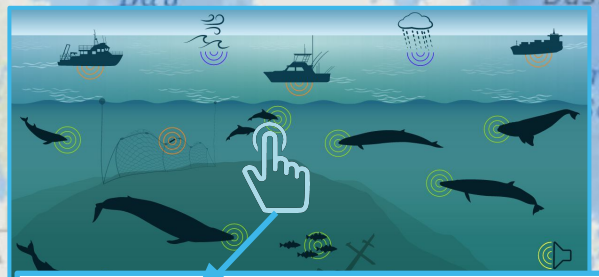
East

Flower Garden Banks

Florida Keys

fic Island Region

an Islands Hump



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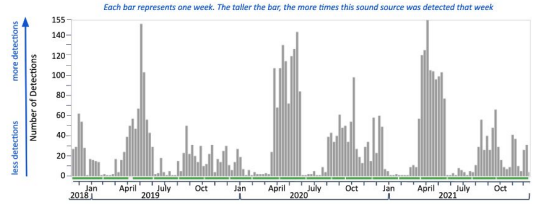
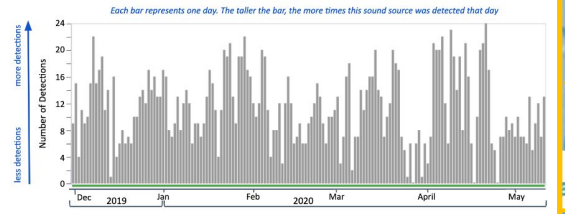
Sights & Sounds | **Time series** | Monthly Patterns | Hourly Patterns



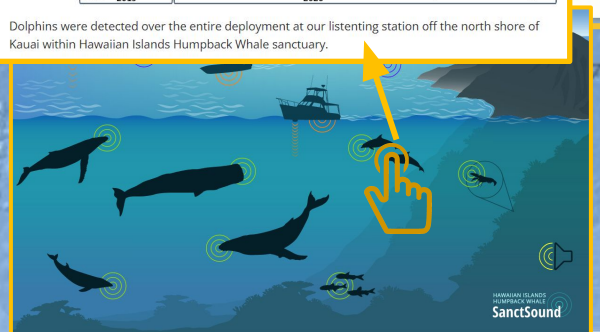
Dolphins were often detected off the northwest corner of Stellwagen Bank and across multiple seasons over the three year project.

Dolphins

Sights & Sounds | **Time series** | Monthly Patterns

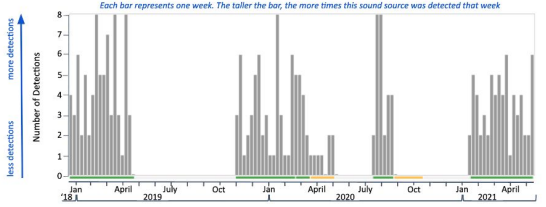


Dolphins were detected over the entire deployment at our listenting station off the north shore of Kauai within Hawaiian Islands Humpback Whale sanctuary.

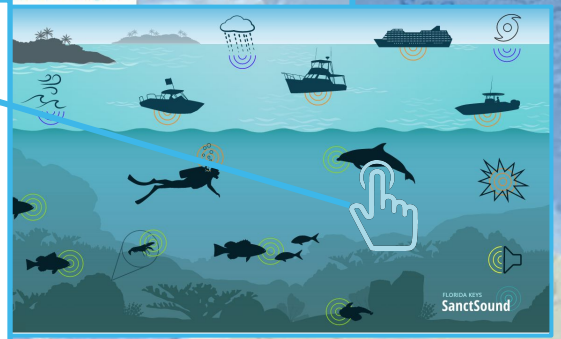


Dolphins

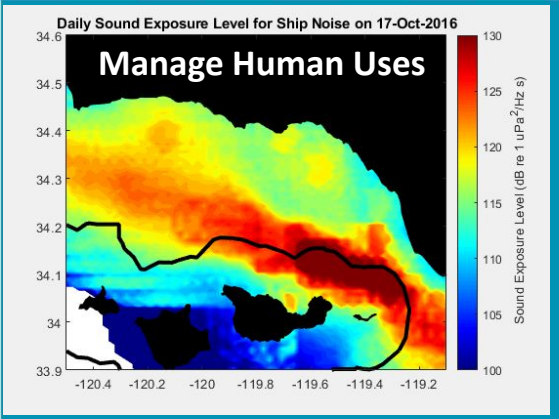
Sights & Sounds | **Time series** | Monthly Patterns | Hourly Patterns



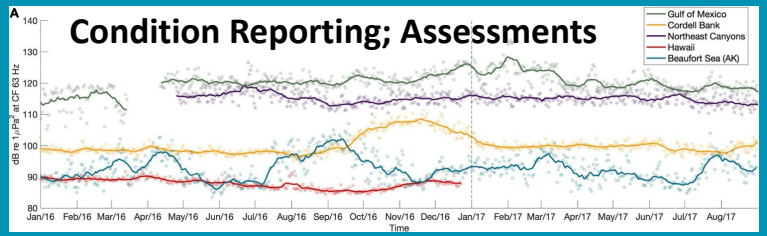
Dolphins were often detected south of Key West in Florida Keys sanctuary over the three year project.



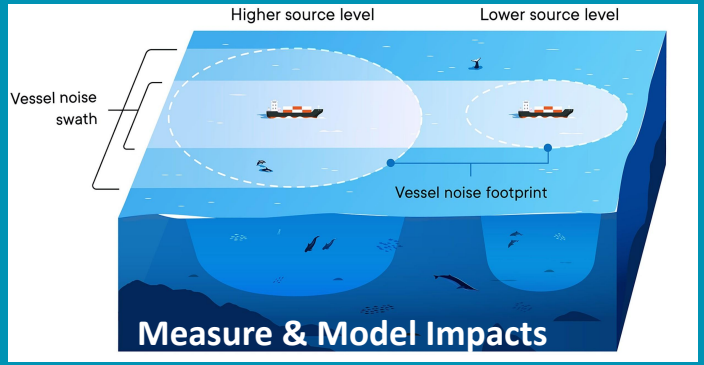
PAM Supporting Management



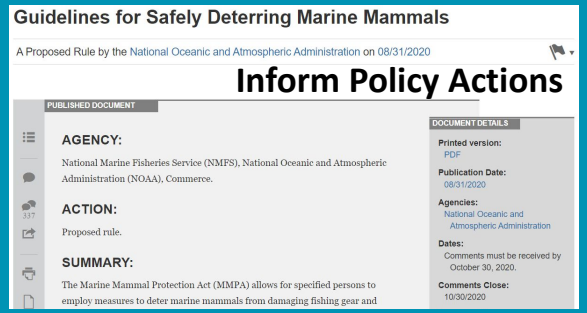
(Zobell et al. *in prep*)



(Haver et al. 2021)



(Findley et al. 2023)

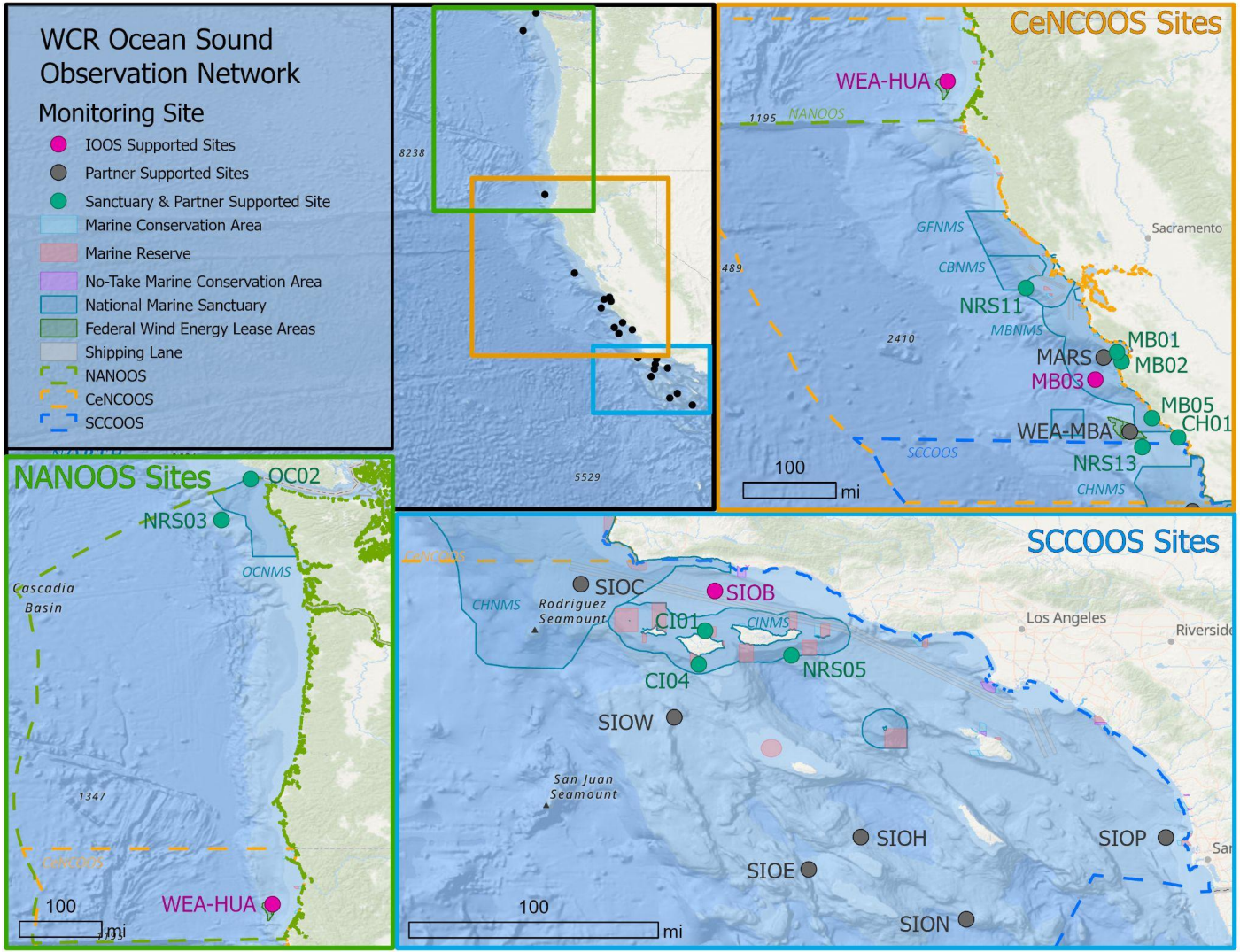


Climate Change; Biodiversity

(Palumbi et al. 2019)

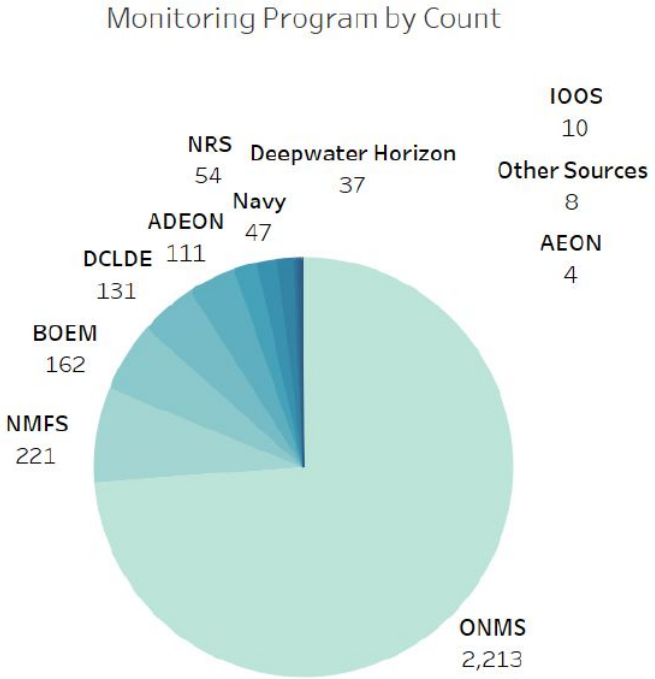
West Coast Ocean Sound Observation Network

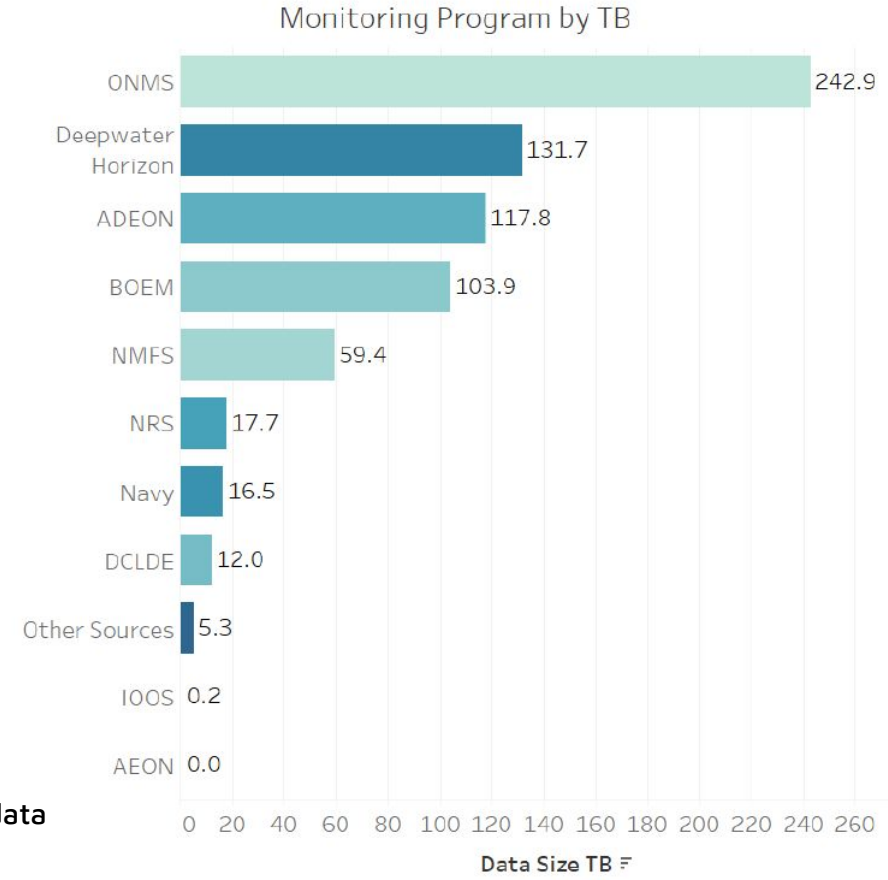
- Longevity
- Coordinated
- Standardized
- Centralized
- Accessible
- Supports Mandates




Monterey Bay Aquarium
MBARI
CIMEAS
CHUMASH HERITAGE
National Marine Sanctuary
Northern Chumash Tribal Council
NOAA
NOAA FISHERIES
IOOS
Integrated Ocean Observing System
National Marine Sanctuary Foundation
CIMERS
Cooperative Institute for Marine Ecosystem and Resources Studies
NCEI
living marine RESOURCES
SCRIPPS WHALE ACOUSTICS LABORATORY
SCRIPPS ACOUSTIC ECOLOGY LABORATORY
sea
SOUTHALL ENVIRONMENTAL ASSOCIATES, INC.
Scripps Machine Listening Laboratory
PMEL
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
PACIFIC MARINE ENVIRONMENTAL LABORATORY
1868
BENIOFF OCEAN INITIATIVE
NPS
PRAESTANTIA PER SCIENTIAM
1909
NAVAL UNDERSEA WARFARE CENTER
NUWC
DIVISION NEWPORT, RI
Oregon State University
Conservation Metrics
Improving conservation through better monitoring
Synchro
BOEM
Bureau of Ocean Energy Management
CIRES
Axiom
DATA SCIENCE
University of Colorado Boulder
CMSF
BioSound
Cascadia Research Collective
CENTRAL & NORTHERN CALIFORNIA OCEAN OBSERVING SYSTEM
SOUTHERN CALIFORNIA COASTAL OCEAN OBSERVING SYSTEM

Opportunities for coordination: national marine sanctuaries

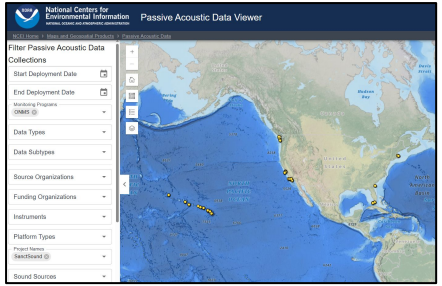




SanctSound, Noise Reference Station (NRS), and OSON data makes up the majority of the archive as of March 2025.

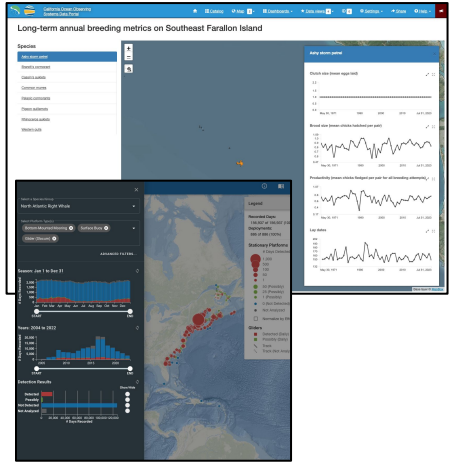
Focus on Dissemination of Data & Products: Continuum to Match Target Audience

NCEI Passive Acoustic Data Archive



Audio data and products archived at NCEI; SanctSound's data products also available via ERDDAP

NOAA (OOS/Fisheries) dashboards/portals

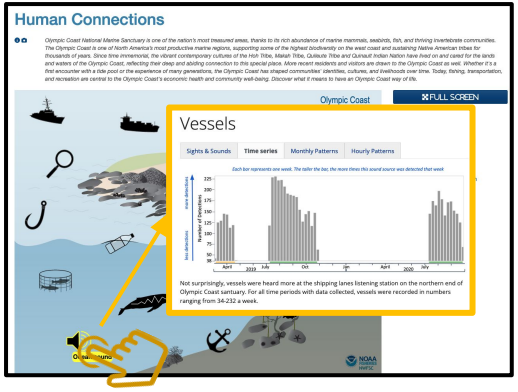


Data exploration & comparison platforms

Sanctuary Soundscape Inventory Reports

Provides access to all periodically updating reports; compare certain indicators across system

Sanctuary Ecosystem Tracking Tool



Site-specific tracking information pulled from periodically updating reports

J. Brown, Sanctuary Watch

Level of **Interpretation**

Level of **Technical expertise**

Expanding the NOAA Fisheries Passive Acoustic Monitoring Strategic Initiative (PAM SI) to IOOS

How we're leveraging national collaborations

NERACOOS

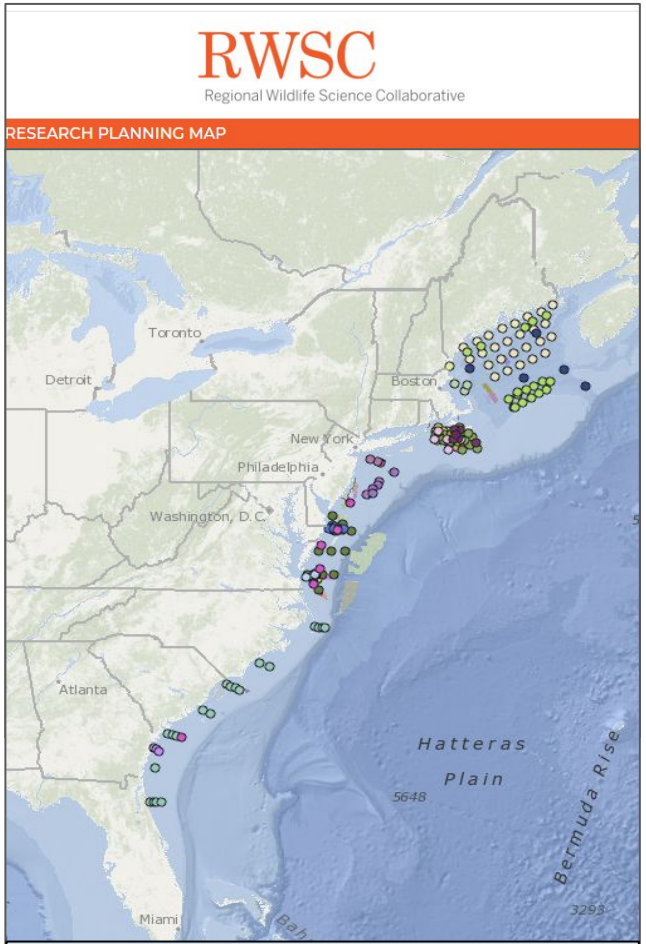
WOODS HOLE OCEANOGRAPHIC INSTITUTION
Our Ocean. Our Planet. Our Future.®

NOAA FISHERIES

Office of Naval Research
ONR
Science & Technology

The PAM data deluge

- Steep increase of PAM data collection in the Northeast US
- Data collection from:
  - NOAA
  - States
  - Industry
  - Academia
- Need for:
  - Standardized data processing
  - Computation capabilities
  - Public data archival (often a requirement)
  - Unified data integration and visualization



Current and planned PAM locations

The PAM data deluge

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- Data collection from
  - NOAA
  - States
  - Industry
- Nee
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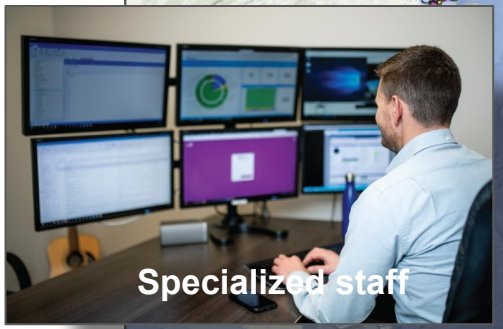


Current and planned PAM locations

PAM Strategic Initiative at National Marine Fisheries Service

Creating standardized, comparable, and open source workflows for PAM data

Data Collection

Scalable workflow that works across recording platforms

Data Storage

Building capacity and test case for enterprise cloud storage

Processing

Moving towards open source software and cloud processing

Data Management

Database development supporting standardized data exports

Visualization & Integration

Open source packages for standardized visualization and data integration

Data Accessibility

Streamlined NCEI archiving through PACE and expanded visualization on PACM

Management Products

Advancing applications for protected species management and assessing long-term trends

Integrating sound into the Northeast Ocean Observing System

NERACOOS:

- Non-profit organization
- One of the eleven IOOS regional associations (RAs)
- Coordinates regional observing systems
- Operates various observational platforms
- Public/private partnerships with institutions across **academia**, **industry**, and **government** sectors.

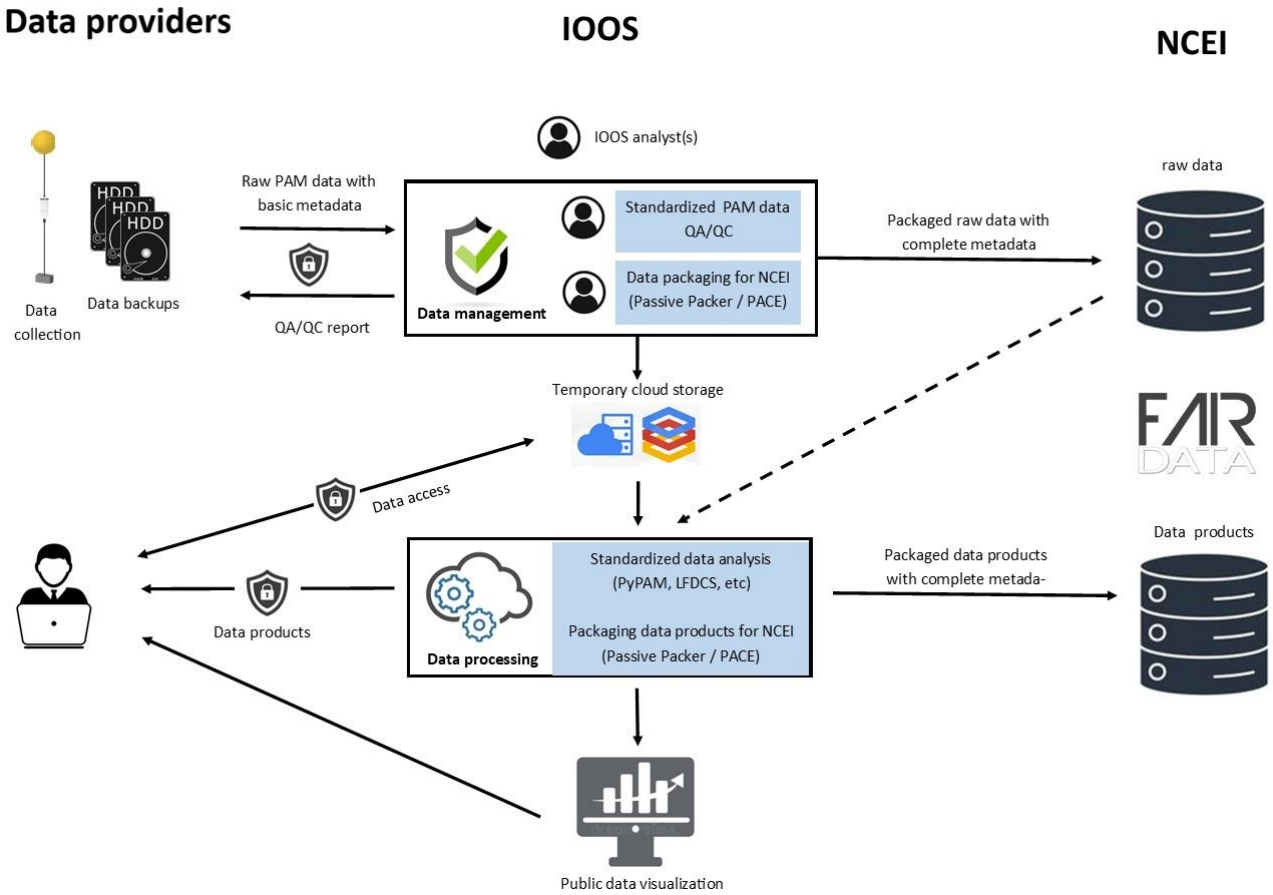
Essential Ocean Variables (EOV)

EOVs measured by NERACOOS

Physics	Biochemistry	Biology and Ecosystems
Sea state ★		
Ocean surface stress		
Sea ice		
Sea surface height ★	Oxygen ★	Phytoplankton biomass and diversity ★
Sea surface temperature ★	Nutrients ★	Zooplankton biomass and diversity ★
Subsurface temperature ★	Inorganic carbon	Fish abundance and distribution
Surface currents ★	Transient tracers	Marine turtles, birds, mammals abundance and distribution
Subsurface currents ★	Particulate matter	Hard coral cover and composition
Sea surface salinity ★	Nitrous oxide	Seagrass cover and composition
Subsurface salinity ★	Stable carbon isotopes	Macroalgal canopy cover and composition
Ocean surface heat flux	Dissolved organic carbon ★	Mangrove cover and composition
Ocean bottom pressure		Microbe biomass and diversity (*pilot)
Turbulent diapycnal fluxes (*pilot)		Invertebrate abundance and distribution (*pilot)

The Global Ocean Observing System

A PAM cyberinfrastructure accessible outside of NOAA



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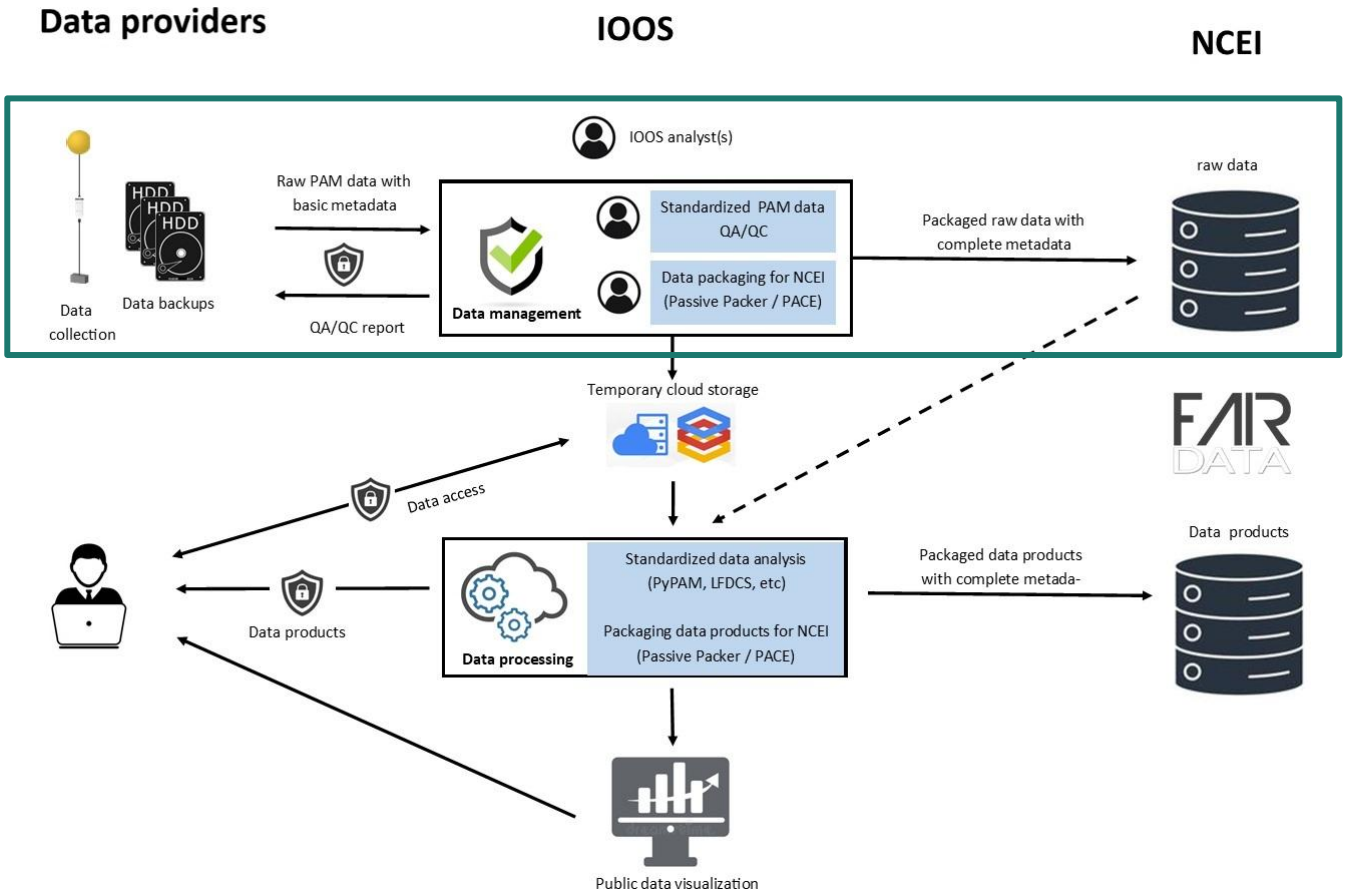

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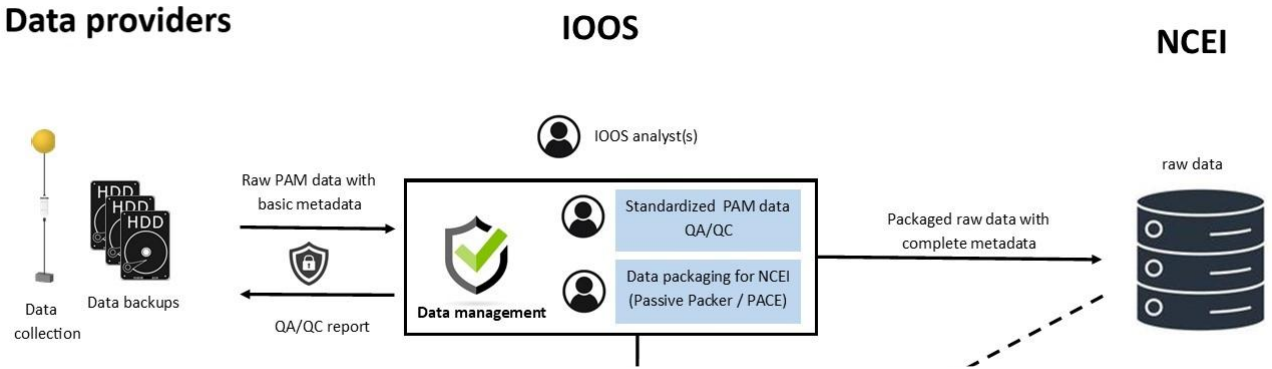

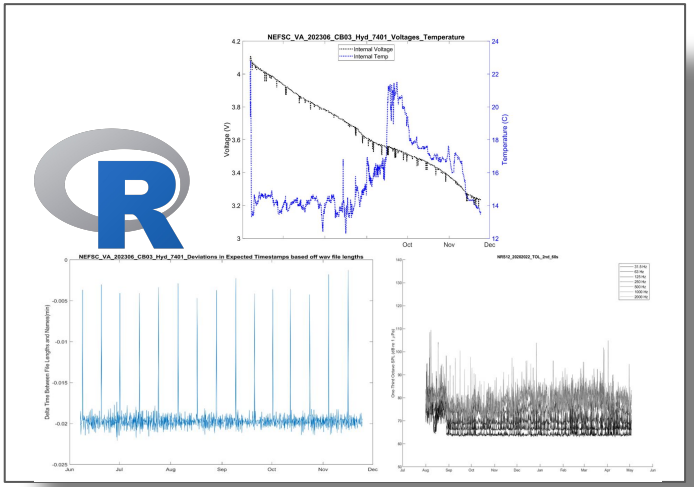

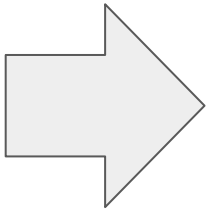

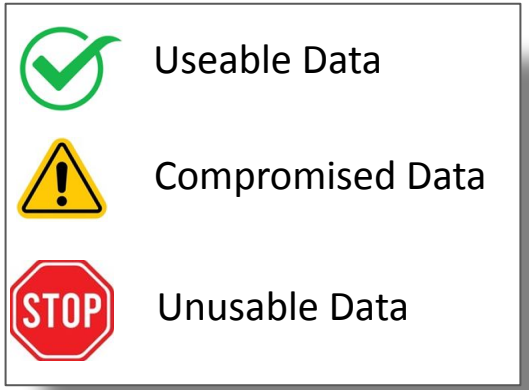

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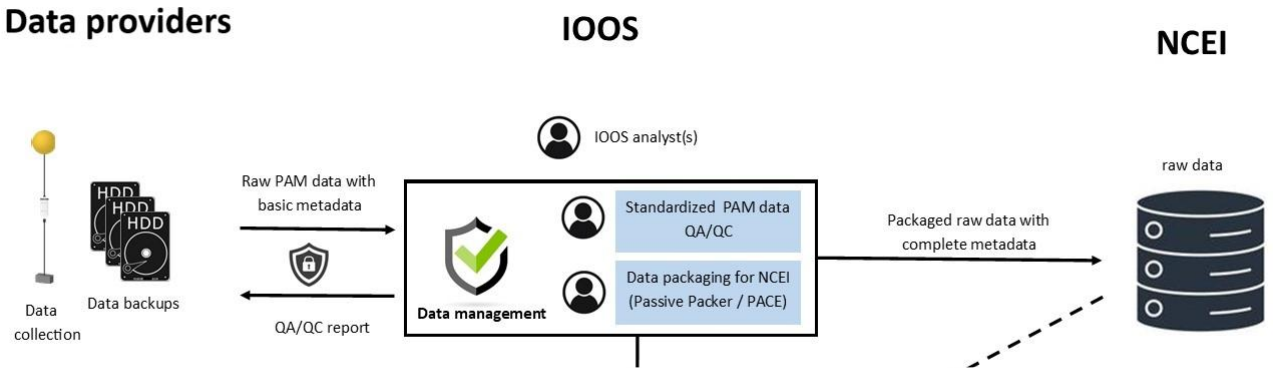

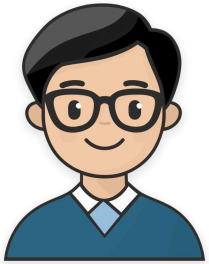

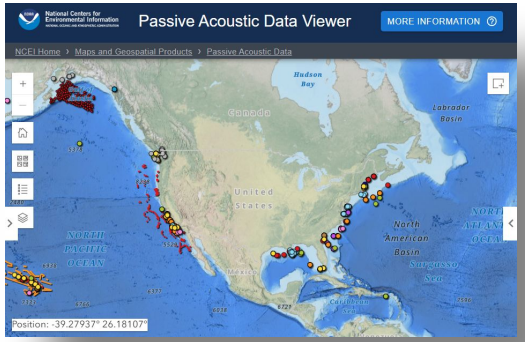

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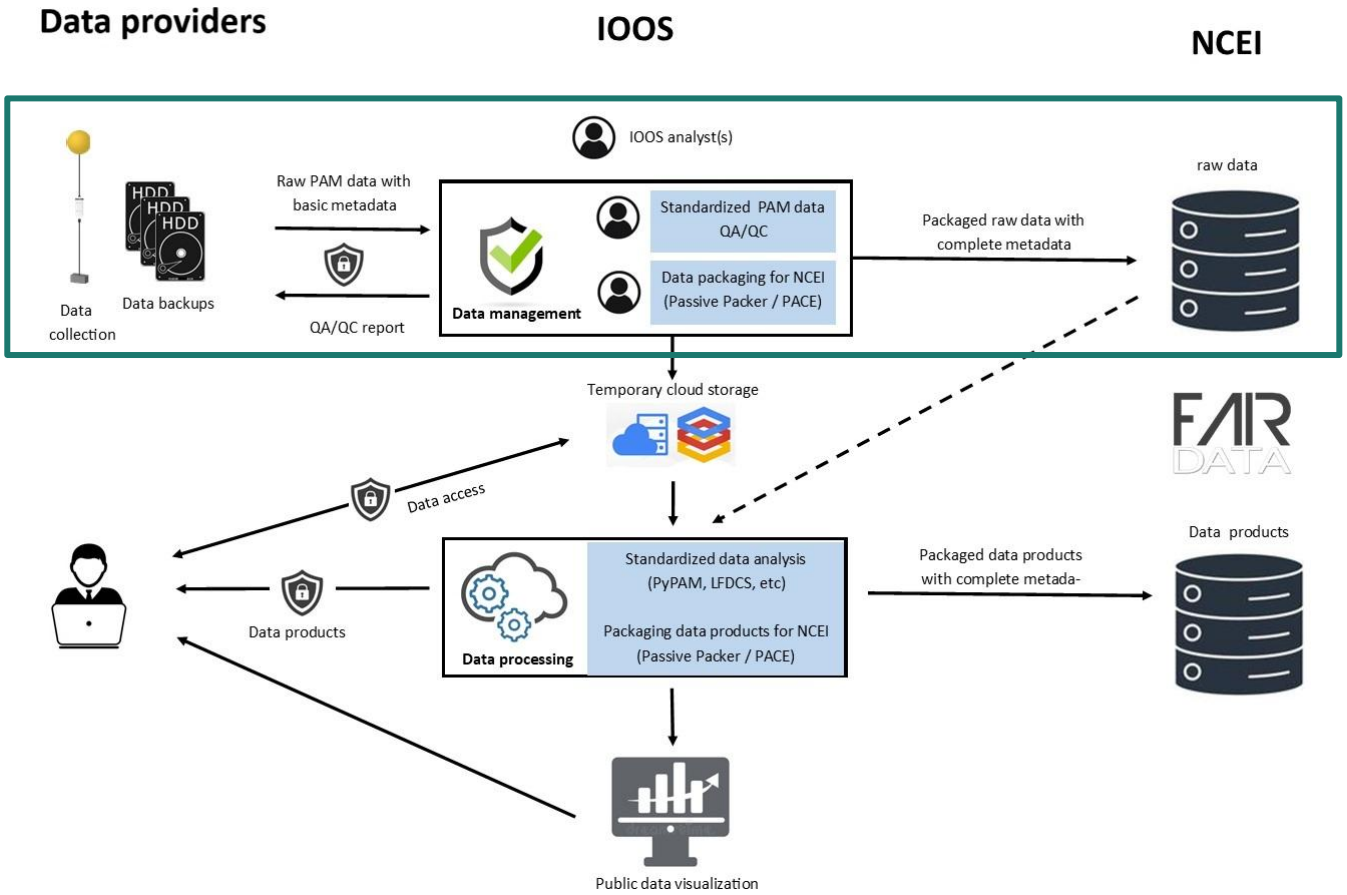

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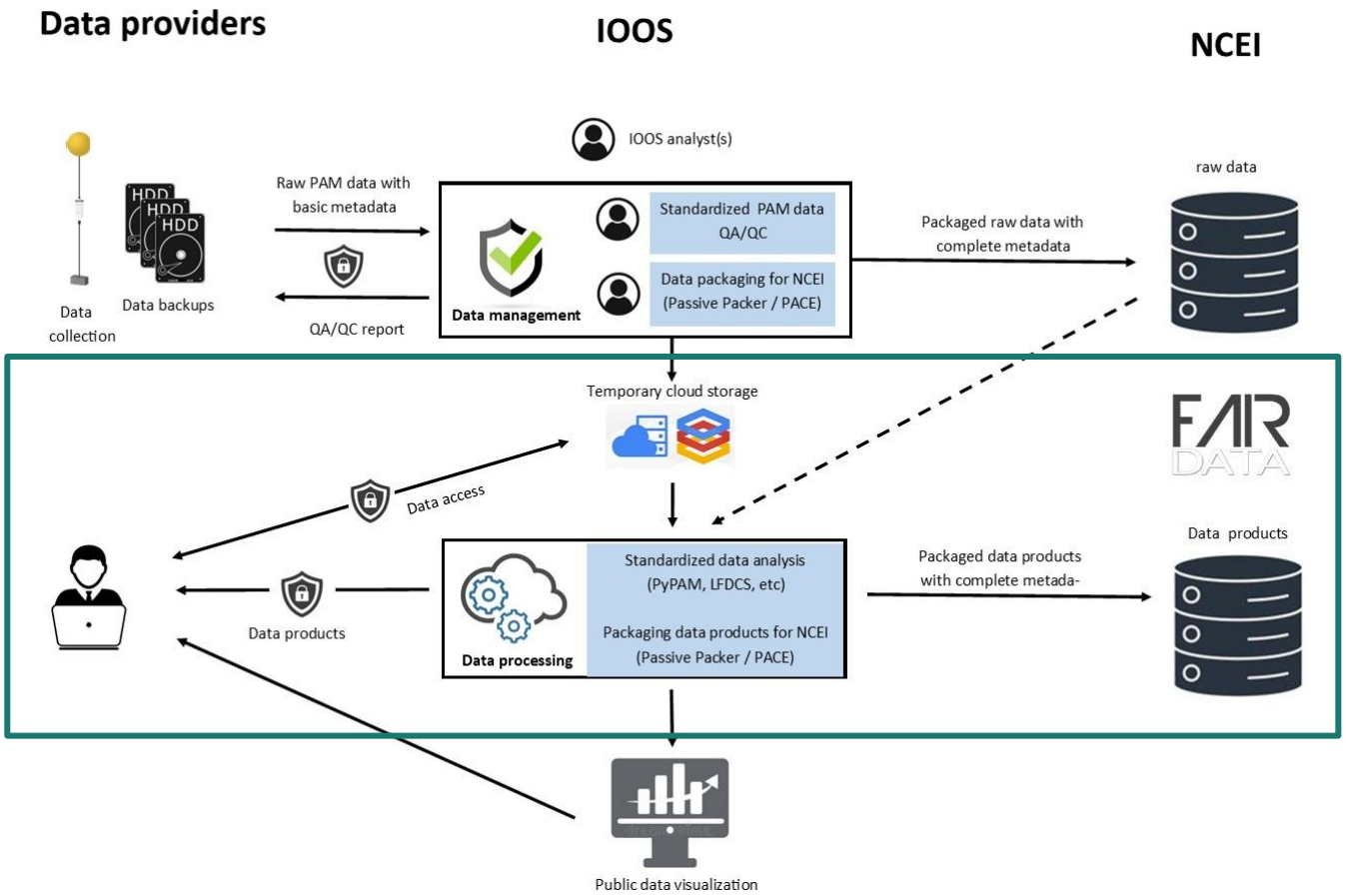

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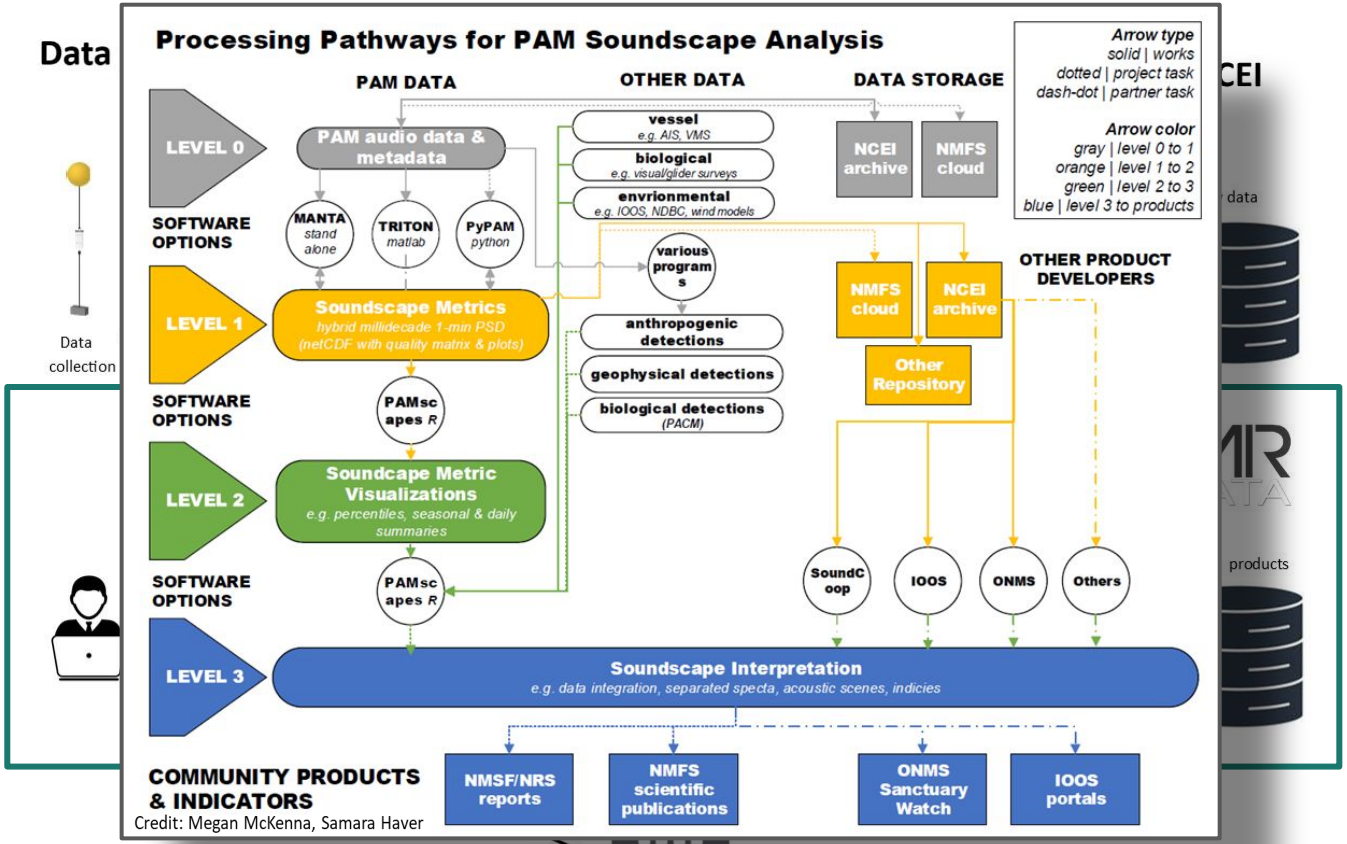

Credit: Megan McKenna, Samara Haver

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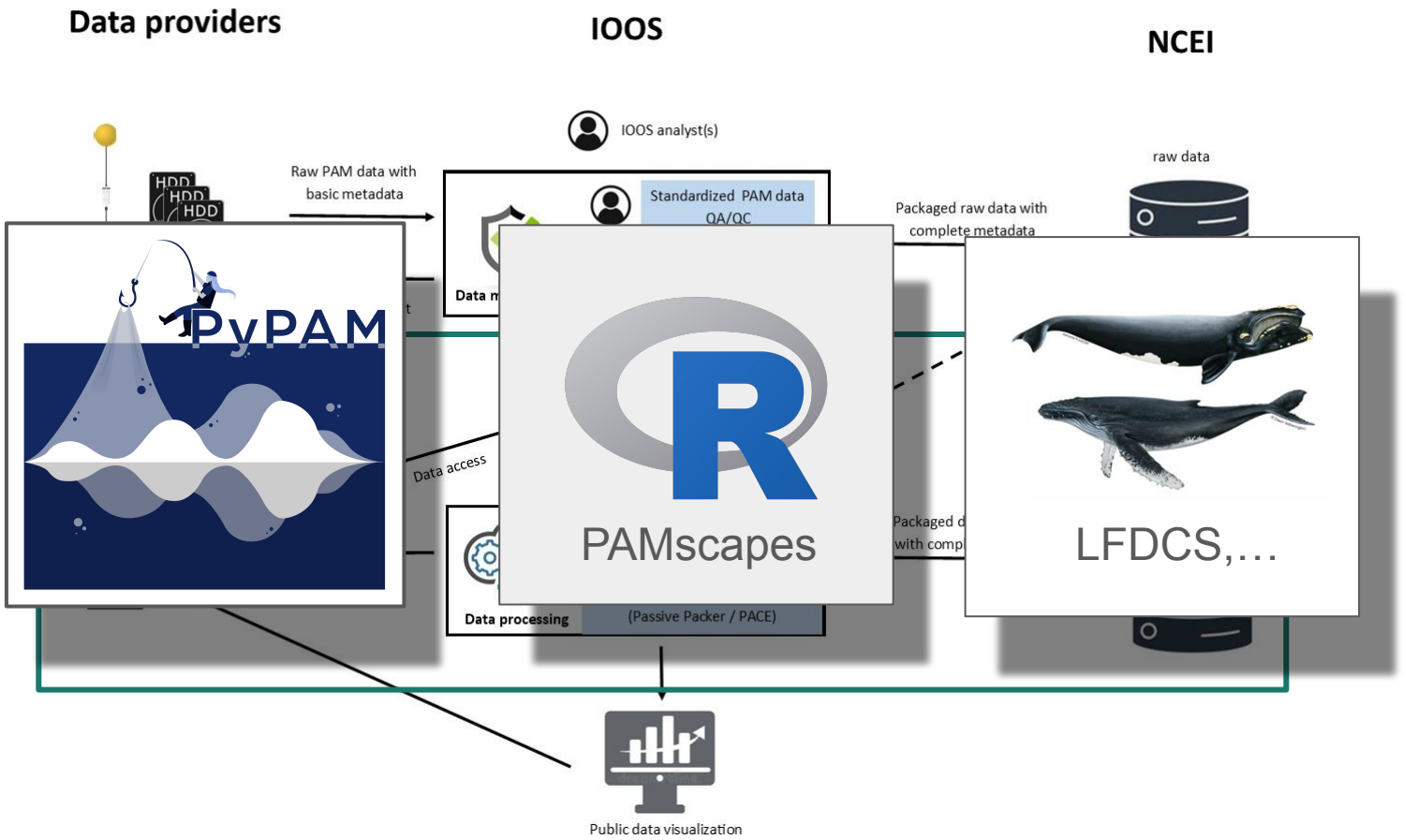

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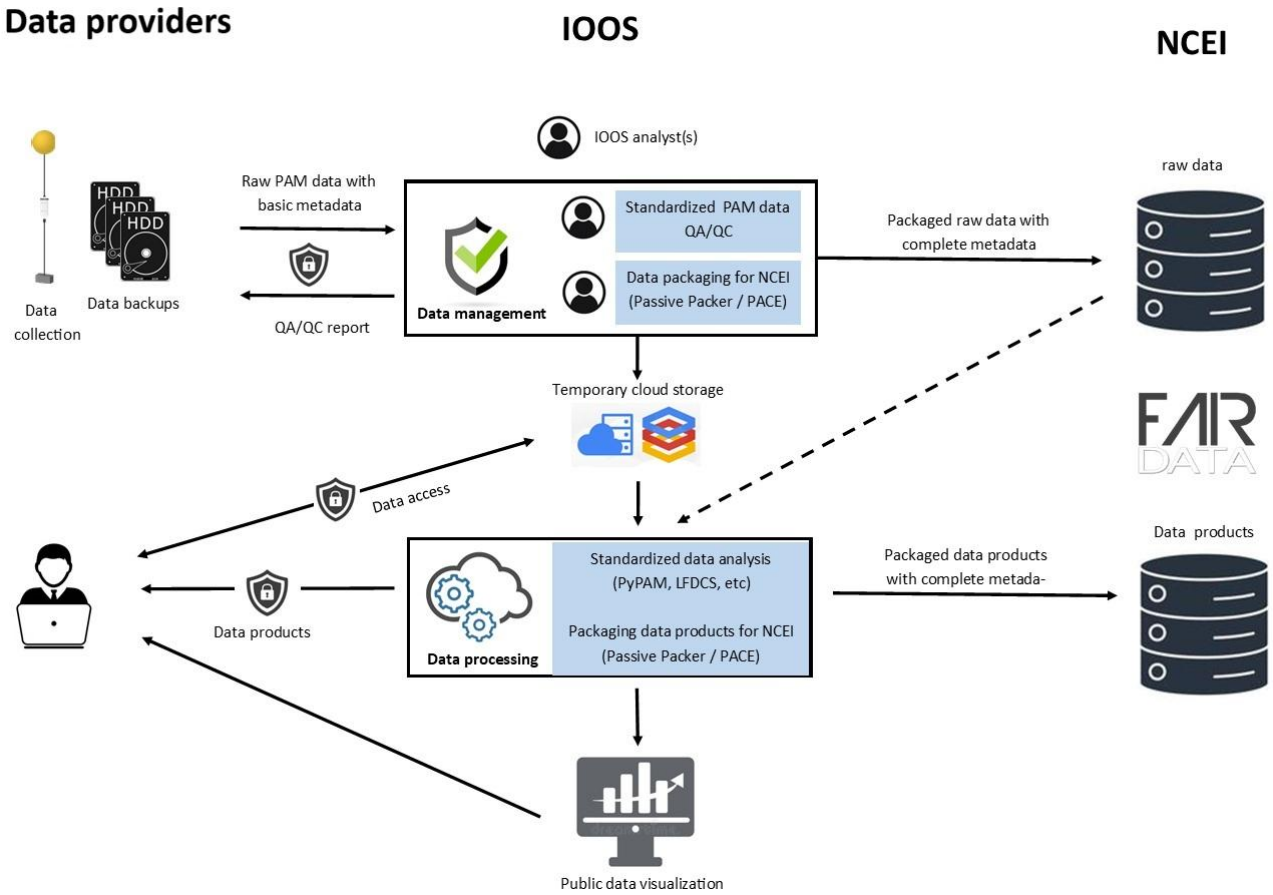

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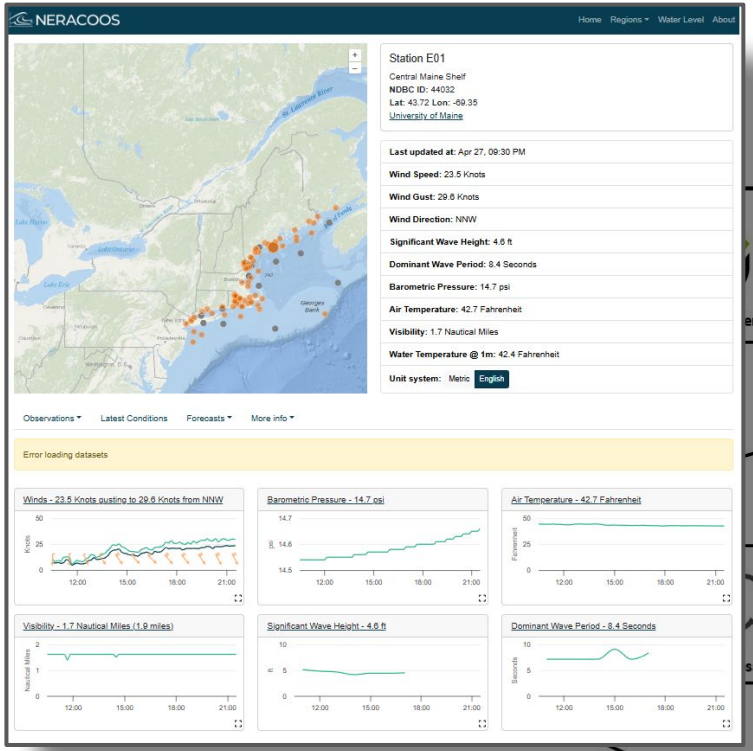

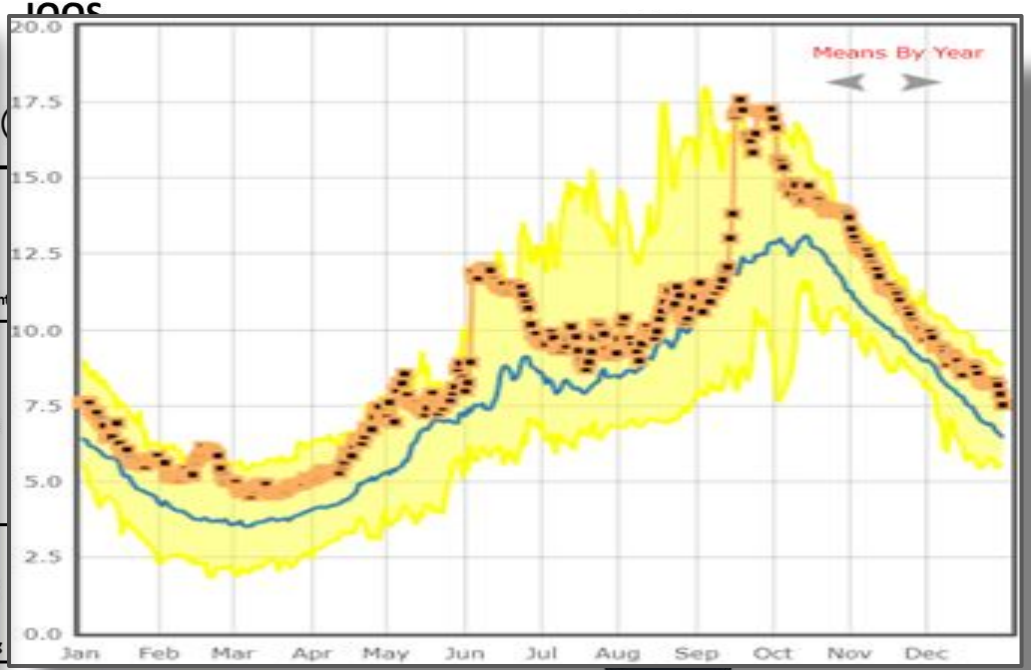

Public data visualization

A cyberinfrastructure accessible to other IOOS RAs

NOAA

IOOS

Conclusions & Discussion

The Sound Cooperative (SoundCoop) Project: Community-informed foundational best practices and open source workflows built to create, visualize, and disseminate standardized sound level products for comparative analyses Carrie.Wall@noaa.gov

The Ocean Sound Observing Network (OSON): We have built it (networked data collection infrastructure), and partners are here – opportunities now to solidify a national OSON using SoundCoop foundation, and software, tools & coordination PAM SI is building Lindsey.Peavey@noaa.gov

Expanding the NOAA Fisheries Passive Acoustic Monitoring Strategic Initiative (PAM SI) to IOOS: Implementation of cyberinfrastructure, tools and standard data processing from these previous efforts for applications beyond NOAA. Xavier.Mouy@whoi.edu