Coastal and Ocean Community Modeling Workshop Summary

October 19-21, 2021

1.0 Executive Summary

The National Oceanic and Atmospheric Administration (NOAA) is responsible for predictions of marine environmental conditions in and along our Nation's coasts, oceans, and Great Lakes. These waters sustain complex ecosystems and species and are also critical to safe and efficient transportation and commerce and for stewardship, recreation, and tourism. The need for more comprehensive and higher resolution data, information, and predictions about these waters has never been greater and our Nation especially needs information about extreme events, coastal flooding, water quality, marine navigation, ecosystem health, and the long-term impacts of climate change, among many other areas.

NOAA is building the Unified Forecast System (UFS), which will result in an interoperable ocean modeling backbone and data assimilation capability that supports regional and global coastal/estuarine, ocean, and Great Lakes modeling capabilities for integration into an operational Earth System modeling enterprise. The UFS has constructed weather-scale models successfully keying off the modules from NOAA's Flexible Modeling System (FMS), including the atmospheric Finite-Volume Cubed-Sphere Dynamical Core (FV3) and the ocean model Modular Ocean Model (MOM6). FMS is generating seamless models for weather to climate timescales for understanding the Earth system, including predictions and projections for the North American MultiModel Ensemble, World Climate Research Program (WCRP) Model Intercomparison Project (MIP), and the Sixth Assessment of the Intergovernmental Panel on Climate Change (IPCC).

The 2021 Coastal and Ocean Community Modeling Workshop (October 19-21, 2021) included modelers from government, academia, and the private sector and was hosted by NOAA's National Ocean Service (NOS). Participants addressed issues related to the development and transition of community-developed models into NOAA's operational oceanography suite, as well as NOAA's current and future priorities for coastal and ocean modeling within the Earth System prediction framework and the UFS.

Workshop panelists discussed their lessons learned from successfully, and sometimes unsuccessfully, transitioning community-developed models into NOAA that may serve as lessons learned for the efficient and smooth transitions of research into operations. Speakers, panelists, and participants noted that the successful transition of community-developed models into operations at NOAA requires: (1) a strong, integrated and sustained partnership consisting of a core team made up of NOAA and external partners involved in developing, transitioning, running, and/or operationalizing the model; (2) a common goal to develop an operational model; (3) clear understanding of what user need(s) will be addressed and the operational requirements imposed by these need(s); (4) identifying the NOAA office that will run and maintain the operational product before transition planning begins; (5) a clear, documented transition plan; (6) early and continual communication, coordination, and collaboration amongst the core team; (7) communication of all metrics and/or standards that the model must meet at the outset of model development; (8) an agile approach to model development and transition, both in terms of how the team works to achieve outcomes and to meet the goals of the project; (9) hard deadlines; (10) access to a parallel shadow system to test and analyze data or code in new ways in a rigorous, efficient, cost-effective manner;

(11) all members having access to the data used to develop, test, validate, and run the operational model; (12) effective project and data management systems be in place; and (13) documentation and dissemination, via open source repositories and peer-reviewed journals, of model configurations, inputs, parameters, and outputs, including model archives for boundary conditions, supporting downscaling systems data used for assimilation and/or validation, and quantitative validation metrics.

Workshop participants identified key areas for which focused effort in research and development over the next three to five years will deliver fundamental capabilities via an expanded suite of ocean observations and an integrated coastal modeling and observation system. These research and development priorities are not specific to a given model or user community but are instead relevant across a variety of models and applications for integrating research, development, observations, data management, and models. They include: (1) a comprehensive and robust ocean modeling system that resolves the full suite of ocean properties (e.g., physical, biogeochemical and ecological) and drivers (e.g., terrestrial and ocean), as well as unifies regional systems; (2) research and development on data assimilation (DA) and DA-system inter-comparison frameworks emphasizing use of the full suite of remote and *in situ* ocean observations, including biogeochemical and ecological data; (3) model coupling (e.g., ocean-atmosphere and terrestrial-ocean model coupling) to improve ocean-state realism; (4) providing all internal and external partners access to all data, metadata, software, code, and model output used to develop, test, validate, and run operational models; and (5) cyberinfrastructure and model skill assessment to include the development of comprehensive tools and benchmarks for interoperability, modeling metrics, and skill assessment.

Finally, workshop participants identified recommendations for growing the coastal and ocean modeling community. Building a regional-to-Federal partnership will ensure that the expertise resident among NOAA and partners results in the technical and scientific solutions required to deliver models that scientifically inform effective actions around extreme events, coastal flooding, water quality, marine navigation, ecosystem health, and the long-term impacts of climate change, among many other areas. Recommendations include, but are not limited to: (1) commiting to open development paradigms; (2) establishing a Coastal and Ocean Modeling Center without Walls; (3) establishing a Coastal & Ocean Modeling Community of Practice; (4) hosting regular workshops and training events; (5) articulating and socializing NOAA's priorities for coastal and ocean modeling; (6) sustaining and improving capacity; (7) aligning NOAA's modeling investments through synchronized cross-Line Office resourcing and priorities; (8) highlighting the economic benefits of ocean and coastal data and models; and (9) defining what it means for a model to be "operational."

2.0 Introduction

NOAA's mandates for science, service, and stewardship require the agency to understand and predict changes in coasts, oceans, Great Lakes, weather, climate, and ecosystems; share that knowledge and information with others; and conserve and manage coastal and marine ecosystems and resources. These mandates continue to be critical: The effects of a changing climate have been observed in our Nation's coastal communities and oceans for decades and the impacts are increasing in frequency, with rising sea levels, extreme storm events, shifting species distributions, coral bleaching, and more. At the same time, U.S. coastal counties are home to over 128 million people (nearly 40 percent of the total population) and produce more than $9.5 trillion in goods and services, employ 58.3 million people, and pay $3.8 trillion in wages annually.[1] The need for more comprehensive and higher resolution data, information, and predictions has never been greater.

Numerical modeling allows for the interpolation, interpretation, and prediction of the environment, and combining data with models aids the conversion of observations into meaningful information products. Sustained development of modeling capabilities, the application of models to enhance the design and operation of observing systems, and effective data management and communication are vital components of a truly integrated observing, modeling and prediction system resulting in environmentally informed decisions and resilient coastal communities.

Why a workshop? Historically, Federal agencies were the primary institutions implementing U.S. operational coastal and ocean models, while academic institutions concentrated on process studies and model development and experimentation. With the growing need for coastal, ocean, Great Lakes, weather, climate, and ecosystem forecasts across multiple temporal and spatial scales, many non-Federal entities routinely run real-time modeling systems. Though these systems might not meet Federal requirements for operational robustness and reliability as it relates to the provision of weather information, many user communities find the immediate environmental information served by non-Federal entities to be valuable.

NOAA is building the Unified Forecast System (UFS), which will result in an interoperable ocean modeling backbone and data assimilation capability that supports regional and global coastal/estuarine, ocean, and Great Lakes modeling capabilities for integration into an operational Earth System modeling enterprise. Developing these capabilities is essential to providing the coastal, ocean, Great Lakes, weather, climate, and ecosystem forecasts our Nation needs across multiple temporal and spatial scales. To do this, NOAA must enhance their community modeling efforts by leveraging external expertise to improve: (1) the process for transitioning community-developed research into operations; (2) current operational models; (3) models to meet local and national user needs in skill, time, and resolution; and (4) dissemination and decision support.

The 2021 Coastal and Ocean Community Modeling Workshop, part of an ongoing conversation among stakeholders, model developers, and operators is intended to enhance NOAA's coastal and ocean community modeling efforts. This workshop was designed to: (1) enhance communication and

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[1] NOAA's Office for Coastal Management. 2021. "Economics and Demographics." Updated November 4, 2021. https://coast.noaa.gov/states/fast-facts/economics-and-demographics.html

collaboration among Federal and non-Federal modeling communities; (2) identify best practices for transitioning community-developed models into NOAA; (3) identify roadblocks in the research-to-operations transitions, as well as recommendations for breaking down these barriers; and (4) understand NOAA's coastal and ocean modeling landscape and how community modeling is supported to achieve NOAA's coastal and ocean missions.

Why now? Our Nation is facing a profound climate crisis. The ocean plays a central role in regulating the Earth's climate and is at the front line of climate change as coastlines, coastal communities, and oceans are disproportionately impacted by increasing carbon dioxide and other anthropogenic greenhouse gas emissions. Ocean acidification, unsustainable fishing practices, sea-level rise, and stronger and more frequent hurricanes are already damaging our coastal industries, coastal and ocean ecosystems, seafood supplies, and local communities.

As the impacts from global and ocean warming continue to increase in intensity and frequency, so too does the Nation's need for accurate and timely ocean predictions and projections to protect our ecosystems, economy, national security, and lives and livelihoods. By engaging the broader coastal and ocean modeling communities, NOAA is leveraging whole-of-society expertise to deliver the technical and scientific solutions required to meet our Nation's coastal and ocean modeling needs.

For which outcomes? The workshop and subsequent workshop summary were co-developed with the workshop steering committee and workshop participants—both internal and external to NOAA—to leverage NOAA's community modeling efforts and advance NOAA's coastal and ocean modeling missions. Together, the workshop and workshop summary were designed to enhance collaboration and partnerships across NOAA's mission areas, programs, and service areas, as well as with NOAA's partners by: (1) enhancing communication and collaboration between Federal and non-federal modeling communities; (2) identifying recommendations that will increase the efficiency of transitioning modeling systems from research to operations; (3) ensuring the concerns, needs, and aspirations in building a community of practice across government and non-government entities are understood; (4) understanding the community models NOS will develop for the UFS next-generation ocean and coastal components.

3.0 Draft Workshop Themes: Best Practices, Priorities, and Recommendations

3.1 Best Practices for Transitioning Community-Developed Models into NOAA

The following best practices were synthesized from the workshop discussions of successful—and unsuccessful—transitions of community-developed models into NOAA operational practices. These best practices may inform guidance for efficient and smooth research-to-operations (R2O) transitions.

3.1.1 User needs

The needs of users, and the operational requirements imposed by these need(s), are co-developed, documented, and shared amongst developers, operators, and user communities to ensure that the final operational product meets these needs. Users may be end users, beneficiaries, or recipients of model products (e.g., forecast guidance), such as NWS forecasters, coastal managers, marine operators, local decision makers or users may be modelers developing related or ensemble models (e.g., modelers supporting the Unified Forecast System).

3.1.2 Integrated and sustained partnerships

NOAA and external partners involved in developing, transitioning, running, and/or operationalizing the model form a core team focused on the successful transition and operationalization of the product. The formation of a long-term collaborative relationship between core developers and operators (e.g., the core team) is important for sustained innovation and the incorporation of scientific and technological advances from the external research community into NOAA. The team must be completely integrated, as each member plays a critical role in the project, with clearly articulated and understood roles and responsibilities for each team member.

3.1.3 Common operational goals

All partners have the common goal to generate a modeling product that meets end user needs and/or requirements; this may result in an operational product run by NOAA or a product that is run and maintained by an external partner. An operational outcome requires an understanding of the performance metrics that the model must meet, the transition timeline, user needs, roles and responsibilities, and identification of the NOAA program that will run and maintain the operational model.

3.1.4 Operational programs

The NOAA program office and/or external partner that will be accountable for running and sustaining the operational model is identified and involved before any transition planning begins. This ensures that the expertise, resourcing, and capacity are available for running and maintaining an operational model. Identification of the operational entity may require approval from NOAA leadership and/or other entities, which should also be secured before transition planning begins.

3.1.5 Transition plans

The efficient and smooth transition of research into operations requires a clear transition plan that includes documentation of: (1) goals and objectives; (2) roles and responsibilities of team members;

(3) transition timeline and deadlines; (4) priorities, including time and resources; (5) user and operational requirements; and (6) operational metrics and standards. [Editor's note: In contrast, the sample transition plan in the Handbook[2] for NOAA Administrative Order 216-105B[3] lists eleven sections: (1) purpose/objective; (2) research background; (3) business case; (4) capabilities and functions; (5) transition activities; (6) schedule and deliverables; (7) roles and responsibilities (for the transition); (8) budget overview; (9) impacts of transition; (10) references; and (11) signature page.]

3.1.6 Early and continual communication, coordination, and collaboration

The core team establishes communication early in the development process and sustains continual communication throughout the transition process. The team meets at least monthly, and sometimes multiple times per day, when transitioning code. Cadenced meetings allow the team to be highly collaborative, allow data to be shared efficiently, and ensure consistent communication and coordination of tasks and outcomes.

3.1.7 Metrics and standards

All performance metrics and/or standards are communicated to developers at the outset, and that communication includes the approaches for demonstrating and disseminating metrics to team members. Metric assessment allows frequent evaluation of model performance, and meeting the required metrics is a powerful driver for moving the project forward while also improving the understanding of computational and physical sciences.

3.1.8 Agile approaches

The team is able to take an agile approach to model development and transition, both in terms of how the team works to achieve outcomes and to meet the goals of the project. Nimbleness and agility allow the team to quickly work around problems, to flexibly pivot, to advance innovative computational and physical science, and to develop the best operational product for NOAA. Agile approaches also allow the team to do more toward advancing NOAA's state-of-the-art model vision.

3.1.9 Hard deadlines

The team understands that achieving an operational outcome requires adhering to a strict internal NOAA timeline with deadlines to demonstrate model performance and to transition the research into operations. Achieving the deadlines requires understanding the goals, objectives, priorities, and timeline. These deadlines also provide a powerful driving force for moving the project forward.

3.1.10 Shadow system

A shadow system may be run in parallel by external partners to test and analyze data or code in new ways while in an efficient, cost-effective manner. Parallel systems also allow for a more agile approach to test and track the outcomes of new or proposed upgrades and provide important feedback to the development team.

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[2] National Oceanic and Atmospheric Administration. 2017. NAO 216-105B Handbook. March 21, 2017. https://sciencecouncil.noaa.gov/Portals/0/Handbook_NAO216-105B_03-21-17.pdf?ver=2020-09-10-173207-147#:~:text=NAO%20216%2D105B%20establishes%20the

[3] National Oceanic and Atmospheric Administration. 2019. NAO 216-105B: Policy on Research and Development Transitions. February 26, 2019. https://www.noaa.gov/organization/administration/nao-216-105b-policy-on-research-and-development-transitions

3.1.11 Materials access for model development

Every team member has access to all data, metadata, software, code, and model output used to develop, test, validate, and run operational models. This access allows the development team members to track the outcomes of new upgrades and ensures that the metrics and standards are accurately met before the code is transitioned to NOAA.

3.1.12 Project and data management

Project and data management systems are in place to allow the team to move project goals forward efficiently and effectively. The tools are used to assign, track, and manage tasks, as well as to efficiently transfer data between team members.

3.1.13 Documentation

Model configurations, inputs, parameters, and outputs, including model archives for boundary conditions, supporting downscaling systems data used for assimilation and/or validation, and quantitative validation metrics are documented, disseminated, and accessible in model repositories as well as in peer-reviewed journals.

3.2 Priorities for Focused Community Effort in Research And Development

The following priorities for coastal and ocean modeling research and development are not specific to a given model or user community but are instead relevant across a variety of models and applications for integrating research, development, observations, data management, and models. Improvements in these priority areas over the next three to five years will deliver improvements in fundamental capabilities that are necessary for expanded, comprehensive use of the full suite of coastal and ocean observations and integrated coastal and ocean modeling.

3.2.1 Comprehensive ocean modeling system

The priority for meeting NOAA's ocean and coastal mandates requires developing a comprehensive and robust ocean modeling system that resolves the full suite of ocean properties (e.g., physical, biogeochemical, and ecological) and drivers (e.g., terrestrial and ocean), as well as unifies regional systems. Building a comprehensive system may include improving current modeling skill as well as developing new models.

3.2.2 Data assimilation

The priority for data assimilation (DA) is research and development on DA methods, and DA-system inter-comparison frameworks emphasizing use of the full suite of remote and *in situ* ocean observations, including biogeochemical and ecological data.

3.2.3 Model coupling

The priority for model coupling is improving estimates of the ocean state through coupling technique developments applicable to ocean circulation, ice, hydrology, air, ecosystem, wave, and other components.

3.2.4 Data and model accessibility

The priority for data and model accessibility is allowing external partners access to all of the data sets and code used to build and enhance operational models.

3.2.5 Cyberinfrastructure and model skill assessment

The priority for cyberinfrastructure and model skill assessment includes development of comprehensive tools and benchmarks for interoperability, modeling metrics, and skill assessment.

3.3 Recommendations for Growing the Coastal and Ocean Modeling Community

The following recommendations were motivated by the ideas of building a nationally coordinated coastal ocean analysis and prediction system that is responsive to user requirements, takes advantage of the best numerical codes and algorithms, and uses the full spectrum of *in situ* and remotely sensed data. Each of these recommendations depend upon enhanced regional-Federal partnerships in the U.S. coastal and ocean modeling community in order to reap the benefits of community-developed models: to understand and predict changes in coasts, oceans, Great Lakes, weather, climate, and ecosystems; to share that knowledge and information with others; and to conserve and manage coastal and marine ecosystems and resources. Recommendations were synthesized from the Workshop keynote, speaker series, panels, brown bag sessions, and the community showcase and are listed in no particular order; all are equally important.

[Editor's notes: Many of the concepts in this Subsection are already envisioned for EPIC, UFS, and other community and interagency programs, but are listed here to accurately reflect the ideas that emerged in the Workshop.]

3.3.1 Commit to an open development paradigm

Enhancing community modeling requires committing to a fully open-source, decentralized software development model (e.g., MOM6) that encourages open collaboration between partners and organizational entities. This move to a fully open system is a challenging, but critical first step for fully community development and is not fully met by current open source approaches. Adopting open source working methods allows more opportunity to review model code, provide comments and feedback to improve code quality and functionality, perform earlier tests to catch bugs, and provide enhancements as early as possible in the development cycle. The result will be an improved, high quality code that fosters innovation and more efficiently supports continuous improvements to model skill.

3.3.2 Establish a "Coastal and Ocean Modeling Center without Walls" (Cw/oW)

The research priorities required to meet NOAA's operational coastal and ocean modeling and prediction require collaborative activity among coastal, ocean, and information science experts across agencies and institutions. Learning from past collaborations and successfully working virtually through a pandemic has given NOAA and external partners the confidence and experience to collaborate virtually, and to know that a Coastal and Ocean Modeling Center without Walls (Cw/oW) could meet NOAA's coastal and ocean research priorities. By formalizing such a center, it is possible to provide a computing and data access environment in which NOAA and academic researchers can collaborate. The center would coordinate with NOAA's Unified Forecast System (UFS) and Earth Prediction Innovation Center (EPIC) efforts to ensure alignment of priorities and code.

The virtual Cw/oW would facilitate synergies where appropriate but would not be focused on particular coastal geographic regimes. The center would also foster close collaboration and bring together diverse expertise to make rapid and significant progress on targeted projects, while simultaneously providing a home for a professional staff to sustain ongoing development of tools and best practices for working with ocean models and observational data. The Cw/oW would provide the infrastructure and protocols that enable experimentation within a virtual operational environment (e.g., a 'computational sandbox') to accelerate research-to-operations-to-research (R2O2R) transitions and encourage coastal and ocean modeling researchers from universities and other agencies to spend extended periods of time working on problems directly related to improving operational modeling within Federal agencies.[4]

3.3.3 Establish a "Coastal & Ocean Modeling Community of Practice"

A Coastal and Ocean Community of Practice (CoP) would be comprised of modelers and model users from across NOAA Line Offices, the IOOS Regional Associations, and academia, with added involvement from Federal counterparts and private industry. The CoP would foster interchange of research and development experience and needs within the U.S. coastal ocean research community through events, such as focused workshops, training events, proving grounds, testbeds, and themed publication collections. The CoP may also foster community-building efforts, such as a Science Fair of Failed Projects, a Failed "Zombie" Proposal Revival and Renewal, or Twitter hashtags (e.g., #helpmycoastaloceanmodel or #coastaloceanmodel911).

The collaborative programs and/or teams that evolve from the CoP will work with NOAA's cross-Line Office efforts (e.g., UFS, EPIC, Climate Fisheries Initiative (CFI), Precipitation Prediction Grand Challenge (PPGC), etc.) to enable NOAA and the external community to deliver coastal and ocean model-based products and information that meet user needs on a sustained basis.

3.3.4 Host regular workshops and training events

One of the biggest challenges for maintaining and enhancing community modeling is sustaining regular communication and efficiently coordinating efforts across entities, both within NOAA (e.g., Line Office and cross-Line Office efforts) and external to NOAA (academia, Federal partners, private partners, etc.). Holding workshops and training events on a regular cadence is an effective way to sustain communication among active partners while engaging new partners.

An annual Ocean and Coastal Community Modeling Workshop would bring partners together to discuss current efforts, state-of-the-art research, challenges, recommendations, and research and operational priorities. Such a workshop may be held independently, or may be hosted alongside other workshop efforts such as an EPIC Community Modeling Workshop, the proposed Climate-Fisheries Initiative Workshop, or the proposed NOAA Modeling Fair to be hosted by the NOAA Modeling Board. Further, additional smaller and specialized workshops and training events would communicate priorities and address roadblocks for specific areas of research and/or operationalization of models.

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[4] See also the European Centre for Medium-range Weather Forecasting (ECMWF) Fellowship Program

3.3.5 Articulate and socialize NOAA's priorities for coastal and ocean modeling

NOAA's current and future plans and priorities for operational coastal and ocean models should be clearly articulated and disseminated to the community, including academic, Federal, and private partners, as well as across NOAA Line Offices and cross-Line Office efforts (e.g., UFS, EPIC, CFI, PPGC, etc.). These plans need to clearly lay out: (1) user needs and model requirements; (2) research and operational priorities; (3) timelines for development and transitions; and (4) the Line Office and program office that will operate the identified models. Opportunities and priorities for community development are highlighted, along with opportunities for funding.

3.3.6 Sustain and improve capacity

Securing knowledgeable, experienced personnel to fill the positions for ocean modelers, including model coupling and advanced data assimilation, is a key priority and an unmet need. Beyond coordinated, targeted research and development, it is therefore also important that students and early career scientists be entrained into these efforts to ensure the evolution of a skilled workforce that can sustain applied coastal and ocean modeling in the long term.

3.3.7 Align NOAA's modeling investments through synchronized cross-Line Office resourcing and priorities

Building an interoperable ocean modeling backbone and data assimilation capability that aligns with the UFS is a NOAA-wide effort that requires aligning Line Office priorities and resourcing. At a minimum, aligning resources and priorities will depend upon sustained engagement with NOAA leadership as well as cross-Line Office bodies, such as the NOAA Modeling Board (NMB), CFI, PPGC, NOAA Science Council (NSC), Weather Water Climate Board (WWCB), NOAA Water Team, NOAA Climate Team, NOAA Weather Team, or the EPIC Team.

3.3.8 Highlight the economic benefits

NOAA is transitioning enormous amounts of coastal and ocean data into the cloud with the intention of leveraging community modeling and public-private partnerships to drive scientific discovery and innovation and improve decision making across numerous industries. These data have significant value with even more value to be realized through the power of big data and cloud computing. Given resourcing challenges and the increasing impacts of the climate crisis, calculating the economic benefits of these data for decision makers and communities, while also tracking the use of cloud data, are key metrics for understanding and communicating the value of coastal and ocean data.

3.3.9 Define "operational"

NOAA and partners must agree on what it means for a model to be "operational." They must also decide whether there should be tiers and/or different operational categories to evaluate and, if there are tiers, whether they should be based on the type of model/subject matter or should be all-encompassing (see also the panel discussions in Subsection 4.3).

4.0 Workshop Details

4.1 Keynote

Mark Osler, Senior Advisor for Coastal Inundation and Resilience Science and Services

Mark Osler opened his keynote address by noting that climate science is a priority for the Biden-Harris Administration and that coastal resilience is one of the top five priorities for this Administration's interagency and intra-agency activities. Mr. Osler noted that NOAA should: (1) strive to be the leading source of climate science products; (2) carefully consider equity and social justice in all of its work; and (3) advance environmental stewardship to support the Blue Economy.

Success in coastal resilience depends largely on NOAA's ocean and coastal modeling capabilities; however, historically, oceans have been modeled mainly as a component of the larger weather system. Recent climate events (e.g., 82 days of flooding/coastal inundation in Key Largo, FL[5]) have highlighted the need to improve the collective understanding and modeling of ocean systems to improve forecasts and predictions. Further, NOAA's Science Advisory Board's recent report on Advancing Earth System Prediction emphasized that NOAA currently lacks the ocean modeling and decision support systems needed to meet NOAA's mandates (primarily focused on storm forecasting, clear gaps in timescales, resolutions, and environmental parameters) and that there is a need to rapidly increase and improve ocean model predictions to save lives and property. Community modeling can ensure that NOAA is serving society with climate-science products, equity and social justice, and environmental stewardship.

Mr. Osler reviewed the intentions of the Workshop: (1) improve the understanding of what NOAA can predict; (2) how NOAA can more effectively develop next generation coastal and ocean models; and (3) how community modeling and co-development can help NOAA throughout the process. Additionally, Mr. Osler emphasized that partnerships, not just collaborations, will be key to the success as partnerships require a shared vision and a shared risk/reward calculus for achieving the outlined objectives. In the spirit of partnerships, Mr. Osler highlighted the diversity of offices and community members in attendance and encouraged everyone to respectfully join the workshop dialogue with radical candor and to be brave in voicing areas where support for their current work is needed. In this way, participants can learn from each other and identify synergies, redundancies, and deficiencies between their individual efforts.

During the question period, Mr. Osler acknowledged the importance of moving science towards openness, as outlined in the Weather Research and Forecasting Innovation Act of 2017 and promoted by NOAA's Science Advisory Board. It is anticipated that within the next few months there will be a formal NOAA order on this topic and potentially a new law. To that end, NOAA is already making some codes and software publicly available and open source. Mr. Osler also agreed that there is room for improvement in the public's understanding around NOAA's research trajectory. In the meantime, there is room for people to be doing similar research, especially as there is excellent intellectual capacity outside of NOAA. NOAA's role is to think through how to bring those valuable

[5] Mazzei, Patricia. 2019. "82 Days Underwater: The Tide Is High, but They're Holding On." November 24, 2019. https://www.nytimes.com/2019/11/24/us/florida-keys-flooding-king-tide.html

contributions into the agency. He closed by thanking everyone for embracing the shared responsibility of creating a shared ocean vision.

4.2 Speaker Series

4.2.1 How community modeling can support NOAA's ocean and coastal missions

John Wilkin, Professor of Marine and Coastal Sciences at Rutgers University

Background. Wilkin et al. 2017. Advancing coastal ocean modeling, analysis, and prediction for the U.S. Integrated Ocean Observing System

Areas of consensus. John Wilkin noted that there is general consensus amongst the academic community on: (1) science/research priorities; and (2) embracing standardizations and model-agnostic approaches to data access (e.g., FAIR principles; ERDDAP; NetCDF/Zarr), earth-system model component coupling (e.g., National Unified Operational Prediction Capability (NUOPC)), data assimilation frameworks (e.g., Joint Effort for Data assimilation Integration (JEDI)), and collaborative software management (e.g., GitHub). However, some concerns have been raised concerning UFS, including the lack of coastal ocean models, community engagement, and documentation for, and access to, Federal operational systems.

Opportunities for community support. Areas in which community modeling development can support NOAA's coastal and ocean missions include:

- Coordinating model developers and users, including clarifying roles for researchers.
- Reducing subjectivity in model implementation.
- Creating a common repository for reference model results, including crowd-sourced skill assessment.
- Developing Coastal Impact Model Inter-comparison Project studies.
- Developing new models and improving existing models; model diversity is desirable, and convergence towards a single model is neither needed nor scientifically healthy.
- Developing common interfaces for model coupling.

Mechanisms for facilitating community modeling development. Two potential mechanisms for facilitating, encouraging, and enabling community modeling development engagement with NOAA include:

- Conducting "caucuses" between modelers and model users. These events can be conducted in a variety of ways (e.g., focused workshops, trainings, testbeds) and can facilitate: Intellectual exchanges; identification, development, and consensus around best practices; and publication of themed collections and documentation that helps to improve Federal models and systems.
- Establishing a "center without walls." Linking together multidisciplinary scientific programs and expertise can help to:
    - Incorporate non-traditional groupings of ocean and information science.
    - Bridge gaps in funding mechanisms.
    - Develop targeted projects for applications.

- Experiment in “sandboxes” or virtual operational environments.
- Train the next generation of our workforce.

Discussion.
In addition to lauding success, it’s important to also discuss problems in research and model development. This openness is often more useful and leads to community building.

[Model infrastructure] There is a critical need to maintain a diversity of algorithmic capabilities while also standardizing interfaces (e.g., software and code). Standardizing interfaces allows people with different models to experiment with different pieces and configurations. Perhaps models should be designed as infrastructures from the start and not as a single model. From an academic perspective, UFS offers an interesting research platform that could facilitate experimentation and examination of earth system models combinations, both novel and established, to explore which component models work best for certain purposes.

[Documentation] NOAA’s model and data documentation is not easily accessible and lags behind the international community.

[Model outputs] It is hard to compare model output from different models; structure and rigor in ocean model comparisons is needed. Perhaps this issue deserves a “community caucus.”

[Community input] NOAA is making progress on important questions (e.g., collaboration versus partnership, open source versus open development, documentation of code); however, the community should also be included in developing these answers.

4.2.2 NOAA programs that support community-developed modeling

Derrick Snowden, Chief of the Operations Division at the U.S. Integrated Ocean Observing System

NAO-216-105B. Derrick Snowden provided an overview of NOAA’s Policy on Research and Development Transitions (NAO 216-105B) and the different NOAA programs that support community-developed modeling. NOAA’s Policy on Research and Development Transitions establishes the process for identifying, transitioning, and coordinating research and development output to operations, applications, commercialization, and other uses.

NOAA programs. For detailed information about NOAA programs that support the process of transitioning research into operations, see the Day 1 meeting slideset here, slides 28-40.

Discussion.
[Collaborative environments] Program funding can help draw the modeling community to work on a problem, although the participants often simply focus on solving the problem with their own tools and within their usual networks. Creating programs that result in new networks of collaboration can be effective in bringing about community growth. Given that: (1) funding opportunities are low; and (2) the potential movement forward for collaborative environments is high, it would be great to find the pieces of community engagement that do not require additional funding. In particular, cooperation and coordination among NOAA programs is imperative in supporting collaborative

environments. The hard work is creating programs that encourage groups to work together from the beginning.

[Research-to-Operations (R2O)] Relative to research-to-operations: (1) transition plans have helped NOAA leadership to be more proactive with innovations coming from the community; and (2) focusing only within certain groups has a massive hidden cost for R2O as NOAA needs to duplicate most of the research. With the NOAA Hurricane Forecast Improvement Project (HFIP) "forcing" Principal Investigators (PIs) to use Hurricane Weather Research and Forecasting (HWRF) for their research and development and R2O, the number of innovations per year has increased by a factor of two-to-three times.

4.2.3 NOAA's modeling landscape for community model developments

NOAA Modeling Board Co-Chairs: Brian Gross, Director of NOAA's Environmental Modeling Center • Dorothy Koch, Director of NOAA's Weather Program Office

NOAA Modeling Board. The NOAA Modeling Board is a cross-agency body that was created in April 2021 and envisions unified production of world-leading, fully coupled Earth System models for research, operations, and applications. While the Board does not make decisions for others about their modeling needs and budget, it is chartered for the following purposes and accountabilities:

PURPOSE	ACCOUNTABILITIES
Coordinate on environmental modeling systems with consensus	Defining and streamlining the routine pathway into operations
Provide strategic advice and guidance	Facilitating innovations into operations and applications
Serve as a NOAA point of contact for community collaboration and coordination	Coordinating modeling systems investments
Work within the principles of: fairness and integrity, transparency, accountability, viability, collaboration, attribution, and effectiveness	Co-developing the continuous process of agile, integrated research, applications, and operations
	Coordinating with community partners
	Fostering innovative science in support of NOAA's mission and Earth System prediction

Community modeling experiences. Each of the NOAA Line Offices has summarized their experiences and challenges in working with the community as well as recommendations for future engagements:

- The National Marine Fisheries Service (NMFS) relies on the community for technical advice and assistance in developing products. The community, specifically regional partners, helps derive fishery management recommendations.

- The National Weather Service (NWS) uses the community to develop and implement the National Water Model and UFS. Further, NWS is currently trying to upgrade their software practice and emulate UFS more.
- The National Environmental Satellite, Data, and Information Service (NESDIS) has a goal of better integrating and engaging with the community in order to develop a rapid path for transitioning community research and applications into NOAA.
- The Office of Oceanic and Atmospheric Research (OAR) identified accelerating transition innovations into operations as a priority.
- The National Ocean Service (NOS) is in the process of: (1) developing sustained relationships with the non-NOAA modelers to coordinate research to operations and operations to research activities; and (2) supporting a community of practice focused on using a small number of core ocean models to conduct research in hopes of improving operational outcomes.

UFS. The Unified Forecast System is a community-based, coupled, comprehensive Earth modeling system that aims to improve operational forecasts and research in a unified system. The UFS has eight components, which include atmosphere, ocean, wave, land, storm surge, composition, sea ice, and ionosphere. UFS is currently addressing some of the challenges shared with the NOAA Modeling Board, including:

- With NMFS, a nationally organized modeling framework.
- With NWS, governance, routine coordination, availability of common data sets, workforce with required skills.
- With NESDIS, aligning community modeling with tools and models consistent with NOAA's operational environment.
- With OAR, more understanding about the requirements to transition from research into operations is needed.
- With NOS, logistical and organizational support to maintain the connectedness of a distributed community.
- Throughout NOAA, organization and funding paradigms and the need to improve access to high-performance computing.

EPIC. The Earth Prediction Innovation Center (EPIC) plays an important role in UFS and aims to modernize NOAA's modeling infrastructure. EPIC is charged with removing barriers, developing prediction models outside of NOAA, leveraging existing resources, and establishing predictive models that are accessible to the public. EPIC is intended to accelerate community contributions to UFS, akin to what was observed on GitHub when the medium range weather application came online. Examples where the community has been essential in advancing NOAA's missions include the North Atlantic right whale distribution modeling and the West Coast Operational Forecast System (WCOFS). Additional information about EPIC is available in the next subsection.

Discussion.
[Unified but not unitary] Can you speak more about a unified but not unitary forecast system? It comes down to the efficiency of doing business: NOS observed that there were more coastal

models than applications. In order to simplify, NOS determined that there were three different models that had separate functionalities that were not possible to get from one model. The ability to test alternatives comes from model diversity and common interfaces and offers the ability to see which configuration provides the best information.

[What will be next for UFS?] The UFS R2O Project, starting in FY2023, could include additional applications, such as seasonal-to-subseasonal (S2S), space weather, or coastal.

4.2.4 Leveraging community-developed models with EPIC and UFS

DaNa Carlis, Deputy Director of NOAA's Global Systems Laboratory • Maoyi Huang, Program Manager for NOAA's Earth Prediction Innovation Center

Background. Given the climate crisis, the demand for information is increasing. In response, scientists are interested in developing Earth System prediction models; however, until the advent of EPIC, there was no one entity capable of coordinating weather research and prediction. As articulated in the EPIC Strategic Plan, the goal for the program is to: "Accelerate scientific research and modeling contributions through continuous and sustained community engagement to produce the most accurate and reliable operational modeling system in the world."

What is EPIC. EPIC's mission is to become the catalyst for community research and modeling system advances that continually inform and accelerate advances in operational forecast modeling systems. EPIC is:

- A virtual center for community model development.
- Management of cloud-ready code.
- Community access to NOAA observations, data, and tools.
- Community support and engagement.
- Clear priorities for research & model transition to operations.
- Expected expansion to other additional model components.
- Focused on the UFS.

Measures of success. In a short amount of time, EPIC must:

- Increase usage of the models (e.g., downloads, community code contributions, tutorials, research projects, peer-reviewed papers).
- Improve synoptic scale forecasts (e.g., 500 hPa anomaly correlation scores for global weather and ensemble forecasts).
- Improve usability and reliability of subseasonal and seasonal forecasts.
- Increase accuracy of forecasts of high-impact weather events (e.g., hurricane track and intensity and tornado warning lead-time).
- Foster long-range Earth System modeling planning out to ten years.
- Provide the world's best forecasts at all timescales and phenomena.
- Accelerate the rate of innovation from the external community by 50 percent.

Next. In the next year, EPIC is planning to stand up community supporting infrastructure to accelerate transition from community to UFS code repository. The UFS code repository will be public facing and the community will be able to use the code and make contributions to update and improve code-skill scores. EPIC activities in FY2022 include:

- Release publically the EPIC community portal.
- Establish the EPIC Student Program.
- Host the EPIC Symposium and Student Workshop at the 2022 American Meteorological Society annual meeting.
- Host the 2nd Annual EPIC Community Workshop.
- Facilitate public releases of Joint Effort for Data assimilation Integration (JEDI).
- Release the cloud-ready UFS Medium Range Weather application.

Discussion.
[NOMADS included in EPIC?] Will existing services like the National Operational Model Archive and Distribution System (NOMADS) be brought into the EPIC framework? This is outside the scope of EPIC.

[EPIC role?] EPIC is providing software engineers and infrastructure to support code based for UFS. All the code bases for UFS are open development and the community is critical to the ongoing progress of UFS/EPIC.

4.2.5 NOAA's coastal and ocean ecological modeling imperative

Steve Thur, Director National Centers for Coastal Ocean Science

Background. Ecological modeling at the National Centers for Coastal Ocean Science (NCCOS) is needed for: (1) recreation and tourism; (2) risk reduction; and (3) the Blue Economy.

What is needed? To develop ecological models, the following are required:

- An understanding of the user decisions to be addressed by the model.
- A coordinated research and development enterprise to develop the models.
- Sustained observations necessary to feed the models.
- An operational unit, connected to the research-to-operations-to-research loop.

Model development. The questions that are being asked at the start of model development include: What is needed? What is the application? Can it be delivered in a time frame responsive to user needs?

What's not being asked? The questions that should be included in this list include: Should we do it? Is this an appropriate role for the Federal government? Is the investment worth the taxpayers' dollars? Can it be developed and passed off to someone else? Asking these questions more frequently will crystalize the justifications for addressing the needs.

Challenges. Partnerships are necessary due to the lack of a singular funding stream for ecological models. However, while partnerships are important, challenges can occur when a partner has a change of funding, priorities, or staff.

Solutions. Develop a marine ecosystem prediction system that links together systems for ocean observing, modeling, reporting, and governance.

Effective transition management. Effectively transitioning eco-forecasting research and development into operations will require:

- Joint understanding of requirements (e.g., observations, modeling, decision support) through co-development of stakeholder needs.
- Aligning investments through synchronized resourcing decisions and shared priorities.
- Increasing engagement at both the technical and leadership level.
- Touting successes as new ecological modeling efforts yield societal benefits.
- Highlighting unmet needs and the potential for economic and environmental benefits.

Discussion.
[Collaboration for ecological models] How can NOAA and academia collaborate to develop ecological models that couple to physical models? By aligning incentives for a win-win by each group.

[Cost-benefit] What is the cost-benefit calculation underlying the rationale for the proposed National Marine Ecosystem Prediction Center? Additional studies on the value of ecological information are needed. NOAA has conducted some preliminary studies (see the "Eco-Forecasting Economic Analysis" here and the "Use and Value of NOAA Ecological Forecasting Products" here), although more is needed.

[Unified] How can mechanisms be developed that are not stovepiped? Constrained resources have led to partnerships being incentivized, which leads to greater dissolution of the stovepipes. However, solid and robust methods to move resources to the highest priority are lacking, which results in continued funding through these stovepipes. The Coral Program is a good example of a unified source of funding that gets distributed according to a governance structure.

[Ecological needs and validation] How could ecological needs be factored into routine model validation? Successful programs lower the costs of validating the models by finding partners that are already out in the field doing something else.

[Funding for hydrodynamic models] How can NCCOS be more involved and strategically fund the hydrodynamic models? The NOAA Modeling Board now serves as a resource for coordination and collaboration.

[Societal benefits] Determining societal benefits is challenging. How many people have to benefit from it before it can be a public good versus a private good? Economics is not really able to explain variation, so stories can be powerful instead. There are non-economic ways to explain how to provide societal benefits. For example, reduction in emergency room visits during red tide events or vessel routing structures and speed limits to reduce impacts to whales.

4.3 Panels

4.3.1 NOAA's operational requirements

Avichal Mehra, Chief of Dynamics & Coupled Modeling Group, Modeling & Data Assimilation Branch at NOAA's Environmental Modeling Center • Trey Flowers, Director of the Analysis and Prediction Division at NOAA's Office of Water Prediction • Greg Seroka, Storm Surge Operations Lead at NOAA's Coastal Marine Modeling Branch at NOAA's Office of Coast Survey • Jon Hare, Science and Research Director at NOAA's Northwest Fisheries Science Center • Patrick Burke, Oceanographic Division Chief at NOAA's Center for Operational Oceanographic Products and Services

The panel on NOAA's operational requirements launched their discussion by answering two questions: What do you want the community to know about operationalizing models in your Line Office? How can the community contribute to developing your models?

[Avichal Mehra] The operational requirements for NWS can be grouped as follows:

- Science and engineering that is focused on: (1) upgrades/improvements to current models; and (2) the development of new models. These models should be community-based (open source/open development), must meet dissemination guidelines, and should maintain existing products.
- Concept of operations that ensures systems: (1) are robust, stable (numerically), and resilient; (2) fit within their designated operational slot; and (3) follow coding standards.

[Trey Flowers] Challenges with community engagement include:

- From a research and development perspective, the models that have been operationalized are now obsolete.
- If the goal is to allow the community to have an impact on modeling systems that have not yet been released, outstanding questions to be addressed by NOAA include: How can NOAA bring the community into the development streamline? How does NOAA engage them in development at a meaningful stage? How should NOAA communicate with the community? How does NOAA communicate their priorities?

[Greg Seroka] Currently, the Office of Coast Survey (OCS) Global ESTOFS model supports several different user groups, including disaster mitigation groups and navigators. Bathymetry data is the most important model input so OCS is continuously looking for better bathymetry data. OCS needs continuous community support in order to transition models to operation and to keep the models updated. These efforts tend to be resource intensive and to have tight turn arounds so OCS may prefer to rely on academic partners.

[Jon Hare] In the fisheries world, operational modeling means conducting stock assessment to support living marine resource (LMR) management. NOAA's Climate and Fisheries Initiative will provide a means to link biological modeling and climate and environmental modeling to better support communities at a national and regional scale.

[Patrick Burke] At present, the Center for Operational Oceanographic Products and Services (CO-OPS) does not develop its own code and thus relies on the community for code development. Often, models are outdated as soon as they are operationalized due to the approximately 18-months it takes to test and onboard a model. CO-OPS asks the community to be vocal about their needs and to engage early and often in the development process so that community inputs can be integrated and considered throughout the model development process.

Discussion.
[Coastal information] Do you have great high-resolution sources for detailed coastal information? The best baseline product we've found is the USGS's Global Shoreline Vector (GSV). NOAA's Continually Updated Shoreline Product (CUSP) is good for the domestic shoreline and there are additional products that are useful.

[Canada and the National Water Model (NWM)] Is there a plan for the NWM to provide river forecasts for the streams/rivers on the Canadian side (e.g., Great Lakes, Gulf of Maine)? The Great Lakes waterways are in the NWM; however, they are masked for public release. There are no plans to include the Canadian side of the Gulf of Maine.

[Biogeochemical (BGC) and the NWM] Will biogeochemical (BGC) aspects be incorporated into the Nextgen Water Model? Not immediately; however, later versions of the model will integrate BGC. It is likely that water temperature and salinity will be included in the latter half of this decade.

[BGC and CO-OPS] Prior to advancing community funding opportunities related to coastal BGC modeling, should programs consult with CO-OPs regarding constraints and considerations that should be included in the Notice of Funding Opportunity (NOFO) in order to better position the project outcome for transition to CO-OPs? The academic community should develop coastal BGC models with input from CO-OPS on: (1) needs; and (2) proper resourcing of operations.
Modeling and fisheries: How robust is the integration between coastal models and predictions and fisheries management? There are research examples of use; however, the operational use is very limited. To make progress in this area, the goal of the Climate Fisheries Initiative is to develop a robust, national integration of coastal and regional models to regional fisheries applications.

[Hindcasts and fisheries] Can hindcasts from high-spatial resolution coastal models for fisheries and other living marine resource management be made routinely available?

- A 14-year 1-hourly interval 7-km data assimilating reanalysis of the northeast shelf (Hatteras to Halifax) is available. These data currently exist (8TB) on the Thematic Real-time Environmental Distributed Data Services (THREDDS) server but is not yet in the cloud.
- Such a product would be useful in Alaska. While there has been tremendous uptake of The University of California, Santa Cruz's West coast reanalyses in fisheries, it definitely requires someone to facilitate the handoff (e.g., turning Regional Ocean Modeling System (ROMS) outputs into fields appropriate for ecological models), which is time consuming.

Reducing the output to some key 2D fields can also facilitate uptake and make the THREDDS approach more tractable. The Integrated Ocean Observing System (IOOS) Regional Associations (RAs) are a great resource for making such regional products available. ROMS-based hindcasts of the Bering Sea (weekly averages) are hosted at the Pacific Marine Environmental Laboratory (PMEL) and available here.

[Continuity of operations] What is the solution to the issue of guaranteeing continuity of operations; in particular, that NOAA has the expertise to support the maintenance of the models in the long run? NOAA is aware of this issue and tries to plan for operations and maintenance costs to ensure model longevity. For instance, UFS provides an infrastructure for bringing together community developers and relevant government agencies so that the developers understand code updates.

[Data needs] What are the top three specific topics in which more work or data are needed to improve operational coastal model predictions? Coupling, data assimilation, JEDI, and bathymetry are all important. One aspect on the operational side is getting feedback from customers so that gaps and problems can be identified. One solution is to establish a co-development process, where users and model developers confer with each other regularly to ensure that user needs/feedback are incorporated throughout the process. It is also important to understand how new observations impact our models.

[IOOS sandbox] Is there a mechanism to move improvements identified via the IOOS sandbox to an operational framework? Not currently; it would be good to set up evaluation metrics and platforms. No matter how the community is involved, some of the work to be done (e.g., benchmarking runtime efficiency) will have to be done by Federal employees on Federal assets. A shadow model of ESTOF is being run that allows a similar environment for testing; EPIC may be in a position to enable a broader testing environment.

[Cloud computing] Is cloud computing a viable approach for operational ocean modeling in NOAA? Running modeling systems on the cloud is not complicated; it's about setting up the infrastructure and enabling the necessary services. The challenge is not technical as much as it is cost.

[Transparency] Can details (e.g., specific library versions, operating system, compilers used, etc.) be made more transparent to aid in reproducibility? See NOAA's GitHub repositories here.

[Flexibility] Are the emerging couplers (e.g., the National Unified Operational Prediction Capability (NUOPC)) sufficiently flexible to accommodate the evolving scientific understanding of the rapid interactions among components (e.g., ocean, atmosphere, waves, ice, etc.)? The design of the coupling tends to be model specific and provide important variables to run the models. If there is a new scientific innovation, there is some flexibility in how to couple but the flexibility is not wide enough to deal with changes in the future. The coupler is a main part to worry about, but the difficult part is that the receiving component needs new physics, which can be very time intensive. The coupling of the components is not simply communication; that new field requires a place to come into the model which requires physics. The mediator between different components makes it easier for the physics to be done. One advantage of the mediators is that you can avoid going into the individual components.

4.3.2 What does it mean to be operational?

Panelists: Mike Jacox, Research Oceanographer at NOAA's Southwest Fisheries Science Center (SWFSC) and Physical Sciences Laboratory • Chris Edwards, Professor at the University of California, Santa Cruz • Joe Sienkiewicz, Chief of the Ocean Applications Branch at NOAA's Ocean Prediction Center • Philip Chu, Supervisory Physical Scientist at NOAA's Great Lakes Environmental Research Laboratory

This panel opened by addressing: How have products or models been operationalized from a user's point of view?

[Mike Jacox] There is a large amount of high-resolution ocean and climate information that is being used by fisheries scientists, largely due to relationships with academic partners. The application of data and models is wide ranging and covers a range of timescales. The most important piece for models to be operationalized is the reliable delivery of useful and needed products, which requires institutional support for the coastal modeling infrastructure.

[Chris Edwards] The operational system was easier to use than expected due to open development and the THREDD servers. However, there are significant challenges with sustained funding for operations and maintenance (e.g., staffing, quality checking, etc.). Additionally, the UCSC lab has had to deal with natural disasters that can affect the operational status of these systems.

[Joe Sienkiewicz] Fully operational warning offices produce information that has to meet national and international standards/requirements. Many of the Ocean Prediction Center's (OPC) users rely on accurate and reliable information for safety and navigation purposes.

[Philip Chu] To be "operational" at NOAA means: (1) a long and expensive research-to-operations process; (2) a check on all of the components that make a model operational; and (3) constant staff and funding to support the daily operations of the system. In reality, not everything in the research pipeline will transition into operations. However, there are multiple avenues to take if your product is not transitioned by NOAA; the challenge for the data user is that they may not be aware of these alternate opportunities.

Discussion.

[High Performance Computing (HPC) capacity] Do NOAA's challenges around creating sustained, operational products involve challenges related to resource and capacity limits? Cloud services are rapidly changing the equation, although there may be hidden costs in addition to the known benefits. Historically, NOAA had complete control over the models and data by utilizing the hardware and infrastructure at academic institutions, which are difficult to maintain. It would be better to rely on NOAA for providing the infrastructure on models and data. Cyberinfrastructure is an ongoing discussion at NOAA.

[NOAA's handoff] What does NOAA need to do and what does it not need to do because there is already external capacity for this? There is a restricted dataset and an unrestricted dataset. All of the datasets sit behind a firewall. Currently NOAA does not have capacity to support unrestricted datasets that sit outside of the firewall. There are too many operational models and there is a cost to running things in operations (e.g., data has to be reliable, backups, etc).

[Quasi-operational] There are two discussions underway by the participants: (1) using the NOAA definition of "operational;" and (2) acknowledgement that there are also non-NOAA sanctioned operational tools in use.

- There are problems with users depending on a quasi-operational system run by a research group that may run out of funding.
- Can a reliability level be developed for "quasi-operational" models? The Integrated Coastal and Ocean Observation System (ICOOS) Act allows for flexibility to use a standard of "operational" that works for this community better. This alternate definition opens the door for IOOS Regional Association involvement in operational model development, delivery, and applications to meet societal needs.
- CO-OPS has developed a tiered data standard for water level that could be used for inspiration in developing "tiered operational levels" that clearly define for users what level of operations a particular model or product can reliably provide.
- Must also acknowledge that R2O is a time-consuming and expensive process that requires commitments and trust from all parties. There is a strong need to do basic research that will eventually evolve into operations.

[Fisheries needs] For fisheries, there needs to be: (1) proof of verification that the model consistently resolves ocean features relevant to the distribution and/or productivity of marine fish or crab; (2) a measure of the uncertainty surrounding time series derived from the models; and (3) reliable and dependable delivery of the model product. Purpose: NMFS is bound by Congressional mandates to use the best scientific information available. Timing: Real-time forecasts for bycatch avoidance and marine safety; weekly predictions for most stock assessments.

- Perhaps reliable delivery on an agreed schedule (e.g., weekly or monthly) would be the best option.
- Reliability is great, and it would be helpful for us to have clear and transparent protocols for managing expectations and progress. Further, it would be helpful to develop a dialogue that assists regional operators in prioritizing their modeling investments in order to avoid duplication and/or competition. There are many needs to fulfil and sometimes the external community has better solutions that could meet the needs of all parties if the understanding on who is doing what and when is known.

[Confidence] For fisheries, there needs to be rigorous tests to demonstrate to the fishery councils that the model output: (1) is accurate; (2) provides benefit; and (3) includes uncertainty. In addition to forecasts, hindcasts and/or reanalysis also provide valuable information and utility. Additionally, NOS models are optimized for navigation purposes and not for potential other uses (e.g., larval transport, etc.). Confidence needs to be understood to use such navigation models for other applications.

[Hindcasts] Rebuilding the hindcast product on a yearly basis is resource intensive (i.e., collecting and processing all observational data). Are there parts of the process that can be generalized enough to allow for: handle once, use by many groups. The major effort is to collect the field survey data. Since they change year to year, it takes a lot of time, and it's hard to have a generalized method.

[Data tank] Is there a list of what is in the approved "NOAA data tank?" The IOOS Modeling Task Team called for community access to the same data streams that NOAA sees inside the firewall, which has not yet happened. JEDI's Interface for Observation Data Access (IODA) / Unified Forward Operator (UFO) might provide this by creating a duplicate of firewalled data.

[Operational datasets] Does inclusion in the NOAA data tank mean that a dataset is considered "operational?" The dataset must be: (1) highly reliable; and (2) supported 24/7 in case issues with the data and/or transmission arise.

[Limitations] Are there limitations to the data that operational regional ocean models use? For instance: Can it include Canadian Rivers? Non-NOAA weather product? Non-NOAA-open ocean boundary conditions? Data that is in the operational data tanks and reliably available (i.e., not "data of opportunity") can be used in NOAA models.

4.3.3 Lessons learned from successfully transitioning community models into NOAA

External NOAA & NOS/OCS Partnership: Global Extratropical Surge and Tide Operational Forecast System (ESTOFS): Joannes Westerink, Joseph and Nona Ahearn Professor in Computational Science and Engineering at the University of Notre Dame • Ed Myers, Chief of the Coastal Marine Modeling Branch at NOAA's Coast Survey Development Laboratory.

External NOAA & NOS Partnership: Salish Sea: Tarang Khangaonkar, Program Manager Specializing in Integrated Coastal Ocean Modeling at the Pacific Northwest National Laboratory Marine Sciences Laboratory • Lei Shi, Physical Scientist at NOAA's Coast Survey Development Laboratory • Machuan Peng, Physical Scientist at NOAA's Center for Operational Oceanographic Products and Services with NOAA's National Ocean Service.

NOS Partnerships: OCS and CO-OPS: Aijun (AJ) Zhang, Hydrodynamic Ocean Modeler and Lead of the NOS/CO-OPS Modeling Team • John Kelley, Meteorologist and Coastal Modeler with NOAA/National Ocean Service's Coastal Marine Modeling Branch within the Coast Survey Development Lab

Global ESTOFS. NOAA's global storm and tide model is an integrated global model with unstructured finite elements from down to 80m/30m and up to 24km resolution that runs operationally forced within the Global Forecast System's Finite-Volume Cube-Sphere Dynamical Core (GFS-FV3). This community is successful in part because of: (1) continuous and regular engagement (up to a couple of meetings a day even over the weekend prior to code delivery); (2) full integration of government and academic teams and trust on both sides; (3) smooth and shared project management environment and data sharing; (4) operational needs driving innovations in the science; (5) flexibility to pivot; and (6) willingness to take risks in order to advance NOAA's state-of-the-art modeling vision.

Next steps include:

- Continuous advancements of physics, numerical engines, resolution, and bathymetric/topographic details.
- Advance NEMS (NOAA's Environmental Modeling System) capabilities with the Advanced Circulation model (ADCIRC) community.
- Continue to engage the bathymetry/topography data communities as this is critical to success.
- Academic developers have access to a parallel environment that resembles NOAA's High Performance Computing (HPC) to test upgrades for stability and accuracy
- Continuity of support to operators from developers.

External NOAA & NOS Partnership: Salish Sea. The Salish Sea and Columbia River Operational Forecast System (SSCOFS) model will be implemented in 2024. Transitioning the community model to NOAA operations is on-track; with two caveats:

- Files during the transition process needed to be shared with CO-OPS, where the strict firewall requirements were a challenge. This issue was solved by creating the Salish Sea Computational Center at University of Washington.
- A commitment for operations funding is needed to make this project successful.

NOS Partnerships: OCS and CO-OPS. Lessons learned by NOS in developing and implementing operational forecast systems over the past 20 years includes:

- Providing a clear vision and goal and transition pathway to make transition from research and development to operations efficient and smooth.
- Establishing and sharing standards of infrastructure and codes is critical in operational applications and products to ensure efficient transitions from research and development to operations and continued maintenance and future updates.
- Defining clear roles and responsibilities of all involved collaborators will make transition processes more efficient and smoother.
- The key is creating a robust collaborative relationship between core model developers and Federal operators to ensure that: (1) user requirements are understood from the beginning; and (2) NOS is able to leverage scientific and technological advances in the academic research community.

Discussion.
[Does the panel have any ideas on how to speed up the 18-month transition to operations timeline?] In large part, the 18-month period is about risk aversion for NOAA and its stakeholders. The way to a faster transition is to get stakeholders who are willing to risk an unforeseen error. Only about 90-days of the 18-months are spent with NCEP Central Operations (NCO); by far the largest amount of time is spent on testing to prove that nothing will go wrong. One potential solution is to provide the developers with access to the type of testing that NOAA does for operations so that the Environmental Modeling Center (EMC) does not have to do 15 months or so of retrospective work.

Additionally, time can be saved if everyone is working in the same code base (e.g., GitHub). This issue will be addressed in the UFS report that is coming out in 2022.

[How important is Tier 3 support from core model developers for operations and maintenance?] It is critical to have an established relationship so that the developer is able to help the Office of Coast Survey (OCS) get the model running again. The more closely the systems are matching in configuration, the better the model will run and the easier it is to diagnose problems and to upgrade.

[But is the model output available in a "pre-operational" mode for users to experiment with while the system goes through final clearance?] Culture change is needed. The software industry has adopted "dev-ops" methods that are already solving these types of issues. We should have everything running off of GitHub. The development team should run like operations.

[Does NOAA have concerns about accepting external models because of the potential of an individual leaving a project that can cause credibility and consistency to suffer?] The answer is to ensure that the model is supported by a community, which ensures that another trained individual can step in efficiently and effectively. There are guidelines within NOS/CO-OPS for accepting model output from 3rd parties as an operational product.

[The academic community needs more than 30-days to evaluate outputs during the transition to operations.] This is a lost opportunity because the community could do a lot in terms of critically evaluating a system that is pre-operational. But the notice given to the community is too short and not widely disseminated. Agreed. NOAA is moving away from the 30-day limit and is allowing the community to take as long as needed to ensure that the system is stable.

[What are the steps NOAA is taking to develop algorithms to produce forecasts of wind and surface currents in and around wind farms, which are critical for the U.S. Coast Guard in search and rescue efforts?] This is a future item for NOAA as there is a need to gather and test additional observations.

4.3.4 Breaking down R2O2R barriers

Dwight Gledhill, Deputy Director of NOAA's Ocean Acidification Program • Marjy Friedrichs, Research Professor at the Virginia Institute of Marine Science • Arun Chawla, Physical Scientist at NOAA's Environmental Modeling Center

Ocean Acidification Program (OAP). OAP is a research program that is not suitable for developing operational products. While OAR regularly transitions research to the NWS, as yet there is not a broad portfolio of acidification projects. As a small program, OAP typically relies on pooling of funding from other programs, which means that OAP cannot be confident about the continuity of the product over the long-term. In these cases, OAP takes a leap of faith that the other programs are going to remain stable. Hopefully, EPIC will be helpful here in the future.

Hypoxia in the Chesapeake Bay. The issues that are generally concerning (e.g., funding and staffing) were all surmountable in the development of this model and yet it still failed to transition to operations. In hindsight, the biggest challenges were the lack of trust and partnership between the development and operational teams, and the limited expertise within NOAA's operational ocean modeling centers to take on a hypoxia model. It was noted that, although NOAA did not operationalize this model, the product was ultimately delivered and continues to be delivered within the operational requirements of their user community through the IOOS Mid-Atlantic Coastal Ocean Observing System (MARCOOS) Regional Association. Perhaps the definition of operational needs to be redefined.

Need for community. People inside the government often think of themselves as facing a unique problem that can only be addressed internally. However, many times the same problems have occurred elsewhere, and solutions may be more available than realized.

Discussion.
[Is "operational" defined by the provider or the user?] For example, the hypoxia model met the operational requirement of the fishermen, but not for NOS. NOAA has created a binary decision point of operational versus non-operational, even though many non-NOAA models achieve an operational threshold for its intended use and meet user requirements. Participants recognized that operational models requirements vary by application and user communities. If the model is meeting the needs of a stakeholder group, then it is NOAA's responsibility to make sure that stakeholder group gets the product even if it is not incorporated into NOAA's "operational" framework.

[Is there a minimum threshold of what should be transitioned to the government?] The hypoxia project forced NOS to re-envision the Coastal and Ocean Modeling Testbed (COMT) process, with the result being that NOS wants to provide routine, high value information to the public when they need it. The model should not be the end result; the fulfilling of user needs should be.

[What are you taking from this conversation that is making you excited?] [Marjy Friedrichs] Optimism! We all want the same thing; we just need to figure out how to get there. I'm excited that researchers like me can make progress quickly on this topic by tinkering around with the operational models. We can reassess what we mean by "operational" and define tiers versus not tiers. [Dwight Gledhill] I'm excited for Marjy, I don't care that it isn't operational! I'm excited to meet and work with this community and create a network to craft the research calls in a way that positions them to meet the user needs. [Arun Chawla] If you build something that the community depends upon then you could be legally on the hook for it, so that is something to consider.

4.4 Brown Bag Sessions

4.4.1 COMT opportunities, priorities, and proposals (Part One)

Tracy Fanara, Coastal Modeling Portfolio Manager at NOAA's National Ocean Service

Background. At present, the Coastal and Ocean Modeling Testbed (COMT) provides cyberinfrastructure resources to encourage collaboration between NOAA and external partners, including a cloud sandbox (virtual test areas for models), compliance checker, and upload tool. NOAA's Big Data Program (BDP) allows for large, time series datasets to be uploaded and downloaded from a centralized location.

The BDP was originally initiated to ensure that: (1) NOAA could put enough data into the cloud; (2) NOAA's data are discoverable and accessible in a centralized place; and (3) cloud providers could make a profit. Now, questions around the BDP for this community include:

- What can NOAA do to make the data more useful to the community via the cloud?
- What can the community do to shape the policies around use cases?
- Can the community develop a smaller workshop and/or meetings on how to get model and associated data up and running on the BDP?
- Can the community better better understand who is using the data on BDP and how they are using it? With this understanding, the community could then map out the value of each individual dataset and have a better understanding of the value that NOAA's data brings.

Big Data Program datasets can be found here; specific inquiries can be sent to NOAA.BDP@noaa.gov.

Discussion.
[Process] What is the process for getting data into the BDP? (1) Contact: https://nosc.noaa.gov/EDMC/; and (2) if it is NOAA data and relevant to IOOS, there are some qualifiers that will need to be met and you will have to identify a cloud service provider for housing the data. Each cloud service provider has its own capabilities.

[Sandbox] Can you download the sandbox and test it on your own modeling system? It is a goal. See NOAA's GitHub repositories here.

[OFS hindcast] Is the Operational Forecast System (OFS) hindcast a time series dataset that is updated and grows over time? It will get added to, so it will get longer and longer. However, there are analytics that are needed to understand how much of this data are used.

4.4.2 Brown Bag Session: UFS Coastal Application Team on Water Quantity

Shachak Pe'eri, Chief of NOAA's Coast Survey Development Laboratory • Steven Earle, Lead IT Specialist with NOAA's NWS/NCEP • Joe Sienkiewicz, Chief of the Ocean Applications Branch at NOAA's Ocean Prediction Center • Diego Arcas, Oceanographer with NOAA's Pacific Marine Environmental Laboratory • Andre Van der Westhuysen, Associate at NOAA's NWS/EMC

Operations at NOAA. NOAA's National Centers for Environmental Prediction (NCEP) delivers national and global weather, water, climate and space weather guidance, forecasts, warnings and analyses to its partners and external user communities. The NCEP Center of Operations (NCO) meets or exceeds the Weather and Climate Operational Supercomputer System (WCOSS) requirements of 99.9% operational use time, 99.0% on-time product generation, and 99.0% development use time.

Navigation. NOS and its partners continue to develop, evaluate, and implement operational oceanographic forecast modeling systems to provide forecast guidance for existing and additional coastal and lake areas within the U.S. and with greater accuracy. Safe, efficient marine navigation is a core mission and core statement.

Over the last few decades, user requirements have been collected from the marine navigation and related communities, including commercial and recreational mariners, port authorities, NWS and private forecasters, marine educators/researchers, search and rescue, manufacturers of marine navigational systems, and offshore wind energy operators. Primary user requirements include water levels, surface water currents, sea and lake ice (e.g., concentration, thickness, and velocity), and water temperature and salinity; secondary requirements include wind and atmospheric pressure, riverine, wave forcing, shorefast ice, and ice pressure.

NOS developed criteria for selecting oceanographic models based on user requirements and the UFS framework. Using those criteria, the initial list of recommended oceanographic models includes: Finite Volume Community Ocean Model (FVCOM), Regional Ocean Modeling System (ROMS), Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM), and Modular Ocean Model Version 6 (MOM6). A future evaluation of the models will be performed by a separate independent team.

Risk reduction. For this effort, risk reduction is defined as a risk management technique that involves reducing the damaging consequences in the form of human or financial loss. In order to better understand past coastal hazard events and also potential coastal exposure to specific hazards, hindcast analysis is used to support the development of products such as hazard maps and coastal flooding return periods. As it is impossible to use one model for all risk reduction applications within a certain group, this effort focused on the Consumer Option for an Alternative System to Allocate Losses (COASTAL) Act and tsunami applications. A white paper report with model evaluation recommendations for short-term and long-term risk reduction applications and a summary of current model capabilities will be submitted to the Unified Forecast System Steering Committee by early November 2021.

Total Water Level. In this community effort, a coupled coastal modeling system is being developed that will dynamically link all contributing processes to provide Total Water Level (TWL) forecast guidance for both tropical and extratropical conditions. To provide hourly guidance out to seven days, user requirements include: water level, wave height, period, direction, streamflow, maximum inundation height and extent, erosion, rip currents, and uncertainty estimates. This TWL application will: (1) serve all user TWL requirements with a smaller set of coupled models; (2) be based on the Earth System Modeling Framework (ESMF)/NUOPC coupling framework and developed together with the community; and (3) include both ESMF coupled components (circulation, waves, sea ice, hydrology), as well as downstream models (e.g., erosion/overtopping and rip currents). Model components will be selected based on objective criteria, including both accuracy metrics and operational considerations. As different types of hindcasts and forecasts are needed for water quantity applications, there is no “one model to rule them all.”

Discussion.
[CoastalApp] Is the CoastalApp that we heard about previously related to the work discussed here? Yes, this presentation was focused on the conceptual work of total water, the physical manifestation of which is the CoastalApp.

[Sea-level rise] How is sea-level rise being incorporated into the risk section? Storm surge, hurricane, and tsunami are already focus areas, with sea-level rise considered as an "add on" to those hazards, but not as a hazard on its own.

4.5 Community Showcase

4.5.1 An on-demand cloud-based storm surge prediction system

Jesse Lopez, Computational and Data Scientist at Axiom Data Science

Abstract. The ability to better predict inland flooding resulting from hurricane induced storm surge and severe precipitation has been identified as a top priority by NOAA leadership. Here we describe a multi-institute effort to develop an on-demand storm surge modeling system capable of accurately resolving high fidelity inundation and compound inland-coastal flooding at 10 m horizontal resolution. The system is designed following code-as-infrastructure philosophy to dynamically generate boundary conditions and the computational mesh for the SCHISM coastal ocean modeling system for a given hurricane trajectory, perform the simulation, post-process the results, and disseminate the results and products in a seamless end-to-end manner. Designed with flexibility in mind, the modeling system is capable of running on traditional HPC systems and cloud infrastructures, or some combination thereof. The presentation will detail the system design, implementation, deployment strategies, and preliminary results.

Takeaways. The process of developing these predictions is short and fast, making it an economical way of computing, processing and storing information/data/predictions. The code repository for the automatic generated mesh is here.

Presentation. Available online.

4.5.2 Short-term forecasts of acidification metrics in the Chesapeake Bay

Marjorie A.M. Friedrichs, Research Professor at the Virginia Institute of Marine Science

Abstract. Increasing urbanization and eutrophication of coastal regions, together with increasing global atmospheric temperature and CO2 concentrations, are leading to acidification in many coastal aquatic systems across the globe. Such changes have been shown to impact shellfish growth and survival. The Chesapeake Bay region is particularly vulnerable to such changes due to the combined impact of multiple stressors (hypoxia and acidification) and the impacts on shellfish populations, as well as the communities that depend on the shellfish industry. Hatchery-based shellfish aquaculture has expanded in the Chesapeake region over the last several decades, however, early life stages of shellfish in hatchery and nursery settings are highly vulnerable to mortality events resulting from poor water quality. To address this problem, we have expanded our Chesapeake Bay Environmental Forecast System (www.vims.edu/hypoxia) to include nowcasts and short-term (2-day) forecasts of acidification metrics, such as pH and aragonite saturation state. Specifically, we use the Estuarine- Carbon-Biogeochemistry model based on the Regional Ocean Modeling System (ChesROMS-ECB) forced with real-time and forecasted environmental parameters such as atmospheric temperature, wind, humidity, solar radiation and riverine inputs. These short-term forecasts can be particularly useful to hatchery operators as an early warning system for poor water quality. For example, if a decline in saturation state is projected as a result of heavy rain conditions, a hatchery may delay spawning and/or avoid supplying spawning tanks with intake water from the Bay until conditions improve. Through our Shellfish Aquaculture Industry Advisory Committee, we are working closely with industry members, obtaining feedback from them on the information and visualizations we are providing, and helping them better incorporate this type of predictive capacity into decision-making practices at the hatcheries.

Takeaways. The Chesapeake Bay Environmental Forecast System (CBEFS) can provide nowcasts and 2-day forecasts for physical and biogeochemical variables; underdevelopment are longer term forecasts (5-7 days), forecasts of food availability and quality (HABs), and information for oyster growth.

Presentation. Available online.

4.5.3 CoastalApp: A NUOPC/ESMF coupling application based on Unified Forecast System best practices

Panagiotis Velissariou, Scientist/Project Lead at NOAA's Coastal Marine Modeling Branch

Abstract. Coastal Marine Modeling Branch (CMMB) of the Office of Coast Survey (OCS) at NOAA/NOS, develops a fully coupled multi-model coastal application (CoastalApp: https://github.com/noaa-ocs-modeling/CoastalApp) to advance our understanding on the coastal processes and the land-sea interactions. The goal is to provide a flexible and portable modeling framework for coastal applications that includes storm surge modeling and inundation studies, wave modeling and wave-coast interactions, sediment transport and morphological changes, and water quality studies. In this presentation we will inform the community regarding the current status and future plans of the CoastalApp on the following areas:

- Application structure and usage.
- Current modeling components and plans.
- NUOPC/ESMF Coupling Infrastructure (current status and future plans).
- Plans for the inclusion of 3D modeling calculations.
- Improve coupling experience.
- Code management (GitHub).
- Regression tests.
- Automation of compile tests (GitHub actions).

Takeaways. By design, the CoastalApp is flexible (new components can be added or swapped) and portable (can be used in different operating systems).

Presentation. Available online.

4.5.4 NOAA Climate and Fisheries Initiative: Building an end-to-end system for climate-ready Living Marine Resource Management

Roger Griffis, Climate Coordinator at NOAA's National Marine Fisheries Service

Abstract. Climate change is significantly impacting the nation's valuable marine ecosystems, fisheries and the many people that depend upon them. These changes affect many parts of NOAA's mission, from fisheries management and aquaculture to conservation of protected resources and habitats. To prepare for and respond to these changes, the NOAA Climate and Fisheries Initiative (CFI) will build a nation-wide integrated ocean modeling and decision support system to help decision-makers reduce impacts and increase resilience of fisheries and protected resources to changing conditions today, next year, and for decades to come. Working with existing programs, the cross-NOAA, end-to-end CFI system will use state-of-the-art climate, ocean and ecosystem modeling to provide robust future scenarios and actionable advice for climate-informed decision-making. The system is composed of three inter-linked components that ensure operational delivery of information, services, and feedback for sustained performance and innovation. The first component (Ocean Forecasts and Projections) will provide state-of-the-art ocean forecasts and projections for use in developing climate-informed management advice. The second component (Operational Decision Support Systems) provides the capacity to turn the ocean forecasts and projections into robust advice for climate-informed management. The third component (Climate Ready Decision-Making) provides the capability to incorporate climate-informed advice into fisheries management. Working with many partners, the CFI is a timely, efficient, and effective way to increase NOAA's ability to implement climate-ready fisheries management.

Takeaways. Ultimately, CFI will provide: (1) state-of-the-art ocean forecasts and projections; (2) climate-informed ecosystem projections, stock assessments, risk assessments and management strategies; and (3) increased capacity to prepare for and respond to climate impacts.

Presentation. Available online.

4.5.5 Quantifying the impact of ocean observing systems on model forecast skill

Andrew Moore, Professor, University of California Santa Cruz

Abstract. Community tools have been developed for the Regional Ocean Modeling System (ROMS) to quantify the impact and sensitivity of ocean analyses and forecasts to observations from the different platforms that are assimilated into ROMS using 4-Dimensional Variational (4D-Var) data assimilation. The approach used parallels that employed routinely in operational numerical weather prediction. These tools provide a quantitative measure of the "value added" by different components of the observing system and can provide guidance on the efficacy of the current and future observing system. An example will be presented.

Takeaways. Radar stations in Oregon and Washington are incredibly important for improving the forecast skill of sea surface temperature along the West Coast, which shows that value can be assigned to particular pieces of the data observation stream.

Presentation. Available online.

4.5.6 Predicting high crosscurrents near South Florida ports using machine learning: Initial results

Steven Meyers, Research Scientist at the University of South Florida

Abstract. Global economic expansion and competition has driven an increase in the number and size of commercial vessels for many years, putting pressure on operational safety margins. Management of dense, near-shore vessel traffic relies on knowledge of the water depth and currents in proximate waters. Near some ports, major ocean currents can generate hazardous crosscurrents. In south Florida, at the Ports of Miami, Everglades, and Palm Beach, high crosscurrents occur irregularly, and generally persist for hours to days as meanders in the Florida Current / Gulf Stream shift position westward into the port access channels. A proto-type algorithm based on logistic regression was developed to predict the probability of high crosscurrents near the Port of Miami as represented in output from the HYbrid Coordinate Ocean Model (HYCOM) 1/12° global hindcast from early 2018 to mid-2020. For the highest current threshold examined (2 standard deviations above the mean) the 12-hour forecasts had an initial True Positive (TP) rate of ~90%, though the False Positive (FP) rate was ~30%. TP rates declined for lower thresholds, dropping to ~80% for 1.5 standard deviations above the mean, but the FP was essentially unchanged. Improvements in accuracy for lower thresholds are being pursued. A transition from the model-based algorithm to one based on observations and analysis of the Gulf Stream frontal position provided by the U.S. Navy/Fleet Numerical Meteorology and Oceanography Center (FNMOC) is underway.

Takeaways. There are two phases to this predicting high crosscurrents near South Florida ports using machine learning project:

- Phase 1: Calculate the probability of current speeds above a threshold.
- Phase 2: Apply what has been learned during Phase 1 to develop an operational tool based on real observations. Results are expected by the end of the year.

Machine learning shows promise as a tool for prediction of hazardous currents, as the prototype tool has higher prediction accuracy for faster currents and a small number of well-chosen predictor variables can produce a useful prediction.

Presentation. Available online.

4.5.7 Assessing hydro- and sediment dynamics of hurricane-induced compound flooding using a dynamically coupled ocean-river modeling suite

Z. George Xue, Associate Professor at Louisiana State University

Abstract. We introduced Weather Research and Forecasting (WRF)-Hydro to the Coupled-Ocean-Atmosphere-Wave-Sediment Transport (COAWST) Modeling System to simulate the water and sediment dynamics during the compound flooding caused by Hurricane Florence in 2018 in the Cape Fear River watershed. The river model (WRF-Hydro) is coupled with the ocean model component (ROMS) along the land-ocean boundary where water level information is exchanged dynamically. A newly developed physics-based, fully distributed soil erosion and sediment transport model, WRF-Hydro-Sed, was used to represent the sediment dynamics in the watershed. Calculated river and surface runoff from hurricane-induced precipitation is ten times the volume of the Cape

Fear River Estuary. The model's performance in water-level simulation is largely improved (0.3-1.0 m) in the upper Cape Fear Estuary, NC. The spatial-temporal distribution of soil erosion was largely controlled by the rainband structure evolution and slow storm movement. Diagnostic analysis indicates that the compound flooding process can be categorized into four different stages: swelling, local wind dominated, transition, and river dominated.

Takeaways.

- The dynamically coupled model performed better than the National Water Model (the NWM underestimated). The two-way coupled model improves predictions of water levels in estuaries. As a next step, the plan is to couple this model with a sediment-transportation model.
- How to handle moving hydraulic control points and waterfalls? Put the available observations, if there are any, at the grid downstream of control/dam into the model stream network.
- Experience of flooding so severe that the dams or usual control points stopped being control points? Not in this case, where the main control project is Lake Jordan further upstream; suggest performing a longer simulation/experiment to derive a relationship between control and possible overbank flow and then apply it back to the model.

Presentation. Available online.

4.5.8 Multi-model joint probability method for estimating compound flood risk

David Johnson, Assistant Professor at Purdue University

Abstract. The Louisiana Watershed Initiative is a multi-agency integrated planning effort that aims, in part, to coordinate flood risk management across the entire state and from multiple sources of flooding: storm surge, rainfall, and riverine discharge. As part of a pilot study in the Amite River Basin, we have developed a multi-resolution, multi-model framework for estimating compound flood hazard. Estimates of the true compound flood risk have been hindered by the fact that studies of each source of flooding commonly use different models and statistical approaches. Risk analyses also commonly face a tradeoff between the number of events that can be simulated and the resolution/fidelity of those simulations. To address these issues, we extend the joint probability method with optimal sampling (Joint Probability Method with Optimal Setting (JPM-OS)) to characterize the joint probability not only of tropical cyclone parameters (e.g., central pressure deficit, radius of maximum windspeed), but also of the spatiotemporal distribution of rainfall (using a novel probabilistic rainfall generator) and antecedent conditions in the affected watershed. This compound JPM-OS procedure runs a large quantity of equiprobable rain fields for each storm through the computationally cheap Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) model of river discharge under different antecedent baseflow conditions. We apply principal component analysis and k-means clustering to select a reduced set of events to run through a high-resolution Hydrologic Engineering Center's River Analysis System (HEC-RAS) model of inundation, also including storm surge forced by the ADCIRC model as a boundary condition, resulting in estimates of the compound flooding annual exceedance probability (AEP) distribution. We show that in areas of Louisiana's Amite River Basin at risk of storm surge inundation from tropical

cyclones, accounting for variability in rainfall and antecedent conditions [in riverine baseflows and soil moisture] adds more than a foot to flood depth exceedances over a range of annual exceedance probabilities (i.e., return periods). This equates to substantial marginal vulnerability to inundation in populated areas. A major motivator for the modeling approach and statistical framework is that state-level planning efforts are constrained computationally, so the use of multi-fidelity modeling and optimal sampling lowers the cost of obtaining accurate estimates of compound flood hazard. When incorporating predicted rainfall into the design of protection systems, development of flood risk maps, or early-warning systems, it is critical to acknowledge and quantify uncertainty. We see major differences in estimated average annual losses to thousands of structures in the Amite River Basin; better procedures for estimating compound risk are needed to inform flood insurance policies, building codes, and other flood risk management mechanisms.

Takeaways.

- Generate a large quantity of equiprobable rainfall fields for each synthetic storm.
- Select a reduced set of synthetic tropical events to approximate AEP distributions for surge and rain.
- Simulate the resulting discharge hydrographs using HEC-HMS under different antecedent conditions.
- Apply principal components analysis on:
    - Discharge characteristics (e.g., peak discharge, rates of runup/drawdown) at multiple inflows to the basin;
    - Surge characteristics (e.g., peak surge, rates of rising and falling surge levels); and
    - Relative timing of peak surge and peak discharge.
- Apply *k*-means clustering to the principal components to generate clusters of events with similar outcomes.
- Assign the summed probability mass of all events in a cluster to a single representative event and run it through HEC-RAS with surge from ADCIRC as a boundary condition.
- Numerically integrate the resulting distributions to generate AEP curves for peak water surface elevations.

Presentation. Available online.

4.5.9 Two examples of actionable science

Peter Sheng, Emeritus Professor and Adjunct Research Professor at the University of Florida

Abstract. This presentation will showcase the recent developments of two decision support tools for coastal communities to plan for future coastal flood vulnerability and develop wetland restoration strategy to reduce future flood damage due to the compound effects of tropical cyclones (TCs) and sea level rise (SLR), with funding from the National Estuarine Estuarine Reserve program and the NOAA NCCOS, respectively. We will demonstrate two tools, one for the Village of Piermont about 15 miles north of NYC, another for Collier County, Florida, developed with the best available climate, coastal, ecological, and economic sciences and models. These tools include the probabilistic coastal flood maps for current and future climate (early and late 21st century), infrastructure maps, and coastal wetland maps. Using a dynamically coupled vegetation-resolving hydrodynamic-wave model

and the JPM-OS statistical method, we produced the probabilistic current and future coastal flood maps in the Piermont region (including the Village of Piermont and Piermont Marsh) and the large coastal flood plain in Collier County, Florida. Future tropical cyclone ensembles predicted by climate and downscaling models and probabilistic SLR scenarios predicted by NOAA were used. Simulation results show that future coastal flood hazard will increase substantially over time, but coastal wetlands may maintain their values for flood protection, depending on the local storm and wetland conditions.

Takeaways.

- In Piermont Marsh, the marsh reduced property damage by 8% in Hurricane Sandy and 12% in the 1% flood scenario.
- In Southwest Florida, the Adaptation of Coastal Urban and Natural Ecosystems (ACUNE) Geo Tool coupled climate, hurricane, mangrove, urban stormwater, and hydrologic models. During Hurricane Irma, mangroves were found to save $13 million in damages and $30 million in the 1% flood scenario.

Presentation. Available online.

4.5.10 Flood inundation model development for coastal-urban areas using the WRF-Hydro Framework in Tybee Island, GA

Youngjun Son, Graduate Student at the Georgia Institute of Technology

Abstract. An increasing number of urban areas located in coastal floodplains are threatened by multiple flooding drivers, including high tide, storm surge, intensive rainfalls, and groundwater inundation. Moreover, the built environment, in the form of roads and stormwater drainage systems, adds complexity to the evolution of these flooding mechanisms. The advances in the Earth System models and their capability of integrating inland hydrology and hydraulics have facilitated a reasonable prediction of coastal inundation mostly in a regional scale. However, there are still constant demands from local government planners and emergency managers for more localized and detailed flooding information in a timely manner. To provide such information in the coastal city of Tybee Island, we use a hydrometeorological framework, known as Weather Research and Forecasting (WRF)-Hydro. To simulate multiple flooding drivers in coastal urban areas, we impose regional-scale boundary conditions from both coastal-scale models and local observations and also integrate a hydraulic flow solver for the stormwater drainage system, Storm Water Management Model (SWMM) 5. The city of Tybee Island in Georgia was chosen for our study as it has been experiencing a range of different flooding dynamics due to intensive rainfalls with high tide as well as storm surge. Our approach allows delineating the high-resolution (10 m) inundation depth, timing, and extents that are highly affected by the prevalent flooding drivers in a compounding case. We expect that local coastal communities can take advantage of the top-down transitions of the flooding information from a regional scale to a city or town scale to prepare seamlessly for future flooding events by different sources.

Takeaways. There are multiple flood modeling frameworks that conduct large-scale modeling; however, communities and local stakeholders require information to help narrow the gap between regional-scale outputs and local contexts.

Presentation. Available online.

4.5.11 Multi-model joint probability method for estimating compound flood risk

Trey Flowers, Director of the Analysis and Prediction Division at NOAA's Office of Water Prediction

Abstract. The NOAA, National Weather Service, Office of Water Prediction (OWP), working with Federal water prediction partners, has designed and developed the Next Generation Water Resources Modeling Framework (Nextgen). The motivating objectives of the Framework include increasing water resources model interoperability, intercomparison, testing of research hypotheses, and deploying into operations science-driven, evidence-based models while enabling rapid adoption of research advances. As of 2021, the current operational National Water Model (NWM) applies a single model formulation, using calibration and regionalization to emphasize stormflow generation process. At the time scale of individual events, the NWM performance varies regionally. Calibration has improved performance in some regions but not all. The literature supports the hypothesis that appropriately applied models formulated for specific dominant local processes consistently outperform general models (uniqueness of place); given the lack of a comprehensive stormflow generation theory, there is no "one model to rule them all". By 2024, the NWM will consist of a particular configuration of the Nextgen framework. Nextgen is model agnostic with maximum flexibility, allowing the framework to adapt as models, data sources, and water prediction needs change. Nextgen uses unifying standards. The Basic Model Interface (BMI) model coupling standard for a common architecture that avoids duplication and promotes interoperability. The WaterML 2.0 HY_FEATURES data model provides standard description of surface water features. The framework, which is written in C++ and supports parallel computing, links models written in C, C++, Fortran and Python. Nextgen development occurs transparently using open-source practices that promote code reuse and development efficiency and encourages participation by our Federal partners and the research community. The Nextgen Framework supports hydrologic, hydraulic, and land-surface specific models and process modules while facilitating coupling with other earth system models through modeling systems such as the UFS. The Nextgen code exists on the NOAA OWP GitHub repository, and we invite community involvement. The repository includes examples, sample data sets, and documentation explaining the step-by-step process to adapt models to use the BMI coupling standard and interoperate with the framework. User friendliness is a goal with a target of two weeks for a new employee or graduate student with programming skills to add new domain science capabilities to Nextgen.

Takeaways. Models that perform the best are those that are unique to the local environment and have fewer adjustable parameters. The next generation water model will leverage modern computer science best practices, state-of-the-art hydrologic science, and community data standards in geosciences, together giving modelers flexibility to apply the right model in the right location for the right reason.

Presentation. Available online.

4.5.12 Developments of Global ESTOFS: NOAA's integrated multi-scale multi-process operational water level model

Johannes Westerink, Professor, University of Notre Dame

Abstract. The operational version of Global ESTOFS has been running with finite element variable resolution between 120m and 24km. The model incorporates optimized high resolution along all U.S. coastlines and extends onto the coastal floodplain and is driven by tides and GFS-FV3 winds and atmospheric pressure. Developmental versions increase resolution down to 30m and suggest that it is only in select regions that the additional resolution is critical. These include complex inlet systems with jetties such as the St. Johns River entrance and Sabine Lake entrance, intricate shoal systems such as in Shinnecock Bay, and complex intra-tidal crosscut shoals such as the Biscayne Flats in Florida. In addition, as both inlet connections to the ocean and upland dendritic floodplain channel systems narrow, increased resolution becomes increasingly important. Further mesh developments include an optimized global shell and improvements in global and regional bathymetry. Bathymetry in key locations both globally and locally remain the most important controls of model fidelity. Process integration advances include coupling with WAVEWATCH III in order to account for wave radiation stress induced set up, particularly important during tropical storm events; coupling with Global Real-Time Ocean Forecast System (G-RTOFS) in order to include the impact of the ocean's baroclinic drivers including large current systems such as the Gulf Stream, cold core eddies impinging on the coast, and seasonal steric expansion and contraction, all significantly affecting coastal water levels; to the National Water Model in order to account for upland hydrology and stream flows into the coastal zone; and to Sea Ice Model (CICE) in order to account for the effects of sea ice which can dramatically increase or decrease air to sea momentum transfer and/or impact boundary layer dissipation.

Takeaways.

- Does the global ESTOFS replace the different ESTOFS models in operations? Yes, it replaced ESTOFS-Atlantic, -Pacific, and -Micronesia in late 2021.
- How is the impact of temporal changes in the near-bottom density stratification (at both seasonal and longer timescales) on the generation of internal tides handled? The next upgrade will hopefully include the G-RTOFS coupled into Global ESTOFS to introduce baroclinicity.
- Is the sea-level datum for the US NAVD88? What about globally? Sea-level datum in Global ESTOFS is (approximately) global mean sea level (MSL) and a "Global ESTOFS" model MSL product is in production to better reference output to a known vertical datum.
- Which bathymetry database is used for global water level? Baseline global bathymetry is GEBCO 2020 with refinements locally.

Presentation. Available online.

4.5.13 Improving the Northeast Coastal Ocean Forecast System (NECOFS) with transition to upgraded models and new higher resolution simulation domain to address needs of the stakeholder community

Changsheng Chen, Montgomery Charter Chair Professor at the University of Massachusetts-Dartmouth

Abstract. Recent development of coupled atmosphere-ocean-freshwater models and higher temporal and spatial resolution in the input data improves quality of the forecast of the coastal ocean conditions that is being used for the Northeast Coastal Ocean Forecast System (NECOFS) supported by NOAA and NERACOOS. A set of models are coupled to near-real-time system that includes a regional Weather Research and Forecasting (WRF) model for the Northeastern U.S. and the coastal circulation model FVCOM (Finite Volume Community Ocean Model), NOAA National Water Model (NWM), and UNH Water Balance (WBM) model to provide 5-day operational forecast for the Land-Atmosphere-Ocean system for the NE coastal research community and stakeholders. The system had recently adopted a new substantially higher resolution coastal ocean lattice grid (GOM-6), newest version of FVCOM and its coastal inundation sub-model, and WBM transitioned from daily to hourly operation. The latter required a significant re-formulation of land surface hydrological processes, model calibration, performance assessment, and validation of the output data and forecast quality. The transition to a new simulation domain is now synchronized between all components of the NECOFS system providing a more reliable, stable, and much improved forecast product for the interested communities. The specific developments and changes to the model and their setup was guided by the feedback from the stakeholders and learning from the knowledge base of the NOAA Community Modeling work groups.

Takeaways. A new version of NECOFS has improved the forecasts of coastal salinity and flow, allowing for better coastal inundation models. The goal is to have NECOFS as a fully coupled atmosphere-ocean model that can provide forecasts, nowcasts, and hindcasts for estuarine-bay-shelf interactions, upstream flow, and Gulf Stream-shelf interactions as these predictions will need to be considered in all offshore windfarm development.

Presentation. Available online.

4.5.14 Assessment of alternative models for NOAA's Lake Erie HAB forecast

Pengfei Xue, Associate Professor, Michigan Tech University

Abstract. Lake Erie has experienced a re-emergence of cyanobacterial harmful algal blooms (CHABs) since the early 2000s. CHABs have significant socioeconomic and ecological costs, impacting drinking water, human health, fisheries, tourism, and water quality. Developing an operational short-term forecast system for CHABs abundance and spatial distribution is critical to decision-making for drinking water safety and water quality management. Current numerical methods for simulating CHAB transport use Lagrangian-based particle tracking models (e.g., NOAA's Lake Erie HAB Forecast), soluble tracer models in an Eulerian framework, or a combined Eulerian-Lagrangian approach to forecasting the Lake Erie CHAB transport. A comprehensive evaluation of the performance of these three types of models for 3-dimensional simulations of CHAB transport was conducted based on 24-240 hour forecast results for three consecutive CHAB

seasons (2017-2019). Results were evaluated against the latest high-resolution satellite product from the European Space Agency's Sentinel-3 OLCI sensor. Analyses of the simulation results revealed the relative importance of physical processes, including horizontal transport, vertical turbulent mixing, and algal buoyancy on the CHAB inter- and intra-day variability. Sensitivity analyses were conducted to examine the influence of the distribution of algae buoyant velocity on the model forecast performance. This effort represents a collaboration between NOAA and academic researchers, which revealed potential research pathways to improve NOAA's Lake Erie HAB Forecast.

Takeaways. Of the three models evaluated, Structural Topic Model (STM) had the best prediction skills, Property-Carrying Particle Model (PCPM) was next, and the HAB Tracker was last; however, the differences between these values were small, indicating that these models had similar performances. In future applications, the model should be chosen based on needs and situations (e.g., computational efficiency, structure flexibility to couple bio-models, and buoyancy velocity distributions).

Presentation. Available online.

4.5.15 Toward a nation-wide seasonal to multi-decadal regional ocean prediction system to serve NOAA's Living Marine Resources mandates

Charlie Stock, Research Oceanographer at NOAA's Geophysical Fluid Dynamics Laboratory

Abstract. Meeting NOAA's mission to conserve and manage coastal and marine ecosystems requires climate-informed decisions across management time horizons. NOAA's Climate-Fisheries Initiative (CFI) has thus proposed development of a national system of regional ocean models to reliably provide high-resolution physical and biogeochemical predictions across seasonal to multi-decadal time horizons. The system will harness NOAA's Modular Ocean Model 6 (MOM6), High Performance Computing, and associated Earth System components to robustly deliver coastal and marine resource focused predictions spanning the range of potential ocean futures. Prototype CFI configurations for the U.S. East Coast, U.S. West Coast, and Arctic have been developed. CFI implementations for the Pacific Islands and Great Lakes are in the design phase, and numerous other prototypes have been developed (Nordic Seas, Indian Ocean, Equatorial Pacific). CFI Configurations reflect desires to seamlessly address cross-boundary issues under climate change, to capture the ocean basin to shelf connections that underlie ocean predictability at longer time horizons, and to ease operation requirements by limiting the number of configurations. Efforts are moving from establishing regional MOM6 infrastructure toward optimization of model performance, exploration of shelf-scale process simulation within MOM6's flexible vertical coordinate system, and expansion to include comprehensive ocean biogeochemical dynamics. External partnerships are supported by open model development principles within MOM6, and these partnerships will continue to have a key role with the CFI. Regional CFI-associated MOM6 efforts are being coordinated across NOAA to synergize with parallel ocean prediction efforts on shorter time horizons and finer spatial scales, and to ensure that model outputs can be effectively translated to improved LMR decisions. More broadly, MOM6 will also be integrated with cross-NOAA data assimilation and initialization research to provide the ocean component of NOAA's global Medium

Range Weather, Subseasonal to Seasonal prediction, and regional hurricane applications within NOAA's Unified Forecast System.

Takeaways. The regional MOM6 prototypes will be able to produce 5-10km configurations with 3-10 simulation-years. These data will be made available via the Climate and Fisheries Initiative data portal, which will provide access to standardized quality-controlled ocean and biogeochemical predictions and projections and training for the community.

Presentation. Available online.

4.5.16 Assessing the inland-coastal flooding operational guidance system with Hurricane Ida (2021)

Fei Ye, Assistant Research Scientist at the Virginia Institute of Marine Science

Abstract. The performance of the preoperational Inland-Coastal Flooding Operational Guidance System (ICOGS) has been continuously assessed with hurricanes and tropical storms since its inception in Dec 2020. The most recent assessment uses data collected during Hurricane Ida in 2021, which was a Category 4 hurricane accompanied by heavy precipitation that caused extensive damage after its landfall in Louisiana, USA. Based on the hydrodynamic core of the Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM), ICOGS is specifically designed to simulate and forecast compound inland-coastal flooding events during wet storms. The regional model domain covers the Northwest Atlantic and Gulf of Mexico, with the land boundary along the U.S. East Coast and Gulf Coast set at 10 meters above the NAVD 88 datum to include inland floods. The upstream river flow beyond the land boundary is calculated by National Water Model (NWM) forecast and injected as volume sources at the intersections between NWM stream segments and ICOGS land boundaries, whereas the flow movement and wettings/dryings in a significant portion of the coastal watersheds (below 10 meter, NAVD 88) are directly handled by the hydrodynamic core. Fine structures such as levees are explicitly represented by meter-scale elements in the unstructured model grid. On a 2.5-million-node unstructured mesh, the 3D baroclinic forecast runs 110 times faster than real time (i.e., 50 minutes for a 3-day forecast) using 3360 cores on Texas Advanced Computing Center's Frontera supercomputer. This presentation shows some most important aspects of the assessment during Hurricane Ida, including coastal surges measured at NOAA stations near the landfall site, and inland flooding compared with the inundation map published by Louisiana Department of Transportation and Development. Sensitivity tests were also conducted to isolate the individual contributions of NWM river flow and precipitation to the observed compound flood. ICOGS 3D implementation for the Atlantic basin is planned to be included in current ESTOFS as its three-dimensional core to support disaster mitigation and safe navigation. ICOGS 2D/3D Atlantic and Pacific set-ups are planned to support the COASTAL Act program as one of the storm surge components to account for inland flooding on coastal inundation for post storm assessment studies.

Takeaways. This modeling system provides major benefits to coastal communities by simulating and forecasting compound inland-coastal flooding events during wet storms.

Presentation. Available online.

4.5.17 Ocean model diagnostics and pathways towards community engagement

John Krasting, Physical Scientist at NOAA's Geophysical Fluid Dynamics Laboratory

Abstract. Evaluating the fidelity of ocean model simulations and ensuring their suitability for different applications is an important part of the model development and data delivery processes. In addition to mean-state and variability benchmarks, the emergence of more process-based diagnostics is ensuring that models are increasingly producing the right results for the right reasons. Much of the existing body of process-based diagnostics exists for the atmospheric realm and more analysis of the ocean component of models is needed. Ocean models generate large streams of output data that pose a technical challenge to produce diagnostics efficiently. Here, we survey efforts on how engagement with the broader community through the development of the Modular Ocean Model version 6 (MOM6) and NOAA's Model Development Task Force (MDTF) can increase the breadth and depth of ocean-based diagnostics. As open-source community software packages, both MOM6 and the MDTF provide mechanisms for model developers to engage with the academic, operational, and private sector communities to leverage process-level expertise to improve model fidelity and performance. Currently under development and planned ocean model diagnostics will be discussed as we highlight important areas where additional efforts can be concentrated.

Takeaways.

- Some recent accomplishments include: the diverse community of diagnosticians; modern Python-based framework; extensive documentation and tutorials; and leveraging open source tools (e.g., GitHub, cloud-based testing)
- The diagnostics thus far have a climate focus and plans for expanding to more weather to seasonal time scales are under consideration. The MDTF framework does have a hook that will allow it to run on Coupled Model Intercomparison Project (CMIP)-formatted data.
- The diagnostics are calculated based on model versus data and model versus multi-model ensemble comparisons.

Presentation. Available online.

4.5.18 Modeling the ice-attenuated waves in the Great Lakes

Jia Wang, Ice Climatologist at NOAA's Great Lakes Environmental Research Laboratory

Abstract. A partly coupled wave-ice model with the ability to resolve ice-induced attenuation on waves was developed using the Finite-Volume Community Ocean Model (FVCOM) framework and applied to the Great Lakes. Seven simple, flexible, and efficient parameterization schemes originating from the WAVEWATCH III® IC4 were used to quantify the wave energy loss during wave propagation under ice. The reductions of wind energy input and wave energy dissipation via whitecapping and breaking due to presence of ice were also implemented (i.e., blocking effect). The model showed satisfactory performance when validated by buoy observed significant wave height in ice-free season at eight stations and satellite-retrieved ice concentration. The simulation ran over the basin-scale, five-lake computational grid provided a whole map of ice-induced wave attenuation in the heavy-ice year 2014, suggesting that except Lake Ontario and central Lake Michigan, lake ice

almost completely inhibited waves in the Great Lakes under heavy-ice condition. A practical application of the model in February 2011 revealed that the model could accurately reproduce the ice-attenuated waves when validated by wave observations from bottom-moored acoustic wave and current (AWAC) profiler; moreover, the AWAC wave data showed quick responses between waves and ice, suggesting a sensitive relationship between waves and ice and arguing that accurate ice modeling was necessary for quantifying wave-ice interaction.

Takeaways. The FVCOM ice+wave model was applied to Lake Erie in 2011 and both the measurement and model show ice cover significantly reduces wave height. Nevertheless, the model cannot reproduce fast melting, as observed; thus, two-way coupling is necessary, among other factors. Future efforts will focus on how waves break ice through two-way coupling.

Presentation. Available online.

4.5.19 The LiveOcean Daily Forecast System

Presenter: Parker MacCready, Research Professor, University of Washington

Abstract. LiveOcean is a computer model of ocean circulation and biogeochemistry that makes detailed, daily forecasts of currents and water properties in the Salish Sea and coastal waters of the Northern California Current System. It is widely used by a variety of stakeholders concerned with the effects of ocean acidification, hypoxia, harmful algal blooms, and larval transport on fisheries. The forecast system has been running pre-operationally for several years, and transition to operations is being funded by a new COMT grant.

Takeaways. The LiveOcean forecasts has been used for the following applications: larval oysters in coastal estuaries harmed by ocean acidification; coastal razor clam harvest closed by harmful algal blooms; dungeness crab fishery damaged by hypoxia; and invasive European green crab larval dispersion.

Presentation. Available online.

4.5.20 Self-consistency testing in the MOM6 ocean model in support of open development

Robert Hallberg, Oceanographer at NOAA's Geophysical Fluid Dynamics Laboratory

Abstract. The Modular Ocean Model, Version6 (MOM6) is a community open-development ocean model. With open development, contributions are increasingly frequent, and come from a diverse group of collaborators. To accommodate open development, we have developed an extensive automated testing protocol for contributions to MOM6 in order to maintain ocean model code quality and to detect and eliminate many types of bugs; these self-consistency tests complement the traditional regression tests that are used to ensure that important configurations are never unwittingly changed. MOM6 code is automatically tested for exact reproduction of all solutions and diagnostics across parallel decomposition, restarts, exact rotational symmetry, memory usage patterns, and a wide range of compiler settings, with automated dimensional consistency tests being a particularly valuable and novel capability in MOM6. In each case, these tests unambiguously pass or fail. Together these tests prevent the introduction of many types of software bugs and algorithmic inconsistencies into the shared MOM6 code repository, and contributors can receive immediate automated feedback highlighting any such problems with their suggested code changes, which we think helps to encourage such contributions. These self-consistency tests can help provide the level of quality control required for a modern ocean model codebase to be rapidly developed under an open development paradigm without compromising its utility for research or operational applications.

Takeaways. The open development framework for MOM6 has been successful in allowing multiple people to contribute to and improve code without causing any issues with model outputs.

Presentation. Available online.

4.5.21 Modern Lagrangian tools aid in predicting transport from an imperfect velocity

Rodrigo Duran, Research Scientist at the National Energy Technology Laboratory

Abstract. Simulating oil transport in the ocean can be done successfully provided that accurate ocean currents and surface winds are available—this is often too big of a challenge. In this presentation, we focus on one of the main problems oil-spill modelers face, which is determining accurate trajectories when the velocity has localized errors that result in large trajectory errors. Advanced Lagrangian techniques that build on the theory of Lagrangian Coherent Structures can bypass localized velocity errors by identifying regions of attraction likely to dictate fluid deformation. The usefulness of Objective Eulerian Coherent Structures is demonstrated by revisiting the 2010 Deepwater Horizon accident in the Gulf of Mexico and predicting a prominent transport pattern from an imperfect altimetry velocity eight days in advance.

Takeaways. While operational models are able to closely predict oil transport in the ocean, incorrect projections are likely if there are even slight differences from reality (e.g., velocities). Based on Deepwater Horizon, this model was able to predict a prominent transport pattern from an imperfect altimetry velocity eight days in advance.

Presentation. Available online.

4.5.22 Latest developments of the CARICOOS ROMS 3D circulation model

Juan Gonzalez-Lopez, Oceanographer and Modeler at the Caribbean Coastal Ocean Observing System

Abstract. Over the past years there has been an ongoing effort by the Caribbean Coastal Ocean Observing system (CARICOOS) to use HF-Radar current fields to aid in the development of a regional, operational ocean current model for Puerto Rico and the U.S. Virgin Islands. This region has proven to be a challenge for ocean current modeling, as a narrow and steep shelf interacts with eddies and jet-like features that meander from the Caribbean Current in the Eastern Caribbean. Given the spatial and temporal variability of these meanders that directly affect the coastal flow in the South of Puerto Rico, accurate boundary conditions along with data assimilation become a critical factor for developing a successful model. As such, HF-Radar has proven to be a valuable asset to capture observations at the range of spatial and temporal scales that are necessary given these regional and local flow features. In this lightning talk we present an overview of the latest developments of the CARICOOS ROMS 3D circulation model, including results and validation with

the HF-Radar fields, as well as outlining opportunities of mutual collaboration with NOAA and the modeling community, such as two-way nesting of regional data-assimilated 3D models into global models, and availability/archival of RTOFS as boundary conditions for both operational and hindcasting purposes.

Takeaways. Puerto Rico and the U.S. Virgin Islands have proven challenging for ocean current modeling, as a narrow and steep shelf interacts with eddies and jet-like features that meander from the Caribbean Current in the Eastern Caribbean. CARICOOS has established a baseline ROMS; next steps include improving the short-term forecast and testing an extended ROMS domain.

Presentation. Available online.

5.0 Onward

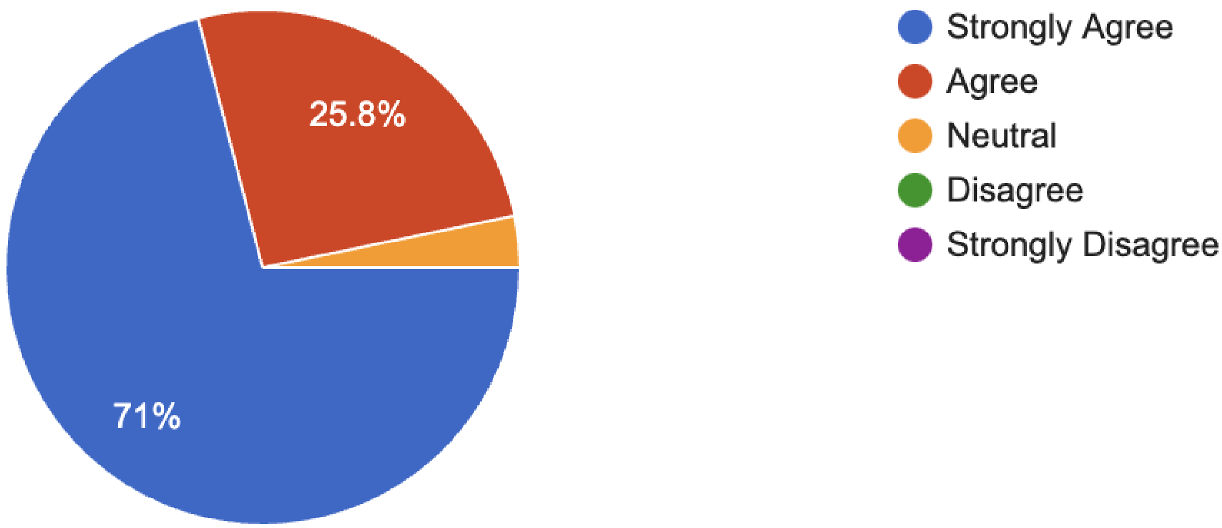
Consistent with the Workshop's four outcomes, participants: (1) advocated steps be taken to enhance communication, collaboration and co-development between Federal and non-federal modeling communities; (2) identified recommendations that will increase the efficiency of transitioning modeling systems from research to operations; (3) ensured understanding of the concerns, needs, and aspirations in building a community of practice across government and non-government entities; and (4) increasing understanding about the community models NOS will develop for the Unified Forecast System next-generation coastal and ocean components.

As the impacts from global and ocean warming continue to increase in intensity and frequency, so too does the Nation's need for accurate and timely ocean predictions and projections to protect our ecosystems, economy, national security, and lives and livelihoods. NOAA's National Ocean Service is committed to engaging the coastal and ocean modeling communities to deliver critical technical and scientific solutions.

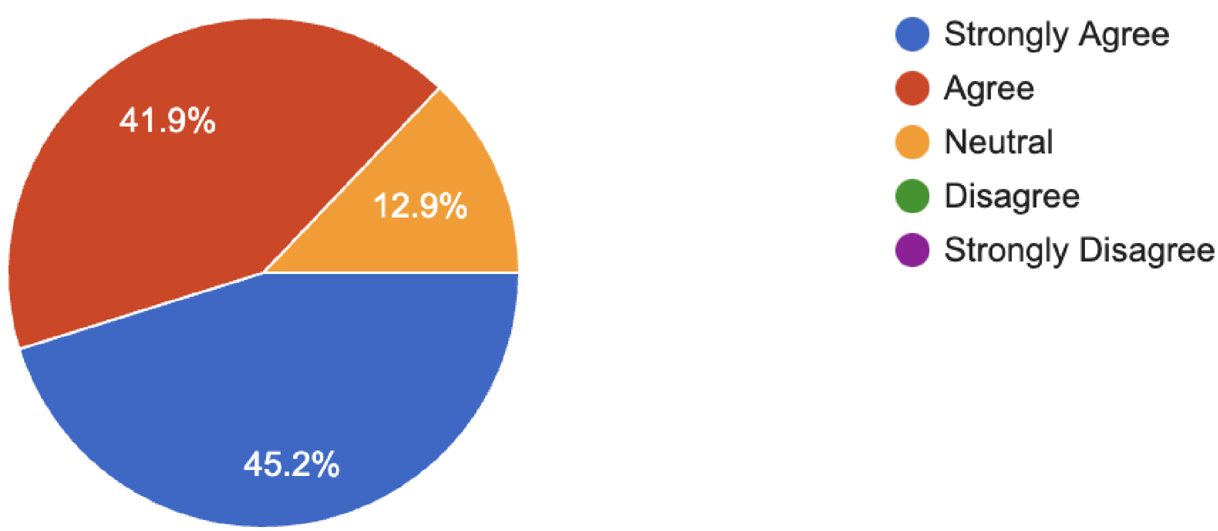
Appendix A. Post-Workshop Survey Results

A.1 Responses (quantitative)

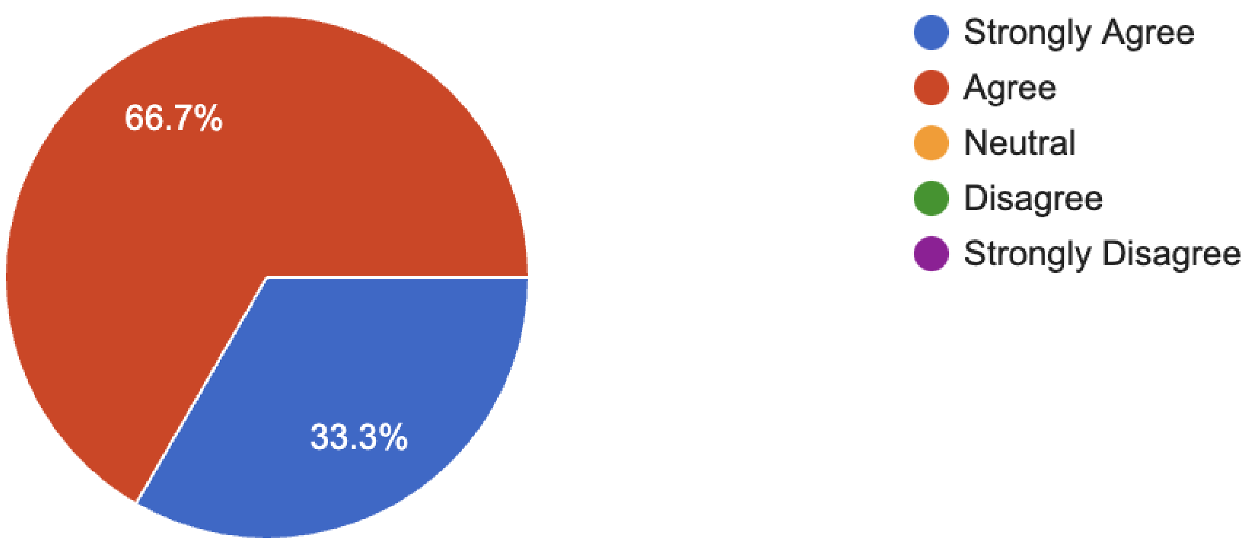
304 participants registered to attend the 2021 Coastal and Ocean Community Modeling Workshop and 31 participants completed the post-workshop survey: Of the survey respondents, 96.8% found the Workshop to be a valuable use of time.



87.1% of respondents thought the Workshop was an effective way to expand community modeling efforts and better transition community-developed models at NOAA.



100% of respondents now have a better idea of NOAA's coastal and ocean modeling landscape and where community modeling will be leveraged.



A.2 Responses (qualitative; lightly edited for clarity)

For improving the state of NOAA's community modeling efforts, additional recommendations:

- Develop and fund a routine process and structure for: (1) integrating community-based OFS requirements (stakeholder needs); (2) OFS model improvements; and (3) OFS-based applications. The natural place to do this would be as a partnership among IOOS Program Office, CO-OPS, Coast Survey Development Lab (CSDL) and IOOS RAs. These efforts have been done as project-based efforts, but not as an expected, routine part of the OFS development, operation, and improvement cycle.
- Socialize the idea that some products should be delivered by non-NOAA entities so that it becomes a strategy that NOAA prioritizes in internal budget formulation.
- More focused workshops such as topic-based, technology-based (cloud versus HPC), project based (specific COMT project), code management standards and methods, code development standards and methods, and model assessment standards and methods.
- Establish a centralized ecosystem forecast delivery center (or virtual center) with the IOOS Regional Associations that can transition projects not suited to Co-OPS or the NWS.
- In his presentation, Derrick Snowden, gave an overview of all of the different entities at NOAA that look to the community for various aspects of modeling. At the workshop there seemed to be a new entity that was trying to guide, inform, etc., all of these NOAA groups and perhaps play the role of an interface with the community. It wasn't clear if this entity would be collecting and maintaining a list of all opportunities available for community engagement but that would certainly be useful and preferable. It is difficult to keep track of all of NOAA's parts and what they are seeking; worse, community solutions tend to be more piecemeal and specific, not something that pushes NOAA forward in their vision of a more

unified system of modeling and more coherent, collaborative community engagement that has lasting impact.
- NOAA should start a series of webinars, hackathons, etc. to instruct/upskill the non-NOAA community on how to use UFS as a research tool.
- Integrate funding support in proposals for the "O" side of the R2O pipeline in NOS—this support is highly important and funding for contractors (as one example) in NOS would be helpful to do so.
- Improve analysis tools and enable the sharing of models through GitHub.
- I would suggest an internal (NOAA) Federal meeting to discuss issues that may arise such as: ensuring continuity of operations; allocation of resources; how this might affect the current partnership with the cooperative institutes; better documentation of infrastructure, not just that of ESMF but of NEMS, Community Mediator for Earth Prediction Systems (CMEPS); and repositories of model components.
- Develop a whitepaper (or something) that describes the different types of operational requirements (1 per day, or week, or season, etc.) that are valuable and valued (i.e., we don't all have to meet the weather service definition to be operational). We need new language that doesn't call them tiers or quasi-operational, terms which can be viewed as negative or hierarchical. Embrace that there are different approaches for different applications (fit for purpose).

For enhancing communication and coordination between the external modeling communities with NOAA's internal modeling communities, additional recommendations:
- Establish routine (annual or more frequent), regionally-based discussion forums for discussions between external and internal modeling communities—maybe with smaller group meetings organized around specific regional models, with less frequent meetings at the national level (like this workshop) to exchange information among regions. Ideally, this would be in parallel with routine discussions between modelers and those who are trying to facilitate development and use of model-based applications. The Fisheries and Climate Decision Support System (FACSS) efforts proposed under the NOAA Climate and Fisheries Initiative would be an example of the latter forum between modelers and those working with stakeholders. The IOOS Regional Association could be a mechanism to facilitate these routine forums.
- Have some of the NOAA Modeling Board meetings open to partners.
- The Coastal Coupling Community of Practice is a good example of communication and coordination between an external modeling community and NOAA's internal modeling community. More of this that addresses other modeling needs at NOAA would be valuable.
- Give external modelers a platform to present their work, like highlighting models developed by others through webinars, newsletters, or social media. More of this kind of event helps.
- Increased transparency/information in Request for Proposal (RFPs)/NOFOs as to what is expected and involved in transitioning forecasts to operations, especially for ecological forecasts for which the process and end goal is extremely blurry. Reassess what it means for ecological forecasts to be operational—external and internal communities seem to have very different ideas about this. Transition-focused projects should require regular meetings

between internal and external groups. Encourage NOAA's internal modeling community to trust external modeling communities to do what they cannot do; increase partnership as described in Mark Osler's introductory talk.

- Let's build on the successful science showcase presentations and the spirited discussion that followed by instituting a regular Coastal Modeling Showcase series. The example of the Pangeo Showcase is useful: offer short talks (15 minutes) followed by an open mike session at times that alternate (noon and 4 PM ET) to allow pan-coastal participation. Topics emphasize problem solving and tools, not fully formed science results.
- Have this workshop on a regular basis: annual or bi-annual? Instead of just FVCOM, just ROMS, just ADCIRC hosted at NOAA, having one for overall NOAA coastal modeling with the communities would be extremely helpful for future improvement and coordination.
- Offer catalyst funding for a seed project from where new external people can start participating in the activities of NOAA-relevant modeling.
- Host smaller, more focused versions of this workshop.
- Figure out how to transparently inform the inside and outside NOAA modeling community of ongoing and planned work. Ideally, strategic (multi-year) and annual implementation plans would be co-developed.
- There are various groups within NOAA giving various messages with respect to transitioning research to operations. It leads to confusion and frustration for those who offer research for transition.
- Identify mechanisms to enable IOOS Regional Associations to partner with NOAA and do things that both value but which the RAs are better able to deliver.

For improving the transitioning of community-developed models into operations at NOAA, additional recommendations:

- Develop a consistent process to evaluate cost-benefit of model applications—both those from external and internal side.
- Make open source code a mandate in grants. Offer training on software management best practices, especially for NOAA internally. Follow up on the idea of defining operations better. NOS is beholden to NWS policies for operations because we use NWS-managed computers. Is that the right way to determine the necessary requirements for NOS products?
- Better define goals and objectives at the beginning of a potential transition.
- Have three tier classification of forecast modeling systems: experimental, forecast system of opportunity (may be operated by NOAA and on NOAA infrastructure OR by external organization funded by NOAA [i.e., ROOS or private sector]), and operational.
- Serious and detailed follow up regarding promised technology transitions and data sharing in the last 6 month of the projects. Find the actual roadblocks and ways to remove them.
- The next time you transition a model into operational status, archive a few (one or two or three) sets of inputs and outputs of key milestones so that the milestone task could be replicated outside of NOAA. I am suggesting that with a few of these cases archived, it would provide a community researcher the ability to replicate your test results and a subset of the significant performance metrics. When the researcher replicates these results and subsequently improves upon them, it would provide the foundation to begin a conversation

about the potential for transitioning their community-developed model into operations.

- Making available to the community operational requirements, specifications, and products *a priori* is extremely valuable. These set the target for the external modeling community. Establishing coding standards is also critical for improved transition to operations.
- The discussion about what is NOAA-operational has been ongoing for so long that I find it hardly relevant anymore. Transition of outside models to NOAA operations is so lengthy and hard that one is frankly excused for giving up on that. Instead, new funding vehicles to spur innovation within NOAA, but also, and moreover, in academia and industry are needed and are the real issue, especially in the coastal arena. IOOS is something, but it needs to diversify, and a for-profit extension is natural and needed that could stand on its two feet in the marketplace and make money, perhaps through paid subscription services and a system of credits. This will unlock talent and creativity, hopefully through business incubation and competition. New funding vessels should not be devised only to help NOAA compete with an increasingly wide field of players but with the mindset of serving the Nation's needs, within and outside of its borders. To that effect, there should also be a recognition that there are parts of the country, or valuable but not monetizable ecosystem services, that would be underserved by a free market and this is where NOAA could expand on. A system of service credits to industry and incubators could also help fill this gap too.
- Revisit the definition of what is "operations" so the community will be guided.
- The process may need to be different for ecological models, compared to water level and circulation models. If NOAA is serious about the need for reliable, robust, useful, usable and used ecological models, they need to rethink their definition of "operational" and their transition steps along the way. Allowing/encouraging external modeling communities to make use of the cloud sandbox to run operational versions of NOAA models would greatly facilitate efforts devoted toward ecological forecasting. Encourage diverse funding sources for academic versions of operational models—diverse funding is by nature more stable than single-stream funding sources.
- The community could formulate agreed skill metrics for models (they will be numerous) and build infrastructure to facilitate rapid skill assessments in a community framework. Components of UFS, integrated with IOOS Data Assembly Center (DACs), could assist in this. IOOS should consider building on the Model Data Viewer and Cloud Sandbox concepts to facilitate distributing model outputs to users outside the confines of needing the modeling system to run inside the NCEP firewall. A coordinated system would aid model output discovery, and interoperability. Formats that are cloud-ready should be sought.
- Identify members of the community who are committed to improving models used by NOAA. Coordinate closely with them throughout the development and transition process to assure that expectations on the model and its associated products are met.
- I liked the idea that was mentioned, bypassing NWS by having a product/model operation on one of the IOOS platforms. Sounds like it would save a lot of time and headache for everyone. The suggested tier system could also work, but I can also imagine it being overly complicated.
- Identify mechanisms to enable IOOS Regional Associations to partner with NOAA and do things that both (NOAA and associations) value but that the associations may be better able

to deliver; identify mechanisms that enable co-funding of inside and outside NOAA modeling teams including adjusting NOFOs for modeling work that: (1) support inside-NOAA Principal Investigators; and (2) support longer term transition work.
- NOAA needs to give clear messages regarding what they want to transition, the criteria that would need to be met to qualify for transition, and who will run the operational model, then maintain consistency long enough for the development and transition process to successfully complete over years.

To improve future community modeling workshops, recommendations:
- Encouraging that level of open, frank discussion between internal and external to NOAA participants would be great to continue.
- Allow presenters to upload the presentation to a shared folder from which it will be run. That way last minute updates to the presentations can be done.
- The community modeling 5-minute sessions were a bit much. Instead, perhaps send those slides out in advance and then convene panels of groups of people to discuss related topics. What was not clear was the relationship of all of the presenters to NOAA activities.
- Include more virtual social icebreakers like the NOAA Data Management Workshop did.
- Give more time for the external teams to present their work; promote benchmark exercises.
- Breakout groups with longer talks will be better than the lightning talks—it was difficult to follow.
- I think the UFS Coastal Applications Team brown bag should have been an integral part of the workshop, as it is an important topic to cover and let the community be aware of. Hopefully next time it can be so. Thanks!
- Break up the lightning talks over the course of the workshop. Allow for updates from the operational centers on model development and implementation plans.

Appendix B. Supporting Materials

B.1 Workshop Materials

Workshop Booklet

Day 1 Workshop Slides

Day 2 Workshop Slides

Day 3 Workshop Slides

B.2 Supplemental Materials

Wilkin et al. 2017. Advancing coastal ocean modeling, analysis, and prediction for the U.S.

Integrated Ocean Observing System

Earth System Modeling Framework Recommendations for High Performance Modeling Infrastructure

Organizing Research to Operations Transition

Unified Forecast System (UFS) Strategic Plan 2021 - 2025

Draft UFS Organization and Governance

EPIC Strategic Plan 2020 - 2025

Strategic Implementation Plan for Evolution of NGGPS to a National Unified Modeling System

Appendix C. Steering Committee Members and Registered Workshop Participants

C.1 Steering Committee Members

(listed alphabetically by last name)

Clarissa Anderson (cra002@ucsd.edu) is the Executive Director of the Southern California Coastal Ocean Observing System (SCCOOS) at Scripps Oceanography

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Maoyi Huang (maoyi.huang@noaa.gov) is the Earth Prediction Innovation Center Program Manager at NOAA

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Emily Landeen (emily.landeen@noaa.gov) is the Executive Secretariat for the Coastal and Ocean Community Modeling Workshop

Ed Myers (edward.myers@noaa.gov) is the Chief of the Coastal Marine Modeling Branch at NOAA

Katie Robinson (katelyn.robinson@noaa.gov) is an Ocean Portfolio Advisor at NOAA

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Appendix D. Acronyms

ACRONYM	DEFINITION
4D-Var	4-Dimensional Variational
ADCIRC	ADvanced CIRCulation model
AEP	Annual Exceedance Probability
AFSC	Alaska Fisheries Science Center
AMS	American Meteorological Society
AOML	Atlantic Oceanographic and Meteorological Laboratory
AOOS	Alaska Ocean Observing System
ARL	Air Resources Laboratory
AWAC	Acoustic Wave and Current
BDP	Big Data Program
BGC	Biogeochemical
BMI	Basic Model Interface
CARICOOS	Caribbean Coastal Ocean Observing System
CBEFS	Chesapeake Bay Environmental Forecast System
CBOFS	Chesapeake Bay Operational Forecast System
CCCOP	Coastal Coupling Community of Practice
CDIP	Coastal Data Information Program
CeNCOOS	Central and Northern California Ocean Observing System
CFI	Climate-Fisheries Initiative
CHAB	Cyanobacterial Harmful Algal Blooms
ChesROMS-ECB	Chesapeake Bay Regional Ocean Modeling System–Estuarine Carbon Biogeochemistry model
CI	Cooperative Institute
CICE	Sea Ice Model
CICOES	Cooperative Institute for Climate, Ocean, and Ecosystem Studies
CIGLR	Cooperative Institute for Great Lakes Research
CIMAS	Cooperative Institute for Marine and Atmospheric Studies
CIMES	Cooperative Institute for Modeling the Earth System
CMEPS	Community Mediator for Earth Prediction Systems
CMIP	Coupled Model Intercomparison Project
CMMB	Coastal Marine Modeling Branch

CO-OPS	Center for Operational Oceanographic Products and Services
COASTAL Act	Consumer Option for an Alternative System to Allocate Losses Act
COAWST	Coupled-Ocean-Atmosphere-Wave-Sediment Transport
COMT	Coastal and Ocean Modeling Testbed
CPO	Climate Program Office
CSDL	Coast Survey Development Lab
CSDL	Common Schema Definition Language
CUSP	Continually Updated Shoreline Product
Cw/oW	Coastal and Ocean Modeling Center without Walls
DAC	Data Assembly Center
DOE	Department of Energy
EMC	Environmental Modeling Center
EPIC	Earth Prediction Innovation Center
ESMF	Earth System Modeling Framework
ESTOFS	Extratropical Surge and Tide Operational Forecast System
FACSS	Fisheries and Climate Decision Support System
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FP	False Positive
FVCOM	Finite Volume Community Ocean Model
G-RTOFS	Global Real-Time Ocean Forecast System
GCOOS	Gulf of Mexico Coastal Ocean Observing System
GFDL	Geophysical Fluid Dynamics Laboratory
GFS-FVS	Global Forecast System's Finite-Volume Cube-Sphere Dynamical Core
GLERL	Great Lakes Environmental Research Laboratory
GLOS	Great Lakes Observing System
GOMO	Global Ocean Monitoring and Observing
GSL	Global Systems Laboratory
GSV	Global Shoreline Vector
HAB	Harmful Algal Bloom
HEC-HMS	Hydrologic Engineering Center Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HFIP	Hurricane Forecast Improvement Project
HF Radar	High Frequency Radar
HPC	High Performance Computing

HWRF	Hurricane Weather Research and Forecasting
HYCOM	Hybrid Coordinate Ocean Model
ICOGS	Inland-Coastal Flooding Operational Guidance System
ICOOS	Integrated Coastal and Ocean Observation System
IODA	Interface for Observation Data Access
IOOS	Integrated Ocean Observing System
JEDI	Joint Effort for Data assimilation Integration
JPM-OS	Joint Probability Method with Optimal Setting
JRC	Joint Research Centre
JTTI	Joint Technology Transfer Initiative
LMR	Living Marine Resources
LNEC	Laboratório Nacional de Engenharia Civil
MARACOOS	Mid-Atlantic Regional Association Coastal Ocean Observing System
MDTF	Model Development Task Force
MEMP	Marine Ecosystem Modeling and Prediction
MOM6	Modular Ocean Model, Version 6
MSL	Mean Sea Level
NAVD	North American Vertical Datum
NCAR	National Center for Atmospheric Research
NCCOS	National Centers for Coastal Ocean Science
NCEI	National Centers for Environmental Information
NCEP	National Centers for Environmental Prediction
NCO	NCEP Central Operations
NECOFS	Northeast Coastal Ocean Forecast System
NEMS	NOAA's Environmental Modeling System
NERACOOS	Northeastern Regional Association of Coastal Ocean Observing Systems
NESDIS	National Environmental Satellite, Data, and Information Service
NGGPS	Next Generation Global Prediction System
NMB	NOAA Modeling Board
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOFO	Notice of Funding Opportunity
NOMADS	National Operational Model Archive and Distribution System
NOS	National Ocean Service

NRDD	NOAA Research and Development Database
NRL	Naval Research Laboratory
NSC	NOAA Science Council
NUOPC	National Unified Operational Prediction Capability
NWFSC	Northwest Fisheries Science Center
NWM	National Water Model
NWS	National Weather Service
OAP	Ocean Acidification Program
OAR	Office of Oceanic and Atmospheric Research
OCFO	Office of the Chief Financial Officer
OCS	Office of Coast Survey
OFS	Operational Forecast System
OGSSD	Oceanographic and Geophysical Science and Services Division
OPC	Ocean Prediction Center
OS	Operating System
OSAAP	Office of System Architecture and Advanced Planning
OSS	Office of Science Support
OSTI	Office of Science and Technology Integration
OTT	Ocean Technology Transition
OWP	Office of Water Prediction
PacIOOS	Pacific Islands Ocean Observing System
PCPM	Property-Carrying Particle Model
PMEL	Pacific Marine Environmental Laboratory
PNNL	Pacific Northwest National Laboratory
PPGC	Precipitation Prediction Grand Challenge
PRSSO	Performance, Risk, and Social Science Office
PSL	Physical Sciences Laboratory
R2O2R	Research-to-Operations-to-Research
RA	Regional Association
RENCI	Renaissance Computing Institute
RFP	Request for Proposal
RISA	Regional Integrated Sciences and Assessments
ROMS	Regional Ocean Modeling System
RTOFS	Real-Time Ocean Forecast System

S2S	Seasonal-to-Subseasonal
SCCOOS	Southern California Coastal Ocean Observing System
SCHISM	Semi-implicit Cross-scale Hydroscience Integrated System Model
SECOORA	Southeast Coastal Ocean Observing Regional Association
SLR	Sea-Level Rise
SSCOFS	Salish Sea and Columbia River Operational Forecast System
STAR	Center for Satellite Applications and Research
STM	Structural Topic Model
SWFSC	Southwest Fisheries Science Center
SWMM	Storm Water Management Model
TC	Tropical Cyclones
THREDDS	Thematic Real-time Environmental Distributed Data Services
TP	True Positive
TWL	Total Water Level
UCAR	University Corporation for Atmospheric Research
UFO	Unified Forward Operator
UFS	Unified Forecast System
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WBM	Water Balance Model
WCOFS	West Coast Operational Forecast System
WCOSS	Weather and Climate Operational Supercomputer System
WHOI	Woods Hole Oceanographic Institution
WPO	Weather Program Office
WRF	Weather Research and Forecasting
WWCB	Weather Water Climate Board