NERACOOS: A responsive ocean observing system for the changing Northeast region.

TABLE OF CONTENTS

I. Title Page

Project Title: NERACOOS: A responsive ocean observing system for the changing Northeast region

Primary Contact: Jacob Kritzer
Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS)
195 New Hampshire Ave, Suite 240, Portsmouth, NH 03801
(603) 319 1785 - Office
(617) 869 1336 - Mobile
(603) 570 3030 - Fax
Jake@neracoos.org

Financial Contact: Robert Cardeiro
Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS)
195 New Hampshire Ave, Suite 240, Portsmouth, NH 03801
(603) 319 1785 - Office
(401) 215-5777 - Mobile
(603) 570 3030 - Fax
Rob@neracoos.org

Recipient Institution: Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS)

Project Duration: June 1, 2021 – May 31, 2026

Funding Type: Cooperative Agreement

Funding Request: $30,000,000

Funds to NOAA: $534,198 to Northeast Fisheries Science Center

PEA Statement: This project complies with the PEA, specifically the Project Design Criteria

II. Project Summary

Project Title: NERACOOS: A responsive ocean observing system for the changing Northeast region

Primary Contact: Jacob Kritzer
Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS)
195 New Hampshire Ave, Suite 240, Portsmouth, NH 03801
(603) 319 1785 – Office
(617) 869 1336 – Mobile
(603) 570 3030 – Fax
Jake@neracoos.org

Recipient Institution: Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS)

Other Investigators:
Mark Baumgartner (Woods Hole Oceanographic Institution), Robert Beardsley (Woods Hole Oceanographic Institution), Timothy Becker (University of Hartford), Damian Brady (University of Maine), Robert Cardeiro (NERACOOS), Changsheng Chen (University of Massachusetts Dartmouth), Amy Costa (Center for Coastal Studies), Jason Goldstein (Wells National Estuarine Research Reserve), Carla Guenther (Maine Center for Coastal Fisheries), Leila Hatch (Stellwagen Bank National Marine Sanctuary), David Hebert (Bedford Institute of Oceanography), Brian Helmuth (Northeastern University), Anthony Kirincich (Woods Hole Oceanographic Institution), James Manning (NOAA NMFS), Jennifer Miksis-Olds (University of New Hampshire), Jacqueline Motyka (NERACOOS), Julianna Mullen (NERACOOS), James O'Donnell (University of Connecticut), Erin Pelletier (Gulf of Maine Lobster Foundation), Francesco Peri (Charybdis Group, LLC), William Perrie (Bedford Institute of Oceanography), Neal Pettigrew (University of Maine), Jeffrey Runge (University of Maine), Thomas Shyka (NERACOOS), Emily Silva (NERACOOS), Heather Stoffel (University of Rhode Island), Andrew Thomas (University of Maine), David Townsend (University of Maine), Douglas Vandermark (University of New Hampshire), Sofie Van Parijs (Northeast Fisheries Science Center), Jesica Waller (Maine Department of Marine Resources), Alison Watts (University of New Hampshire), Riley Young-Morse (Gulf of Maine Research Institute), and Mingxi Zhou (University of Rhode Island)

Project Summary:
The Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) serves ocean-dependent users and communities from Nova Scotia through the New York Bight. This region is characterized by complex geographic, oceanographic, and bathymetric features that combine to promote remarkable ecological productivity. Marine resources have long shaped the economy and culture of the Northeast, beginning with the first Native American inhabitants and continuing today. However, the ocean ecosystem and economy are in a state of rapid change driven by ongoing effects of human use and climate change that are being compounded by a shifting portfolio of industries. Fishing and tourism have long dominated the region's blue economy, but these sectors will increasingly need to co-exist with wind energy development, increased aquaculture production, and changes in shipping traffic. Climate change is also creating greater hazard risks and threatening biodiversity. A robust and responsive ocean observing system in the Northeast is more important than ever to adapt to these unprecedented changes.

Over the next five years, NERACOOS and our partners will work to achieve the following goals:

1. Support safe and efficient **Marine Operations** for commercial, recreational, scientific, emergency services, and regulatory stakeholders.
2. Enhance **Coastal Resilience** to hazards, effects of climate change, evolving ocean uses, and increasing demands on coastal resources.
3. Promote **Healthy Ecosystems** able to deliver a range of ecosystem services.
4. Provide data access and services to users through modern **Data Management and Cyberinfrastructure (DMAC)**.
5. **Engage Stakeholders** to ensure products and services are understood, valuable, and responsive to user needs.
6. Continue to build a **Sustainable Organization** as the indispensable foundation for effective observing, DMAC, and engagement activities.

Our observing system is built around an established network of fixed buoys providing real-time and historic data on weather and ocean conditions to mariners, regulators, researchers, and other users. The buoy network is complemented by other fixed stations measuring specific variables at targeted locations; autonomous gliders and vessel-based observing to provide more widespread and flexible coverage; high-frequency radar that is particularly important for search-and-rescue operations; and satellite observations at a regional scale. These observing tools supply a growing portfolio of innovative models and data products that make the voluminous and multifaceted data streams accessible and understandable for users.

Engagement with users is at the heart of everything NERACOOS does. We will continue to work together with our local, state and regional stakeholders to better understand their ocean needs. Additionally, in the years ahead, we will strive to promote diversity, equity, and inclusion through our engagement, observing, and data delivery activities. We will also take advantage of the opportunities presented by the U.N. Decade of Ocean Science to bring greater attention to the achievements of NERACOOS and the entire U.S. IOOS enterprise. At the same time, international engagement will provide scientific benefits by connecting our systems with the wider Northwest Atlantic region of which we are a part, and open channels for new ideas, partnerships, and funding.

To realize this vision, we will ensure professional development of our capable and committed staff while bringing on new capacity to keep pace with organizational growth. With future support and partnership, we at NERACOOS will continue to bring the vision of U.S. IOOS to life.

Partners:

Bedford Institute of Oceanography
Center for Coastal Studies
Charybdis Group, LLC
Gulf of Maine Lobster Foundation
Gulf of Maine Research Institute
Maine Center for Coastal Fisheries
Maine Department of Marine Resources
NOAA Northeast Fisheries Science Center
Northeastern University
University of Connecticut
University of Hartford
University of Maine
University of Massachusetts at Dartmouth
University of New Hampshire
University of Rhode Island
Wells National Research Reserve
Woods Hole Oceanographic Institution
Woods Hole Group

III. Project Description and Narrative

A. Background.

NERACOOS, the Northeastern Regional Association of Coastal Ocean Observing Systems, is a certified Regional Information Coordination Entity (RICE) encompassing coastal waters from the Canadian Maritime Provinces to the New York Bight (Figure 1). Over the past decade, we have worked with a wide range of partners to build an observing system for a community of users who depend on the ocean for their livelihoods and culture (Figure 2). Our international boundary with Canada introduces both complexities and opportunities into our work given the important oceanographic, ecological, and economic connections. As we move into our next decade, our foundation of diverse observing assets, committed operators, engaged users, and robust data systems will need to remain strong and responsive. This is especially true as we address new challenges facing our ocean, economy, and coastal communities.

The coastal and ocean waters of the Northeast are of tremendous cultural and economic value due in large part to their unique ecology. A source of food, transportation, and folklore for millennia, the sea has nurtured the Native Peoples of the Algonquin group and settlers from other corners of the globe alike, supported a vast network of maritime commerce, and touched nearly every aspect of our regional identity. The confluence of complex geographic, oceanographic, and bathymetric factors creates a mosaic of marine habitats able to support rich biodiversity. The convergence of warm water spinning off the Gulf Stream, cold water inputs from the tail end of the Labrador Current, and freshwater flow from a series of major river systems combine to promote remarkable ecological productivity (Figures 1, 3). Indeed, the Northeast is home to the two most valuable fisheries in the United States: American lobster and Atlantic sea scallop[1].

The region is experiencing profound changes, however, which threaten its natural productivity and value. Effects of global climate change are unfolding more rapidly in the waters of the Northeast than almost anywhere else on Earth. Over the past two decades, ocean warming has accelerated, salinity regimes have been interrupted by more frequent and variable precipitation, and the trophic base is more vulnerable to these and other stressors such as decreasing pH (Figure 4). In addition to localized effects, major currents such as the Gulf Stream and Labrador Current bring large-scale climate impacts to our region, with the Labrador Current creating strong linkages between the melting Arctic region and the Northeast (Figure 5). Climate change is also causing accelerated sea-level rise, which is projected to have profound impacts on the coastal ecology and economy. The effects of climate change and unrest in the commercial fishing industry, which has long been the dominant sector in the region's blue economy, are ushering in a new landscape of maritime industries. Energy development, particularly offshore wind, parallels the growth seen in aquaculture production. The regional shipping industry is on the verge of a major shift as reduced high-latitude ice cover enables more vessel traffic along new routes. New commercial actors offer an economic portfolio that could create more resilient coastal communities, but also pose new challenges for safety, governance, and operations. Moreover, growth in these sectors will undoubtedly interrupt ecological processes and complicate environmental management efforts.

This context of change, opportunity, and uncertainty make ocean observing more important than ever, and a critical attribute of the system in the years ahead will be responsiveness. We must maintain even tighter feedback loops between user needs, observing tools, modeling, and the

[1] https://www.fisheries.noaa.gov/national/sustainable-fisheries/fisheries-united-states

data delivery systems that connect them. Technological innovation will progress, and we will need to continuously identify ways in which we can provide higher-resolution data more quickly, cost-effectively, and at a greater scale to the broadest possible number of users. The high cost of maintaining an aging observing array and integrating new technologies necessitate expanding our funding base to encompass other government sources, the private sector, philanthropic foundations, and the international community. Demonstrated responsiveness to the needs of prospective contributors will be critical in making the case for investment.

Support from the U.S. IOOS Program Office has been foundational to our success to date and will be essential in maintaining and enhancing our effectiveness in the future. We look forward to continuing our partnership over the next five years as we collaboratively implement and evolve the ambitious agenda outlined herein.

B. Goals and Objectives.

We aim to achieve six broad goals and associated objectives. The first three relate to the priority outcomes that our work will serve, and the second three relate to the essential systems needed to achieve those outcomes. The specific and time-dependent milestones summarized in section E and listed in Table 1 indicate how we will track progress toward these goals and objectives.

1) Support safe and efficient **Marine Operations** for commercial, recreational, scientific, emergency services, and regulatory stakeholders.
    a. Sustain and expand the buoy network while adapting to changing conditions and needs.
    b. Increase the buoy network's resilience to external stresses and improve data delivery to users.
    c. Sustain and expand high-frequency radar coverage in the Gulf of Maine, Long Island Sound, and Southern New England.
    d. Sustain and expand the complementary networks of gliders and other platforms to fill observational gaps.
    e. Sustain and improve the resolution, accuracy, and coverage of modeling and forecasting.
2) Enhance **Coastal Resilience** to hazards, effects of climate change, evolving ocean uses, and increasing demands on coastal resources.
    a. Continue to support and develop coastal inundation and flooding models to meet the needs of managers and communities.
    b. Expand coverage of water level, nutrient, and pH sensors and improve data accessibility and products.
    c. Foster new research and applications for responding to ocean and coastal acidification through the Northeast Coastal Acidification Network (NECAN) and related initiatives especially through partnership with the NOAA Ocean Acidification Program (OAP).
3) Promote **Healthy Ecosystems** able to deliver a range of ecosystem services.
    a. Coordinate regional initiatives related to biodiversity and ecosystems through the Integrated Sentinel Monitoring Network (ISMN) and the Marine Biodiversity Observation Network (MBON).
    b. Initiate ISMN observing activities focused on monitoring of new sentinel indicators.
    c. Deploy strategic autonomous glider missions and other assets to detect North Atlantic right whales and other species and observe additional aspects of ecosystem health.
4) Provide data access and services to users through modern **Data Management and Cyberinfrastructure (DMAC)**.
    a. Sustain and enhance data management services per IOOS requirements.

    b. Maintain, improve, and develop data products in response to evolving user needs.
    c. Continue collaboration with regional and national DMAC teams to support and build DMAC capacity.
5) **Engage Stakeholders** to ensure products and services are understood, valuable, and responsive to user needs.
    a. Continue ongoing engagement activities with key stakeholder groups to stay abreast of changing needs.
    b. Unify engagement efforts between NERACOOS and partners to improve reach, impacts, and value of services.
    c. Expand engagement efforts to meet the needs of emerging industries and underserved communities.
    d. Establish a presence and role in the U.N. Decade of Ocean Science to communicate the successes of NERACOOS globally, create pipelines for new ideas and partners, and connect observing systems with the wider Northwest Atlantic.
6) Continue to build a **Sustainable Organization** as the indispensable foundation for effective observing, DMAC, and engagement activities.
    a. Sustain organizational capacity and add new staff to alleviate internal strain and keep pace with organizational growth and expanding activities.
    b. Provide staff with opportunities for professional development and new responsibilities to ensure continued growth, stimulation, and commitment.
    c. Promote diversity, equity, and inclusion through staff and Board composition, educational endeavors, and other activities.
    d. Participate in regional and national coordination mechanisms organized by the IOOS Program Office, IOOS Association, and other entities.
    e. Develop a Master Plan outlining high-level goals over the U.N. Decade of Ocean Science and stepwise strategic implementation plans to achieve those goals.
    f. Diversify the funding base to increase reach, resilience, and effectiveness.
    g. Employ best practices for financial management.
    h. Successfully renew RICE Certification.

C. Connection to Users/Stakeholders and Benefits.

NERACOOS provides highly valued products and services that benefit a diverse group of regional and national stakeholders. The ongoing economic valuation study being conducted by the IOOS Association and Middlebury Institute for International Studies shows that approximately 30% of NERACOOS users are from the private sector and 23% serve in federal, state, tribal, or local government, with others representing academic institutions (13%) and non-governmental organizations (10%)[2].

The portfolio of NERACOOS observations and model predictions has become a particularly critical component of maritime operations in the Northeast. A recent NERACOOS website survey revealed that 73% of the respondents use NERACOOS services for maritime safety decisions and 87% of respondents view the data provided by NERACOOS as being either very valuable or extremely valuable to their decision making. NERACOOS observations and forecasts are routinely used by National Weather Service (NWS) Weather Forecast Offices to verify and improve forecasts; United States Coast Guard (USCG) stations to plan search-and-rescue

[2] Updated results provide by project lead Dr. Charlie Colgan on December 9, 2020.

operations (SAROPS); and commercial and recreational mariners to make operational decisions. Of the many NERACOOS observing assets and data systems, the real-time data and forecasts provided by the buoy network are especially important for maritime operations, accounting for 75% of pageviews on the NERACOOS website over the past year.

While maritime operators represent the largest user group, NERACOOS products and services are valued for assessment and planning by coastal resource and water quality managers, emergency managers, consulting companies, aquaculture companies, energy companies, formal and informal educators, recreational boaters, and coastal property owners. NERACOOS data also have notable research and educational value, and have supported important publications related to oceanography[3], ecology and fisheries[4], coastal resilience[5], economic development[6], and other issues. The letters of support in Appendix **e** provide additional insights into the benefits of NERACOOS services from a representative set of partners and users[7].

NERACOOS conducts extensive engagement with stakeholders to ensure that user requirements guide our work. Stakeholder engagement activities are described in sections D.1. and D.5. Section D.3. describes how we respond to identified needs by creating data delivery systems.

D. Work Plan.

To meet our goals and objectives, we have crafted an ambitious body of work tailored to an annual budget of $6M/year. If fully funded at this level (Tier II), we will be able to sustain existing systems that are highly valued by users, increase the resilience and effectiveness of those systems, and expand in new directions. As requested in the Notice of Funding Opportunity, we have also determined how resources would be allocated among the major IOOS subsystems with funding closer to our current level of approximately $3M/year (Tier I). Approximate annual allocations at each tier are as follows:

	Tier I		**Tier II**	
Subsystem	**%**	**$**	**%**	**$**
Management & Governance	18%	$535K	14%	$840K
Observing				
Fixed platforms: buoys and other stations	45%	$1.35M	40%	$2.5M
Mobile platforms: gliders and vessels	7%	$210K	14%	$840K
Remote sensing: HFR and satellites	7%	$210K	14%	$840K
Data Management & Cyberinfrastructure	11%	$330K	6%	$384K
Modeling & Analysis	6%	$180K	5%	$300K
Engagement	6%	$190K	6%	$360K
Total	**100%**	**$3M**	**100%**	**$6M**

At either level of funding, our budget reflects the regional importance of fixed platforms, particularly the NERACOOS buoy network. Nevertheless, at Tier I the frequency of maintenance

[3] E.g., Townsend et al. 2015, *Journal of Marine Research.* doi:10.1357/002224015815848811.
[4] E.g., Goode et al. 2019. *Global Change Biology.* doi:10.1111/gcb.14778.
[5] E.g., Twardowski et al. 2015. *Marine Technology Society Journal.* doi:10.4031/MTSJ.49.3.11.
[6] E.g., Viselli et al. 2015. *Ocean Engineering*. doi:10.1016/j.oceaneng.2015.04.086.
[7] A particularly informative first-hand look at the application of NERACOOS services for marine operations can be viewed at: http://www.neracoos.org/ioosvideo/2014

and replacement of equipment jeopardizes data flow, while Tier II provides an opportunity to build greater resilience into the network. Similarly, for the Management & Governance and Engagement subsystems, Tier I maintains the status quo, with current gaps and stretched capacity, whereas Tier II enables much more diverse and expansive operations and activities.

This budget also reflects a need to invest more in both the DMAC and Modeling & Analysis subsystems[8]. Best practices call for investment of at least 5-10% of data collection costs as a "floor" for data management[9]. Our Tier I budget aims to exceed this threshold for DMAC and increase investment in Modeling as another aspect of post-collection data processing. The DMAC and Modeling budgets also increase substantially at Tier II, even as the proportional investment decreases (but still keeps above the "floor"). At Tier II, observing asset operators make additional contributions to DMAC and modeling that increase the *de facto* investment.

At Tier I, maintaining the buoy network while investing more in the DMAC and Modeling subsystems comes at a cost of deployment of other observing tools. At Tier II, we are able to more fully complement the buoy network with glider deployments, high-frequency radar, and other assets to deliver a comprehensive picture of the ocean.

Our budget is discussed further in section F and Appendix **a**. The exact reductions to be made at funding levels below the full Tier II budget will be based on several context-dependent factors. These include the total funding available, evolving stakeholder priorities, response to crises, potential match funding raised by NERACOOS or our collaborators for certain projects, and other considerations. In the following sections on each subsystem, we describe the full body of work needed to achieve our vision at the $6M/year level of funding.

1) <u>Governance and Management</u>

NERACOOS is an efficient and nimble 501(c)(3) nonprofit organization. A 22-member Board of Directors governs our organization, providing oversight, approving policies, and helping set strategic priorities (Table 2). The NERACOOS Board covers the Northeast region geographically, with members hailing from all coastal New England states and the Canadian Maritimes. Board members also represent key ocean stakeholders, including academic and non-profit research institutions, state and federal government, and the private sector, with expertise spanning science, engineering, policy, finance, business administration, and more. The Board meets four times per year, twice in person and twice by teleconference[10]. One of the in-person meetings coincides with the NERACOOS Annual Meeting.

Our capable staff orchestrate all of the activities that encompass the regional ocean observing system. Our internal capacity is near its limit and must grow to keep pace with expanding needs and opportunities. Therefore, we propose adding two additional employees. First, an **Industry Partnerships Manager** will be a mid-level position responsible for cultivating relationships with emerging industries and coordinating the proposed Wind Industry Collaboration Fund and Aquaculture Collaboration Fund (see sections D.2. and D.5.). This position will enable us to devote attention to the opportunities presented by the shifting regional economic portfolio. Second, an **Observing Systems Coordinator** will be an entry-level position assisting the Operations Manager and system operators with tracking progress and assisting all staff with day-

[8] https://www.usgs.gov/products/data-and-tools/data-management/value-data-management
[9] http://reports.opendataenterprise.org/Ocean_Data_Paper_May1_DRAFT.pdf
[10] The coronavirus pandemic forced all Board meetings to be held by teleconference in 2020, which will continue until public health officials advise otherwise.

to-day troubleshooting across the subsystems. Delegating these tasks will enable senior staff to devote more attention to strategy and engagement. We are also exploring ways to use new hires to increase diversity and inclusiveness in the work of NERACOOS, possibly through filling the Observing Systems Coordinator position as a **RAY Diversity Fellow**[11].

NERACOOS operators are integral to our work. In 2019, we held a NERACOOS Operators Meeting that brought all key contributors together to share updates, discuss best practices, promote greater integration, and foster a sense of community. The workshop was incredibly productive and so well-received that we plan to make it an annual event.

Operators also provide the NERACOOS office with semi-annual technical reports that detail the progress of their work. The Operations Manager and Observing Systems Coordinator (once hired) will check in with individual operators quarterly, meet one-on-one in person or virtually at least once per year, and troubleshoot issues affecting the observing system as needed.

As an adaptive and responsive integrated ocean observing system, we continue to evaluate our services and priorities to ensure all are aligned with stakeholder needs. As we begin the U.N. Decade of Ocean Science for Sustainable Development, we will work with the Board, stakeholders, and an independent facilitator to create a 2021-2030 Master Plan. The Master Plan will define priorities and measurable outcomes for our work, and connect regional needs and activities with national and global opportunities over the Decade to provide a high-level vision for the organization. We will then review and respond to this vision by developing an updated strategic plan every three years. Additionally, our staff will hold an annual retreat to revisit the Master Plan and current strategic plan, develop work plans for the coming year, and review the needs of our stakeholders. Each year, we also contract with an independent certified public accountant to conduct a rigorous organization-wide audit that looks at both our financial management of federal funds and our compliance with federal regulations, terms, and conditions.

We also regularly engage with the IOOS enterprise at the national level through a variety of mechanisms coordinated by the IOOS Program Office and IOOS Association that relate to financial matters, reporting and administration, strategic alignment, and other aspects of effective governance and management. Like all of the IOOS Regional Associations, our Executive Director and Board President serve on the Board of the IOOS Association, and our Executive Director also serves on its Nominating Committee. Given the overlap in our regions and interests, we hold regular calls to align our work with the Mid-Atlantic Regional Association of Coastal Ocean Observing Systems (MARACOOS) and the Canadian Integrated Ocean Observing System Atlantic (CIOOS Atlantic).

2) Observing

During our first decade, NERACOOS developed a robust ocean observing system in the Northeast (Figure 2). Following, we describe how different types of observing tools are employed by NERACOOS, including ongoing operations and new work that responds to emerging needs. Table 3 summarizes which of the IOOS Core Variables are measured by these different categories of tools and Table 4 provides more detail on specific assets currently in operation. Additional details regarding deployment, operational, and maintenance costs are included in Appendix **a**.

[11] https://rayfellowship.org/

Fixed platforms

Buoys

The complexity of New England's marine environment and human uses calls for ocean observing data and models with high spatial and temporal resolution that are available to mariners and first responders in real time for operational decisions. There is also need for reliable time series that enable researchers and policymakers to understand system dynamics, predict future states, and manage competing uses. Our network of fixed buoys has proved to be the most effective way to meet these needs (Figure 6). Over the next five years, NERACOOS and our operators will sustain the operation of the current network of buoys, including:

- Three multi-purpose moorings – Western Long Island Sound (WLIS), Central Long Island Sound (CLIS), and Execution Rocks (EXRK) – in Long Island Sound (University of Connecticut [UConn]);
- Real-time and/or historic data access for seven of the buoys within the Narragansett Bay Fixed Site Monitoring Network (NBFSMN) (University of Rhode Island [URI]);
- A Coastal Data and Information Program (CDIP) wave buoy in Cape Cod Bay and an Acoustic Doppler Current Profiler (ADCP) at the western entrance to the Cape Cod Canal, with a second CDIP wave buoy to be installed in Buzzards Bay in 2021, as part of the National Ocean Service (NOS) Physical Oceanographic Real-Time System (PORTS) (Woods Hole Group [WHG]);
- Multi-purpose buoys in Great Bay, NH, and off the Isles of Shoals, and a CDIP wave buoy on Jeffreys Ledge. The Isles of Shoals buoy is the only station in the Gulf of Maine that measures CO_2 in the ocean and atmosphere (University of New Hampshire [UNH]);
- Seven multi-purpose moorings – A, B, E, I, F, M, and N – throughout the Gulf of Maine. On Buoy M in Jordan Basin, we will continue to support the deployment of *in situ* Submersible Ultraviolet Nitrate Analyzer (SUNA) sensors, which have proven to be especially important for understanding the oceanography of the Gulf of Maine and explaining trends in Harmful Algal Blooms (HABs) (University of Maine [UMaine]).

Our buoy network has evolved as an interconnected network of assets that were each positioned based on local user needs to address operational, regulatory, environmental, or other issues. Siting is also based on the arrangement of other assets to achieve complementarity and avoid redundancy, both with NERACOOS stations and others. Notably, NERACOOS data products incorporate data from platforms that are not funded or managed by NERACOOS, including National Data Buoy Center (NDBC) buoys, NOS water level stations, the Ocean Observatories Initiative (OOI) Pioneer Array[12], the Cornell Whale Array, and private sector assets. In turn, data generated by the NERACOOS network of buoys and other fixed stations feed into other platforms, especially NDBC. The national and international use of NDBC data products gives NERACOOS-generated data additional reach.

The larger offshore buoys are particularly important for providing data and forecasts to mariners transiting far beyond the coast, where conditions can be considerably more dangerous. The same data and forecasts are likewise utilized by emergency services that ensure those mariners' safety. Furthermore, offshore buoys also aid in shoreline protection throughout the coastal zone by

[12] Funded by the National Science Foundation. https://oceanobservatories.org/array/coastal-pioneer-array/

defining boundary conditions for the NERACOOS-supported oceanographic models that predict wave intensity and flooding risk.

Given the importance of buoys for NERACOOS, over the first two years of the next five-year cycle, we will conduct a full **audit of the buoy network** now that the network has matured and been tested by users for a full decade. The audit will look for gaps and redundancies, make operational and data management recommendations, advise on partnership and cost-sharing opportunities, and address other issues. Moreover, the audit will benchmark the buoy network and other NERACOOS observing components against national standards and plans for design and implementation. Among other factors, this audit is prompted by operational interruptions, some modest and some more pervasive, caused by the coronavirus pandemic that underscored our need to build a more resilient system. To this end, we plan to create a centralized **Buoy and Sensor Replacement Fund** that will be managed by NERACOOS and accessible to all operators. We plan to operate the fund in a manner that promotes greater cost-sharing with operators and users by prioritizing proposals that can match funds from other sources.

We propose a notable addition to the offshore buoy network: a station at the edge of the Scotian Shelf to be maintained by UMaine, which will complement Buoy N in tracking critical inflows into the Gulf of Maine. Buoy N observes the deep Labrador Slope Water and Warm Slope Water entering the Gulf of Maine through the Northeast Channel from the Labrador Current and Gulf Stream, respectively. However, we lack observations of the Scotian Shelf Water flowing from the Nova Scotia Current and shallow limb of the Labrador Current, a gap the Scotian Shelf Edge buoy will fill. As we look to fully engage in the forthcoming 2021-2030 U.N. Decade of Ocean Science for Sustainable Development, we will focus on connecting the work of NERACOOS with observing activities across the wider Northwest Atlantic region (Figure 3)[13]. The Scotian Shelf Edge buoy will provide a new point of collaboration with Canadian partners.

Closer to shore, the area covered by each station is limited by the complex coastal geography. Furthermore, the number and density of users, proximity of shoreside infrastructure, and pace of environmental change call for observing with higher spatial resolution. To effectively serve our region, NERACOOS activities in the coastal zone rely more heavily on financial, operational, and engagement cooperation with a range of federal, state, and local entities connected to many observing assets. These include, but are not limited to:

- **Environmental Protection Agency National Estuary Program** (NEP) sites across New England, from Long Island Sound to Casco Bay, Maine;
- **National Estuarine Research Reserve** (NERR) sites in Narragansett Bay (RI), Waquoit Bay (MA), Great Bay (NH), and Wells (ME), which are supplementing oceanographic, meteorological, and ecological data through their System-Wide Monitoring Program (SWMP) stations;
- **United States Geological Service** (USGS) coastal monitoring stations and integration of data from other stations into data products;

[13] NERACOOS has submitted a project concept, or “ocean-shot”, to this effect to the U.S. National Committee for the U.N. Decade, and will also submit the concept directly to the global Decade governance early in 2021.

- The newly formed **United States Department of Agriculture** (USDA) and **UMaine Aquaculture Experiment Station** in the Damariscotta River estuary[14] and **UNH Sustainable Seafood Initiative** spanning Great Bay and the adjacent waters of the Western Gulf of Maine[15];
- The **Department of Housing and Urban Development** Natural Disaster Resilience grant to the Connecticut Institute for Resilience and Climate Adaptation based at UConn focused on responses following flooding impacts of Hurricane Sandy[16];
- State agencies including the **Massachusetts Water Resources Authority** (MWRA), **Massachusetts Department of Environmental Protection** (MADEP), **New Hampshire Department of Environmental Services** (NHDES), **Rhode Island Department of Environmental Management** (RIDEM), and **Maine Department of Marine Resources** (MEDMR) (Figure 7).

Additionally, a new monitoring program will be initiated by UMaine aimed at observing support for the expanding nearshore aquaculture industry, connected to the USDA/UMaine Aquaculture Experiment Station[17]. This initiative will work with industry partners to determine the most effective spatial and temporal placement of smaller and more nimble buoys to provide priority information to a variety of businesses, as well as supporting researchers and regulators. In conjunction with the program's start, we will develop a new web interface based on our Mariners' Dashboard (Figure 8) to deliver program data in a timely and user-friendly manner.

The emerging wind energy industry in the Northeast presents particularly strong prospects for new data streams. We are currently serving data provided by the Mayflower Wind buoy in their Southern New England lease area (Figure 7) and working with Ørsted to serve data from their buoy as well. Similarly, nearshore and offshore aquaculture operations present additional fixed platforms from which data can be gathered. Accordingly, we propose the creation of a new **Wind Energy Collaboration Fund** and a new **Aquaculture Collaboration Fund** to support collaboration with these growing sectors on data integration, data products, and other initiatives of mutual interest. We expect most of these funds to be passed through to partners who will execute the projects, matched by funds from the industry and other new sources.

<u>Other fixed platforms</u>

Although the buoy network is the backbone of the NERACOOS observing system, additional fixed platforms provide data on targeted variables at strategic locations (Figure 6). Deployment of these platforms will expand over the next five years to meet user needs, including:

- <u>Coastal observing in Downeast Maine</u> – Despite becoming the new center of the Maine lobster industry, many ocean-dependent communities of Downeast Maine are underserved and economically strained. To address these imbalances, and as a tangible step towards our commitment to diversity, equity, and inclusion, we will support partners

[14] https://umaine.edu/news/blog/2020/10/14/umaine-aquaculture-research-institute-usda-agricultural-research-service-partner-to-help-salmon-and-oyster-aquaculture-succeed-in-the-u-s/

[15] https://marine.unh.edu/publication/unh-receives-5m-expland-its-commitment-sustainable-seafood

[16] https://circa.uconn.edu/2018/06/28/university-of-connecticut-receives-grant-award-from-the-department-of-housing/

[17] NERACOOS recently outlined opportunities for ocean observing to support aquaculture development in response to the USDA Request for Information on the Agriculture Innovation Agenda: https://beta.regulations.gov/comment/USDA-2020-0008-0099

in the Eastern Maine Coastal Current Collaborative (EM3C) including the Maine Center for Coastal Fisheries, Passamaquoddy at Pleasant Point, and MEDMR in the installation and operations of four new observing stations. Installed in stages over the first three years of the award, these stations will cover the coast from the lower St. Croix River estuary to Boothbay Harbor. The St. Croix River is the site of a major public restoration investment and is an important upstream driver of the Maine Coastal Current system, so improved observing of its outflows will benefit downstream oceanographic predictions. Because the St. Croix forms part of the United States/Canada border, the project is supported by Canadian partners, including the Passamaquoddy community in New Brunswick. A new station in Boothbay Harbor will be installed by MEDMR to expand and validate their 100+ year time series, the longest continuous record of sea surface temperature on the North American Atlantic Coast.

- <u>Tide gauges and water level sensors</u> – We will continue to support observing for hazard preparation and response in coastal communities, as well as long-term infrastructure planning:
  - Sustained operations at three key locations (Hampton, NH; Gloucester, MA; Scituate, MA) by Charybdis Group;
  - Joint support with USGS for operations of the Saco, ME station:
  - Installation of up to ten new stations strategically located across the region from the Gulf of Maine to Long Island Sound by WHG.
- <u>Ocean and coastal acidification</u> – We will support several efforts to sustain and expand the growing acidification observing network in the region, including:
  - Continued operation of the flow-through system at the UNH Coastal Marine Laboratory that provides a critical coastal acidification time series for the region;
  - Installation of pCO_2 sensors at each of the four NERR sites in New England to create a regionally intensive *in situ* acidification monitoring network that complements observing through the SWMP stations, under the leadership of Wells NERR;
  - Expanded water quality monitoring throughout Cape Cod Bay and Nantucket Sound conducted by the Center for Coastal Studies, MADEP, and Barnstable County to include carbonate parameters.
- <u>Passive acoustic recorders</u> – Collaboration with Stellwagen Bank National Marine Sanctuary, UNH, and the Northeast Fisheries Science Center (NEFSC) will combine data from new fixed stations with glider-based observations to develop a soundscape baseline for the Gulf of Maine. This will improve the ability to detect critically endangered North Atlantic right whales, as well as other applications.
- <u>Rocky intertidal temperature microsensors</u> – The ISMN *Science and Implementation Plan* identifies a suite of sentinel indicators, including rocky intertidal habitats, which have not yet been the focus of NERACOOS observing work. We will work with Northeastern University and the University of Porto (Portugal) to deploy novel and low-cost temperature microsensors in these intricate systems, including a citizen science program for data retrieval. Notably, this will expand regional observing being conducted within the global MBON Pole-to-Pole Initiative[18], and therefore presents an opportunity for new international engagement by NERACOOS.

[18] https://marinebon.org/p2p/

- eDNA monitoring – Conducted per MBON protocols, new observing of biodiversity, from microbes to plankton to macrofauna, using eDNA will be piloted by UNH at the NERR sites in Great Bay, New Hampshire and Wells, Maine.

Mobile platforms

Gliders

The importance of fixed platforms in the Northeast notwithstanding, mobile platforms have important advantages in terms of spatial coverage and flexibility, which make them essential components of the NERACOOS observing system. We expanded autonomous glider observations in the Gulf of Maine through supplemental funding from the IOOS Association-led "Fill the Gaps" campaign (Figure 6). Woods Hole Oceanographic Institution (WHOI) and UMaine deployed gliders to expand ecosystem monitoring. The WHOI gliders also use passive acoustic sensors to detect endangered North Atlantic right whales and other species, and we plan to install those sensors on the UMaine gliders as well.

Moving forward, the WHOI and UMaine deployments will continue to provide broad coverage of the Gulf of Maine, targeting key times, places, and events and filling gaps between the buoys. However, we have yet to deploy gliders in Southern New England, where human population density, activity, and development are especially concentrated. Long Island Sound is bordered by several urban centers, including New York City. As development progresses in the adjacent offshore wind energy lease areas, Rhode Island Sound will soon be the site of greatly increased construction and maritime traffic, causing ecological impacts and operational challenges. Therefore, new glider deployments in Long Island Sound conducted by UConn and in Rhode Island Sound conducted by URI will more closely observe these congested areas. We will coordinate glider deployments with MARACOOS as Southern New England is a region of shared interests and operations.

Increased glider activity in the region creates an urgent need to plan missions more strategically. A priority recommendation from the 2019 Operators Workshop was to develop a regional glider plan consistent with national guidance. We will develop such a plan in cooperation with our operators and users over the first two years of the award. In the final three years, we will modify deployments to be consistent with the plan. Development of the glider plan will be coordinated with the audit of the buoy network, as the two platforms must work in concert.

Vessel-based observing

NERACOOS will also support ocean observing conducted through scientific cruises and ships of opportunity (SOOPs). With Canada's Department of Fisheries and Oceans (DFO), we will continue to jointly support the Browns Bank transect within DFO's Atlantic Zonal Monitoring Program (AZMP) that runs south from the Scotian Peninsula to the Northeast Channel. AZMP observing includes phytoplankton, zooplankton, and a range of standard physical and chemical oceanography variables. This represents our most significant collaboration with Canadian partners to date and an important starting point for expanding international partnerships.

In previous years, we have helped to support NOAA's East Coast Ocean Acidification (ECOA) cruise, with funding from the OAP, and initiated vessel-based observing of oceanography and plankton communities as part of ISMN, with support from MBON. These cruises continue monitoring at the Coastal Maine Time Series and Wilkinson Basin Time Series sites, and the plankton sampling methodology replicates AZMP to facilitate data integration. Plankton observations have many applications for fisheries, aquaculture, and conservation, including predicting the behavior of North Atlantic right whales. MBON funding for ISMN expires after the first year of the next five-year cycle, and we propose continued funding thereafter.

NEFSC has recently resumed U.S. support for the long-running international Continuous Plankton Recorder (CPR) program[19]. NEFSC and NERACOOS will develop a program to coordinate plankton observing and data management across ISMN, AZMP, and CPR. Integration of regional plankton data, which is an objective of our MBON-supported ISMN work, is important not only to improve *in situ* plankton observing but also to ground-truth satellite remote sensing of plankton communities. Together, *in situ* and satellite-based observing can be used to develop new forecasting tools, an objective of NASA's Ecological Forecasting Program[20].

SOOPs have played a smaller role in the NERACOOS observing system to date. However, the wide array of mariners in our region present opportunities to greatly expand spatial and temporal observing coverage. Commercial fishing fleets comprise the most numerous and active vessels in the region, with the added bonus of deploying gear that can support sub-surface observing. Accordingly, NEFSC and the Gulf of Maine Lobster Foundation have been running the Environmental Monitoring on Lobster Traps (eMOLT) program, which installs environmental sensors on commercial fishing gear, visualization hardware in vessels' wheelhouses, and telemetry systems to make the data available in near-real-time[21]. The program began with lobster traps and has expanded to other fixed gears and trawlers, increasing the spatial and temporal coverage. We will support the continuation and growth of eMOLT, including integration of the data into NERACOOS data systems. We will also support construction and deployment of passive drifters from participating vessels as an additional component of eMOLT.

Going forward, the project will include U.S. vessels fishing in areas managed by the Northwest Atlantic Fisheries Organization (NAFO) and International Commission for the Conservation of Atlantic Tunas (ICCAT), especially on the Grand Banks. The Grand Banks is where the southward-flowing Labrador Current turns westward and runs over the Scotian Shelf toward the Gulf of Maine (Figure 3). Observing temperature anomalies and other oceanographic attributes at this critical juncture can provide U.S. users with improved forecasts of forthcoming changes while improving boundary conditions for oceanographic models. Mobilizing SOOPs in NAFO and ICCAT fisheries presents another opportunity to collaborate with Canadian partners and connect with observing in the wider Northwest Atlantic over the U.N. Decade of Ocean Science.

Remote sensing

<u>High-frequency radar</u>

As with glider deployments, NERACOOS was able to increase application of High-Frequency Radar (HFR) systems thanks to the "Fill the Gaps" campaign (Figure 9). Our region now includes four stations providing coverage in the southern Gulf of Maine, from the New Hampshire Seacoast to Cape Cod Bay, and three stations in the northern Gulf of Maine from Penobscot Bay across to the Scotian peninsula. A gap remains in the waters off southern Maine and into the central Gulf of Maine, and we will support installation of a new station near Portland, ME, to extend coverage. Additionally, significant gaps remain in Southern New

[19] https://www.fisheries.noaa.gov/feature-story/long-running-plankton-survey-resume-gulf-maine
[20] https://appliedsciences.nasa.gov/what-we-do/ecological-forecasting
[21] http://emolt.org/

England, especially Long Island Sound, a highly populated area of particular importance for SAROPS. In coordination with MARACOOS we propose installation and operations of two new stations in Long Island Sound by UConn. HFR data are the primary input to the Short-Term Prediction System (STPS) being operated by UConn, an important tool used by USCG in planning and executing SAROPS.

Satellite observations

UMaine's coordination of satellite observations is widely used, and funding from NERACOOS is supplemented by other sources. Satellite observations are used by a variety of mariners to visualize ocean conditions such as temperature fronts and chlorophyll concentrations. Observations also enable research on longer-term trends in climatology and oceanography. Both near-term and long-term satellite-based observations inform communications with stakeholders, such as the quarterly reports for the Gulf of Maine produced by the National Integrated Drought Information System[22].

3) Data Management and Cyberinfrastructure (DMAC)

Approach

The NERACOOS Data Assembly Center (DAC), maintained by the NERACOOS DMAC team at the Gulf of Maine Research Institute (GMRI), is powered by a standards-based data management framework for aggregation, interoperability, discovery, and dissemination of ocean observing data (gridded and observational) from the region. The DAC is based on standards and best practices developed, tested, and recommended by IOOS and the IOOS Regional Associations' DMAC community. The DAC provides the core capabilities that connect and integrate the Observing and Modeling & Analysis Subsystems, and make quality-controlled data discoverable and accessible to stakeholders through a range of products.

We acquire data directly from providers through a Service Oriented Architecture approach. Data providers are encouraged to expose data through standards-based web services (e.g., web-accessible data directories, local THREDDS and ERDDAP systems), which increases efficiencies, reduces redundancy, and ensures that the highest quality data are available to end-users. The NERACOOS DMAC team at GMRI works closely with providers to produce data in compliant formats (NetCDF, ISO 19115) and adopt data and quality control standards (QARTOD) and protocols to improve interoperability. Data are integrated from distributed systems, aggregated, and distributed through region-wide products and services. Using automated services and scripts, data are acquired directly from providers through a range of processes (e.g., rysnc, ftp, remote connection to locally hosted THREDDS Data Server, or ERDDAP) and autonomously ingested into the DAC. For data providers lacking bandwidth or capacity, the DAC can ingest file formats (csv, txt) and then process, store, and distribute through standardized formats. Web services for accessing data directly are registered with the IOOS Catalog and exposed through search-friendly Web Accessible Folders. The protocols and services of the DAC provide a roadmap to integrate new providers quickly and efficiently[23].

The DAC is deployed on the Amazon Web Services Cloud utilizing best-of-breed services for computing, storage, container and cluster management, and data processing. The system is

---

[22] https://www.drought.gov/drought/documents/quarterly-climate-impacts-and-outlook-gulf-maine-region-june-2020

[23] NERACOOS Data Management Plan and Policies: http://neracoos.org/documents

backed up nightly to preserve the data, software, and configuration of the machine setups for disaster recovery. This cloud-based system has been in place for over 10 years, and the flexibility has facilitated hardware and software upgrades to accommodate ongoing evolution of the DAC.

With level funding for the last 10 years, the NERACOOS DMAC team has been able to implement the DAC according to best practices, fully or partially adopting the majority of the guiding principles put forward by NOAA and IOOS. Over the years, the NERACOOS DMAC team has collaborated with other Regional Associations on product development and data sharing initiatives and will continue to do so going forward.

Activities

On an annual basis, the NERACOOS DMAC team will prioritize a series of activities to maintain and improve DMAC services. First and foremost, the team will **maintain and enhance a robust, standards-based regional DAC** that includes back-end data management systems, data integration software and tools, data and information products, the NERACOOS website, and data access portals. Maintenance strategies will include efforts to update, improve, and, in some cases replace, legacy elements of the data systems.

With this robust DAC, the team will **develop and manage systems to integrate data from regional initiatives**. Priority efforts will ensure that all IOOS-supported gridded and observational data products are available through standards-compliant data services and products. GMRI will provide direct support to new and existing NERACOOS-funded data providers to produce and upgrade data streams to meet current and emerging standards requirements, including Climate and Forecast compliance of data streams, full implementation of the National Centers for Environmental Information archive process, and implementation of QARTOD processes for both historic and real-time observation data. This support will be provided through regular meetings and work sessions with data providers. We will collect archives of data from funded providers in a phased manner and make additional efforts to integrate emerging data streams from providers not directly supported by IOOS but relevant to regional priorities (e.g., CPR, industry assets).

To ensure that NERACOOS DMAC conforms with best practices and integrates where needed with systems across the IOOS enterprise, the team will regularly **collaborate with national and regional DMAC activities**. These collaborations include monthly webinars, annual meetings, and cross-regional and topic-based workshops (e.g., QARTOD implementation, product development workshops, data management policy and collaboration). An important Year 1 task will be to work with NDBC to implement the ERDDAP harvester to improve access to near real-time observation data from the region. We will also update and improve NERACOOS DMAC policies and guidance documentation to prepare for RICE recertification in 2023.

During each year of the award, the DMAC team will work with NERACOOS program staff to **maintain existing data products and develop new products** based on emerging needs. An important milestone in 2020 was the launch of the Mariners' Dashboard, our improved interface for accessing real-time buoy data and forecasts (Figure 8)[24]. We plan to launch a new layout for the NERACOOS website in 2021 to enhance communication with users and the wider public and improve access to data products. In 2021 and 2022, we will conduct a thorough review of data products to determine which are functional, obsolete, or in need of upgrades. Once the new

[24] https://mariners.neracoos.org/

website has been live for a full year, we will fully integrate existing data products into the new format. We will also develop and roll out new data products, with a target of at least one per year as funding and workload permit. New data products that we are considering include an updated tool for access to and visualization of historic data, SMS-based query and alert tools for observation and forecast data, a water level data archive and visualization tool connected to coastal tide stations, and improved tools for visualizing satellite data.

4) **Modeling and Analysis**

Numerical modeling is a vital component of NERACOOS that delivers the capacity to simulate the past, present, and future ocean environment. Model simulations combined with high-quality observations support a wide range of user requirements. Over the last decade, we have developed an advanced regional modeling capacity that effectively delivers meteorological and oceanographic hindcasts, nowcasts, and forecasts to key regional users, which is helping to advance national coastal modeling capabilities. More recently, we have supported efforts to couple regional models with national modeling systems and the development of regional hydrological and biogeochemical models that are improving and expanding the NERACOOS forecasting portfolio.

FVCOM and NECOFS

The primary modeling capability developed by NERACOOS is the Northeast Coastal Ocean Forecast System (NECOFS), which is an integrated atmosphere-ocean prediction model based on the Finite Volume Community Ocean Model (FVCOM) (Figure 10). Operated by the University of Massachusetts at Dartmouth (UMassD), NECOFS produces a 5-day hourly forecast every 24 hours, in addition to a series of high-resolution coastal inundation forecasts for flood-prone coastal regions. The standardized forecast output is routinely ingested into the USCG SAROPS system and several NWS Regional Weather Forecast Offices. Over the next five years, UMassD will use FVCOM and NECOFS to continue forecast operations, as well as annual updates of our historical climatology product (1978-present) with data-assimilated hindcasts.

UMassD will also implement a new version of FVCOM that will be nested within the Global-FVCOM model, which will improve the forecast capability of the Gulf Stream shelf interaction and inflows from the Labrador Seas and Arctic Ocean. Additionally, the updated NECOFS will merge the forecast and hindcast versions to make the hindcast assimilation field simultaneous with the forecast field.

UMassD has progressively improved the resolution of FVCOM and NECOFS at high-priority locations throughout the region. Long Island Sound is a particularly important area given its geography and urbanization. Therefore, NERACOOS and MARACOOS jointly funded UConn in the development of the LIS-FVCOM sub-model and its first year of operations. We will continue to fund operations with MARACOOS going forward. LIS-FVCOM connects with the larger regional FVCOM model for boundary conditions, and UConn and UMassD regularly coordinate on model development and operations.

UmassD is expanding the ability for FVCOM to serve as a prediction tool for offshore wind energy lease areas by implementing a wind turbine resolving subdomain. Further development and eventual application of this capability is a candidate project for the proposed Wind Energy Collaboration Fund, pending interest and investment by the industry or other sources.

Other ocean modeling

We support Canada's Bedford Institute of Oceanography (BIO) in the operation of a state-of-the-art surface wave model, Wave Watch 3 (WW3). BIO will continue 24/7 operations and delivery of predictions from WW3, improve wave forecasts by including updated water levels, wave-ice interactions, and implement an improved formula for nonlinear wave-wave interactions.

NERACOOS remains committed to the continued development and application of STPS at the national scale by UConn, especially given its importance for USCG SAROPS, as noted above. Therefore, we will follow the direction of the U.S. IOOS Program Office in the administration of funding for STPS through NERACOOS as needed.

Coastal modeling

UMassD is improving the resolution of the coastal inundation model by including the effects of saltmarshes, tidal creeks, and other estuarine features. The improved coastal model will then be expanded to cover the northeast coastal region from Rhode Island to Maine. NECOFS is also providing critical modeling infrastructure for other coastal model development efforts. An IOOS Coastal and Ocean Modeling Testbed (COMT) award is currently supporting a project to couple NECOFS with the National Water Model and the UNH Water Balance Model to improve the understanding and prediction of the combined effects of land processes and ocean circulation on coastal inundation. A project funded by NOAA's National Centers for Coastal Ocean Science and OAP is supporting the development of a Northeast biogeochemical model within the NECOFS framework. These model development efforts are helping to better meet the needs of regional stakeholders and the objectives of NOAA's Water Initiative[25].

Coordination and delivery of outputs

NERACOOS staff and modeling PIs participate in the NOAA-sponsored Coastal Coupling Community of Practice. The NECOFS team works with NOAA's Coastal Development Lab to support FVCOM development and thus have a direct interface with federal modeling systems. The NECOFS team is also directly contributing to several of the topics identified by the national Model Task Team, including model coupling, data assimilation, nearshore processes, and cyberinfrastructure and skill assessment[26].

All NERACOOS model outputs are delivered through IOOS-recommended formats and services and registered with the IOOS catalog. These standard services allow NERACOOS model outputs to be effectively integrated into national products like the IOOS Environmental Data Server Model Viewer[27] and NERACOOS products such as the Mariners' Dashboard. All NERACOOS-supported model outputs include appropriate metadata and follow the IOOS metadata profile.

5) Engagement

NERACOOS predicates every aspect of our observing, modeling, and DMAC subsystems on the stated needs of our stakeholders. We estimate that engagement activities account for nearly 25% of the NERACOOS organizational budget, including staff time, travel, workshops and meetings, publications, and more, in addition to dedicated engagement activities such as ISMN, NECAN, and the Ocean Acidification Information Exchange (OAIE). Immersing ourselves within our community of partners and users is essential to building relationships and keeping open lines of communication. A number of regional, national, and international forums enable that immersion,

[25] https://www.noaa.gov/water/explainers/noaa-water-initiative-vision-and-five-year-plan
[26] https://www.tandfonline.com/doi/pdf/10.1080/1755876X.2017.1322026?needAccess=true
[27] https://eds.ioos.us/

including quarterly meetings of the Northeast Regional Ocean Council (NROC), the annual meeting of the Regional Association for Research on the Gulf of Maine (RARGOM), industry meetings such as the Maine Fishermen's Forum, activities across the six New England NEPs, Port Safety Forums, and more. Engagement priorities for the next five years are as follows:

Diverse and inclusive stakeholder relationships

Our engagement program educates stakeholders about NERACOOS products and services, and seeks to understand how they use those products and services so we may quickly and effectively respond to needs and address gaps. NERACOOS employs an ongoing stakeholder-driven process to determine what information to collect and how best to streamline access to information[28]. Key stakeholders, both organizations and individuals, are often longtime users who have relied on NERACOOS observing data for years. Maintaining relationships with these stakeholders, which include NWS Weather Forecast Offices, USCG, the private sector, commercial and recreational mariners, and others, and responding to their needs is at the heart of NERACOOS's mission. We review feedback collected through stakeholder focus groups, interviews, surveys, and website analytics, the results of which we compile and review yearly and incorporate into our work plan when appropriate (see section D.1.).

The NERACOOS Board of Directors is our most important vehicle for sustained and substantive stakeholder engagement (Table 1). Our Board is especially supportive of our organizational commitment to diversity, equity, and inclusion[29] and active in the early steps to actualize the commitment. Our Board and staff are striving to more fully include and represent all the communities we serve, especially those who have been historically underrepresented. To this end, we added three new Board members in 2020 and are working to identify underrepresented sectors and communities that we might look to for additional Board members.

To further advance this commitment, we propose the creations of a new **Diversity, Equity, and Inclusion Fund**. The Fund would cover the non-salary costs of the RAY Fellowship (retreats, professional development) through which we hope to recruit our new Observing Systems Coordinator, diversity training for NERACOOS staff, and other initiatives such as mini-grants and outreach activities to engage new stakeholders, especially in marginalized communities.

These steps are consistent with discussion and action that are rapidly accelerating at the IOOS enterprise scale. NERACOOS will work with the other IOOS Region Associations, IOOS Association, and the IOOS Program Office on workforce development initiatives to expand and diversify the ocean, coastal, and Great Lakes workforces and to improve our ability to provide relevant ocean and coastal information to underserved or underrepresented communities.

Bolster regional coordination

ISMN, a joint initiative of NROC and NERACOOS, is focused on observing changes in our region's ecosystem and interpreting those changes for stakeholders. Over the course of three years, nearly 50 organizations worked together to write the ISMN *Science and Implementation Plan*, which outlines the need for greater regional monitoring collaboration and a blueprint for its realization. To that end, we will hold annual workshops to bring together key stakeholders and identify priority activities for observing, analysis, and engagement. We will advance engagement

[28] https://www.frontiersin.org/articles/10.3389/fmars.2019.00290/full
[29] http://www.neracoos.org/neracoos.org/about/resources/solidarity

with ISMN through buildout of the newly launched ISMN website[30] and outreach materials that communicate the outcomes of synthesis efforts, including the integration of external biological datasets into NERACOOS and ISMN products. In the face of changing U.S. climate policies, we may see demand to comprehensively measure ocean carbon stores. The ecosystem-scale perspective of ISMN is well suited for regional and national leadership on this emerging issue.

NECAN is an important regional coordination entity providing stakeholders with information about ocean and coastal acidification they can use to make decisions affecting environmental and socioeconomic health[31]. The demand for this information is evident from the more than 600 people who subscribe to the NECAN newsletter. We will continue engagement through webinar series, stakeholder workshops, and the outputs of Working Groups, which include materials for outreach and education such as VOCAL New England[32]. NECAN has also piloted citizen science monitoring through the first Shell Day in 2019, during which more than 50 participating organizations collected in excess of 500 water samples. Following the success of Shell Day, we are planning new opportunities for active involvement by regional citizen science groups.

OAIE is a members-only online community of practice purpose-built to engage professionals working on or interested in ocean and coastal acidification[33]. In addition to maintaining our current efforts with the site's 1,000+ members, we plan to foster more cross-disciplinary engagement through content seeding and more structured guidance for team leaders. In 2020, OAIE awarded mini-grants to support the creation of educational materials for use in Alaskan and Southeastern indigenous communities. We plan to release additional mini-grant funds to incentivize the use of OAIE and facilitate innovative member projects. Furthermore, we will increase the visibility of the OAIE through our presence at both in-person and virtual conferences, workshops, meetings, and events.

Our work on the coastal and ocean waters of the Northeast U.S. can be enhanced by connecting more fully to the wider Northwest Atlantic and global ocean observing communities through the **U.N. Decade of Ocean Science**. Building from our collaboration with Canadian partners, further engagement across the Northwest Atlantic would call for collaboration with Greenlandic and Icelandic partners given the strong oceanographic connections (Figure 3). Such partnerships would be consistent with bilateral scientific cooperation agreement between the U.S. Department of State and both nations[34]. This scale of engagement can generate broader recognition for the work of NERACOOS, opening channels for new ideas, tools, partnerships, and funding. The oceanographic, ecological, and economic influences on our region do not end at the limits of our current work, so our scientific understanding will improve by broadening our horizons.

Increase engagement with emerging industries

In addition to sectors that have long been connected to NERACOOS services, such as fisheries and tourism, three industries are poised for particularly rapid growth and warrant new dedicated engagement activities:

---

[30] http://www.sentinelmonitoring.org
[31] http://www.necan.org/
[32] https://www.vocalindustry.info/
[33] https://www.oainfoexchange.org/
[34] Greenland: https://dk.usembassy.gov/our-relationship/u-s-greenland/usglscience/; Iceland: https://is.usembassy.gov/business/environment-science-technology-health-relationship/

The **offshore wind energy sector** is an up-and-coming stakeholder with whom we began collaborating in 2019. In 2020, data from the Mayflower Wind buoy (Figure 7) became available through our Mariners' Dashboard (Figure 8). We have also begun discussions with Ørsted about serving data from their lease site buoy and other areas of mutual interest (see Appendix **e**), and will conduct similar outreach to other lease holders. In support of these engagements, NERACOOS worked with NROC, the Mid-Atlantic Regional Council on the Ocean (MARCO), and MARACOOS to organize a workshop in October 2020 that introduced wind energy companies and agencies to the existing regional platforms where they can both find and provide data to meet operational, regulatory, and public service objectives. The emergence of this sector and the opportunities it presents underscore the importance of the proposed Wind Energy Collaboration Fund as a source of flexible resources to quickly capitalize on shared interests and launch new projects.

We will continue engaging the **aquaculture industry** through NECAN, in particular through the Industry Working Group. In 2019, NECAN surveyed aquaculture operators to better understand their knowledge of and responsiveness to coastal acidification, the preliminary results of which have been used to create educational infographics for industry members. The full survey report and a summary are now available online[35], and we will use the findings to tailor future engagement and product development for the sector. These efforts are already underway through several supplemental funding proposals in development with industry members, and we aim to expand partnerships and projects through the proposed Aquaculture Collaboration Fund.

Current engagement with the **shipping industry** includes our regular participation in the USCG-sponsored Northeast Port Safety Forums and direct communication with shipping companies and pilot associations. The development of Cape Cod PORTS, which is improving navigation in and around the Cape Cod Canal, is a direct result of our engagement with commercial mariners. We will continue to engage with the Port Safety Forums, pilots, and shipping companies, and plan to enhance our collaboration with NOAA's Northeast Navigation Manager. We have also held initial discussions about collaboration opportunities with the New England Ocean Cluster based in Portland, Maine, an important regional convening point for the shipping industry. Looming changes in the regional shipping industry driven by Arctic melting will unfold slowly, giving us time to build relationships and understand their needs. The shipping industry connects the Northeast with the wider Northwest Atlantic and Arctic, so it will be a particularly important target for engagement as we connect internationally over the U.N. Decade of Ocean Science. This could introduce prospects for new funding, either from the industry itself or other sources.

E. Milestone Schedule.

The milestones that we have defined to achieve the goals and objectives outlined in section B are listed in Table 1. In order to sustain our effective and reliable observing system, multiple milestones related to governance and management, operations, DMAC, modeling, and engagement must be met annually. Over the first three years of the five-year cycle, there will be several key milestones related to deployment of new assets, including water level and other coastal monitoring stations, passive acoustic recorders, HFR stations, and the Scotian Shelf Edge buoy. During those early years, we will also conduct important planning processes related to efficiency and resilience of the buoy network, increasing glider deployments, and diversity, equity, and inclusion. In Year 1 and Year 4, we will update our organizational strategic plans

[35] http://www.necan.org/industry-working-group

based on a Master Plan to be developed before the five-year cycle begins. We expect pioneering new partnerships focused on emerging industries and promoting diversity to take shape during the early years and to become fully active in later years. We expect to see particular growth of our DMAC and modeling subsystems as a result of the increased investments we will make, resulting in integration of a wider array of data, exciting new data products, and improvements in model resolution, accuracy, and timeliness. To achieve this ambitious agenda, it will be essential to recruit and onboard new staff early in the five-year cycles so they can quickly contribute to shepherding the growth of our systems.

F. Project Budget.

Allocation of resources among subsystems at different funding tiers is outlined in section D and the full budget breakdown with accompanying narrative is provided in Appendix **a**. An overall budget summary by major cost categories is as follows:

	Year 1	Year 2	Year 3	Year 4	Year 5	TOTAL
a. Personnel	437,033	458,886	481,833	505,925	531,220	**2,414,897**
b. Fringe	157,201	165,061	173,315	181,981	191,080	**868,638**
c. Travel	69,159	71,234	73,372	75,573	77,840	**367,178**
d. Equipment	500,000	420,000	420,000	420,000	459,000	**2,219,000**
e. Supplies	25,000	25,750	26,523	27,319	29,139	**132,731**
f. Contractual						
g. Construction						
h. Other	4,591,355	4,689,717	4,682,751	4,639,180	4,568,902	**23,171,905**
i. Total direct	5,779,748	5,830,648	5,857,794	5,849,978	5,856,181	**29,174,349**
j. Indirect	199,165	150,571	133,677	149,478	143,814	**776,705**
k. TOTAL	5,978,913	5,981,219	5,991,471	5,999,456	5,999,995	**29,951,054**
Subawards are included in “Other” above	4,023,505	4,085,427	4,231,319	4,080,901	4,099,224	**20,520,376**

We pass through approximately 80% of the NERACOOS budget outside of the organization, including all equipment costs (d; our new Buoy Replacement Fund), the majority of other expenses (h; subawards), and a portion of travel (c). We have strived to allocate funds in ways that sustain and build resilience into systems that have matured and are valued by users, while bringing in new operators to help us expand in new directions. We aim to diversify our partners and the communities we serve, observe the ocean in new ways and new places, and deepen the connections between NERACOOS and observing systems at national and international scales.

The remaining 20%, comprising all personnel (a), fringe (b), supplies (e), and indirect (j) costs; the majority of travel costs (c); and a portion of other costs (f), is invested in the people, systems, and resources needed to sustain an organization that can effectively implement IOOS in the Northeast. We need to expand our internal capacity while increasing diversity and cohesiveness, and ensure that every member of our staff feels valued, has opportunities for growth, and remains challenged without being strained.

By supporting this agenda, NERACOOS can set an example of a modern and responsive Regional Association, while continuing to bring the vision of U.S. IOOS to life.

Appendix d: Tables & Figures

Table 1. Schedule of milestones for NERACOOS over 2021-2026.

Milestones	Related goals & objectives	Y1	Y2	Y3	Y4	Y5
Governance & Management Subsystem						
Develop 3-year strategic plans based on 10-year Master Plan	5d, 6b, 6c, 6e	X			X	
Conduct annual financial audits	6g	X	X	X	X	X
Hire & onboard two new positions	6a, 6b, 6c	X	X			
Provide DEI training for staff & develop action plan	6b, 6c	X				
Quarterly Board meetings + committee meetings as needed	5a, 5b, 5c, 6c					
Adapt Board composition & activities to promote DEI	5a, 5b, 5c, 6c	X	X	X	X	X
Continue annual Operators Workshops	5a, 5b, 6d	X	X	X	X	X
Participate in IOOS Program Office & IOOS Assn. activities	3a, 4c, 6d	X	X	X	X	X
MOUs to codify new industry partnerships	1a, 1d, 5c, 6f	X	X	X	X	X
Attain RICE recertification	6h		X	X		
Observing Subsystem						
Fixed platforms						
Buoys						
Maintain & operate regional buoy network	1a, 1b, 1e	X	X	X	X	X
Audit of gaps, efficiencies & opportunities	1a, 1b, 1e, 6g	X	X			
Pilot new coastal network targeted at aquaculture operators	2c, 5c	X	X	X	X	X
Install new Scotian Shelf Edge buoy	1a, 1e, 5d		X			
Other fixed platforms						
Maintain & operate network of fixed platform	1d, 1e, 2a, 2b	X	X	X	X	X
Install new water level sensors at priority locations	1d, 1e, 2a, 2b	X	X	X	X	X
Install Downeast Maine coastal stations	1d, 1e, 2a, 6c	X	X	X		
Install rocky intertidal temperature microsensors	3a, 3b	X	X			
Install pH sensors at NERR sites & Mass. Bay/Cape Cod Bay	2c	X	X			
Install PAM recorders & develop soundscape baseline	3a, 3c	X	X	X	X	X
Mobile platforms						
Gliders						
Continue & expand Gulf of Maine deployments	1d, 1e, 3c	X	X	X	X	X
Develop regional glider strategy	1d, 1e, 3c	X	X			
Initiate new Southern New England deployments	1d, 1e, 3c			X	X	X
Vessel-based						
Continue ISMN & AZMP surveys	1d, 1e, 3a	X	X	X	X	X
Coordinate plankton observing (ISMN, AZMP, CPR, NASA)	3a, 4b, 5b	X	X	X	X	X
Initiate new sensor & drifter deployments through eMOLT	1d, 1e, 5a, 5b	X	X	X	X	X
Remote sensing						
High-frequency radar						
Maintain & operate existing regional HFR network	1c, 1e, 6d	X	X	X	X	X
Install new Gulf of Maine station near Portland, Maine	1c, 1e			X		
Install two new stations on Long Island Sound	1c, 1e	X		X		

Milestones	Related goals & objectives	Y1	Y2	Y3	Y4	Y5
Satellite-based						
Delivery of customized satellite data products	1d, 3a, 4b	X	X	X	X	X
Data Management & Cyberinfrastructure Subsystem						
Maintain & enhance NERACOOS Data Assembly Center	4a, 4b	X	X	X	X	X
Integrate data from external sources (e.g., CPR, industry)	4a, 4b, 5b, 5c	X	X	X	X	X
Collaborate with national & regional DMAC activities	4a, 4b, 4c, 6d	X	X	X	X	X
Maintain existing & develop new data products	4b, 5a, 5b, 5c	X	X	X	X	X
Refresh & upgrade the NERACOOS website	4b, 5a, 5b, 5c		X			
Modeling & Analysis Subsystem						
Produce 5-day hourly forecasts every 24 hours using NECOFS	1e	X	X	X	X	X
Nest new version of FVGOM within Global FVCOM	1e	X	X			
Continue operations of LIS-FVCOM	1e, 2a	X	X	X	X	X
Develop wind turbine subdomain for FVCOM	1e, 5c, 6f			X	X	X
Continue operations of surface wave model WW3	1e	X	X	X	X	X
Support development of STPS as directed by IOOS PO	1e, 6d	X	X	X	X	X
Include estuarine features within coastal inundation model	1e, 2a	X	X			
Expand high-resolution coastal inundation model to entire NE	1e, 2a			X	X	X
Engagement Subsystem						
Attend key conferences, workshops & engagement events	4b, 5a, 5c, 6c	X	X	X	X	X
Implement DEI strategy (following staff training)	5a, 5b, 6c		X	X	X	X
Coordinate ISMN activities	3a, 3b, 5a, 5b	X	X	X	X	X
Coordinate NECAN activities	2c, 5a, 5b, 5c	X	X	X	X	X
Manage and grow the OAIE	2c, 5a, 5c	X	X	X	X	X
Implement Wind Energy Collaboration Fund	5c, 6f	X	X	X	X	X
Implement Aquaculture Collaboration Fund	2c, 5c, 6f		X		X	
Define & fill role(s) in the U.N. Decade of Ocean Science	5d, 6f	X	X	X	X	X

Table 2. NERACOOS Board of Directors for 2021. Officers (President, Vice President, Secretary, and Treasurer) comprise the Executive Committee. Other committee appointments are indicated.

Director	Affiliation
Larry Alade*	*NOAA Northeast Fisheries Science Center*
Nicole Bartlett*	*NOAA North Atlantic Regional Collaboration Team*
Todd Callaghan	*Massachusetts Coastal Zone Management*
Pamela DiBona	*Massachusetts Bays National Estuary Program*
Shayla Fitzsimmons	*Canada IOOS Atlantic*
Diane Foster	*University of New Hampshire*
Janet Freedman *Finance Committee Chair*	*Rhode Island Coastal Resources Management Council*
Jason Goldstein *Nominating Committee Chair*	*Wells National Estuarine Research Reserve*
Dave Hebert	*Bedford Institute of Oceanography*
Regina Lyons* *Nominating Committee*	*Environmental Protection Agency*
Rhonda Moniz *Secretary, Nominating Committee*	*Woods Hole Group*
Todd Morrison	*Woods Hole Group*
Andy Pershing	*Climate Central*
Tom Pham	*Massachusetts Maritime Academy*
Thomas Taylor	*Cooke Aquaculture, Inc.*
David Townsend	*University of Maine*
John Trowbridge *President, Finance Committee*	*Woods Hole Oceanographic Institution*
Philip Trowbridge *Vice President*	*Connecticut Dept. of Energy & Environmental Protection*
David Ullman	*University of Rhode Island*
Michael Whitney	*University of Connecticut*
Chris Williams *Treasurer, Finance Committee*	*New Hampshire Dept. of Environmental Services*
Carl Wilson	*Maine Department of Marine Resources*

**Employees of federal agencies are non-voting members per agency rules.*

Table 3. IOOS core variables and the type of NERACOOS assets that measure or model the core variables.

IOOS Core Variables	Fixed			Mobile		Remote		Models
	Mooring	Water Level	Other	Gliders	Other	HFR	Satellite	
Bathymetry								
Bottom character								
Currents	X		X	X	X	X		X
Heat flux								X
Ice distribution								
Salinity	X		X	X	X			X
Sea level		X						X
Surface waves	X							X
Stream flow		X						X
Temperature	X		X	X	X		X	X
Wind speed and direction	X		X					X
Acidity	X		X		X			X
Colored dissolved organic matter	X							
Contaminants								
Dissolved nutrients	X		X	X	X			X
Dissolved oxygen	X			X	X			X
Ocean color	X						X	
Optical properties	X			X				
Pathogens			X		X			
Partial pressures of CO2	X		X		X			X
Total suspended matter	X							X
Biological vital rates								
Coral species and abundance								
Fish species and abundance			X					
Invertebrate species and abundance			X					
Marine mammal species and abundance	X		X	X	X			X
Microbial species, abundance, and activity			X		X			
Nekton diet								
Phytoplankton species and abundance			X		X			X
Sea birds species and abundance								
Sea turtles species and abundance								
Submerged aquatic vegetation species and abundance								
Sound	X		X	X				
Zooplankton species and abundance					X			X

Table 4. NERACOOS funded observing and modeling assets, the varaibles that they measure/model, and the organizatgion that operates the assets.

Fixed Stations - Moorings with NOAA ID	Variables Measured	Operator
A01 Massachusetts Bay- 44029	Wind Speed/Direction, Barometric Pressure, Air Temperature, Visibility, Wave Height/Period/Direction, Water Temperature, Salinity, Current Speed/Direction, Dissolved Oxygen, Chlorophyll, Turbidity	UMaine
B01 Western Maine Shelf- 44030	Wind Speed/Direction, Barometric Pressure, Air Temperature, Visibility, Wave Height/Period/Direction, Water Temperature, Salinity, Current Speed/Direction	UMaine
E01 Central Maine Shelf- 44032	Wind Speed/Direction, Barometric Pressure, Air Temperature, Visibility, Wave Height/Period/Direction, Water Temperature, Salinity, Current Speed/Direction	UMaine
F01 Penobscot Bay- 44033	Wind Speed/Direction, Barometric Pressure, Air Temperature, Visibility, Wave Height/Period/Direction, Water Temperature, Salinity, Current Speed/Direction	UMaine
I01 Eastern Maine Shelf- 44034	Wind Speed/Direction, Barometric Pressure, Air Temperature, Visibility, Wave Height/Period/Direction, Water Temperature, Salinity, Current Speed/Direction	UMaine
M01 Jordan Basin- 44037	Wind Speed/Direction, Barometric Pressure, Air Temperature, Visibility, Wave Height/Period/Direction, Water Temperature, Salinity, Current Speed/Direction, Nitrate	UMaine
N01 Northeast Channel- 44024	Wind Speed/Direction, Barometric Pressure, Air Temperature, Visibility, Wave Height/Period/Direction, Water Temperature, Salinity, Current Speed/Direction	UMaine
Great Bay	Wind Speed/Direction, Barometric Pressure, Air Temperature, Visibility, Hyperspectral Surface Irradiance, Downwelling Irradiance, Upwelling Irradiance, Water Temperature, Salinity, pH, pCO2, Dissolved Oxygen, Nitrate, Phosphate, Chlorophyll, CDOM	UNH
C02 Appledore Island- 44073	Wind Speed/Direction, Air Temperature, Water Temperature, Salinity, pCO2, Dissolved Oxygen, Chlorophyll, CDOM Fluorescence, Turbidity	UNH
Jeffrey's Ledge- 44098	Wave Height/Period/Direction, Water Temperature	UNH
Cape Cod Bay- 44090	Wave Height/Period/Direction, Water Temperature	WHG
Execution Rocks- 44022	Wind Speed/Direction, Barometric Pressure, Air Temperature, Relative Humidity, Water Temperature, Salinity, Current Speed/Direction, Dissolved Oxygen, PAR, Nitrate	UConn
Western Long Island Sound- 44040	Wind Speed/Direction, Barometric Pressure, Air Temperature, Relative Humidity, PAR, Wave Height/Period/Direction, Water Temperature, Salinity, Current Speed/Direction, Dissolved Oxygen, Phosphate, Nitrate, pCO2, Turbidity	UConn
Central Long Island Sound- 44039	Wind Speed/Direction, Barometric Pressure, Air Temperature, Relative Humidity, PAR, Wave Height/Period/Direction, Water Temperature, Salinity, Current Speed/Direction, Dissolved Oxygen, Nitrate, pCO2, Turbidity	UConn
Fixes Stations - Other		
UNH Coastal Marine Lab- CMLN3	Wind Speed/Direction, Air Temperature, Air Pressure, Water Temperature, Salinity, Dissolved Oxygen, Chlorophyll, PAR, pCO2, pH, Total Alkalinity	UNH
Saco Tide Gauge	Sea Level	USGS
Hampton Tide Gauge	Sea Level	Charybdis
Gloucester Tide Gauge	Sea Level	Charybdis
Scituate Tide Gauge	Sea Level	Charybdis
Cape Cod Canal Current Profiler- ca0101	Current Speed/Direction	WHG
Greenwich Bay Dock Nutrient Sensors	Nitrate, Phosphate	URI
Mobile Stations		
WHOI Glider	Sound (Marine Mammals), Temperature, Salinity, Chlorophyll, Turbidity	WHOI

Fixed Stations - Moorings with NOAA ID	Variables Measured	Operator
UMaine Glider	Temperature, Salinity, Chlorophyll, Turbidity, Nitrate, Currents	UMaine
AZMP Vessel Based Monitoring	Temperature, Salinity, Chlorophyll, Dissolved Nutrients, Phytoplankton, Zooplankton, pH, pCO2	
ISMN/MBON Vessel Based Monitoring	Temperature, Salinity, Chlorophyll, Dissolved Nutrients, Optical Properties, pH, Bacteria, Phytoplankton, Zooplankton, DNA Composition	UNH, UMaine
Remote Sensing		
Cape St. Mary's HFR	Surface Current Speed/Dirction	UMaine
Grand Manan HFR	Surface Current Speed/Dirction	UMaine
Green's Island HFR	Surface Current Speed/Dirction	UMaine
Scituate HFR	Surface Current Speed/Dirction	WHOI
Nauset HFR	Surface Current Speed/Dirction	WHOI
Gloucester HFR	Surface Current Speed/Dirction	WHOI
AVHRR Satelite Imagery	Sea Surface Temperature	UMaine
Models		
Northeast Coastal Ocean Forecast System	Wind Speed/Direction, Air Temperature, Air Pressure, Air Humidity, Heat Flux, Sea Level, Wave Height/Period/Direction, Current Speed/Direction, Water Temperature, Salinity, Icing, Coastal Inundation	UMassD
Wave Watch III	Wave Height/Period/Direction	BIO
Short Term Prediction System	Surface Current Speed/Direction	UConn

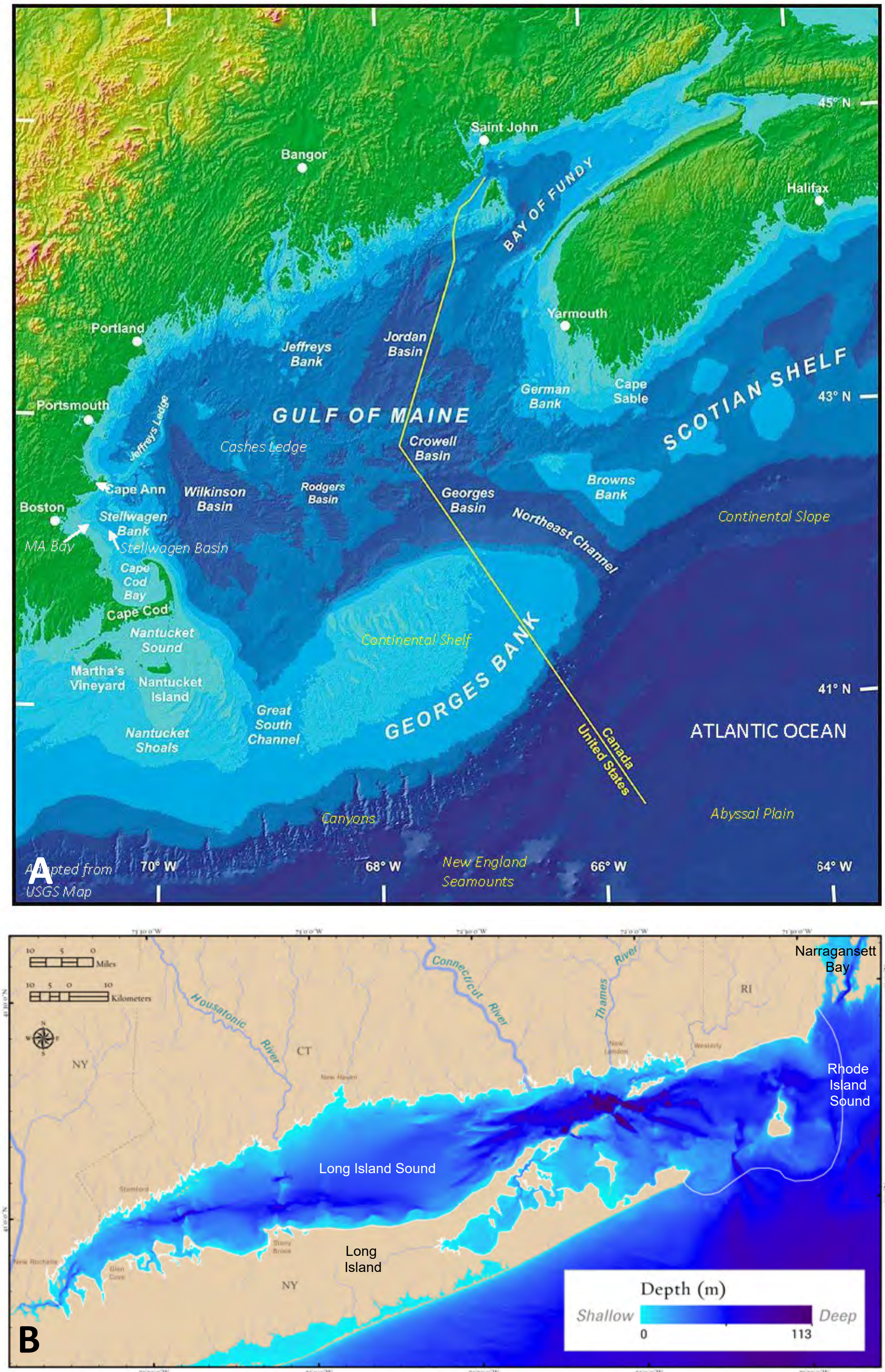


Figure 1. Geography and bathymetry of the Gulf of Maine, Georges Bank, and Scotian Shelf (A), and Long Island Sound and Rhode Island Sound (B). (A from NOAA; B modified from The Nature Conservancy)

Figure 2. Components of the NERACOOS observing system and system operators in 2020. Over the next five years, we will add new operators to the system, including the Maine Department of Marine Resources, Maine Center for Coastal Fisheries, Passamaquoddy at Pleasant Point, National Estuarine Research Reserves, Center for Coastal Studies, Northeastern University, Stellwagen Bank National Marine Sanctuary, Northeast Fisheries Science Center, Gulf of Maine Lobster Foundation, and University of Hartford.

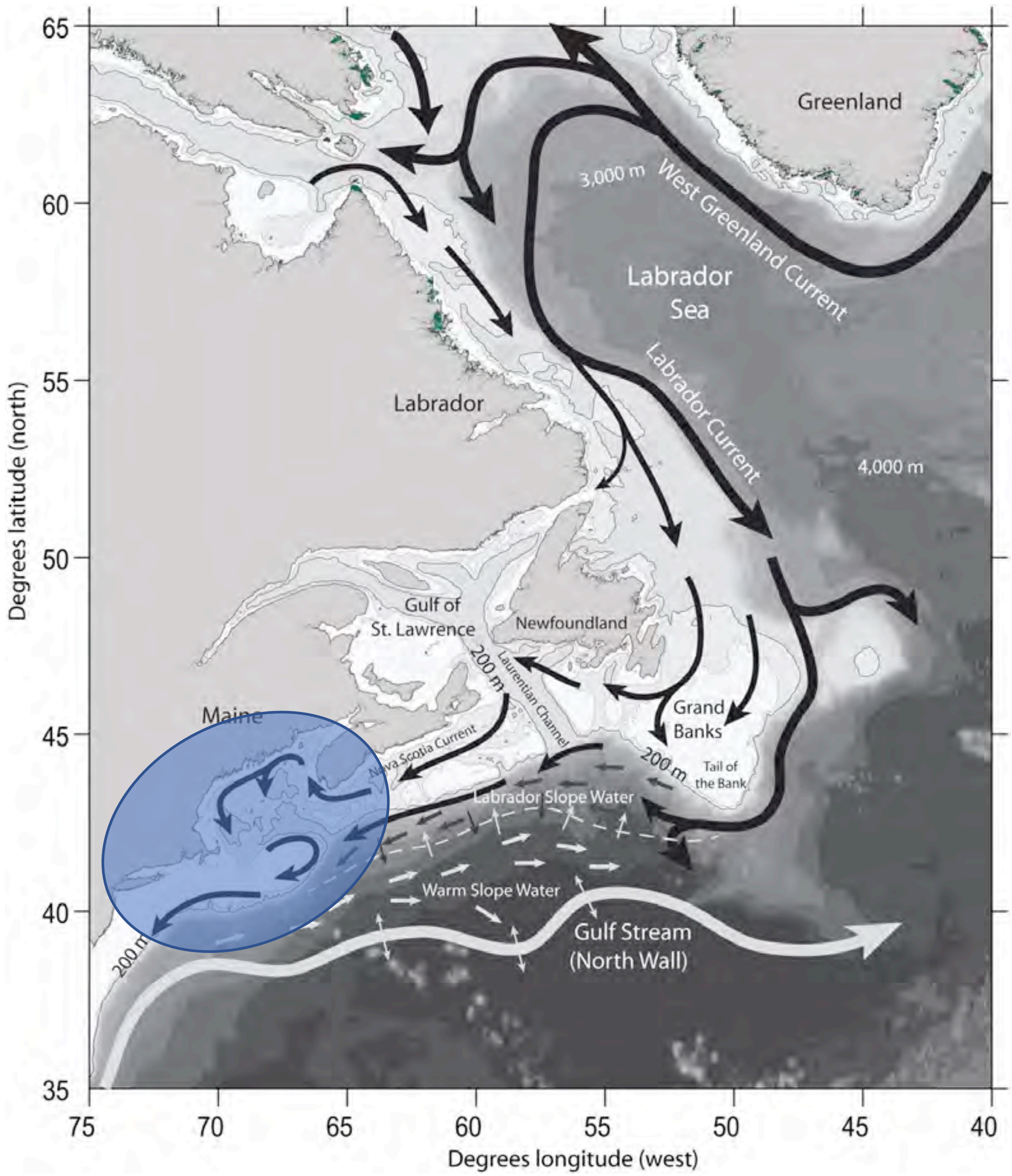
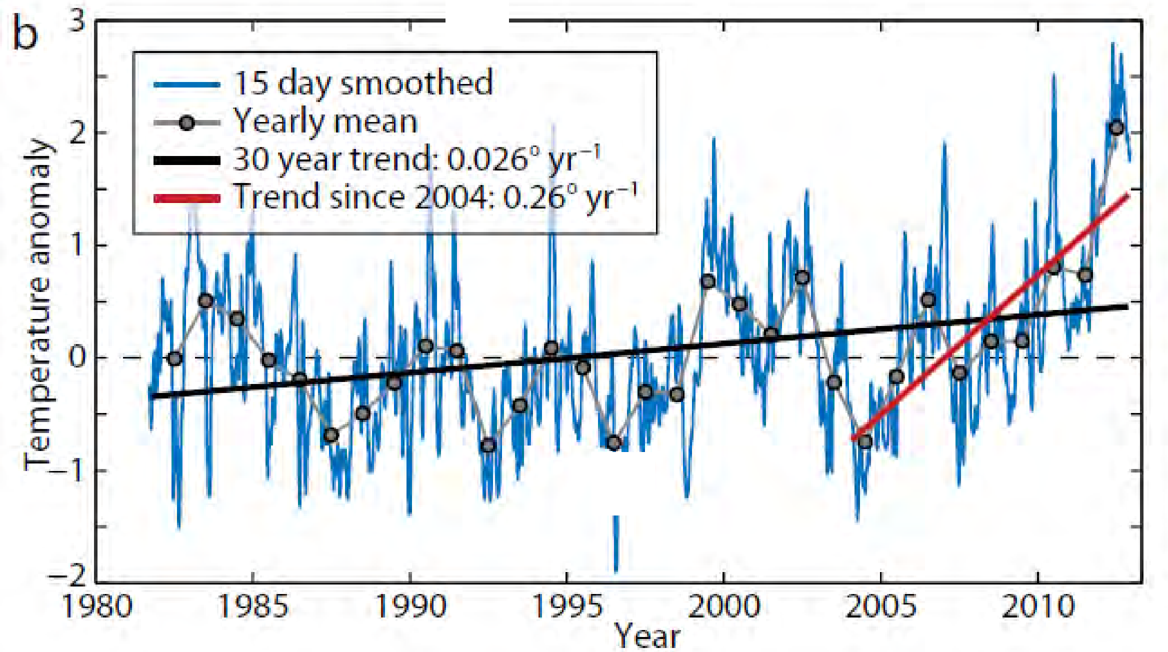
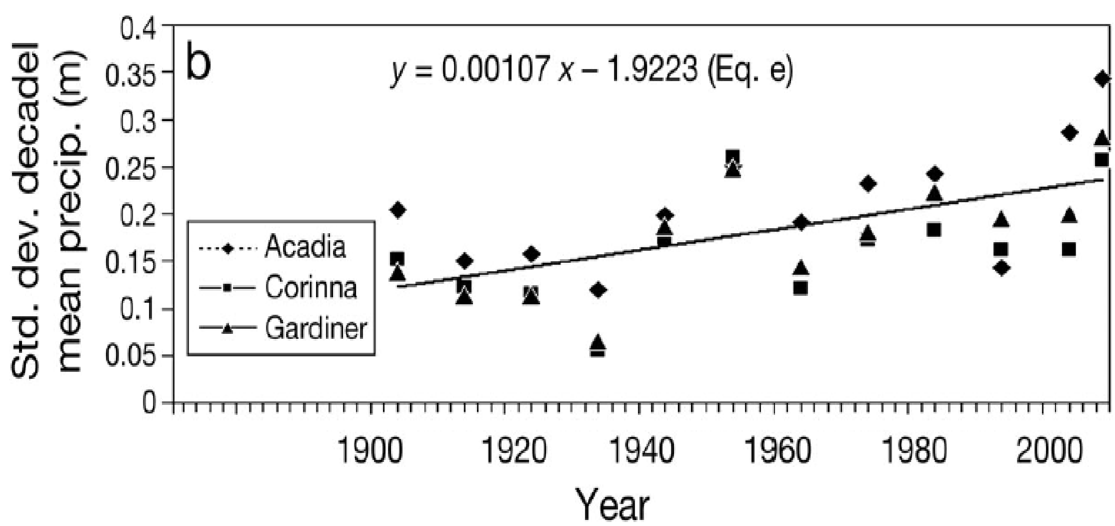


Figure 3. Location of the NERACOOS focal region (shaded blue) within the major current systems of the Northwest Atlantic. (modified from Townsend et al. 2015. *Journal of Marine Research*. doi:10.1357/002224015815848811)

Figure 4. Evidence of increasing climate change impacts and vulnerability in the coastal and ocean waters of the Northeastern United States:

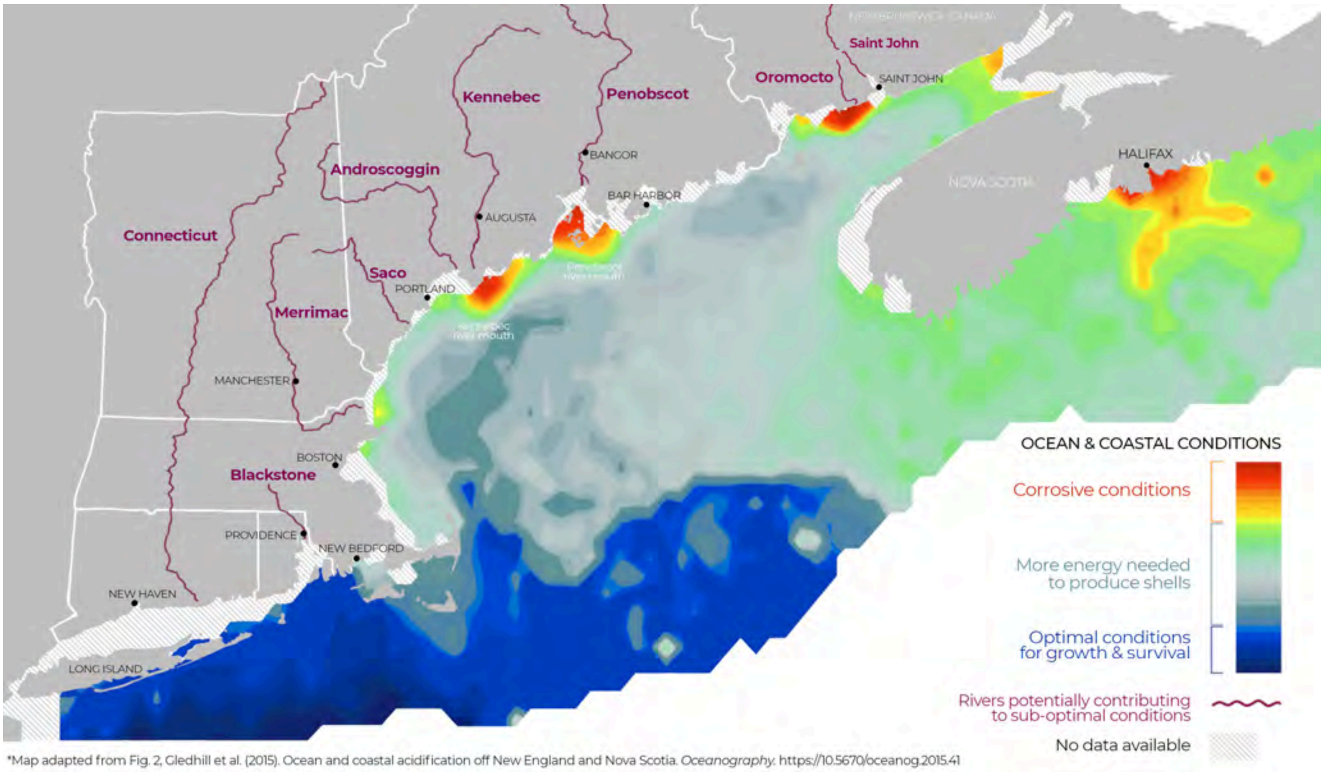


A. Gulf of Maine sea surface temperatures from 1980-2012 showing multidecadal increasing trend and accelerating rate in recent years.
(Mills et al. 2013. *Oceanography*. doi:10.5670/oceanog.2013.27)



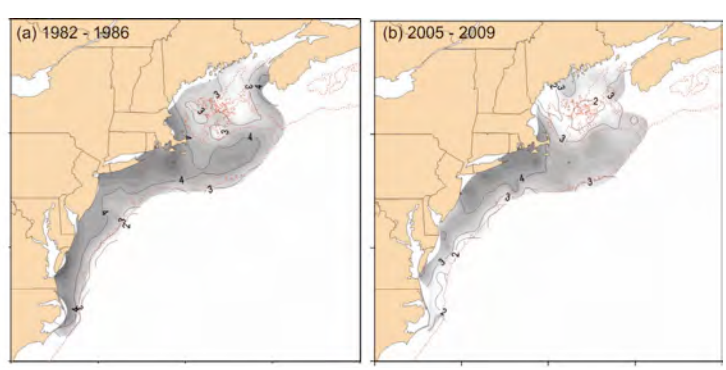
B. Long-term increase in variability in precipitation in the Gulf of Maine, resulting in increasing frequency of both flood and drought events.
(Balch et al. 2012. *Mar. Ecol. Prog. Ser.* doi:10.3354/meps09555*)*

Figure 4. continued.



C. Mean monthly aragonite saturation in the Gulf of Maine and Scotian Shelf sits close to the thermodynamic threshold (1.0), below which calcification ceases. Changes in salinity and pH might cause this threshold to be crossed
(Adapted with permission from Gledhill et al. 2015. *Oceanography.* doi:10.5670/oceanog.2015.41)
https://vocalindustry.info

D. Decreases in zooplankton abundance *(Pseudocalanus)* from the 1980s to 2000s due to changing environmental conditions. (Friedland et al. 201s. *Progress in Oceanography.* doi:10.1016/j.pocean.2013.05.011)



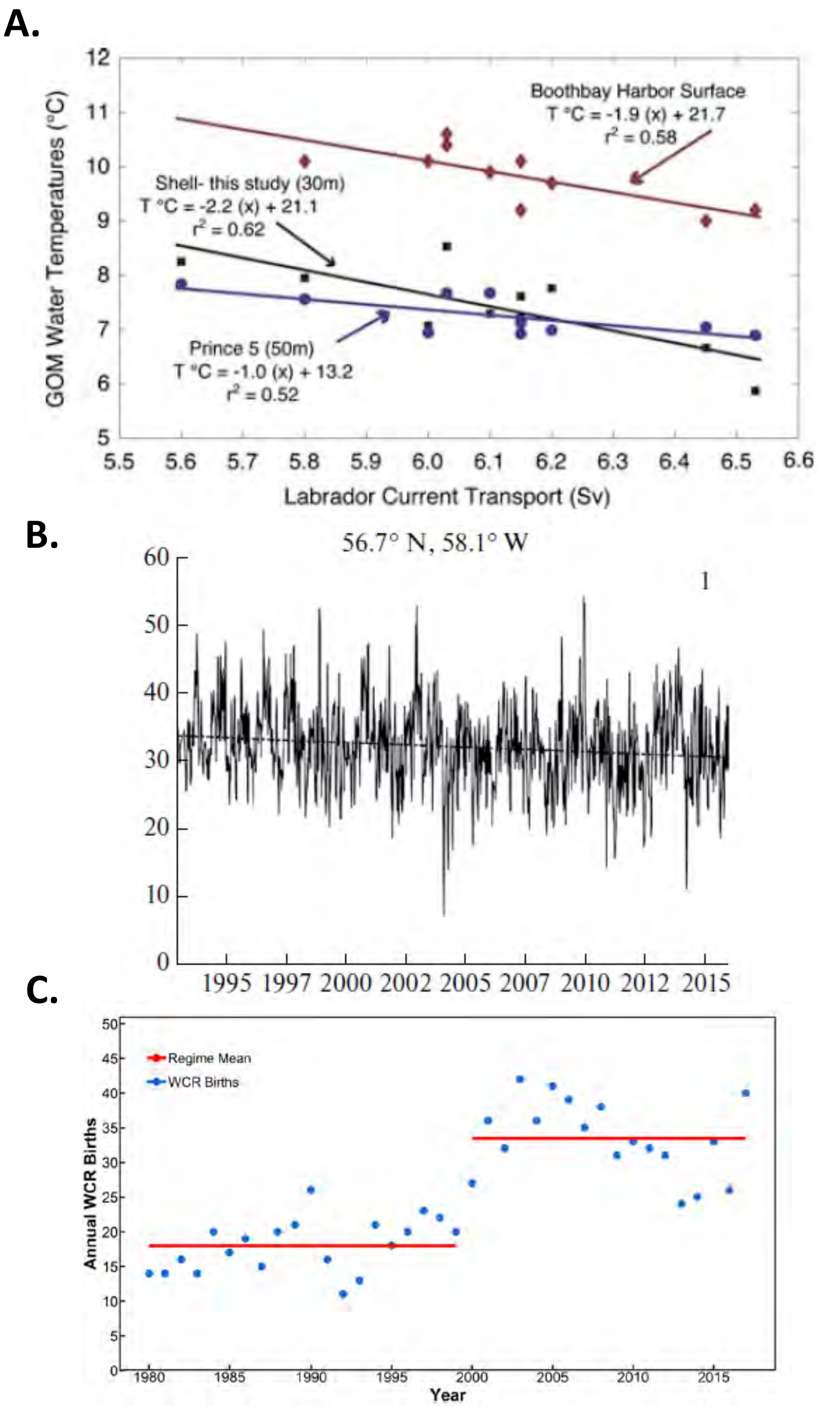


Figure 5. Ocean temperatures in the Gulf of Maine decline with increasing strength of the Labrador Current (A), which has become progressively weaker over the past two decades (B). Meanwhile, increasing frequency of warm core rings (WCRs) from the Gulf Stream is bringing more warm water to the region. (A. Wannamaker et al. 2008. *Climate Dynamics*. doi:10.1007/s00382-007-0344-8; B. Beloenko et al. 2019. *Izvestiya Atmospheric and Oceanic Physics*. doi: 10.1134/S0001433818090074; C. Gangopadhyay et al. 2019. *Nature Scientific Reports*. Doi:10.1038/s41598-019-48661-9)

Figure 6. Fixed observing platforms and glider deployments currently supported by NERACOOS. Existing operators are identified in Figure 3 (with new operators listed in the caption). Over the next five years, we aim to add a new buoy at the edge of the Scotian Shelf, passive acoustic recorders in the Gulf of Maine, new water level stations and rocky intertidal temperature microsensors at priority locations along the coast, and new coastal oceanographic and water quality stations in Downeast Maine, at National Estuarine Research Reserves, and in Massachusetts Bay and Cape Cod Bay. We also aim to initiate new glider deployments in Long Island Sound and Rhode Island Sound.

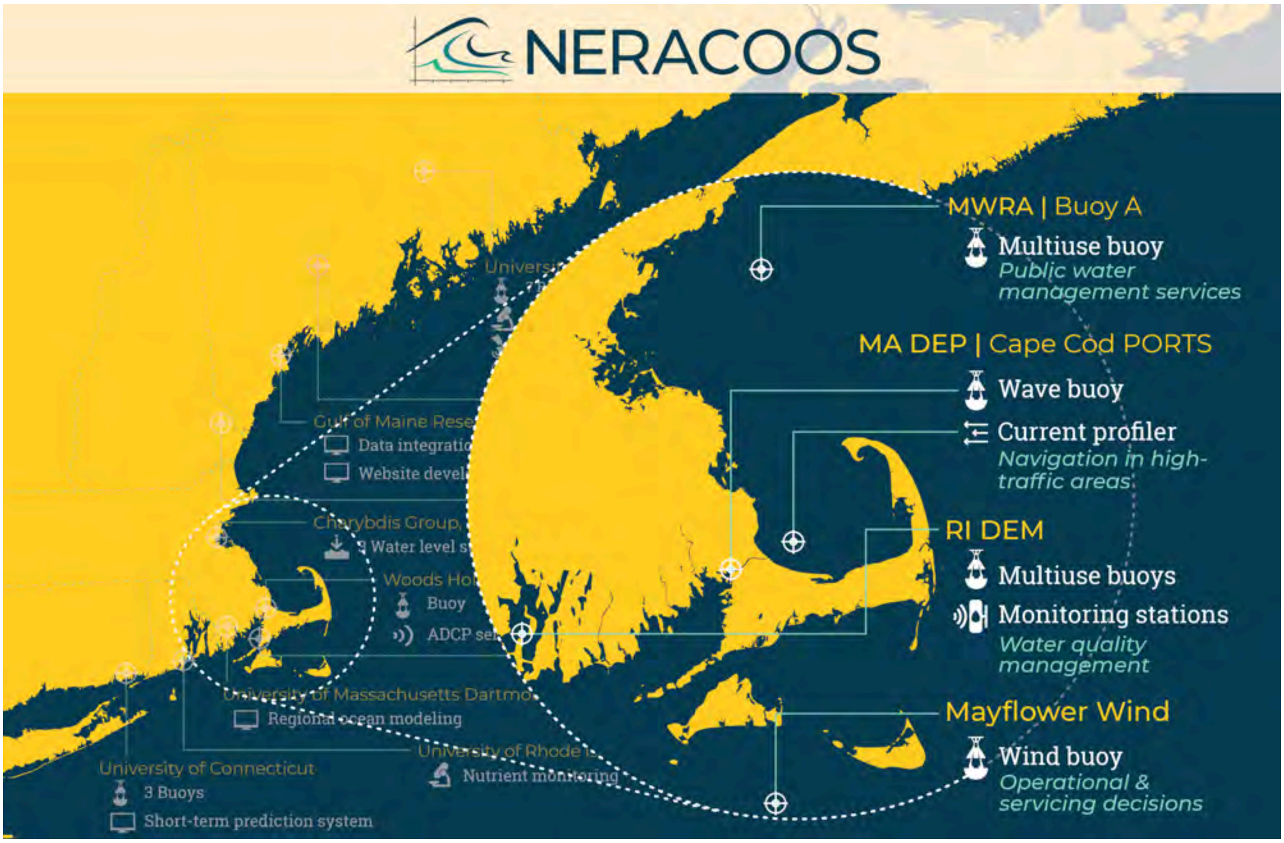


Figure 7. Several important assets in the NERACOOS observing system are supported through cost-sharing arrangements with state agency and private sector users, which include capital costs, operations and maintenance, data management, or a combination. (MWRA: Massachusetts Water Resources Authority; MA DEP: Massachusetts Department of Environmental Protection; RI DEM: Rhode Island Department of Environmental Management; RI DEM is the lead agency for the Narragansett Bay Fixed Station Monitoring Network that also includes the University of Rhode Island, Narragansett Bay Commission, Narragansett Bay National Estuarine Research Reserve, MA DEP, and Narragansett Bay Estuary Program)

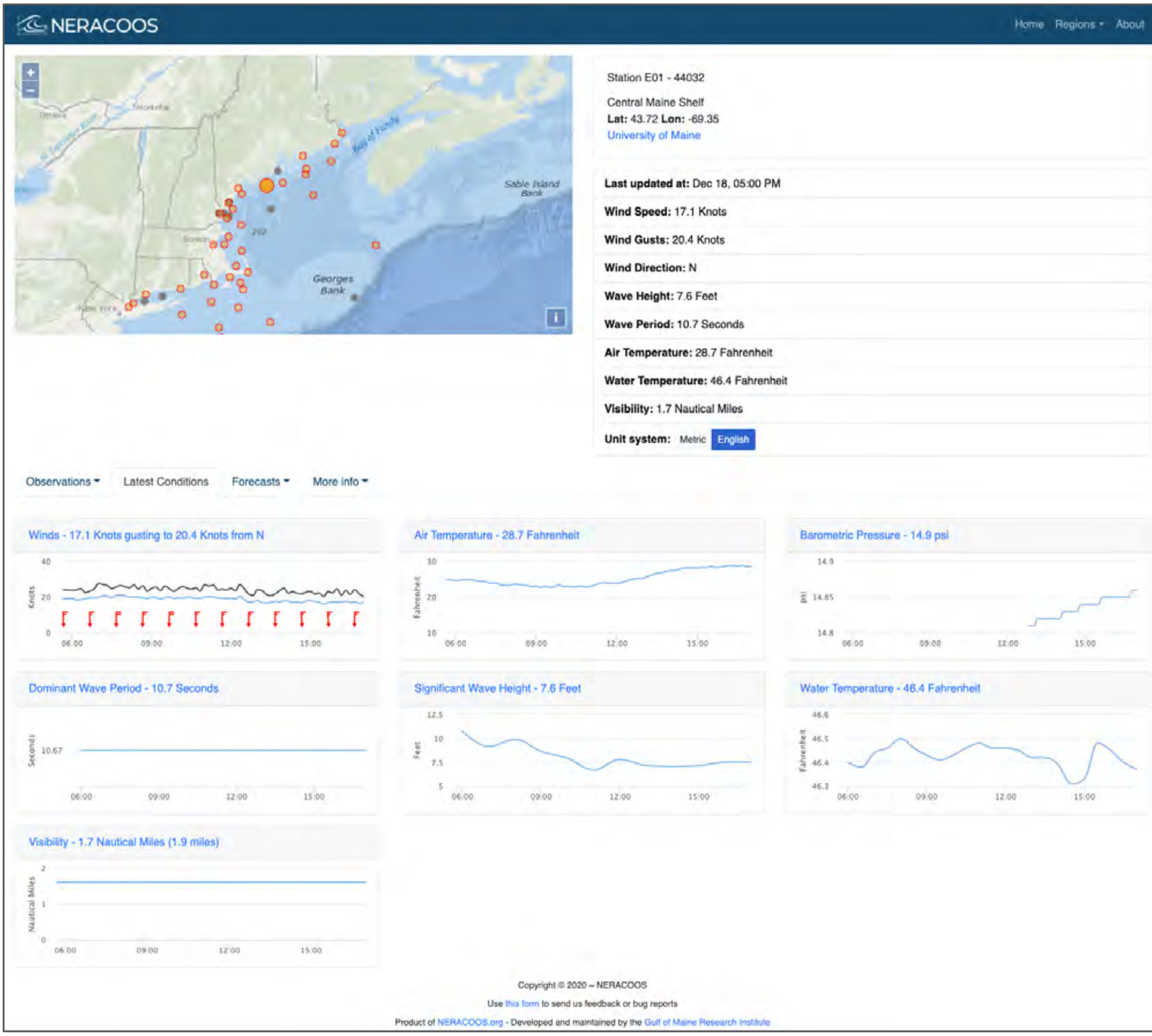


Figure 8. The NERACOOS Mariners' Dashboard real-time buoy data interface. The inset map shows the location of all buoys accessible through the system, including those managed by NERACOOS and our operators, and those managed by other entities such as the National Data Buoy Center and the Ocean Observatories Initiative.

Figure 9. Existing and planned high-frequency radar stations in the Northeast region. New installations will help to fill coverage gaps in Long Island Sound (in partnership with MARACOOS) and the coast of Southern Maine. The Northern Gulf of Maine stations require maintenance following service delays due to the pandemic.

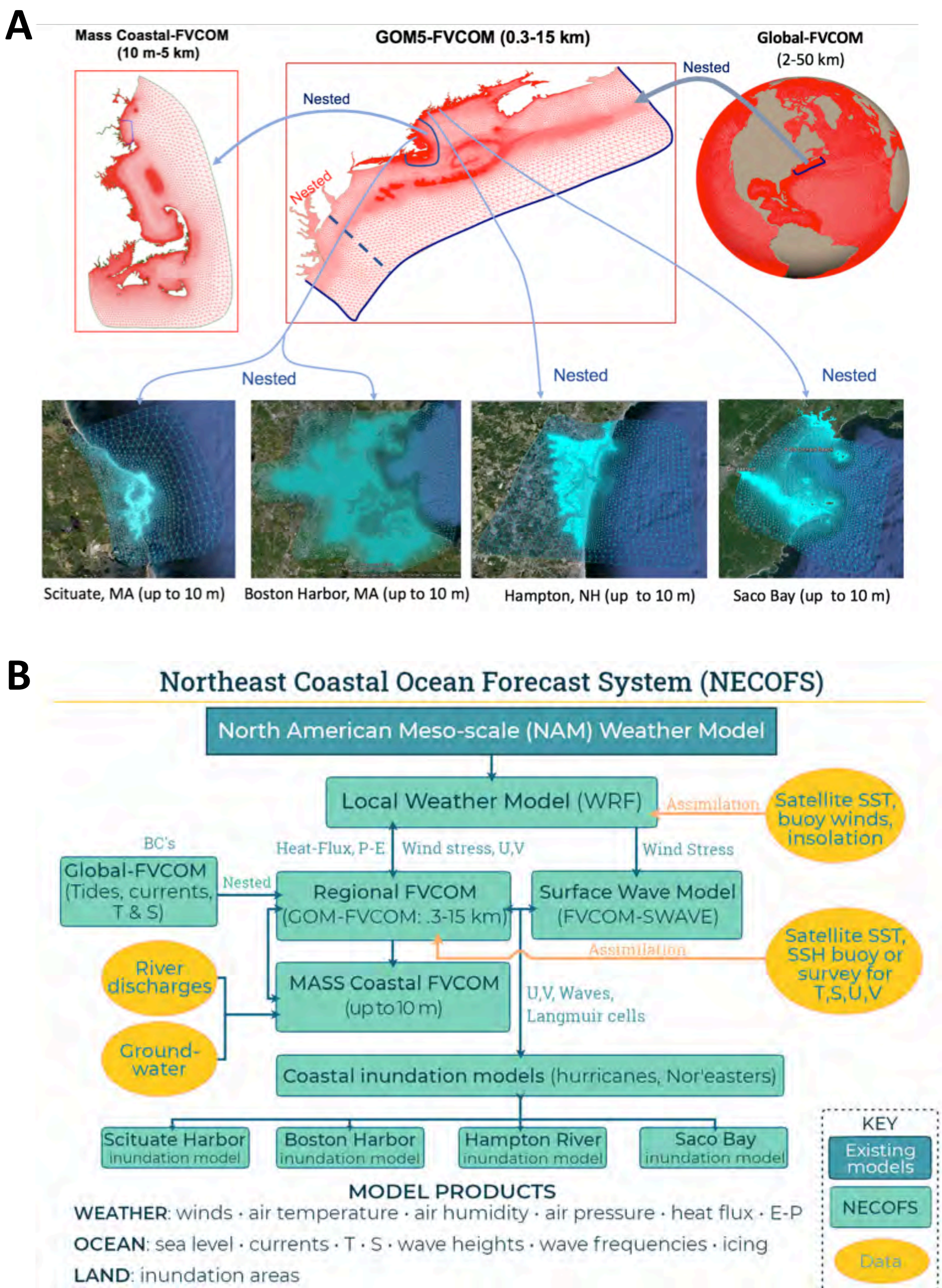


Figure 10. Nested domains of the Northeast Coastal Ocean Forecast System (NECOFS) with detailed grids overlaying satellite images of selected coastal areas in the Western Gulf of Maine (A), and schematic of components of NECOFS and their relationships to one another (B).