The Ongoing Evolution of Ocean Observing Systems: Aligning with Regional Priorities

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***Abstract*—Ocean observing systems, including the Great Lakes, are critical for monitoring environmental conditions that impact humans. A network of Regional Associations has developed observing systems that are responsive to regional priorities and meet national data management standards. As part of the continued evolution of these observing systems, there are more pan-regional coordinated projects moving forward that are providing societal benefits across many sectors.**

***Index Terms*—ocean observing, data management, pan-regional, community engagement**

I. Introduction

Ocean observing is essential to understanding how changing environmental conditions impact humans, from daily weather patterns to harmful algal blooms to efficient maritime shipping. Ocean observing systems are designed to best capture the information that is of highest value to customers based on their information needs. The value chain is determined and evaluated through high level governance groups, frameworks, and funding priorities.

The Global Ocean Observing System (GOOS) provides an international governance structure, while various nodes, such as the U.S. Integrated Ocean Observing System (IOOS), provide measurements and regional data services. The U.S. IOOS is comprised of 11 IOOS regional associations (RAs) and 17 federal agencies as authorized by Congress [1], [2]. The IOOS RAs span all coastal waters of the United States, including the Great Lakes, U.S. territories, and the freely associated states (Fig. 1; Table I). The RAs have maintained regionally fit-for-purpose observing systems for ∼20 years [3], while also working towards integration to address broader pan-regional needs. Each region is driven by distinct environmental, socioeconomic, and resource management priorities. The RAs are coordinated by both the National Oceanic and Atmospheric Administration (NOAA) IOOS Program Office and a non-profit, the IOOS Association.

TABLE I
Regional Associations and their Acronyms

Regional Association Name	Acronym
Alaska Ocean Observing System	AOOS
Caribbean Coastal Ocean Observing System	CARICOOS
Central & Northern California Ocean Observing System	CeNCOOS
Great Lakes Observing System	GLOS
Gulf of America Coastal Ocean Observing System	GCOOS
Mid-Atlantic Regional Association Coastal Ocean Observing System	MARACOOS
Northeastern Regional Association of Coastal Ocean Observing Systems	NERACOOS
Northwest Association of Networked Ocean Observing Systems	NANOOS
Pacific Islands Ocean Observing System	PacIOOS
Southern California Coastal Ocean Observing System	SCCOOS
Southeast Coastal Ocean Observing Regional Association	SECOORA

The IOOS RAs have evolved significantly over the last two decades, serving as a critical backbone for sustained and coordinated coastal and ocean observations across the United States [4]. IOOS's mission, to provide quality and accessible ocean, coastal, and Great Lakes data for decision-making,

Fig. 1. Map showing the geographic boundaries of the 11 U.S. Integrated Ocean Observing System (IOOS) Regional Coastal Ocean Observing Systems (RAs). Each RA is responsible for collecting, integrating, and delivering coastal and ocean data specific to its region, supporting local, regional, and national decision-making. The regions include: Alaska (AOOS), Pacific Northwest (NANOOS), Central and Northern California (CeNCOOS), Southern California (SCCOOS), Pacific Islands (PacIOOS), The Gulf (GCOOS), Southeast Atlantic (SECOORA), Caribbean (CARICOOS), Mid-Atlantic (MARACOOS), Northeast (NERACOOS), and the Great Lakes (GLOS).

is increasingly vital in the face of growing maritime and coastal economies, climate dynamics, biodiversity loss, public health concerns, and human impacts on marine ecosystems. Ocean observing plays a central role in informing emergency response, resource management, navigation, fisheries, and environmental protection. While regional diversity has spurred innovation and grassroots community support, it has also paved the way for pan-regional integration. Through shared practices, standardized protocols, and collaborative governance, IOOS has matured into a coordinated network, capable of leveraging individual successes into a recognized national program.

Ocean observing systems include talented scientists, communicators, data managers, field technicians, and engineers. These people are all vital to keeping the deployed infrastructure maintained and the observations flowing to the communities the RAs support. As IOOS has matured and as the RAs have evolved, there are increasingly more opportunities to address pan-regional concerns, such as marine heat, coastal hazards (e.g., flooding), and harmful algal blooms (HABs), which has necessitated standardizing the deployed hardware and the data architecture that supports good decision making. Many of the RAs work together to leverage knowledge, skills, and abilities to grow these pan-regional networks and the adoption of new types of technology and data management systems that support pan-regional collaboration.

II. Growth and Evolution of the Regional Observations

As independent observation networks under the broader IOOS umbrella, each RA has developed and expanded its observing network to meet the needs of its regional stakeholders. For example, in the Great Lakes, drinking water quality is paramount. Biogeochemical sensors are commonly deployed on fixed platforms and are relied upon by water treatment plants to determine if they need to alter their treatment protocols. In hurricane- and typhoon-prone regions, such as the Gulf, Southeast, Caribbean, and Pacific Islands, autonomous underwater gliders monitor ocean heat content, providing critical data that is fed into forecast models to improve model products like hurricane intensity and track forecasts. Alaska and Hawaii have remote coastal villages and islands, making partnerships to leverage sensor deployments crucial to successful monitoring of ocean conditions, tracking of marine organisms, and monitoring of coastal hazards.

The evolution of IOOS regional networks has been shaped by a convergence of environmental, technological, and user-driven factors, along with federal agency mission drivers such as energy development, fisheries management, search and rescue, and weather forecasting. A major catalyst was the Integrated Coastal and Ocean Observation System (ICOOS) Act of 2009 [1], which authorized IOOS, providing legislative legitimacy, national visibility, and additional funding. The IOOS Program Office is charged with meeting the legislative mandates, as well as setting data standards and supporting data management and cyberinfrastructure (DMAC) needs. The IOOS Association (IOOSA) was created in response to the ICOOS Act of 2009. The IOOSA, a non-profit organization, was established to represent and support the RAs, working closely with federal agencies, particularly NOAA, to ensure that regional data needs and capabilities are incorporated into national planning. By bringing the regions together, the IOOSA helps coordinate efforts, secure funding, and promote the use of ocean and coastal data for purposes such as public safety, economic development, and environmental protection.

Increasing threats from climate variability, including sea-level rise, intensified hurricanes, and ocean acidification, have compelled regional systems to expand and adapt their observing capabilities to enhance resilience and preparedness. Technological progress has also played a key role, with improvements in sensor affordability and reliability, the rise of autonomous platforms, artificial intelligence and machine learning algorithms, and innovations in remote data delivery transforming what regional systems can monitor and share. This technical evolution is closely matched by a rise in user demand from sectors such as fisheries management, maritime transportation, and coastal planning, driving the development of tailored, application-ready observation products. Furthermore, IOOS's collaborative model, with strong partnerships among federal agencies, academic institutions, and private industry, has facilitated continuous innovation and diversified the use of ocean observing data.

During the initial development of the RAs in the mid-2000s, an RA may have relied heavily upon one or two types of observing platforms forming their flagship programs. For example, some RAs relied heavily on moored buoys (e.g., NERACOOS, SECOORA, GLOS), while others focused on gliders and high-frequency radars (HF radars; e.g., SCCOOS, CeNCOOS, and MARACOOS). In most cases, the systems were operated by a series of disparate partners and the RA framework was leveraged to create a coherent observing network. By 2010, adoption across all platform types had grown within and across RAs. Additionally, the IOOS program office began establishing quality control tests for real-time oceanographic data (QARTOD) that allowed for expanded confidence and use of data [5]. The adoption and use trajectory continued through 2015 and 2020, with each component of the observation network maturing: fixed platforms and moored buoys became more common across RA and gliders and HF radars reached national scale. After 2020, RA observing systems became more regionally coordinated and increasingly characterized as integrated, networked, and interoperable. Advances in artificial intelligence and adaptive technologies have enabled real-time data fusion and forecasting, ushering in a new era of AI-augmented, predictive ocean observing networks.

Since its inception, the IOOS observing infrastructure has undergone substantial advancement in both the diversity and capability of deployed technologies. Observing platforms common across RAs include moored buoys, underwater gliders, and HF radars. Each of these fills a gap and can serve a multitude of purposes. This advancement has been shaped by critical investments in technology, partnerships, and data infrastructure that strengthened the capacity of each RA. For example:

A. *Buoys and moorings*

Weather and oceanographic buoys have been widely deployed for a variety of purposes across the RAs. Buoys may be equipped with a range of meteorological, water temperature, salinity, and wave sensors. Initial deployments and sites were typically selected for improving safe marine navigation and to improve maritime forecasts. More recently, the expansion of in-water sensors to include biogeochemical parameters, provides data for improved HABs, hypoxia, and ecosystem understanding. Many of the RAs are also incorporating smaller buoys, such as Sofar spotter wave buoys, as well as profiling moorings (e.g., WireWalkers) to capture full water column dynamics, into their observing systems.

In recognition of the value these observing platforms provide and the RA data management structure, NOAA's National Data Buoy Center (NDBC) and other entities now directly ingest data from the RAs instead of individual buoy and mooring operators. NDBC then shares the data through the Global Telecommunications System, making it available to operational elements of the National Weather Service (NWS) and modeling communities, as well as the global weather enterprise.

B. *Gliders*

Gliders are autonomous underwater vehicles (AUVs), that are vital observational systems that provide subsurface measurements of physical and biogeochemical conditions. Their applications have expanded over the past two decades based on regional stakeholder needs and maturation of the technology [6].

Gliders first captured data in coastal storms in 2003 [7] and were used for continuous cross-shore transect monitoring to create detailed climatologies as early as 2005 [8]. Following deployments in the early 2010s, gliders have become essential components of hurricane forecasting, with pan-regional RAs supporting continuous glider deployments from May through November for the Hurricane Gilder effort (more below), as well as informing fisheries management and ecosystem modeling [9], [10]. Gliders are also being outfitted with acoustic receivers to capture sound such as marine mammal vocalizations and acoustic fish tag detections as an alternative to traditional fish surveys [11]. Recent investments are focused on modernizing the fleet through the development and adoption of next generation vehicles capable of carrying expanded sensor payloads to measure key variables like pH, nitrate, irradiance, passive acoustics, and acoustic tag detections.

Notably, in 2014 the IOOS Program Office created a centralized glider Data Assembly Center (DAC) to most effectively support the dissemination of glider data more broadly [12]. Data from gliders are transmitted and standardized via this public platform, which enables quick access to the data by forecasters at the National Hurricane Center and the NWS.

C. High-Frequency Radars

High-frequency radars (HF radars) are land-based systems that derive the speed and direction of ocean surface currents in near real-time. The technology was demonstrated for coastal ocean surface current mapping and was deployed primarily by U.S. universities [13]. Today, HF radars support multiple sectors for coastal management (e.g., water quality), maritime navigation (e.g., port operations), environmental monitoring, military and defense, commercial industries (e.g., fisheries), and U.S. Coast Guard search and rescue operations [14], [15].

IOOS manages the only national HF radar network, which is a credit to the investment in infrastructure and data dissemination for this flagship observing program [16]. Each RA has deployed HF radars to meet these region-specific challenges. Deployments are performed by the RA directly or through regional partners [2]. The national HF radar DAC (https://hfradar.ioos.us/hfrnet) was developed externally to NOAA and was officially transitioned to NOAA in 2025 to help maintain the level of operability that is needed for the use of data.

As the IOOS ocean observing enterprise moves forward, the RAs must highlight the ocean's interconnectedness and emphasize the need to collaborate across regions. This collaboration is essential to effectively address emerging pan-regional issues and for the continued evolution of IOOS and the RAs.

III. Growth and Evolution of the IOOS Network

The evolution of the regional observing networks has progressed through three distinct phases shaped by environmental events, policy shifts, stakeholder needs, and technological advancements. From 2000 to 2010, most RAs originated as independent academic or state-led pilot programs targeting localized concerns such as HABs, fisheries, and port safety, with infrastructure limited to fixed buoys, tide gauges, and sparse HF radar coverage. Between 2010 and 2020, the RAs observing systems expanded and standardized through the integration of AUVs, webcams, and biogeochemical sensors, alongside the modernization of data systems such as the use of specific data servers such as ERDDAP and THREDDS. RA governance systems also matured as stakeholder engagement became more formalized, propelled by events like the Deepwater Horizon oil spill and NOAA's certification requirements [17]. Since 2020, the focus has shifted toward integrated, interoperable networks through collaborative cross-RA projects, such as low-cost buoy deployments for tribal partnerships and coastal webcam networks to support rip current monitoring, coastal process research, and public safety. These cross-RA projects also leverage community science opportunities, fostering the growth in cloud services for data management and the development of AI/ML tools. Despite the regional focus, IOOS RAs increasingly recognize the value of collaboration in tackling transboundary environmental challenges. By leveraging shared infrastructure, expertise, and data systems, these partnerships enhance both efficiency and impact.

A. Projects and initiatives

In the last 3-4 years, RAs have started to increase coordination through pan-regional and national projects like Backyard Buoys, WebCOOS (Webcam Coastal Observation System), hurricane gliders, and a marine heatwave collaboration project.

1) Backyard Buoys: Backyard Buoys is a collaboration started by the Alaska, Pacific Northwest, and Pacific Islands RAs (AOOS, NANOOS, and PacIOOS) to work with local communities to deploy small, low-cost wave sensors. The goal of the project is to put wave data into the hands of local communities through co-designed stewardship plans, data tools, and educational materials [18]. This project is now gaining traction to expand across other regions in the IOOS enterprise, enabling additional RAs to benefit from the tools developed during the pilot phase in the Pacific.

2) WebCOOS: All 11 RAs are participating in WebCOOS by adding coastal web cameras to their fleet of ocean observing sensors. WebCOOS supports the installation and operation of low-cost webcams for coastal monitoring applications, including rip current detection, shoreline change and coastal erosion, beach usage, and flood documentation. WebCOOS cameras can also be used for other applications, including ecological monitoring (i.e. object detection to count seals or leatherback sea turtles) and general viewing and awareness of coastal or maritime conditions. WebCOOS began as a pilot project in the SECOORA region in 2017 [19], grew to include more cameras and a larger geographic footprint from 2020 to 2024, and now is expanding into all 11 RAs in the current national phase of the project. As this monitoring network expands, RAs are working in partnership with the WebCOOS science team, contractors, and local stakeholders and partners to install cameras that meet stakeholder-identified monitoring and observation needs at priority locations in each region. WebCOOS data and imagery are publicly accessible through webcoos.org, providing a repository for coastal observations.

3) Gliders: Tropical cyclones account for 52.8% of the $2.950 Trillion USD in damages from the US Billion Dollar Weather and Climate disasters from 1980-2024 [20], yet are only 16.6% of the number of events. The Mid-Atlantic, Southeast Atlantic, Gulf, Caribbean, and Pacific Island regions

(MARACOOS, SECOORA, GCOOS, CARICOOS, PacIOOS) deploy gliders to monitor subsurface temperature and salinity in hurricane prone regions. These data are provided to the IOOS glider DAC (https://gliders.ioos.us/) in near real-time continuously where they are then ingested into operational ocean models used to initialize hurricane forecasting systems [9], [10]. Organizations whose operational ocean forecasting systems that utilize glider data include NOAA's National Centers for Environmental Prediction, the Naval Research Laboratory, and Mercator Ocean. Autonomous underwater gliders have significantly enhanced the accuracy of hurricane intensity forecasts by improving our understanding of subsurface ocean conditions [21].

4) Marine Heat: The ocean plays a vital role in regulating Earth's climate by absorbing excess heat and storing it below the surface. In the Caribbean, Southeast, and Gulf regions, RAs (CARICOOS, SECOORA, and GCOOS) are collaborating to improve understanding of how major ocean currents, like the North Equatorial Current, the Caribbean Current, the Gulf Stream, and the Loop Current, interact. Their goal is to fill data gaps that affect forecasting and responses to environmental changes. A major focus of this collaboration is analyzing both surface and subsurface temperature data to better detect and understand marine heatwaves and their effects on sensitive habitats. Using temperature sensors mounted on gliders, buoys, and moorings, scientists gather detailed information and compare it with satellite sea surface temperature data. This approach helps paint a clearer picture of what's happening beneath the surface during marine heatwaves. The insights gained are critical for coral reef restoration, fisheries management, marine operations, HAB monitoring, public health, and planning for extreme weather events. On the West Coast, as part of an ongoing initiative by the North Pacific Marine Science Organization (PICES), IOOS West partners, SCCOOS, CeNCOOS, and NANOOS, are analyzing over a decade of moored station data. Their goal is to better understand subsurface marine heatwaves and document their impacts on ecosystems and fisheries over time.

5) Marine Animal Tracking: Tracking of animals in the marine environment can be difficult and very expensive. Acoustic telemetry provides an efficient way to track fish, large invertebrates, turtles, and marine mammals. Researchers attach acoustic transmitters (or "tags") to fish or other marine animals. Each tag emits unique sound pulses that are heard and understood by underwater tracking stations (receivers) placed in strategic locations [22]. Receiver arrays are managed by state and federal agencies and individual researchers and are part of the larger Canadian run Ocean Tracking Network (https://oceantrackingnetwork.org/). To enable the sharing of tag detections by the receivers, the receiver array operators contribute tag detections to regional U.S. based acoustic telemetry nodes. All of the nodes are interoperable, allowing for tag detections in one node to be shared with other regional nodes. This makes acoustic telemetry an inherently collaborative technology: sharing detections between receiver array operators extends the detection area of the tagged animal.

IOOS RAs have played a central role in helping stand up and facilitate the Ocean Tracking Network nodes in the United States. These nodes automate the process of matching tag detections so that the researcher who tags an animal can access all that animal's detections across receiver arrays. Until recently, the U.S. West Coast did not have a regional node to support animal tracking efforts. Starting in 2024, AOOS, NANOOS, CeNCOOS, and SCCOOS have worked together to develop the Northeast Pacific Acoustic Telemetry (N-PAcT) node (https://npact.aoos.org/) to provide the platform and cyberinfrastructure that allows for data sharing from Alaska to Baja California.

6) Harmful Algae Blooms: HABs have been a focal point for coordination across regions through the National Harmful Algal Bloom Observing Network (NHABON), which is a joint effort between IOOS and the National Centers for Coast Ocean Science. HABs are a nation-wide problem but with regional differences in the underlying dynamics and the public impacts of HABs.

One of the development areas has been around HAB Early Warning Systems. RAs have taken a multi-tiered approach by combining observations and regional models to create community focused resources for early warning of HABs. The utilized observations include regionally relevant technologies, such as Imaging FlowCytobots (CeNCOOS, SCOOS, AOOS) or uncrewed surface vessels equipped with HAB-detecting instruments (NERACOOS, GLOS), grab sampling, and satellite imagery. These, combined with modeling efforts, result in community resources, such as the California HAB Bulletin (CeNCOOS, SCOOS), Sargassum Inundation Forecasts (CARICOOS, GCOOS, SECOORA), or tools, such as a user-customized alerting feature (GLOS).

B. Data Management framework

All of these pan-regional and national endeavors require a common data framework and consistent data management approaches, which allow the data collected by these projects to be turned into information required by the stakeholders. Each RA has invested in robust data management structures while also benefiting from accessible and standardized data servers and services provided by ERDDAP. These pan-regional and national projects are now moving the RAs toward shared data management structures that allow data from across RAs to be seamlessly viewed together, essentially removing RA boundaries and allowing users to easily access data without visiting multiple RA sites.

Operating as a unified system enables a more sustainable, accessible, and reliable ocean observing network. This coordinated approach strengthens support for key sectors such as tourism, maritime operations, public safety, and hazard response. By leveraging combined efforts, the system can close critical information and decision-making gaps, driving economic growth, and enhancing safety across the region and the nation.

Effective collaboration among RAs depends on strong, interoperable data systems. While each RA has created its

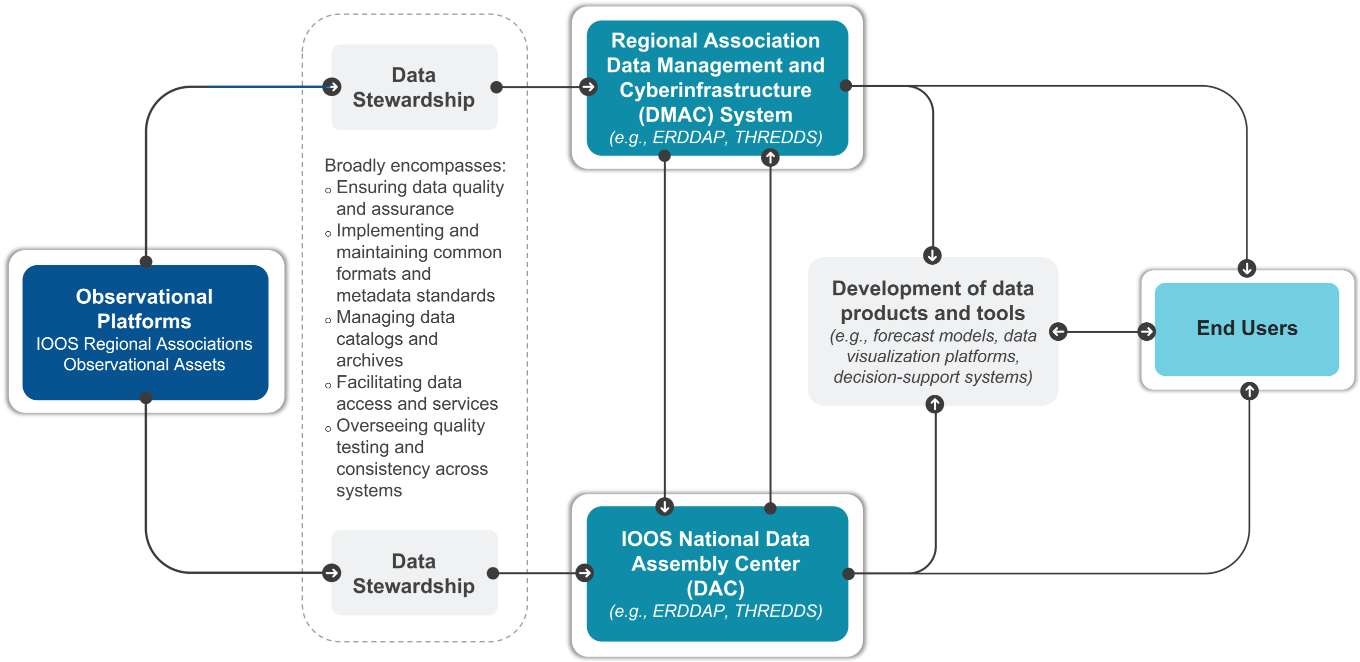

Fig. 2. The IOOS Regional Associations follow a data management workflow that allows real-time data from observational assets to be reviewed and disseminated in a standardized way, then made available to data products that are utilized by end users.

data management framework to address regional needs, they all leverage standardized systems such as ERDDAP, which facilitates consistent and accessible data delivery, alongside IOOS-certified data management protocols that ensure quality assurance, metadata integrity, and interoperability [23], [24]. ERDDAP services allow users to access a wide range of data across different regions through a single platform, making the information easier to use and reducing duplication. It provides seamless access across regions, combining various types of data, such as models and glider data, and lowers barriers for real-time decision-making (Fig. 2). This unified network benefits society in many ways, from supporting sustainable tourism and improving maritime safety to enhancing emergency response and climate resilience. It also helps fill gaps in data and aligns observation efforts across regions for better coastal management. Economically, the system saves resources by avoiding repeated work, encourages innovation, and provides better data for industries such as fisheries, shipping, and resource management.

Leveraging the value of shared infrastructure, pan-regional projects like Backyard Buoys and WebCOOS are poised to easily expand their assets and regional support using the foundational data services. For example, as regions add new camera systems to WebCOOS, the data feeds are all centralized through a single data management system (at webcoos.org or through an API). Each RA can then access imagery and products from this system to display imagery on another site or to create and provide customized analysis products. Similarly, all wave buoys added to the Backyard Buoys network appear in a centralized ERDDAP server from which each region can then ingest data. This allows RAs to create customized data visualizations that meet their user needs, while also enabling easier access for pan-regional data access. Additionally, all of the buoys that appear in the Backyard Buoys ERDDAP server are available through a Backyard Buoys smart-phone app. These designs have led to standardization and a streamlining of development costs.

The evolution of IOOS from a collection of regionally focused systems to a coordinated national network marks a critical turning point in ocean observation. Tailored regional systems remain essential, but so too does the recognition of the ocean's interconnectedness and the importance of collaboration. By fostering a culture of shared learning, joint initiatives, and interoperable data infrastructure, IOOS and its RAs are laying the foundation for a more responsive, inclusive, and effective ocean observing system. Such collaboration will be key in addressing emerging environmental challenges and delivering maximum value to stakeholders across the United States.

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References

[1] United States Congress, Integrated Coastal and Ocean Observation System Act of 2009, Pub. L. No. 111-11, §§ 12301–12312, 123 Stat. 991, codified at 33 U.S.C. §§ 3601–3610, Mar. 30, 2009.

[2] J. Snowden et al., "The U.S. Integrated Ocean Observing System: Governance Milestones and Lessons From Two Decades of Growth," Front. Mar. Sci., vol. 6, May 2019, doi: 10.3389/fmars.2019.00242

[3] M. M. Iwamoto et al., "Meeting Regional, Coastal and Ocean User Needs With Tailored Data Products: A Stakeholder-Driven Process," Frontiers in Marine Science, vol. 6, p. 290, 2019, doi: 10.3389/fmars.2019.00290

[4] Z. Willis, "US Integrated Ocean Observing System (IOOS®): Delivering benefits to science and society," in 2012 Oceans - Yeosu, May 2012, pp. 1–5. doi: 10.1109/OCEANS-Yeosu.2012.6263613.

[5] M. Bushnell et al., "QARTOD - Prospects for Real-Time Quality Control Manuals, How to Create Them, and a Vision for Advanced Implementation" , 2020, doi: 10.25923/ysj8-5n28

[6] D. L. Rudnick, R. E. Davis, C. C. Eriksen, D. M. Fratantoni, and M. J. Perry, "Underwater Gliders for Ocean Research," mar technol soc j, vol. 38, no. 2, pp. 73–84, June 2004, doi: 10.4031/002533204787522703.

[7] S. Glenn et al., "Glider observations of sediment resuspension in a Middle Atlantic Bight fall transition storm", Limnology and Oceanography, vol. 53, no. 5part2, pp. 2180 – 2196, 2008, doi: 10.4319/lo.2008.53.5_part_2.2180

[8] D. Rudnick, "California Underwater Glider Network." Scripps Institution of Oceanography, Instrument Development Group, 2016. doi: 10.21238/S8SPRAY1618.

[9] R. Domingues et al., "Ocean Observations in Support of Studies and Forecasts of Tropical and Extratropical Cyclones," Front. Mar. Sci., vol. 6, 2019, doi: 10.3389/fmars.2019.00446.

[10] T. N. Miles et al., "Uncrewed Ocean Gliders and Saildrones Support Hurricane Forecasting and Research," Oceanography, vol. 34, no. 4, pp. 78–81, 2021.

[11] C. Janzen, M. McCammon, H. Kent, D. Dugan, R. Bochenek, and W. Koeppen, "The Alaska Ocean Observing System's Past and future presence in the Arctic," in OCEANS 2016 MTS/IEEE Monterey, Sep. 2016, pp. 1–8. doi: 10.1109/OCEANS.2016.7761428.

[12] B. Baltes et al., "Toward a US IOOS® Underwater glider network plan: part of a comprehensive subsurface observing system," DC: US Integrated Ocean Observing System Program Office, vol. 54, 2014.

[13] J. Harlan et al., "The Integrated Ocean Observing System High-Frequency Radar Network: Status and Local, Regional, and National Applications," Marine Technology Society Journal, vol. 44, no. 6, pp. 122–132, Nov. 2010, doi: 10.4031/MTSJ.44.6.6.

[14] J. Harlan et al., "National IOOS High Frequency Radar Search and Rescue Project," in OCEANS'11 MTS/IEEE KONA, IEEE, 2011, pp. 1–9.

[15] H. Roarty et al., "The Global High Frequency Radar Network," Front. Mar. Sci., vol. 6, May 2019, doi: 10.3389/fmars.2019.00164.

[16] J. Harlan, E. Terrill, L. Hazard, M. Otero, and H. Roarty, "The Integrated Ocean Observing System HF Radar Network," in OCEANS 2015 - MTS/IEEE Washington, Oct. 2015, pp. 1–4. doi: 10.23919/OCEANS.2015.7404587.

[17] U.S. Integrated Ocean Observing System (IOOS), "Certification: Extending the Reach of Regional Data," NOAA, online. Available: https://ioos.noaa.gov/about/governance-and-management/certification-extending-reach-regional-data/. Accessed: July 31, 2025.

[18] J. Newton, S. Wisdom, M. Iwamoto, R. Carini, and J. Watson, "Backyard Buoys: Meeting Needs of Coastal, Indigenous Communities Through Co-Design and Co-Production," Oceanography, vol. 38, no. 1, pp. 91–93, Sept. 2024, doi: 10.5670/oceanog.2025.105

[19] G. Dusek et al., "WebCAT: Piloting the Development of a Web Camera Coastal Observing Network for Diverse Applications," Front. Mar. Sci., vol. 6, June 2019, doi: 10.3389/fmars.2019.00353

[20] North Carolina Institute for Climate Studies (NCICS), "Billion-Dollar Disasters Are Happening More Often," NCICS, 27-Sep-2022. [Online]. Available: https://ncics.org/cics-news/billion-dollar-disasters-are-happening-more-often/. [Accessed: 31-Jul-2025].

[21] G. J. Goni et al., "Autonomous and Lagrangian ocean observations for Atlantic tropical cyclone studies and forecasts," Oceanography, vol. 30, no. 2, pp. 92–103, 2017.

[22] SECOORA FACT Network, "How Acoustic Telemetry Works," SECOORA FACT, [Online]. Available: https://secoora.org/fact/acoustic-telemetry/ . [Accessed: 31-Jul-2025].

[23] C. Wilson, D. Robinson, and R. A. Simons, "ERDDAP Providing Easy Access to Remote Sensing Data for Scientists and Students," in IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium, Sept. 2020, pp. 3207–3210. doi: 10.1109/IGARSS39084.2020.9323962.

[24] National Centers for Environmental Information (NCEI), "ERDDAP Data Access," National Oceanic and Atmospheric Administration (NOAA), [Online]. Available: https://www.ncei.noaa.gov/erddap/index.html. [Accessed: Jul. 31, 2025].