MEASURING THE PERFORMANCE OF OCEAN OBSERVING SYSTEMS

PILOT METRICS 2021

Interagency Ocean Observation Committee

July 19, 2021

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AIMS IN YEAR 2

In order to build on the baseline metrics collected in the first year, the Metrics for Ocean Observing Systems Task Team (MOOS-TT) implemented a second year of metric collection in 2020 that extended the initial suite of metrics and added an additional set of metrics evaluating U.S. hurricane observation systems. This report provides an updated look at the state of selected observing capabilities and analyzes how those capabilities have changed since the metrics were initially collected. It should be noted that data were collected in the second half of 2020 during the global COVID-19 pandemic. As a few of our metrics indicate, observing systems were affected by shutdowns and operational delays spurred by the crisis.

EXECUTIVE SUMMARY

Effective management of the ocean requires the ability to track, predict, manage, and adapt to changes in the marine environment, all of which are made possible through ocean observing. Across the ocean at any given moment, vast and varied ocean observing platforms are gathering data: ships, buoys, floats and drifters, autonomous and remote vehicles, tagged marine animals, aircraft and satellites, and coastal radars record immense amounts of physical, chemical, and biological data. When compiled and synthesized, the data from these ocean observing platforms are essential to understand weather and climate, maritime operations, natural hazards, national security threats, public health, and living resources. They also aid in responding to challenges like sea level rise, extreme weather, and other ocean conditions that significantly impact economies, ecosystems, and society.

Sustained, integrated ocean observing systems have been evolving rapidly over the last century; over the last several years this growth has been accelerated due to major innovations in data processing methods, machine learning and artificial intelligence, technology miniaturization, cloud computing, and other technological advancements. These new capabilities have created robust global and regional ocean observing networks. Measuring and assessing the performance and value of these networks is increasingly critical for characterizing the state and progress of the ocean observing system, maximizing and optimizing the efficiency of the system, guiding future ocean observing programs, prioritizing asset placement, and tracking the wealth of impacts of observation-based ocean knowledge towards meeting societal needs.

Deriving metrics for ocean observing systems can take on an extensive number of different forms, considering the range of themes, categories, and criteria that comprise the ocean science and technology enterprise. Consequently, the United States Interagency Ocean Observation Committee (IOOC) commissioned an expert group, the Metrics for Ocean Observing Systems Task Team (MOOS-TT), to assess metrics based on readiness and feasibility, and the inherent value to the target audience of U.S. federal agencies, policymakers, and the general public. Year One of the project resulted in a framework that was applied to selected thematic areas with fairly mature observing systems: sea level rise, ocean acidification, and harmful algal blooms. This was done to constrain the metrics to a few manageable pilot studies. The resulting pilot metrics covered a range of activities, from observing infrastructure and assets to economic impacts, in an effort to assess the baseline, measure progress, and identify gaps in the selected observing systems. In March of 2020, the metric collection efforts culminated in the flagship report *Measuring the Performance of Ocean Observing Systems: Pilot metrics for sea level rise, ocean acidification, and harmful algal blooms*. The report highlighted the challenges (development, resourcing, coordination, etc.) and potential value (economic impacts, management decisions) of implementing a more robust U.S. Integrated Ocean Observing System (IOOS), and included recommendations for next steps towards achieving such a System. For Year Two of the Metric Study, pilot metrics were re-assessed based on the value of the information provided and effort required to collect. Most of the metrics in the three original themes were deemed worthwhile to extend, with only minor modifications to a few of these metrics. Additionally, an entire new suite of metrics to assess hurricane observations was added to the study. Tracking metrics from year to year will provide a baseline for understanding changes, gaps, and opportunities for our observing systems.

BACKGROUND AND METHODS

BACKGROUND:

Metrics are tools for supporting actions that allow programs to evolve toward successful outcomes, promote continuous improvement, and enable strategic decision making. Additionally, they are now utilized as a means of communicating the goals, status, and progress of large-scale ocean observing programs, such as the Joint Technical Commission for Oceanography and Marine Meteorology in situ Observations Programme Support Centre (JCOMMOPS) and Ocean Networks Canada (ONC). The purpose for developing a set of ocean observing metrics for U.S. IOOS is to:

- Characterize the scope and nature of IOOS observations
- Gauge progress toward achieving established ocean observing goals
- Identify gaps in observations

These metrics are intended to help monitor and evaluate the status of U.S. observing activities at-large, which can then be used to assess the entire IOOS and determine the health of the System as well as how adjustments to smaller component programs can improve the System. These metrics should reflect indicators related to essential ocean variables (EOVs)—physical, chemical, or biological—to help understand how well elements of the ocean domain are observed in time and space, determine vulnerabilities and opportunities in observing systems, and inform management and policy decisions to promote oceanographic research and operations. Detailed metrics relating to the management of individual observing networks are not the aim of this effort and are left to agency programs to develop and utilize.

From a technical perspective, ocean observers often use a metrics framework in the management of collecting and evaluating oceanographic measurements from specific platforms (data quality assurance, best practices in deployments, etc.). However, metrics at a broad-scale are relatively undefined, and so have been made the focus of this report. The primary objectives for this effort are:

- Identify the audience for IOOS metrics
- Develop a suite of measurable and repeatable metrics
- Recommend a process for agencies to contribute towards those metrics
- Assess future pilot metric development projects
- Suggest ways to assess the impact of metrics on the target audience
- Provide next steps towards moving beyond pilot metrics

The aim of the metrics is to integrate across various system components, characterize the status and overall progress of the system development over time, determine and track the performance of observing activities, and ultimately measure impacts on socio-economic indicators. Such observing metrics can generate information applicable to wide-ranging audiences, including lay, managerial, and subject matter experts. For example, measuring the overall progress of ocean acidification observations could be very useful to program managers and policy makers as they strive to understand the strengths and weaknesses of the networks and guide future priority activities. Linking metrics on the progress of observing systems to metrics on the impacts of those systems will generate public and political intelligence on the inherent value of long-term programs that measure carbon uptake in the ocean and their benefits to people and the planet. In other words, metrics that characterize status/progress along the value chain, from observing to impact, would generate incredible short- and long-term value to the ocean observing enterprise.

AUDIENCE

The team identified five audience categories for these metrics: Policymakers, U.S. Federal Agency Managers, Scientists/Researchers, Operational Experts, and the General Public. The "type" of audience comes from standard nomenclature used in journalism and technical communication developed by *Colorado State University*, which determines how the metrics might be used for interactions with particular groups. The three types of audiences are: 1.) "lay" who are most likely unfamiliar with ocean observing and connect with the societal impacts, require more explanation and visual aids; 2.) "managerial" who require the metrics for decision-making and need only the facts or statistics; and 3.) "experts" who demand technical and specialized information. The table below lists potential specific audiences within each category and the primary (1°) audience type -- acknowledging that multiple audiences can exist within each entity (table X). The ocean observing metrics identified in this exercise yielded information relevant to managerial and expert audiences principally. The authors attempted to identify and provide ocean observing metrics applicable to lay audiences in this report; however, more research is needed for translating technical ocean observing information to lay audiences.

Table 1. Potential audiences of metric findings by category.

AUDIENCE	TYPE
Policy-Makers	
G-7: Multinational	Managerial
International Organizations: IOC, IOCCP, IOCCG, etc.	Managerial
Legislative Branch:U.S. Government and State Level	Lay
Executive Branch – OMB, NSTC, OSTP, CEQ, CENR	Managerial
Executive Branch – USGCRP, NOC, IARPC, National Science Board	Lay
U.S. Federal Agencies	
Program Managers	Managerial
Interagency Ocean Observation Committee	Managerial
Scientists/Researchers	
NGO's, Federal, State, Academia, Industry	Experts
Managerial/Operational	
NGO's, Federal, State, Academia, Industry	Managerial
Public	
Informational, Citizen Scientists	Lay

METHODS:

The first year report selected three major ocean themes around which to collect pilot metrics: sea level rise (SLR), ocean acidification (OA), and harmful algal blooms (HABs). For this second year report, a theme of metrics evaluating hurricane observation and forecasting abilities was added. Within each theme, the MOOS-TT developed metrics that met the following criteria: impactful, easy to track over time, and highlight progress and/or gaps in the science. Metrics were selected based on the feasibility of acquiring the information and the anticipated impact of the resulting data. Additionally, the resulting metrics are designed to represent the capabilities of most federal agencies that collect ocean observations with the IOOS regional partners.

Metrics were collected in coordination with many of the federal agencies involved in ocean observing, primarily the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the Bureau of Ocean Energy Management (BOEM), the Environmental Protection Agency (EPA), the United States Geological Survey (USGS), the National Science Foundation (NSF), and the IOOS Regional Associations. Some of the metrics data were collected from federal or interagency databases or websites. Other metrics were developed from federal agency reports or by directly posing questions to agency scientists. In some cases, metrics data were collected through the creation of survey materials that were circulated among agencies/groups for population.

THEME: SEA LEVEL RISE

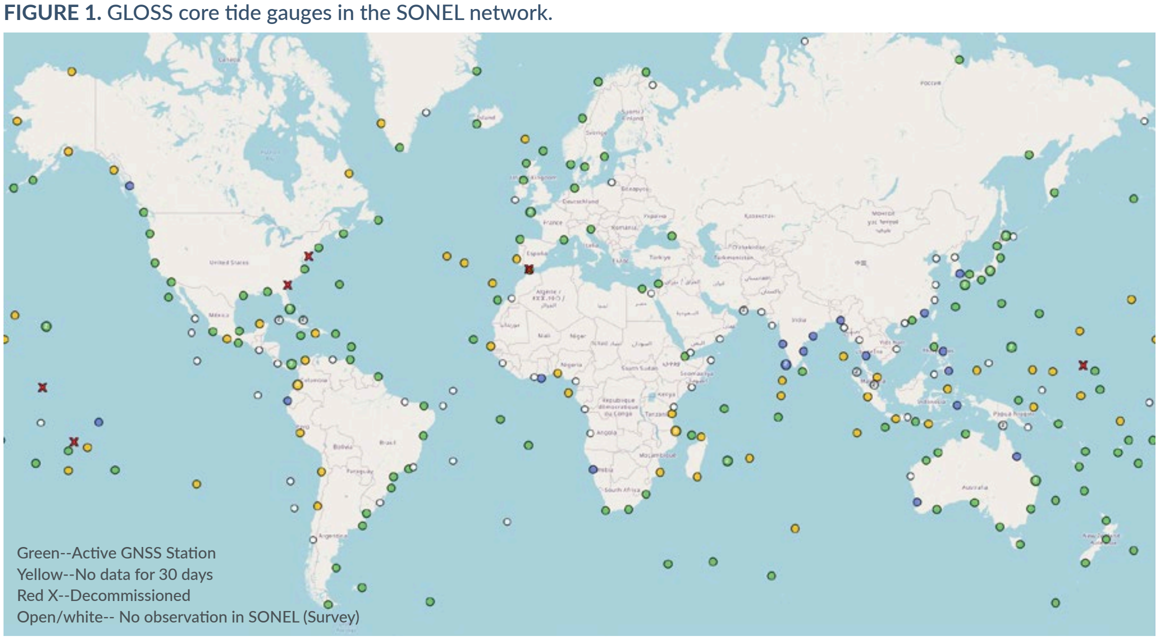
Sea level is rising globally due to the melting of land glaciers and thermal expansion of water (Church and White, 2011). Sea level rise is also a contributing factor to more frequent flooding events. These events can be a threat to coastal communities and have several negative impacts, including habitat destruction, damage to infrastructure and property, and large impacts on local economies.

Sea level rise is measured by several different observing systems. One is with tide gauges that measure the daily fluctuations in sea levels. Over a long period of time, trends in sea level can be determined. Global measurements are done by using tide gauges around the world and averaging their change. Since tide gauges can only be installed where land exists, there are large portions of the ocean that were previously not monitored. Satellite altimeters were first launched 30 years ago to measure sea level from a global perspective. Altimetry measures ocean surface topography, or sea surface height, by determining the distance from the ocean's surface to the satellite. Altimetry has improved our knowledge of ocean circulation, mesoscale eddies, waves and tides, enabled development of global tide models, and, due to their high-precision, are able to detect rise and acceleration of global mean sea level (NASA, 2021). Monitoring the changes in sea level rise through observations can help predict, mitigate and adapt to the changing sea level.

METRIC: % of GLOSS tide gauges co-located with GPS or GNSS capabilities

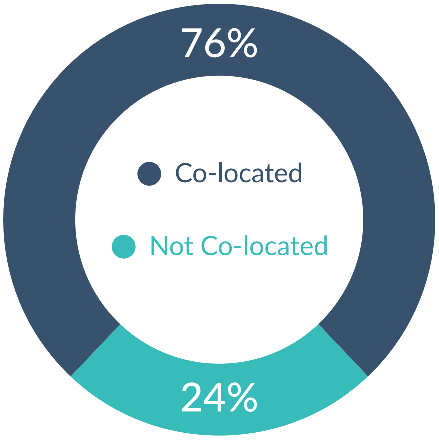
Sea Level change does not just happen in the U.S., but globally. In order to monitor this change, there is a global set of almost 300 tide gauge stations that make up the Global Sea Level Observing System (GLOSS) network and provide the optimal sampling of the global ocean. Two gauges were added in 2020 bringing the total to 293 in the array (300 is the goal). Over 100 countries contribute to this network. In 2012, this network agreed that having co-location of Global Positioning System (GPS)/Global Navigation Satellite System (GNSS) capabilities at tide gauges would give a better accuracy of the change at that location. The definition of co-location used for this metric is having a tide gauge and GPS/GNSS antenna (or benchmark) less than 10 km away and tying the two stations together routinely with the tide gauge calibrated to an accuracy better than 1mm/year, preferably at annual intervals but up to every three years (IOC UNESCO, 2016).

FIGURE 1. GLOSS core tide gauges in the SONEL network.



Currently there are 222 out of 293 (76%) GLOSS core tide gauges that report their co-located GPS/GNSS data to the GLOSS data center (SONEL). This represents a 1% increase over the number of co-located tide gauges in 2019.

FIGURE 2. GLOSS tide gauges with co-located GPS or GNSS capabilities.

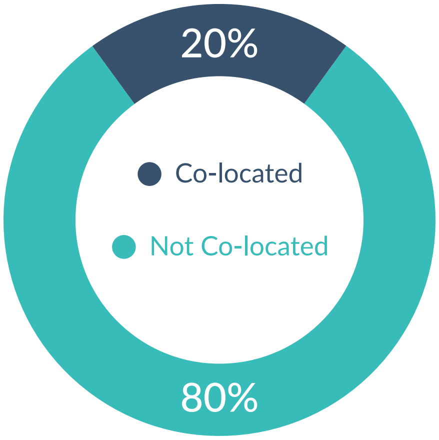


METRIC: % of U.S. tide gauges with ties to co-located GPS or GNSS capabilities

Using the same standard as the global tide gauges to define co-located and tied capabilities, the U.S. has lagged behind the global percentage. Only 31 out of the 157 coastal stations (20%) are currently fully meeting this metric. While the majority of U.S. tide gauges have a GNSS station within 10 km, most of them have not had leveling ties connecting the two sensors. The main reason for this lack of ties is the fact that the GNSS stations were installed by third parties for other reasons and were not coordinated with the tide station.

No new co-located U.S. tide gauges were added in 2020, due to the global COVID-19 pandemic. The U.S. is also working to make these data accessible through SONEL (currently only 3 sites are available). Ideally, the number of U.S. tide gauges co-located with GPS/GNSS would increase each year.

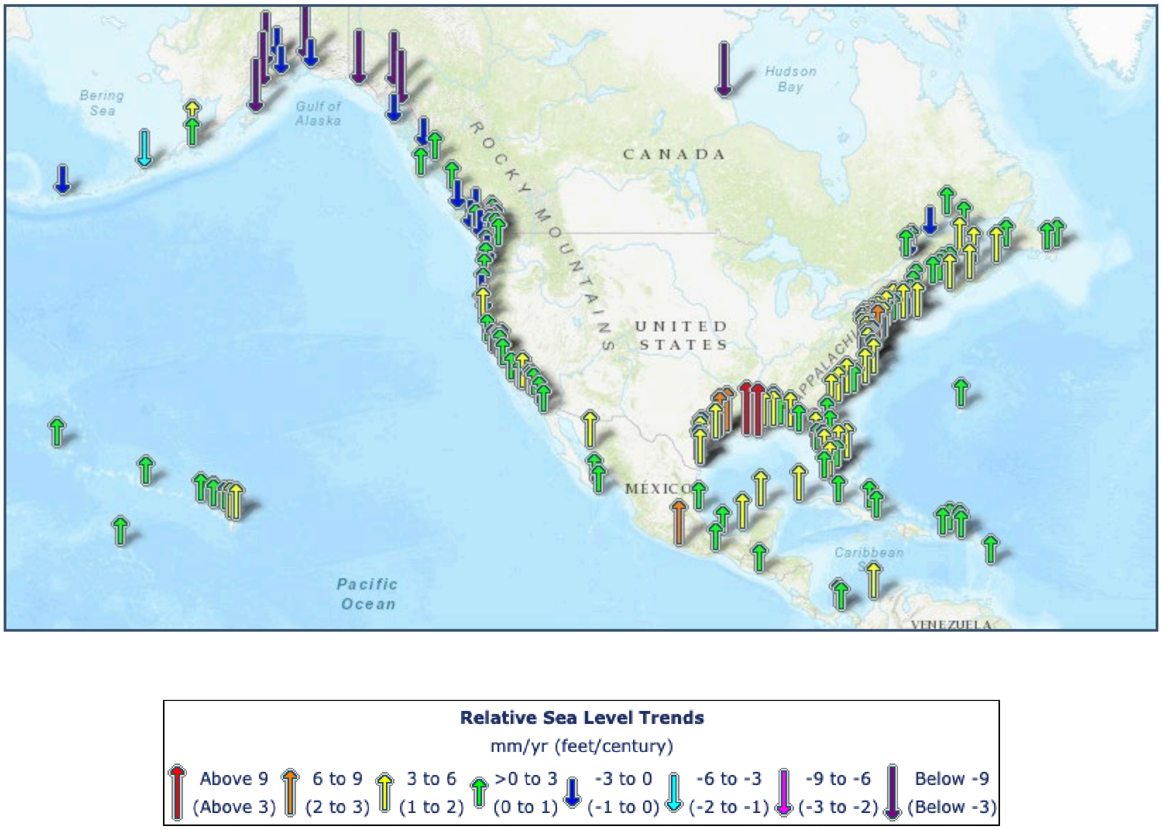
FIGURE 3. U.S. tide gauges with co-located GPS or GNSS capabilities.



METRIC: # of U.S. tide gauges reporting real time (within 24hrs)

Real time data from tide gauges allows for immediate detection of sea level changes. This can show short term changes as well as long term ones. For the short term, these changes can show important information about tsunamis and storm surges. In the U.S., NOAA operates 210 tide gauges as part of the National Water Level Observing Network (NWLON) reporting in real time, 157 of which are located on the coasts (the remainder are located in the Great Lakes). No new tide gauges were added from 2019 to 2020. All of these gauges have real time data accessible.

FIGURE 4. NOAA 2017 Sea Level Trends.



Satellite altimetry METRIC: % of 0.25 degree ice-free regions covered every 10 days by satellite altimetry measurement

There are a number of satellites dedicated to monitoring changes in ocean height. The current constellation is capable of measuring ocean height only directly under each satellite, which does limit coverage, but nevertheless covering the ice-free oceans up to 88° latitude. When the globe is broken into segments using half degree (latitude/longitude) boxes, then a percentage of how much of the Earth is observed by these satellites can be calculated. These are still very large boxes, approximately the size of Rhode Island.

In the fall of 2019, the satellite Jason-2 was decommissioned. Loss of this satellite resulted in a drop of altimetry coverage from nearly 80% down to 70%-72% coverage. Coverage has fluctuated due to periodic failure of instrumentation on AltiKa/SARAL. However, it should be noted that the joint US-European satellite Sentinel-6 Michael Freilich was launched in the fall of 2020. Sentinel-6 is a joint project of NASA, NOAA, the European Space Agency (ESA), the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), and the French Space Agency (CNES). This satellite is continuing the multi-decadal legacy of the Jason series of satellite altimetry, and will eventually become the reference sea level mission. In early 2022, Jason-3 will be moved into an orbit interleaved with Sentinel-6, which will increase the satellite altimetry coverage.

= Land; = Sea Ice; = Altimeter coverage; = Open ocean/no altimeter coverage

FIGURE 5. Satellite coverage plot at .25 degrees for 10 days in 2015 (January 11-20th). Contributing satellites were Jason-2, Cryosat-2, and AltiKa/SARAL. Coverage in 2015 was 54.1%.

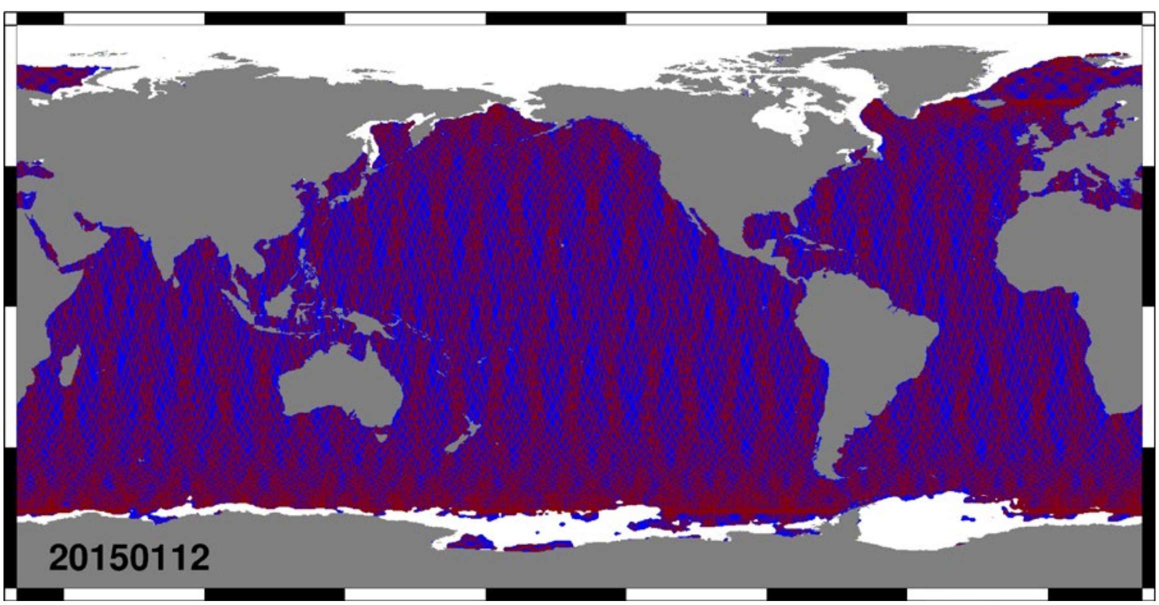


FIGURE 6. Satellite coverage plot at .25 degrees for 10 days in 2019 (January 11-20th). Contributing satellites were Jason-3, Sentinel-3A, and Sentinel-3B, Jason-2, Cryosat-2, and AltiKa/SARAL. Coverage in 2019 was 80.3%.

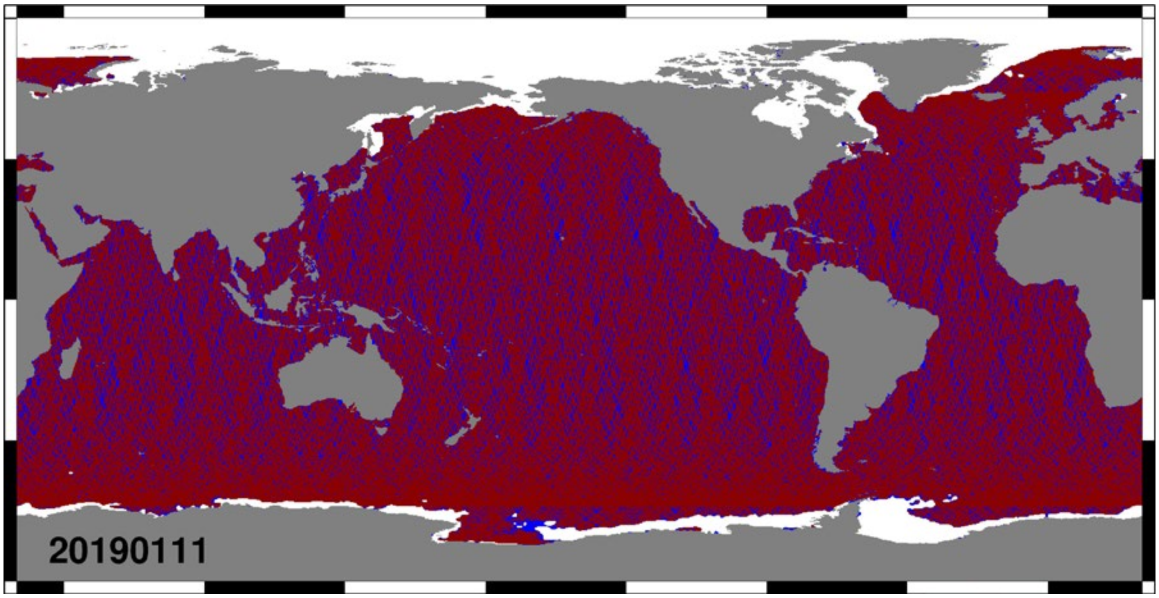


FIGURE 7. Satellite coverage plot at .25 degrees for 10 days in January of 2020. Contributing satellites were Jason-3, Sentinel-3A, and Sentinel-3B, Cryosat-2, and AltiKa/SARAL. Jason-2 was decommissioned in the fall of 2019.

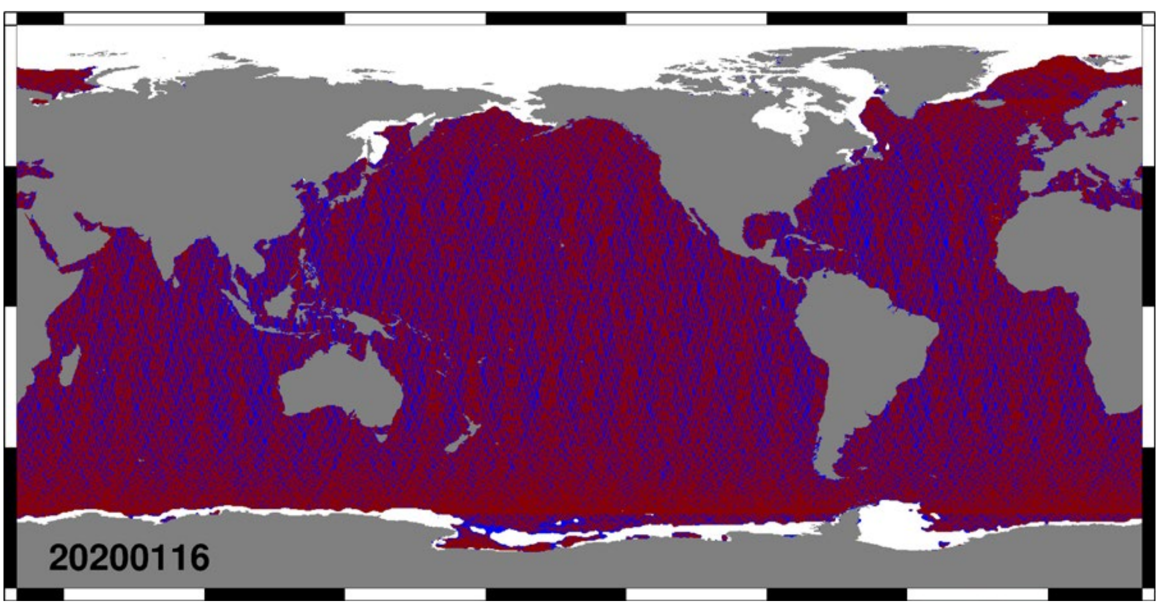


FIGURE 8. Satellite coverage plot at .25 degrees for 10 days in September of 2020. Contributing satellites were Jason-3, Sentinel-3A, and Sentinel-3B, Cryosat-2, and AltiKa/SARAL. After the decommissioning of Jason-2, coverage dropped down to 70-72%.

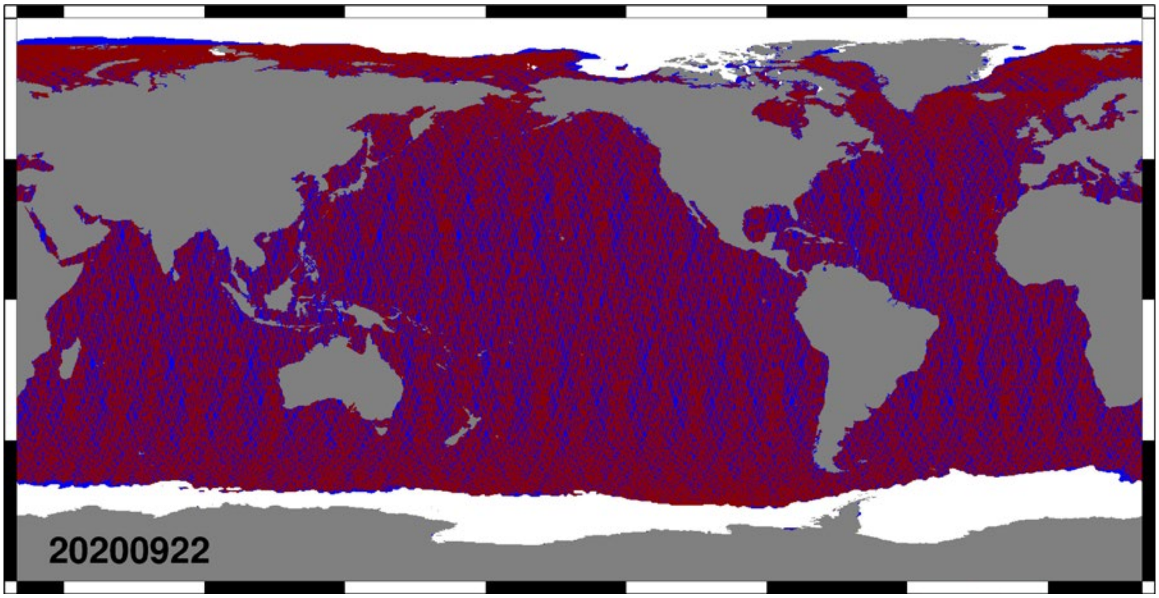
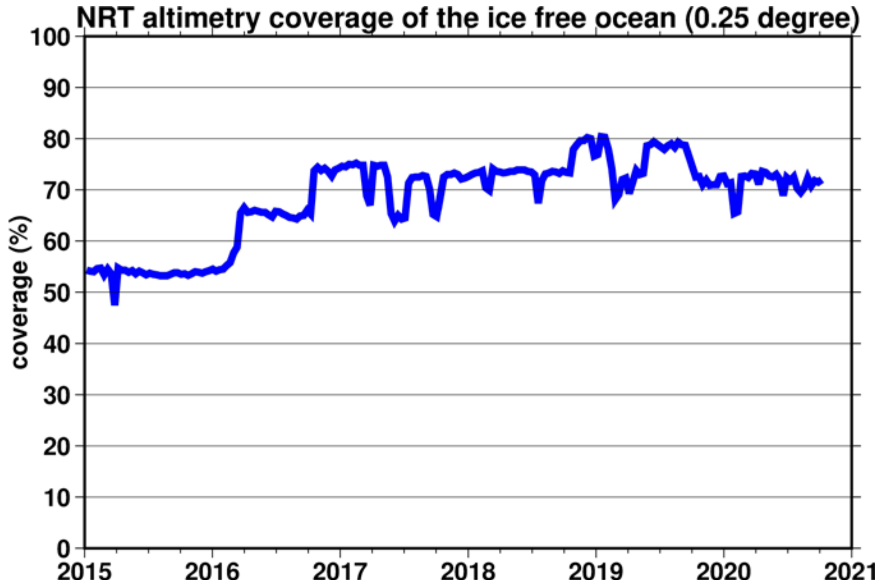


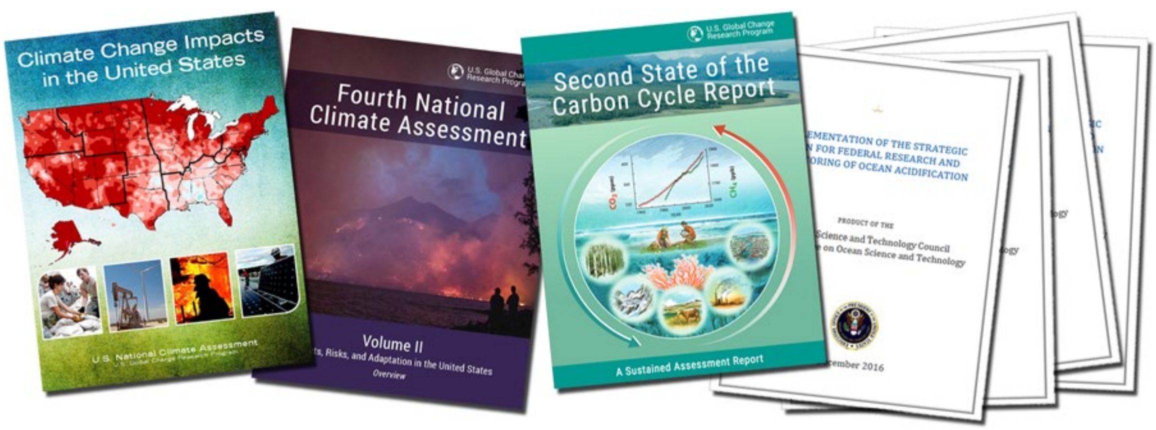
FIGURE 9. NRT Altimetry coverage of the ice free ocean (.25 degree).



THEME: OCEAN ACIDIFICATION

Ocean acidification (OA) refers to the decreasing pH and carbonate ion concentrations of ocean waters, due primarily to the uptake of carbon dioxide (CO_2) from the atmosphere. (e.g. Feely et al., 2004, 2009; Orr et al., 2005). Over the last 250 years, as atmospheric CO_2 emissions from the combustion of fossil fuels and other human activities have increased, ocean waters have become 30% more acidic, due to the absorption of the increased atmospheric CO_2 (Feely et al., 2009; Gruber et al., 2019). Over the past 50 million years there hasn't been a change in ocean chemistry as dramatic - or as fast - as this one. Field studies have demonstrated that OA impacts the ocean and organisms that inhabit it, as it reduces the capacity of many calcifying organisms to produce and maintain their shells or skeletons, which are made of calcium carbonate (Busch et al., 2014; Riebesell et al., 2016). These organisms range from pteropods to shellfish to corals, all of which contribute to global job and food security. Ocean observations of key physical, chemical, and biological parameters are critical to understanding and predicting how the ocean will respond to increasing OA. Documenting these changes can alert stakeholders and industry partners to corrosive (e.g. decreased pH) events which can impact coastal communities and economies.

Tracking OA on a national level over time allows the scientific community and the public to understand how ocean acidification may affect ocean ecosystems and the communities that depend on them around the United States. National assessments utilize scientific data produced by observing assets and put the data in a context that is useful for decision makers. OA reports that are produced at a national level provide information on the rate of data usage for decision making and public awareness products (bottom up), as well as on the need of such reports by decision makers (top down). Since 2013, there have been 15 national-level reports documenting the state of ocean acidification. Federal monitoring and reporting on this issue will ideally continue and reflect increasing investment in addressing OA.



The U.S. has invested significantly in observing ocean acidification. Figure 10 represents an inventory of U.S.-owned OA assets. The inventory was collected through the Global Ocean Acidification Observing Network (GOA-ON) Data Portal, which includes a non-comprehensive list of assets operated by NOAA, the National Science Foundation Ocean Observatories Initiative (OOI), and several academic institutions. Representatives from NOAA and BOEM also supplemented the inventory information with assets not listed in GOA-ON.

For the second year of OA metrics collection, a total of 88 assets were inventoried. This represents a decrease from the Year One inventoried assets (101 assets). A number of assets were delisted from the GOA-ON Data Portal or discontinued. A subset of these data were used to inform metrics, as described below. Understanding the quality and quantity of OA assets/measurements that the U.S. has is critical to be able to monitor the health of the observing system. A healthy observing system can track changes of water properties that are of importance to stakeholders, and provide forewarning of imminent changes that could result in catastrophic economic losses.

FIGURE 10. Map of U.S.-Operated/Maintained OA Assets

METRIC: # of observing days during which surface moorings measure the full dynamic range of the ocean acidification system (*Optimal Observing Days*)

One metric for capturing the overall capacity to observe ocean acidification is by tracking the total number of observing days each year. As the number of observing platforms increases, so should the overall number of observing days. There is not a specified target for how many observing days are needed. In general, the ocean is under-observed, so the goal is to grow the capacity to detect ocean acidification and hence, increase the number of observing days each year. For this metric we consider surface moorings that include a suite of sensors which describe the daily cycle of ocean carbonate chemistry. This is needed in order to measure and track long-term changes in ocean chemistry in response to OA. Sensors which measure temperature, salinity, and carbon parameters, such as the partial pressure of carbon dioxide (pCO_2), are necessary to accurately estimate ocean acidification; these sensors must be located on the same platform (or in close proximity). Each day, every mooring should provide data for the determination of a complete daily cycle with a fully functioning sensor suite (a minimum of eight observations per 24 hours distributed across the diel cycle). Thus, a single mooring deployed for a full year should achieve a maximum number of observing days of 365. An observing day only counts if all three sensors (temperature, salinity, and pCO_2) measure and report data eight times in a 24 hour period. This is a measurement of the footprint of the system, and this number of observing days increases as more moorings are deployed (i.e., as coverage of the network is extended). In the first year of deployment, this number may be less if deployed mid-way through the year.

In some regions, the maximum number of observing days for a given asset may be less because of environmental conditions, e.g. ice coverage. If the asset is taken offline and not replaced, the number of observing days will decrease; such a decrease may indicate that there may be issues with the observing system network. The U.S. federal observing capacity for ocean acidification is captured here by including surface mooring assets funded by two agencies: the National Science Foundation's Ocean Observatories Initiative (OOI) and the National Oceanic and Atmospheric Administration's Ocean Acidification Program (OAP).

Since fiscal year 2015, the overall observing capacity has remained relatively stable, between 5,485 and 7,499 days per year, reflecting relatively consistent resource availability.

FIGURE 11. Number of NOAA OAP Observing Days from fiscal year 2015 to fiscal year 2020.

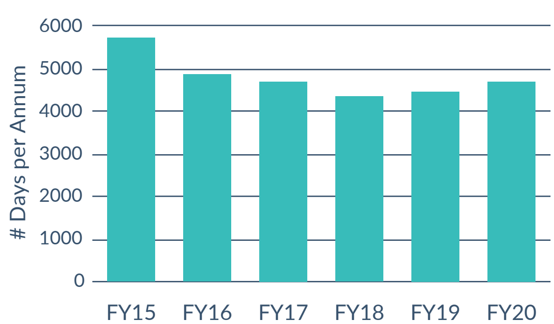


FIGURE 12. Number of OOI Observing Days from fiscal year 2015 to fiscal year 2020.

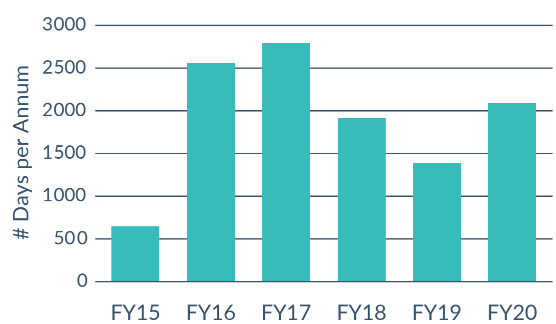
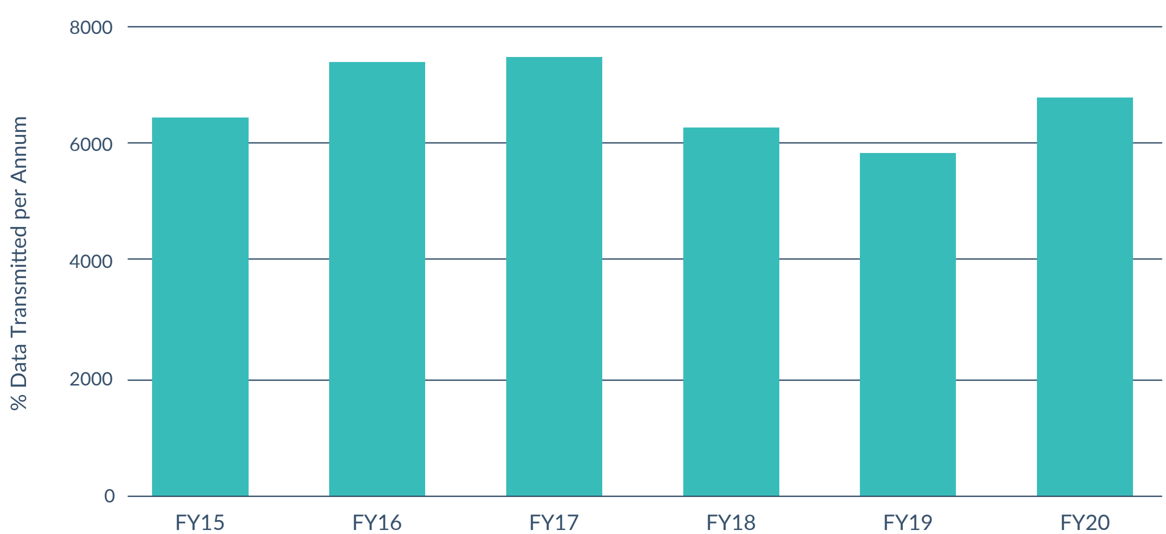


FIGURE 13. Interagency observing days, OOI + NOAA OAP from fiscal year 2015 to fiscal year 2020.



METRIC: Delivery of data from surface moorings (70% target)

It is important that the data being collected by surface moorings are transmitted from the observing platform to the scientists. This indicator is a quality metric and is calculated as the number of *actual observing days* divided by *optimal observing days* possible for a given mooring (see above). An actual observing day occurs when an observing asset successfully transmits a minimum of eight observations obtained from each of the three sensors (temperature, salinity, and pCO_2) each day distributed across the diel cycle. Ideally, the number of actual days should equate to the optimal number of observing days such that the derived indicator is 100%. However, provided that each GOA-ON asset demands annual servicing and maintenance, it is expected that no GOA-ON asset will successfully report 100% of the time. Rather, depending on the asset, it may be taken off-line for a period of days to weeks if there is a problem or to complete regular servicing and maintenance. In addition, sensors fail and it takes time to organize a sensor replacement or the replacement is done on the next planned maintenance cruise. As a result, we define 70% network-wide as a suitable objective for the network. Due to unforeseen events such as sensor failure or extreme weather events which demand off-lining an asset, it is possible that the indicator may not achieve 70% in a given year, but in general, this is the intended target. Consistent low delivery

FIGURE 14. NOAA OAP asset data transmission rates from fiscal year 2015 to fiscal year 2020.

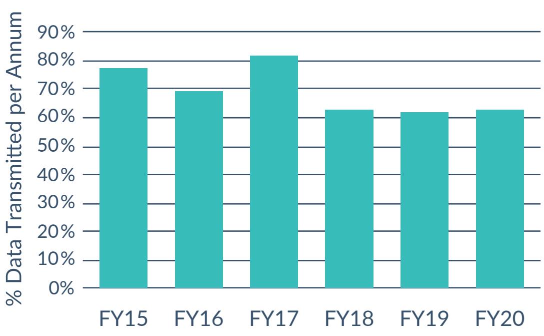


FIGURE 15. % Data transmission rates from OOI from fiscal year 2015 to fiscal year 2020.

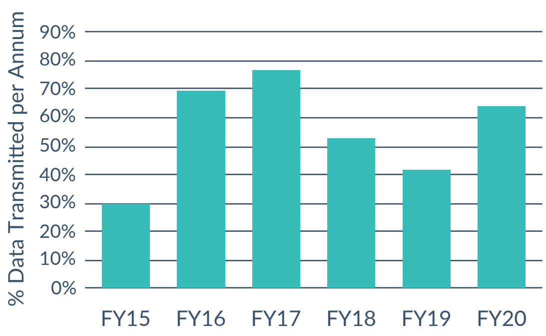
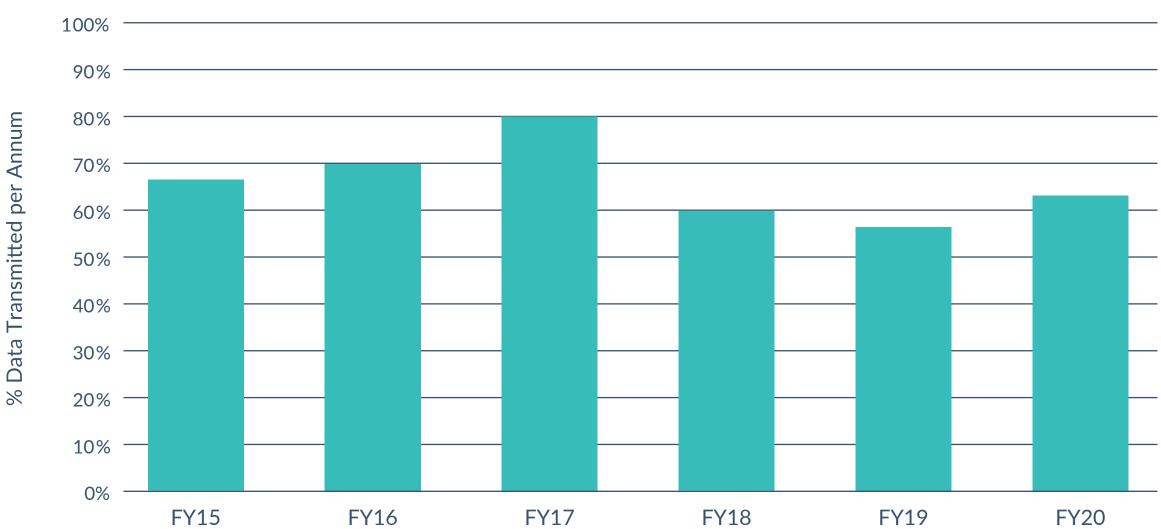


FIGURE 16. Data transmission rates from fiscal year 2015 to fiscal year 2020 for NOAA OAP and OOI assets.



of data may indicate a systemic problem in the network. Since FY 2015, the overall delivery of data has been relatively stable, ranging from 56% to 80% per year, with some sustained decrease in performance since FY 2018. Data returns in FY 2019 and FY 2020 were due in part to the government shutdown and COVID-19, both of which resulted in limited access to the moorings.

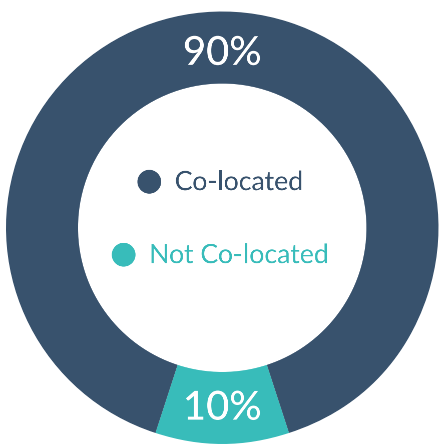
Both the observing days metric and the percent data delivery metric indicate that, since 2018, the overall health of the ocean observing system has decreased slightly, with some recovery in 2020. The decrease is partially due to the extended government furlough in 2019 and COVID-related delays to asset maintenance. The decrease in 2018 was primarily due to OOI sensors failing in exceptionally harsh environments (e.g. the Southern Ocean and the Irminger Sea). The ultimate goal is to have as many assets as possible operating at or above 70% data delivery, with some deviation around this expected from year to year. The observing system is still very dependent on our ability to consistently resource, access, and maintain the sensors.

METRIC: # of co-located complementary observing sensors that include some or all of: dissolved oxygen, optical parameters, turbidity, or nitrate.

For OA, co-location of sensors refers to having an additional sensor in the water (e.g. dissolved oxygen, turbidity, nitrate, and optical parameters such as chlorophyll or CDOM fluorescence, and particle backscattering), on the same platform as where OA measurements are being collected. Having co-located sensors augments the power of OA measurements by providing additional environmental information in which to put measurements in context. Co-locating sensors can, in addition, help improve the ability to quality control sensor data, and provide information on other variables that are important to, for example, water quality. Similar to the number of observing days metric, this metric serves as a baseline indicator of the number of assets that are in the water. Ideally, the complementary observations should either expand (co-located instruments added to existing OA moorings, or OA sensors added to other moorings with additional sensors; this would be a sign of a 'healthier' system) or remain the same. A contraction or reduction of the number of co-located sensors would indicate a decline in the observing system, which would have a negative impact on environmental monitoring. Much like the previous metrics, analyzing the trend from year to year is the most important factor.

Of the 88 assets inventoried in the second year, 79 (90%) of the assets contained an additional sensor and are therefore considered to be co-located. This represents an increase from the pilot year of 2019. However, the delisting of several assets makes the Year Two metric not directly comparable to the Year One[1] metric.

FIGURE 17. Co-located assets out of 88 total assets.

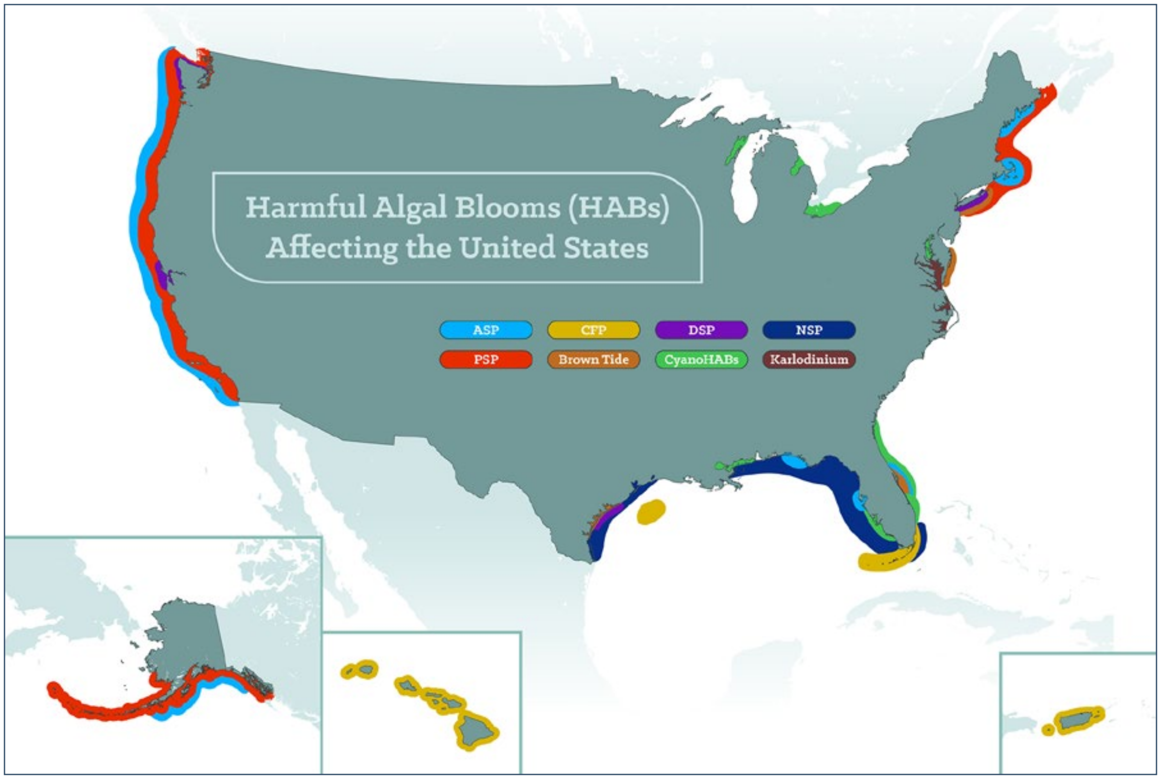


THEME: HARMFUL ALGAL BLOOMS

Harmful algal blooms (HABs) occur when populations of some algal species grow at problematic levels, sometimes producing toxins that can have harmful effects on people, fish, or other animals and can contaminate seafood in the marine and Great Lakes environments. HAB occurrence, intensity, and duration have been increasing in recent years, costing an estimated $100 million in economic losses each year (Hoagland & Scatasta, 2006) and endangering public health and marine ecosystems. Nearly every coastal and Great Lake state is now impacted by HABs. Forecasting and providing warnings of HABs can prevent public consumption of toxic seafood, prevent inhalation of toxic aerosols, prevent harm to fish and marine mammals, and help environmental managers respond effectively. Programs at the state, tribal and Federal levels contribute to algal bloom forecasts and warnings that protect public health and local economies. These efforts also allow researchers to better understand the characteristics of specific HAB species and their potential impacts on coastal communities. Robust observing networks are essential to predicting and mitigating HABs and their adverse effects.

The U.S. coastal marine and Great Lakes regions experience HABs differently based on the species that bloom in the region, the oceanographic and physical drivers of the bloom, the toxins they produce, and the impact they have on the ecosystem, people and economies. Monitoring programs must take into account these regional differences by adopting appropriate methods and technologies.

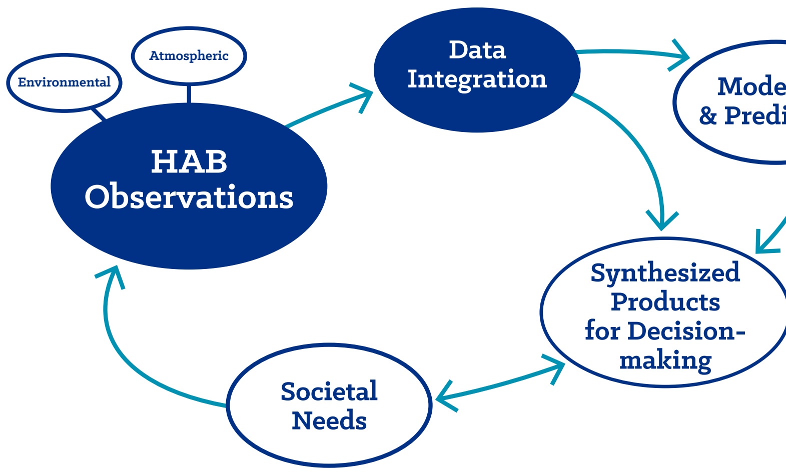
FIGURE 18. HAB threats around the U.S. coastal marine and Great Lakes r egions produce a variety of toxins: Amnesic Shellfish Poisoning (ASP), Ciguatera Poisoning (CFP), Diarrhetic Shellfish Poisoning (DSP), Neurotoxic Shellfish Poisoning (NSP), Paralytic Shellfish Poisoning (PSP), Brown Tide, Cyanobacterial HABs, and Karlodinium.



METRIC: IOOS Regions that contribute to HAB observing network capabilities

Contributions to HAB observing network capabilities include deployment of HAB monitoring platforms, providing HAB observations, or measuring other physical or environmental parameters related to HAB initiation and growth. Some regions with advanced HAB monitoring programs use observations to generate HAB forecasts and alerts for local stakeholders. For the purposes of this metric, we also include regions that contribute to the observing network through coordination of state and local communities to provide and distribute information in coordination with NOAA and the other IOOS regions.

FIGURE 19. HAB observations support early warnings and forecasts that are key to keeping communities safe.



Several of the IOOS regional observing systems and regional scientists have capabilities that contribute directly to forecasting programs. These systems collect observations, as well as developing and contributing to forecast models and data management, integration and dissemination. In the Gulf of Mexico, NOAA's National Centers for Coastal Ocean Science (NCCOS), in partnership with the Gulf of Mexico Coastal Ocean Observing System (GCOOS), contributes funding for HAB forecasts along the coasts of Florida and Texas, helping to predict and monitor *Karenia brevis* blooms that cause red tide. The Center for Operational Oceanographic Products and Services (CO-OPS) and other NOAA offices collect data from a variety of HAB monitoring partners in the region and analyze the information to predict where a bloom might develop and/or travel and publish a forecast bulletin weekly. The Southeast Coastal Ocean Observing Regional Association (SECOORA) supports moorings that are used by the State of Florida to understand bloom dynamics. In the Great Lakes, CO-OPS issues Lake Erie forecasts once or twice weekly during HAB season. The Great Lakes Observing System (GLOS) supports the data portal that provides streamline access to the multiple observations. The NCCOS is also providing funding support for pilot HAB forecasting systems in the Gulf of Maine and the Pacific Northwest. The Northwest Association of Networked Ocean Observing Systems (NANOOS) works with partners to produce a HAB bulletin, detailing current HAB risks for coastal managers. In California, the two IOOS Regional Associations, Central and Northern California Coastal Ocean Observing System (CeNCOOS) and the Southern California Coastal Ocean Observing System (SCCOOS), support the HABMAP project that collects data from shore stations and the C-HARM forecast for predicting outbreaks of *Pseudo-nitzschia*, the diatom that can produce domoic acid that has caused extensive and costly fisheries closures, marine mammal mortality events and is also a health risk to humans.

Another contribution of the regions is facilitating and coordinating HAB networks. HABs have long been an issue in the Gulf of Alaska. Threats to human health and food security are new for Arctic communities, and the danger is rising with unprecedented warming ocean temperatures. AOOS and its partners organize community sampling in remote rural areas that depend on shellfish for subsistence, and have initiated new HAB monitoring technology. In the Caribbean, CariCOOS works with the University of South Florida and displays their Floating Algae Index on their website to alert people to large matts of *Sargassum* that can overwhelm beaches and waterways. MARACOOS has identified HABs as a priority in their new five-year proposal. Ciguatera Fish Poisoning (CFP) is prevalent throughout the Pacific Islands and can have long lasting, devastating impacts on individuals, their families, and fishing communities. While the Pacific Islands have some of the highest rates of CFP, most cases likely go unreported.

FIGURE 20. IOOS regions with HAB occurrences and observing capabilities that contribute to forecasts.

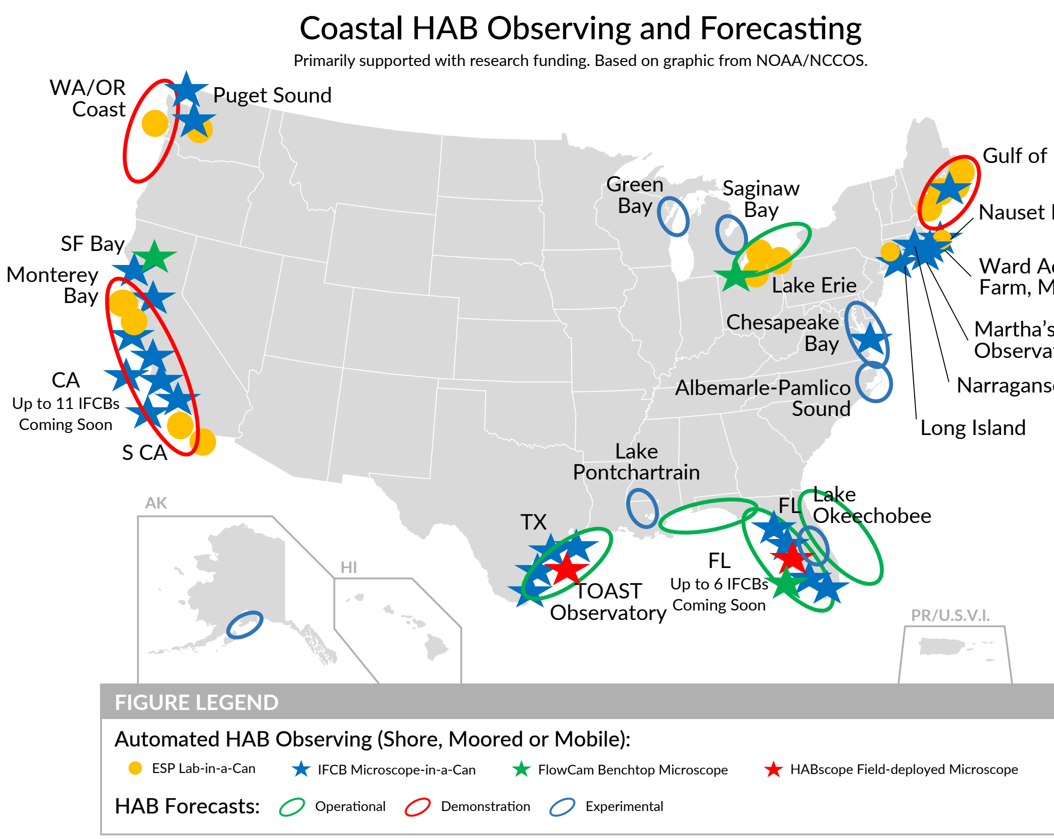
In total, ten of the eleven US IOOS Regional Associations contribute to the HAB observing network (Figure 20). While this is not an increase from the first year report, every region has increased HAB observing efforts and coordination in response to the growing HAB problem in all regions.

HAB monitoring is also conducted by state and other agencies responsible for public health and safety, by researchers and regional observing systems and, in some cases, by volunteers. In the lab, samples can be evaluated through microscopic enumeration, molecular probes and images that measure algal cell abundance, and antibody probes can test for the presence of toxins. Several regions use automated instruments, such as Environmental Sample Processors (ESPs) and Imaging FlowCytobots (IFCBs), which are deployed *in situ* or at shore-based installations to detect, identify, and measure harmful algal cells or toxins. Satellite images of coastal waters can also be used to identify HABs by measuring algal pigments in the water. In the Gulf of Mexico, low-cost observing units called HABscopes rely on citizen science and image analysis software to indicate bloom intensity of *Karenia brevis*, and this technology is currently being expanded to address other species.

Metric: Number of IOOS Regions with automated HAB sensors

Automated sensors provide the capacity to rapidly detect both existing and emerging species. Each region faces unique HAB challenges; the suite of technologies needed in each region varies and depends on the species, physical drivers, platforms available, and other factors. For example, IFCBs do not work well for most freshwater cyanobacteria so in the Great Lakes, ESPs, hyperspectral imaging, and other technologies are appropriate. Accordingly, the actual type and distribution of instruments must be adapted to regional needs. For the purposes of this metric, we are focusing on sensors that can detect either HAB species or toxins such as the ESP, IFCB, HABscope and FlowCam. Currently, eight of the eleven IOOS regions operate at least one type of HAB sensors.

FIGURE 21. HAB observing instruments and forecasts around the marine coastal U.S. and Great Lakes. This map represents two metrics: 1) number of IOOS regions with HAB sensors and 2) number of HAB forecasts transitioned from research to sustained services ("operational") based on information provided by NOAA/NCCOS (5/19/21).



METRIC: Forecast Products to be Transitioned from Research to Sustained Services

Forecasts and early warning systems require sustained observations. Currently, most of the observations that are used in the forecasts models are supported by short-term research grants, not by standing programs. For over twenty years, the IOOS Regional Associations (RAs) have operated coastal observing systems that collect and integrate data, providing a system for sustained support of HAB observations and forecasts. Some of the IOOS RAs support or integrate HAB data collected by ESPs, IFCBs, and other HAB observing instruments. The RAs work with partners from the local, tribal, state, and federal governments, researchers, and others to support these systems.

Since advance or early warning of a possible HAB event is important to managers, fishermen, Tribes and others, the status of forecast products is examined here as an indicator of HAB observing capabilities. Of the 13 forecast products currently active around the U.S., five have been transitioned to NOAA and are considered by NCCOS to be a sustained service (i.e., “operational”). Of the five sustained products shown in Figure 21, four are located in the Gulf of Mexico and the east coast of Florida. The other sustained product provides forecasts for the Great Lakes, primarily western Lake Erie. Demonstration products are those that are consistently delivering forecasts but are not yet determined a sustained forecast according to NCCOS. These include forecasts in the Pacific Northwest, Gulf of Maine, and California. It should be noted that the California Harmful Algae Risk Mapping (C-HARM) model has been transitioned to NOAA’s CoastWatch as an operational product. The goal is to have all demonstration and experimental products transition into sustained services.

THEME: *IN-SITU* HURRICANE OBSERVATIONS AND FORECASTING

This year's report adds pilot metrics for *in-situ* hurricane observing and forecasting. Hurricanes over the past several decades have increased in both number and intensity. One of the main contributing factors to the intensity is warm water. As our oceans warm, they can fuel stronger and potentially more destructive storms (USGCRP, 2018). A single hurricane can cause billions of dollars in damage; the 2017 hurricane season amounted to $265 billion of loss (NOAA, 2019). Direct and indirect effects of hurricanes can result in upheaval of communities and significant loss of life. Improving prediction capability both for track and intensity will save lives and help coastal communities build better infrastructure.

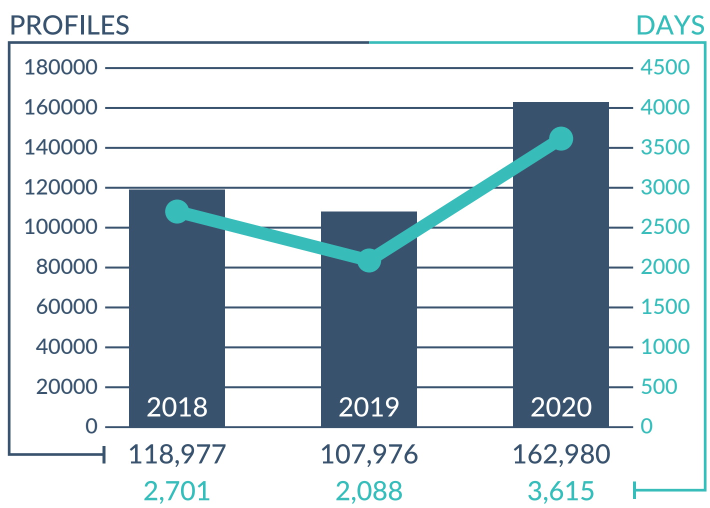
Ocean observations are the backbone for understanding the conditions for these storms and improving forecast capability. Gliders, drifters, and other robotic instruments (including Argo and Air-Launched Autonomous Micro-Observer floats) all contribute to this knowledge by constantly collecting information about oceanic conditions. These data inform hurricane models, which give coastal managers and decision-makers advanced warning of a potentially destructive storm. Improving observations can help increase the lead-time and accuracy of a hurricane forecast.

METRIC: Number of Temperature and Salinity Glider Profiles Providing Observations Per Year

Temperature and salinity profiles help inform hurricane intensity forecasts by providing critical environmental data which informs scientists and gives responders additional time to alert the public about the severity and location of hazards. Research indicates that "the correct monitoring of ocean temperature and salinity in the upper hundred meters of the ocean improves hurricane intensity forecasts" (*NOAA AOML*). Autonomous underwater vehicles, specifically gliders, are an essential platform for collecting subsurface real-time data in the face of a hurricane.

Measuring glider-days is a way of quantifying the temporal coverage of the glider fleets over both shallow and deep water locations. Glider profiles are the actual data, but in shallow water gliders can collect numerous profiles in a short time period, while in deep water only a few profiles are collected in that same time period. Data assimilation methods generally used by operational models are currently only selecting 1 profile/day regardless of how many are collected. Therefore, Glider-days is an approximate metric for the amount of data currently used for assimilation.

FIGURE 22. Annual Glider Profiles and Days



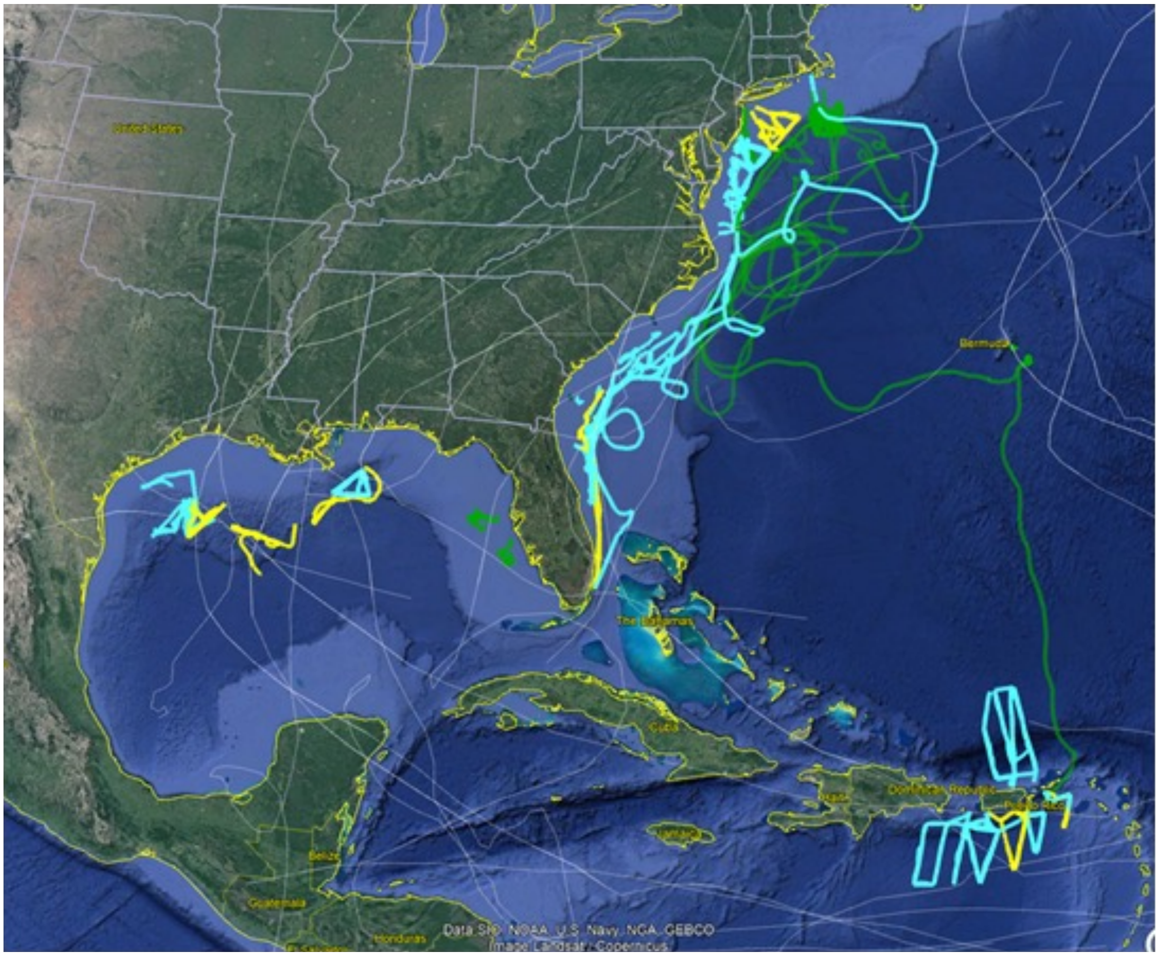
Over the course of the 2020 hurricane season, NOAA, Navy and NSF completed 3,343 glider days and 163,022 profiles. This distributed network allowed for glider operations to continue even during the COVID pandemic, supported in part by supplemental hurricane funding.

METRIC: # of Glider Lines Providing Observations to Hurricane-Prone Areas in the Atlantic

Glider lines in the hurricane-prone Atlantic (defined as the deep water and continental shelves including the Caribbean, Gulf of Mexico, South and Middle Atlantic Bights) are critical to supporting, evaluating, and developing operational ocean models that provide initial ocean conditions to operational coupled hurricane forecast models. The ocean is the source of energy that supports intensification or, when colder than the atmosphere, weakening of storms before they make landfall. Gliders are able to sample across fronts and interfaces horizontally and vertically mapping essential ocean features that can intensify or weaken hurricanes. Specific features of note include the 1) the Caribbean warm pool and salinity barrier layers, 2) the Gulf of Mexico Loop Current, Loop Current eddies, and western gulf eddy fields, and the Mississippi River plume 3) The Gulf Stream, and 4) the Mid Atlantic Cold Pool, among other regional and local features and processes. These glider lines complement Argo floats, surface drifters, and air-deployed assets that cannot sample across these features, have limited ability to maintain a position, and are not designed for shallow water use, filling a critical data gap.

As of Fall 2020, 26 glider lines were providing observations to hurricane-prone areas in the Atlantic Ocean. NOAA,Navy, state governments, private industry and foundations contribute to these observations. (*https://gliders.ioos.us/map/#*).

FIGURE 23. Glider lines providing observations in the hurricane-prone Atlantic.



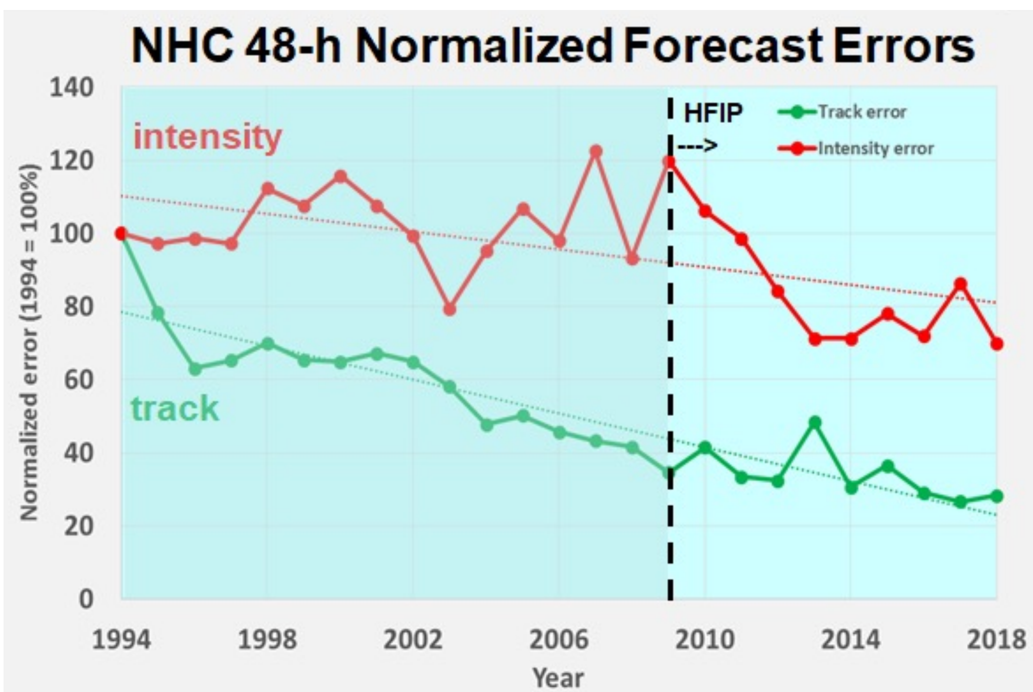
METRIC: Impact of ocean observations to reduce errors in operational hurricane forecasts

Sustained observations (collected year-round or seasonally, including hurricane season) are critical to forecasting the track and intensity of a hurricane. Observations are collected by a suite of different instruments, including satellites, gliders, drifters, moorings, profiling floats, observing ships, and more operated by NOAA, NASA, and the U.S. Navy, in addition to other partners.

In June 2007, the Hurricane Forecast Improvement Program (HFIP) was established within NOAA in order to reduce hurricane track and intensity forecast errors. A reduction in error ultimately results in more accurate forecasts about the track (path) a storm will take and how severe the storm will be. Additionally, models informed by more numerous and accurate observations yield more accurate forecasts, giving coastal communities more warning time. Over the last couple decades, hurricane forecasts have been improved by major investments in oceanographic, aircraft, and satellite observations, as well as improved data assimilation, numerical modeling systems, and expanded forecast applications. However, hurricanes remain a potent threat to the U.S. coastline. Continuing to improve observations and reduce forecast errors will reduce damage by increasing warning time and accuracy of information. This metric characterizes the trend in forecast error since the inception of HFIP. A positive trend would be continued reduction in forecast error and increase in forecast lead-time.

Since 2009 and the implementation of HFIP, **NOAA hurricane track forecast errors have been reduced by approximately 30%. Intensity forecast errors have been reduced by approximately 25%**. While it is difficult to quantify exactly how much of this error reduction is due directly to ocean observations, they are certainly a key piece of the process.

FIGURE 24. Reduction in Hurricane Forecast Track and Intensity Errors from 1994 to 2018. The graph is based on National Hurricane Center (NHC) average operational errors at 2 days (48 h), which is the current actionable time frame for hurricane warnings.



SUMMARY OF FINDINGS

The second annual report, *Measuring the Performance of Ocean Observing Systems*, continued the collection of pilot metrics and added an additional category for hurricanes. Only incremental change was detected between 2019 and 2020, however the process yielded valuable information about repeatability to evaluate collecting these metrics on an annual basis, which will ultimately demonstrate longer term trends. Sustained collection and tracking of these metrics over time will eventually lead to the ability to evaluate the performance of ocean observing systems and identity improvements or gaps in the observing system. These individual ocean observing metrics, compiled and presented as a whole, paint a vivid picture of where the United States, and to a large extent, the world stands in its ability to measure ocean properties and change. The number of instruments in the ocean do not alone provide a meaningful metric, they must connect to the ability to measure something that has relevance to society. For instance, the pilot metrics for this study show that while it appears that the United States has adequate tide gauges dispersed across the coastlines to measure sea level, the percentage of those co-located with GPS are very low (20%), handicapping the ability to accurately distinguish between shifting sea level versus shifting sea beds. Alternatively, observing assets providing ocean acidification data are meeting or exceeding the 70% efficiency metric annually, demonstrating that the current coverage of pCO_2, pH, alkalinity, and dissolved inorganic carbon measurements can provide a baseline of chemical parameters and changes in the regions they are currently deployed. Establishing metrics for other variables of interest is more difficult, as in the case of Harmful Algal Blooms (HABs). The authors were only able to determine "regions" where HABs data are collected or to estimate the damage HABs cause, which highlights the need for more accurate observing capabilities. Overall, this report shows that metrics are essential for evaluating how well the United States monitors and predicts ocean properties and changes.

Establishing metrics across U.S. federal agencies and stakeholders is a challenging process that requires significant time and effort to initiate. This inherent difficulty prompted the task team to constrain the analysis to pilot metrics focused on four topics spanning the biological, physical and chemical sciences, and which have significant relevance to society: Sea Level Rise, Ocean Acidification, Harmful Algal Blooms, and Hurricanes. With the selected metrics topics, the team addressed the two core objectives of this exercise: *identifying the audience for IOOS metrics and developing a suite of measurable and repeatable metrics*. **In total, this report identifies 5 broad audience categories and 13 pilot metrics across 4 themes.** The efficacy of metrics derived in this analysis varied considerably but provides a sound basis for addressing the remaining objectives: *recommending a collection process; assessing future projects; targeting the audience; and providing next steps beyond pilot metrics.*

METRIC RESULTS

Identifying pilot ocean observation metrics for Sea Level Rise, Ocean Acidification, Harmful Algal Blooms, and Hurricanes produced a baseline for evaluating these topics and a potential model for broader data collection. Overall, the metrics demonstrate that observing capabilities vary across themes, and provide useful analysis of observing capabilities.

SEA LEVEL RISE

Changing sea level is primarily observed using tide gauges and satellites. For tide gauges, experts have determined that the accuracy is also dependent on the shifting sea floor on the earth's crust due to a variety of factors – measured using GPS or GNSS. The baseline metric for measuring sea level are the 210 coastal tide gauges in the U.S. that report real-time (within 24hrs) and open data to the public. These tide gauges span the entire U.S. coastline, including Alaska, Hawaii, and the

Great Lakes. Only 31 out of the 157 coastal stations (20%) are currently co-located with GPS or GNSS capabilities. The U.S. is also working to make these data accessible through SONEL. Looking at global sea level observing capabilities, there are 293 GLOSS stations and with 222 (76%) co-located with GPS or GNSS capabilities. Finally, satellite altimetry measurements provide the percentage of the world covered by oceans. Currently, 70%-72% of ice-free areas are observed every 10 days, which will increase with the addition of newly-launched satellite Sentinel-6 Michael Freilich. In summary, the metrics show that while sea level measurements are sufficient for providing estimates, significant improvements are needed in co-locating U.S. tide gauges with GPS and GNSS, as well as feeding the data into global assembly centers.

OCEAN ACIDIFICATION

Observing ocean acidification requires the collection of several ocean variables (pCO_2, pH, alkalinity, and dissolved inorganic carbon, as well as temperature and salinity) to provide an accurate depiction of changes. Successfully capturing ocean acidification measurements in coastal zones with dynamic conditions requires the ability to measure many or all of the referenced variables on one platform with a consistent frequency of sampling. The goal of these metrics is to (1) build a comprehensive list of all OA assets and the data provided from all relevant U.S. government agencies, (2) establish a baseline of the 'health' of the system which can be tracked using the established metrics, and (3) document the state of OA publications on a national level. An inventory of U.S. surface moorings found that there are a total of 88 assets, down from 101 due to delisted, discontinued, or undeployed assets. Of these inventoried assets, the overall footprint of the OA observing, as measured by # of observing days, is fairly consistent, demonstrating consistent investment in OA observing over time. The delivery of data from assets was on average around the target percentage (70%), but with years that were above and below the target. While some variability is normal, it is important to look for long-term trends, to see if there are systemic problems through the observing networks. This is the first year that the task team was able to collect comparable data from two different agencies (NOAA and NSF) and combine the data to produce a truly interagency metric, in this case the number of observing days. This allows us to evaluate the function of U.S. observing systems as a whole, and offers insight into the relative capabilities of each agency. This data will be shared with other interagency groups, and may serve as a model for the potential of metrics moving forward.

In terms of co-located complementary observing sensors, 79 (90%) of the assets contained an additional sensor and are therefore considered to be co-located, with the caveat that there were fewer assets recorded due to the reasons stated above. A future iteration of the metric might compare the percentage of assets solely measuring carbon parameters with the percentage of assets measuring carbon parameters plus one ancillary biogeochemical measure, plus two ancillary biogeochemical measures (and so on). This would provide us a gauge of how many stations are highly instrumented versus sparsely instrumented. Over time, the pie chart would ideally demonstrate an increase in the number of highly instrumented stations.

HARMFUL ALGAL BLOOMS

To characterize the specific and diverse needs for HAB monitoring and forecasting, a regional approach is necessary. Regions work in conjunction with the appropriate state, federal, tribal and other partners. Several of the IOOS regions have observing capabilities that contribute to forecasting programs. IOOS regional observing systems contribute by collecting observations, developing and contributing to forecast models and in data management, integration and dissemination. Almost all of the eleven U.S. IOOS Regional Associations contribute to HAB forecasts and monitoring, and eight of the eleven regions operate automated sensors that help detect or characterize HABs. Sustained observations are needed to support forecasts and warning systems. In 2020, five of the thirteen HAB forecasting products are considered sustained (i.e. “operational”). Sustained programs ensure that observations will be collected consistently from year to year, and provide consistent support to coastal managers.

In iterations of metric collection, this report recommends expanding HAB observing metrics to consider the following:

1. Expanding data collection beyond NOAA NCCOS and IOOS, to include broader interagency contributions;
2. Evaluation of the amount of funding that supports HAB observing and forecasting; and
3. Determining the number of automated HAB sensors per region.

HURRICANES

Ocean observations are the backbone for understanding the conditions for hurricanes and improving the nation’s forecast capability. Gliders, drifters, and other robotic instruments contribute to this knowledge by constantly collecting information about oceanic conditions. Improving observations can help increase the lead-time and accuracy of a hurricane forecast. Over the course of the 2020 hurricane season; NOAA, Navy and NSF completed 3,343 glider days and 163,022 profiles. This distributed network allowed for glider operations to continue even during the COVID pandemic. These data were served by 26 glider lines in the hurricane-prone Atlantic (defined as the deep water and continental shelves including the Caribbean, Gulf of Mexico, South and Middle Atlantic Bights). Since 2009, these in-situ investments have resulted in NOAA hurricane track forecast errors reduced by approximately 30% and intensity forest errors by approximately 25%. These models informed by more numerous and accurate observations yield more accurate forecasts, giving coastal communities more warning time. In future years, metics could be expanded to include analysis of satellite observations for hurricane tracking and forecasting.

LESSONS LEARNED

The metric research produced a wide variety of results—some metrics are easy to track and show clear opportunities for growth, while others revealed gaps in consistent measurements and information-sharing. Metrics that proved more difficult to collect share a number of common challenges, chiefly that Federal agencies may monitor the same type of assets or systems, but the format or tracking methodologies often differ, making standardization and integration challenging. Resources and even definitions are not always consistent. For example, when collecting data on the number of sustained assets for a given measurement, the term “sustained” is defined differently depending on the source, making it difficult to identify contributing assets. Some of the metric data required a specific request of an agency scientist (versus centralized clearing houses of information, such as *GOOS Ocean-Ops*). This makes consistently monitoring the metric over a significant amount of time more burdensome and prone to inconsistencies in the way the metric is calculated. Finally, collecting national metrics may fail to capture the unique challenges and capabilities faced by different regions. With a theme such as Harmful Algal Blooms, observing needs can vary widely based on the characteristics of the coastal area and the algal species. In this case, metrics on HAB observing capabilities are better served by taking a regional approach as opposed to a national one.

NEXT STEPS AND ACTIONS

Developing pilot metrics is only the beginning of the process. Metrics must be used and evaluated over time to determine if they are meeting their intent and showing progress toward goals; ultimately to inform decision-making processes. Moving this effort beyond the pilot phase to sustained collection of metrics, should take into account the following factors:

1. Level of effort and funding required to find the data (weighed in relation to the predicted value of the metric).
2. Identifying an agency or program that will commit to regularly tracking the information;

Moreover, to maximize the potential value of metrics, each should be accompanied by a minimum level of documentation established by the metric developers. This will ensure data are collected with consistent methodology and at the established intervals. Additionally, best practices, including the recommendations listed below, should be standardized and each metric should be provided for review (e.g. by the IOOC) on a regular (perhaps annual) basis:

- **Metric ownership:** While each pilot metric relies on support from multiple federal and non-federal agencies, one federal agency should be named as lead for tracking, evaluating, and reporting on the measure to the IOOC and other groups as identified. All parties contributing to the outcome of each metric should be included in the details for transparency.
- **Metric tracking:** The metric lead should work with contributing parties to develop a process for tracking, to include shared resources to view progress toward the goal. The process should include a schedule for parties to provide information on progress (eg, quarterly, semi-annually) to the lead agency. The lead agency should work with the IOOC to determine the best means for reporting progress to the committee.
- **Metric evaluation and reporting:** During the course of the first year, the lead agency should ask all contributing parties for information on if and how they are using the metric with their stakeholders. Identifying audiences for the metrics should be a component of the annual evaluation and contribute to the success of the metric. Metrics should be evaluated regularly by contributing parties and users to evaluate the success of the measure, including recommendations for improvements or changes as needed. Outcomes and proposed changes from this evaluation should be reported to the IOOC at their discretion.

Program managers should consider how a metric contributes to ocean observing system design and inform the evolution of these metrics. While the complexities of the U.S. ocean observing system certainly make metric collection difficult, these same complexities point to the need for a systematic approach to evaluating our capabilities and ensuring investments are valuable to the ocean sciences community. Successful metrics can benefit program managers and researchers by defining how instruments and capabilities are working together and advancing our knowledge of the ocean.

DETERMINING FUTURE METRICS

The lessons learned in this pilot study are valuable in guiding selection of metrics and topics moving forward. Potential themes should be evaluated based on their feasibility, relevance, and ability to contribute to a more robust understanding of the U.S. ocean observing system. Authors selected four topics in the study, Sea Level Rise, Ocean Acidification, Harmful Algal Blooms, and Hurricanes (added in Year Two) due to their perceived maturity and accessibility of data. Below is a strategic map of the Global Ocean Observing System elements (Figure 13, Table 3), which illustrates relationships to the core GOOS panels across major societal themes. This offers a list of 24 thematic topics, including the three addressed in this report.

FIGURE 25. GOOS Strategic Map, potential topic areas for future metrics.

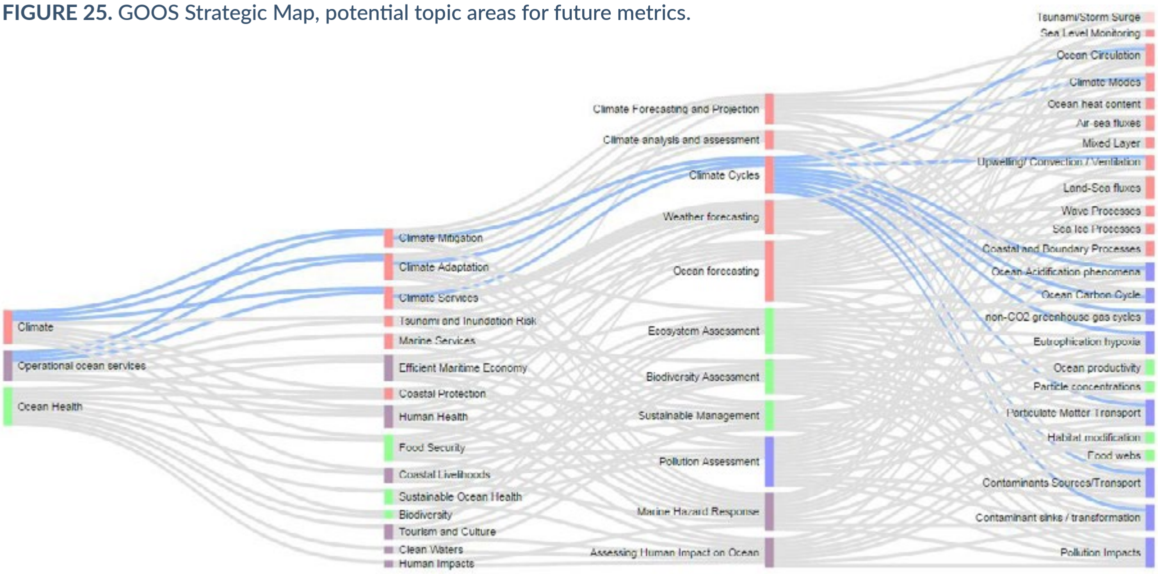


TABLE 3. Status of potential topic areas for future metrics.

Phenomena (Potential Metric Themes)	Status
Hurricanes	Pilot Phase Completed
Tsunami/Storm Surge	Uncollected
Sea level monitoring	Pilot Phase Completed
Ocean circulation	Uncollected
Climate models	Uncollected
Ocean heat content	Uncollected
Air-sea fluxes	Uncollected
Mixed layer	Uncollected
Upwelling convection/ventilation	Uncollected
Land-Sea fluxes	Uncollected
Wave processes	Uncollected
Sea ice processes	Uncollected
Coastal and boundary processes	Uncollected
Ocean acidification phenomena	Pilot Phase Completed
Ocean carbon cycle	Uncollected
non-CO_2 greenhouse gas cycles	Uncollected
Eutrophication hypoxia	Pilot Phase Completed
Ocean productivity	Uncollected
Particle concentrations	Uncollected
Particulate matter transport	Uncollected
Habitat modification	Uncollected
Food webs	Uncollected
Contaminants sources/transport	Uncollected
Contaminant sinks/transformation	Uncollected
Pollution impacts	Uncollected

CONCLUSION

Assembling metrics for ocean observing systems is not only essential for evaluating overall performance, but invaluable to decision-makers and operators for guiding future developments. The exercise in collecting pilot metrics was valuable for determining how much effort is required to collect quality indicators. The IOOS Enterprise - either through the Program Office, IOOC, contractors, or some combination thereof - should invest in collecting high-quality, repeatable metrics. The pilot exercise over two years demonstrated that substantial effort is required up front, but should level-out over time. Additional thematic topics should be investigated or reviewed to determine level of maturity for expanding beyond the pilot metric topics. The IOOC must also assess the process and resources required for agencies to contribute towards those metrics; and suggest ways to assess the impact of metrics on the target audience.

SUMMARY OF RECOMMENDED NEXT STEPS

Based on this effort, establishing metrics beyond the pilot themes will require substantial coordination initially through one or more task teams relying on voluntary federal and non-federal contributions, staff support, and meeting support for at-least one in-person and many virtual. The minimum investment to continue progress is $30,000 and increases beyond that amount will yield higher quality results proportional to the effort. One simple way to calculate an estimate for the optimal initial investment for establishing metrics across all ocean observing phenomena is to multiply the $30,000 invested in this pilot phase for 3 themes ($10,000 per theme) by the number of themes - or $240,000. That would be the high-end initial investment, and then maintaining the collection of these metrics would normalize to half of a full-time employee or intern to update the text and figures each year.

These examples demonstrate the potential for cross-agency metrics and their inherent value to monitor progress towards addressing observing requirements and the increasing need for ocean knowledge as well as successful applications of such knowledge. The primary criteria for such metrics remains its relevance towards articulating the value of ocean observing information and informing decisions. When designed and executed successfully, such metrics should contribute towards guiding and promoting further investments, and the “I” (Integrated) value of IOOS. In the immediate term, the task team will coordinate results with other interagency groups (IWG OA, IWG HABHRCA, etc.) and the broader observing community in order to discuss results, solicit feedback, and discover potential applications of the metric data.

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