REPORT TO CONGRESS

USE OF UNMANNED MARITIME SYSTEMS

Developed pursuant to: The Commercial Engagement Through Ocean Technology Act of 2018 (33 U.S.C. 4101 et seq.)

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THE COMMERCIAL ENGAGEMENT THROUGH OCEAN TECHNOLOGY ACT OF 2018 (33 U.S.C. 4101 ET SEQ.) INCLUDED THE FOLLOWING LANGUAGE

IN GENERAL.—In carrying out this Act, the Administrator shall, not later than one year after the date of the enactment of this Act, and every 4 years thereafter, submit to the appropriate committees of Congress a report on the usage of unmanned maritime systems for the mission of the Administration.

(b) CONTENTS.—Each report submitted under subsection (a) shall include, for the period covered by the report, the following:

(1) An inventory of current unmanned maritime systems used by programs of the Administration, a summary of the data they have returned, and the benefits realized from having such data.

(2) A prioritized list of data requirements of the Administration that could be met with unmanned maritime systems, and the commercially available unmanned maritime systems with the operational capabilities to collect such data.

THIS REPORT RESPONDS TO THE COMMITTEE'S REQUEST.

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I. EXECUTIVE SUMMARY

Unmanned Maritime Systems (UMS) are becoming increasingly important for collecting data to support NOAA's diverse mission requirements, including fishery and hydrographic surveys, oceanographic and atmospheric observations, and information critical for marine ecosystem characterization and assessment. Additionally, UMS have become an important tool for augmenting traditional methods using manned ships and aircraft. They have proven to be particularly adept at facilitating missions in remote, data-sparse locations, hostile environments, and for sampling efforts of long duration. As a force multiplier, UMS are increasing NOAA's presence in and on the ocean, and their use will continue to grow. NOAA's use of UMS spans multiple Line Offices (LO) and includes a wide variety of maritime mission uses. (NOAA has changed their nomenclature to 'Uncrewed Systems' but is maintaining the original congressional language for this report.)

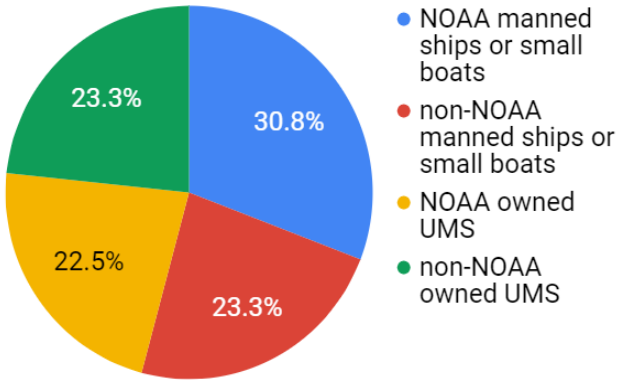
II. NOAA's USE OF UNMANNED MARITIME SYSTEMS

There are many ways in which NOAA currently uses UMS. A few relevant points to consider include:

- The use of UMS by NOAA and NOAA-funded partners is rapidly increasing.
- NOAA's use of UMS meets all applicable requirements for safe navigation.[1] Transitioning UMS from research, i.e., evaluating their effectiveness for meeting NOAA mission requirements, to operations can evolve very rapidly.
- The use of UMS operational approaches varies across NOAA and includes: purchasing, leasing, data buys, and integrated partnerships with other Federal agencies, academia, non-profit organizations, and industry via grants, contracts, and cooperative agreements, and Cooperative Research and Development Agreements (CRADA).
- NOAA has already deeply integrated the use of UMS into its navigation, observation, and positioning products and services. Such systems, including underwater gliders and unmanned surface platforms, are being heavily used by NOAA's Office of Coast Survey and the Integrated Ocean Observing System (IOOS).
- NOAA's Pacific Marine Environmental Laboratory (PMEL) pioneered the use of unmanned surface vehicles for oceanographic and atmospheric observations, as well as for fishery surveys. The use of such observing platforms within NOAA is increasing rapidly, with growing opportunities to transition them from research to systematic operations. These transitions are guided by the NOAA Administrative Order, *Policy on Research and Development Transition*.[2]
- In addition to owning UMS, NOAA Federal Laboratories and programs partner with other institutions that provide UMS for research and development, as well as operations.

[1] NOAA notes that USCG has not yet promulgated Best Practices for UMS, though USCG has taken agency comments on them. NOAA intends for all UMS it operates to be fully compliant with Applicable COLREGS and Best Practices. Generally, current surface vehicles are partially to fully COLREGS compliant to the extent practical.
[2] NAO 216-105B: POLICY ON RESEARCH AND DEVELOPMENT TRANSITIONS (www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216-105B.html)

Figure 1. Proportion of UMS platforms used to collect NOAA-mission data in Nov. 2018, as reported by NOAA's UMS users.



III. NOAA'S USE OF UMS DATA REALIZES NATIONAL AND MISSION BENEFITS

NOAA's existing UMS user community (e.g., scientists, program managers, forecasters, UMS operators who own, operate, task or use data from UMS) collects real world observations that support the agency's mission of science, service, and environmental stewardship. Capabilities are spread across all of NOAA's line offices, with the majority of existing NOAA-owned systems operated by the National Ocean Service, Oceanic and Atmospheric Research, and the National Marine Fisheries Service. Additionally, the National Weather Service provides logistical and information ingest support, while the National Environmental, Satellite, Data, and Information Service provides data processing, data serving, and data archiving support via the National Centers for Environmental Information.

The items on the following pages outline the use of UMS across NOAA. This information was collected by NOAA's Unmanned Systems Executive Oversight Board in the late summer and early fall of 2018 and presented at the NOAA-Unmanned Maritime Systems Symposium on October 31 – November 2, 2018.[3]

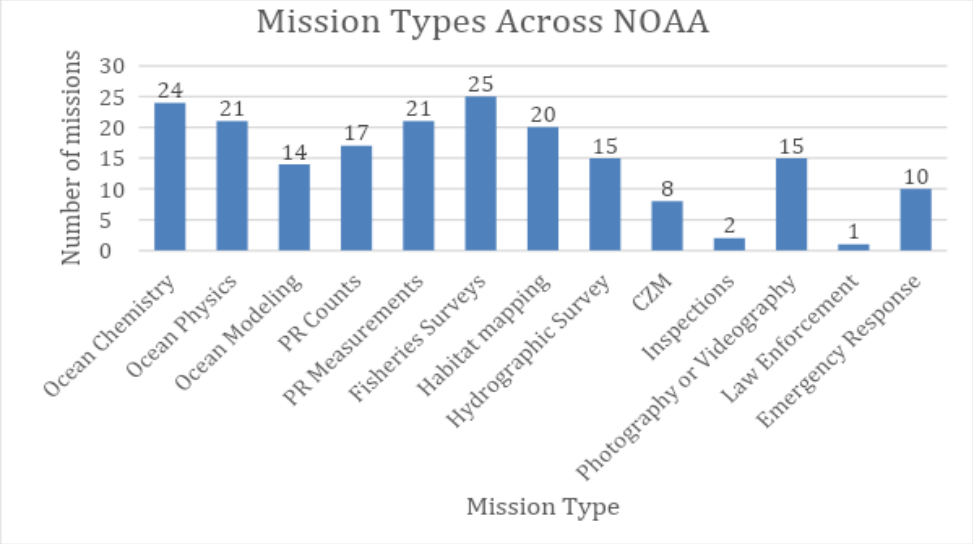
A. Recent Examples of Use of UMS and UMS-Delivered Data Across NOAA

- In 2018, the U.S. IOOS program coordinated efforts among multiple NOAA programs and external partners, including the U.S. Navy's Naval Oceanography Operations Command, to deploy a "picket line" of underwater gliders in the Gulf of Mexico, tropical North Atlantic Ocean, and Caribbean Sea. The gliders gathered

[3] A detailed symposium report that contains publicly releasable presentations and survey data is available online at: www.omao.noaa.gov/sites/default/files/documents/20190429_UMS%20Symposium%20Report.pdf

subsurface measurements to monitor the ocean's complex thermal structure and dynamic features during the Atlantic hurricane season, enhancing understanding of air-sea interaction processes that contribute to hurricane intensification and weakening. The data were transmitted to the World Meteorological Organization (WMO) Global Telecommunications System in real-time for assimilation into ocean and hurricane forecast models. The inclusion of glider data in the models reduced the error in NOAA's Atlantic hurricane intensity forecasts. Underwater glider operations continued in 2019 in support of hurricane studies and forecasts.

Figure 2. Range of mission types where UMS are used by NOAA for collecting observations from Nov. 2018.



Note: "PR Counts" refers to a Protected Resources count of organisms (e.g., organisms protected under the Marine Mammal Protection Act or listed under the Endangered Species Act).

- Texas A&M deployed an Optical Phytoplankton Discriminator sensor on a Slocum Glider as part of its support for NOAA through the Gulf of Mexico Coastal Ocean Observing System. This innovation is helping scientists answer fundamental questions about the composition of the background community structure in the Gulf of Mexico, important for determining the influence of climate change on harmful algal blooms and other phytoplankton and zooplankton communities. The sensor detects the presence of *Karenia brevis,* a toxic organism responsible for harmful algal blooms that negatively impacts both marine ecosystems and local economies.
- NOAA's PMEL worked in partnership with Saildrone, Inc. – a company that designs and manufactures a wind- and solar-powered unmanned surface vehicle – to assess the efficacy of a Saildrone platform in measuring the ocean's uptake of carbon dioxide, as well as passive acoustic tracking of fish schools in the Bering Sea. Collaborating

under a CRADA, the Saildrone transmitted formatted and packaged data from its sensor suites to PMEL for analysis. The data were made available to scientists in near-real-time, as well as to NOAA's National Data Buoy Center (NDBC) within the National Weather Service, for distribution on the WMO Global Telecommunications System. This UMS enables scientists to gather measurements in remote locations, typically under sampled, for longer periods of time than traditional methods. The missions were so successful that the methodology has become routine and is being adopted by other NOAA programs.

- The PMEL also worked on a collaborative venture with Kongsberg and the Joint Institute for the Study of the Atmosphere and Ocean (JISAO)[4] to develop the Oculus Coastal Glider. The Oculus glider works in the highly stratified, high energy, shallow depths of the Arctic Ocean, with sensors that measure temperature, salinity, dissolved oxygen, sunlight, chlorophyll, and other parameters. The Oculus has been successful in identifying numerous small eddies along the Bering Sea shelf. Some of these eddies have never before been observed and may play a significant role in predator-prey relationships among marine species.
- NOAA's Office of Coast Survey has been evaluating the use of UMS for its missions since 2004. Their goal has been to develop and use unmanned systems for more efficient and effective acquisition of environmental data in support of NOAA's navigation products and services, as well as support for NOAA's program requirements for habitat and water column mapping.
- NOAA's Southwest Fisheries Science Center (SWFSC) is incorporating data from buoyancy gliders and unmanned surface vehicles to provide science-based advice for the conservation and management of living marine resources in the California Current, eastern tropical Pacific Ocean, and Scotia Sea. This entails participating in the West Coast Underwater Glider Network as part of its research to understand climate variability. SWFSC also uses Saildrone vehicles to augment fishery surveys, a bottom tracking SeaBED autonomous underwater vehicle for habitat surveys of deep-sea corals and sponges, as well as an UMS in the Antarctic to improve routine sampling in a challenging environment. In 2019, the SWFSC completed an extensive fishery survey off the U.S. West Coast from British Columbia to Baja California using Saildrone vehicles. More than 18,000 nautical miles were surveyed, and ship-based tracklines were extended shoreward to depths of 10 meters along the central California Coast, enabling data collection in areas never before surveyed. The project was successful and demonstrated the value of integrated operations using ships and UMS. Future work (i.e., 2019 and beyond) includes an integrated sampling program using Saildrones, instrumented moorings, periodic sampling using buoyancy gliders, and seasonal sampling using ships. SWFSC has built a test tank for evaluating UMS platforms and sensors, which is available for agency use.

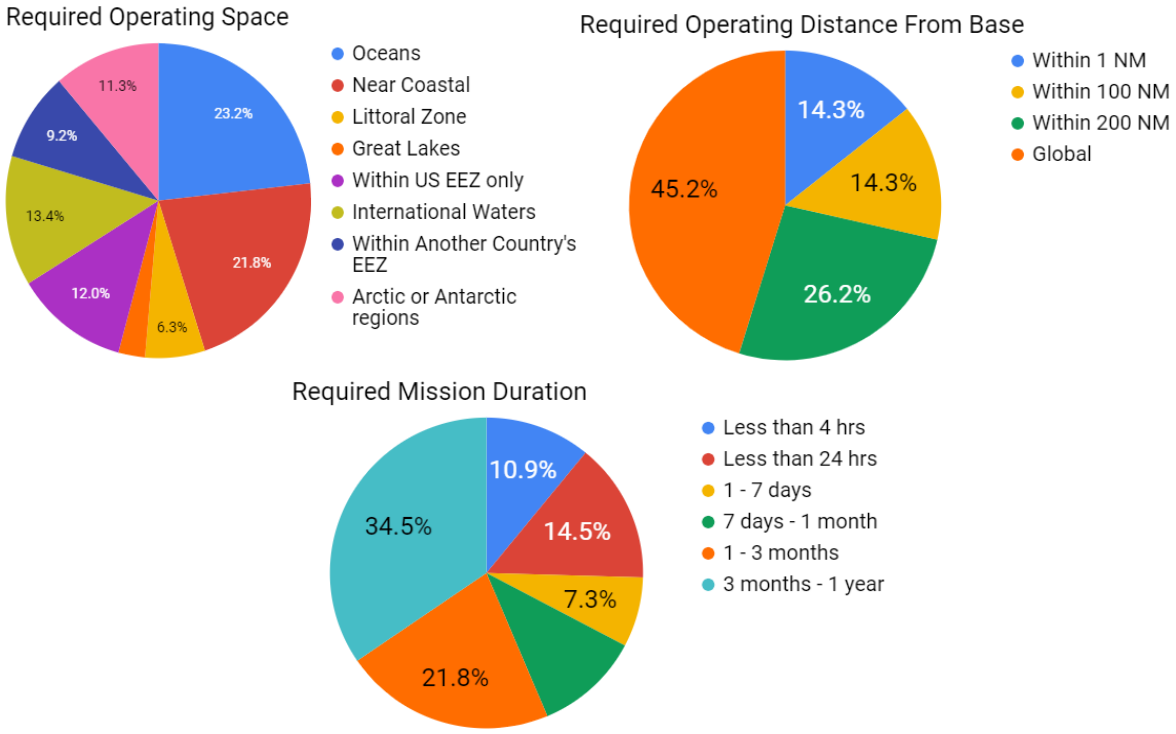
[4] JISAO is wrapping up activities in 2021 and a new Cooperative Institute award was made with the University of Washington in May 2020 (see the Cooperative Institute for Climate, Ocean, and Ecosystem Studies: https://cicoes.uw.edu/.

- The Office of Ocean Exploration and Research routinely tests and evaluates advanced technology. This includes coordinating public and private partnership projects such as the recent survey of the sunken USS *Independence* using a large UMS developed by Boeing, a variety of ecosystem and submerged cultural resource projects using unmanned surface and underwater vehicles, and integrated operations involving ships and unmanned technology.
- The NDBC supports data delivery for NOAA and other partners by assigning unique World Meteorological Organization system identifiers to aid in the management of UMS, from command and control operational functions to the facilitation of best practices in data management. The NDBC also serves as a primary WMO Global Telecommunications System delivery node for ocean observation platforms, including UMS. These tasks ensure data are globally available to NOAA stakeholders for use on a growing list of beneficial applications made possible by the technology.
- The Office of National Marine Sanctuaries has created the Collaborative Center for Unmanned Technologies to engage NOAA and non-NOAA partners in testing and evaluating UMS, with an emphasis on collecting data in support of marine resource management requirements. Recent expeditions have included the use of a Remus-600 UMS to augment ship-based habitat mapping.
- The National Centers for Coastal and Ocean Science and the IOOS Program have collaborated with NOAA's Great Lakes Environmental Research Laboratory (GLERL) and Atlantic Oceanographic and Meteorological Laboratory (AOML), along with the Monterey Bay Aquarium Research Institute, to design and integrate biosensors on UMS for autonomous, *in situ* sample acquisition, processing, and analysis of harmful algal blooms. Two test missions were executed in western Lake Erie in 2018 and 2019 to validate the concept. This work supports NOAA's direction in *Harmful Algal Bloom and Hypoxia Research and Control Amendments Act of 2017*, Public Law 115-423, sec. 9(e)(2), amending 33 U.S.C. 4002(f)(3) to require the NOAA Administrator to "develop and enhance, including with respect to infrastructure, which shall include unmanned systems, as necessary, critical observations, monitoring, modeling, data management, information dissemination, and operational forecasts relevant to harmful algal blooms and hypoxia events."

IV. PRIORITY DATA REQUIREMENTS AND COMMERCIALLY AVAILABLE SYSTEMS TO MEET THEM

NOAA has previously conducted internal surveys to review requirements for operating space, the distance of operations from base, and mission duration as they pertain to UMS (Figure 3). The required operating space pie chart shows potential overlaps, depending on the platform chosen for a particular mission. However, the chart also demonstrates that NOAA is contemplating the use of UMS across all of its operating areas and will be looking for platforms that can cross boundaries.

Figure 3. Proportion of UMS missions operating in different locations and durations.



Note: The Exclusive Economic Zone (EEZ) is the band extending 200 miles off of a Nation's continental shelf, where a Nation has jurisdiction over exploration and exploitation of marine resources. The littoral zone is the near shore environment of an ocean, lake, or river.

In addition to the vignettes described above and the general UMS use requirements developed by an internal survey in 2018, the tables that follow are responsive to the reporting requirements of CENOTE, Public Law 115-394, section 6(b). Tables 1 and 2 present an inventory of current commercially available UMS used by NOAA programs as of December 2019, as well as a summary of the data they have returned and the benefits realized from having such data.

Table 3 provides a summarized list of NOAA's Priority 1 observing requirements, as determined by the Technology, Planning, and Integration for Observation (TPIO) Division of NOAA that can potentially be met by commercially available UMS in the future. The Priority 1 observing requirements are determined as described on the TPIO website,[5] and represent NOAA's mission critical observing requirements, as verified by program leaders and subject matter experts and endorsed by the NOAA Observing Systems Council. For the purposes of this report, the summary table shows a consolidated list of the more than 400 specific types of observation (e.g., salinity, sea surface temperature, carbon dioxide content, etc.) and the potential platforms that could support sensors for collecting the data in question. When analyzing the best solution to address an observing requirement, NOAA looks at the requirement first, the sensor options second, and then the available platforms to carry the best available sensor(s) for the observations needed.

[5] https://nosc.noaa.gov/tpio/main/aboutrap.html

With a growing number of commercial systems available to collect data in the UMS sector, NOAA proposes using existing processes to collect additional data on which commercially available technologies may be best suited to fulfilling its priority UMS observing requirements within the existing understanding of its operational requirements. An example of this approach would be publishing a Request for Information on sensor/platform combinations to meet an observing need. NOAA is also exploring opportunities to partner with other Federal agencies, e.g., the Department of the Navy, to further NOAA's assessment of commercially available UMS with capabilities that may support NOAA's mission. Finally, NOAA will leverage its existing relationships with marine technology professional societies and industry trade groups to determine how to best fill data gaps as they become apparent.

Once this analysis is completed, NOAA will supplement the list of priority observing requirements in Table 3 with a determination of what platform and sensor combinations it may wish to investigate. NOAA anticipates using the full suite of contracts, cooperative agreements (including existing NOAA Cooperative Institutes), and CRADAs to leverage commercially available systems to meet priority data needs and NOAA's mission. NOAA also expects to leverage its Small Business Innovation Research process to fund the initial development of sensor and platform combinations for priority mission needs not currently covered by available commercial products.

Table 1. UMS assets owned by NOAA as of Dec. 2019, including a summary of data returned and benefits realized.

Color coding of the cells denotes similar types of systems, e.g., autonomous underwater vehicles (AUVs – green), autonomous surface vehicles (ASV – blue), and gliders (yellow).

Quantity	Unmanned Maritime System Type	Summary of Data Returned	Benefits Realized from Data
National Ocean Service			
1	Kongsberg-Hydroid Remus 100 (AUV)	Sea surface salinity data only collected. Acoustic Doppler current profiler data available but not used. No planned deployments.	Can be used to collect sea surface salinity data in support of emergency response work. Because there is no bathymetry data collected, cannot collect object detection data.
1	Kongsberg-Hydroid Remus 600 (AUV)	Collects multibeam echo sounder and backscatter data. No current deployment plans.	Mid/deep water high-resolution multibeam echo sounder data. Has been significant for marine habitat mapping, as well as marine archeology.
2	Seafloor Systems Echoboat ASV	Collects multibeam echo sounder and sea surface salinity data, as well as sound velocity profiler casts.	Can collect chart quality data in areas where small boats cannot/should not access. Can be a force multiplier during normal hydrographic survey operations. Can be quickly deployed during response work.
2	Teledyne Z-boat 1800RP ASV	Not currently deployed. Only sea surface salinity data collected.	
National Marine Fisheries Service			
4	Slocum G3 Oceanographic Glider	Acoustic Doppler current profiler, conductivity-temperature-depth measurements, oxygen, fluorescence of chlorophyll-a and color dissolved organic matter, transmissometry.	Enables continued surveys of Antarctic krill (an important part of the marine food web) in the absence of affordable ship time.
1	NOAA Fisheries AUV	Acoustics, optical imagery.	Detection and enumeration of fish and zooplankton in the California Current large marine ecosystem.
3	Emergency Integrated Life Saving Lanyard (EMILY) USV	Bathymetry.	High-resolution surveys in shallow areas.
1	Iver2-580 AUV with a L3 Klein UUV-3500 interferometric side-scan sonar	Side-scan sonar.	High-resolution habitat surveys.
1	SeaBED AUV	Optical imagery, bathymetry.	Identifies species in rough terrain.
Office of Marine and Aviation Operations			

1	Autonomous Hydrographic Survey Launch (AHSL) – optionally manned	Multibeam sonar data containing seafloor bathymetry and backscatter.	Data collected are used for nautical charting, habitat characterization, and ocean modeling. Through optional autonomy, the workforce is trained in next generation technologies and operational methods, while not reducing the capability for current manned operational uses.
1	Autonomous Hydrographic Survey Launch (AHSL) – optionally manned	Multibeam sonar data containing seafloor bathymetry and backscatter.	Data collected are used for nautical charting, habitat characterization, and ocean modeling. Through optional autonomy, the workforce is trained in next generation technologies and operational methods, while not reducing the capability for current manned operational uses.
National Weather Service			
1	Kongsberg Seaglider SN: 601	Not deployed; no data returned, capable of water temperature and salinity measurements.	Not applicable.

Table 2. UMS assets as of Dec. 2019 leveraged from partners by NOAA to augment NOAA's observing capacity.

UMS Type	Owner Location	Summary of Data Returned	Benefits Realized from Data	Type of Relationship to NOAA (including partnering line office)
L3Harris ASV C-Worker 4	University of New Hampshire	Multibeam sonar data containing seafloor bathymetry and backscatter.	Research effort includes development of advanced software, monitoring, and use cases to advance autonomous operations. Data contribute to nautical charting, habitat characterization, and ocean modeling.	Grant recipient from Office of Coast Survey (National Ocean Service).
iXblue DriX	France	Multibeam sonar data containing seafloor bathymetry and backscatter.	Research and development effort leads to better operational models for use by automated surface vehicles with existing launch handling system on hydrographic ships. Data collected are used for nautical charting, habitat characterization, and ocean modeling.	Industrial partner to the University of New Hampshire, recipient of Office of Coast Survey grant (National Ocean Service). Operational testing on NOAA ships through Office of Marine and Aviation Operations funding.
L3Harris ASV C-Worker 5	University of Southern Mississippi	Multibeam sonar data containing seafloor bathymetry and backscatter.	Research effort includes development of advanced software, monitoring, and use cases to advance autonomous operations. Data contribute to nautical charting, habitat characterization, and ocean modeling.	Grant recipient from Office of Coast Survey (National Ocean Service).
Autonomous Underwater Glider - Slocum (G1, G2, G3), SeaGlider, Spray	1. IOOS Regional Associations throughout the U.S. and Territories 2. University of Miami/Cooperative Institute for Marine and Atmospheric Studies	Data are transmitted in near-real-time and made available to the public and operational forecast models via the U.S. IOOS Glider Data Assembly Center.	Underwater glider data have been shown to reduce the error in Atlantic hurricane intensity forecasts within NOAA numerical forecast models.	Cooperative agreements and cooperative institutes (Oceanic and Atmospheric Research).
Autonomous Underwater Glider - Slocum (G1, G2, G3), SeaGlider	Naval Oceanographic Office (NAVO)	Ocean temperature data as a proxy for ocean heat content	Underwater glider data have been shown to reduce the error in Atlantic hurricane intensity forecasts within NOAA numerical forecast models.	Cooperative agreements (Oceanic and Atmospheric Research/AOML).

Slocum Webb Glider G2	Rutgers University	Temperature, salinity, pH, dissolved oxygen, chlorophyll fluorescence, salinity-based estimations of total alkalinity and aragonite saturation.	Research to understand the seasonal and subseasonal variability in carbonate chemistry dynamics to better inform models.	Cooperative agreement (Office of Oceanic and Atmospheric Research/Ocean Acidification Program).
Slocum Webb Glider G3	Stony Brook University	Temperature, salinity, pH, dissolved oxygen, chlorophyll fluorescence, salinity-based estimations of total alkalinity and aragonite saturation.	Research to understand the seasonal and subseasonal variability in carbonate chemistry dynamics to better inform models.	Cooperative Agreement (Office of Oceanic and Atmospheric Research/Ocean Acidification Program).
Slocum Webb Glider G2	University of Maine	Temperature, salinity, pH, dissolved oxygen, chlorophyll fluorescence, salinity-based estimations of total alkalinity and aragonite saturation.	Research to understand the seasonal and subseasonal variability in carbonate chemistry dynamics to better inform models.	Cooperative Agreement (Office of Oceanic and Atmospheric Research/Ocean Acidification Program).
Liquid robotics wave glider	Texas A&M University	pH, chlorophyll fluorescence, partial pressure of carbon dioxide.	Research to understand the seasonal and subseasonal variability in carbonate chemistry dynamics to better inform models.	Cooperative Agreement (Office of Oceanic and Atmospheric Research/Ocean Acidification Program).
AUV Sentry	Woods Hole Oceanographic Institution	Multibeam bathymetry, side-scan sonar, chemical sensing, optical imagery.	High-resolution characterization of the seafloor. Data can be used to better target remotely-operated vehicle dives.	Contracted grant with the National Deep Submergence Facility run by Woods Hole Oceanographic Institution.
Remus 100	University of Delaware	Bathymetry, side-scan sonar.	High-resolution acoustic imagery of the seafloor.	Grant subaward from the Office of Ocean Exploration and Research (Office of Oceanic and Atmospheric Research).
Remus 600	Woods Hole Oceanographic Institution	Bathymetry, side-scan sonar.	Seafloor mapping and characterization.	Grant from the Office of Ocean Exploration and Research to Woods Hole Oceanographic Institution (Office of Oceanic and Atmospheric Research).
Saildrone	Alameda, CA	Bathymetry, backscatter, environmental sample processor (ESP).	Efficient mapping of the deep ocean, chemical and biological characterization of the water column.	Grant to University of New Hampshire from the Office of Ocean Exploration and Research (Office of Oceanic and Atmospheric Research).

New Slocum glider variant – addition of thrusters	Woods Hole Oceanographic Institution	Bathymetry, conductivity-temperature-depth measurements.	Efficient mapping of the deep ocean, chemical characterization of the water column.	Grant to Woods Hole Oceanographic Institution from the Office of Ocean Exploration and Research (Office of Oceanic and Atmospheric Research).
Saildrone	Alameda, CA	Mid-water acoustics, bathymetry, wind speed and direction, sea surface temperature, conductivity-temperature depth measurements, partial pressure of carbon dioxide, wave height, fluorometer, currents.	Increased temporal and spatial coverage for air-sea flux studies, ecosystem surveys, oceanographic process studies.	Contracts and CRADA administered by the Pacific Marine Environmental Laboratory (Office of Oceanic and Atmospheric Research).

Kongsberg-Hydroid Remus 600 (AUV)	Woods Hole Oceanographic Institution	Fluorometry, holocam, water sampler, optical sensor, conductivity-temperature-depth, dissolved oxygen, etc.	Develop REMUS-600 customized with a suite of oil sensing tools (fluorescence, back scatter, holographic imaging, camera and water sampler) for comprehensive 3D hydrocarbon mapping in the water column. Demonstrate the operational readiness of the REMUS via field deployment to quantify and characterize spilled oil (slick and suspended).	Research grant to Woods Hole Oceanographic Institution (National Ocean Service)
Kongsberg-Hydroid Remus 100	Woods Hole Oceanographic Institution	Acoustic sonar, fluorometry, optical sensor, conductivity-temperature-depth	Improved characterization modeling of oil in the water column. This can be used to improve accuracy of oil fate and transport models for spill responses, and improves defensibility of injury assessments (National Resource Damage Assessment).	Grant to Woods Hole Oceanographic Institution (National Ocean Service)
Tethys LRAUV	Woods Hole Oceanographic Institution	Fluorometry, CTD	Develop and test a propeller-driven Long-Range Autonomous Underwater Vehicle (LRAUV) with an integrated sensor package, in parallel with ORR research to develop and test capabilities for 3 dimensional oil in water column characterization in tandem with surface oil characterization using remote sensing, and would incorporate REMUS 100 field trails at the MC20 site (or another site if	Project leveraging with the USCG Arctic Domain Awareness Center using Grant to Woods Hole Oceanographic Institution (National Ocean Service)

			determined to be more suitable). The sensor include commercial-off-the-shelf (COTS) sensors for ADCP/DVL, CTD, dissolved oxygen, calibrated oil detection fluorescence and optical backscatter, as well as GoPro camera and 900/1800 kHz sidescan sonar.	
3rd Generation Environmental Sample Processor/long-range AUV (3G ESP/LRAUV)	Monterey Bay Aquarium Research Institute (MBARI)	harmful algal bloom species and toxin monitoring	Near-real time monitoring and reporting on blooms and their toxicity for Lake Erie cyanobacterial bloom events; will support NOAA HAB toxicity forecast and water management decisions	Grant to MBARI from Office of Oceanic and Atmospheric Research; participation with GLERL/, AOML/Office of Ocean and Atmospheric Research, and NCCOS/National Ocean Service

Table 3. NOAA Priority 1 observation requirements which may be addressed by UMS.

Data collected as of Dec. 2019 by the NOAA TPIO and approved as Priority 1 observing requirements by NOAA leadership through the NOAA Observing Systems Council.

UMS Platform	Global Change Master Directory Variable*
USV/Glider	Air temperature: Surface
USV/AUV/Glider	Ambient noise: Biological
USV/AUV/Glider	Ambient noise: Physical
USV/AUV/Glider	Ambient noise: Total
USV/Glider	Atmospheric carbon dioxide: Surface
USV/Glider	Atmospheric carbon: Surface
USV/Glider	Atmospheric pressure: Sea level
USV/AUV/Glider	Bathymetry
USV/AUV/Glider	Benthic habitat
USV/AUV/Glider	Chlorophyll concentration
USV/AUV/Glider	Coral reef assessment
USV/AUV/Glider	Cultural heritage characterization
USV/Glider	Dew point temperature: Surface
USV/AUV/Glider	Dissolved gases: Carbon dioxide
USV/AUV/Glider	Dissolved gases: Oxygen
USV/AUV/Glider	Ecosystems characterization
USV/AUV/Glider	Gravity field: Ground based
USV/AUV/Glider	Habitat mapping and characterization
USV/AUV/Glider	Harmful algal blooms
USV/AUV/Glider	Hurricanes
USV/AUV/Glider	Hydrography: Bathymetry + water depth
USV/AUV/Glider	Marine habitat
USV/Glider	Nitrogen oxides: Surface
Glider	Nutrients: Profiles
USV/AUV/Glider	Ocean contaminants
AUV/Glider	Ocean currents Subsurface
USV/AUV/Glider	Ocean currents: Direction, profiles
USV/AUV/Glider	Ocean currents: Direction, surface
USV/AUV/Glider	Ocean currents: Speed, profiles
USV/AUV/Glider	Ocean currents: Speed, surface
USV/Glider	Ocean surface winds: Direction
USV/Glider	Ocean surface winds: Speed
USV/Glider	Ocean temperature: Profiles

USV/Glider	Oceanic carbon dioxide: Partial pressure
USV/AUV/Glider	Oceanic Carbon: profiles
USV/AUV/Glider	Oil spills
USV/AUV/Glider	pH: Ocean
USV/AUV/Glider	Plankton
USV/Glider	Radiation, solar: shortwave, incoming, top of atmosphere
USV/Glider	Radiation: Longwave, incoming, surface
USV/Glider	Radiation: Shortwave, incoming, surface
USV/AUV/Glider	Salinity: Profiles
USV/AUV/Glider	Salinity: Surface
USV/Glider	Sea surface height
USV/AUV/Glider	Sea surface temperature
USV/AUV/Glider	Shoreline mapping
USV/Glider	Significant wave height
USV/AUV/Glider	Species/population Interactions: Fish
USV/AUV/Glider	Species/Population interactions: Marine mammals
USV/AUV/Glider	Species/population interactions: Other (turtles, birds, sharks, etc.)
USV/Glider	Swell direction
USV/AUV/Glider	Turbidity
USV/Glider	Wave direction
USV/Glider	Wave height
USV/Glider	Wave period

*Global Change Master Directory keywords (variables) are a hierarchical set of controlled Earth Science vocabularies that ensure Earth science data, services, and variables are described in a consistent and comprehensive manner that allow for the precise searching of metadata and subsequent retrieval of data, services, and variables.

V. LIST OF ACRONYMS

AOML	Atlantic Oceanographic and Meteorological Laboratory
ASV	Autonomous Surface Vehicle
AUV	Autonomous Underwater Vehicle
CRADA	Cooperative Research and Development Agreements
EEZ	Exclusive Economic Zone
GLERL	Great Lakes Environmental Research Laboratory
IOOS	Integrated Ocean Observing System
NDBC	National Data Buoy Center
NOAA	National Oceanic and Atmospheric Administration
SWFSC	Southwest Fisheries Science Center
PMEL	Pacific Marine Environmental Laboratory
UMS	Unmanned Maritime Systems
WMO	World Meteorological Organization

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