STATE OF GLIDERS: UPDATE ON CURRENT AND EMERGING BEST PRACTICES

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EXECUTIVE SUMMARY

Underwater gliders ("gliders") have become a crucial tool for collecting ocean observations. Autonomous vehicles that can cover thousands of kilometers across months now make it possible to gather sustained and event-specific observations about temperature, salinity, currents, and more. These cost-effective observations are informing academic and government models ranging from hurricane-intensity forecasts to seasonal-to-decadal climate models.

As glider technologies mature, academic and government programs also are maturing. Various members of the community have independently figured out monitoring, data, reliability, outreach, and documentation practices but those remain standardized only to specific programs or groups of collaborators. For example, the international community is beginning to standardize on the United States format for data exchange: How might those practices be leveraged for sensor standardization?

For new glider researchers and operators, there are now thousands of resources for coming up to speed: Which resources should be prioritized? To what extent? How might new and existing researchers and operators leverage each others' knowledge, missions, and enthusiasm? Similarly, information about funding mechanisms and reliability is reaching some programs and groups but not the full community.

Together, the opportunities to standardize while spurring growth inspire a vision, mission, and way forward that offers the international glider community the right information at the right time to make the right choices.

Vision and Mission

Vision. An international glider community that operates through best practices to coordinate the efficient execution of high quality research and the collection of observations to support a broad range of stakeholders.

Mission. Empower the international glider community to:

- Share best practices.
- Make efficient use of resources.
- Leverage assets.
- Improve global ocean observations.

The Way Forward

Glider meetings and discussions to date consistently answer the question "Why support gliders?." Informed by the U.S. Underwater Glider Workshop[1] (2017) and the 8th Everyone's Gliding Observatories Meeting and International Glider Workshop (2019), the next question "How do we support the glider community?," can now be answered with the following strategic roadmap of near-term strategic outcomes and priorities. Note: These outcomes and priorities were synthesized from the various meetings and documents; the content and the ordering are notional.

Table 1. Strategic Roadmap of Strategic Outcomes and Priorities

0.0 Overall	
Outcome 0.1 Focus and leverage investments.	**Priority 0.1** To support consistent observations and funding, focus on boundary currents, ocean acidification, storms, water mass transformation, and data management in research, presentations, and coordinated funding requests. **Priority 0.2** Leverage sustained monitoring and event-response, energy enhancement, improved deployment and recovery techniques (e.g., launching from the shore rather than ship), reinsurance, and standardized sensor integration.
Outcome 0.2 Implement supporting systems and approaches.	**Priority 0.3** Establishing a steering committee that includes international and U.S. participants, scientists, glider operators, data users in various career stages can inform and coordinate glider network expansions in consultation with the University-National Laboratory System (UNOLS), the [United States] National Oceanic and Atmospheric Administration (NOAA), United States Navy, the Integrated Ocean Observing System (IOOS), and academic glider operators. **Priority 0.4** To capture and leverage all of the knowledge best practices, know which systems are appropriate for which practices and define the approaches for how and when to deal with each system. Best practices systems, current and needed, are summarized in Table 1.
1.0 Event and Sustained Monitoring	
Outcome 1.1 For event monitoring, observations are consistent and comparable.	See also **Priorities 0.1, 0.2** **Priority 1.1** Invest in improving glider technology.
Outcome 1.2 For sustained monitoring, observations are consistent and comparable.	See also **Priorities 0.1, 0.2, 1.1** **Priority 1.2** Improve ocean models for navigation. **Priority 1.3** Develop a common tool for multi-platform glider operations.
2.0 Data Management	
Outcome 2.1 Data and metadata formats are consistent and accessible in real-time.	**Priority 2.1** Identify and agree to consistent data- and software-sharing requirements.
Outcome 2.2 Quality control is routine and consistent.	**Priority 2.2** Plan for a consistent quality control process and a method for resolving failings.
3.0 Reliability	
Outcome 3.1 Reliability data are captured by gliders and sensors.	**Priority 3.1** Offer open and publicly available data. **Priority 3.2** Increase redundancies. **Priority 3.3** Record reliability data.

Outcome 3.2 Glider researchers and operators organize reliability requests for manufacturers.	**Priority 3.4** Work with manufacturers to share reliability data. **Priority 3.5** Build technical support capacity. **Priority 3.6** Build international coordination for glider reliability.
4.0 Outreach, Coordination, and Collaboration	
Outcome 4.1 Establish an international agreement for operation of AUVs across international EEZs.	**Priority 4.1** Identify an intergovernmental organization to facilitate the agreement for operation of AUVs across international EEZs.
Outcome 4.2 Identify and agree to consistent data-sharing and training requirements among the international funding agencies.	**Priority 4.2** Facilitate a community dialogue to agree to baseline criteria for data. **Priority 4.3** Develop and align on an accreditation process.
Outcome 4.3 Communication is consistent and ubiquitous.	**Priority 4.4** Build the community. **Priority 4.5** Speak with one voice.
5.0 Documentation and Evaluation	
Outcome 5.1 Develop the robust system for documenting and evaluating methodologies across all aspects of glider operation.	**Priority 5.1** Set the criteria for satisfaction and produce an initial draft. **Priority 5.2** Host face-to-face meetings. **Priority 5.3** Adopting the Ocean Best Practices System.
Outcome 5.2 Develope the robust system for training new researchers and operators.	**Priority 5.4** Prepare and support the workforce.
Outcome 5.3 The community has access to documented past, active, and planned glider missions.	**Priority 5.5** Make glider information available at the right time.

Image 1. Grand Challenges for Gliders by 2029 (Image credit: Sasha Makohon-Moore)

With these strategic outcomes and priorities, it is feasible to address three Grand Challenges for Gliders by 2029:

1. **Grand Challenge #1, Decrease costs.** Decrease by half the operation and maintenance costs for glider missions.
2. **Grand Challenge #2, Interconnect stakeholders.** Interconnect researchers, operators, gliders, and other observing systems via international systems that yield consistent data, practices, and training.
3. **Grand Challenge #3, Inform the models.** Identify and fill observation gaps in weather, water, and climate models.

POLICY SUMMARY

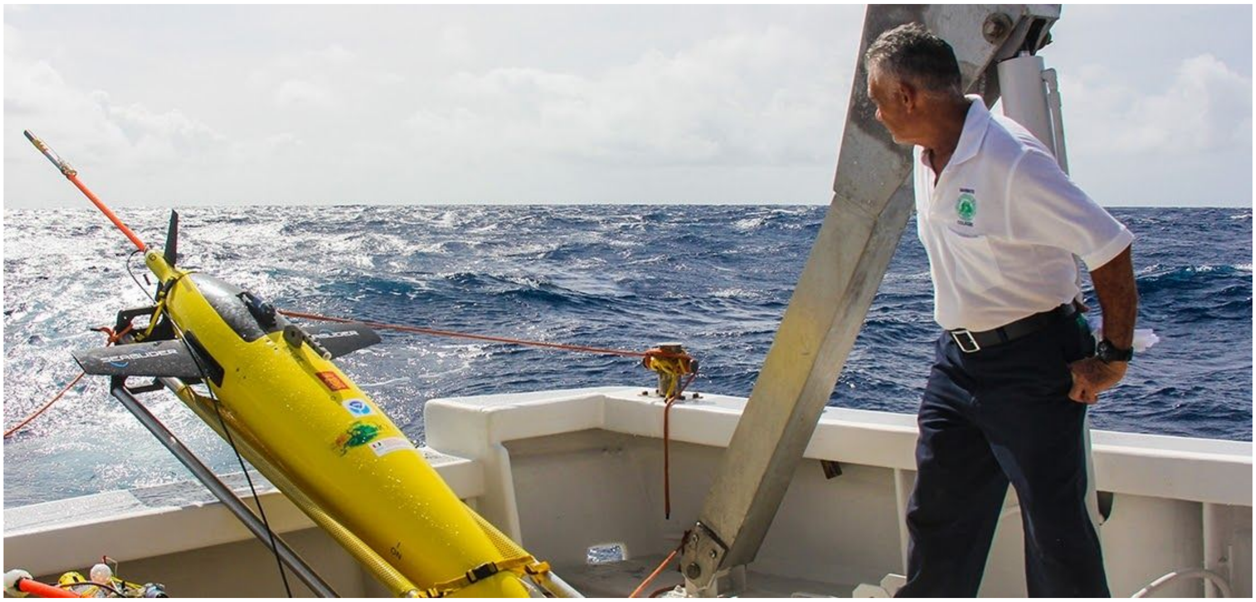

Image 2. Ubaldo Lopez of the University of Puerto Rico at Mayaguez prepares to launch NOAA Ocean Gliders off the Coast of Puerto Rico (Image Credit: NOAA, July 2017)

To prepare for the 2018 hurricane season, NOAA launched a fleet of fifteen underwater gliders (“gliders”) in the Caribbean Sea and tropical Atlantic Ocean. Those gliders measured temperature and salinity at the surface and deeper to improve the track forecast for Hurricane Michael over the traditional forecasts.

Opportunity to Understand

To truly understand the Earth requires sustained observations of the oceans, skies, and land. One of the best opportunities for expanding ocean observations, and thus improving predictions, is to expand the use of gliders: They move autonomously through the ocean with ranges of thousands of kilometers and across time frames of weeks to months. Moreover, inspired by the possibilities of continuous data from autonomous gliders, an international community representing academic, government, and private programs has organized to share knowledge and assets in order to improve global ocean observations.

Opportunity to Predict and Forecast

Supporting this international community on research- and experience-based best practices ensures the efficient execution of high-quality research and the collection of observations to support a broad range of stakeholders and predictions. Expertise and resources must now be deployed to achieve three Grand Challenges by 2029:

Grand Challenge #1 Decrease costs. Decrease by half the operation and maintenance costs for glider missions. To do this, leverage each deployment and payload and develop the capacity for improved asset-sharing, coordination, and liability protection.

Grand Challenge #2 Interconnect stakeholders. Interconnect researchers, operators, gliders, and other observing systems via international systems that yield consistent data, practices, and training. To do this, coordinate the international agreement for glider operations across Exclusive Economic Zones and coordinate the associated international training and accreditation for organizations and glider operators.

Grand Challenge #3 Inform the models. Identify and fill observation gaps in weather, water, and climate models. To do this, agree to data standards and data availability across international funding organizations.

UPDATE ON CURRENT AND EMERGING BEST PRACTICES

Underwater gliders ("gliders") are versatile tools for collecting information about our oceans: Gliders can serve short-term, event-specific missions such as studying oil spills or long-term sustained missions such as understanding changes over time. To do this efficiently, though, the glider community must make consistent and leveraged investments across time and they must implement the supporting systems and approaches across five areas:

1. Event and Sustained Monitoring
2. Data Management
3. Reliability
4. Outreach, Coordination, and Collaboration
5. Documentation and Evaluation

1.0 Event and Sustained Monitoring

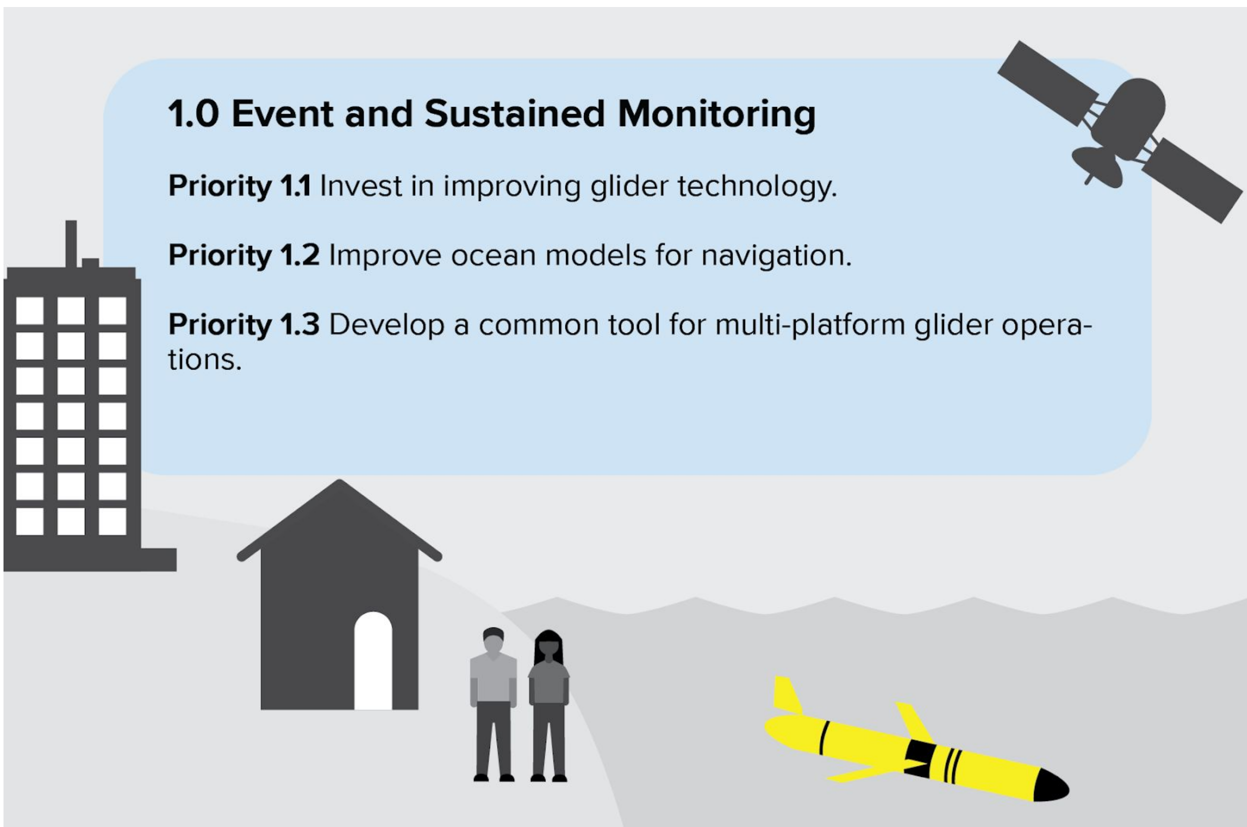

Image 3. Event and Sustained Monitoring Summary[2]

Event monitoring is defined here as targeting or responding to specific events such as a harmful algal bloom, an oil spill, or hurricane. Sustained monitoring, defined here as establishing the baseline condition and/or identifying trends, is critical to understanding longer-term weather patterns, ocean dynamics, and ecosystem health. Gliders are useful for both types of monitoring because they are autonomous, can run short and long routes, can be used independently or in groups, and do well in most environments, including extreme environments such as the Arctic, while returning information as varied as temperature, salinity, or chlorophyll.

1.1 Current Practices in Event and Sustained Monitoring

Glider use emerged over the last forty years as a function of the glider technology itself and the sensor technologies the gliders carry. Now, the community must resolve mesoscale features; collect data on a variety of variables at a variety of depths and regions; and transmit everything in real-time for assimilation into the models. Then, researchers must compare the data and model approaches; strengthen interaction between observational and modeling efforts; and increase international collaborations and partnerships.

More practically, operating teams require specialized, trained personnel to launch and recover the gliders, navigate under ice, build communication networks, develop relationships with local communities, and manage year-round collection in the face of boundary currents and river plumes. They also need improved situational awareness, which could be built into the gliders themselves or can be provided by nearby monitors or operators.

1.2 Current and Emerging Best Practices in Event and Sustained Monitoring

When addressed, the following priorities will improve the value of glider observations and expand the usefulness of glider monitoring:

Priority 1.1 || **Invest in improving glider technology.** The glider community will continue to focus on enhancing battery technologies; figuring out how to deploy gliders from land, sea, or air; increasing the depth of sampling; and developing on-board decision-making and on-board path planning.

Priority 1.2 || **Improve ocean models for navigation.** In order to sustain long missions, gliders are powered primarily by heat-exchange propulsion and are therefore dependent on the currents for navigation. Due to an incomplete understanding of the ocean currents, charting a path for a mission can be challenging. Real-time incorporation of glider observations into ocean models will improve forecasting and while also improving navigation for gliders.

Priority 1.3 || **Develop a common tool for multi-platform glider operations.** Each glider is operated by a unique set of commands and user interfaces. To improve the ability to conduct multi-platform missions, the community is developing platforms. These platforms will decrease the barrier to entry for glider piloting while improving organizational capacity.

Potential disruptors for event and sustained monitoring. Potential disruptors to event and sustained monitoring include emerging autonomous technologies, especially autonomous technologies that launch their own sub-units or shore-launched vehicles; multi-platform operations systems; breakthroughs in battery technologies; and on-board decision-making algorithms.

2.0 Data Management

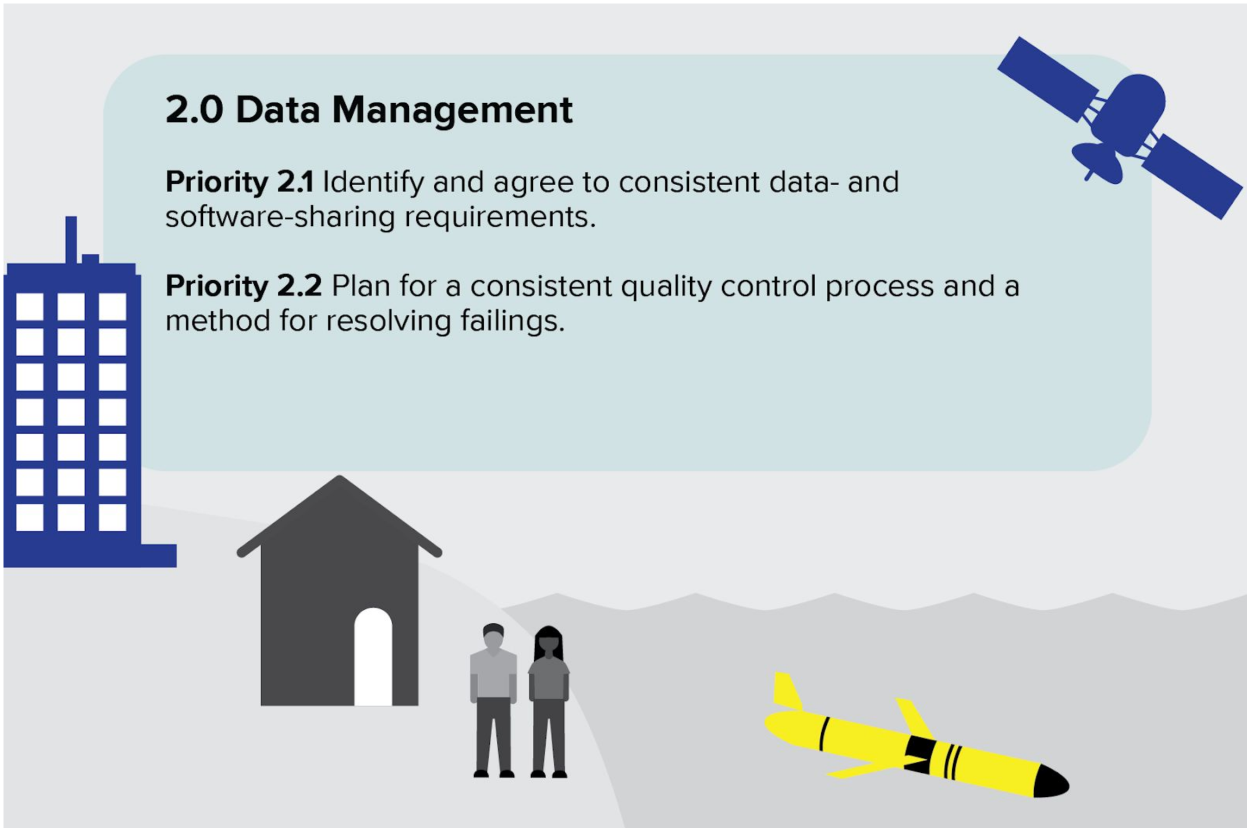

Image 4. Data Management Summary[2]

Data management is defined here as the collective processes of defining, collecting, and accessing data whereas data assimilation is a bridge between data and models, and often provide s the initiating conditions in the modeling.

2.1 Current Practices in Data Management

While some glider data are transmitted from the glider via satellite communications in real time, the majority of the data are transmitted when the glider is retrieved. The current practice is then to aggregate the data at Data Assembly Centres (DACs), ideally at the Global Data Assembly Centre (GDAC) so that the international community has access. From there, the data are assimilated into models. Data with issues such as improbable values or missing metadata are flagged to alert researchers and modelers, although the individual who initially uploaded the flagged data is not alerted.

These processes and practices lead to concerns about data latency, given the delay in transmission, and quality, given factors such as disparities in sensor calibrations and inconsistencies in the underlying metadata. Quality assurance, quality control, and evaluation processes are still in the developmental stages.

2.2 Current and Emerging Best Practices in Data Management

Current and emerging best practices in data management include the creation of a single global glider format, OceanGliders1.0 (OG1.0) with the Binary Universal Form for the Representation of meteorological data (BUFR) format and template. As that format and template are developed, the BUFR Working Group is coordinating with the United Kingdom's Meteorological Office for feedback and then the Working Group will develop a user-friendly, documented process for real-time data submission in the new format.

Priority 2.1 || Identify and agree to consistent data- and software-sharing requirements. Together, the glider community is defining global objectives for glider data management, software sharing, and key performance indicators. An emerging team of international volunteers, including the Joint Technical Commission for Oceanography and Marine Meteorology in situ Observations Programme Support Centre (JCOMMOPS), plans to meet virtually (monthly) and in-person (annually) to define and document the quality assurance, quality control, and evaluation procedures to produce the reference documents for data management. They will pay special attention to calibration coefficients, metadata, integrating different datasets, and climate-and-forecast-compliant data at current standards. They also will address the timeline for archive (e.g., time series, delayed mode, real time) and a minimum metadata standard. The glider community will be trained in this format with consistent standards and guidelines. Funding organizations are encouraged to specify data-sharing requirements as part of the funding conditions.

Priority 2.2 || Plan for a consistent quality control process and a method for resolving failings. With improved data management and sharing, quality control is necessary, as is a method for resolving failings. This is especially imperative because the community plans to increase the frequency of pulls from the GliderDAC to once per hour and the United States' National Weather Service is changing operational approaches to assimilate ocean data. The data management team will write the best practices manual to start, and then develop the process for revisions that meets the following conditions for satisfaction:

- Flexible.
- Accessible.
- Communicates consistently between users and DACs.
- Focuses on flagging data and finding patterns of issues.
- Hosts annual quality control meetings, inspired by the Argo versions, that includes manufacturers and has three outcomes: sort out the key issues; update best practices; train the next generation.

Potential disruptors for data management. Potential disruptors in data management include machine learning technologies that require a smaller learning corpus; quantum computing; and new hardware and sensors with different timing or variable types.

3.0 Reliability

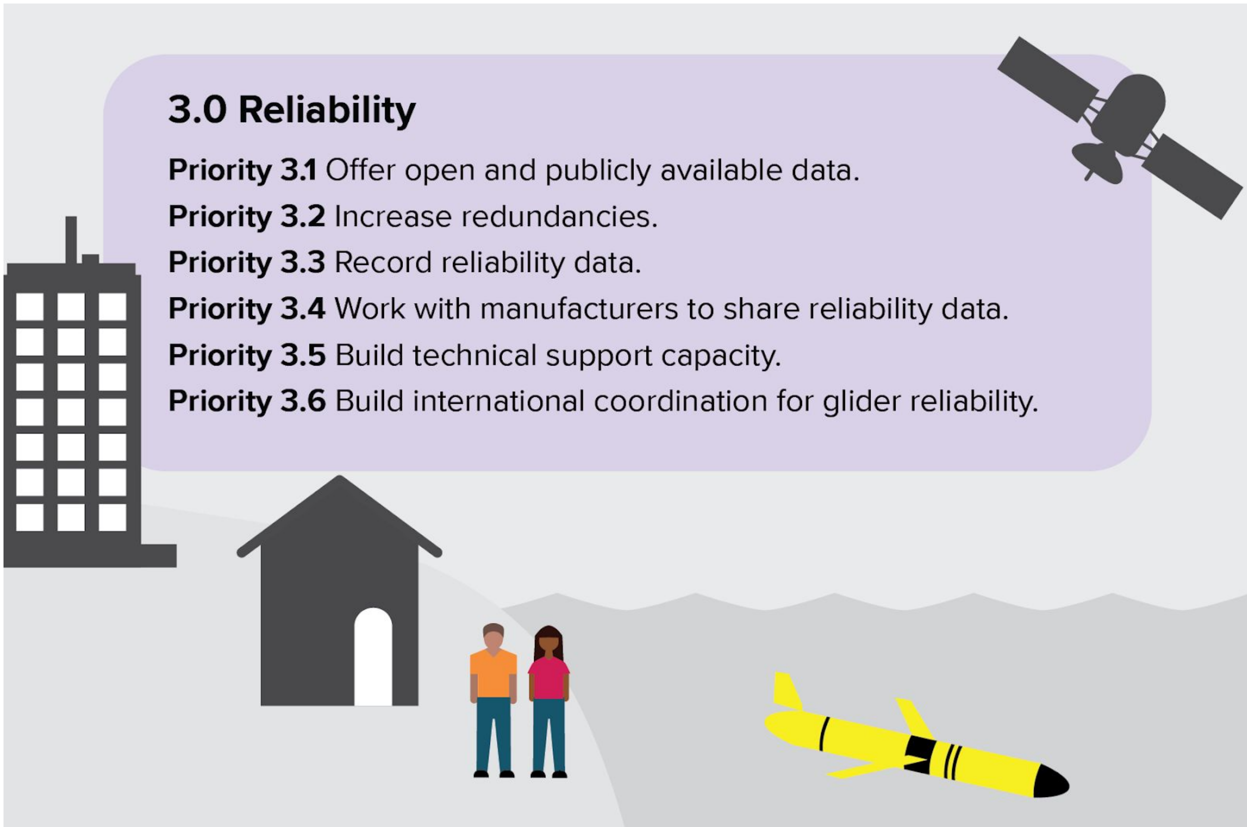

Image 5. Reliability Summary[2]

3.1 Current Practices in Reliability

For many glider operators, to "fly" one glider means owning three gliders: one in the water, one undergoing repairs, and one ready to relieve the operational glider. Glider reliability, here defined as the dependability of gathering the observations, can be compromised by the design, materials, manufacturing/assembly/maintenance errors, incorrect operations or changes in the operating plan. Anecdotally, factors such as biofouling, marine life, and movement into unfriendly waters are among the most common sources of unreliability.

Maintenance issues include ballasting, sensor calibration, factory repair, and telemetry. Because gliders are monitoring continuously, maintenance issues occur anytime, including nights, weekends, and holidays. This demands experienced, senior personnel on an inconvenient schedule and with the potential for overtime charges that overwhelm limited budgets.

3.2 Current and Emerging Best Practices in Reliability

Glider reliability can be improved with the following current and emerging best practices:

Priority 3.1 || Offer open and publicly available data. Make data publicly available and findable with an associated Document Objective Identifier (DOI). Most glider data are sent to a central system, although from there the data are incorporated into operational systems that are not yet attributing the sourcing.

Priority 3.2 || **Increase redundancies.** Some programs purchase two-three gliders for every one in the water. Some operators are considering quick-swapping already-calibrated sensors or other forms of modularity, bearing in mind that the largest operational costs are the ship costs to deploy and retrieve the gliders, which could be lowered if gliders were launched from coasts.

Priority 3.3 || **Record reliability data.** Begin recording reliability data at the sensor level to answer key questions about the glider, data, and failure mode (e.g., power, software, black box, biofouling, ballasting). Denote time out of water and track length. Identify and share the success stories.

Priority 3.4 || **Work with manufacturers to share reliability data.** Coordinate with glider and other sensor manufacturers to make the components more reliable. Share reliability information in near-real-time through strong advocates. Manufacturers confirm that they receive only piecemeal information about issues with the gliders or the sensors, and that they welcome a unified voice that aggregates the community's issues and future wishes.

Priority 3.5 || **Build technical support capacity.** Develop a coordinating structure for local, organizational, community, and manufacturer technical support and best practices.

Priority 3.6 || **Build international coordination for glider reliability.** For international coordination around reliability, begin by: (1) Initiating a community review of the reliability, points of failure with strong user leadership to raise systemic issues to manufacturers; (2) Detailing the requirements for a universal black box; and (3) Aggregating best practices (e.g., calibration facility, backups, seasonal accommodations, track the sensor in every dataset).

Potential disruptors for reliability. Potential disruptors for reliability include optimal path planning and improved situational awareness.

4.0 Outreach, Coordination, and Collaboration

Image 6. Outreach, Coordination, and Collaboration Summary[2]

Outreach, coordination, and collaboration are supporting the dramatic increase in glider activity across the globe. In this context, outreach is defined as the activities to communicate the value that the glider community, glider technology, and the data and information they generate brings to society. Coordination relates to the partnerships in which each partner benefits, although neither partner is required for success. Collaboration is the integrated approach to research and development that would not be possible without each partners' involvement.

4.1 Current Practices in Outreach, Coordination, and Collaboration

The glider community functions primarily through regional coordination to share ideas and strategies and, where possible, provide training to improve member capacity. These activities have resulted in the development of robust regional glider operations throughout the world but have not yet advanced to the level of a global coordinated effort. Most activities are carried out on a one-on-one basis, primarily based on personal relationships, through relatively short-term engagements with limited scientific and geographical scopes. Many of these efforts are generated through the repurposing of existing resources and are rarely the product of new investments.

To expand beyond regional efforts towards effective global coordination, collaboration, and outreach, the glider community must leverage each of the four community network types:[3]

1. Informational network, in which partners exchange policies and programs, technologies, and potential solutions and all actions are entirely voluntary.
2. Developmental network, in which partner information and technical exchange are combined with education and member service that increase everyones' capacity to implement solutions.
3. Outreach network, in which partners come together to exchange information and technologies, plan, exchange opportunities, share contacts, and enhance opportunities. Together, they implement the programs the design.
4. Action network, in which partners make adjustments and formally adopt collaborative courses of action, and/or deliver services, along with exchanges of information and technologies.

Currently, the activities of the glider community are organized primarily as informational and developmental networks. In order to successfully transition to a global community, the community seeks to establish the outreach and action networks.

4.2 Current and Emerging Best Practices in Outreach, Coordination, and Collaboration

In order to develop into an outreach- and action-oriented community, the following best practices are emerging in the community:

Priority 4.1 || Identify an intergovernmental organization to facilitate the agreement for operation of UAVs across international EEZs. Coordinated operation of gliders across Economic Exclusive Zones (EEZs) has the potential to drastically improve the ability of the international community to leverage existing assets, pool resources, and gain access to critical information. However, EEZs raise a number of national security and international relations concerns. The glider community may work with an existing organization such as the Intergovernmental Oceanographic Commission (IOC) within the United Nations Educational, Scientific and Cultural Organisation (UNESCO) to define the minimum expectations for operation of gliders across EEZs that focuses on the benefits to the operator and the partner.

Priority 4.2 || Facilitate a community dialogue to agree to baseline criteria for data. To establish baseline criteria for data sharing, collaboration, and access, clear leadership and a minimum set of expectations are critical and must have the following four characteristics:

- Clearly-defined outcomes.
- Assigned roles and responsibilities.
- A clear mechanism for re-evaluating and re-assigning roles as needed.
- A co-created timeline that aligns with all partners' needs.

Priority 4.3 || Develop and align on an accreditation process. Using the minimum expectations identified in the priority above, create standards that can be used to establish an accreditation process for glider operators and organizations. Partner countries that commit to the formal standards of operation and have accredited glider operators and organizations would then be able to operate across partner Exclusive Economic Zones.

Priority 4.4 || Build the community. The community will continue to develop through in-person technical meetings, co-opting other meetings (e.g., OCEANS, UG2/EGO Meetings, OceanObs'19, Ocean Sciences, etc.), webinars, and other remote/virtual gatherings. Additional communication options include a technical listserv, Slack channel, Twitter hashtag, and/or phone hotline that would answer questions in real-time.

Priority 4.5 || Speak with one voice. In the current competitive funding environment, a clear and concise message is important to articulating the value of any outreach, coordination, or collaboration. Develop consensus recommendations and messaging these efforts provides clarity and purpose to the community. This also provides the clear boundaries and outcomes that offer clear places for external stakeholders to engage with or support the effort.

Potential disruptors for outreach, coordination, and collaboration. Potential disruptors include subsuming other communities or inviting other communities (e.g., Argo) to subsume the glider community).

5.0 Documentation and Evaluation

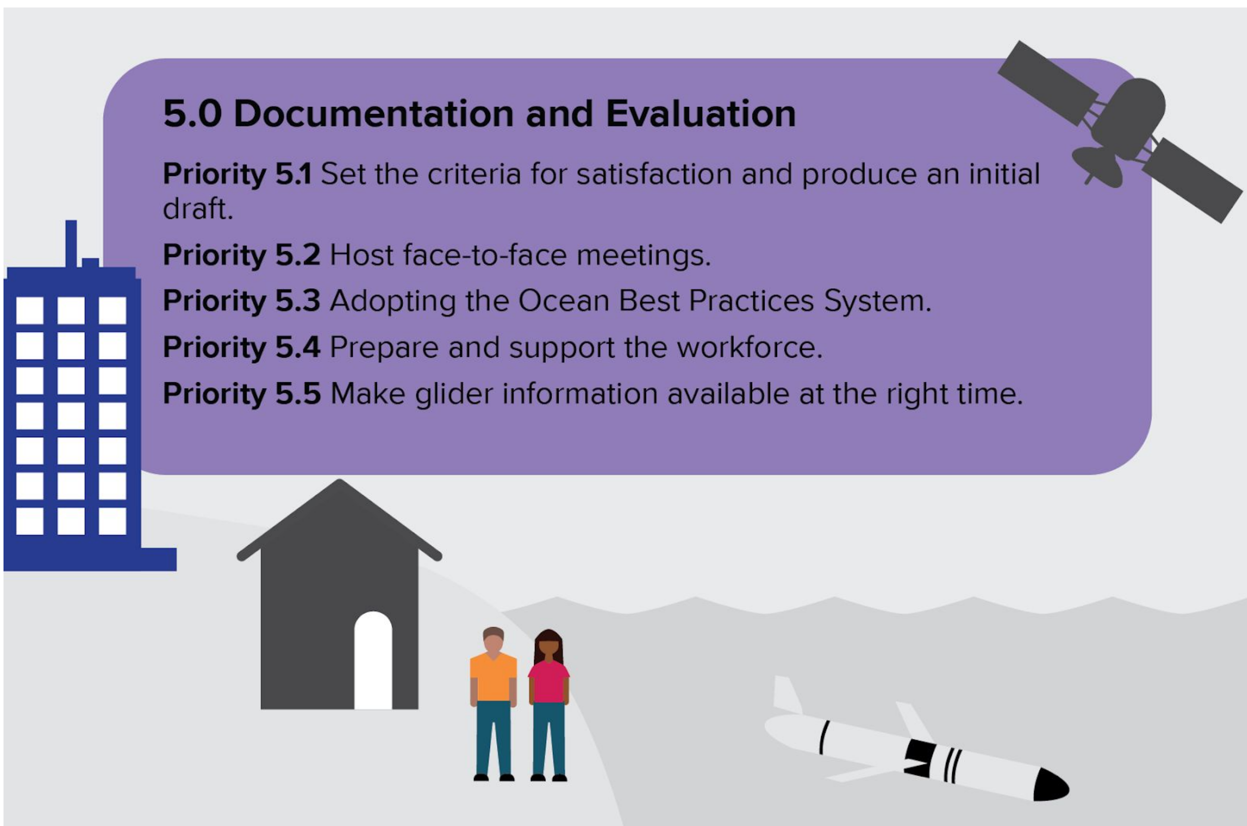

Image 7. Documentation and Evaluation Summary[2]

As the number of gliders deployed across the globe has increased, so has the need for formal mechanisms that leverage the experiences and lessons learned from existing groups. These would serve to decrease the barriers to entry for new glider operations and to increase the efficiency of established organizations.

In this context, documentation is defined as the process of capturing a best practice in a digital format that is widely shareable. Evaluation is the process for reviewing the activity and the documentation.

5.1 Current Practices in Documentation and Evaluation

Best practices are currently evaluated on a trial-and-error basis at the individual mission or program levels. There exist training materials developed by the manufacturers for gliders. However, in many cases, there is neither a standard document format nor a formal mechanism to evaluate best practices and present the evaluation to the community. Documentation is needed for the full life of a glider prior to the mission (e.g., sensor calibration and balisting), during the mission (e.g., for glider piloting, navigation, deployment, and retrieval), and following the mission (e.g., data assimilation and analysis).

The lack of an accepted documentation and evaluation process for best practices limits the capabilities of the community and inhibits wider adoption of gliders. The positive impact of addressing this gap by creating a community with a robust documentation and evaluation process for best practices include:

- Improved data standardization.
- Increased efficiency for glider operation and maintenance meaning lower mission costs.
- Lower barrier to entry for new programs seeking to leverage gliders.
- Improved reproducibility of data collection leading to increased utility of glider observations to a diverse set of stakeholders.

5.2 Current and Emerging Best Practices in Documentation and Evaluation

The community has identified the following best practices for documentation and evaluation:

Priority 5.1 || Set the criteria for satisfaction and produce an initial draft. Below is an initial list of emerging criteria for documentation and evaluation:

- Consistent format of documentation: A standard format for documentation will improve reproducibility and improve usability.
- Consistent standards for data and metadata formats: Machine readability will allow for ease of classification and improved searchability. Centralized location/repository is key to minimizing duplication of effort and increases the ease of access to the information.
- The peer review process: Submitting best practices through the peer review process allows for rigorous evaluation. Moreover, including a mechanism for easily verifying that a document has been evaluated will allow the community to quickly vette the information.
- Assigning a Document Object Identifier (DOI): DOIs allow for ease of citation and sharing across the community.

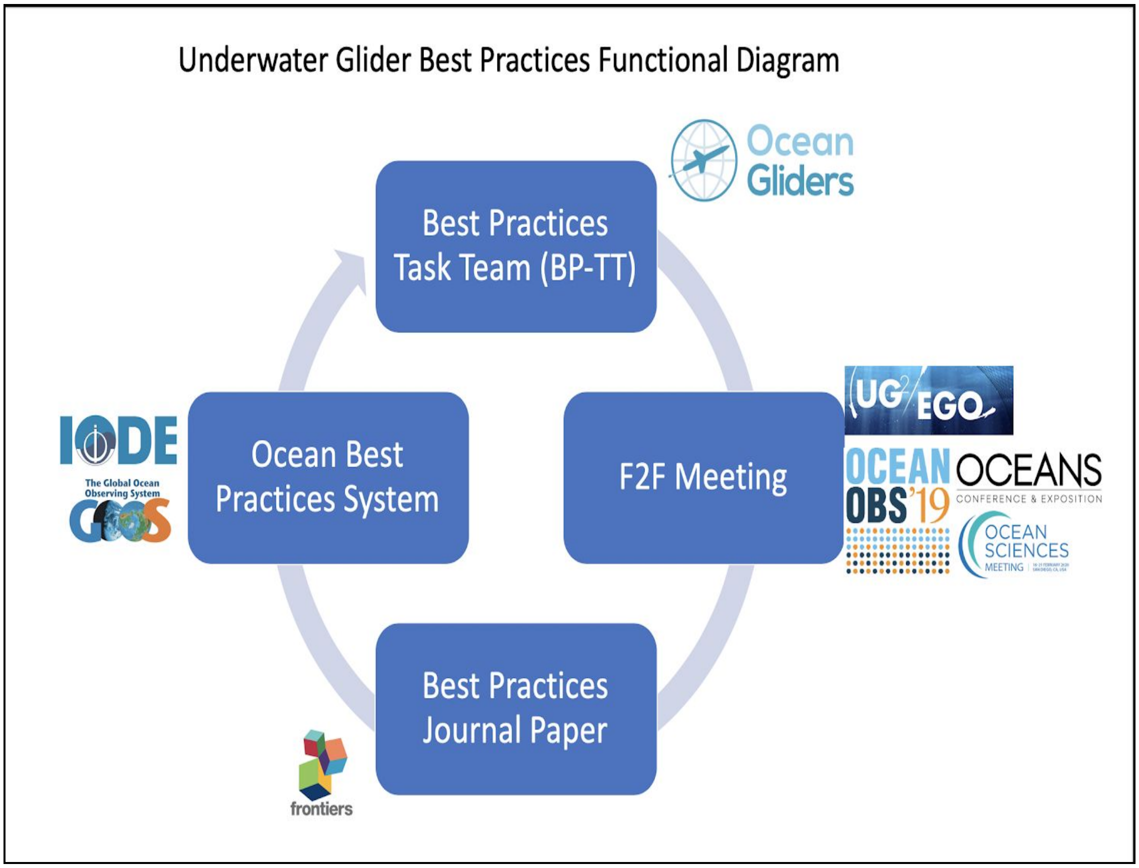

Image 8. Proposed Cycle for Evaluation of Best Practices (Image Credit: 8th EGO Meeting and International Glider Workshop)

Priority 5.2 || Host face-to-face meetings. The community plans to discuss best practices as part conferences like OceanObs'19 OCEANS, EGO Meetings. This includes inviting presentations about what did not work. This information is rarely available through the peer-review process but provides the community an opportunity to share lessons learned that can help move the community forward faster.

Priority 5.3 || Adopt the Ocean Best Practices System (https://oceanbestpractices.net/). This system can be the primary repository for documents. It will be even more useful when it incorporates a method for recognizing Global Ocean Observing System (GOOS) community-endorsed best practices. With Pierre Testor and Mark Bushnell, the community is forming a best Practices Task Team through OceanGliders to develop a paper that describes the various categories of best practices (see also Table 2, Best Practices Databases—Current and Needed).

Table 2. Best Practices Databases—Current and Needed

Category	**System**	**Criteria for Satisfaction** [for needed systems]
Identify partners	Needed	• Connect with people who have similar missions • Learn about those missions with enough

		advance warning to align funds and in-kind contributions • For assembly, deployments, flights, recoveries, and rescues • For shared use of parts, sensors, analysis, and expertise • For coordinated funding from international, national, and state governments that is aligned with the needs • For coordinated liability to cover asset-sharing (e.g., via regional IOOS organizations)
Register past, current, and planned deployments	JCOMMOPS	Note: Consider also the JCOMMOPS work plan
Identify and document current methodologies and approaches	Needed	• Generate consistent observations, formats, and metadata • Stand on the shoulders of the best practices • Expose weaknesses
Manage and archive observations	IOOS Glider DAC	
Catalog and annotate best practices	Ocean Best Practices	Note: This system only captures documents. It must be updated to access information by category or type
Support the network of networks	Boundary Ocean Observing Network (BOON)	Note: This function also could be provided via JCOMMOPS
Reliability and repair database	Needed	• Share maintenance records by device, sensor, circumstances generating the repair • Brief the repair trends to manufacturers • With a consistent and unified voice, request updates and new hardware
Testing and adoption database	Needed	• Share testing and adoption records by device, sensor, circumstances generating the choice • Brief the trends to manufacturers • With a consistent and unified voice, request updates and new hardware
Onboarding, training, and certification system	Needed	• Includes leveled training information with sources • Details the knowledge and skill standards at each level
International agreements	Needed	• Details what is allowed by mission • Details what is allowed by geography • Clarifies the prevailing authority (e.g., Exclusive Economic Zone (EEZ), Safety at Sea, Navy)

Priority 5.4 || Prepare and support the workforce. Ensure there is a sufficient workforce that is ready to engage now, and to replace researchers and operators as they retire. In order for the community to grow, training efforts should integrate individuals at all levels of experience and expertise. This creates an institutional memory that will grow with every successful effort. The glider community must support early career members by providing fast answers to hard questions, mentorship, travel support, and stipends.

Priority 5.5 || Make glider information available at the right time. A system to track glider missions globally must include information about past missions to inform the community about what has been done and to provide an opportunity to leverage existing data sets. Information about current missions would allow the community to identify areas of high activity and plan accordingly. For current and historic information, JCOMMOPS has developed a dashboard for past and active glider missions; however, the community must begin submitting information to continue to maintain the utility of the resource.

Potential disruptors for documentation and evaluation. Disruptors in documentation and evaluation are unlikely.

6.0 The Way Forward

In the earth system ideal, every region must be monitored; every variable must be measured; and all of this is critical for our weather, water, and climate forecasting. Given these, three grand challenges emerge for gliders:

Grand Challenge #1 Decrease costs. Decrease by half the operation and maintenance costs for glider missions. To do this, leverage each deployment and payload and develop the capacity for improved asset-sharing, coordination, and liability protection.

Grand Challenge #2 Interconnect stakeholders. Interconnect researchers, operators, gliders, and other observing systems via international systems that yield consistent data, practices, and training. To do this, coordinate the international agreement for glider operations across EEZs and coordinate the associated international training and accreditation for organizations and glider operators.

Grand Challenge #3 Inform the models. Identify and fill observation gaps in weather, water, and climate models. To do this, agree to data standards and data availability across international funding organizations.

These grand challenges can be met by 2029 if the policy and glider communities together tackle the outcomes and priorities identified for each section, above, and address the technical specifics detailed in each of the appendices, below.

Acronyms List

AIS: Automatic Identification System
ANFOG: Australian National Facility for Ocean Gliders
AOP: Annual Operating Plan
ASA: Applied Science Associates
ASAP: Adaptive Sampling and Prediction
AUV: Autonomous Unmanned Vehicle
BOON: Boundary Ocean Observing Network
BUFR: Binary Universal Form for the Representation [of meteorological data]
CalCOFI: California Cooperative Oceanic Fisheries Investigations
CEQ: Council on Environmental Quality
CONUS: Continental United States
CO-OPS: Center for Operational Oceanographic Products and Services
CTD: Conductivity, Temperature, Depth [sensor]
DAC: Data Assembly Centre
DO: Dissolved Oxygen
DOE: Department of Energy
DOI: Digital Object Identifier
DMAC: Data Management and Communication
DOD: Department of Defense
EEZ: Exclusive Economic Zone
EGO: European Gliding Observatories —or— Everyone's Gliding Observatories
EOC: Education, Outreach and Communication
EPA: Environmental Protection Agency
EuroGOOS: European Global Ocean Observing System
FAIR: findability, accessibility, interoperability, and reusability [data principles]
FTE: Full Time Equivalent
ftp: File Transfer Protocol
GCCS: Glider Coordinated Control System
GCOOS: Gulf of Mexico Coastal Ocean Observing System
GENIOS: Glider Environmental Network Information Operating System
GLOS: Great Lakes Observing System
GMT: Greenwich Mean Time
GOOS: Global Ocean Observing Systems
GPM: Glider Program Manager
GPS: Global Positioning System
GTS: Global Telecommunications System
HAB: Harmful Algal Bloom
HFR: High Frequency Radar
ICOOS: Integrated Coastal Ocean Observing System
IMOS: Integrated Marine Observing Systems
IOC: Intergovernmental Oceanographic Commission

IOOC: Interagency Ocean Observing Committee
IOOS: Integrated Ocean Observing System
IPO: IOOS Program Office
JCOMMOPS: Joint Technical Commission for Oceanography and Marine Meteorology in situ Observations Programme Support Centre
JSOST: Joint Subcommittee on Ocean Science and Technology
MARACOOS: Mid-Atlantic Regional Association Coastal Ocean Observing System
MODIS: Moderate Resolution Imaging Spectroradiometer
NANOOS: Northwest Association of Networked Ocean Observing Systems
NCCOS: National Centers for Coastal Ocean Science
NCEP: National Centers for Environmental Prediction
NDBC: National Data Buoy Center
NESDIS: National Environmental Satellite and Information Services
NetCDF: Network Common Data Form
nFLH: normalized Fluorescence Line Height
NGDC: National Geophysical Data Center
NHC: National Hurricane Center
NJDEP: New Jersey Department of Environmental Protection
NOAA: [United States] National Oceanic and Atmospheric Administration
NODC: National Oceanographic Data Center
NOP IP: National Ocean Policy Implementation Plan
NOPP: National Oceanographic Partnership Program
NRC: National Research Council
NSF: National Science Foundation
NSG: Network Steering Group
NSTA: National Science Teachers Association
Glider Network: National Underwater Glider Network
NWS: National Weather Service
O&M: Operations and Maintenance
OG1.0: OceanGliders 1.0 [unified data format]
ONR: Office of Naval Research
OOI: Ocean Observatories Initiative
OPeNDAP: Open-source Project for a Network Data Access Protocol
OSSE: Observing System Simulation Experiments
OSTP: Office of Science and Technology Policy
PacIOOS: Pacific Islands Ocean Observing System
QA: Quality Assurance
QA/QC: Quality Assurance/Quality Control
QAPP: Quality Assurance Project Plan
QARTOD: Quality Assurance/Quality Control of Real-Time Oceanographic Data
QC: Quality Control
PI: Principle Investigator
RA: Regional Association
RCOOS: Regional Coastal Ocean Observing System

RHIB: Rigid Hull Inflatable Boat
RMS: Root Mean Square
SCCOOS: Southern California Coastal Ocean Observing System
SECOORA: Southeast Coastal Ocean Observing Regional Association
SOS: Sensor Observation Service
ssh: Secure Shell
SSS: Sea Surface Salinity
SST: Sea Surface Temperature
SOP: Standard Operating Procedure
THREDDS: Thematic Realtime Environmental Distributed Data Services
UNFCCC: United Nations Framework Convention on Climate Change
UG2: U.S Glider User Group
UNESCO: United Nations Educational, Scientific and Cultural Organization
UNOLS: University-National Oceanographic Laboratory System
US: United States
USGS: United States Geological Survey
WMO: World Meteorological Organization
WMS: Web Map Services
WRF: Weather Research Forecast

Resources

1. 2017 U.S. Underwater Glider Workshop Report (available online).
2. DRAFT State of Gliders Presentation (available online).
3. Kamensky, John M., and Thomas J. Burlin. 2004. *Collaboration: Using Networks and Partnerships*. In Leveraging Networks: A Guide for Public Managers Working across Organizations. Lanham, Maryland: Rowman & Littlefield Publishers.