Accelerate Improvements in Hurricane Intensity Forecasting Through Underwater Glider Field Campaigns

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Proposed period of performance: September 1, 2022 - August 31, 2025

Proposed total budget: $2,802,480

ABSTRACT: ***Accelerate Improvements in Hurricane Intensity Forecasting Through Underwater Glider Field Campaigns***

Timely and accurate hurricane track and intensity forecasts are critical for coastal communities to prepare and evacuate or shelter in place to save lives and mitigate property damage. While track forecasts have improved over the last 30 years, intensity forecast improvements have lagged. Models require more accurate ocean and atmospheric initial conditions to improve intensity forecasts. This is primarily accomplished through a complementary suite of observing systems (e.g., satellites, aircraft, crewed and uncrewed surface vessels, buoys, profiling floats, and underwater gliders).

Gliders capture high resolution vertical profile data within the water column. This allows them to identify and characterize water masses associated with regional oceanographic features and map the distribution of ocean heat content, which has been linked to rapid Atlantic hurricane intensity changes. Accurate representation of these essential ocean features in ocean models is critical for improving storm intensity forecasts. A distributed network of partners (Integrated Ocean Observing System (IOOS) Regional Associations, Oceanic and Atmospheric Research/Atlantic Oceanographic and Meteorological Laboratory (AOML), the U.S. Navy, and private industry and academic institutions) have demonstrated the use of 'hurricane gliders' to measure essential ocean features in hurricane-prone regions of the Caribbean Sea-Tropical Atlantic Ocean, Gulf of Mexico, the South Atlantic Bight, and Mid-Atlantic Bight (Miles et al., 2021). The glider data are submitted to the U.S. IOOS National Glider Data Assembly Center, where they are delivered through National Weather Service (NWS) pipelines for assimilation into operational NOAA models.

The goal of this proposal is to employ the multi-regional hurricane glider network to provide a dedicated ocean observing field campaign designed to improve NOAA NWS hurricane intensity forecasts. The network will comprise targeted and sustained glider deployments that collect temperature and salinity profiles needed to accurately represent ocean features in ocean atmosphere coupled models used for hurricane intensity forecasts. The IOOS Regional Associations will operate the hurricane glider network in close partnership with NOAA IOOS, AOML, Environmental Modeling Center (EMC), and other NOAA line offices, as well as the U.S. Navy, and academic institutions.

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Overall Goal: Targeted and sustained underwater glider deployments during Atlantic hurricane season that collect ocean observations to optimize the representation of ocean features in ocean-atmosphere coupled models used for hurricane intensity forecasts.

Objectives:

1. Coordinate IOOS Regional Association (RA) and OAR Atlantic Oceanographic and Meteorological Laboratory (AOML) glider sampling strategies with the National Weather Service (NWS) National Centers for Environmental Prediction (NCEP) Environmental Modeling Center (EMC) to improve model forecast accuracy.
2. Measure subsurface temperature and salinity profiles during the Atlantic hurricane season using ocean gliders. These deployments target under-sampled areas in hurricane-prone regions of the Atlantic Basin, where models have struggled to accurately characterize thermal and saline upper ocean features known to impact hurricane intensity.
3. Submit real-time ocean glider profiles to the IOOS National Glider Data Assembly Center (GDAC), where data are quality-controlled and harvested by the NWS for assimilation into the operational NOAA Real-Time Ocean Forecast System (RTOFS).

This effort will advance the transition of the regional hurricane glider networks toward a sustained ocean observing program designed to improve NOAA NWS hurricane intensity forecasts. Rather than transition the hurricane glider network operations into NOAA, the U.S. IOOS Regional Associations, which are federally-certified and include academic, public, nonprofit and for-profit members, will continue to operate the hurricane glider network in collaboration with NOAA/AOML and other NOAA Laboratories/Programs, the U.S. Navy, and academic institutions. This structure allows the NOAA Office of Marine and Aviation Operations (OMAO) Uncrewed Systems (UxS) Operations Center (UxSOC) to capitalize on the existing regional expertise, capacity, and partnerships without the need to build new internal capacity. Operational concepts proposed are part of a larger research-to-operations (R2O)/operations-to-research (O2R) framework that coordinates National Ocean Service IOOS partner ocean observations, OAR testing and evaluation, and NWS modeling activities such that deployment configurations are based on science and modeling requirements. Ultimately, this work contributes to a more Weather Ready Nation through a comprehensive integrated national hurricane observing system that enables emergency managers to make time-sensitive decisions on storm preparation, evacuation, and shelter-in-place orders that protect lives and property.

Background

Autonomous underwater gliders are a unique and versatile platform that can reliably collect data in areas of the ocean where other observing platforms are challenged. Gliders use changes in buoyancy to move through the water column while collecting vertical profiles of surface and subsurface ocean parameters. They can provide flexible, targeted observations through adaptive sampling, and sustain missions from 3 weeks, to up to one year. With typical glide slopes and dive depths of up to 1000 m, a glider can travel up to 5000 m forward during each dive, depending on ambient current speeds. Baseline glider measurements are depth, temperature, and salinity, with vertical resolutions of approximately 1 meter. Additional variables (e.g., oxygen concentration, current profiles, chlorophyll concentration, and passive acoustics) can be measured or estimated depending on the objectives of the mission.

The IOOS RAs, academic partners, OAR, and the U.S. Navy have been deploying underwater gliders to meet observing needs for two decades. In 2013, the U.S. IOOS Program Office established the GDAC that provides all federal and nonfederal operators a centralized data management system through which their glider data can be quality controlled, published, and distributed through the NWS to the Global Telecommunications System (GTS) for access by modelers. Since 2017 AOML and IOOS have led a concerted effort to use data from underwater gliders for the improved prediction and understanding of the ocean's role in hurricane intensity forecasts. To date, this collaboration includes contributions from over 15 institutions (IOOS RAs, federal partners, private industry, foundations, and academia) and the U.S. Navy. This distributed network of partners has coordinated to establish hurricane glider 'picket lines' to monitor upper ocean features throughout hurricane season within the tropical Atlantic Ocean, Caribbean Sea, South and Mid Atlantic Bight, and Gulf of Mexico regions. Gliders performing other missions within hurricane prone regions have also contributed relevant ocean observations through the GDAC that have been leveraged for hurricane forecasting and research efforts. The U.S. Navy involvement in this regional partnership has demonstrated what can be achieved under the collaboration framework established by the Commercial Engagement through Ocean Technology (CENOTE) Act of 2018, P.L. 115-394. These efforts also align with the NOAA Uncrewed System (UxS) Strategic Plan to expand the application and use of UxS to improve NOAA products and services. They are similarly fully aligned with the NOAA Science Advisory Board (SAB) 2021 Priorities for Weather Research (PWR) decadal report's Immediate First Steps - to fill gaps in existing Earth system observing networks with existing, proven or augmenting technologies (#6) to accelerate development of an Earth system modeling approach to improve forecast accuracy and lead time (#1) that target the understanding and prediction of high-impact weather (#8) and water cycle extremes (#9) (NOAA SAB, 2021).

Introduction

Tropical cyclones (TC) are among the costliest and most dangerous natural hazards on Earth. From 1980 to 2021, they accounted for over $1.148 trillion dollars in loss (more than all other weather and climate disasters combined) and resulted in 6,697 deaths in the United States (NOAA NCEI, 2022). Physics-based projections indicate future hurricanes will have stronger winds resulting in higher storm surges, as well as slower translation speeds resulting in more rain and flooding (Gori et al., 2022). Rapid intensification of TCs in the hours before landfall can potentially catch coastal communities off guard, while rapid unforecasted weakening can incur unnecessary evacuation costs and erode future forecast credibility among the public. Hurricane impacted states and territories are home to over half of the U.S. population[1]. With increasing development and growing populations near the coastlines, impacts from hurricanes will continue to increase. Local governments and decision makers need accurate and timely forecasts to make critical decisions needed to protect lives and property.

Gliders continuously observe temperature and salinity profiles in targeted ocean features where hurricanes intensify or weaken, and in locations where other profile observations are not available or feasible. In turn, these observations have led to improved representation of the ocean in numerical models, which can result in a reduction of hurricane intensity forecast errors within

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[1] Estimated July 1, 2021 population totals from https://www.census.gov/quickfacts/fact/map/US/PST045219. Hurricane impacted states and territories here include: VI, PR, TX, LA, MS, AL, FL, GA, SC, NC, VA, MD, DE, PA, NJ, NY, CT, RI, MA, VT, NH, ME, HI.

NOAA experimental ocean-atmosphere forecast models. Recent studies have shown that specific mesoscale features may be key drivers of hurricane intensity, for example: rapid intensification of Hurricane Katrina (2005) over the Loop Current (LC) and LC eddy features in the Gulf of Mexico (Mainelli et al., 2008), weakening of Hurricane Irene (2011) over the Mid-Atlantic Cold Pool (Glenn et al., 2016; Seroka et al., 2017), rapid intensification of Hurricane Maria (2017) over low salinity features in the Caribbean Sea that suppressed mixing (Domingues et al., 2021), unusually rapid intensification of Hurricane Michael (2018) through heating over LC waters combined with reduced mixing from low salinity features and anomalously warm conditions (Le Henaff et al., 2021). Proper representation of these and other key features is critical for accurate prediction of hurricane intensity.

Numerical Observing Systems Simulation Experiments (OSSEs) determined that the spatial and temporal sampling of a moving profiling observing platform (e.g., a glider) produces the best representation of the ocean mesoscale features for hurricane forecasts (Halliwell et al., 2020). In addition, recent research has shown that the assimilation of hurricane glider data resulted in the improved initialization of the ocean within the HYCOM-HWRF ocean-atmosphere coupled model. This improvement consequently led to a reduction of the error of the intensity forecast in data impact studies conducted as proof of concept for Hurricane Gonzalo (2014) and other hurricanes of up to 50% (Dong et al., 2017; Domingues et al., 2015; Domingues et al., 2021; Le Henaff et al. 2021). Data impact assessments performed by NOAA and their Cooperative Institute partners have shown that the most effective representation of these ocean mesoscale features for integration into operational ocean models is the combination of satellite, underwater glider, and float (Argo core and ALAMO) ocean profiles of temperature and salinity. However, a fully integrated observing system of sustained and targeted ocean observations dedicated to measuring surface and subsurface water properties in support of hurricane studies and forecasts has yet to be designed and implemented (Domingues et al., 2019).

The Focus on Essential Ocean Features

Water mass and ocean dynamics that determine stratification, mixing, and total heat content have been linked to Atlantic hurricane intensity changes; in general, these dominant ocean patterns, often referred to as Essential Ocean Features, vary regionally with different properties and specific pathways to hurricane intensification (Figure 1). The ability to accurately identify, correctly represent, and model these features is critical when estimating the hurricane intensity at sea and just prior to landfall.

The proposed work will focus on underwater glider activities in four regions, the Caribbean Sea and Tropical Atlantic Ocean, Gulf of Mexico, South Atlantic Bight and Mid Atlantic Bight, where the following features are present:

The **Atlantic Warm Pool** (AWP) is a seasonally driven body of water that includes the Caribbean Sea and the western tropical North Atlantic. The warm pool is characterized by warm currents, warm rings and eddies, high upper ocean heat content, and low salinity warm waters of riverine (Amazon and Orinoco rivers) origin, all of which have been linked to hurricane intensification (e.g., Gonzalo (2015), Maria (2017), Irma (2017), and Dorian (2019)). These features extend from the eastern to western Caribbean Sea and southwest tropical Atlantic from the Leeward Islands to the Bahamas. Additionally, the extent of the AWP has been linked to landfall potential along the east US coast (Wang et al., 2011).

The **Gulf of Mexico** (GoM) **Loop Current System** (LCS), which is the dominant circulation feature in the GoM, is composed of the Loop Current (LC) and Loop Current Eddies (LCEs). The LC transports warm water into the semi-enclosed basin through the Yucatan Channel and out through the Florida Strait with the position varying between the retracted and extended states on a sub annual to annual time scale; warm core LCEs shed aperiodically from the LC and propagate westward across the GoM. The Mississippi River plume, another dominant feature in the GoM, affects stratification on the shelf, mostly west of the delta, but can be driven east of the delta, especially by westerly winds during the summer (e.g., Walker, 1996). Interactions with the LCS can advect low salinity water through the Florida Strait or into the central GoM (Hu et al., 2005; Schiller et al., 2011; Brokaw et al., 2019). TC interaction with the LCS has been linked to rapid intensification due to high upper ocean heat content: Hurricanes Opal (in 1995, Hong et al., 2000; Shay et al., 2000), Katrina (in 2005, Mainelli et al., 2008), and Michael (in 2018, Le Henaff et al., 2021). Le Henaff et al., (2021) also discussed the role of the plume east of the delta in the intensity of Hurricane Michael.

The **Gulf Stream** (GS) and **Florida Current** (FC) **System** is a western boundary current system that contributes to moderate to extreme weather events off the eastern US seaboard. The Gulf Stream is the dominant ocean feature of the South Atlantic Bight (SAB), and exerts significant control of ocean heat content, stratification, and variability on the shelf and slope of the Southeastern United States. The shoreward edge of the Gulf Stream varies due to the presence of poleward-moving Gulf Stream meanders, and alternates between strongly deflected (offshore) and weakly deflected (onshore) modes downstream of the Charleston Bump off South Carolina (Bane and Dewar, 1988); transitions between these modes can occur rapidly, i.e., within a few days, and are often not captured by models. The strong temperature and velocity gradients at the Gulf Stream edge drive significant air-sea exchange of heat and momentum, force large- and small-scale weather patterns, and affect the total heat content available for storm intensification.

Hindcasts of Hurricane Florence (2018) show that SST resolution and accurate representation of surface wave conditions have drastic effects on predicted intensity, strength, and precipitation (Zambon et al., 2021). Accurate representation of the Gulf Stream position, variability and interactions with the atmosphere is thus critical for tropical forecasting in this region.

The Gulf Stream also plays an important role in the ocean condition of the Mid Atlantic region north of Cape Hatteras. While situated further offshore and separated from the shelf by the Slope Sea, it forms the offshore boundary for the Mid-Atlantic Bight and delivers tropical heat energy into the highly populated region. The Gulf Stream becomes very unstable north of Cape Hatteras which makes accurate forecasting of its location and condition very challenging without real-time data assimilation. The Gulf Stream's instability can often lead to the formation of Warm Core Rings (WCR) which can bring warm tropical water close to the Mid-Atlantic continental shelf.

Warm Core Rings (WCR) in the Slope Sea between the Gulf Stream and the Mid Atlantic continental shelf are a potential source of deep warm water close to the shelf break. The interaction of WCR and the shelf can lead to significant shelf-slope exchange resulting in both large export of colder and fresher shelf water into the Slope Sea as well as very warm saline intrusions of GS water onto the shelf. Surface and thermocline intrusions can be a significant heat source for tropical storms in the MAB. Hurricane Henri in 2021 intensified over a WCR as it moved northward to landfall in Rhode Island, but operational forecast models disagreed on the structure and location of the feature. WCRs in this region are often difficult to identify before hurricane arrival, leading to greater uncertainty in ocean models. Gliders in the Slope Sea provide a means to look below the uniformly warmed summer surface waters to more accurately locate the deep warm waters of these essential ocean features and enable the models to better represent them.

The **Mid Atlantic Cold Pool** (MCP) is a seasonally regulated body of water that extends from Cape Hatteras to southern Georges Bank. The Mid Atlantic Bight in the summer is home to one of the most highly stratified continental shelves in the world (Houghton et al., 1982), which is frequently mixed and advected ahead of both extra-tropical cyclones and hurricanes (Miles et al., 2017). The subsurface bottom water, known as the Cold Pool, has been documented to rapidly reduce hurricane intensity in the final 24 hours before landfall (Glenn et al., 2016; Seroka et al., 2017) and contribute to significant forecast uncertainty in operational coupled hurricane modeling systems. The evolution of the Cold Pool is driven by seasonal surface forcings, large-scale along-shore transport, shelf-break frontal processes, and episodic high energy events such as hurricanes. Quantifying the spatial and temporal variability of the Cold Pool throughout the hurricane season is essential for the accurate assessment of the ocean heat content and improving ocean model forecasts.

Technical Project Plan (CONOPS)

Gliders are mature ocean observing technologies that can be deployed globally for months to more than a year; however, the complete hurricane glider network is currently at a readiness level (RL) 7. In this proposed effort, we will transition the hurricane glider network to a RL8 and develop and demonstrate the pathway to RL9 by 1) integrating deployments supported through this project alongside the broadly leveraged set of gliders planned for deployment in the 2023 and 2024 hurricane seasons; 2) supply real-time data to the NOAA NCEP through established pathways at the IOOS GDAC; 3) coordinate QA/QC expertise at AOML and RAs; and 4) coordinate with NOAA EMC operational modeling teams to ensure data are effectively transmitted, traced, and utilized in operational systems. Regionally focused deployment requirements and strategies, QA/QC procedures, and mechanisms for coordination will be utilized.

Regional deployment strategy and temporal coverage

Proposed glider lines for this initiative are detailed in Figures 2 - 4. A complete sustained hurricane glider network would include additional lines for the full duration of the hurricane season (June 1 - November 30). Deployments supported by this project will be coordinated with additional deployments tasked by IOOS Regional Associations, Global Ocean Monitoring and Observing (GOMO), AOML, the U.S. Navy, and public-private partnerships leading towards a mature fully developed hurricane glider observing system.

A total of 22 glider deployments and operations will be supported by this proposal. This will include:

- 2 glider deployments in the Caribbean Sea off Puerto Rico/USVI (in collaboration with 4 additional deployments by NOAA AOML, separately funded)
- 10 in the northern Gulf of Mexico
- 6 in the South Atlantic Bight to the Gulf Stream at the shelf edge
- 4 in the central Mid Atlantic Bight

CARICOOS proposes to enhance ongoing tropical hurricane glider efforts by collaborating with AOML in the operation of a total of 6 five-month-long deep-water hurricane glider deployments in the US Caribbean. During the 2023 and 2024 Atlantic hurricane seasons, one CARICOOS glider and 2 AOML gliders will be deployed and operated in a joint effort by CARICOOS and AOML. These will provide real-time observations of the three-dimensional structure of Caribbean and Tropical Atlantic waters within the CARICOOS region as driven by mesoscale features including continental river plumes. The area to be sampled includes zonal northwest-southeast transects off the US Caribbean Islands covering the trajectories recurrently followed by major hurricanes before landfall in the region (Figure 2.) All the above efforts are primarily focused on providing real-time observations on the three-dimensional structure of Caribbean and Tropical Atlantic waters within the CARICOOS region as driven by mesoscale features including continental river plumes and the improvement of ocean representation in coupled ocean-hurricane forecast models. CARICOOS, together with partners at AOML will coordinate and provide scientific consultation and technical assistance in deploying and operating the network of underwater gliders in Caribbean waters.

The SECOORA Glider Observatory proposes to contribute three glider deployments each year in the SAB as part of the Hurricane Gliders picket line. To capture the Gulf Stream edge, evolution of stratification on the shelf, and other essential ocean features in the SAB, the gliders will be operated on the shelf out and into the shoreward edge of the Gulf Stream (Figure 3.) Given the large geographic area and potential for biofouling in the warm, shallow shelf water of the SAB, SECOORA will target three 21–28-day deployments annually during hurricane season. Gliders will be prepared for hurricane operations in late spring before hurricane season opens, and reserved for duty at laboratories in Florida, Georgia, and North Carolina. Gliders will be jointly operated by observatory members at Skidaway Institute of Oceanography/University of Georgia, Georgia Tech, University of North Carolina, and University of South Florida, with deployments and recoveries coordinated among the member institutions. PI Edwards will coordinate with the NOAA and Navy partners, as well as other hurricane glider scientists, on strategy as storms enter the Caribbean and move into the SECOORA footprint.

In 2023 the Mid Atlantic glider will be deployed on the continental shelf targeting the seasonal stratification of the Cold Pool. The glider will join approximately six glider lines that are supported currently at ~50% capacity for the 2022 field season (Figure 4). To mitigate these limitations, planned glider deployments will target the time-period with peak stratification and highest likelihood of hurricane impacts (July through September). In 2023 and 2024 deployment support from this project will be expanded on the shelf in addition to deployments farther offshore in the Gulf Stream and its associated eddies and meanders. Participants from the Mid Atlantic region will continue to coordinate these deployments with the other regions and develop shared deployment plans, deployment best practices, and data QA/QC methodology as well as post-season and pre-season debrief and planning exercises.

The Gulf of Mexico’s LCS is extremely dynamic with high variability in its location and eddy shedding (NASEM, 2018). As such, GCOOS deployment strategies are evaluated on an annual basis. In fiscal year 2023, one glider will be purchased by the University of Southern Mississippi to increase the number of regional assets in the Gulf of Mexico. During the 2023 hurricane season, GCOOS will have six glider missions supported through this project to provide improved spatial and temporal coverage of the western, central and eastern regions in the Gulf of Mexico (Figure 5). Peak hurricane activity for the Gulf of Mexico is September 10th, so the anticipated deployments associated with this proposal will be scheduled for early to mid-August with recovery in early to mid-November. It is anticipated that three missions (at ~30 days/mission) will target the shelf north of DeSoto Canyon, the cyclonic eddy typically found near DeSoto Canyon, and will also help define the freshwater barrier layer east of the Mississippi River delta; two missions (at ~90 days/mission) will target the boundary of the northern extension of the LC (or a potentially detached LCE depending on the LCS state); one mission (~90 days) will target frontal eddies along the west Florida escarpment. Four of these glider missions will be repeated during the 2024 hurricane season for an estimated total of 270 glider mission days during that season. GCOOS will coordinate with the NOAA and Navy partners, as well as other hurricane glider scientists, on strategy as storms enter the Caribbean and move into the Gulf of Mexico.

Glider deployment strategies will be coordinated by a hurricane glider steering committee with representatives from each region. This group will be tasked between seasons with assessing operations from the previous years, identifying critical gaps in the network, and coordinating with other ocean observing platforms to ensure broad and impactful spatial and temporal coverage. This approach will ensure that gliders are efficiently distributed, coordinated with local knowledge, and deployments are designed to have the maximum impact on representation of essential ocean features in coupled hurricane forecasts. Table 1 identifies major risks and their mitigation.

Table 1. Major Risks

Risk	Mitigation
Bottlenecks in glider preparation (sensor calibration, glider servicing, personnel limitations, etc.)	Stagger deployments that are funded through other sources to supplement project-funded operations. Share sensor packages, hardware, and expertise across partners.
Faulty gliders during deployment	Pre-deployment testing to identify issues; pre-deployment replacement of user-serviceable parts; stage at least one back-up glider on shore in case replacement is required. Share and re- purpose assets between partners.
Lost gliders during deployment	Mount an emergency glider recovery mission in the case that the glider cannot make it back to the planned recovery waypoint. Coordinate with a broad network of glider capable recovery teams.
Hard to recover gliders due to environmental hazards	Delay recoveries to ensure safety of all crew

Management Plan

The project team will comprise a committee of regional representatives. The team will convene at bi-weekly hurricane glider meetings to communicate project updates and complete project objectives according to the timeline of anticipated milestones and deliverables. The frequency will increase to weekly meetings during hurricane season to report and discuss operational readiness, deployed glider status, deployment challenges, and to develop solutions as needed. The project team will participate in biweekly meetings with the NOAA Extreme Events Ocean Observations Task Team (EEOOTT) and will coordinate deployment plans with the NOAA

AOML Hurricane Research Division (HRD) Hurricane Field Program (HFP), and the NWS NCEP EMC. The team will participate in daily briefings during the hurricane season to coordinate deployed gliders with overlapping aerial flight missions with other targeted ocean and atmospheric observations.

Key Personnel:

- Debra Hernandez, SECOORA Executive Director, will serve as the primary point of contact for all subawardess. SECOORA has extensive project and program management experience to coordinate partners, execute funds, and oversee project plans and deliverables.
- IOOS RA Executive Directors (Gerhard Kuska - MARACOOS, Jorge Brenner - GCOOS, and Julio Morell - CariCOOS) will ensure obligated funds are distributed on subawards and will oversee operator success.
- Field operators from each region will lead and coordinate glider testing and field operations, each with extensive field experience:
  - Mid Atlantic operations: Travis Miles and Scott Glenn (Rutgers University), Donglai Gong (VIMS), Matt Oliver (UDel)
  - South Atlantic operations: Catherine Edwards (Skidaway Institute of Oceanography/UGA)
  - Gulf of Mexico operations: Kerri Whilden (GCOOS/TAMU), Kevin Martin (USM), Chad Lembke (USF), Bob Currier (GCOOS)
  - Caribbean operations: Julio Morell (CARICOOS), Gustavo Goni (AOML), Patricia Chardon-Maldonado (CARICOOS), Doug Wilson (OCOVI)

The above operators' institutions each have facilities designed for glider testing and repair.

Table 2: Key Milestones (Dates are the same for 2023 and 2024 unless where noted.)

Milestones	Annual Schedules	Success Criteria
Caribbean glider missions	6/15 deployment and recovery 11/15	Glider data profiles available in the IOOS Glider DAC
South Atlantic glider missions	8/1 to 9/15 deployment and recoveries 9/1 to 11/1	Glider data profiles available in the IOOS Glider DAC
Gulf of Mexico glider missions	Aug 15 deployment and recovery Nov 15	Glider data profiles available in the IOOS Glider DAC
Mid Atlantic glider missions	8/15 deployment and recovery 10/15	Glider data profiles available in the IOOS Glider DAC
Technical review/ glider operations hotwash	12/1	Hotwash attendees include all regional operators and relevant partners
Hurricane season deployment plans	Complete 4/15	Deployment plans are documented and shared among project partners, with input from NWS and OAR partners
Repair and maintenance cycle completed	4/30 (2022 and 2023)	Gliders pass relevant tests for seasonal deployments
Semi-annual progress report briefing	10/1 and 4/30	Project PIs are briefed and approve operations

Project deliverables:

- Project start and project end technical reviews
- Yearly deployment plan developed in coordination with OAR and NWS/EMC
- Glider data, accessible via the GDAC (https://gliders.ioos.us/data/)
- Semi-annual Project Briefing
- Final Project Report

Data Management Plan

Glider data has well-established pathways for submission to and ingestion in operational ocean models. The data collected during every dive will be transmitted by the gliders in near real-time whenever the glider surfaces. The IOOS Office maintains the GDAC, which allows users to submit glider data to a centralized location from which it is made widely available via web services and archived with NCEI. The GDAC conducts Quality Control (QC) tests on all glider profiles, and QC procedures will be enhanced in FY2022- 2023 in coordination with IOOS, AOML and research community experts. From the GDAC, the glider profile data are delivered through the National Data Buoy Center (NDBC) to the GTS and the NCEP data tanks, where it is available for model assimilation in near real-time (Figure 6). Data are also archived via NDBC at the National Centers for Environmental Information (NCEI).

Budget Summary

The total project funds requested are $2,802,480 for this 3-year project. SECOORA is the fiscal manager for this project and will distribute funds to the SECOORA glider operators and the other RAs. Funds will be distributed as shown in Table 3.

Table 3: Budget Summary by Fiscal Year

RA	FY22	FY23	FY24	Total Project Funds Request (FY22-FY24)
SECOORA admin	$38,800	$23,581	$1,100	**$63,481**
SECOORA glider ops	$379,199	$210,557	$147,242	**$736,999**
GCOOS	$503,137	$368,279	$198,584	**$1,070,000**
MARACOOS	$508,412	$232,588	$0	**$741,000**
CariCOOS	$88,515	$88,515	$13,970	**$191,000**
Total	**$1,518,063**	**$923,521**	**$360,896**	**$2,802,480**

Figures

Figure 1. Essential Ocean Features linked to Atlantic hurricane intensity changes.

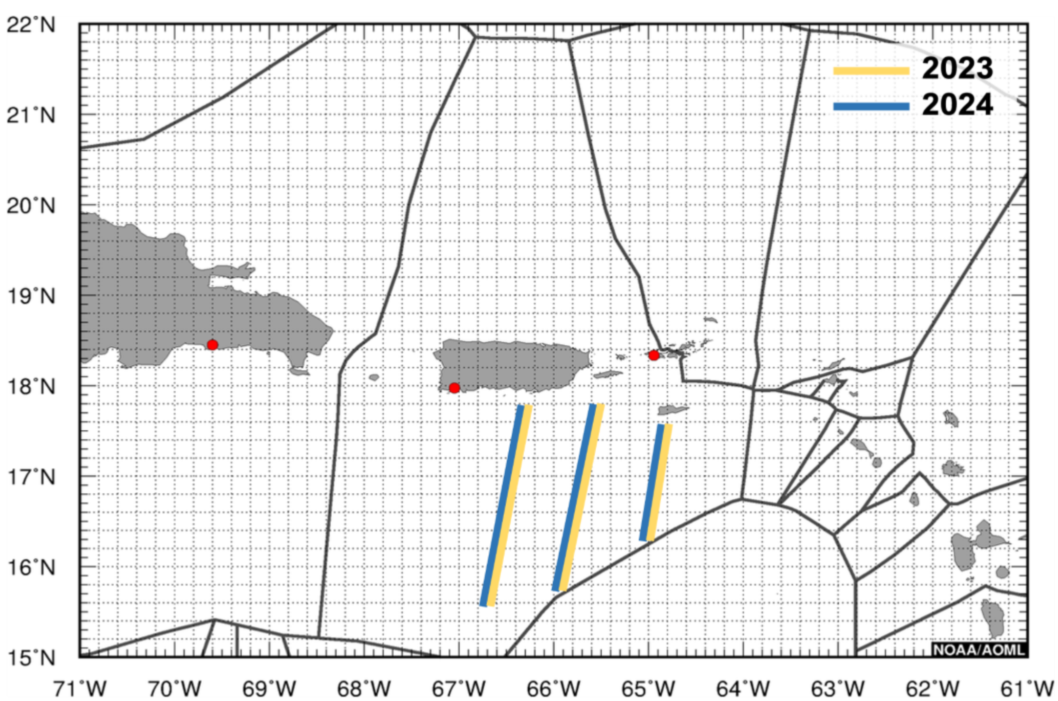

Figure 2. Caribbean Sea: Approximate proposed location of underwater glider observations during the 2023 (yellow lines) and 2024 (blue lines) Atlantic hurricane seasons.

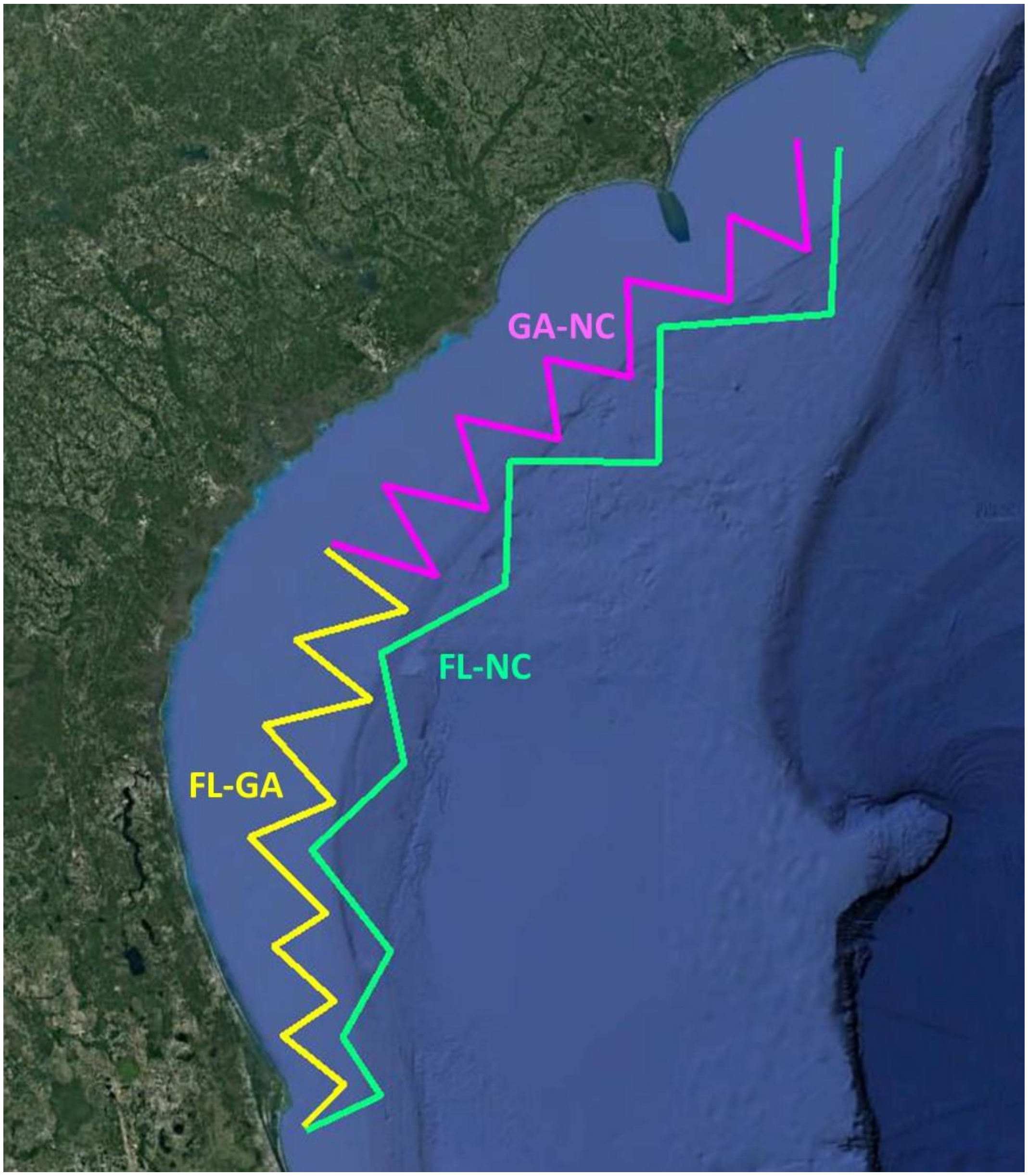

Figure 3. Glider Deployment Transect Estimations Along South Atlantic Bight for both 2023 and 2024.

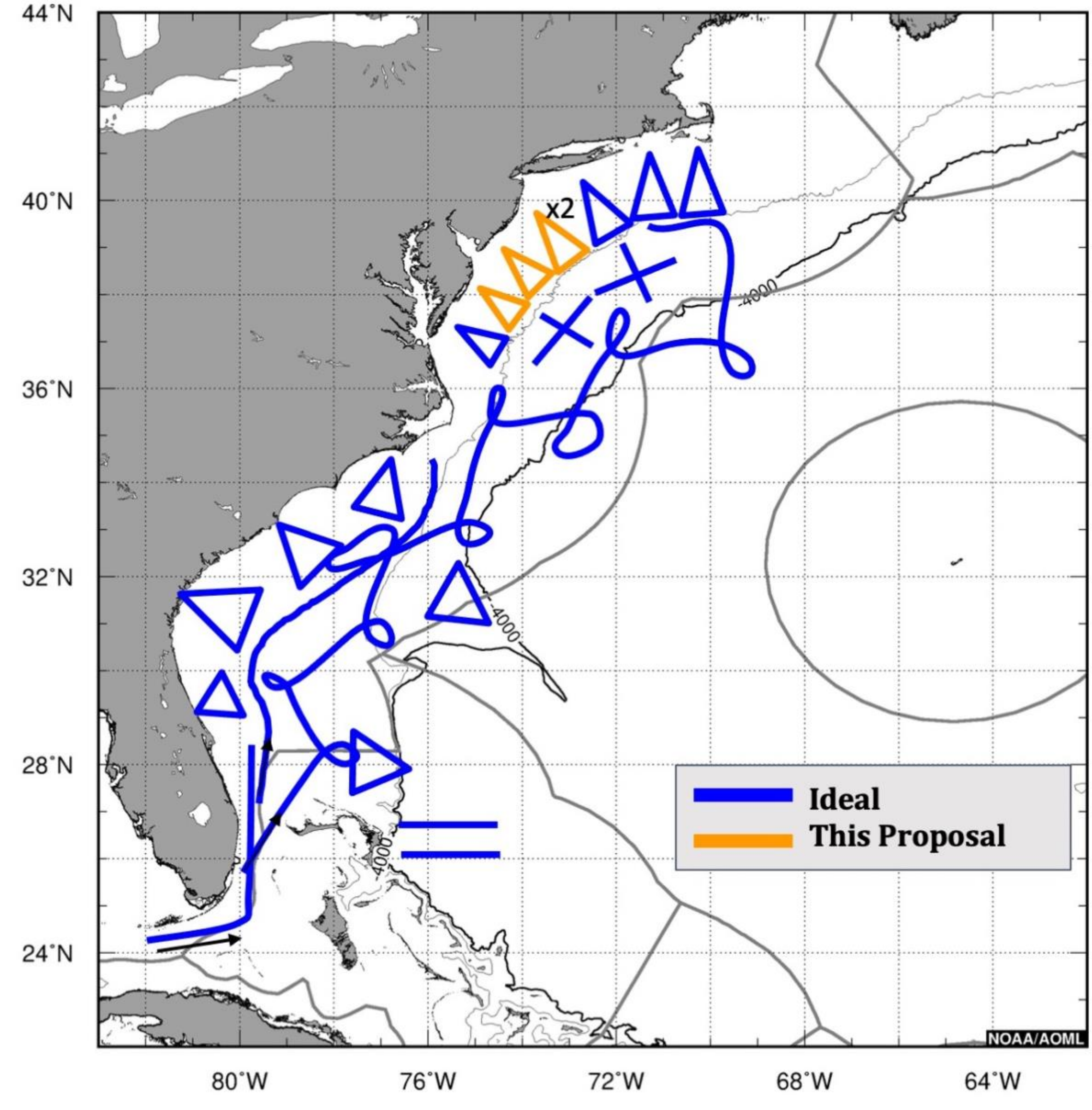

Figure 4. Glider Deployment Transect Estimations Along Mid Atlantic Bight for both 2023 and 2024.

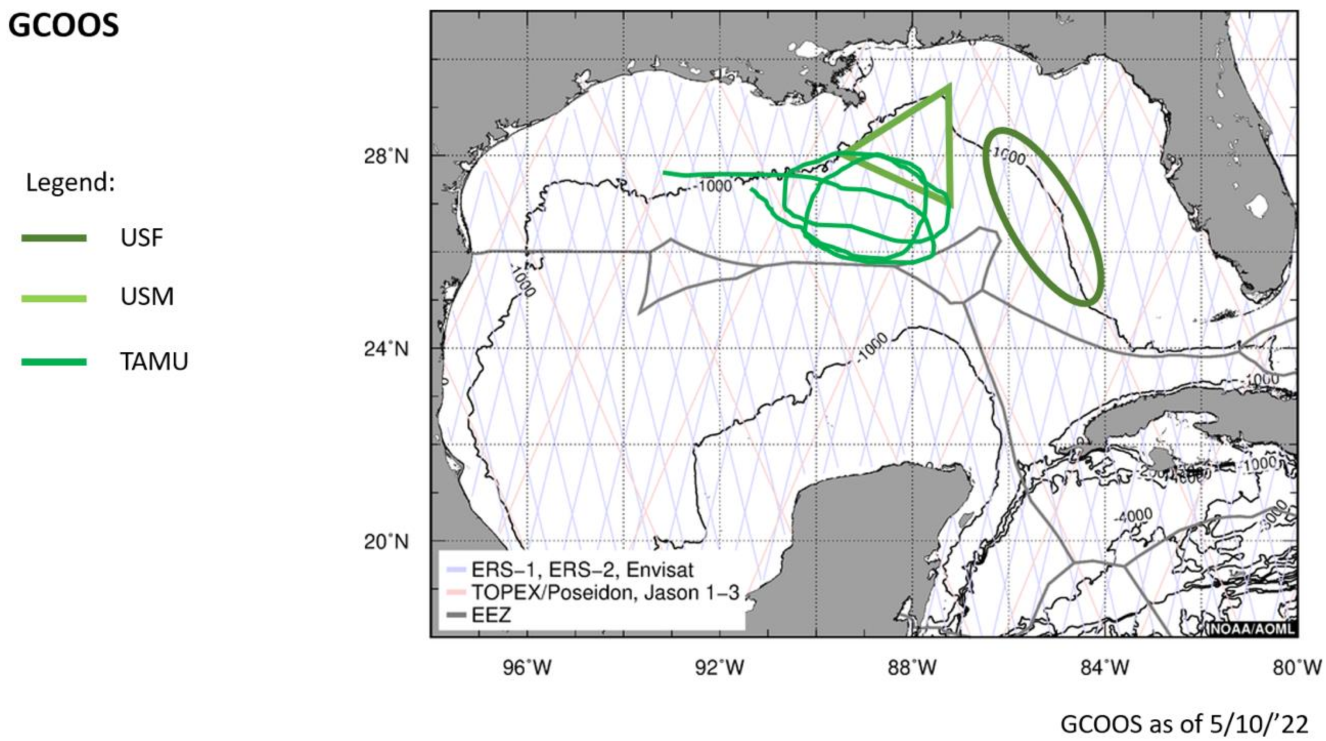

Figure 5. Gulf of Mexico: Glider mission planned paths by partnering institution. Note that paths will be reused in missions during years 2023 and 2024.

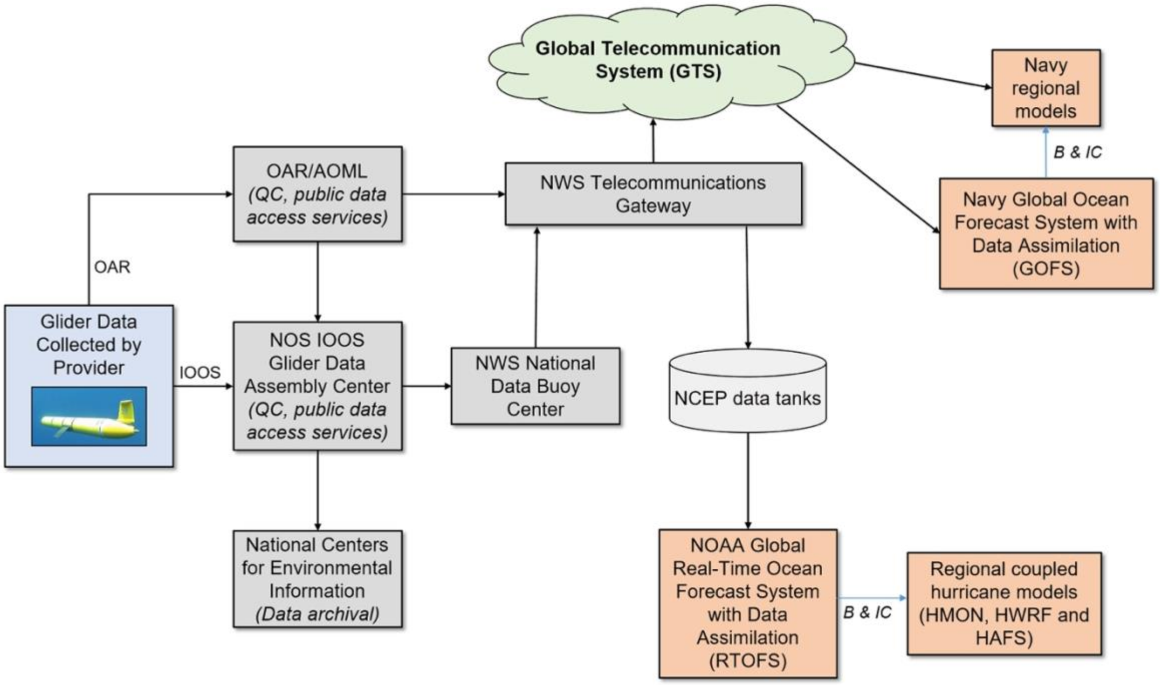

Figure 6. Glider data flow through NOAA NWS pipelines and are assimilated into the NOAA Global RTOFS model, which provides the boundary and initial conditions for regional coupled hurricane models.

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