The Caribbean Coastal Ocean Observing System: A responsive stakeholder-driven observing system addressing regional and national needs in the US Caribbean

A Proposal* in response to:

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Duration of proposed project:
June 1, 2021 –May 31, 2026

TOTAL 5 YEAR BUDGET: $26,564,285

*This proposal complies with the IOOS PEA, specifically with the Project Design Criteria (Sections: 3.1.10 p. 19-20, 3.2.10 p. 53-57, 3.3.10 p. 66)

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1 BACKGROUND

The Caribbean Coastal Ocean Observing System (CARICOOS) is one of eleven regional associations for ocean observing comprising the coastal component of the US Integrated Ocean Observing System (IOOS). Its geographical extent encompasses Puerto Rico (PR), the US Virgin Islands (USVI) and Navassa, their respective coastal waters, and Exclusive Economic Zones (EEZs, **Figure 1**). As in other tropical insular regions, ocean and coastal areas host a dense population as well as key infrastructure and economic activities including transportation, tourism, industrial port operations, commercial shipping, fisheries and recreation. Said convenience comes at the expense of exposure to major natural and anthropogenic hazards and the need for available information to minimize said exposure and protect marine resources.

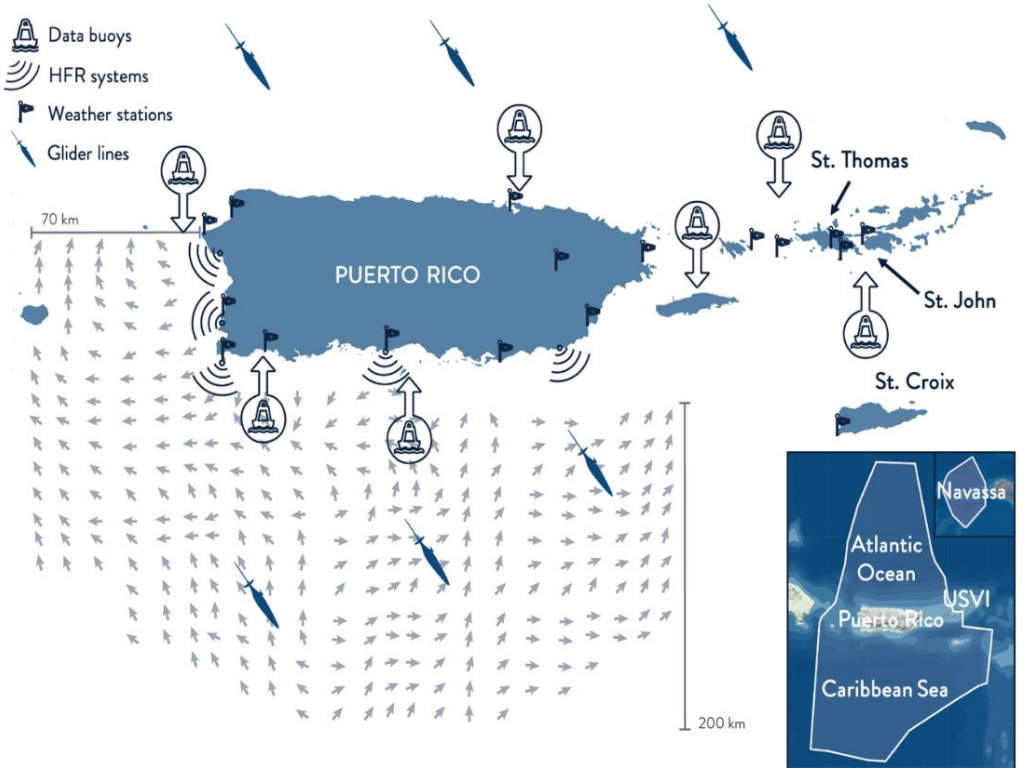

Figure 1. CARICOOS assets as of December 2020. The inset shows the extent of the US Caribbean EEZ.

Since its origins in 2008, CARICOOS members and leadership recognized the opportunity presented by IOOS, then Ocean.US, as the means of securing support for filling critical gaps in the national observing infrastructure of the US Caribbean. Now, as a mature ocean observing system (**Figure 1**) operating five oceanographic buoys, one directional wave buoy, one ocean acidification monitoring buoy, seventeen coastal weather stations, five high frequency radars (HFRs) and six ocean glider lines, as well as operational forecasting models of winds, waves and coastal circulation, CARICOOS is the main source of coastal weather and sea state information supporting a wide range of marine operations and coastal activities. Although observations and information in support of coastal resource management and climate expressions have been resource-limited, investments by partners have allowed for supporting fisheries management, documenting regional climate change expressions, ocean acidification monitoring, and others. More recently, the Hurricane Underwater Glider and Sargasso Harmful Algal Bloom (HAB) programs have extended our range of impact to various sectors.

In order to assure the sustained and responsive operation of the observing system and the timely delivery of accurate data and products to regional stakeholders, as well as national and global databases, CARICOOS

has structured its operations into five subsystems: 1) Governance and Management Subsystem; 2) Observational Subsystem; 3) Modeling and Analysis Subsystem; 4) Data Management and Cyberinfrastructure Subsystem (DMAC); and 5) Engagement in the Management and Operations (EMO, or "Outreach") Subsystem. The Governance and Management subsystem is responsible for providing administrative oversight to the observing system; engaging key stakeholders; identifying and prioritizing needs; reporting to funding agencies and members; and procuring resources, collaborations or partnerships which may enrich the services provided by CARICOOS or its impact. The Observational and Modeling & Analysis subsystems are responsible for the maintenance and operation of assets including observational platforms and sensors, as well as numerical models. The DMAC subsystem is responsible for data reception, management, archival and upkeep of databases for CARICOOS data products, as required by IOOS DMAC guidelines. In addition, the DMAC subsystem is responsible for the operation of CARICOOS' computational infrastructure, including cloud computing and data archival resources. The EMO subsystem is responsible for engaging stakeholders in the broad sense in order to enhance awareness and appropriate utilization of CARICOOS products and services and emergent need identification.

This proposal describes our approach at sustaining CARICOOS' existing capabilities, while also filling informational gaps identified through need assessment efforts. These include, among others, the enhancement and expansion of observational and forecasting efforts that will provide information and products in support of incident response by pertinent authorities, maritime operations, assessment and management of ecosystems and fisheries, post-hurricane restoration and reconstruction initiatives. This information will continue to be available through our bilingual and fully responsive user-friendly web portal, a Boating App designed for small craft operators, and a Beach App for beachgoers.

2 OVERARCHING GOALS

Through a fully participatory and user-driven approach, CARICOOS aims at the following overarching goals:

1) Support safe and efficient **maritime operations**;
2) Minimize impact from **coastal hazards;**
3) Support the effective management of **coastal living resources**; and
4) Monitor **climate variability.**

These goals have become **CARICOOS' FOCUS AREAS**, and they are organized as such throughout the rest of the proposal. The effective operation of our five subsystems is crucial to meeting these goals. Details on specific objectives and workplans for both, focus areas and subsystems, are described in Sections 4 and 5 of this proposal, respectively, while their intertwined relationship is presented in **Figure 2**.

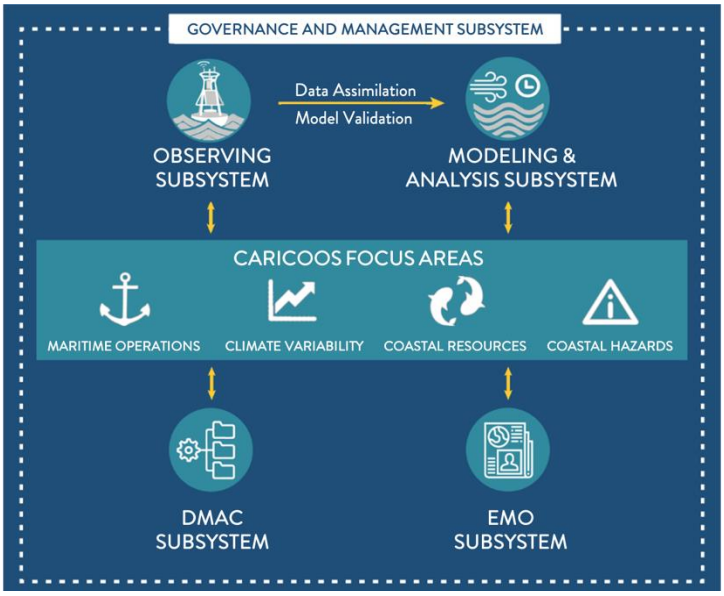

Figure 2. CARICOOS focus areas and subsystems and their relationship.

3 CONNECTION TO STAKEHOLDERS

CARICOOS is, by design, an open and inclusive organization approachable and trusted by stakeholder sectors who understand its mission. Said character has become further ingrained throughout its development. The approaches/opportunities below have assured our mutual accessibility and efficient information exchange with our clientele and partners.

CARICOOS' Board of Directors (CBOD) includes representatives active in maritime operations, fisheries management, meteorology, coastal zone management, recreational boating affairs, oceanography/academy, coastal hazards and coastal and marine affairs. CARICOOS' Technical Leadership (CTL), including PIs and subsystem leads, provide expertise in coastal/ocean engineering and oceanography and are participants in pertinent regional organizations including the Caribbean Regional Response Team, PR Harbor Safety and Security Committee, Jobos Bay NERRS Scientific Advisory Committee, PR Sea Grant Technical Advisory Committee, PR Climate Change Council, USDA-NRCS Technical Committee, and the Board of Advisors of the Ocean Foundation. Additionally, CTL's members are in close communication/collaboration with the National Weather Service (NWS) Weather Forecasting Office-San Juan (WFO-SJ), EPA, USCG Incident Management Division, PR Emergency Management and Disaster Administration, among others. For more information, please see Appendix 21: Letters of Support.

Besides the above stakeholder engagement opportunities, during the last year CARICOOS carried out a dedicated user need assessment effort (see Appendix 22), which provided for engaging individuals, agencies and entities representing various sectors including those addressing emergent challenges. Some of these included ecosystem restoration, coastal hazard prevention, preparedness, mitigation, and adaptation, among others. The findings conveyed in the CARICOOS User Needs Assessment (CUNA – Appendix 22), along with input provided by organizations detailed above, were presented to the CBOD for deliberation and prioritization. Once priorities were established, capabilities within the region (and if not available, outside the region) were explored through a call for Expressions of Interest (EOIs). Submitted EOIs were scrutinized by the CTL for technical and logistical feasibility and recommendations issued to the CBOD for approval. EOIs selected by the CBOD were encouraged to submit full proposals. Proposals submitted are included in this workplan.

4 CARICOOS FOCUS AREAS: GOALS, OBJECTIVES AND WORKPLAN

4.1 MARITIME OPERATIONS

CARICOOS will continue to support user groups that benefit from improved ocean observing and forecasting capabilities. These groups include the NWS, federal and state law enforcement agencies, the shipping and passenger ferry industry, commercial fishermen, and recreational operations ranging from recreational fishing to boaters and paddleboarders, all of which constitute major economic drivers for the region. Since its inception, CARICOOS's main goal is to provide ocean information and decision-support tools to enhance safety and efficiency of the full range of maritime operations taking place in the region. Our specific objectives are:

- Enhance the number and quality of **coastal and ocean observations** that support safe and efficient maritime operations
- Provide **sea state observations and forecasts** in support of WFO-SJ (see SJ WFO' letter of support).
- Support **port and harbor operations**, as well as inter-island shipping and cruising operations, by providing observations and forecasts of coastal weather, waves, winds, currents, and water levels through easy-to-use decision-support tools to aid planning and minimize risk (see letter of support from SE Harbor Pilots).
- To aid the USCG and other incident response agencies by providing the best available surface current and coastal weather data, as well as technical assistance, in support of **search & rescue (SAR) and rapid response operations** (see letter of support from USCG Sector San Juan).

Work Plan:

Ocean observations. While a CARICOOS priority for this funding cycle is maintaining the current system of buoys and sensors in optimal conditions, CARICOOS will seek to expand its asset network as funding allows (further details in Section 5.2). This expansion includes the deployment of small data buoys equipped with meteorological sensors, and current profilers that will provide observations in constrained approaches to critical ports in order to support marine operations while minimizing grounding risks, as well as offering much needed data for circulation model validation. An additional oceanographic data buoy, with surface current measuring capabilities, will be installed near the recently reactivated Limetree Bay LLC (formerly HOVENSA) refinery[T2] to fill a critical gap in wave and currents observations south of St. Croix. CARICOOS will also co-sponsor the operation of a Waverider buoy to be installed in the summer of 2021 off the port of Arecibo, to provide wave observations for PR's northern coast. Real-time cameras, to be installed aboard all CARICOOS data buoys (non-Waveriders), will provide mariners with a visual data stream to gauge visibility and sea state.

Sea state observations and forecasts. In terms of operational forecasting, CARICOOS will continue to improve its suite of wave, wind and circulation models that already provide sea state forecasts at very high-resolution. Further details on the improvement of wave, wind and circulation models are provided in Section 5.3. In response to stakeholder requests identified in the CUNA, sea state modeling efforts will be expanded to include navigation routes between the US Caribbean and nearby countries, such as the Dominican Republic, in order to support safe navigation efforts for US citizens traveling between the US Caribbean EEZ and international waters. A critical decision support tool, the CARICOOS Boating App, which is already in use by a wide array of CARICOOS stakeholders, will be improved and expanded throughout the funding cycle based on stakeholder needs. Finally, FVCOM modeling will be expanded to port areas deemed of high importance such as the Port of Charlotte-Amalie, through a one-way nesting within the CARICOOS FVCOM model.

Port and harbors operations. CARICOOS will continue to develop port-specific products and decision support tools following the successful model that led to the development and implementation of the Yabucoa Port Dashboard. The first interfaces will be developed for the Port of Charlotte Amalie, St. Thomas, where harbor pilots have requested assistance in analyzing the effects of ship wakes on navigation safety, and for the Port of San Juan which ranked 9th in the US in container movement.

SAR and rapid response. Observational data from CARICOOS HFRs has been ingested into the USCG Environmental Data Server (EDS) since 2016. The CARICOOS HFR network will be expanded to allow for coverage of the San Juan-USVI sea-lane, as well as the PR north coast. In addition, the HFR system is being hardened to decrease downtime associated with power and communication outages[T2]. A detailed explanation of the planned HFR coverage expansion is provided in Section 5.2.

4.2 COASTAL HAZARDS

The CARICOOS region is constantly threatened by storm surge inundation, strong winds and storm waves resulting from tropical and extratropical storms in the Caribbean and Atlantic. Our complex shelf and coastal morphology, along with the characteristic wave forcing of the region, result in additional coastal threats, accounting for one of the highest per capita drowning rates in the US. The recurrent presence of potentially pathogenic organisms in coastal waters and the geological/geographical potential for a tsunami landfall represent further coastal hazards in the region. Our rainy Caribbean weather results in significant amounts of surface water runoff entering the coastal environment with potentially detrimental implications to coastal communities and the marine environment. Furthermore, our coastline has suffered alarming rates of coastal erosion as a result of extreme events such as hurricanes Irma and María (2017, see **Figure 3**) and Winter Storm Riley (2018), among others. The goal of this focus area is to support coastal hazard prevention, preparedness, mitigation, and adaptation by providing the best available coastal information and decision-support products while continuing to expand the network of instrumentation platforms and capabilities that provide information

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on coastal weather, waves, currents, beach water quality, and storm surge inundation. Our specific objectives include:

Figure 3. Massive structural damage in Puerto Rico as a result of waves and storm surge from Hurricane María in 2017.

- Deliver accurate wave forecasts and other decision-support tools to help improve **beach safety**.
- Support monitoring programs and operate nowcasts to address **beach water quality issues**.
- Collaborate with state and federal agencies to address **coastal inundation** threats in the region.
- Provide data and products to agencies and industry assessing regional **coastal erosion** problems.
- Explore mechanisms associated with **surface water runoff** that may pose threats to coastal ecosystems and communities (see letter of support from USDA-NRCS).
- Aid in acoustic data collection in shelf waters for feasibility studies of early **tsunami detection**.

Work Plan:

Beach safety. CARICOOS will continue to operate the Nearshore Breaker Model (NBM) that, under the existing cooperative agreement with WFO-SJ, is being utilized as part of their operational Surf Zone Forecast. The NBM, which currently provides breaker forecasts for ~140 beaches in PR/USVI, will be improved with the new unstructured SWAN model, and will continue to provide 5-day forecasts for the Pa' la Playa Beach App. Additionally, a pilot project seeking to monitor potentially hazardous conditions for swimmers is proposed for YR4 and YR5 using the Beach Radar Observing System (BROS)[T2]. BROS is a fully automated, low-power X-band radar sensor to measure wave and current hazards along the beach and surf zone.

Beach water quality. CARICOOS will continue to provide the beach water quality map serving results of the latest Enterococci samples collected by the PR Environmental Quality Board, Surfrider Foundation and Blue Flag. Data from USVI's Dept. of Planning and Natural Resources, as well as additional sources will also be incorporated. The full historical data set will also be provided for each site, as well as experimental nowcasts providing probability of EPA threshold exceedances for 30+ beaches around PR. Latest samples will continue to be provided in the Pa' la Playa Beach App along with a beach water quality rating spanning the last three months of samples.

Given the low sampling frequency and small extent of current monitoring efforts, added to a sampling infrastructure significantly weakened by the 2020 earthquakes and pandemic, CARICOOS proposes to expand beach water quality monitoring efforts by supporting community-driven initiatives. Two satellite water quality laboratories will be established in the northwest and southwest coast of PR. The groups will be trained and sponsored through the Blue Water Task Force Rincón team. An additional pilot project to quantify the abundance, co-ocurrence and distribution of Vibrio spp. in areas affected by natural disasters[T2] will be implemented for Guánica Bay, PR, as it has been the region most affected by the January earthquakes.

A pilot project seeking to assess coastal water quality through ground based RGB and thermal camera systems is proposed for YR2[T2]. Jobos Bay NERRS and Isla Verde have been chosen as the key sites to evaluate turbidity and other optical properties with potential implications to water quality. This non-intrusive system can

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yield information on several water quality parameters, such as chlorophyll and suspended sediment. These camera systems will also aid with coastal inundation (see next item) and Sargassum beaching/inundation events.

Coastal inundation. A key need of CARICOOS stakeholders has been the accurate simulation and mapping of coastal compound flooding (storm surge maps combined with freshwater inundation). An initiative towards this goal proposes a pilot project for a representative watershed in PR. If successful, this effort will be expanded to additional watersheds in the region (see Section 5.3 for further details).

Coastal erosion. CARICOOS will continue to support state and federal agencies dealing with the coastal erosion issue in PR/USVI. We also propose to continue the implementation of remotely sensed video data to monitor shoreline changes at erosion-prone beaches in PR[T2]. The system will provide spatial and temporal coverage of beach morphology previously unavailable in the region and additional support to other areas of interest such as beachgoer safety, storm damage assessment, and beach water quality. Additionally, we propose to launch from the third year onwards the Caribbean Shoreline Monitoring Program to develop a long and regular time series of beach profiles at key erosional hotspots around PR and the USVI[T2]. Such data sets will aid in the evaluation of erosional trends, ongoing shoreline protection initiatives and validation of numerical modeling efforts.

Surface water runoff. CARICOOS proposes to implement a high-resolution coupled hydrodynamic-weather-riverine model (YR3-YR5) that incorporates ongoing numerical products (FVCOM, WRF-ARW, SWAN) and a new WRF-HYDRO effort[T2]. Installation of three stream gauges/year[T2] is also proposed to validate WRF-HYDRO and provide data for other beach water quality efforts. A pilot project seeking to resolve coastal sediment transport resulting from riverine input[T2] is also proposed.

Tsunami detection. CARICOOS will support the PR Seismic Network in their early efforts of coupling ocean acoustic data to seismic information from the 2020 southwest PR earthquake sequence to explore the feasibility of developing an operational early tsunami detection system (see letter of support from Director V. Huerfano).

4.3 COASTAL RESOURCES

Coastal ecosystems services are of particular importance to the well-being of tropical insular communities. While fostering economic activity by attracting tourism, supporting fisheries and other activities driving the blue economy, many of these ecosystems can act as coastal barriers that provide critical protection from extreme events. Barrier-forming systems such as coral reefs, mangroves and seagrasses have suffered overexploitation, anthropogenic sediment and nutrient loading, ocean warming and acidification, among other stressors leading to severe ecosystem damage and loss of ecological functions. The seasonal arrival of massive quantities of pelagic Sargasso, a macroalgae HAB, since 2011 presents an additional persistent threat to these systems.

Major hurricanes María and Irma (2017) and winter storm Riley (2018) evidenced the level of protection provided by coastal ecosystems; the fringing reefs off San Juan's densely populated coastline dissipated more than 90% of the wave energy delivered by H. María. Furthermore, said extreme events have given rise to multiple ecosystem restoration initiatives by researchers, NGOs and governmental entities, who have requested assistance from CARICOOS regarding coastal engineering and restoration designs. Specific objectives in this focus area include:

- Provide managers and ecosystem restoration programs with hydrodynamic, **ecosystem health** and water quality pertinent to coastal ecosystem restoration/reparation initiatives. (see HJR Reefscaping's)
- Implement efforts to assess zooplankton and mesophotic coral reef **biodiversity** while ensuring the inclusion of regional available datasets into the IOOS **MBON** database (see letter from Protectores de Cuencas)
- Assess the spatial and temporal variability of anthropogenic and natural disturbances, including ocean acidification and warming, as well as sediment and organic carbon loading anomalies, **threatening our coastal ecosystems** (see letters of support from Sociedad Ambiente Marino and ISER,).

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- Furthering the implementation of a **Sargasso HAB inundation** forecast in the CARICOOS region and assess its impacts in coral reefs, seagrasses and mangrove areas.
- Support a numerical analysis on the role of environmental events in modulating **fisheries** yield.

Work Plan:

Ecosystem health. CARICOOS proposes to provide physical and biochemical data pertinent to ecosystem health to state and federal management agencies, marine resource specialists, NGOs and researchers proposing, planning and executing coastal ecosystem restoration and reparation efforts following major hurricanes Irma and María (see letters of support from *Protectores de Cuencas* and HJR Reefscaping). In order to identify areas requiring active management/monitoring and documenting shore to shelf edge biogeochemical/water quality gradients, sensor ensembles will be deployed to report salinity, temperature, pH, turbidity, DO, pCO_2 and colored dissolved organic matter (eco sensor ensembles). These will be installed aboard three CARICOOS data buoys in the outer shelf, two lightweight ecosystem/water quality buoys in the mid shelf, and at eight bottom mounted platforms to be located at coral nurseries, potential restoration sites, and areas impacted by Sargasso inundation, river plumes and other anthropogenic disturbances. Mid shelf waters will be monitored with "virtual buoys" reporting critical data such as turbidity, SST, and CDOM derived from remotely sensed data (currently funded project, H. Chuanmin, U. of South Florida).

Biodiversity. We propose to implement a mesophotic reef monitoring effort[T2] which will provide for managers and scientists to assess their biodiversity and role as sources for coral larvae to euphotic coral reefs impacted by coral bleaching and diseases. Furthermore, we propose a monitoring program towards documenting variations in zooplankton biomass and diversity using metabarcoding in inner shelf waters off the coast of southwest PR. We also propose to continue processing and entering available biological data (i.e. USVI Territorial Coral Reef Monitoring Program, the Caribbean Fishery Management Council (CFMC) Mesophotic Coral Reef Monitoring Program, the Southeast Area Monitoring and Assessment Program (SEAMAP) and the National Coral Reef Monitoring Program) into the MBON system. This effort will support assessing impact of anthropogenic, chronic and extreme climatic events. We will also work to increase awareness and understanding of potential data providers about the MBON web mapping application features and the convenience of use of Darwin Core standard as a common practice during data management routines.

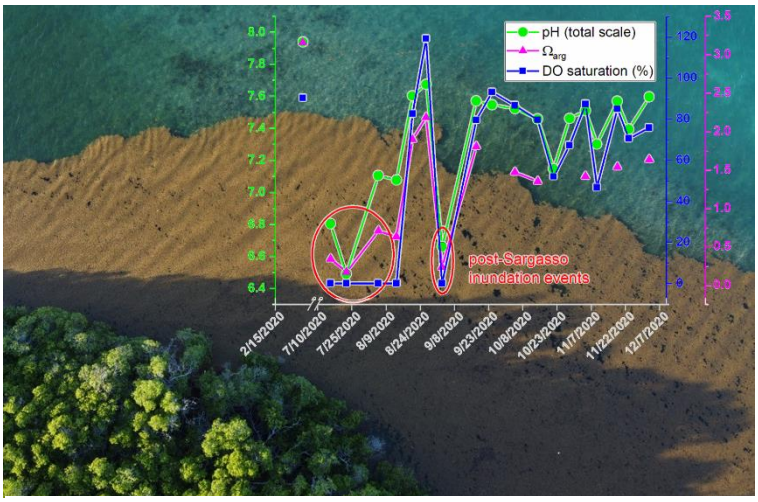

Figure 4. Anoxia and ocean acidification resulting from Sargasso inundation at La Parguera Marine Reserve.

Coastal ecosystem threats. Given the impact of extreme weather events and Sargasso inundation, we will continue documenting changes in mangrove and benthic flora, using high resolution remotely sensed data, every two years at representative areas[T2]. The acquired data will support planning and execution of restoration activities and mitigation of Sargasso and land borne threats to seagrasses, coral reefs and mangroves. Additionally, we will support the operation of 20+ virtual buoys reporting remotely-sensed derived water quality data at sites of interest for fisheries and ecosystem monitoring (including one in Navassa Island National Wildlife Refuge).

Sargasso inundation impact.

CARICOOS proposes to continue ongoing observational efforts using discrete sampling/analysis (TA, H_2S) and sensors (T, S, pH, pCO_2), to assess temporal and spatial expressions of biochemical anomalies arising from Sargasso inundation (**Figure 4**). This effort will be accompanied by a pilot project for forecasting inundation

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events, which will provide for beached Sargasso clean-up, harvesting and impact assessment (collaboration with GCOOS, SECOORA). NOAA's CW-CGOM Regional Node will provide remotely sensed imagery for YR1. High-resolution imagery for YR2 and YR3 will be acquired from C. Hu at U. of South Florida. Observations derived from this effort will allow for the inclusion of Sargasso inundation in foreseeable ecological forecasting initiatives.

Fisheries. Support to fisheries management will be provided by funding a postdoc[T2] to assist the CFMC in exploring the empirical relationships between CARICOOS hydrodynamic data and fisheries yield in the region. Additionally, CARICOOS will continue to provide hydrodynamic data for fish larvae dispersion studies sponsored by the CFMC (see letter of support from Director M. Rolón).

4.4 CLIMATE VARIABILITY

Our oceans influence both regional and extra-regional climate and weather processes, and their variability can fundamentally alter many of its properties and spatial distribution, which may in turn impact the sustainable management, conservation and restoration of coastal and marine ecosystems, the diversity and abundance of marine species, and the frequency, intensity and impact of extreme weather events. Changes in frequency and intensity of extreme weather events such as hurricanes, extratropical cyclones, storm surge and floods can be a significant hazard for coastal areas and habitats, which challenges their capacity to recover and adapt. Our understanding of climate and weather mechanisms that produce extreme events is improving, and progress is being made in the methods that are used for event attribution. Our goal in this area is to use data from CARICOOS network of observing assets to assess and document climate trends and variations in ocean properties attributable to regional climate processes. Our specific objectives include:

- Providing technical and logistical support to **national targeted programs**, such as NOAA's Ocean Acidification and Hurricane Glider programs.
- Continue gathering, analyzing, and assessing data pertinent to **climate-related trends** and impacts, thus leveraging the observing investment of federal and state agencies in the region.
- Contribute to **national and global data sets** through the continued operation of observing assets.

Work Plan:

National-targeted programs. Acknowledging that resolving, understanding, and monitoring upper-ocean dynamics will improve forecasting tropical cyclone intensification [Domingues et al., in review, 2019], CARICOOS proposes to enhance ongoing tropical Hurricane glider efforts by operating a network of six (6) gliders in the Caribbean Sea and Tropical Atlantic Ocean in collaboration with NOAA-Atlantic Oceanographic and Meteorological Laboratory (AOML)[T2]. These gliders will be part of a larger fleet deployed throughout the western Atlantic Ocean with partners from the US NAVY, MARACOOS, SECOORA, GCOOS and Rutgers U. to carry out upper ocean observations of temperature and salinity in support of tropical cyclone intensity (intensification and weakening) studies towards improving operational forecasts. Moreover, underwater glider observations will serve for documenting the response of oceanic environment to regional (i.e., eddies, sea surface temperature/salinity trends, continental riverine influence) and remote climatic forcing (ENSO, NAO) and the improvement of ocean numerical model's representation of the ocean.

The continued anthropogenic increase in atmospheric carbon dioxide concentration and the resulting ocean warming and acidification have had a significant impact on the region's coral reefs and associated ecosystems. CARICOOS proposes to continue the efforts of adequately understanding the cumulative effects of coastal ecosystems stressors using in situ observations from sensor ensembles aboard several platforms (see Ecosystem health above) and satellite-based virtual buoys. CARICOOS will continue to operate the $MAPCO_2$ buoy and related routine water sampling/analysis with funding from NOAA's Ocean Acidification Program. This effort will be paralleled by a CARICOOS-sponsored regional assessment of dissolved and particulate carbon fluxes required for proper interpretation of $MAPCO_2$ buoy/discrete water sample data.

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Climate-related trends. This issue has drawn public attention due to the increased frequency and intensity of extreme weather events. There is an interest in understanding the connection between climate, extreme weather events, and marine biodiversity/fisheries because of its potential value for informing choices about assessing and managing risk, and for guiding climate adaptation strategies. Aware of this, CARICOOS proposes to initiate a comprehensive analysis of a wide range of ocean and weather variables (i.e. waves, winds, salinity, temperature, precipitation) to explore the role of climate variability in ocean conditions, regional weather patterns, coastal marine ecosystems, fisheries, among others. This assessment will be performed using the historical data from CARICOOS observational assets, numerical models, and satellite-based virtual buoys, as well as datasets from other partners and collaborators such as Jobos Bay NERRS (see letter of support from Director A. Pabón), San Juan Bay Estuary Program (EPA, see letter of support from Director B. Torres) and NGOs (i.e. Sociedad Ambiente Marino, see letter of support from Director S. Suleimán). A postdoc will derive an advisory report which will include the collection and analysis of all physical oceanographic, meteorological and climate data[T2].

National data sets. CARICOOS will continue to provide support for a long-term sustained observing network to track ocean, weather, and marine ecosystem changes. CARICOOS is collaborating with regional and national agencies to help maintain long time series data collection, develop consistent data quality protocols, synthesize new and existing data streams and make data accessible.

5 CARICOOS SUBSYSTEMS: GOALS, OBJECTIVES AND WORKPLAN

5.1 GOVERNANCE AND MANAGEMENT SUBSYSTEM

CARICOOS Inc. is a nonprofit corporation organized and operated exclusively for scientific, and/or educational purposes within the meaning of § 501(c)(3) of the US Internal Revenue Code of 1986 and §1101.01(a)(2) of the PR Internal Revenue Code of 2011. Since 2017, NOAA has certified CARICOOS as a Regional Information Coordinating Entity (RICE). CARICOOS Inc. will serve as the sole fiscal agent for the observing system and provide the administrative support required for the implementation and management of the here proposed initiatives.

CARICOOS Inc.'s open membership policy has assured ample participation from all major stakeholder sectors (i.e. maritime industry, academic institutions, government agencies NGO and others), but also individuals. All of these are represented in the CBOD and participate in CARICOOS Annual Meeting. They provide the CTL with a first-hand account on their data and information needs and urgency. The CBOD is also informed by the CTL participation in organizations and forums with diverse interests in the region's coastal ocean. The awareness nourished by stakeholder's input, along with focused need assessment efforts, has provided the CBOD and CTL with the guidance required for CARICOOS to evolve into as a distinct observing system well focused on our region's high priority data and information needs and responsive to emergent regional and national priorities.

CARICOOS management/operational structure follows a strategic operational plan that ensures the efficient and effective administration of programs and assets to support observations for integration into IOOS. The design and construction of data and products for dissemination to the public via caricoos.org, as well as CARICOOS mobile applications result from close collaboration of the CTL and various contractors. Details of all subsystems are provided in sections 5.2-5.5.

Work Plan:

Regional and national data and product needs and prioritization. Through CBOD engagement approaches, we will continue to gather the needs and carefully match them with the capabilities and resources of the CARICOOS enterprise, in order to create a cost-effective, successful, and operational observing system for the Caribbean. The CBOD and the CTL will meet annually to review completed activities and shape future activities to best meet stakeholder requirements in line with available resources. The input received from the broader community will shape priority setting and influence the annual program plans and budgets submitted to IOOS.

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Reporting. The CTL team will continue to evaluate and ensemble mid-year reports from key personnel and subrecipients, in order to assess satisfactory progress towards annual milestones. End-of-year reporting will help assess success in achieving yearly milestones. After evaluation, the CTL team, in consultation with the CBOD, will prioritize activities and milestones to be included in the rescoped work plan for the next year.

Funding. CARICOOS requires significant and consistent annual support to provide for basic operations and allow for successful achievement of strategic goals. The IOOS program has provided such support; however, CARICOOS will continue to pursue and obtain funding from partner agencies and organizations, while at the same time work with elected officials, federal agency personnel, and members of the IOOS community to assure and increase support for the IOOS program within the federal budget process. In parallel, the CTL will engage potential partners from the government and private sectors that provide data to meet CARICOOS user needs, or will support and emplace observational efforts consistent with CARICOOS data needs. Such efforts will require exploring the possibility of proposing "partner projects" and optimize the investment by both entities. Partner projects currently represent 24% of CARICOOS total funding.

5.2 OBSERVING SUBSYSTEM

CARICOOS will continue to sustain and enhance its observing subsystem through the operation and maintenance of its core observing assets including: a network of five oceanographic buoys, one directional wave buoy, one ocean acidification monitoring buoy, the HFR network consisting of five systems, the Mesonet and Windnet network consisting of seventeen weather stations, and the autonomous hurricane underwater gliders program, operated in collaboration with NOAA-AOML and consisting of six glider lines (**Figure 1**). The current observing assets arrangement was designed considering stakeholder and national needs for wave and wind observations, surface current mapping and ocean water quality indicators. The observing system design and its planned expansion has been executed taking into consideration both the National Operational Wave Observation Plan and the IOOS National Strategy for a Sustained Network of Coastal Moorings. Following this, CARICOOS will continue to meet existing and emerging user needs by expanding its observing capabilities. The goal is to operate and expand an observational subsystem capable of providing timely ocean coastal data and products in support of maritime operations; coastal hazard awareness, prevention, and mitigation; coastal ecosystem management; and climate monitoring. The specific objectives are:

- To provide real-time **metocean data** for the US Caribbean EEZ and contiguous waters.
- To provide **meteorological data** in support of WFO-SJ (see letter of support), assimilation by the World Meteorological Organization's Global Telecommunication System, and CARICOOS forecasting models.
- To provide **surface current data** for model validation, SAR operations, eddy detection, and spill response.
- To **monitor potentially hazardous conditions** in nearshore waters.
- To provide **upper ocean observations** of temperature and salinity in support of tropical cyclone intensification studies and forecasts.
- To provide critical data for monitoring and assessing the **vulnerability coastal and marine ecosystems and resources** to climate change expressions.

Work Plan:

Metocean observations. CARICOOS proposes an expansion of the buoy network and its capacity to provide more real-time accurate meteorologic and oceanographic information in support of coastal hazard prevention, preparedness, mitigation, and adaptation, safety and efficiency of maritime operations (i.e., marine transportation, recreational activities), fisheries, among other shore dependent activities/sectors. In response to the USCG's role in safeguarding maritime transportation system components (i.e., vessels, harbors, ports, waterfront) and operations (i.e., pilotage, tug/towing services, vessel traffic services), from YR2 onwards, small

and easy deployable data buoys will be installed near entrances to major seaports in PR and USVI. The data buoys will provide real-time sea state data, including profiles of current velocity for ship maneuvering decisions when approaching the port/bay entrances under normal and adverse conditions. In addition, existing oceanographic data buoys will be equipped with RGB cameras to provide daytime horizontal visibility estimates. Also, CARICOOS has been collaborating with DOE's National Renewable Energy Lab (NREL) for the deployment of a Datawell Waverider buoy off Arecibo in PR's northern coast. From YR2 onwards, CARICOOS will provide support services, including maintenance and operation.

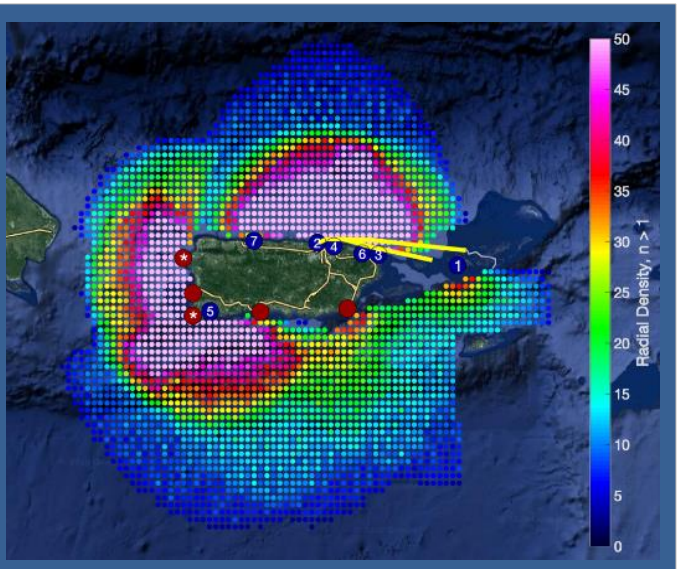

Figure 5 CARICOOS proposed HFR expansion will provide a higher density of surface current data.

Meteorological data. To continue delivering accurate and reliable data to our high-priority stakeholders, CARICOOS will add a meteorological station in the central mountainous range of PR, as requested by WFO-SJ, to improve the understanding of orographic effects on small-scale convective processes and improve forecasts of local weather patterns (i.e., mesoscale meteorological phenomena, low level winds, precipitation). This addition will enhance CARICOOS Mesonet network.

Surface currents. CARICOOS proposes an expansion of the HFR network (**Figure 5**) to provide more observations of surface circulation patterns for decision-making and appropriate planning of maritime and port operations. CARICOOS expects to install seven HFR antennas to meet the nation's needs for surface current mapping and in response to USCG Sector San Juan's request for near real-time surface currents in the San Juan-St. Thomas sea-lane and along the north coast of PR. Said deployments will supplement the assessment of multidata assimilation approaches for near-surface current observations to optimize CARICOOS circulation modeling efforts. Given the documented inaccuracy of models currently available via the USCG EDS for SAROPS, the results of this integrated effort will be of precious use to SAR and response operations. The CARICOOS HFR network will be refurbished and hardened using practical and cost-effective solutions (e.g., solar panels, batteries)[T2] to ensure a continuous operation under a broad range of environmental conditions, in remote areas, or during prolonged power outages. Appendix 24 provides further details of the expansion plan including detailed depictions of existing and expected increase in HFR coverage, data quality and density.

Nearshore hazardous conditions. Extreme weather events have significant impacts on the nearshore water-land interface that threaten the well-being of the coastal communities and marine environment. To understand the dynamic processes at play and the impact of compound flooding, it is important to consider the interaction and feedback between the natural coastal environments (i.e., ocean, beach, dune, rivers) and anthropogenic sources (i.e., discharges). CARICOOS proposes the installation of three streamgages[T2] a year to provide data in support of assessments of compound flooding, validation of WRF-HYDRO[T2], and additional beach water quality efforts.

To monitor potentially hazardous conditions for swimmers, CARICOOS proposes a pilot project to use a fully automated, low-power X-band radar (BROS)[T2] for measuring wave and current hazards in enclosed areas and along the coastal zone. BROS data will be exploited to resolve the morphology of nearshore sandbars and holes, the slope of the foreshore, surface currents such as rip and alongshore currents, as well as basic wave parameters. Products will be generated automatically within 15 minutes of the observations and posted online

T2: Projects / efforts to be funded in Tier 2

on an hourly basis. Isla Verde, PR has been chosen as the first site for the pilot project. Results from this site will inform the alternatives for a potential second site.

Upper ocean observations. CARICOOS will continue collaboration with NOAA-AOML/RSMAS in a NOAA-OAR funded collaborative project (Morell and Chardón-Maldonado, Co-PIs) entitled "CARICOOS Support for Hurricane Glider Operations in NE Caribbean Region" focused on improving hurricane forecasts by assimilating data from SeaGliders. This initiative is consistent with the IOOS Underwater Glider Network Plan. In addition, the CARICOOS underwater glider acquired under the 2020 Fill the Gaps initiative, will be deployed after the hurricane season for monthly sampling at the Caribbean Time Series station (CaTS) and targeted sampling of sub and mesoscale structure including eddies, river plumes, and marine heat wave "blobs".

Coastal and marine ecosystems and resources vulnerability. Observing subsystem enhancements towards documenting ecosystem pertinent physical and biochemical parameters will include deployments of sensor ensembles reporting CTD, DO, pH, turbidity, Chl a and CDOM, fluorescence and pCO_2w. Sensors will be deployed along with inductive modems in the San Juan, Ponce and St. John buoys (located near the insular shelf edge). Two analogous packages will be deployed along with an ADCP in mid-shelf representative ecosystems aboard a buoy bottom platform tailored for easy deployment and retrievals to be designed by U. of Washington and NANOOS. Additionally, six relocatable bottom mounts will be located on coastal barriers and shelf ecosystem restoration/coral nurseries. These sensors, as well as discrete sampling and analyses for alkalinity and sulfide content, will also aid in the documentation of impacts from major Sargasso inundation events and other disturbances. In addition. CARICOOS will continue to provide support for NOAA-OAP ocean acidification monitoring buoy at La Parguera Marine Reserve. Capabilities to resolve the current profile will be added with an ADCP, which will provide for improved data interpretation.

5.3 MODELING AND ANALYSIS SUBSYSTEM

CARICOOS will continue to support and augment its modeling and analysis subsystem, including maintenance and optimization of operational wave, wind, and ocean circulation models. Our goal is to develop and improve a redundant sea state modeling and analysis subsystem capable of accurately forecasting ocean and weather conditions. The specific objectives are:

- To provide accurate and timely **wave, wind, water levels, circulation, SST and salinity forecasts** for the entire US Caribbean EEZ.
- To **assimilate data** into models, as required, to achieve the most accurate results possible.

Work Plan:

CARICOOS' numerical modeling efforts have, since inception, been designed and implemented to complement federal capabilities and to downscale regional models already in operation by federal agencies. This allows CARICOOS to improve wind, sea state and circulation predictions in coastal areas of the US Caribbean while leveraging considerable federal investments in regional and global modeling capabilities (**Table 1**).

Table 1. Summary of CARICOOS modeling efforts.

	Wind	Waves	Circulation	Surge
Model(s)	WRF	SWAN, SWASH	FVCOM	FVCOM, ADCIRC-PUNSWAN
Operational?	Yes (link)	Yes (link)	Yes (link), experimental	No
Spatial resolution	1-2 km	1 km - 20 m nearshore	2 km - 100 m nearshore	Up to 30 m nearshore
Maritime Operations	X	X	X	X
Coastal Hazards	X	X	X	X
Coastal Resources	X	X	X	X
Climate Variability	X	X	X	X

Wave modeling. CARICOOS will continue the operation and maintenance of the CARICOOS Nearshore Wave Model (CNWM) which provides 120-hour forecasts of the nearshore wave climate for PR and the USVI. The model is coupled in an offline fashion through spectral forcing to NOAA NCEP's latest Multigrid WaveWatch III implementation. In YR1, the CNWM will be transitioned to a hybrid structured-unstructured (SWAN-PUNSWAN, **Figure 6**) mesh version that eliminates the need for nested grids and significantly improves nearshore spatial resolution (up to 20 meters) while optimizing computational efficiency. The CNWM will continue to run operationally in AMAZON EC2. The CARICOOS Nearshore Breaker Model (NBM), which estimates breaking wave heights at 100+ beaches in PR/USVI, will continue to be operated and enhanced and will follow the migration of the CNWM to the hybrid structured-unstructured mesh. The improvements to the CNWM and the NBM will positively impact all existing CARICOOS decision tools, including the Pa' la Playa Beach App and the CARICOOS Boating App.

CARICOOS wave modeling efforts will also be enhanced by partner initiatives. An ongoing collaboration between CARICOOS and the USGS seeks to better understand how waves propagate across coral reefs and cause coastal flooding along tropical shorelines using ARGUS cameras, wave sensors, and the XBEACH and SWASH phase-resolving wave models. The results from this study will help improve the breaking wave height predictions used in the NBM, with implementations expected for YR2. CARICOOS will also evaluate the feasibility of an operational wave runup and overtopping warning system for critical locations subject to strong winter swells using operational 1D SWASH modeling through an offline coupling to the new hybrid structured-unstructured implementation of the CNWM. Additionally, as a result of a funded project from PR-DNER, Co-PI Canals conducted a 40-year (1979-2019) high-resolution wave climatology study for PR. In FY20, with ROP funds, CARICOOS is developing an online interface that will provide user-friendly access to the study results. Throughout the next funding cycle, this wave energy atlas will be updated by CARICOOS at the end of each year to include the previous calendar year's wave hindcasts in order to maintain the atlas up to date.

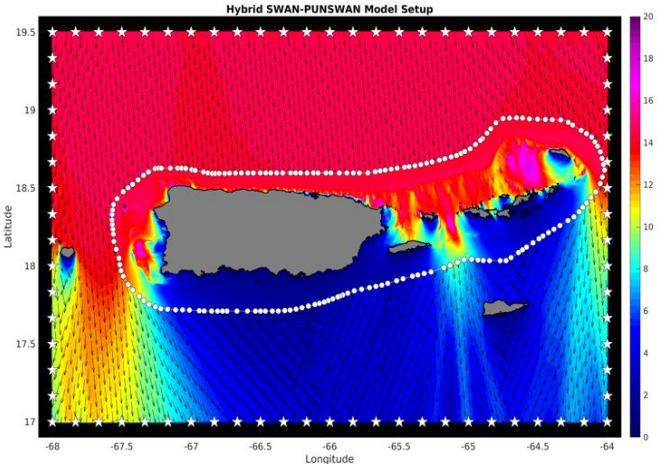

Figure 6 . New version of the CARICOOS Nearshore Wave Model with a hybrid structured/unstructured (SWAN-PUNSWAN) mesh.

Circulation modeling. CARICOOS has adopted the Finite Volume Coastal Ocean Model (FVCOM) as its main coastal circulation model. This model is currently running daily in experimental mode. The performance of FVCOM in simulating tidal, wind and geostrophic driven components of the coastal circulation has been satisfactory, however, accurate modeling of the coastal manifestation of baroclinic forcing across the US Caribbean has been a serious challenge. The main culprit for the underperformance of FVCOM in simulating these low frequency baroclinic flows is the inadequacy of the regional, three-dimensional circulation models being used to provide boundary conditions to FVCOM such as AMSEAS and HYCOM. To address this limitation, a pre-operational implementation of ROMS, including data assimilation of near-surface currents using OSCAR and HFR data observations (from surface to 15 m) will provide initial and boundary conditions for an FVCOM validation exercise[T2]. Starting in YR2, in an effort to include wave forcing and its effect on nearshore currents, CARICOOS will begin coupling FVCOM nested domains with the hybrid SWAN-PUNSWAN operational model to be implemented in YR1. The one-way nesting method will be expanded to generate high-resolution domains (from 100 m to 1 m) to resolve complex features near the coast, harbors and ports. The nesting methods will allow for the development of a quasi-operational regional-coastal forecast system for the CARICOOS region.

T2: Projects / efforts to be funded in Tier 2

Wind modeling. CARICOOS will continue the operation and maintenance of the CARICOOS Operational Wind Model (COWM), based on the Advanced Research Weather Research Forecast (WRF-ARW) operational wind model, which provides 36-hour forecasts of the regional wind climate with a spatial resolution of 1 km with 45 vertical levels and a 120-hour forecasts with a spatial resolution of 2 km with 45 vertical levels. In YRs 1-2, CARICOOS will improve model physics to better resolve the synoptic-, meso- and local-scale processes for a more accurate wind forecast on the coastal areas. In addition, a sensitivity analysis will be performed to improve the spatial resolution of the numerical domain (up to 500 meters). These initiatives will help improve precipitation forecast for the CARICOOS beach water quality nowcasts and the wind forecast for the coastal areas, and consequently the CARICOOS decision-support tools. The COWM will continue to run operationally in AMAZON EC2.

Storm surge. In FY16 CARICOOS completed the PR/USVI Storm Surge Atlas under the supervision of Prof. Aurelio Mercado. Since then, CARICOOS' storm surge modeling efforts have occurred under the scope of the PR/USVI Storm Surge Coastal Ocean Modeling Testbed (COMT) project. A key area of interest for CARICOOS stakeholders for the last several years has been the ability to simulate and map coastal compound flooding. The need for developing these capabilities became even more important after the impact of Hurricanes María and Hurricane Irma on the US Caribbean. Starting in YR1, a group led by Matthew Bilskie from U. of Georgia will begin a pilot project to examine compound flooding at a characteristic watershed in PR by leveraging the existing ADCIRC+SWAN model developed by CARICOOS as part of the COMT PR/USVI testbed [Joyce et al., 2019]. This model will be modified as needed to include additional details and resolution for the selected coastal watershed. The compound flood modeling framework will result in the capability to produce a three-day total water level forecast. Under a Tier 2 funding scenario, the compound flooding efforts would be expanded to three additional watersheds, with the end result of producing a three-day total water level forecast from a combination of freshwater flood levels (i.e., rainfall-runoff) and storm surges[T2].

5.4 DATA MANAGEMENT AND CYBERINFRASTRUCTURE SUBSYSTEM

When preparing the CARICOOS 2016-2021 proposal five years ago it was impossible to foresee the variety and magnitude of hazardous natural phenomena that would impact our region during that period. Two major hurricanes during 2017, an ongoing and prolific earthquake sequence since late 2019, and the ongoing, worldwide COVID-19 pandemic are some of the challenges CARICOOS encountered during the five-year period. However, the CARICOOS DMAC subsystem, developed and implemented over previous funding cycles, has proved to be quite resilient throughout very rough times. The cloud-based redundant component of our DMAC server suite has been able to maintain the flow of data and products to our stakeholders to sustain and support marine commerce, navigation safety and ocean hazards warning systems during long-term power and communications outages.

Considering all challenges, CARICOOS DMAC mandate to steward the ocean observations in the US Caribbean EEZ was fulfilled. The CARICOOS DMAC subsystem, fully integrated into the IOOS-DMAC Service Oriented Architecture (SOA) and operating as the Regional Data Assembly Center (DAC), will continue to provide operations and maintenance for the various system components of CARICOOS. The goal of this subsystem is to perform essential steps to develop and improve host user-friendly tools for data browsing and discovery and development of effective core products. The specific objectives are to:

- Improve efficiency, coordination, and **sustainability** of the data management system, including the operation, maintenance, and enhancement of high-performance computing (HPC) infrastructure.
- **Augment capabilities** of the existing CARICOOS data management system and respond to guidance and requirements.

T2: Projects / efforts to be funded in Tier 2

Work Plan:

Sustainability of the system. Taking in consideration the different challenges and stakeholder needs, CARICOOS seeks to maintain and augment[T2] the cloud presence to ensure the flow of data and products to our stakeholders during any disruption of the power and/or communication systems.

Augmenting capabilities. After the successful ingestion of 20 years of data from the PR Coral Reef Monitoring Program to OBIS/MBON, CARICOOS-DMAC is fully committed to the discovery and processing of other regional data sets. The USVI Territorial Coral Reef Monitoring Program and a fisheries independent larval stock assessment conducted following the SEAMAP protocol are currently under evaluation for translation through Darwin Core/OBIS/MBON. We seek to develop a capacity-building effort by linking this process with interested graduate students from the USVI, so they become knowledgeable about the Darwin Core standard and MBON.

DMAC is proposing to reinforce several program areas through development strategies: (1) team personnel via turnover and upgrades, (2) equipment upgrades or replacements and enhanced cloud assets and (3) nurture a local code development culture. As DMAC development strategies we envision greater integration with DMAC PO and closer ties with IOOS-DMAC contractors. The long-term strategic plan initially proposed for the 2016-2021 cycle will continue to be developed for the sustained operation of CARICOOS DMAC and the Regional DAC.

5.5 ENGAGEMENT IN THE MANAGEMENT AND OPERATION SUBSYSTEM

CARICOOS recognizes that a key component for a successful user-driven observing system lies in the effective engagement of target communities in the management and operation of the program. The goals of this subsystem are: to establish effective communication pathways and strategies with stakeholders in order to enhance awareness and encourage appropriate utilization of CARICOOS products and services; evaluate these products and services; and further develop products and services based on stakeholder's needs. The specific objectives are to:

- **Engage stakeholders** through iterative and participatory processes to prioritize development, evaluation, and maintenance of CARICOOS products and services.
- Procure data accessibility, adequate use and interpretation of products, and informed decision-making through **product awareness** initiatives.
- Operate an innovative **educational program** to support NOAA's mission to understand and protect marine resources.
- Aid in **building capacity** for operating a responsive ocean observing system in the region.

Work Plan:

Stakeholder Engagement. Assessing awareness, prioritizing needs, and evaluating product feedback, interpretation and cost-effectiveness are essential to ensure system's responsiveness, and dictate its programmatic strategies and operations. To this end, CARICOOS led a needs assessment process to guide the 2021-2026 strategic planning and improve its capacity to support coastal and marine activities in the US Caribbean. Input from the CBOD guided this process, which included interviews, focal groups and online/telephone surveys with a number of stakeholders' sectors representing federal, state and local government, maritime operations, academia and research, ecosystem restoration, tourism and recreation, and private interests. Our transparent and inclusive needs assessment process helped to identify new challenges, emerging issues, and opportunities for CARICOOS.

Of all users engaged, the maritime sector has been identified as a high priority stakeholder sector, specifically port pilots and SAR authorities. Port operations are essential to PR and the USVI, as most of the island's goods, fuel, and commodities are imported. Although rare, SAR operations cost more than $80,000/hour and often end unsuccessfully. Moreover, in the aftermath of Hurricane María, CARICOOS leadership was asked

T2: Projects / efforts to be funded in Tier 2

by the USCG to survey and visually identify bathymetric anomalies prior to the opening of Port of the Americas in Ponce, PR. CARICOOS will continue to engage these two user groups, who rely on accurate prediction of surface currents, winds, and waves (see letters of support from Southeast Harbor Pilots, South Coast Harbor Safety and Security Committee and USCG Sector San Juan).

Product Awareness. Effective response to emergent stakeholder needs is not possible without public awareness, convenient delivery, and correct interpretation of CARICOOS data and products. CARICOOS will continue its active presence on social media to keep users informed about current conditions, new products, and asset status. Issuance of quarterly newsletters and the CARICOOS NEWS website will also continue, with the purpose of attracting new users and engaging current ones in additional products. Likewise, CARICOOS will continue participating in recreational ocean-related activities (e.g. surfing and fishing tournaments, beach cleanups, etc.) and radio/tv shows to promote safety through the use of CARICOOS products and services. Additionally, CARICOOS will continue to deliver short video clips highlighting products and users. New initiatives to increase product awareness include an institutional video highlighting CARICOOS trajectory and its service to the region, and a Public Service Campaign in collaboration with the PR Sea Grant College Program to promote drowning prevention. Additional educational activities (described in the next section) will serve the dual purpose of educating the community in marine-related issues and increasing awareness of CARICOOS products and services.

CARICOOS strives for data accessibility to the general public through our convenient and user-friendly data portal and mobile applications. Real time data and forecasts are delivered to users through a fully responsive, bilingual data portal. Two mobile applications are also available to beachgoers (Pa' la Playa BEACH APP) and recreational boaters (CARICOOS BOATING APP). These two were designed after a customer discovery process and will be maintained and further developed in consultation with stakeholders. Additionally, CARICOOS will continue to operate its network of tablets and TVs at strategic locations (e.g. yacht clubs and beach convenience stores) to promote boater safety and increase product awareness.

To ensure an accurate data interpretation, CARICOOS will continue to host general and targeted training workshops for stakeholders and local authorities, from teachers to emergency management agencies, to facilitate interpretation of data and products and obtain essential feedback. Other information transfer efforts include internet-based (e.g. YouTube) tutorials, webinars and virtual conferences, and training modules available in the CARICOOS SCHOOL portal. CARICOOS will continue to interact with other RAs to share effective strategies for outreach and engagement.

Education. CARICOOS will continue to operate and update its outreach and education webpage (CARICOOS SCHOOL); procure an active presence in partnering educational efforts; and develop and maintain its own K12 initiatives. CARICOOS SCHOOL will be further enhanced to include 3D rendering[T2] and digital animations[T2] of buoys and other observing assets. Educational modules, training videos, and webinars will also be accessible through this site.

CARICOOS has also partnered with the EcoExploratorio Science Museum (ESM) to include a permanent exhibit[T2] at their location in Plaza Las Americas, the most popular mall in PR. The ESM will also design and produce the mobile exhibit *CARICOOS: Understanding our Oceans in the Digital Era*[T2], which is expected to impact 10 intermediate schools a year. Additionally, CARICOOS will partner with PR Sea Grant to develop and participate in educational podcasts highlighting the importance of marine resources and promoting marine safety.

Additional ongoing efforts, such as participation in summer camps, advice for Capstone projects and science fairs, and educational workshops will also be maintained. Further development in K12 education will be directed towards educational modules to be included in the K12 curriculum. Modules on marine currents, ocean acidification, and beach erosion will be added to our menu currently including winds and waves.

Capacity Building, Diversity & Inclusion. CARICOOS is deeply commitment to provide opportunities for capacity building within the region, while also promoting diversity and inclusion at the regional and national level.

T2: Projects / efforts to be funded in Tier 2

CARICOOS main pool of student talent, U. of Puerto Rico and U. of Virgin Islands, are Minority Serving Institutions, whose population has been historically underrepresented in ocean observing and ocean sciences in general. To this end, CARICOOS will continue to support a critical mass of outstanding students whose research work become essential parts of CARICOOS' products and services. Likewise, we will continue to foster higher education and unique research opportunities through our summer internship program. A new travel grant program will be implemented during this upcoming cycle to provide our students with supra-regional opportunities including coastal management and policy, ocean observing in mid- and high-latitudes, among others. Additionally, two full graduate scholarships at UPRM-CARICOOS will be awarded to outstanding USVI students committed to increasing participation of Virgin Islanders in ocean observing and forecasting. Finally, in order to better serve linguistic minorities in the region, all video materials will be translated and/or subtitled and edited with sign language interpreters.

6 PROJECT BUDGET AND MILESTONE SCHEDULE

The base funding level (Tier 1) has been set at ~$3M/yr, which is the minimum amount that would allow for effective governance, continued operation (but no major enhancements) of all observing assets, operational modeling and modest enhancement of these models, and growth of the DMAC and outreach subsystems. An enhanced funding level of ~$5.5M/yr (Tier 2) would allow for near-full HFR coverage of PR/USVI waters, as well as the addition of buoys, implementation of new water quality and shoreline monitoring programs, new compound flood modeling initiatives, and various pilot projects on ecosystems health and swimmer safety. Project costs for each year are summarized in Table 2 following the cost categories included in the main SF424A form CARICOOS INC. Further budget details and SF-424A are included in Appendix 1.

Table 2: CARICOOS INC Budget Summary (SF424 format).

BUDGET SUMMARY (in $k)						
	YR1	YR2	YR3	YR4	YR5	TOTAL
	Tier 1 (Tier 2*)	Tier 1 (Tier 2*)	Tier 1 (Tier 2*)	Tier 1 (Tier 2*)	Tier 1 (Tier 2*)	Tier 1 (Tier 2*)
Personnel	552.4 (552.7)	552.4 (763.3)	552.4 (763.3)	552.4 (763.3)	552.4 (763.3)	**2,762.4 (3,606.0)**
Fringe Benefits	116.5 (116.5)	116.5 (169.6)	116.5 (169.6)	116.5 (169.6)	116.5 (169.6)	**582.3 (795.0)**
Travel	47.0 (47.0)	47.0 (47.0)	47.0 (47.0)	47.0 (47.0)	47.0 (47.0)	**235.0 (235.0)**
Equipment	399.2 (811.7)	463.2 (684.0)	463.2 (737.5)	463.2 (791.0)	463.2 (844.5)	**2,251.9 (3,868.6)**
Supplies	192.9 (287.7)	173.4 (268.2)	191.4 (285.9)	192.5 (287.3)	191.8 (286.5)	**941.7 (1,415.6)**
Contractual	1,363.0 (2,844.3)	1,332.9 (3,090.1)	1,303.4 (3,213.7)	1,301.9 (3,215.4)	1,302.7 (2,405.9)	**6,604.0 (14,769.4)**
Construction	-	-	-	-	-	-
Other	140 (140)	140 (140)	140 (140)	140 (140)	140 (140)	**700 (700)**
Total Direct Charges	2,811.3 (4,799.9)	2,825.4 (5,162.2)	2,813.6 (5,357.0)	2,813.5 (5,413.6)	2,813.5 (4,656.9)	**14,077.2 (25,389.6)**
Indirect Charges	188.7 (211.6)	174.6 (240.5)	186.4 (239.3)	186.5 (242.8)	186.5 (240.4)	**922.8 (1,174.6)**
TOTALS	**3,000 (5,012)**	**3,000 (5,403)**	**3,000 (5,596)**	**3,000 (5,656)**	**3,000 (4,897)**	**15,000 (26,564)**

*Tier 2 includes Tier 1.

Personnel: A total of $2.8M ($3.6M[T2]) are requested to defray the cost of salaries for CARICOOS Executive Director J. Morell, Deputy and Technical Director P. Chardón, CBOD Chairman, and DMAC lead J. Capella. Salaries for technical and administrative support (4 FTEs and 2.9 FTEs, respectively) are also included here. The Tier 2 level contemplates 3 additional FTEs (YR2-YR5) corresponding to an Oceanographic Data Analyst, a Chemical Oceanographer, and a Numerical Modeler. **Fringe Benefits**: 582.3k ($795.0k[T2]) are requested for fringe benefits computed at the 14.40% rate, plus medical and unemployment/incapacity insurance. **Travel:** A 5-year total of

T2: Projects / efforts to be funded in Tier 2

$235k ($235k[T2]) will allow PI, Co-PIs and/or collaborators participation in IOOS, IOOS Association and CARICOOS Inc. meetings and activities as required by the IOOS office, as well as other scientific conferences and local travel related to field work or stakeholder engagement in the CARICOOS region. **Equipment:** $2.3M ($3.9M[T2]) over 5 years is requested for the purchase of metocean, biogeochemical and computing equipment to support the operation and enhancement of observing, modeling and DMAC subsystems **Contractual:** ~$6.0M ($14.8M)[T2] over 5 years is requested for contracts and subawards. This figure includes **subawards** to the following institutions: (1) A Cooperative Agreement with UPRM will support the participation of Dr. S. Rodríguez and Dr. M. Canals as CARICOOS Co-PIs; (2) A subaward to the Ocean and Coastal Observing-Virgin Islands NGO (PI: L. Sylvester) will support CARICOOS outreach and education efforts in USVI; (3) A subaward to the University of Maine (PI: N. Pettigrew) for the maintenance, monitoring and data management of the 5 oceanographic data buoys; (4) A subaward to U. Miami's Dr. Beron for the development of a Sargasso Inundation forecasting system; (5) Dr. J. Mickett at U. of Washington for the development of an Adaptable Moored Ocean Monitoring Platforms; (6) A subaward to Dr. E. Otero at UPRM to sustained observations of water quality and bioluminescence[T2] at the Phosphorescent Bay in La Parguera; (7) Dr. N. Schizas at UPRM to implement a zooplankton biodiversity monitoring effort in PR's inner shelf using metabarcoding[T2]; (8) Dr. W. Silva at UPRM for the development of a model to quantify/forecast riverine sediment input to coastal ecosystem[T2]; (9) Dr. A. Amador at Oleada LLC to implement a shoreline monitoring program[T2]; (10) Mr. C. García at Oleada LLC for the design, construction and installation of backup power systems in HFR sites[T2]; (11) Dr. M. Bilskie at the U. of Georgia for developing a forecast system for compound flooding and prediction of total water levels at one watershed[T2]; (12) Dr. D. Soto for the implementation of Altiphotic and Mesophotic Ecosystems Monitoring effort[T2]; (13) Dr. A. Rodríguez at Taller Ecológico de PR to implement a zooplankton biodiversity and biomass study; (14) Dr. E. Padilla at IUPR-Aguadilla for a coastal surveillance network for the detection of emergent pathogens in PR such as Vibrio sp.[T2]; and (15) Mr. R. Nichols/MIRC proposes the implementation of a plan for Spotter Buoy deployments as a rapid response tool before extreme weather events and provide the required training to tech personnel[T2]. In addition to the subawards, **major contracts** include several contracts for the maintenance of CARICOOS webpage domain and cloud infrastructure hosting, communications and telemetry service providers, legal counseling, production of instructional material including videos and graphical tools, installation and maintenance of new and current metocean monitoring platforms, maintenance of satellite-based products, MBON visualization tools, among others (see details in Appendix 1). (13) **Other:** $700k ($700k)[T2] over 5 years are requested for membership of the IOOS Association, CARICOOS Inc. office and laboratory maintenance and utilities, liability insurance costs, Amazon Web Services and participant support costs. **Indirect Costs:** $922k ($1.2M) in indirect costs are requested at the applicable "*de minimis*" IDC rate (CFR§200.414(f)). Indirect cost totals the 10% of the MTDC which includes all direct costs except equipment, participant support, rent and amount exceeding the first $25k of each subaward.

MILESTONES	FY21				FY22				FY23				FY24				FY25			
PROJECT/INITIATIVE/ITEM	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
OBSERVING SUBSYSTEM																				
Operation of existing buoy, HFR, meteo networks	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Maintenance of Waverider buoys (Rincon, Arecibo)		■	■			■	■			■	■			■	■			■	■	
Install eco sensor ensembles aboard ODAS buoys					■	■	■	■	■	■	■	■	■	■	■	■				
Maintenance of ODAS data buoys		■	■			■	■			■	■			■	■			■	■	
Deploy small buoys at major port entrances									■	■	■	■	■	■	■	■	■	■	■	■
Deploy water quality buoys mid-shelf					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Install oceanographic buoy south of St. Croix[T2]					■	■	■	■												
Install real-time cameras on buoys (1 per year)						■	■			■	■			■	■			■	■	

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Deployment, retrieval and refurbishment of AOML and CARICOOS hurricane underwater gliders	
Beach water quality monitoring	
Pilot project for Vibrio spp. Monitoring[T2]	
HFR network expansion: SJ Port sea lane	
HFR network expansion: North coast of PR	
Caribbean Shoreline Monitoring Program[T2]	
Deploy nearshore eco sensor ensembles for assessing threats to ecosystem (i.e. Sargasso)	
Pilot project for water quality assessments using RGB and thermal camera systems [T2]	
BROS X-band radar pilot project[T2]	
Deploying mid shelf buoys w. eco sensors ensembles	
Installation, maintenance and operation of the remotely sensed coastal video system[T2]	
Hardening HFR network [T2]	
MODELING & ANALYSIS SUBSYSTEM	
Maintain and enhance the CNWM, NBM, WRF (1km & 2km), and FVCOM models	
Implement hybrid SWAN-PUNSWAN into CNWM	
Coupled hybrid SWAN-PUNSWAN & FVCOM	
Annual update of PR/USVI Wave Climate Atlas	
1D SWASH wave breaking and runup forecast model	
Compound flood modeling for PR[T2]	
Maintenance of beach water quality nowcasts	
Surface water runoff coupled modeling[T2]	
Assess surface current data assimilation[T2]	
Implementing/validating Sargasso beaching forecast	
DATA MANAGEMENT & CYBERINFRASTRUCTURE SUBSYSTEM	
Continued dissemination of sea state data and products (winds, waves, currents) in real time	
Compliance with IOOS DMAC metadata, file and data discovery standards and checks	
Continue CARICOOS DMAC and Regional DAC efforts as detailed in the RICE DMS Plan	
Continue operating DMAC computational and HPC infrastructure (including cloud S3 & EC2)	
NCEI-compliant historic data archival	
Maintain and enhance web portal and apps	
Continue to develop port-specific web tools in response to stakeholders	
Continue expanding the regional MBON database	
GOVERNANCE AND EMO SUBSYSTEMS	
Host training workshops, webinars and podcasts	
Host the CARICOOS summer internship program	
Produce short video and Public Service Campaign	

T2: Projects / efforts to be funded in Tier 2

Include digital animations and 3D-rendering in CARICOOS SCHOOL[T2]			■				■				■				■				■	
Develop CARICOOS permanent exhibit[T2]	■	■	■	■																
Develop and operate CARICOOS mobile exhibit[T2]		■	■	■		■	■	■		■	■	■		■	■	■		■	■	■
Award CARICOOS travel grant				■								■								■
Award CARICOOS scholarship to Virgin Islanders								■								■				
Develop educational modules		■				■				■				■				■		
Issue communications via newsletters, social media, CARICOOS NEWS and CARICOOS School	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Stakeholder engagement throughout the region	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Conduct Board of Directors meetings		■		■		■		■		■		■		■		■		■		■
Host CARICOOS Annual Meeting				■				■				■				■				■

T2: Projects / efforts to be funded in Tier 2