CARICOOS

CARICOOS STRATEGIC OPERATIONAL PLAN

2021-2026

CARICOOS

Contents

CARICOOS Board of Directors 4

Executive Summary 6

1. Introduction 7

2. CARICOOS Focus Areas 9

2.1 Safety and Efficiency of Maritime Operations 10

2.2 Coastal Hazards 13

2.3 Coastal Resources: Monitoring & Management 16

2.4 Climate Variability 19

3 CARICOOS Subsystems 21

3.1 Observing Subsystem 21

3.2 Modeling and Prediction Subsystem 24

3.3 Data Management Subsystem 26

3.4 Outreach, Education & Engagement Subsystem 29

4 Running and Expanding CARICOOS 32

4.1 Governance 32

4.2 Funding CARICOOS 34

4.3 Toward International Collaboration 37

4.4 Research and Development 38

CARICOOS

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EXECUTIVE SUMMARY

The mission of the Caribbean Coastal Ocean Observing System (CARICOOS) is to provide accurate and timely coastal and ocean data and decision support tools to enhance safety in our coasts and ocean, improve the efficiency of maritime operations and support coastal resource management. CARICOOS was born in 2007 as the Caribbean Regional Association for Ocean Observing (CaRA), with the mission of providing guidance and advice towards the design and implementation of a needs-driven coastal observing system in the US Caribbean archipelago: Puerto Rico (PR), the US Virgin Islands (USVI), and Navassa. Fifteen years after inception, CARICOOS has maintained a strategic approach to populating the region with essential observing and modeling assets to meet identified needs. In the last funding cycle (2016-2021) CARICOOS deployed several new ocean observing assets, designed and implemented several decision support tools such as the CARICOOS Beach App and Boating App, engaged new partners, responded to several natural disasters, and strengthened its outreach and funding capabilities.

The CARICOOS Strategic Operational Plan (The Plan) described in the present document provides a program description, and outlines the program's goals, objectives, and action items within each of our focus areas for the next five years (2021-2026). The Plan is meant to be a guiding document for the successful and efficient development of CARICOOS into the future. Prepared by CARICOOS staff and approved by the Board of Directors, The Plan is built upon the successes and lessons learned from the first fifteen years of engagement, collaboration, and response with ocean and coastal stakeholders. The Plan demonstrates a continued commitment to building and sustaining a resilient observing system in the coming years, as the Caribbean regional component of the U.S. Integrated Ocean Observing System (IOOS). The Plan is a living document. While based on extensive feedback and years of work in the region, it is developed to be responsive and adaptable to changing priorities and guidance from users, stakeholders, IOOS, and our Board of Directors.

In this Plan, CARICOOS describes how it will support **Safe and Efficient Maritime Operations**; **Minimize Impacts from Coastal Hazards**; provide support for **Coastal Resource Management**; and **Monitor Climate Variability** through appropriate development of its **Observing, Modeling and Analysis**, **Data Management**, and **Outreach, Education & Engagement** subsystems. CARICOOS will operate under a management structure following this Plan. It will ensure the efficient and effective administration of programs and assets to support observations for integration into IOOS. It will work cooperatively with governmental and non-governmental entities at all levels to identify and provide information products for multiple users including federal and state agencies, researchers, the maritime and recreational sectors, individuals, educators, and others seeking to know current and foreseeable ocean conditions; to understand

the coastal environment; to manage coastal resources; and to develop commercial uses of marine resources, data, and information.

1. INTRODUCTION

The Caribbean Coastal Ocean Observing System, Inc. (CARICOOS), previously named Caribbean Regional Association for Ocean Observing (CaRA), was established on April 12, 2013. CARICOOS is a not-for-profit organization incorporated under the laws of Puerto Rico, and one of eleven Regional Associations (RAs) comprising the coastal component of the U.S. Integrated Ocean Observing System (IOOS). The geographical extent of CARICOOS, with an area of more than **230,000 km^2** is the coastal zone and the Exclusive Economic Zone in the region of Puerto Rico, the U.S. Virgin Islands and Navassa Island (the 'Caribbean Region').

Consistent with the requirements for a Regional Information Coordinating Entity (RICE) as defined by the ICOOS Act of 2009, CARICOOS has become a distinct observing and modeling system tailored to regional priorities as defined by its diverse stakeholder sectors. At the same time, CARICOOS is designed to meet the requirements of the U.S. IOOS Program Office to ensure consistency and meet standards at the national level and remain competitive for continued funding. CARICOOS Inc. is now 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. 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 system.

As the Caribbean regional component within IOOS, CARICOOS is committed to the following within its geographical region:

(i) providing integrated, remotely-sensed, forecasted and in-situ information about the U. S Caribbean coastal ocean region and related ecosystems for timely use by a diverse range of stakeholders including recreational operators, federal and state agencies, researchers, fishers, the maritime sector, industries, educators, and others seeking to know current and foreseeable coastal ocean conditions, to understand this coastal environment, to manage ocean and littoral resources, and to develop commercial uses of marine resources, data, and information;

(ii) helping to anchor a national ocean observing system;

(iii) working with partners to promote innovation by supporting new and expanded business opportunities in areas such as, but not limited to, energy, ocean and coastal engineering, information technology, and living marine resources;

(iv) Providing opportunities for capacity building within the region, while also promoting diversity and inclusion at the regional and national level.

In coordination and recognition of the societal goals established by IOOS, the results of extensive stakeholder engagement, needs assessments, and planning documents, CARICOOS has and will continue to sustain and enhance observational and modeling efforts to provide information on coastal weather, waves, currents, water quality, and storm surge inundation to address these main focus areas: Maritime Operations; Coastal Hazards; Coastal Resources; and Climate Variability. To achieve success in any of these focus areas, CARICOOS also focuses on providing effective data management, education and outreach, and governance.

This document serves as a reference for the development of the Caribbean Coastal Ocean Observing System. The goals and recommended actions in each section represent a collection of expressed needs, gathered over years by CARICOOS and its partners, carefully matched with the capabilities and resources of CARICOOS to create an efficient design minimizing observing assets that meet stakeholder needs for coastal ocean information. The CARICOOS Board of Directors (CBOD) will review The Plan biannually at a minimum, or as deemed necessary. The Plan will be updated at least every five years and future activities will span out to 5 years from each review period.

2. CARICOOS FOCUS AREAS

Through continuous and enhanced observational and modeling capabilities, CARICOOS seeks to integrate new and existing data streams into practical tools for information delivery to stakeholders at different levels of ocean literacy and expertise, ranging from everyday commercial fisherman, to beachgoers, researchers, and vessel operators. The goal is to provide comprehensive and accessible coastal intelligence to satisfy user-specific needs, while still serving as the source of reliable and timely ocean data in the region. CARICOOS will focus resources over the next five years towards supporting safe and efficient maritime operations; minimizing impacts from coastal hazards; monitoring and management of coastal resources; and continuous monitoring and assessing climate trends and variations in ocean properties attributable to regional climate processes.

2.1 SAFETY AND EFFICIENCY OF MARITIME OPERATIONS

Since the early ages tropical insular societies have lived on the ocean's edge, depending on it for essential functions and services, ranging from transportation and nourishment to recreation. These services are also accompanied by the risk posed by hazardous winds, waves, currents and storm surge, among others. The CARICOOS region is no exception. In the U.S. Caribbean, shipping and ferry sectors represent essential lifelines providing the main means of transportation for food and fuel. Recreational operations and activities, ranging from cruise ships to individual paddle boarders, constitute a crucial component of the tourism industry, a major economic driver in the region.

Figure 1. Entrance to Las Mareas Port in Guayama, Puerto Rico.

Recent technological and scientific advances have made it possible to detect and even predict with reasonable accuracy the majority of threats and opportunities presented by the ocean. In line with the U.S. Integrated Ocean Observing System's mission, CARICOOS strives to support decision making by providing critical information to improve safety and efficiency of marine operations in the region.

Goal: Provide coastal ocean information and decision support tools to enhance safety and efficiency of the full range of maritime operations taking place in the region.

Objective 1: Support port and harbor operations, as well as inter-island shipping and cruising operations, by providing observations and models of coastal weather, waves, winds, currents, and water levels.

Action 1a: Provide accurate and timely observations of meteocean conditions, as well as forecasts of winds (WRF), waves (SWAN), and currents (FVCOM, ROMS) in support of navigational planning.

Action 1b: Support collection and dissemination of data and products and identification of potential navigational hazards (under keel clearance issues, strong currents, etc.) at the major ports in the region (e.g. San Juan, Ponce, Yabucoa, Charlotte Amalie, Guayanilla and Las Mareas ports).

Action 1c: Operate, further expand and strengthen (backup power and comms) the regional HFR network to provide near real-time surface currents information covering major sea-lanes used by recreational and commercial vessels.

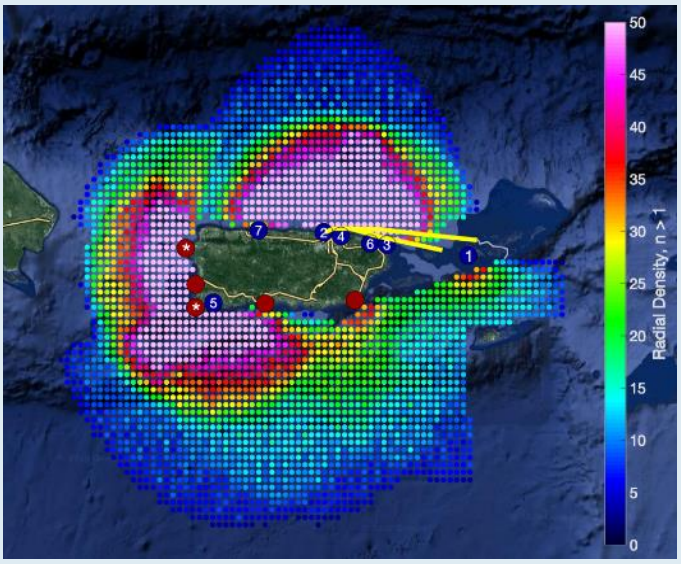

Figure 2. CARICOOS proposed HFR expansion will provide a higher density of surface current data.

Action 1d: Develop a simplified visual representation for a website or mobile device that focuses on the prioritization of available content and functionalities for maritime and port operations.

Action 1e Develop a simplified visual representation for a website or mobile device that focuses on the prioritization of available content and functionalities for maritime and port operations: Continue the enhancement and optimization of decision support tools in support of navigational safety such as the CARICOOS Boating App and include route-specific forecasts of sea state conditions.

Action 1f: Promote the novel use of oceanographic (waves, currents) and meteorological (wind) sensors and platforms providing real-time acquisition and transmission.

Objective 2: Provide recreational operators and users with decision support tools to aid planning and minimize risk.

Action 2a: Provide very high-resolution predictions of waves, winds, and currents to meet stakeholder needs, as well as timely and accurate wind, wave, and surface current information.

Action 2b: Continue to engage the recreational sector in order to design and develop sector-oriented tools and integrated products.

Objective 3: To aid the USCG and other incident response agencies by providing the best available surface current and coastal weather data in support of search and rescue and rapid response operations.

Action 3a: Assimilate HFR surface current observations into CARICOOS FVCOM in order to improve current forecasting in the region and make model output as well as additional HFR data available to the USCG Environmental Data Server (EDS) and to NOAA GNOME for response operations.

Action 3b: Carry out Lagrangian drifter deployments in collaboration with USCG in order to validate performance of ocean circulation models used by SAROPS & GNOME software.

Action 3c: Provide real-time HFR-derived particle trajectories as additional data products for use by incident response personnel.

Action 3d: Present periodical updates on SAR pertinent observations and forecasts at Harbor Safety and Security Committee Meetings.

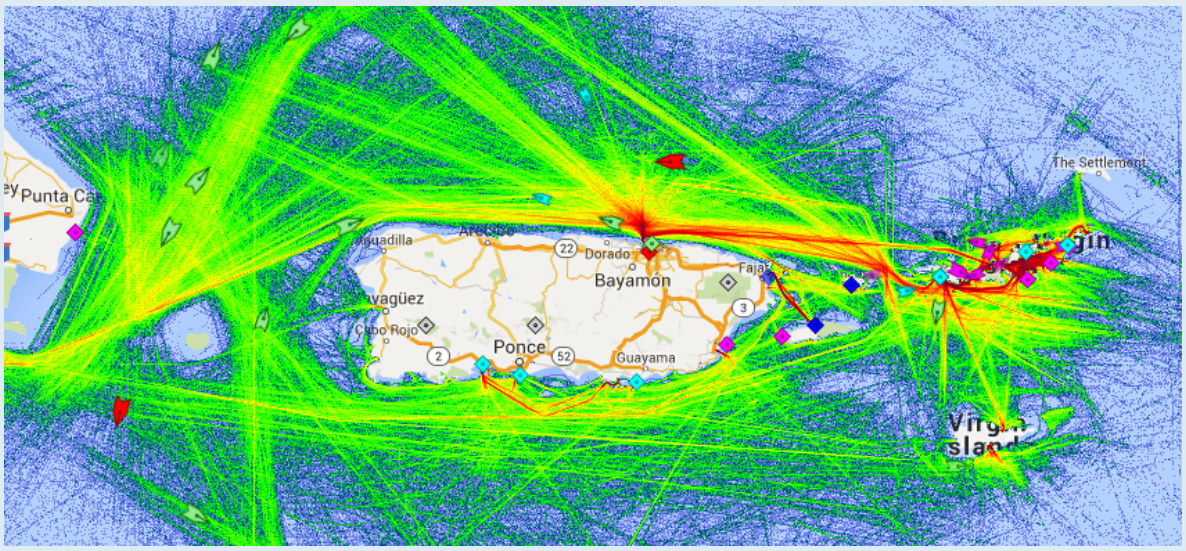

Figure 3. Annual AIS ship traffic density map showing major shipping lanes in the region (source: marinetraffic.com). The CARICOOS Safe Navigation Tool will provide for efficient means of navigation through the integration of data into pre-computed shipping and other navigational routes.

Action 3e: Develop and/or operate new ocean observing platforms such as, but not limited to, deep water data buoys, existing fish aggregating devices (FADs), autonomous underwater vehicles (AUVs), etc.

2.2 COASTAL HAZARDS

The CARICOOS region is constantly threatened by storm surge inundation, strong winds, and major wave action resulting from tropical and winter storms in the Caribbean Sea and the Atlantic Ocean. Strong wave-induced currents account for one of the highest per capita downing rates in the U.S. Furthermore, the recurrent presence of potentially pathogenic organisms in coastal waters and the geological/geographical potential for a tsunami landfall represent unique challenges and opportunities for the region.

Goal: Provide coastal information and decision support tools in support of coastal hazard prevention, preparedness, mitigation, and adaptation. Continue to expand, as required, the network of observing and modeling assets and capabilities that provide information on coastal weather, waves, currents, water quality, and storm surge inundation.

Objective 1: Deliver accurate wave forecasts and decision support tools to help improve beach safety in the region.

Action 1a: Continued operation and enhancement of the high-resolution CARICOOS Nearshore Wave Model, including the transition to an unstructured mesh to allow for increased resolution while achieving better computational efficiency.

Action 1b: Continued collaboration with partners (e.g. UPR Sea Grant) to operate and further enhance and validate an operational nearshore breaker prediction system to provide estimates of breaker heights at the most popular beaches in the region.

Figure 4. Wave-induced currents pose a major threat to beachgoers throughout the Caribbean. CARICOOS has partnered with UPR Sea Grant and the National Weather Service to develop an operational model, the CARICOOS-Sea Grant Nearshore Breaker Model, to predict breaker heights through the region.

Action 1c: Collaborate with the San Juan NWS WFO in support of their rip current risk prediction system.

Action 1d: Support efforts to monitor and/or predict other coastal processes that may pose hazards to beachgoers.

Objective 2: Address storm surge hazards in the region in collaboration with state and federal agencies.

Action 2a: Make available the CARICOOS Storm Surge Atlas and provide technical assistance to state and federal agencies to help with the revision of storm surge inundation maps to be used for long term and pre-incident planning purposes.

Action 2b: Support pilot projects and research efforts to improve our capabilities to simulate compound flooding caused by the interaction of storm surge and freshwater inundation.

Action 2c: Continue to generate and enhance web-based visualization portals to share hazard planning and response tools.

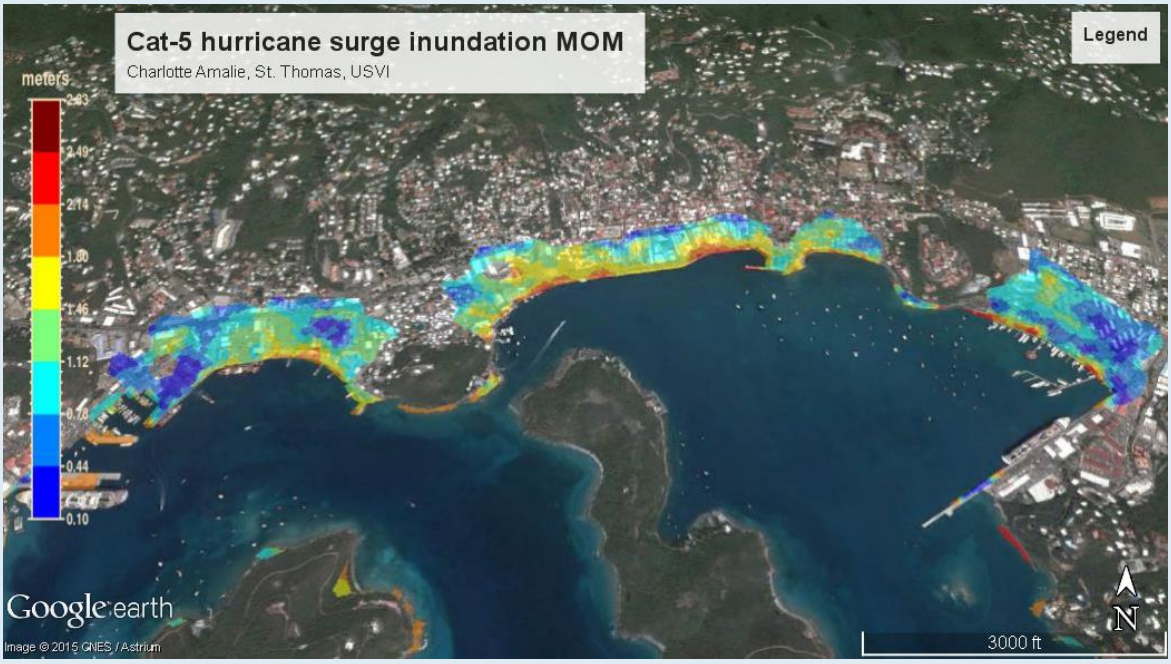

Figure 5. CARICOOS has developed coastal inundation maps for Puerto Rico and the US Virgin Islands. The figure shows coastal inundation for a CAT5 hurricane at Charlotte Amalie, St. Thomas, USVI.

Objective 3: Provide data and decision support tools to agencies (CZMP, USACE) and industry in order to address short-term and climate-induced coastal hazards in the region.

Action 3a: Implement shoreline monitoring techniques at critical locations to obtain long term time series of beach evolution in response to normal and extreme events.

Action 3b: Provide data support to agencies and industry for specific erosion prevention and mitigation projects.

Action 3c: Implement a natural coastal barrier assessment program to assess their status, trends and vulnerability to climatic change (e.g. sea level rise, increases in ocean temperature, ocean acidification) and other anthropogenic disturbances).

Objective 4: Develop decision support tools to address beach water quality issues in the region.

Action 4a: Increase sampling frequency of microbial monitoring at already sampled sites and incorporate new beach sites into the program.

Action 4b: Develop and validate local nowcasting and forecasting tools to predict the potential for unallowable bacteria levels in beach water.

Action 4c: Support research and development efforts towards improved beach water quality monitoring and simulation techniques.

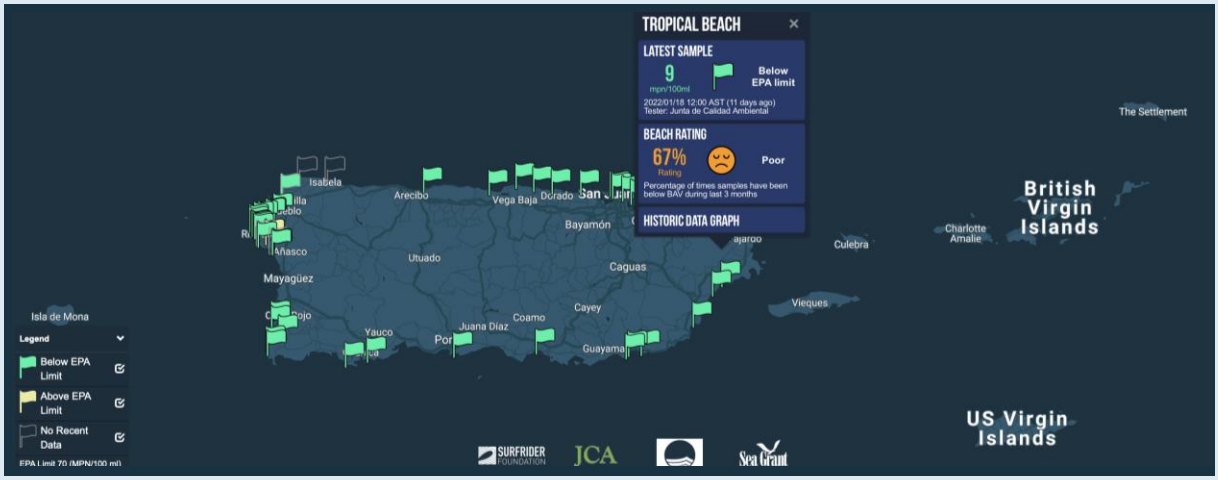

Figure 6. CARICOOS beach water quality map serves results of the latest Enterococci samples collected by the Puerto Rico Environmental Quality Board, Surfrider Foundation and Blue Flag. The product also includes experimental nowcasts providing probability of EPA threshold exceedances for 30+ beaches around Puerto Rico.

2.3 COASTAL RESOURCES: MONITORING & MANAGEMENT

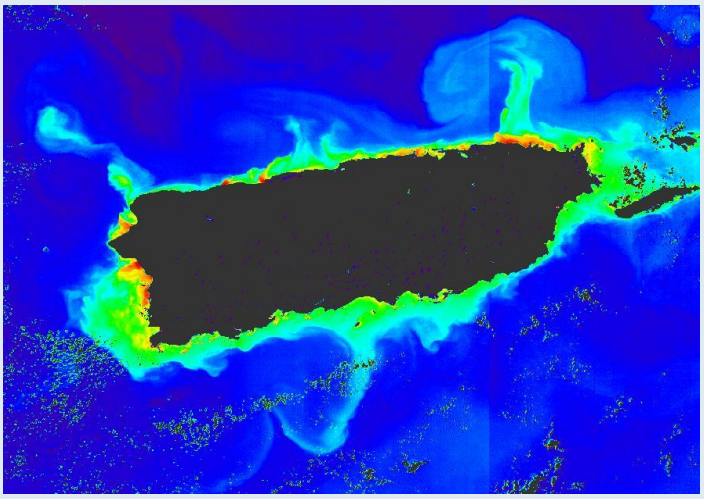

Figure 7. Coastal water quality, turbidity and sediment plumes are a major issue for coastal ecosystems in the US Caribbean.

The archipelagic nature of the CARICOOS region results in a marked dependency on coastal resources and the vital services these provide. Such services include fisheries, protection by coastal barriers, tourism and recreation among many others. Major threats to coastal ecosystems in the region include coastal development, anthropogenic sedimentation and eutrophication, more frequent high SST events, coral diseases, ocean acidification, hypoxia, extreme weather events (hurricane, swell), and since 2011, sustained pelagic Sargasso inundation events.

Goal: Provide data products and services to inform state and federal agencies and NGOs on ecosystem heath status and trends, identification of significant threats to these and assist said entities in identifying management needs and their implementation.

Objective 1: Aid coastal decision-making entities by providing data products in support of fisheries and ecosystem management.

Action 1a: Support fisheries restoration initiatives (e.g. Caribbean Fisheries Management Council) by addressing hydrodynamic connectivity in the region through observations (buoy, HFR, and drifters) and numerical simulations using, among others, biophysical models of larval dispersal.

Action 1b: Expand observational efforts by deploying sensors for salinity, temperature, dissolved oxygen, turbidity, acidity, CDOM and chlorophyll aboard the existing data buoys and aboard two additional buoys to be installed the Atlantic and Caribbean inner shelves. Sensor packages will be also deployed for discrete periods responding to ecosystem threatening events (e.g. major warming, Sargasso inundation) and at benthic ecosystem restoration sites.

Action 1c: Complement in situ sensor observations with "virtual buoys" reporting estimates of SST, turbidity, chlorophyll and CDOM derived from remotely sensed (satellites & cameras) optical measurements.

Action 1d: Continue operation of the MAP CO2 buoy and a discrete sampling program through the National Ocean Acidification Program.

Action 1e: Assess exogenous organic loading of sensitive nearshore ecosystems.

***Objective 2*:** Gather information and develop the understanding required to implement ecological forecasting tools in support of ecosystem health, seafood poisoning prevention, and rapid response to environmental emergencies.

Action 2a: Develop data products based on National and State Coral Reef Monitoring Program data series depicting the status and trends of reef health indexes and available data on threats including SST, turbidity, and extreme weather events (winds, waves) and others.

Action 2b: Implement a coastal barrier status assessment effort for mangroves and sand dunes using drone observations and historic photographs.

Action 2c: Mine existing nearshore beach pathogen data sets in support of probabilistic forecast development. Couple operational nearshore hydrodynamic modeling with passive and non-passive tracer transport for water quality assessments.

Action 2d: Continue deep and shallow water drifter campaigns in support of model validation of sea surface dispersion processes.

Action 2e: Provide support for ongoing research assessing the link between ciguatoxins and low turbulence-high temperature benthic environments.

Action 2f: Continue deep and shallow water drifter campaigns in support of model validation of sea surface dispersion processes.

Action 2g: Provide stakeholders with state-of-the-art graphical interfaces for depiction of regional ecosystems-related variables including temperature, chlorophyll, and floating algae.

Objective 3: Develop early warning systems for Caribbean's vulnerable ecosystems.

Action 3a: Continue monitoring Sargassum Inundation rates and biochemical expressions (hypoxia, acidification, zooplankton biodiversity) at representative stations within the mangrove,

seagrass, reef complex. Said database will be utilize for deriving predictions of Sargasso Inundation driven acidification and hypoxia.

Action 3b: Implement and validate a Sargasso inundation forecast system

Action 3c: Provide stakeholders with state-of-the-art graphical interfaces for depiction of regional ecosystems-threats (temperature, chlorophyll, Sargasso inundation, extreme weather events (waves, wind) and ecosystem status indexes (e.g. biodiversity, coverage)

Objective 4: Provide technical support to managers of protected areas.

Action 4a: Continue ongoing collaborations with Jobos Bay National Estuarine Research Reserve, Tres Palmas Marine Natural Reserve, San Juan Bay Estuary Program, and the Northeast Ecological Corridor Nature Reserve.

Action 4b: Support Marine Protected Areas as designated by state and/or federal law.

Action 4c: Support research initiatives into the use passive acoustic techniques to locate fish spawning aggregations; as well as identifying and tracking sperm whales using animal telemetry to document their distribution and abundance.

Action 4d: Support emergency responses (Sargasso, oil spills etc.) at protected areas.

2.4 CLIMATE VARIABILITY

The tropical nature of our region does not come without a price. Every year our benthic ecosystems are subjected to increased seasonal temperatures, while our lives, resources and infrastructure are threatened by the potential for tropical storm activity. While these processes are normal for our latitudes, there is scientific consensus that they can be intensified by a changing climate.

Goal: Document and report variations in ocean properties attributable to regional and extra-regional climate processes with the potential to impact marine operations, coastal resources, and increase coastal hazards.

Figure 8. CARICOOS glider being deployed in the Caribbean Sea to gather temperature and salinity profiles (from surface to 900 m) for improved understanding and forecasting of hurricane intensification.

Objective 1: Contribute information to national datasets through the continued operation of regular observing assets.

Action 1a: Continue to operate a network of oceanographic data buoys and wind stations contributing a continuous source of oceanographic and meteorological information to the region and beyond.

Action 1b: Augment existing NOAA's Coral Reef Watch system with the implementation of a graphical tool depicting remotely sensed SST at 1km resolution and "in situ" measurements from existing assets, CARICOOS and otherwise. Upper water column temperature, salinity and dissolved oxygen anomalies, computed as the difference between observations from by Sea Gliders and existing climatology (WOA 2013) will also be depicted.

Objective 2: To provide technical, logistical, and scientific support to large-scale investigations related to climate variability.

Action 1a: Improve forecasts of tropical cyclone intensification and seasonal hurricane frequency by operational monitoring of the water column structure through deployment of Sea Gliders in collaboration with NOAA AOML.

Action 1b: Continued operation of the La Parguera MAPCO2 buoy and discrete validation program with the purpose of addressing the goals of the NOAA Ocean Acidification Program and the National Coral Reef Monitoring Program.

Action 1c: To collaborate with the Jobos Bay National Estuarine Research Reserve to gather, analyze, and assess data pertinent to climatic trends, variability and impact on coastal ecosystems thus fully exploiting NOAA's NERRS observing investment in the region.

3 CARICOOS SUBSYSTEMS

A number of program components are essential for achieving the goals and objectives for each of the above focus areas. Successful implementation requires maintaining and growing these main subsystems:

3.1 OBSERVING SUBSYSTEM

The CARICOOS observing subsystem consists of (as of April 2016): a network of five oceanographic data buoys; two directional wave buoys; one ocean acidification monitoring buoy; the CARICOOS Operational High-Frequency Radar (HFR) Network, consisting of five HFR antennas; the CARICOOS Mesonet and Windnet, a network of eighteen coastal weather stations; the CARICOOS Lagrangian Drifter Program; and the Seaglider Program operated in collaboration with NOAA AOML.

Goal: To operate an observational subsystem capable of providing timely ocean data and data products in support of maritime operations; coastal hazard awareness, prevention, and mitigation; coastal resources management; and climate monitoring. Acquired data will continue to be available to national and international databases and for assimilation/validation of atmospheric and ocean models.

Figure 9. CARICOOS planned and existing observational assets as of June 2021.

Objective 1: Provide point oceanographic observations to relevant users within the United States Caribbean Exclusive Economic Zone (EEZ).

Action 1a: Operate and maintain a network of five oceanographic data buoys at strategic locations within the EEZ (i.e. south of Ponce, north of San Juan, northwest of Vieques, north of St. Thomas, and south of St. John).

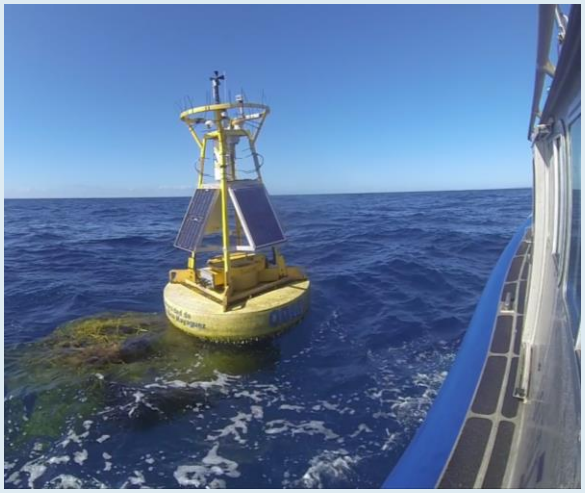

Figure 10. CARICOOS operates a network of real-time ocean data buoys around PR and the USVI.

Action 1b: Operate and maintain two directional Waverider buoys in Rincón and Arecibo, sites where the local economy and resources are highly dependent on wave conditions.

Action 1c: Acquire, operate, and maintain a network of portable small buoys for model validation, rapid response, and hydrodynamic characterization in response to stakeholder requests.

Action 1d: Expand the CARICOOS buoy network by adding "port buoys" reporting wind speed and direction as well as current profiles. These will be deployed in the approaches to two harbors where currents/winds present a challenge to port pilots

Objective 2: Provide real-time information of ocean surface currents for the entire EEZ and contiguous waters.

Action 2a: Operate and maintain a network of eight HFRs to meet the nation's need for surface current mapping and in response to USGC's request for near-real time surface currents in Puerto Rico and U.S. Virgin Islands.

Objective 3: Provide atmospheric pressure and wind speed and direction data in support of San Juan NWS-Weather Forecasting Office, assimilation of WMO-Global Telecommunication System, and CARICOOS Weather Research and Forecasting (WRF) Model.

Action 3a: Operate and maintain a network of 5 Windnet and 13 Mesonet meteorological stations.

Action 3b: Operate and maintain meteorological stations at existing oceanographic data buoys.

Action 3c: Expand the Mesonet to include additional meteorological stations to support forecasting needs expressed by NWS SJU WFO and other agencies.

Objective 4: Provide data in support of HFR data validation, search and rescue, mesoscale eddy detection, and oil spill response.

Action 4a: Develop and operate a fleet of portable biodegradable Lagrangian ocean drifters.

Action 4b: Deploy SeaGlider AUVs in collaboration with NOAA AOML, for operational monitoring of salinity, temperature and dissolved oxygen in the upper 1000m of ocean within the Atlantic and Caribbean EEZ. Data is utilized for improved hurricane intensity forecast, documenting climate change expressions in the region's oceanic waters and assessing mesoscale processes.

Action 4c: Secure a vessel capable of providing operational support for deep sea activities within the CARICOOS and adjacent regions of interest.

Objective 5: Monitor beach evolution, benthic ecosystems and water quality.

Action 5a: Acquire specialized camera systems capable of monitoring shoreline changes in response to regular and extreme wave conditions, rip currents, and coastal sediment loading among others.

Action 5b: Acquire sensor packages a portable nearshore water quality buoy capable of detecting potentially harmful bacteria, oxygen concentration and other parameters as required.

Action 5c: Acquire shallow water AUVs for benthic mapping and nearshore oceanographic assessments in support of rapid response and ecosystem monitoring efforts.

3.2 MODELING AND PREDICTION SUBSYSTEM

With the goal of developing an ocean modeling and prediction subsystem capable of timely and accurate forecasting of ocean conditions, CARICOOS has implemented and validated very high-resolution models utilized by agencies (e.g. NWS, PREMA, USCG, Fish and Wildlife Service) and operators all across the region. CARICOOS currently provides in-house operational forecasts of waves (Simulating WAves Nearshore, SWAN), winds (Weather Research Forecast, WRF), coastal currents (Finite Volume Community Ocean Model, FVCOM). CARICOOS also provides graphical products depicting output from external modeling tools such as AMSEAS, RTOFS and WaveWatch, among others. The main components of the CARICOOS modeling and prediction subsystem are as follows:

- The CARICOOS Nearshore Wave Model: A high-resolution operational wave model for Puerto Rico and the USVI.
- The CARICOOS-Sea Grant Nearshore Breaker Model.
- The CARICOOS Storm Surge Modeling Program.
- The CARICOOS WRF: An operational wind model for PR/USVI at 1 and 2 km resolution.
- The CARICOOS FVCOM high-resolution model of coastal and ocean circulation.

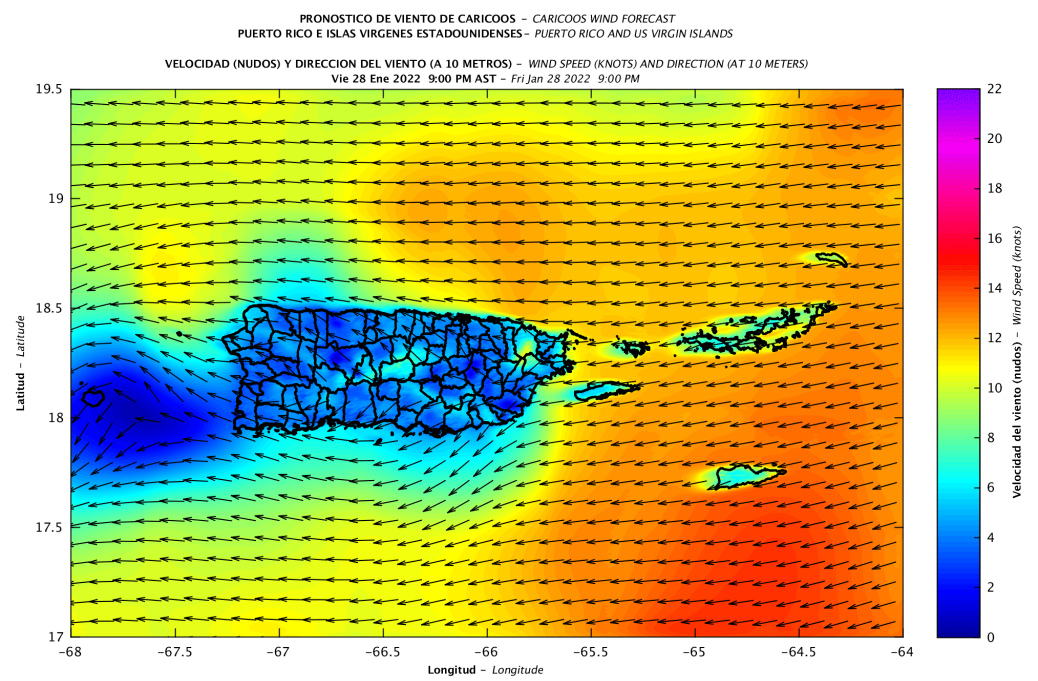

Figure 11. CARICOOS runs WRF operational wind models at 1 km (shown above) and 2 km resolution. Figure data labels are provided in English and Spanish.

Goal: To develop a redundant ocean modeling and prediction subsystem capable of timely and accurate forecasting of ocean conditions throughout the Caribbean EEZ.

Objective 1: Provide accurate and timely wave, wind, and ocean currents predictions for the entire EEZ.

Action 1a: Operate and enhance the CARICOOS Nearshore Wave Model.

Action 1b: Operate and enhance the CARICOOS Nearshore Breaker Model.

Action 1c: Operate and maintain the CARICOOS WRF Wind Model.

Action 1d: Operate, validate and enhance CARICOOS ROMS Model.

Action 1e: Continue enhancement of the CARICOOS operational FVCOM-based circulation modeling system for shelf, coastal and nearshore areas of PR/USVI.

Action 1f: Develop a coupled wave, circulation and atmospheric modeling system using FVCOM, WRF and SWAN.

Objective 2: Assimilate data into models, as required, to achieve the most accurate results possible.

Action 2a: Implement state of the art 4D-VAR data assimilation techniques into CARICOOS ROMS using HFR data.

Action 2b: Explore other assimilation techniques for circulation modeling including satellite, Sea Glider, and buoy data.

Objective 3: Provide operational water level predictions for strategic locations along the coast.

Action 3a: Improve water level predictions during storms by incorporating freshwater runoff into current storm surge maps.

Action 3b: Work in collaboration with federal and state partners towards the development of an operational storm surge prediction system for the region.

Objective 4: Optimize the CARICOOS high-performance computing infrastructure

Action 4a: Operate high-performance computing infrastructure for research and development of new models and tools

Action 4b: Operate all operational CARICOOS models using cloud-based infrastructure to maximize model uptime and minimize exposure to threats such as communication and power outages

3.3 DATA MANAGEMENT SUBSYSTEM

The CARICOOS Data Management Subsystem (DMS) serves as the backbone for success to all program components. The DMS is involved in all aspects of data flow, including archive, discovery, and transport. It allows for the development of user-friendly data and decision-making products while improving access to and exploration of information.

Developed and implemented over previous funding cycles, the CARICOOS DMS currently operates as the Regional Data Assembly Center (DAC). It archives and serves data and model output for the entire U.S. Caribbean geographical region. By focusing on the management, service, and delivery of CARICOOS-related data, the DMS allows CARICOOS to respond to partner needs for sharing and integrating data, offer decision-making products and access to data download sites, and to display information in real-time and forecasting formats. Many of the CARICOOS DMS details are included in a separate 'CARICOOS Data Management Subsystem Plan".

CARICOOS DMS efforts are primarily geared towards: 1) obtaining and distributing a variety of quality data from external partners and CARICOOS assets across the region; 2) managing model outputs (WRF, SWAN, FVCOM); 3) maintaining the flow of data into the Data Access Services and web products; and 4) enhancing product development. Over the next 5 years, CARICOOS DMS will continue to respond to directives from the Board of Directors to expand and enhance data management and visualization capabilities, including the development of products for stakeholders. CARICOOS DMS will continue to search for regional data sets to be included in the portfolio and expand geographical coverage beyond the CARICOOS region to include international waters.

Goal: Create and host user-friendly tools for data browsing and discovery, and to develop effective core products.

Objective 1: Perform essential steps that allow provision of data and data products via the web.

Action 1a: Move data from CARICOOS and partners to the local archive.

Action 1b: Host data on cloud computing servers/services; operate, maintain, and upgrade computational infrastructure.

Action 1c: Develop data products from raw data streams; operate and maintain data streams, archival and publication of data products, and dissemination interfaces.

Action 1d: Distribute data, products, and interpretations of information via the web, social media, and other online platforms in response to stakeholder needs.

Objective 2: Maintain constant communication with national DMAC efforts and respond to guidance and requirements.

Action 2a: Continue supporting the development, in collaboration with various partners, of its DMAC subsystem and meeting IOOS requirements.

Action 2b: Maintain a presence in the National IOOS-DMAC and QARTOD communities through participation in monthly conference calls and annual meetings.

Action 2c: Assure that all data providers meet the data management and quality control criteria established by the U.S. IOOS Program Office and QARTOD.

Action 2d: Create and maintain a Data Management Plan for CARICOOS based on national and regional DMAC requirements.

Figure 12. CARICOOS strives for data accessibility to the general public through a convenient and user-friendly data portal and mobile applications.

3.4 OUTREACH, EDUCATION & ENGAGEMENT SUBSYSTEM

Stakeholder needs, communication preferences, and feedback are essential for successful coastal intelligence, and dictate programmatic strategies and operations of the observing system. The continued success of CARICOOS relies of forging strong partnerships, maintaining an engaged, informed and interactive user base, consistently addressing user demands for data and products, and maximizing the effectiveness of our products and services. These activities intimately inform the foundational goals for the CARICOOS Outreach, Education & Engagement Subsystem.

Goals: To maintain and further develop effective communication pathways and strategies with stakeholders in order to: 1) enhance awareness and encourage appropriate utilization of CARICOOS products and services; 2) evaluate these products and services; and 3) further develop products and services based on stakeholder's needs.

Objective 1: Outreach effectively to a wide and diverse set of stakeholders through iterative, participatory processes.

Action 1a: Deliver CARICOOS messages via periodical newsletters, press releases, public service announcements, and social media.

Action 1b: Engage and consult stakeholders via direct communication and interaction at sector focused meetings and CARICOOS General Assembly.

Action 1c: Maintain and procure an active presence in pertinent forums, such as Harbor Safety and Security Committees, PR Climate Change Council, Caribbean Regional Ocean Partnership, UPR Sea Grant Advisory Board, the Caribbean Landscape Conservation Cooperative, Caribbean Regional Response Team, among others.

Action 1d: Coordinate with island liaisons (through the Ocean and Coastal Observing – Virgin Islands, OCOVI, to support CARICOOS outreach and education efforts in the USVI.

Action 1e: Participate in recreational ocean-related activities to promote safety through the use of CARICOOS products and services.

Action 1f: Interact with other RAs to share effective outreach and educational efforts.

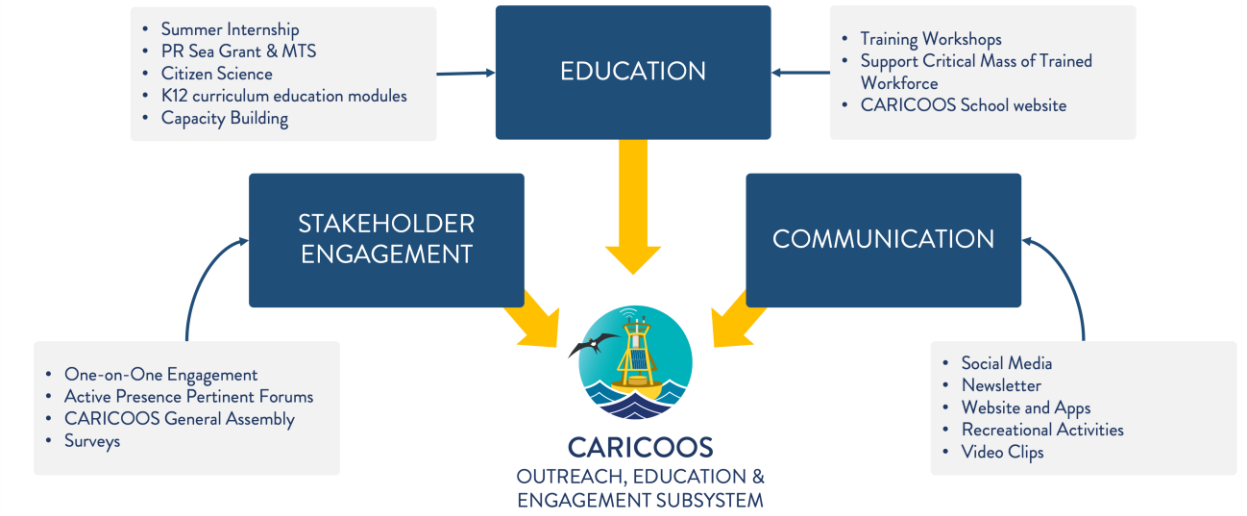

Figure 13. CARICOOS Outreach, Education & Engagement tools.

Objective 2: Procure data accessibility to the general public and facilitate informed decision-making and interpretation of data and products via stakeholder engagement.

Action 2a: Develop and maintain a user-friendly webpage and mobile apps to provide real time data and forecast to users.

Action 2b: Secure an active presence on social media to keep users informed about current conditions, new products, and asset status.

Objective 3: Facilitate informed decision-making and interpretation of data and products via information transfer.

Action 3a: Host general and targeted training workshops for stakeholders and local authorities, from teachers to emergency management agencies, and obtain essential feedback and input.

Action 3b. Continued the issuance of internet-based media (e.g. YouTube channel) courses on data and product interpretation.

Objective 4: Evaluate CARICOOS products and services on an annual basis.

Action 4a: In concert between the Board of Directors and CARICOOS staff, assure and refine timely evaluation processes, analyses of cost effectiveness and stakeholder need prioritization.

Action 4b: Assess awareness and evaluate product feedback and interpretation through formal surveys.

Objective 5: Aid in shaping the next generation of Caribbean ocean scientists and engineers.

Action 5a: Support a critical mass of outstanding undergraduate and graduate students, whose research work become essential parts of CARICOOS' products and services.

Action 5b: Host an undergraduate summer internship program in an effort to recruit future graduate students.

Action 5c: Procure an active presence at local educational activities for the youth and permanent exhibits.

Action 5d: Continue to operate and update CARICOOS Outreach and Education webpage.

Action 5e: Assess the outcome of the efforts towards inclusion of CARICOOS data and products into middle school curricula and, if required, revise as required.

Action 5f: Further develop the K12 curriculum education modules on marine currents, ocean acidification, and beach erosion.

4 RUNNING AND EXPANDING CARICOOS

4.1 GOVERNANCE

CARICOOS employs a variety of strategies to support identification of data and product needs, priority setting, strategic planning and progress. Overall, the program is designed based on need assessments and consultation with stakeholders, operating in a continuous effort to meet the needs of widely distributed stakeholder communities throughout the U.S Caribbean region. Simultaneously, the program operates as one of eleven Regional Associations under the U.S. IOOS Program Office, and is therefore guided by funding levels, policies, and priorities set forth at the national level. Strategic planning and priority setting are periodically determined and revised by the CARICOOS staff and Board of Directors (CBOD) who work together and with sectorial representatives to balance the benefits, costs, and risks of the program's diverse projects and observing efforts at local, regional, and national levels. The input received from the broader community shapes priority setting and influences the annual program plans and budgets submitted to IOOS.

CARICOOS identification of user needs, their consideration, and adoption of system priorities and evaluation of stakeholder satisfaction are built upon an inclusive, iterative, and bottom-up stakeholders input process. Initial engagement of stakeholders was extensive. Professionally implemented 'needs assessment' campaigns have been by the University of Puerto Rico (UPR) Sea Grant Program and by the Centro Interdisciplinario de Estudios del Litoral. In addition, throughout the past year, CARICOOS management and staff implemented stakeholder consultations through a variety of means including web-based surveys, sector-focused workshops, one-on-one meetings, and teleconferences targeting Federal, State, and local/regional government, ocean recreation and commercial sectors, the hotel and tourism industry, nongovernmental organizations, the media, community groups, as well as residents and visitors.

Currently, the BOD and CARICOOS staff utilize the above methods to engage stakeholder communities and ensure a continuous feedback loop with the staff, regional partners, and the IOOS program office. This process ensures that stakeholder feedback is integrated into the short-term annual priority setting as well as the long-term strategic planning. CARICOOS also still relies heavily on the stakeholder engagement and needs assessments conducted by the UPR Sea Grant Program for program guidance and the Puerto Rico Coastal Zone Management Program (PRCZM). OCOVI also conducts stakeholder engagement as well as need/awareness/satisfaction assessments and survey specific for the U.S. Virgin Islands stakeholders following the same approaches detailed above. With this information, and approval from CBOD, CARICOOS establishes priorities for operation and

expansion, including but not limited to maintaining the current ocean observing and modeling subsystems; integrating data and predictions into user-oriented products; and improving data dissemination through better visualizations and user-friendly tools.

Through the CBOD, CARICOOS will continue to gather the needs and carefully match them with the capabilities and resources of the CARICOOS enterprise in order to create cost effective, successful, and operational observing system for the Caribbean. The CBOD 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. The mechanism is as follows: CARICOOS will carry out need and satisfaction assessment, the results will be brought to the CBOD for deliberation and prioritization. Once CARICOOS establishes priorities, the capabilities within the region will be explored through either a RFP or a call for EOIs. Proposals are scrutinized by the CARICOOS scientific leadership and recommendations issued to CBOD for approval.

Evaluation of the program and its priorities occurs twice a year. The CARICOOS scientific team submits mid-year and end-of-year reports to the Board for evaluation of progress toward milestones. After evaluation of the reports, the CARICOOS team, in consultation with the CBOD, prioritizes and proposes the work plan and milestones for the next year based on the most recent needs assessments, funding levels, progress toward goals/objectives in this Plan, existing program capabilities, partner support for activities, national guidance, and the potential impact of investment to individuals, organizations, and populations as a whole. The proposed work plan and milestones must align with the goals and objectives outlined in this Plan.

This ongoing prioritization and strategic planning process provides CARICOOS with the tools necessary to meet goals and objectives for each focus area. Programmatic and operational priorities are collected continuously and evaluated with each annual award proposal due to IOOS. Over the course of a five-year planning cycle, short- and long-range objectives are defined, refined, and adopted to ensure that investments made by CARICOOS have lasting value to the U.S. Caribbean region.

4.2 FUNDING CARICOOS

As part of U.S. IOOS program, CARICOOS annually engages with the U.S. IOOS office to determine the maximum amount of federal funds, awarded as a result of the competitive review process, available to CARICOOS for the continuation of annual operations and the development of new capabilities. The U.S. IOOS program has been a steady and consistent supporter of the CARICOOS program and it is expected that CARICOOS will continue to receive a share of the federal funds allocated to the IOOS program through the federal budget process. However, long-term federal support for IOOS and CARICOOS is not guaranteed, and uncertainties in future federal funding preclude CARICOOS from planning for or solely relying on IOOS program support to maintain and expand operations in the region.

The organization needs significant, sustained, and consistent annual support to provide for basic operations and allow for successful execution of strategic activities. To date, the IOOS program has provided the bulk of such support; however, CARICOOS would benefit from exploring additional means for obtaining funds for basic operations. For the foreseeable future, IOOS program office funding is anticipated to be the primary source of income for CARICOOS. Nevertheless, CARICOOS, under its BOD guidance, will continue to seek out and obtain funding from partner agencies and organizations, while at the same time working with elected officials, federal agency personnel, and members of the IOOS community to sustain and grow support for the IOOS program within the federal budget process.

Since its inception, CARICOOS has actively pursued diversification and amplification of it funding base. Notable achievements include consistently securing academic release time from UPRM for researchers collaborating with the program; and the continued use of two HFR antennas, initially as part of a subaward with Rutgers U. and Stevens Institute of Technology, and now in service by means of loans from Rutgers and Texas A&M. Also, the applied science and research capabilities emplaced for CARICOOS have been successfully employed for the development of projects and products identified as priorities and co-funded by the UPR Sea Grant and the PRCZM programs. Analogous collaborative efforts have been funded by the Jobos Bay National Estuarine Research Reserve, the Coral Reef Conservation Program, and the Caribbean Fisheries Management Council. Recently, congressional funding has supported the operation of gliders in the region; while CARICOOS investigators secured funding from the private sector for the development of wave and wind forecasts in support of an under the keel clearance project for the Yabucoa Harbor. In kind support has been provided by two recreational marinas, two municipalities and a state police station which host HFR

antennas in their facilities. Logistic support for buoy maintenance is provided by the PR Ports Authority and the West Indian Company in St. Thomas, USVI.

An analysis of the support, depicted in the figure below, evidences IOOS core program as the main contributor, followed by the UPR Mayaguez Campus, which during the past five years has authorized $545k in academic release time to faculty members engaged in the operation and development of CARICOOS.

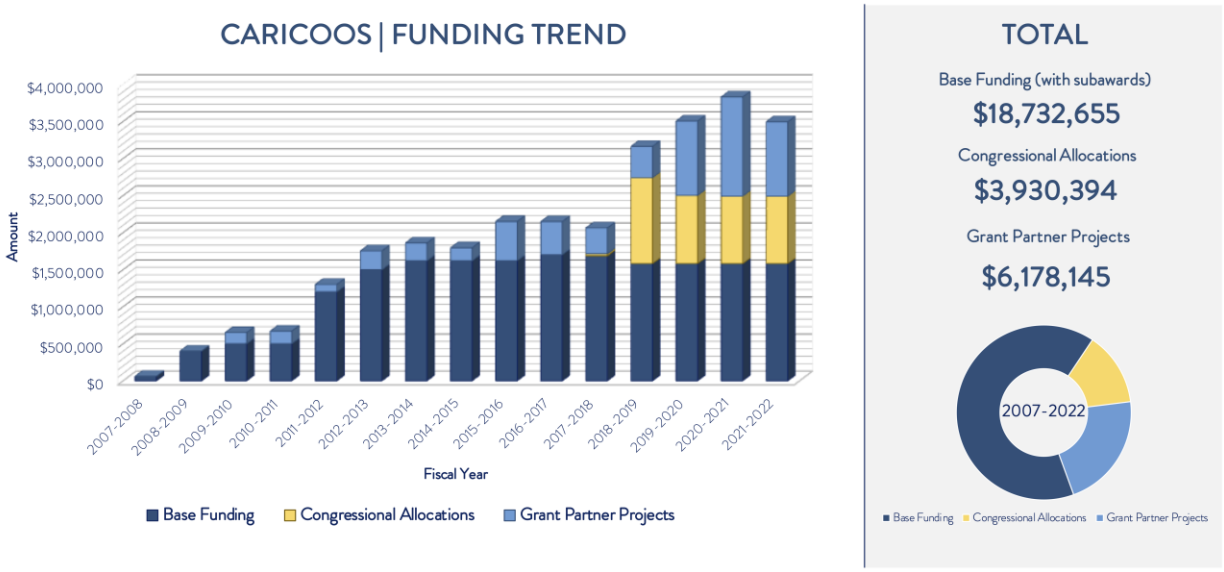

Figure 14. CARICOOS has focused on developing a balanced, externally funded project portfolio that combines funding from federal agencies, state entities and private industry. The figure on the left shows a breakdown of CARICOOS-related funding since 2008. Partner projects generally provide additional funds for development of new products and acquisition of additional observing assets and computational capabilities. These projects provide a large number of student research assistantships at all levels ranging from undergraduate to doctoral students and provides important job opportunities for technical personnel. The figure on the right depicts CARICOOS funding for the last fiscal year, including UPRM's matching funds and academic release.

Given the limited level of funding from IOOS and the need to strengthen the fiscal basis of CARICOOS in order to support its further development CARICOOS leadership is committed to explore new approaches for further diversification of its funding base. Additional funding sources pending analysis by CARICOOS BOD include donations from private partners who derive income from the use of data provided by CARICOOS such as app developers, port operators, the shipping industry and the tourism industry. CARICOOS' technical leadership is already engaging state and federal agencies which require essential information in order to define adaptation plans facing sea level rise (see partner projects in the plots above). Funding will also continue to be sought from agencies and

private entities funding applied science research required for understanding coastal systems, enhancing the resilience of coastal environments in the US Caribbean and furthering Blue Economy initiatives which should be explored in our regions in the upcoming years. Such efforts will require exploring the possibility of proposing “partner projects” and optimize the investment by both entities.

4.3 TOWARD INTERNATIONAL COLLABORATION

Since inception, CARICOOS has recognized the importance of forging relationships with Caribbean countries. This is especially important given the hydrodynamic connectivity between the U.S. Caribbean and neighboring countries, as highlighted by the trajectories of CARICOOS drifters released near Puerto Rico and the USVI (Figure 14). With this in mind CARICOOS has initiated efforts into reaching out to neighboring islands. Forthcoming opportunities for international collaboration have been discussed with the Dominican Republic's National Authority for Maritime Affairs (ANAMAR), and the Vice Minister for Health and the Environment. Eastwards. Any international expansion would take place within the context of GOOS and IOCARIBE.

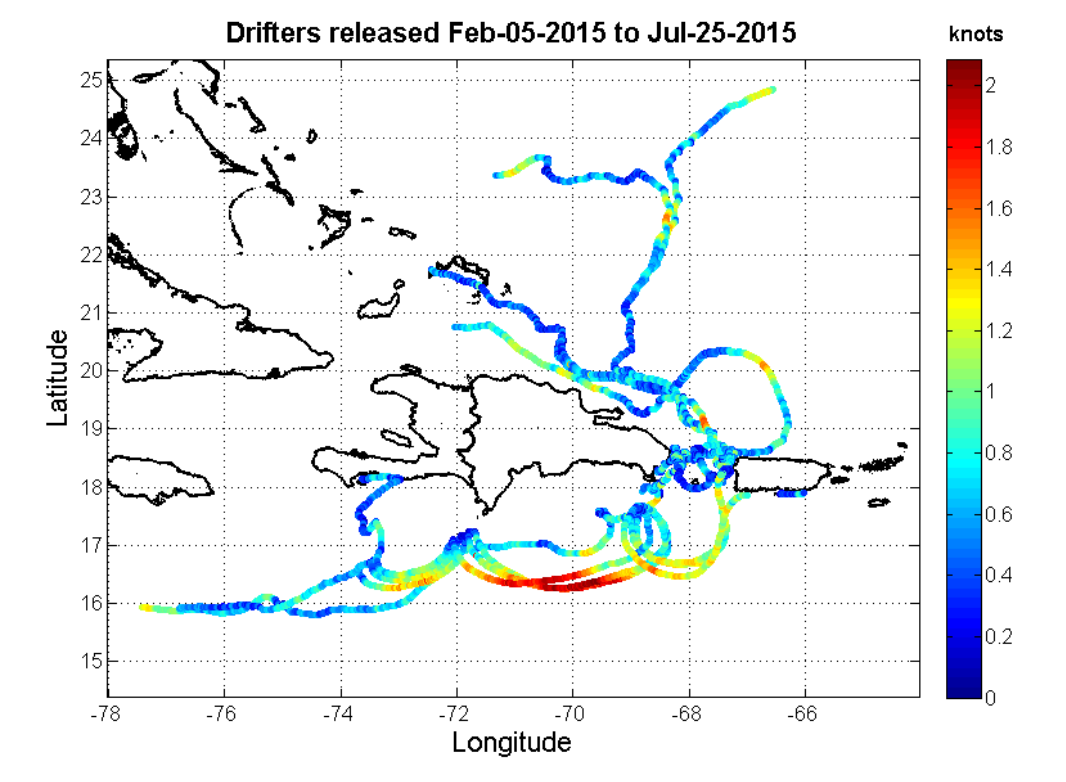

Figure 15. Trajectories for 19 CARICOOS drifters showing the extent of the drifter program and connectivity between Eastern Caribbean Islands. Color bar indicates current speed in m/s.

4.4 RESEARCH AND DEVELOPMENT

CARICOOS Research and Development (R&D) efforts are carried out by faculty members, students and technical personnel at UPRM's Department of Marine Sciences and Center for Applied Ocean Science and Engineering. Most of CARICOOS' modeling initiatives go through an R&D stage, where validation and fine-tuning take place. In collaboration with NOAA-AOML, CARICOOS supports a continuous time series of AUV deep ocean data providing basic science in support of hurricane forecasting research. CARICOOS also conducts R&D on model development and validation in support of NWS San Juan's Weather Forecast Office, a collaborative effort which is formalized through an MOA between NWS and CARICOOS.

CARICOOS takes part on sporadic observational campaigns to further understand coastal and ocean processes taking place in our region. While providing in situ data in support of remotely sensed observations such as HFR surface currents, these efforts are fundamental for the strategic expansion of the observing system.

CARICOOS is committed to disseminate research products with significant impact. R&D initiatives are publicly available in peer-reviewed journals, online tools data portals, conference proceedings and presentations.

As the oceanographic project with perhaps the most profound societal impact in the U.S. Caribbean, CARICOOS strives at nourishing the next generation of ocean scientists and engineers. CARICOOS will continue to support a wide variety of undergraduate and graduate students performing meaningful research, in an effort to expand the critical mass of local expertise toward building a solid applied ocean sciences industry for the US and neighboring Caribbean.