Meeting Stakeholder Ocean Data Needs In The Eastern Caribbean

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I. INTRODUCTION

Historically, the US Caribbean coastal region has been under-observed. Reliable 24/7 sources of such basic data as waves and currents have never been available. Recently NOAA, through its IOOS Program Office, has taken the initiative to provide funding, support and guidance for the development of a Caribbean Regional Association for Ocean Observing (CaRA), and a Caribbean Coastal Ocean Observing System (CariCOOS) capable of providing sustained observations of these parameters in the region. CaRA and its 10 sister Regional Associations across the coastal United States constitute an integral part of the operational component of the U.S. Integrated Ocean Observing System (IOOS), which is the U.S. contribution to the Global Ocean Observing System, or "GOOS." GOOS is a global system for sustained ocean observations designed to improve weather forecasts and climate predictions. GOOS is also the ocean component of an even larger system, known as the Global Earth Observation System of System (GEOSS). A bill that includes authorization for IOOS as part of NOAA was signed into law earlier this year by President Obama and while the legislation does not secure future funding for IOOS it does establish the program and constitutes a clear statement that Congress believes that IOOS is valuable and necessary. Our long-term goals within the IOOS program are to: 1) improve safety at sea, 2) assure continued economic and ensuring business benefits from the ocean, and 3) protect our ocean environment).

CaRA/CarICOOS is being implemented collaboratively through the University of Puerto Rico-Mayaguez (UPRM) and the University of the Virgin Islands (UVI) with assistance from federal and state agencies. CaRA, an alliance of private and public entities and individuals encompassing maritime commerce, recreational concerns, commercial fishermen, safety responders, environmental managers and the general public, oversees planning and implementation of the system and evaluates its products and services. Observational ocean data needs in the Eastern Caribbean Sea have been assessed through extensive consultations with CaRA stakeholders who have not surprisingly identified the need for data on coastal weather, waves, currents, water quality and coastal inundation as prioritary. To meet identified needs while minimizing infrastructure deployment and maintenance, CaRA/CarICOOS and associated experts have designed a system combining ‘in situ” and remotely sensed observations with a strong numerical modeling component. CaRA-CarICOOS is committed to the adoption and to the implementation of IOOS DMAC standards throughout our model and data services.

II. STAKEHOLDER PRIORITIES AND SYSTEMS INTEGRATION

As a first priority CaRA stakeholders need data on winds, waves, currents, water quality and coastal inundation. We are not talking about research data or process studies, both limited in space and time, but of long-term observations at adequate spatial and temporal scales throughout the coastal regions. Each of the 11 Regional Associations within IOOS has crafted its own response to the particular demands of their stakeholders and it turns out that most IOOS observation systems, including CaRA/CarICOOS, follow a basic core structure consisting of a sparse network of real-time sensors at sea and in the coastal environment that is synergistically complemented by ocean modeling at higher spatial resolutions. The observational components described herein will serve for the initialization and validation of a set of numerical models being developed through multiple collaborations. These models will provide forecasts for winds waves, currents and coastal inundation. The near absence of pre-existing coastal observational assets in the region have allowed CaRA to chart its own course, unburdened, as described below.

Integrated Systems

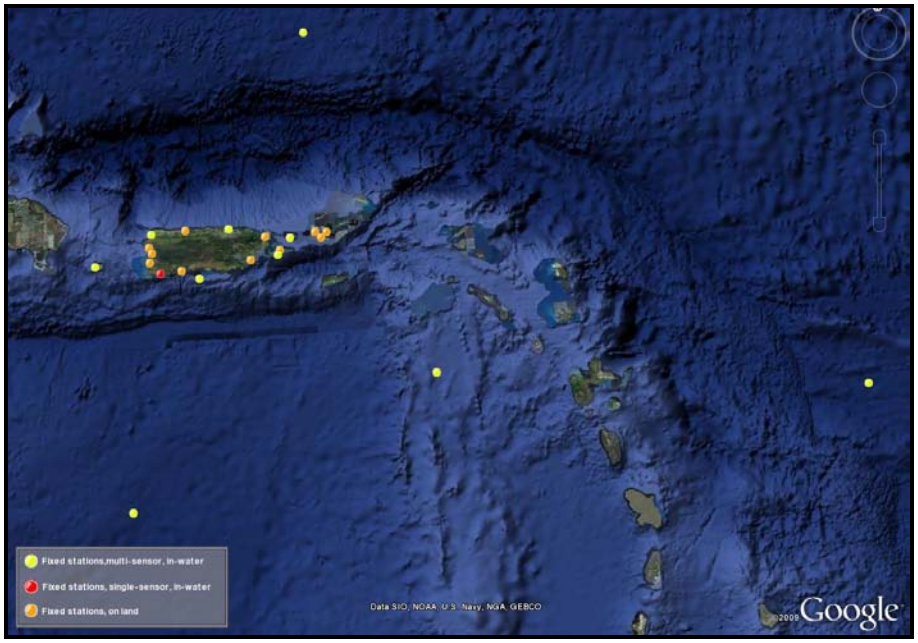
During this funding cycle the CarICOOS portfolio of observing system tools consists of

- CariCOOS Data Buoys - two permanent data buoys to be installed in areas representative of the Caribbean and Atlantic coastal regimes. The Caribbean buoy (CarICOOS Buoy A) was recently deployed on June 9 and the observations may be accessed through caricoos.org, NDBC (station 42085) and the University of Maine (mooring PR101). The Atlantic buoy is scheduled for deployment in early 2010. These buoys are being fabricated at the University of Maine's Physical Oceanography Laboratory to CarICOOS specifications and data from the various sensors include winds, waves, currents (near-surface single point and acoustic Doppler vertical profiles), temperature and salinity. These first

two buoys are being emplaced to the north and south of the island of Puerto Rico (PR). Plans are being drawn up for installation of a third data buoy in the area between St. Thomas and St. Croix in the US Virgin Islands (USVI) while longer term plans call for a fourth buoy in the Mona Passage between Puerto Rico and Hispaniola;

- CariCOOS/WeatherFlow MESONET - 12 hurricane hardened stations in collaboration with WeatherFlow Inc.
- CSR/CariCOOS HF Radar Network - Through a Department of Homeland Security-funded Center of Excellence, the National Center for Secure and Resilient Maritime Commerce and Coastal Environments (CSR), and with administrative and technical support from CaRA/CariCOOS, UPRM, Rutgers University (New Jersey) and Stevens Institute of Technology (New Jersey) are implementing a dual-use HF network on the west coast of PR for current visualization and ship identification and tracking. One emplacement is now active and the second installation is planned for late 2009. This system will provide the cornerstone for the CariCOOS HF radar network. Current plans call for 18 mid-range and 9 short-range emplacements throughout PR and USVI. This system will provide seamless coverage throughout the region to distances of up to 80 miles.;
- Numerical Models: Weather Research and Forecasting (WRF), Simulating Waves Nearshore (SWAN), ADCIRC coastal circulation and storm surge (various versions), Regional Modeling System nested within Hybrid Coordinate Ocean Model (HyCOM-ROMS);
- CarICOOS data and information web portal;

which together with the NOAA ICON/CREWS buoy, the NOAA-NOS tidal network, several sea level stations managed by the Puerto Rico Seismic Network and two DART deep water buoys round up all existing ocean observing assets in our region as displayed in Fig. 1 and listed in Table 1. What is not readily appreciated in Fig 1 is the steep relief of Puerto Rico's mountainous interior, therefore the need for high resolution wind data, and the potential for damage from severe cyclones. The following sections describe how these systems have been applied to specific stakeholder priority items, resulting in the CaRA/CarICOOS suite of products available to our stakeholders and to anyone with an internet connection.



Winds

The wind fields around islands with steep topography are very complex due to topographic steering, vertical advection and cloud formation, and due to the influence of tropical cyclones and other synoptic weather systems. Not only are fair weather winds needed, but precious data needs to be collected during the worst storm scenarios for storm model validation and for the development of coastal design criteria. The spatial coverage and the adequacy of pre-existing weather stations in the CaRA region was evaluated jointly with WeatherFlow Inc. and it was found that most stations are located near the coast (i.e., NOAA-

NOS tide stations) and that several of these stations are located in sheltered areas or near structures that might affect wind observations. It is for these reasons that existing coastal weather observations in the region are being augmented with the installation of 12 hurricane hardened stations in collaboration with WeatherFlow Inc. plus 2 full meteo stations aboard CarICOOS data buoys off the Caribbean and Atlantic coasts. We are committed to providing the best wind data coverage to our stakeholders.

To complement the relatively sparse weather station network the Weather Research & Forecasting Model (WRF) is being executed in near-operational mode for the high-resolution modeling of regional winds. Currently using a 4 km grid size we recently expanded the model domain and will soon migrate to the WRF version 3. Model output grids are available to our stakeholders through our THREEDS/OpenDAP server. Validation of model output vs. observations from the meteorological grid is a continuing effort and with the new version 3 we will commence optimization and validation of modeled precipitation. Future plans also contemplate the design of a higher resolution, 2 km, model grid. In this endeavor CaRA is collaborating with the meteorology section of the Physics department and the Coastal Engineering section at UPRM and with the PR office of the NWS.

We have initiated the long-term process of wind model validation vs. observations and will continue to refine and improve our WRF implementation to further satisfy our stakeholders. Our staff has developed the Windstreams® graphical utility (see Fig. 2a) to jointly display model and observational data in a user-friendly format.

Waves

Direct wave observations are very scarce in the CaRA region. As of August 2009 there are only two wave monitoring platforms within the United States Caribbean Exclusive Economic Zone (EEZ, the *de facto* definition of the CaRA region aside from the far away island of Navassa) and one of these is our Buoy A which was deployed in June 2009. The other wave platform in our region is NDBC station 41140, a movable buoy currently positioned at a depth of 244 meters north of the island of St. Croix. Note that buoy 41140 had been previously deployed at the position indicated by a yellow dot very near the center of Fig. 1. The north coast of Puerto Rico is exposed to seas and swell generated throughout the North Atlantic whereas the south coast is open to very different Caribbean Sea weather patterns. This Atlantic-Caribbean characterization of our zonally-oriented north and south coasts, respectively, allows us to categorize the CaRA Buoy A as our Caribbean buoy; the corresponding Atlantic buoy will be deployed in 2010.

Given our regional propensity to the arrival of intense tropical cyclones our Buoy A is equipped with a fully detached bottom mounted Waves-ADP coupled to an acoustic modem that serves as the wireless, subsurface, data conduit to the communications package on the buoy itself. Extreme buoy motion under the influence of a severe hurricane should not result in the loss of the bottom package and highly valuable wave and sea surface elevation measurements collected under these conditions will therefore be safeguarded.

Deep-water wave model forecasts, currently available from NOAA WWIII, are being augmented with in-house SWAN model output that is particularly applicable to nearshore regions not adequately resolved by the former. Model output grids are available to stakeholders through our THREEDS/OpenDAP server. SWAN as well as WWIII forecasts are expected to benefit from the "in situ" data to become available. We have also initiated the long-term process of wave model validation vs. observations and will continue to refine and improve our SWAN implementation. Our staff has developed the Wavestreams® graphical utility (see Fig. 2b) to jointly display model and observational data in a user-friendly format.

Currents

CaRA Buoy A is the only asset currently providing real-time water velocity time series to our stakeholders, and only for the south coast of PR. As described above the bottom package associated with this buoy contains an acoustic Doppler profiling current meter that observes flow velocities throughout the water column at 1 meter intervals. The buoy itself contains a complementary fixed depth acoustic Doppler current meter for the monitoring of near-surface currents at a depth of 2 meters. Future CaRA buoys will provide the same functionality.

CaRA is also participating in the development of a national network for surface costal current visualization using high frequency (HF) radar systems to be installed along the island coasts. Current plans call for 18 mid-range and 9 short-range emplacements throughout PR and USVI. This system will provide seamless coverage throughout the region to distances of up to 80 miles. Through a Department of Homeland Security-funded Center of Excellence, the National Center for Secure and Resilient Maritime Commerce and Coastal Environments (CSR), and with administrative and technical support from CaRA/CariCOOS, UPRM, Rutgers University (New Jersey) and Stevens Institute of Technology (New Jersey) are initially implementing a dual-use HF network on the west coast of PR for current visualization and ship identification and tracking. One emplacement is now active and the second installation is planned for May 2009. This system will provide the cornerstone for the CariCOOS HF radar network.

The experience gained during our coastal inundation studies has prompted us to utilize the very high spatial resolution velocity fields from ADCIRC simulations to investigate the highly complex structure of coastal flows in our region. Dr. David Hill from Penn State is collaborating with us in this initiative. Results from our tests and validations so far look very promising. Regional

offshore circulation and mesoscale process assessment are being approached through a piecewise regional implementation of the Regional Ocean Model System (ROMS) nested into the Hybrid Coordinate Ocean Model (HyCOM) which provides a baroclinic perspective to the regional offshore circulation in the CaRA region. Dr. Laurent Cherubin from the University of Miami and Dr. Nasseer Idrisi from the University of the Virgin Islands are the lead investigators in this initiative. Further products on offshore conditions are being generated locally using standard output from NOAA's Real -Time Ocean forecast System (RTOFS) and from the Navy Coastal Ocean Model (NCOM) and are published in the CarICOOS web portal. Due to bandwidth limitations in our region we also provide some of these outputs through our THREEDS/OpenDAP server as a service to our stakeholders.

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Water Quality

Water quality concerns in our region are being addresses through collaboration with NOAA's CoastWatch program and with the European Space Agency which provide regionally targeted imagery. CariCOOS implements coupled in-situ validation of the remote-sensing products. Our European partners are committed to the future delivery of ocean color imagery at 300m resolution which will be of great use for water quality monitoring in our region.

Additional initiatives are being crafted in response to stakeholder needs in regards to quantifying the microbiological load of beach waters (i.e., beach safety) and to nearshore coastal pollution concerns.

Coastal Inundation

In collaboration with PR government agencies we have developed skill in the modeling of coastal water elevations resulting from the arrival of tropical cyclones into our region. ADCIRC is used to obtain storm surge elevations and winds which are then fed into SWAN to obtain additional wave setup information. Various experts in this field currently collaborate with CaRA in this effort. Coastal inundation levels arising from the combined effect of the storm surge and of wave setup are being catalogued by storm intensity, storm translation speed and by angle of incidence. Maximum elevation levels for each storm intensity and angle are calculated from numerous parallel tracks spaced by 10 nm. Maximum elevation contours are then exported as shapefiles into ArcMap and superimposed on very high resolution orthophotography for PR and the VI.

III. PRODUCTS

The interested reader is encouraged to browse our portal caricoos.org to experience our full suite of products and services. Selected products will be displayed during our presentation at *OCEANS 2009* MTS/IEEE and a copy of the Powerpoint presentation will also be available at caricoos.org after the meeting.

One of our main priorities is to provide coastal information in ways and in formats that all our stakeholders can access and interpret correctly, a very demanding task given our wide spectrum of stakeholders. User outreach and feedback are therefore very important to us in order to maximize stakeholder benefit from our activities and to achieve our long-term goals within the IOOS program to: 1) improve safety at sea, 2) assure continued economic and ensuring business benefits from the ocean, and 3) protect our ocean environment).

IV. CLOSING

The role of CaRA/CarICOOS is currently limited to the US Caribbean EEZ, however, our unique location amidst the greater Caribbean prompts us to collaborate with neighboring countries in aspects related to ocean observing systems, regional modeling and data management. The Gulf of Mexico regional association (GCOOS) and Cara/CarICOOS are ideally located to bridge a system of ocean observing systems across the Intra Americas Seas and extending across the Americas. From the Ocean Data and Information Network for the Caribbean and South America (ODINCARSA), which extends southward into Chile, to the Alaskan regional association (AOOS) ocean observing systems are promoting marine safety and economic development in the Americas while monitoring the oceans during a period when rapid changes are occurring and great uncertainty prevails.