Increasing the Coverage of an Island-Based HF Radar Network

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***Abstract*— High frequency (HF) radar networks are operated in different regions around the world for use in monitoring ocean surface currents and coastal wind dynamics. These networks are individually composed of multiple HF radar surface current monitoring systems, each installed at a different coastal research site. The data derived from these networks is used to study coastal currents, offshore wind, oil spill response, algal bloom movements, and also used by the United States Coast Guard (USCG) as part of their Search and Rescue Optimal Planning System (SAROPS). We describe here the HF radar network that is part of the Caribbean Coastal Ocean Observing System (CariCOOS). The existing HF radar network covers parts of the southern and western coast of Puerto Rico, and is currently managed and operated by the University of Puerto Rico Mayaguez (UPRM). Rutgers University Center for Ocean Observing Leadership (RUCOOL) has been collaborating with UPRM on the Integrated Ocean Observing System (IOOS) program "Advancing the Caribbean Ocean Observing System". Increasing the coverage of the UPRM-CariCOOS HF radar network could be used to enhance the operational abilities of the USCG and other local and regional emergency response agencies.**

Keywords—HF radar, ocean currents, emergency response

I. INTRODUCTION

Rutgers University Center for Ocean Observing Leadership (RUCOOL) is a member of the Mid-Atlantic Regional Association of Coastal Ocean Observation Systems (MARACOOS), which itself is part of the Integrated Ocean Observing System (IOOS) program administered by the National Oceanic and Atmospheric Administration (NOAA). The University of Puerto Rico Mayaguez (UPRM) is a member of the Caribbean Coastal Ocean Observing (CariCOOS), which is also part of NOAA's IOOS program. RUCOOL has been working with UPRM to develop and enhance the High-Frequency Radar (HFR) Network around the coast of Puerto Rico. The HFR Network is a key component of the CariCOOS observational system, and the ocean surface current data provided by the HFR Network is currently being used by the United States Coast Guard (USCG) to assist in search-and rescue operations, as well as oceanographers studying coastal ocean dynamics.

The initial HFR network in Puerto Rico consisted of two 13 MHz Coastal Ocean Dynamic Application Radar (CODAR) sites located on the west coast if the island. The northern site, named FURA, was installed in September 2009, and is located at 18.2919N, -67.1983W, at the Forces United for Rapid Action (FURA) station in Anasco. The southern site, CDDO, was installed in February 2009, and is located at 18.0999 N, -67.1905 W, at the Club Deportivo del Oeste in Cabo Rojo. Both of these sites produce hourly surface current radial vector maps with approximately 3km range cell spacing, with coverage extending to approximately 100km offshore. The data from these sites have been used to create hourly surface current total maps using the Optimal Interpolation (OI) combining method, as seen in Figure 1.

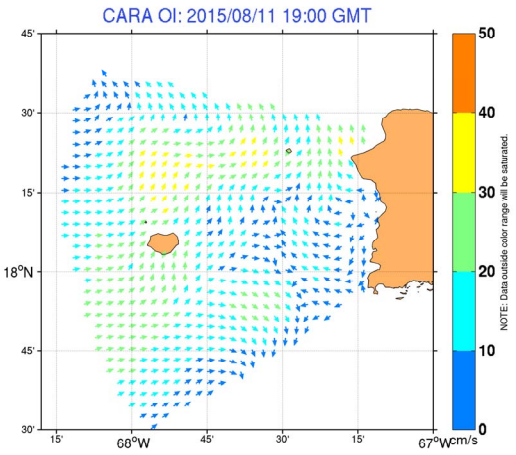

Figure 1- Map of OI surface currents with 3km resolution off the west coast of Puerto Rico, created from radial files from CDDO and FURA.

Over the last year, two additional HFR sites have been installed along the southern coast of Puerto Rico. The western site, which is named FARO, is located at 17.9334 N, -67.1920 W, at the Cabo Rojo Lighthouse in Cabo Rojo. The eastern site, named PYFC, is located at 17.9628 N,

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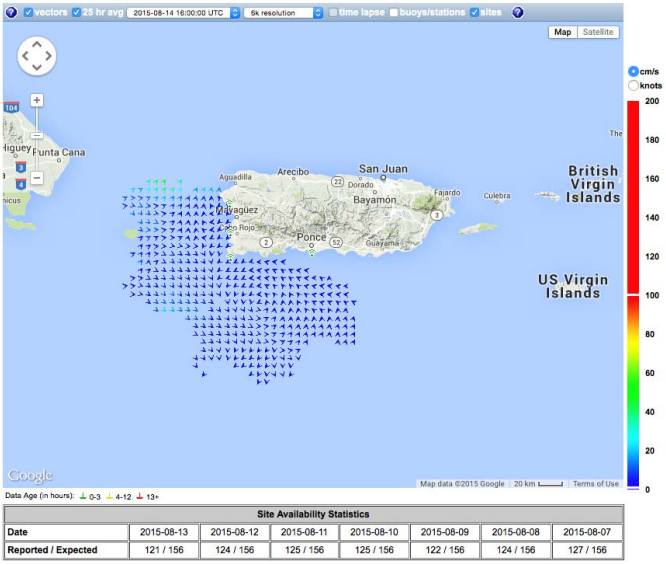
-66.6183 W, at the Ponce Yacht and Fishing Club in Ponce. These sites are both 5 MHz systems with approximately 6 km range cell resolution and approximately 200 km range.

Using the unweighted least squares (UWLS) combining method, surface current total maps have been created using radial files from the FURA, CDDO, FARO and PYFC sites, as seen in Figure 2.



Site Availability Statistics							
Date	2015-08-13	2015-08-12	2015-08-11	2015-08-10	2015-08-09	2015-08-08	2015-08-07
Reported / Expected	121 / 156	124 / 156	125 / 156	125 / 156	122 / 156	124 / 156	127 / 156

Figure 2- Surface current total map with 6km resolution, created by combining radial files from the CDDO, FURA, FARO, and PYFC sites.

In order to increase the HFR Network's total coverage area around the southern and eastern sides of Puerto Rico, one or two additional sites are potentially going to be installed at new locations in Emajagua, PR, and on St. Croix, British Virgin Islands. The placement of new HFR sites must take into account the location and coverage area of existing sites, as surface current total vectors can only be created in areas of ocean that have overlapping coverage from more than one HFR site.

II. METHODOLOGY

Using SeaDisplay and SeaDisplaySetup software developed by Codar Ocean Sensors, potential individual site coverage areas, as well as areas of overlapping coverage, can be estimated and plotted, as seen in Figure 3.

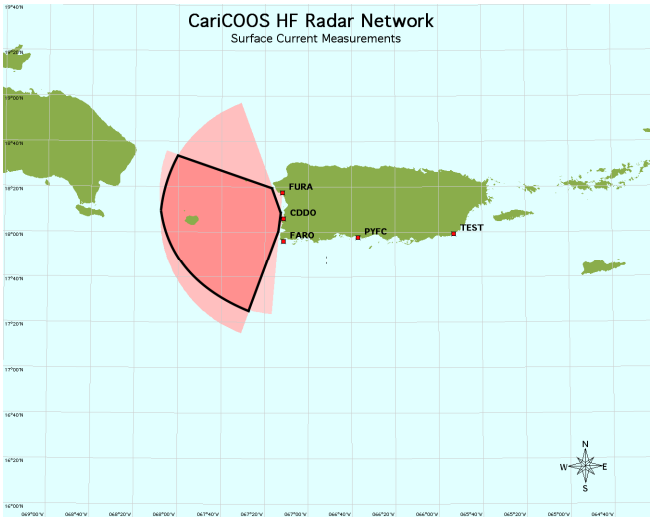


Figure 3- Potential coverage areas of the FURA and CDDO sites. Area of overlapping coverage/potential total current coverage is outlined in black.

Due to coastal geography, and the limitations of HFR sites to efficiently transmit and receive signals over land due to attenuation, the bearing range for the coverage area of the FURA site is limited to approximately 105 degrees. The bearing range for the coverage area of the CDDO is limited to approximately 140 degrees.

The first 5 MHz HFR site in Puerto Rico, FARO, was installed in February 2015 at the Cabo Rojo Lighthouse last year. The bearing range for is coverage area is limited to approximately 170 degrees. Although this site can produce radial vector files covering the majority of the coastal waters off the southern coast of Puerto Rico, the increase of coverage of surface current total generation is limited to the small areas that overlap with existing sites' radial coverage, as seen in Figure 4.

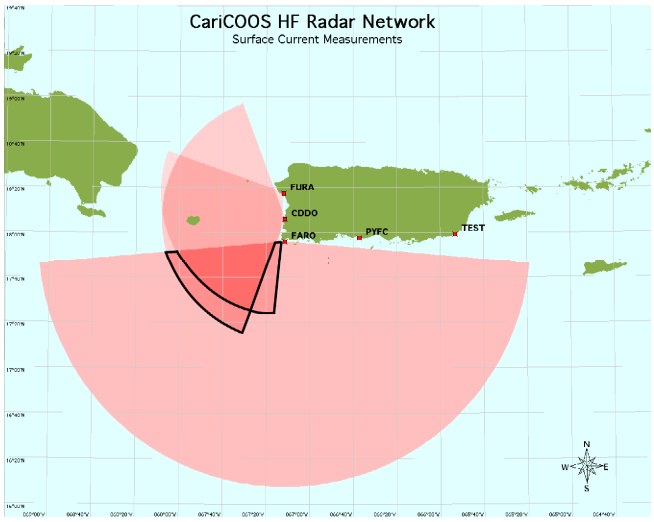


Figure 4- Approximate radial coverage of the FURA, CDDO, and FARO HFR sites. Areas outlined in black indicate the potential increase in total surface current coverage when combining data from FARO with data from CDDO and FURA.

The second 5MHz in Puerto Rico, PYFC, was installed in April 2015 at the Ponce Yacht and Fishing Club. This site has radial coverage out to approximately 200km, and has an approximate bearing coverage range from 160 degrees. When combined with radial files from FARO, CDDO, and FURA, the total surface current coverage area is greatly extended over the southern and south western waters off the coast of Puerto Rico, as seen in Figure 5.

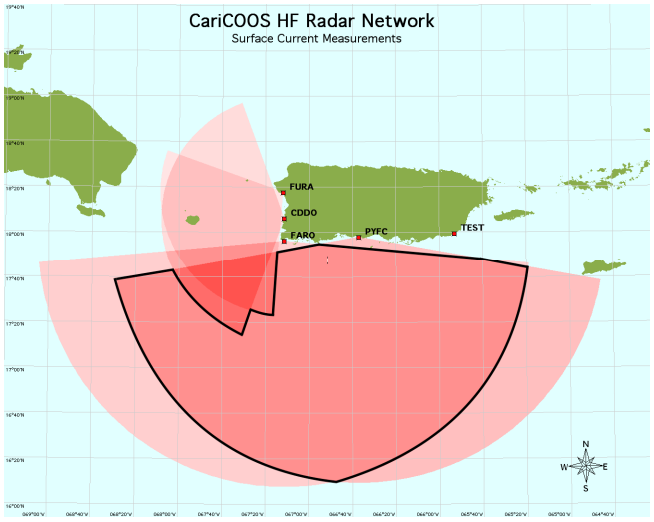


Figure 5- Approximate radial coverage of the FURA, CDDO, FARO, and PYFC HFR sites. Areas outlined in black indicate the potential increase in total surface current coverage when combining data from PYFC with data from FARO, CDDO, and FURA.

Future plans for the CariCOOS HFR Network include potential placement of a third 5 MHz site, named TEST, in Emajagua, at the Tuna Point Lighthouse. This site would have radial coverage out to approximately 200km, and an approximate bearing coverage range from 185 degrees, as seen in *Figure 6*.

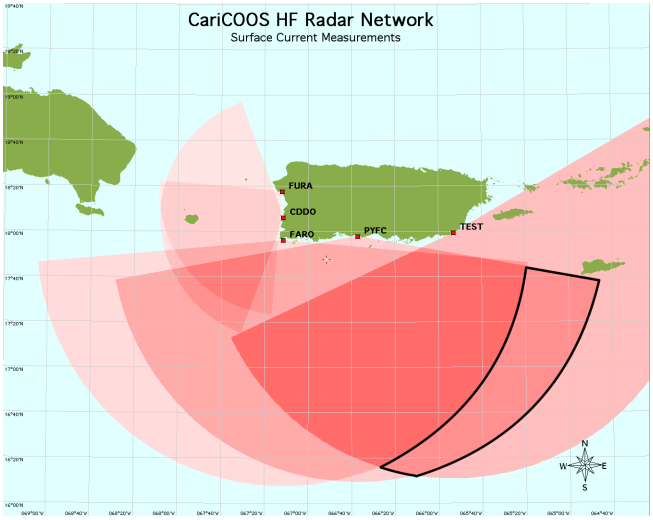


Figure 6- Approximate radial coverage of the FURA, CDDO, FARO, PYFC, and TEST HFR sites. Areas outlined in black indicate the potential increase in total surface current coverage when combining data from TEST with data FURA, CDDO, FARO, and PYFC.

In order to further increase the total surface current coverage areas around the eastern part of Puerto Rico, an additional 5 MHz or 13 MHz HFR site, named TEMP, may be installed on the western side of St. Croix, British Virgin Islands, as shown in Figure 7 and Figure 8, respectively. This area would cover the flow through the Virgin Passage.

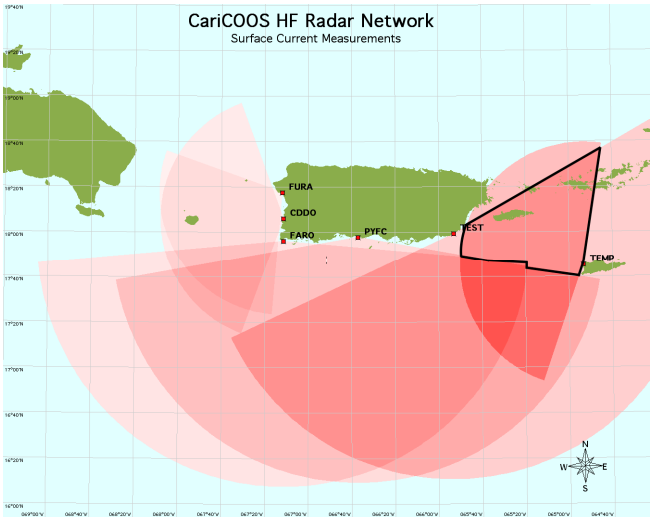


Figure 7- Approximate radial coverage of the FURA, CDDO, FARO, PYFC, TEST, and TEMP HFR sites. Areas outlined in black indicate the potential increase in total surface current coverage if TEMP is a 13 MHz site with an approximate coverage range of 100km.

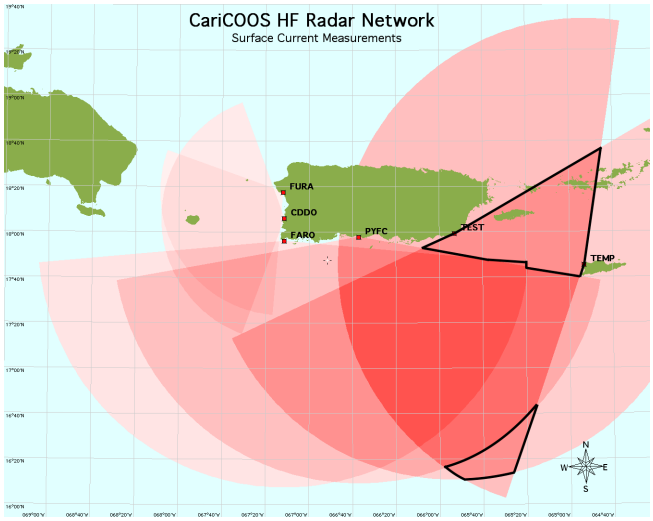


Figure 8- Approximate radial coverage of the FURA, CDDO, FARO, PYFC, TEST, and TEMP HFR sites. Areas outlined in black indicate the potential increase in total surface current coverage if TEMP is a 5 MHz site with an approximate coverage range of 200km.

III. RESULTS

Data from the two 13 MHz HFR sites, FURA and CDDO, as well as data from the two 5 MHz sites, FARO and PYFC, are currently being served to the United States National HFR Network. These data sets are being used to calculate ocean surface currents along the large parts of the southern and western coasts of Puerto Rico. An example 25hr averaged 6km resolution total current map is shown in Figure 9.

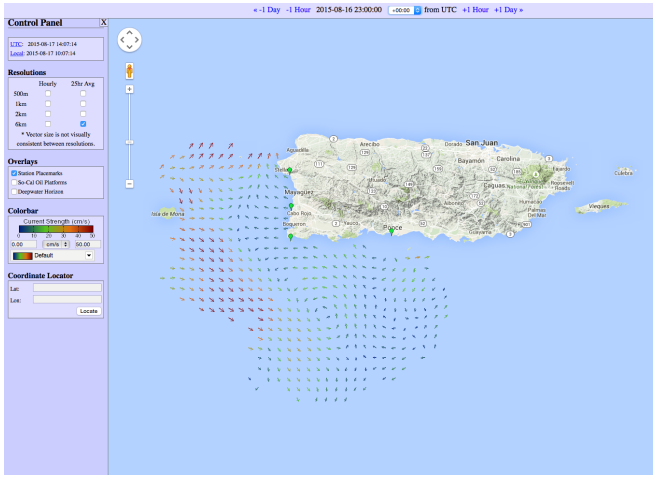


Figure 9- 25hr averaged 6 km resolution total surface currents from 08/16/2015 2300UTC.

These data are also being used by CariCOOS to generate hourly surface current total maps with 180min averaging, as seen in Figure 10.

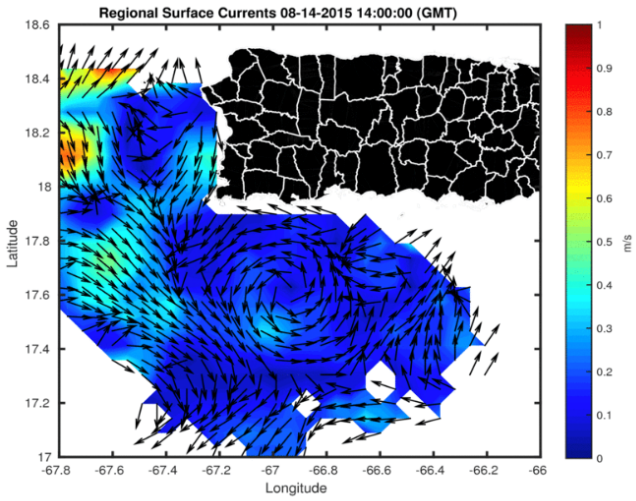


Figure 10- Hourly CariCOOS HFR Network total surface currents map, with 180min averaging and 6km resolution.

An analysis of six months of data from the two 13 MHz sites covering the west coast of Puerto Rico and the waters in the Mona Passage was also conducted.

The past six months of data from the 13 MHz network were analyzed. The surface current data within 4 km of 67°30' W and 18° 10' was averaged to produce a north (U) and east (V) current time series. The results are shown in Figure 11 and Figure 12, respectively. The hourly surface current measurements were filtered with a Lancocz filter with a cut-off period of 32 hours to remove the tidal variability. The low pass filtered data is shown as the green line. We also calculated the monthly average with 95% confidence interval error bars. Those are shown as the black lines and error bars.

The hourly data varied between ±40 cm/s in the zonal direction and ±80 cm/s in the meridional direction. The monthly plots show a consistent flow that is towards the north and west. The monthly average transport to the north varied between 16.5 and 1.6 cm/s and was between 7.8 and 2.2 cm/s to the west.

The low pass data reveals several events in the record where the flow switched from the dominant mode towards the south or east. We are analyzing the wind data from the CariCOOS Mesonet for possible correlations between the currents and winds.

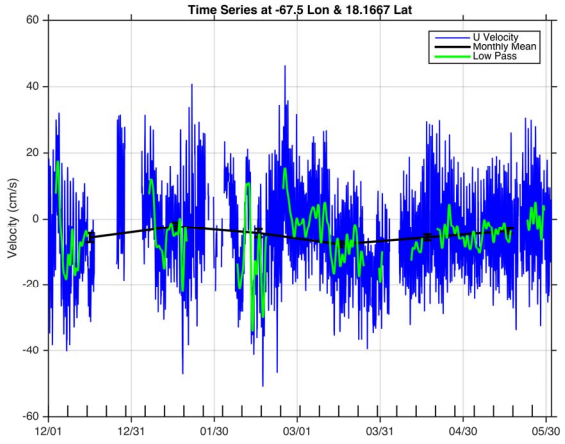


Figure 11- Six-month average of 13 MHz totals north (u) time series.

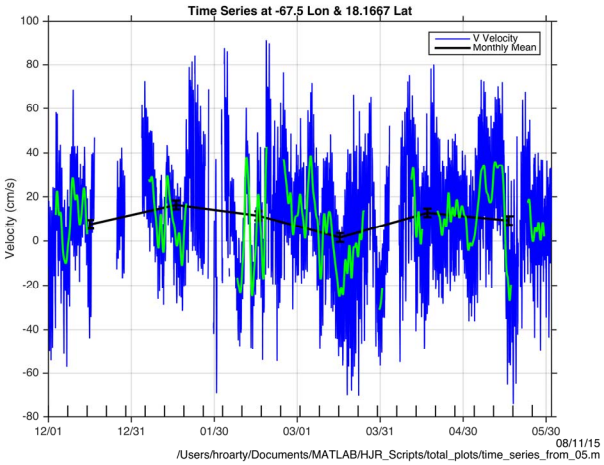


Figure 12- Six-month average of 13 MHz totals west (v) time series.

IV. Conclusions

To date, the CariCOOS HFR Network in Puerto Rico consists of two 13 MHz sites on the west coast of the island, and two 5 MHz sites on the southern coast. These sites have been running well and providing data to the IOOS National HFR Network, as well as the United States Coast Guard search-and-rescue operators in North America and the Caribbean. As the coverage of the network has grown, so has the desire to have ever-larger areas covered by this data. Choosing the most appropriate location for future HFR site installations requires taking the coverage of existing sites into consideration, as total surface current maps can only be created for areas that have overlapping data from at least two separate sites. In order for the CariCOOS HFR Network to be able to produce surface current total maps covering all the coastal waters around Puerto Rico, additional sites must be installed. These additional sites will most likely be located in the southeastern part of the island and on the island of St. Croix, BVI. Adding sites in these two locations would enable surface current totals to be calculated off all of the southern coast of the island, as well as well as off a large part of the eastern coast, too. If additional future funding becomes available to supplement growth of the Caribbean HFR Network, new locations will be analyzed, selected, and tested for additional HFR sites.

V. Acknowledgments

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United States Integrated Ocean Observing Serving

National Data Buoy Center HF Radar National Server

National Oceanographic and Atmospheric Administration

Rutgers University Center for Ocean Observing Leadership

Mid-Atlantic Regional Association of Coastal Ocean Observing Systems

University of Puerto Rico Mayaguez

Caribbean Integrated Ocean Observing System

Scripps Institution of Oceanography Coastal Observing Research and Development Center

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