A Regional HF Radar Pilot Product: Serving IOOS needs in the Mid-Atlantic Bight

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***Abstract*- Surface currents are an integral component of the Integrated Ocean Observing System (IOOS) and High Frequency (HF) radar technologies provide the means to measure these data across regional scales. A national committee on surface current mapping, supported by OCEAN.US, has outlined an organizational structure for a national HF radar system. This plan separates the national system into regional centers responsible for the operation and maintenance of the network. Recently MACOORA, the Mid-Atlantic Coastal Ocean Observing Regional Association, identified HF radar as an important component of the coastal observatory. In the context of MACOORA and the regional landscape outlined in the IOOS plan, the HF radar operators from Cape Cod to Cape Hatteras have formed a consortium for the operation and maintenance of the HF radar network, including system hardware, data management, and product delivery. Through this consortium the existing pockets of systems can be operated as part of one regional network. This network consists of 11 long-range sites providing total vector coverage across a large majority of the region. Additional sites are proposed in Moriches, NY, Block Island, RI, and Martha's Vineyard, MA to completely fill in the shelf-wide coverage from Cape Cod, MA to Cape Hatteras, NC. In addition there are three higher resolution systems made up of 13 sites in operation in the Chesapeake Bay, New York Harbor, and Long Island Sound estuaries with plans for 2 more sites in Delaware Bay. This nested network makes the Mid-Atlantic Bight the most heavily HF radar instrumented region in the world. In addition to scientific research and education applications, the data has already been ingested into United States Coast Guard Search and Rescue planning tools. An overview of the network including existing products and system infrastructure will be discussed as well as plans for the continued operation and reliable product delivery supporting the regional IOOS mission. By leveraging off national efforts like the Radiowave Oceanography Working Group (ROWG) for operation and maintenance and ROADNET for data management, the MACOORA HF radar consortium has moved from small groups of systems to a single integrated regional system, a model that could be scaled around the nation..**

I. THE NEED AND VISION

Real-time currents are one of the "holy grails" for the operational oceanography community. Real-time surface currents information will be used to help ensure human health and safety in the coastal ocean. For example, real-time data has been demonstrated to improve search and rescue operations and if an operational system was established, the data would be rapidly incorporated in modern search and rescue tools. Real-time surface currents will be used by coastal water quality and resource managers to more effectively sample the marine environment. With the advent of wireless communication networks, real-time currents are allowing fishery biologists to identify frontal boundaries and potential larval fish transport

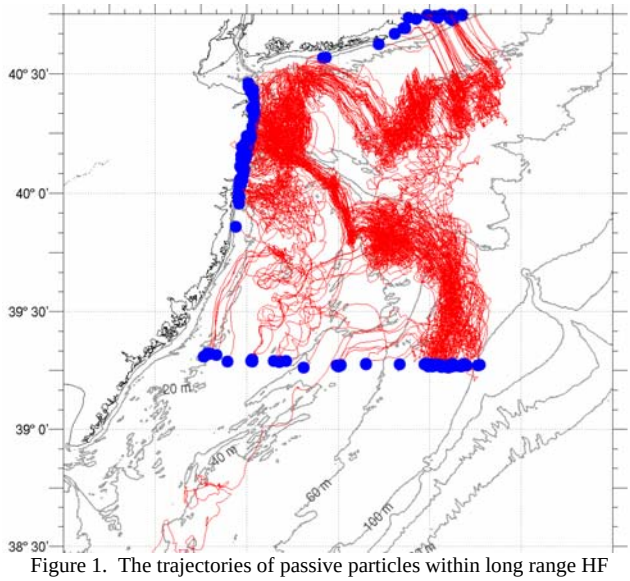


Figure 1. The trajectories of passive particles within long range HF CODAR on the Mid-Atlantic Bight.

pathways (Fig. 1). Real-time surface current radar will also be used to detect surface objects (eg. ships) (Fig. 2). This provides numerous homeland security applications. Therefore compared to many oceanographic technologies the ability to

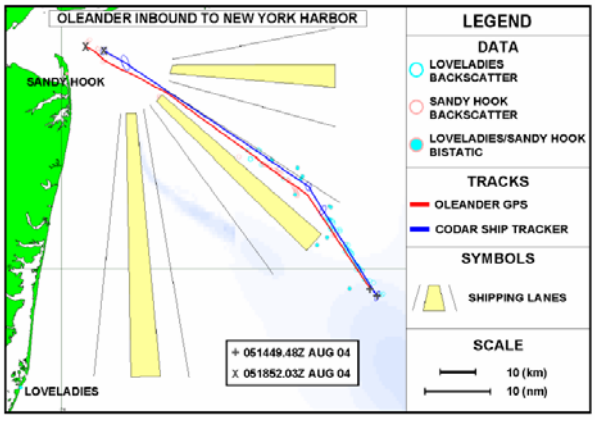


Figure 2. Actual and HF radar predicted trajectory for the Oleander. The HF radar shows great promise in detecting the ships.

map surface currents in real-time will serve many operational needs.

Given this and the demonstrated capabilities of High Frequency (HF) radar, measurements of real-time surface current maps are planned to be an integral component of the Integrated Ocean Observing System (IOOS). A national committee on surface current mapping, supported by OCEAN.US, has already outlined a structural plan to implement a national HF radar network. This plan separates the national network into regional centers responsible for the operation and maintenance of the systems. Recently MACOORA, the Mid-Atlantic Coastal Ocean Observing Regional Association, identified HF radar as an important integrating component of their envisioned Regional Coastal Ocean Observing System (R-COOS). A Mid-Atlantic HF Radar network would be capable of providing high resolution nested coverage within the five sub-regions while simultaneously linking the sub-regions together in one coastal network that covers the full range of the Mid-Atlantic coastal ecosystem. To implement a regional HF Radar network for the MACOORA R-COOS, radar operators in the region have formed the Middle Atlantic High Frequency Radar Consortium (MAHFRC). The partners in the MAHFRC are listed in Table 1.

TABLE 1.
Member institutions in the MAHFRC

University of Massachusetts, Dartmouth
University of Rhode Island
United States Coast Guard R&D Center
University of Connecticut
Stevens Institute of Technology
Rutgers University
University of Delaware
University of Maryland
NASA, Wallops Island
Old Dominion University
NOAA, Chesapeake Bay
University of North Carolina, Chapel Hill

II. WHY START IN THE MID-ATLANTIC BIGHT?

The first continuously operated systems in the Mid-Atlantic Bight (MAB) were deployed in 1998. Since that time the MAB has become the most heavily instrumented HF radar network in the world (Table 2). Academic and government groups currently operate 19 radar systems and have 7 funded systems with deployments planned over the next 6 months. There are proposals pending for 7 additional systems. Site permission has already been granted for 5 of the proposed systems. Individual radars are operated at one of three different frequencies that can be used to adjust range and resolution to provide both regional and nested sub-regional coverage. At present there are 8 long-range sites that provide shelf-wide coverage in three distinct clusters, New England, New Jersey, and North Carolina. These systems are in various levels of operation and development (Fig. 2). A recent effort through NASA Wallops will provide three additional long-range sites in Virginia and Maryland. These new sites will fill the gap between North Carolina and New Jersey. Nested within this long-range network are several higher resolution systems strategically placed at the entrances to the largest estuaries within the region (Fig. 3). These include the eastern and western Long Island Sound, New York Harbor, and Chesapeake Bay totaling 11 high resolution sites. There is currently an effort at the University of Delaware to instrument Delaware Bay with an additional 2 sites and at the University of Maryland to extend the Chesapeake Bay coverage north with 4 additional sites. In addition there are three sites in Block Island, RI, Moriches, NY, and Fire Island, NY that have permission granted with a Rutgers/Stevens collaborative proposal pending for the equipment

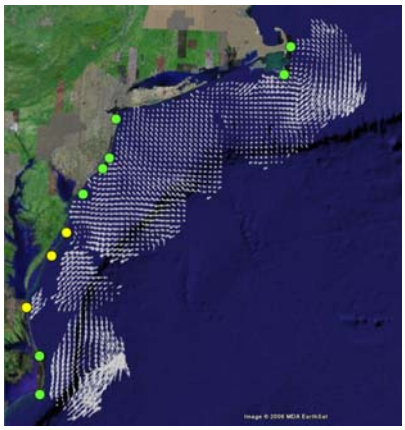


Figure 3. Coverage of the MAB Long range network. Green indicates operating sites, yellow indicates funded sites.

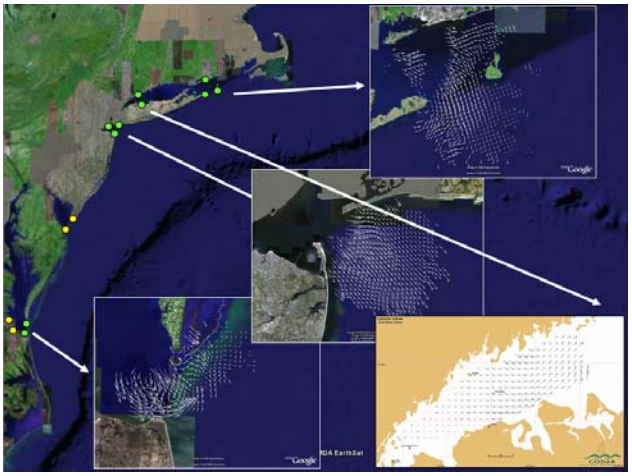
TABLE 2.
Existing sites in the Mid-Atlantic Bight.

Site Location	Site Operator	Site Frequency
Nauset, MA	U. Mass., Dartmouth	5 MHz
Nantucket, MA	Rutgers University	5 MHz
Block Island, RI	URI/UConn	25 MHz
Misquamicut, RI	URI/UConn	25 MHz
Montauk, NY	URI/UConn	25 MHz
Great Captain Is, NY	UConn	25 MHz
Bayville, NY	UConn	25 MHz
Staten Island, NY	Stevens Institute	25 MHz
Breezy Point, NY	Rutgers University	25 MHz
Sandy Hook, NJ	Rutgers University	25 MHz
Sandy Hook, NJ	Rutgers University	13 MHz
Sandy Hook, NJ	Rutgers University	5 MHz
Loveladies, NJ	Rutgers University	5 MHz
Tuckerton, NJ	Rutgers University	5 MHz
Wildwood, NJ	Rutgers University	5 MHz
Chesapeake BBT, VA	NOAA, Chesapeake Bay	25 MHz
Norfolk, VA	NOAA, Chesapeake Bay	25 MHz
Duck, NC	UNC-CH	5 MHz
Buxton, NC	UNC-CH	5 MHz

Completed installation, validation and operation of the above radars has already resulted in over 50 person-years of local HF

radar experience in the Mid-Atlantic. The experience covers the full range of skills from installation to product delivery. Every piece of an end-to-end system has been individually demonstrated in the Mid-Atlantic. Leveraging this experience and the above infrastructure investment, the HF Radar operators in the Mid- Atlantic have outlined an efficient route to demonstrate a regional capability within the structure of an R-COOS for MACOORA.

III. THE PROPOSED SYSTEM



The MAHFRC proposes a phased implementation of a regional scale HF Radar network that is scaleable to both the national and international level. The Mid-Atlantic Bight is an excellent test-bed for this because most of the HF radar systems are already in place but are operated in small clusters at different resolutions by a variety of groups, each with different funding profiles and different interests. MACOORA already provides a forum for this distributed group of HF radar operators to set priorities with users. The HF Radar Consortium Pilot will enable these operators to provide MACOORA a regional product in response. The proposed phased approach will extensively leverage the existing radar infrastructure, including a NOAA investment in a HF radar regional computer server. It immediately demonstrates interactions with SECOORA to our south through the North Carolina sites and GoMOOS to our north through the Massachusetts sites. The phased approach enables a product to be generated now on a regular basis with radars of opportunity. This will jumpstart the process of building a full scale regional network by making a demonstration product available now for users to evaluate, identifying the key needs and gaps, and using this experience to direct further investment. To ensure future growth, the ONR-sponsored Radiowave Oceanography Workshop (ROW) provides an international forum for new HF Radar technology developers to interact with scientists. Similarly, the NOAA-sponsored Radar Operators Working Group (ROWG) provides an international forum for HF radar operators to share ideas and distribute workloads.

IV. PROPOSED OPERATION AND MAINTENACE

The existing network in the Mid-Atlantic Bight consists of 26 sites (19 deployed and 7 funded). We propose a four phase approach to maintaining and operating this network. The first phase relies heavily on the existing infrastructure with minimal investment to keep it up and running on a regional scale. Phase two has additional technicians with site support to increase system uptime. Phase three brings the entire network up to SCMI standards for personnel support. Phase four fills data gaps with additional systems and maintains the SCMI personnel standards. This final phase has a funding level to ensure system uptime across the entire region with a fully nested approach.

The operation and maintenance costs can be split into two categories, (i) technicians and (ii) power and communication systems. To maintain this regional scale system we define two classes of technicians, regional and remote. Regional technicians will oversee a group of sites and ensure that all sites are operating properly from a data latency and quality perspective. Specifically they will:

1) Monitor radial file transfers from the remote sites to the central site.
2) Ensure radial level QA/QC.
3) Monitor vector combination and distribution to products.
4) Ensure total level QA/QC.

The remote technician will serve as a first responder to issues at the site that disrupt data flow. Specifically they would.

1) Perform regular site hardware and software maintenance.
2) Maintain communication lines between radial and central sites.
3) Respond to site outages.
4) Diagnose and repair hardware/software failures.

The level of system reliability will be related to the level of support for the operation and maintenance. Here we lay-out the costs for the proposed a phased approach.

Phase 1 (A single regional technician with limited site support): Under this first phase, a single full-time person will monitor the health of the existing and available sites. They will ensure that the data is coming from the remote sites and into a regional product. If data is disrupted from a site within the network, the response will be from existing personnel in the area. With this level of funding, the regional product will be maintained with response time relying heavily on existing sub-regional infrastructure. In addition to the central technician, limited support is needed for those sites that do not have existing support for power and communications.

Phase 2 (2 remote technicians and a regional technician with site support): Phase 2 builds on phase one by adding two remote technicians and increasing the level of site support to include redundant communications. The central and remote technicians will work together to both monitor and respond to outages within the network. If data from a particular site is disrupted, then the remote technicians will respond. If more than one site is down, the second site will be out until the remote technician repairs the first outage. Under this phase of operation the regional product will experience less downtime than phase 1 but will still rely on the infrastructure already invested in the sub-regional systems. In addition to the technicians, site support is required for all existing sites in the region. This will cover power, communications, raw data backup media and travel to the site for regular and unexpected maintenance.

Phase 3 (2 for every 5 sites with site support): The third phase of the operation and maintenance of this regional system comes directly from the SCMI (OCEAN.US) recommendations of 2 technicians for every 5 sites. For the existing Mid-Atlantic network we suggest 3 regional technicians (north, central, and south) and 11 remote technicians spread throughout the region. This network of technicians will be a regionally distributed group responsible for a smaller group of sites. In addition to the larger pool of technicians, operational support is requested for each site to cover power, communications, raw data backup media and travel to the site for regular and unexpected maintenance. Under this phase of operation the regional network will experience much greater uptime and no longer be reliant on the unpredictable funding on the sub-regional level.

Phase 4 (Robust nested regional products): This final phase expands phase 3 to a completely filled in regional product. The first three phases were all using the existing site hardware. This existing network in the Mid-Atlantic Bight consists of 26 sites (19 deployed and 7 funded). With three more long-range sites, most likely deployed in Moriches NY, Block Island RI, and Martha's Vineyard MA, the only remaining gap would be filled completing the shelf-wide coverage from Cape Hatteras North, Carolina to Cape Cod, Massachusetts. An additional medium range site and 10 standard range sites distributed in each of the 5 sub-regions will produce a fully connected nested regional product with sufficient redundancy that the loss of a single site does not produce a coverage gap and higher resolution at the major estuaries in the region. To maintain this fully nested network, support for 5 regional technicians (1 for each MACOORA sub-region), and 11 remote technicians spread throughout the region. Under this final phase of operation, there would be operation and maintenance in place for a completely nested surface current array with suitable uptime to fulfill the requirements of a variety of different users.

V. DATA MANAGEMENT

Radial Data Archive: The radial data from each site will be fed into a prototype data management system already funded through NOAA. A surface current mapping network is characterized by a tiered structure that extends from the individual field installations of HF radar equipment (a site), a local regional operations center which maintains multiple installations (a node), and centralized locations which aggregate data from multiple regions (portal). This data system development effort focuses on building robust node to node communications with centralized data repositories that are updated in real-time. Through the NOAA funding, Rutgers was selected as a repository for east coast radial data. NASA Wallops will also serve as a radial data node to mirror the system at Rutgers. Radial data collected during this pilot could easily be ingested into this structure to facilitate radial data combination over the entire region.

Total Vector Combination and Distribution: A prototype server for providing HF radar vector current fields has been developed through a collaboration between the University of Rhode Island (URI) and the Open source Project for a Network Data Access Protocol (OPeNDAP) organization [1]. The OPeNDAP HF radar combining server directly will access the archived radials from the regional archive housed at Rutgers. Through this pilot, vector combination throughout the region will be calculated using an OPeNDAP radial server that will be installed at the HF radar archive that is proposed for the region. To facilitate use of the OPeNDAP combining server, a web-site will be constructed to provide a simple user-interface to define the user's desired spatial and temporal extent, as well as optional parameters available in the processing algorithms. In addition to the user-selectable archived data retrieval, real-time maps will be created over fixed regions within the Mid-Atlantic Bight. This vector combination and distribution system would be implemented in phase two of this project with a more consistent data stream.

Short Term Forecast Products. To allow the US Coast Guard and other users to begin incorporating HF radar based surface current forecasts in their operational procedures, in Phase 2 of this project we will implement the prediction system described by [2] and [3] throughout the Mid-Atlantic Bight and provide open access to the product in a format compatible with the USCG software. These data have already been incorporated into Coast Guard planning tools as part of a Coast Guard R&D center funded project.

VI. Project Management

Throughout the development of this regional network, there has been great collaboration among the operators and product developers. Recently, those involved in all aspects of the HF radar network in the Mid-Atlantic Bight have formed a consortium. This consortium will oversee the regional product delivery throughout the project. This document is a result of the first consortium meeting at the Ocean Sciences meeting in February 2006. Rutgers is in the process of drafting a

document to formalize the consortium through a common Memorandum of Understanding.

VII. REFERENCES

[1] Holloway, D. and D. Ullman, 2005. Seamless access to surface current vectors from the IOOS HF radar backbone, *OCEANS 2005*, MTS/IEEE Conference proceedings (in press).

[2] O'Donnell, J., D.et al. Integration of Coastal Ocean Dynamics Application Radar (CODAR) and Short-Term Predictive System (STPS) Surface Current Estimates into the Search and Rescue Optimal Planning System (SAROPS). U.S. Coast Guard Technical Report DTCG39-00-D-R00008/HSCG32-04-J-100052, 2005.

[3] Ullman, D. et al.. Use of Coastal Ocean Dynamics Application Radar (CODAR) Technology in U. S. Coast Guard Search and Rescue Planning, US Coast Guard report CG-D-09-03. 2003.