Phased Implementation of the Mid-Atlantic Regional HF Radar System: A Pilot Study for the Mid-Atlantic Coastal Ocean Observing Regional Association (MACOORA)

Submitted by the Mid-Atlantic HF Radar Consortium (MAHFRC)
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Members Institutions include:

- 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

Introduction:
High Frequency (HF) radar derived real-time surface current maps are envisioned 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).

Past Accomplishments:
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 1). Academic and government groups currently operate 19

Table 1. 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

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

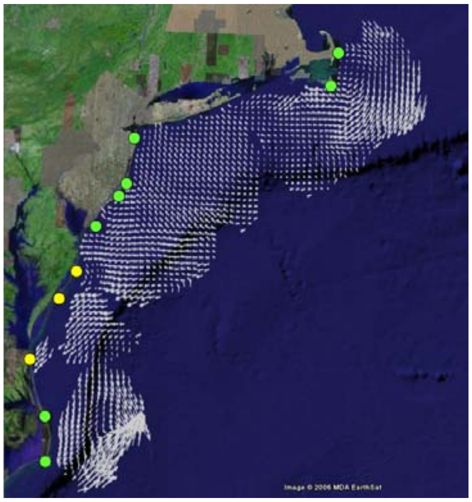

Figure 1. Coverage of the MAB Long range network. Green indicates operating sites, yellow indicates funded sites.

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 (Figure 1). 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 (Figure 2). 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.

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.

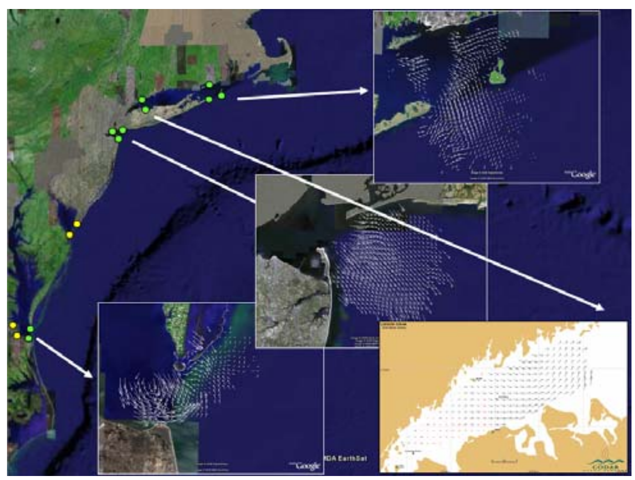

Figure 2. Nested high resolution coverage near the estuaries. Green indicates operating sites, yellow indicates funded sites.

Proposed Effort:

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.

Operation and Maintenance:
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 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 requested for those sites that do not have existing support for power and communications. This will be used bridge the potential funding gaps inherent with research grant funded sub-regional scale systems.

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 requested 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 propose 3 regional technician (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, we request 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.

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 (Holloway and Ullman, 2005). 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 Ullman et al (2003) and O'Donnell et al (2005) 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.

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. Josh Kohut, Dave Ullman, and James O'Donnell will oversee the regional radial data archive, OPeNDAP combiner, and STPS components of the project, respectively.

References

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).

O'Donnell, J., D. Ullman, M. Spaulding, E. Howlett, T. Fake, P. Hall, I. Tatsu, C. Edwards, E. Anderson, T. McClay, J. Kohut, A. Allen, S. Lester, and M. Lewandowski (2005). 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

Ullman, D., J. O'Donnell, C. Edwards, T. Fake, D. Morschauser, M. Sprague, A. Allen, LCDR B. Krenzien, (2003). 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.

Budget

	Year 1	**Year 2**
Operation and Maintenance		
Phase 1		
1 Regional Technician ($150,000/year)	$150,000	$150,000
Site support (Bridge Money)	$50,000	$50,000
Phase 1 Sub-Total	**$200,000**	**$200,000**
Phase 2		
1 Regional & 2 Remote Technicians	$450,000	$450,000
Site Support (All Existing Sites)	$260,000	$260,000
Phase 2 Sub-Total	**$710,000**	**$710,000**
Phase 3		
Technicians (SCMI Recommendations) [3 Regional and 7 Remote]	$1,500,000	$1,500,000
Site Support (All Sites)	$260,000	$260,000
Phase 3 Sub-Total	**$1,760,000**	**$1,760,000**
Phase 4		
Ten (10) 25 MHz Bay Radar Sites @ $95,000/Site (2 per subregion)	$950,000	
Three (3) 5 MHz and one (1) 13 MHz Coastal Radar Sites @ $125,000/site (To fill the coverage gap between NY Harbor and Nantucket)	$500,000	
Central Computer Sites – 3 Computers @ $36,666/Computer	$110,000	
System Setup ($10,000/site)	$140,000	
Technicians (SCMI Recommendations) [5 Regional and 11 Remote]	$2,400,000	$2,400,000
Site Support (All Sites)	$400,000	$400,000
Equipment Replacement/Repairs ($15,000/cluster)	$120,000	$120,000
Phase 4 Sub-Total	**$4,480,000**	**$2,920,000**
Data Management		
2 Full-Time People	$300,000	$300,000
OPeNDAP	$40,000	$30,000
Data Management Sub-Total	**$340,000**	**$330,000**
Data Product		
Short Term Prediction System (STPS)	$80,000	$60,000

APPENDIX 1: Serving National IOOS needs:

Data products from the Mid-Atlantic network have already supported many applications including Coast Guard Search and Rescue, NOAA NWS forecasts, and scientific research. Data from this network would support all seven of the national IOOS needs. A brief presented by Josh Kohut is available on the web for more information (http://marine.rutgers.edu/cool/coolresults/2005/KohutOS22F_03.ppt). Specifically:

Detecting and forecasting oceanic components of climate variability

Surf Zone Forecasts, NOAA National Weather Service

Presently, several NOAA National Weather Service (NWS) Weather Forecast Offices (WFOs) around the country issue rip current warnings as part of a daily surf zone forecast. Within each forecast is a three tiered rip current outlook. Forecasters at the Mount Holly WFO indicate that the model is data limited and more near-shore wave and current observations are needed to improve the daily rip current outlooks (James Ebberwine, NWS; personal communications). Data from existing components of the regional system are already being used in this near-shore forecast. The regional scale of the HF radar system proposed here would provide additional data to support similar effort along the entire coastline from Cape Cod, MA to Cape Hatteras, NC.

Facilitating safe and efficient marine operations

Safe Harbor Operations, NOAA PORTS

The NOAA National Ocean Service has a Physical Oceanographic Real-Time System (PORTS) program supports safe operations in and out of major ports along the coasts of the United States. Each PORT program provides nowcast and forecast information based on available in situ data. With new technology, real-time data can be sent to operator aboard the ships for more informed decision making. Five of the thirteen currently operating PORTS are located within the Mid-Atlantic Region. These include Narragansett Bay, New Haven, New York/New Jersey Harbor, Delaware River and Bay, and Chesapeake Bay. Data from this pilot would be available to the existing PORTS programs for full surface current coverage in and around the approaches to these estuaries. These data could provide near real-time surface current maps and be assimilated into the existing forecasts models for improved predictions.

Ensuring national security

Vessel Tracking, Department of Homeland Security

Recently the DHS completed its external review of over-the-horizon HF radar technology and determined that it is a cost-effective surveillance gap-filler between satellites with global coverage but low revisit intervals and line-of-sight microwave radars deployed near-shore. The cost effectiveness is achieved by deploying a distributed network of compact HF radars that are linked in a multi-static network. The Office of Naval Research (ONR), the Department of Defense (DoD) Counter NarcoTerrorism Project Office (CNTPO) and the Department of Homeland Security (DHS), through a continuing series of research grants, have established the Mid-Atlantic as the U.S. testbed for over-the-horizon vessel tracking technology development. The approach is to expand CODAR compact HF Radar technologies for dual-use current mapping and vessel tracking applications.

Managing resources for sustainable use
Adaptive Sampling Strategies, NOAA Fisheries
Traditional fisheries or plankton surveys, based on fixed grid or stratified random designs, may not adequately describe conditions in the coastal ocean. These environments are driven by dynamic and episodic processes which can intensify, relax, or translate important features (fronts for instance) during a survey. Field studies should be aware of changes in the study area and should adapt to evolving conditions. Recent bioacoustic surveys in the New York Bight have made use of the near real-time surface current product to target specific features of interest. Remotely sensed CODAR, SST, chlorophyll and suspended sediment maps were relayed to the survey vessel from the Rutgers Coastal Ocean Observation Laboratory. Shipboard bioacoustics and hydrographic measurements augmented the remotely sensed data and enabled tracking and targeting of fronts, eddies, convergence/divergence zones during various sea states (high/low Hudson River discharge, coastal up/downwelling). Surface current products delivered in real-time have changed the way NOAA fisheries samples the coastal ocean. With these new data, sampling is more strategic and adaptable to the We argue that IOOS hold the promise for a new generation of fisheries surveys.

Preserving and restoring healthy marine ecosystems
Pollution Spill Response, NOAA OR&R/HAZMAT
Thousands of incidents occur each year in which oil or chemicals are released into the environment as a result of accidents or natural disasters. Spills into our coastal waters, whether accidental or intentional, can harm people and the environment and cause substantial disruption of marine transportation with potential widespread economic impacts. NOAA's Office of Response and Restoration (OR&R) Hazardous Materials Response Division (HAZMAT) provides scientific expertise to support an incident response and initiates natural resource damage assessment. Through this pilot, high resolution surface current maps near the estuary mouths and shelf-wide regional scale surface current map will be available to operators and scientists for incorporation into operational tools used during spill response. These data have been and could be incorporated into existing forecast systems (GNOME).

Mitigating natural hazards
Storm Response, NOAA National Hurricane Center & National Weather Service
Throughout the year significant storms including tropical storms, Hurricanes and Nor'easters impact the Mid-Atlantic region. These storms have the potential to cause significant coastal flooding and erosion. The surface current response to these storms as mapped by a fully nested CODAR network would provide data for both analysis and assimilation into numerical models for improved prediction. Data from existing systems in this network have already supported scientists of the NWS during the passage of a strong nor'easter in 200? And a tropical storm in 1999. Through this pilot the coverage area would be extended to include the entire area with more complete representation of the ocean response to these significant atmospheric systems.

Ensuring public health

Search and Rescue, United States Coast Guard, Office of Search and Rescue

In 2002, the USCG Research and Development center sponsored an investigation of the utility of HF radio sensed of coastal circulation to improve the prediction of target drift in search and rescue operations. That project (see Ullman et al, 2003) developed an operational algorithm to transform observations from Block Island Sound and the adjacent continental shelf into forecasts of the circulation. The forecasts exploit the periodicity of the tide and the serial correlation in the residual motion to forecast the current 24 hours into the future. These forecasts were then used to predict the drift of search and rescue targets. In a subsequent project, (O'Donnell et al, 2005) demonstrated that the prediction algorithm could readily be applied to data from new area, a section of the Middle Atlantic Bight where Rutgers University operate a CODAR network. Forecasts and uncertainties were then provided to the developers of the USCG's new search planning tool (SAROPS) so that the new capabilities could be rapidly integrated to their operations. Tests were conducted using drifters deployed in Block Island Sound and demonstrated to search planners at USCG Group Moriches. Demonstrations have already shown that the observations and short term statistical forecasts can be injected directly into current Coast Guard search planning tools. Results indicated that this infrastructure has the potential to be a valuable asset to the USCG search and rescue mission. Operational use of this technology awaits the development of a sustainable infrastructure for the observation and prediction system.