Integration of Satellite Imagery with Surface Current Mapping Radar in Near Real Time

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Background

High Frequency (HF) radar measurements afford oceanographers and resource managers unprecedented synoptic views of coastal surface currents. This technology generates high spatial resolution hourly maps of the surface velocity field. Previous studies have illustrated the ability to delineate very complex circulation patterns. In California, a broad network of coastal HF radar systems is being implemented to monitor coastal currents as part of the Coastal Ocean Currents Monitoring Program (COCMP) http://www.cocmp.org. Real-time availability of data from those systems will enable improved tracking of buoyant drifting particles, including hazardous materials and missing persons.

This OSPR-sponsored project took advantage of the existing HF radar coverage areas around Monterey Bay and San Francisco Bay to develop methodologies and data formats for real-time tracking of drifting material. In turn, these techniques are being made available to the larger statewide monitoring network. Steps involved in creating these capabilities include filling gaps in the hourly HF radar-derived surface current maps and computing particle trajectories based on the evolving, two-dimensional velocity fields. In addition, short-term (24 hour) *predictions* of the particle trajectories are routinely produced based on a constantly updating analysis of the velocity data during the past 48 hours. Finally, work was initiated to standardize data structures and availability that match the requirements for a number of potential users, including the spill response teams within California Fish and Game Office of Spill Prevention and Response (OSPR) and the NOAA/HAZMAT.

Objectives

To develop the methods for correlating satellite imagery with surface current velocity vectors in near real time to produce a tool for improved understanding of surface circulation. This program will advance fulfillment of three of the OSPR Scientific Study and Evaluation Program (SSEP) intents: a) investigation and evaluation of applied prevention and response programs and technologies; d) best achievable protection strategies; i) baseline monitoring information.

The State COCMP program is using voter-approved (Propositions 40 & 50) bond funds to develop the COCMP Surface Current Mapping (SCM) arrays covering the entire California coast. These funds are restricted to infrastructure development only and the researchers have sought other funds to develop products that are useful to regulators and managers. This SSEP contract provided essential funds for product development.

The primary goal of this research is to provide OSPR with new tools, based on the fusion of emerging capabilities, to respond to oil spills and to use the products for training and prediction. In addition, development of these products now based on the existing SCM arrays will insure that the proposed COCMP SCM network is developed and implemented with OSPR needs in mind.

Project Accomplishments

In order to promote a central access point to reaching ocean related data, all of the work and products that have been accomplished in this program are hosted on the Central and Northern California Ocean Observing System (CeNCOOS) web site; http://www.cencoos.org. Data are also accessible at a number of other sites, but the intent of the investigators is to promote the development of an accessible Regional Association for the general access of ocean related data and products. The data and products developed through this SSEP contract are hosted on the CeNCOOS site. Future developments will also occur on this site.

Gap-Filling

In working with OSPR and NOAA/HAZMAT it became clear that an important need for their spill preparation and response strategies is surface current maps that cover the whole area of interest without gaps from missing data. Therefore, considerable effort has gone into developing tools for taking real-time data, which by nature is "gappy," and creating current vector maps with complete fields of evenly spaced surface current vectors. This is the first step in any analyses and product development for OSPR and NOAA/HAZMAT.

The availability and spatial coverage of HF radar-derived surface current maps depend on a number of environmental factors. In all cases, the resulting maps contain spatial gaps. For many of the derived products, such as particle trajectory estimates, these gaps must be filled using the best available techniques. This project has taken advantage of, and expanded on, a series of experiments to develop a spatial mapping technique that takes advantage of the combination of densely sampled velocity and known coastal boundary shapes. The technique in use has evolved from what is known as Normal Mode Analysis (NMA; Lipphardt et al., 2000) into an augmented version known as Open Modal Analysis (OMA; Lekien et al., 2004; Kaplan and Lekien, 2007). The latter implementation has several advantages, including: 1) use of a finite element, triangle grid to define mode structures that better follow the coastal boundary, 2) use of independent boundary modes constrained by the observed interior velocities that eliminate the need to specify normal flow values along the open boundaries, 3) specification of mode amplitudes based on HF radar-derived radial velocity components directly, which eliminates errors introduced in the radial-to-total vector mapping step, 4) use of a penalty function that keeps solution values from growing unrealistically large in areas away from observations, and 5) propagation of errors that provide error maps along with every OMA velocity map.

This project also contributed to the creation of a new, open-source, MATLAB-based toolbox to process HF radar data, including the latest OMA procedures. The toolbox is called HFR_Progs and is the focal point for community development going forward. The software toolbox is based on an earlier toolbox known as HFRadarmap, which was developed by Michael Cook at the Naval Postgraduate School. The new toolbox includes contributions from Mr. Cook and Dr. Lipphardt, although the primary author and maintainer of the new toolbox is Dr. David Kaplan of UC Santa Cruz, a member of the COCMP science team. The new toolbox can be downloaded at: https://erizo.pmc.ucsc.edu/COCMP-wiki/index.php/HFR_Progs_download_page. This toolbox contains all the programs and steps necessary to go from the radial surface speed estimates for each antenna system to the filled surface velocity fields needed for particle tracking and spill response. It also includes the routines to output the data fields in formats that are immediately readable by the programs used by OSPR and NOAA/HAZMAT.

Integration of HF radar surface current vectors with satellite imagery

The integration of HF radar-derived velocity maps with other mapping data, such as satellite-derived sea surface temperatures (SSTs), is a natural goal of the overall development of the HF radar network. In this project, the investigators partnered with the west coast Node of the NOAA CoastWatch program to create demonstration products for the area of central California. The demonstration integrated the various data streams using a three-stage process:

- *Establish access to surface current data*. This step was accomplished for the Monterey Bay and San Francisco Bay arrays using simple, automated file transfers. Follow-on projects will incorporate OPeNDAP servers on the various data nodes to provide a truly distributed system.
- *Serve the surface current data together with satellite data using protocols compliant with IOOS Data Management and Communication recommendations.* CoastWatch and its host institution, the Environmental Research Division (ERD) of NOAA's Southwest Fisheries Science Center, have long maintained Live

Access Servers, which are recommended by the IOOS DMAC for data browsing. Similarly, Coastwatch and ERD maintain the OPeNDAP servers recommended for data sharing. Through this demonstration, surface current data have been incorporated in the Live Access Server.

- *Develop a suite of satellite products relevant to specific regions.* A number of multi-platform data products can now be accessed through CeNCOOS at: http://oceanwatch.pfeg.noaa.gov/CeNCOOS/.

Standardized File-Handling Procedures

A major requirement for exporting any mapping or prediction technique is the development of standard file-handling procedures. The data are collected from multiple sites by many different groups and they may be used in different applications. This means that their usefulness depends on their accessibility and readability. This project has worked to increase access to HF radar-derived products by: 1) insuring that the data are continuously available online, 2) documenting and publicizing the data formats, and 3) creating dedicated file formats that match the existing data requirements for OSPR and for NOAA/HAZMAT. The data are hosted on servers at the regional operating nodes, which for this demonstration project includes the central California node at: http://www.cencoos.org/currents and http://cencalcurrents.org. Vector current data files are updated hourly at the sites. In addition, special-purpose versions of the data are produced to support spill response agencies. A complete procedure has been established to supply data formatted for use by the NOAA spill response model called GNOME. These files are in netCDF format using structure and variable names specified by the NOAA team and ready for direct ingestion into GNOME. The files are updated every hour. But each file includes the observations for the past 48 hours plus predictions for the upcoming 24 hours as described below. As an example, the GNOME-formatted files for the test region offshore San Francisco can be downloaded from: http://www.cencalcurrents.org/Data/SFB1/GNOME/.

A second, critical formatting effort was begun under this project to automate the production of Graphical Information System (GIS)-readable data files. These “shape files” are used by OSPR and other management groups to display environmental data. However, GIS routines have not commonly been available to display vectors or other velocity related data. A test version of a GIS vector representation was created using scalable symbols to represent the vectors. A sample plot for the San Francisco area can be seen in Figure 1. This file took a great deal of time for one individual to generate the file. Optimization and automation of a true vector shape file format procedure will be completed as part of the NOAA follow-on project described below.

The latest version of ArcGIS (9.2) now has the capability to import netCDF files and to create animations from these imported files. This capability was added to ArcGIS/ArcView after the work period of this contract. Future collaboration between OSPR and CeNCOOS will ensure that these files are created as needed by OSPR. A test case clearly demonstrated the ease of loading the netCDF vector files into an ArcGIS display.

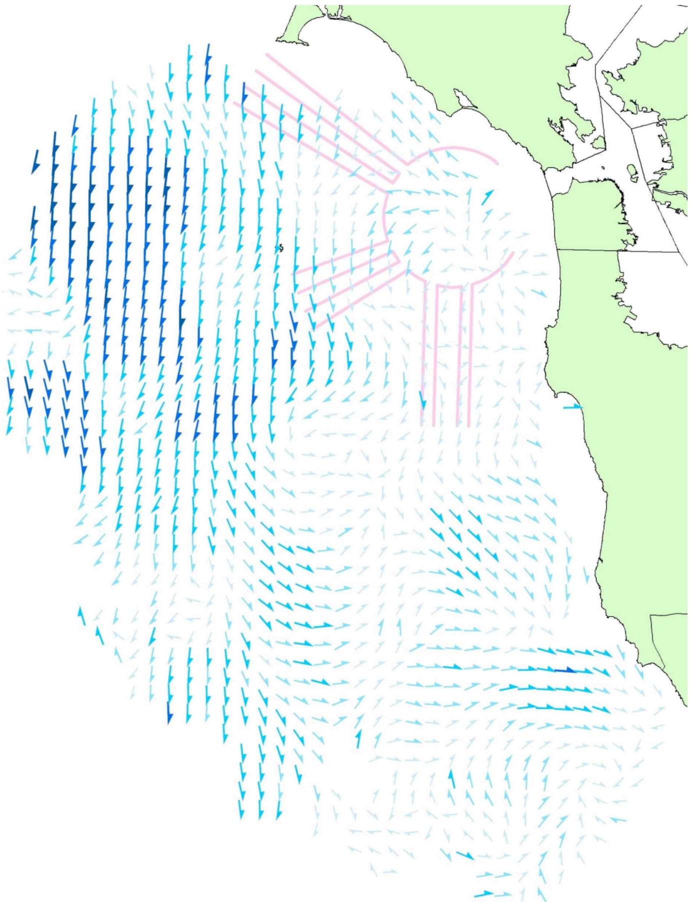

Figure 1. Example GIS image showing HF radar-derived ocean surface current vectors offshore San Francisco (the radiating lines represent major shipping lanes into San Francisco Bay). The velocity layer was created using symbols positioned at the locations of the velocity observations and scaled and rotated according to the velocity speed and direction, respectively.

Standardized Web Displays

In addition to standard and specially formatted data access, several derived products are being automatically produced based on the HF radar observations. A subset of those products have been standardized across several regional nodes. They are displayed through the Central and Northern California Ocean Observing System (CeNCOOS) web site: http://www.cencoos.org/currents/. Figure 2 illustrates the geographically based web interface, which leads to standard products such as hourly surface current maps and error maps, daily averaged surface current maps, hourly OMA surface current maps and error maps, observed 24-hour particle trajectories based on the OMA results, and predicted surface current trajectories produced by the short term forecast system described below. On an even larger scale, the HF radar observations from the central California test region are transferred in real time to the nation-wide data server in San Diego and they appear in scalable, Google Maps-based displays at: http://cordc.ucsd.edu/projects/mapping/maps/. At this time, the number of derived products available through the national server is limited. However, over time more sophisticated products, such as those now available through the CeNCOOS web site, will be ported to the national site making for better one-stop access to surface current mapping products through national interface pages, such as: http://oceancurrents.us. An example of the California surface current mapping capability established under COCMP as of the time of this report is shown in the national data server surface current map in Figure 3.

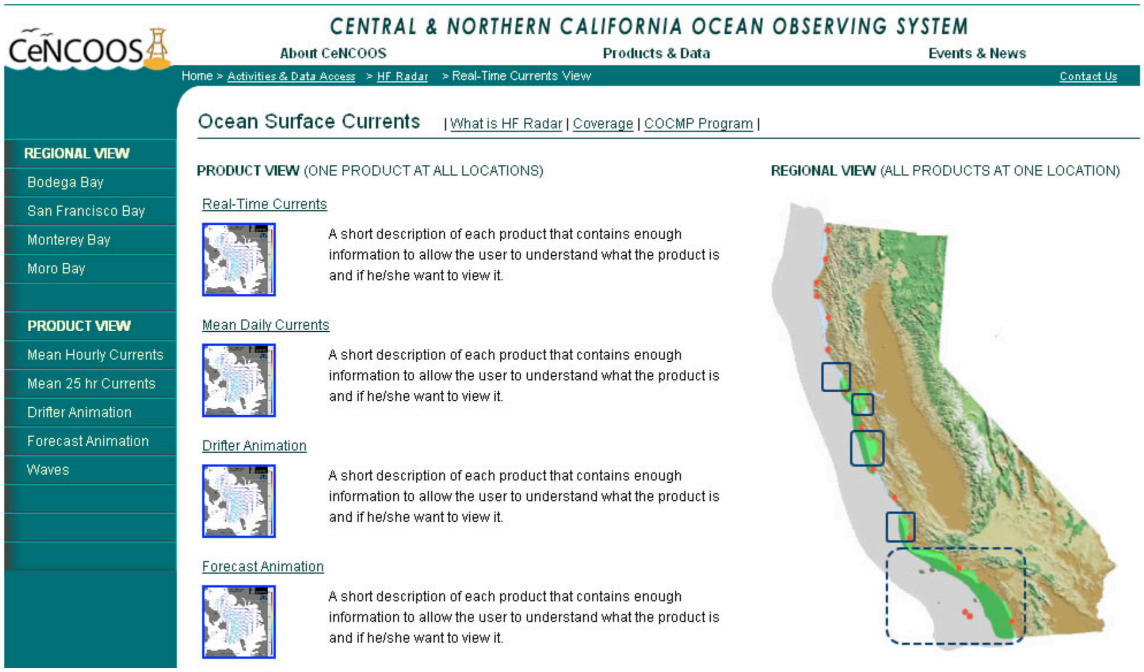

Figure 2. Web page for access to real time CeNCOOS surface current mapping products. The solid rectangles show the regions of coverage and the four product options are described in the center of the page. The dashed rectangle outlines the Southern California Coastal Ocean Observing System (SCCOOS), which is a sister organization to CeNCOOS in southern California.

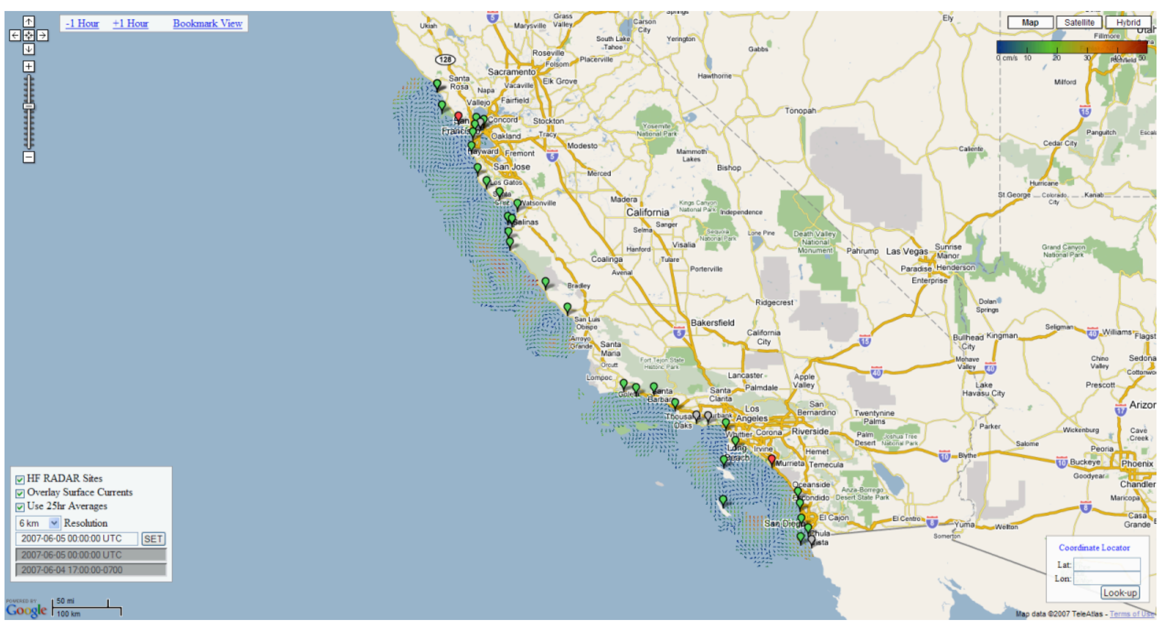

Figure 3. Ocean surface current map based on input from HF radar systems in central and southern California on 5 June 2007.

Short Term Forecasts and NOAA/HAZMAT Support

The core of this project has been to establish routine and automated procedures based on real time data from the HF radar network to inform hazardous spill response teams. The data access and formatting procedures described above have been part of the effort. In addition, procedures have been developed to create short term *predictions* of where surface drifting particles will move within the area monitoring by the HF radar array. The basis for the predictions is the assumption that future surface currents can be modeled by the observed tidal-period fluctuations plus sub-tidal-period mean currents. To that end, a procedure was created that takes continually analyzes data from the processed surface current maps based on time series observations. At each mapping location, velocity observations for the past 48 hours are subjected to a harmonic analysis for the major tidal constituents. Those results, plus the sub-tidal residual currents, are used to predict the time varying velocity at the mapping location for the subsequent 24 hours. The entire procedure is updated every hour for each mapping location.

The short-term prediction system allows for the production of forecast particle trajectories as one of the critical HF radar-based products. An example for the region offshore San Francisco Bay from the period of NOAA's Safe Seas 2006 oil spill exercise is shown in Figure 4. Quantifying the accuracy of the short-term predictions under various wind conditions will be the focus of the NOAA follow-on study described below.

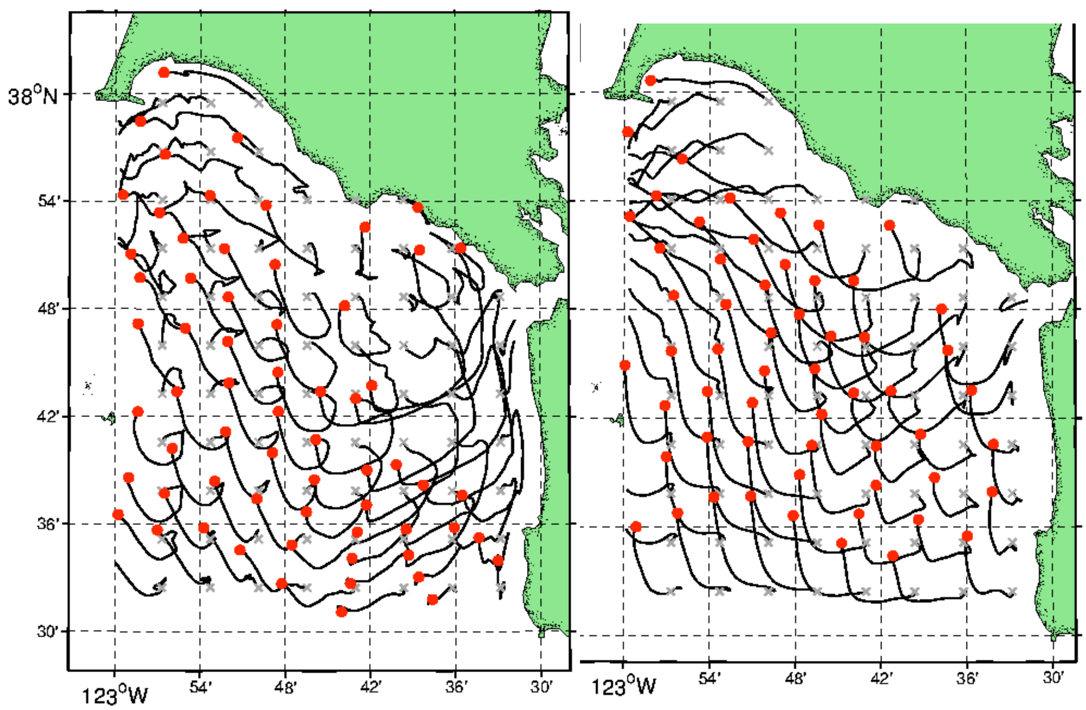

Figure 4. Observed (left) and predicted (right) surface particle trajectories for the period 7 August 2006 at 2100GMT to 8 August 2006 at 2100GMT. Initial (x) and final (•) locations are also shown.

In addition to the trajectory forecasts available through the CeNCOOS web site, the short term forecast data are routinely incorporated within the netCDF data files produced for ingestion within ArcGIS or the GNOME model. In this way, the HF radar-derived products are made available each hour to the NOAA hazardous spill response team, as well as all other potential users. The netCDF file naming convention is:

GNOME_SSSS_yyyy_mm_dd_hh00.nc

where:

SSSS is the site designator
yyyy_mm_dd_hh00 is the year_month_day_hour of the last actual surface current field.

An example of the use of HF radar-derived velocity data within GNOME is shown in Figure 5 for the area of Monterey Bay. Real time GNOME support was implemented for the region offshore San Francisco as part of this project for the Safe Seas 2006 exercise. Support for that region is being continued via the web data page shown above. Support for other regions within California will be implemented as part of COCMP and the follow-on NOAA project described below.

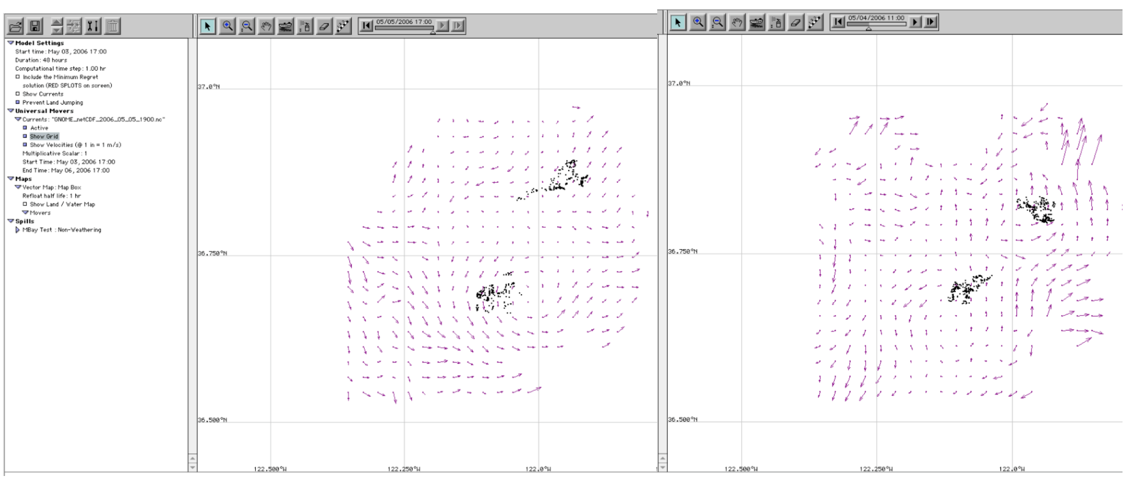

Figure 5. Screen shots from two different times in the evolution of a simulated oil spill for the region of Monterey Bay using the NOAA/HAZMAT GNOME model. The model was run with only the current field and without bathymetry or the coastal boundary.

Follow-On Projects

As described throughout, this project has been highly integrated with ongoing efforts of the State of California's COCMP and CeNCOOS. Those efforts will continue to develop products from the HF radar observations. They will also continue to work to standardize product design and to centralize product delivery through the national HF radar demonstration projects headed up by SCCOOS.

In addition to those regional and national efforts, two important areas of related follow-on activities have been supported by NOAA. These include a project to improve quality control-quality assurances practices related to HF radar data. In that project, the investigators here, together with Drs. Kenneth Laws, David Kaplan, and John Vesecky, will participate in a project entitled "HF Radar National Network Data Management Development: Error estimation and prediction capabilities." The project is centered at UC Santa Cruz and is funded by NOAA Integrated Ocean Observing System (IOOS) office. Results from the project will be used to improve the error propagation model already embedded in the mapping procedures developed here.

The second, critical project that is following on directly from this effort is entitled "Delivery and Quality Assurance of Short-Term Trajectory Forecasts from HF Radar Observations." The principal investigators are Dr. Newell Garfield of San Francisco State University, Dr. Jeffrey Paduan of the Naval Postgraduate School, and Dr. Carter Ohlmann of UC Santa Barbara. The project sponsor is the Coastal Response Research Center at the University of New Hampshire (CRRC; http://crrc.unh.edu/). CRRC itself receives its funding from NOAA to manage various research projects related to oil spill mitigation. This new project will address directly the accuracy of the short term prediction procedure. Beyond that, it will continue to work directly with the NOAA hazardous response team to expand access to GNOME-formatted data files, to develop an additional wind-coherent correction based on forecast winds, and to create a manual for the use of HF radar-derived products in hazardous spill response scenarios. It will also work with OSPR personnel to optimize the procedure for creating GIS-readable shape files. All of the recommended procedures will be tested in spring 2008 through a week-long "catch-and-release" drifting buoy program in the waters offshore San Francisco and Monterey Bay.

Summary

This OSPR project sponsored value-added extensions to observing system developments underway as part of COCMP. The growing network of HF radar systems is providing wide-area surface current mapping data on a regular basis. Two important outcomes of the SSEP program are the generation of automatic real time forecasts of surface currents and the specialized products needed by spill response teams. The first means at in the event of a spill, response teams can go online immediately and observe both conditions for the last 24 hours as well as a 24 hour forecast. The second means that if a spill occurs, COCMP will be able to quickly coordinate with OSPR to produce the specialized products that will be unique to each event.

This project created routine, automated procedures for making those data available to hazardous response teams and for providing short-term trajectory forecasts that can be used to further optimize any spill response. The results are available online through http://www.cencoos.org/currents/ and http://cencalcurrents.org.

The project also helped to develop the CeNCOOS data integration procedures that overlay real time HF radar-derived surface current maps and satellite-derived SST: http://oceanwatch.pfeg.noaa.gov/CeNCOOS/. Finally, results from this project led directly to the creation of two, additional follow-on projects funded by NOAA to validate and expand the basic procedures developed here. The investigators involved with this

project will continue to work with OSPR to ensure that the necessary products are easily accessible by OSPR personnel.

References

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