

National IOOS High Frequency Radar Search and Rescue Project

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Abstract

The U.S. Integrated Ocean Observing System (IOOS®) partners have begun an effort to extend the use of high frequency (HF) radar for U.S. Coast Guard (USCG) search and rescue operations to all U.S. coastal areas with HF radar coverage. This project builds on the success of an IOOS and USCG-supported regional USCG search and rescue product created by Applied Science Associates (ASA), Rutgers University and University of Connecticut for the mid-Atlantic region. We describe the regional product and the expanded national product's two main components: optimally-interpolated velocity fields and a predicted velocity field.

The regional product uses optimally-interpolated fields of HF radar-derived ocean surface current component estimates and then an extrapolation in time using local estimates of the autocorrelation function. The forecast fields are the result of a suite of applications known as the Short Term Prediction System (STPS). STPS, originally developed by the University of Connecticut for the USCG, uses a Gauss-Markov approach to compute forecasts of the surface velocity field. The USCG search and rescue operations center began operational access to the regional product in May 2009.

Presently, the IOOS national HF radar network is composed of 128 radars covering most of the coastal waters of the U.S. The data from each radar are ingested by a trio of national servers, providing data redundancy and failover capability. To provide further robustness, these servers are widely separated geographically, being located at Scripps Institution of Oceanography in California, Rutgers University in New Jersey and the NOAA National Data Buoy Center in Mississippi.

The current project, extending the optimal interpolation and STPS products to all coastal areas, began in FY2011 with the original partners, mentioned above, as well as Scripps Institution of Oceanography which is implementing nationwide the optimal interpolation code (originally developed at SIO) and providing near-real-time HF radar data to ASA, developers of the USCG's data server system. Rutgers University originally implemented, tested and hardened the optimal interpolation software code for the mid-Atlantic region and will test and validate the new code

for the entire East and Gulf coasts. Testing will involve comparisons of the optimally interpolated HF radar data fields with USCG Self-Locating Data Marker Buoys (SLDMB), similar to the well-known Davis drifters and other conventional current measurement sensor data provided by IOOS regional partners. Meanwhile, STPS will be tested throughout those U.S. coastal waters monitored by HF radars. STPS parameters are optimized to ensure realistic regional coastal ocean dynamics are represented in the forecasts.

The optimal interpolation software (also known as an objective mapping technique) is applied to the HF radar surface velocity vector field using both observed and idealized covariance matrices. This mapping results in a smoothed vector field and fills in spatial gaps as well. This is in contrast to the conventional widely-used unweighted least squares technique. A further benefit is that the method provides an improved uncertainty estimate of the velocity vector field. Both the gap-filling and the uncertainty estimates will be beneficial for the ingest of HF radar data into the NOAA Office of Response and Restoration's General NOAA Operational Modeling Environment (GNOME). GNOME provides its own prediction algorithms so would not need to use the the STPS.

By providing both the optimally-interpolated HF radar-derived surface current velocity fields and the STPS-derived predictions, we will enhance the information available for both USCG coastal search and rescue operations and NOAA's oil spill response operations.

Background

The Integrated Ocean Observing System (IOOS®) is a federal-regional partnership working to provide new tools and forecasts to improve safety, enhance the economy, and protect our environment. Once complete, IOOS will be a nationally important infrastructure enabling many different users to monitor and predict changes in coastal and ocean environments and ecosystems. This infrastructure is critical to understand, respond, and adapt to the effects of severe weather, global-to-regional climate variability, and natural hazards. One of the key networks within this infrastructure is a high frequency (HF) radar network, designed to bring ocean surface current velocity information to decision-makers and the broader public.

Nationally, the IOOS Program has been supporting the operations and maintenance of partner-owned HF radars throughout US coastal area. Additionally, IOOS has continued to facilitate the development of a national data management and distribution system for all US HF radars as well as radars operated by the Canadian Coast Guard in Nova Scotia. Presently, 128 HF radars and 30 institutions are part of the network and their data are delivered by IOOS national data servers. The development server resides at Scripps Institution of Oceanography's Coastal Observing R&D Center (<http://cordc.ucsd.edu/projects/mapping/>) and its mirror is at the NOAA National Data Buoy Center (<http://hfradar.ndbc.noaa.gov/>). Data file management and distribution follow internationally accepted standards, for example, netCDF-CF file and metadata formats and OpenGIS® Web Coverage Service Interface Standard (WCS) for interoperable delivery of gridded data.

For fiscal year 2010, NOAA IOOS and its regional partners and USCG search and rescue experts conferred on a design for national scale use of HF radar in the USCG Search and Rescue

Optimal Planning System (SAROPS) (Harlan et al, 2010). On a national scale, two important applications of HF radar are: 1) US Coast Guard (USCG) Search and Rescue (SAR) operations and 2) NOAA oil spill response operations. These applications use ocean surface current data to track and predict the flow of the uppermost layer of the ocean and IOOS is providing resources to bring new capabilities to both of them. Each of them requires reliable two-dimensional fields of surface currents. A schematic representation of the components and data pathways of the enhancements being undertaken with the IOOS community is shown in Figure 1.

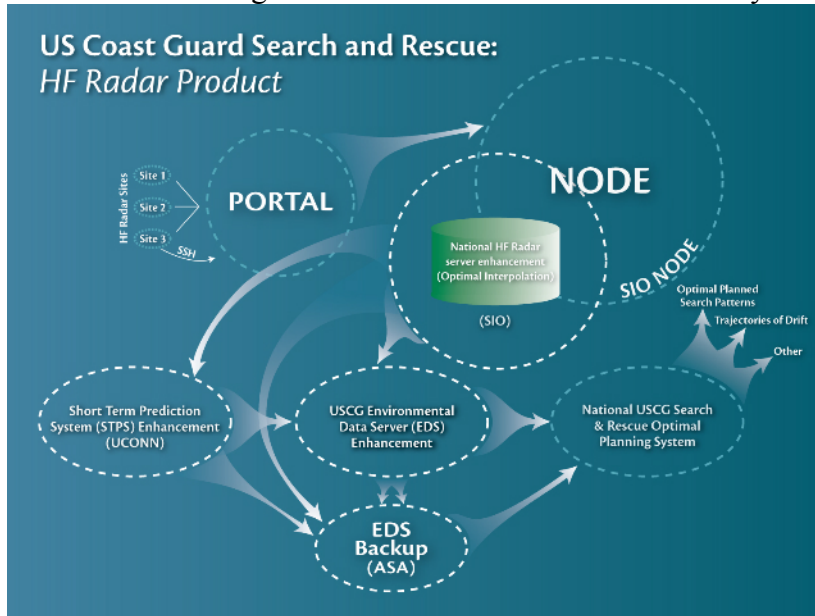


Figure 1. Schematic of the data pathways and components of the IOOS enhancements to the HF radar component of USCG SAROPS. The blue dotted lines enclose components that existed prior to the project. The enhancements are shown within the white dotted lines.

A description of the national HF radar network data management and delivery (Harlan et al, 2010) illustrated the ingest and distribution of radial surface current velocity data from the 128 HF radars presently in the national network. Here we present discussion of a project to enhance the IOOS HF radar component of SAROPS and for NOAA oil spill response.

Application of Optimal Interpolation

Once the HF radar radial velocity data are ingested, the data are combined to form total velocity vectors in two-dimensional grids. An un-weighted least-squares fitting (UWLS) method has been used by many authors to extract the vector currents from the radial velocities, e.g., Lipa and Barrick (1983), Gurgel (1994), Graber et al.(1997). Implicit in this approach is an assumption of a uniform vector velocity producing the radial velocities within the search radius for a given vector grid point. In other words, the correlation of the vector current is assumed to be one everywhere within the search radius and zero outside. The optimal interpolation (OI) method is a biased estimator and assumes a (continuous) spatial covariance function, derived from the observed spatial scale and structure. It improves both baseline consistency (the direct over-water line between two separate HF radar sites) and the uncertainty definition in the estimates, e.g., Kim et al.(2008), Kim (2010).

The vector current field computed using UWLS has sparse spatial coverage due to the assumption of finite correlation function (e.g. step function) and the baseline inconsistency. However, the OI approach reduces the outlier near the baselines and offshore area and provides a unified uncertainty information.

These OI-derived two-dimensional grids of surface current velocity are the input to the Short-term Prediction System (STPS), the predictive portion of the HF radar component of SAROPS, which creates provides a 24-h forecast of surface currents based on the statistics of the previous 30 days of HF-radar-derived surface current data. Figures 2 and 3 show separate examples of one-hour-averaged vector fields in the vicinity of San Diego, California. Note that the UWLS approach (Figures 2 and 3, upper left) can yield physically inconsistent vectors in regions of fewer radial velocities. In these cases, the OI approach provides a more realistic solution as it tapers the solutions toward zero (Figures 2 and 3, upper right) where there are insufficient data. The OI approach also yields 30-40% more vector current solutions than the UWLS method when using the same input HF radar radial velocity data fields (Kim et al, 2008).

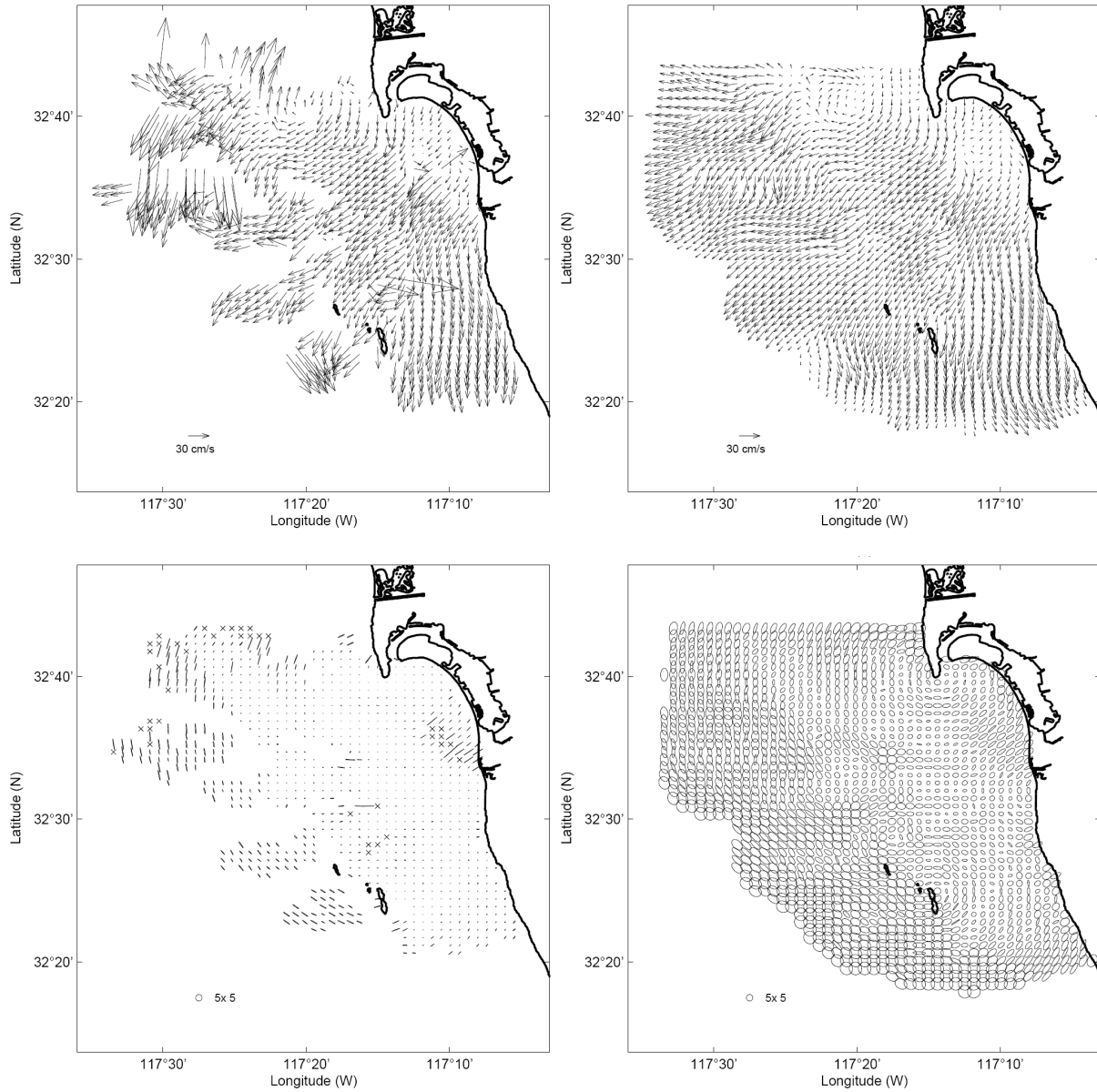


Figure 2: An example of the surface current vector fields for UWLS and OI and a posteriori uncertainty ellipses normalized by the observational error variance: UWLS (top left), OI (top right), UWLS normalized uncertainty (ϕ) (bottom left), OI normalized uncertainty (ϕ) (bottom right) for San Diego, California region.

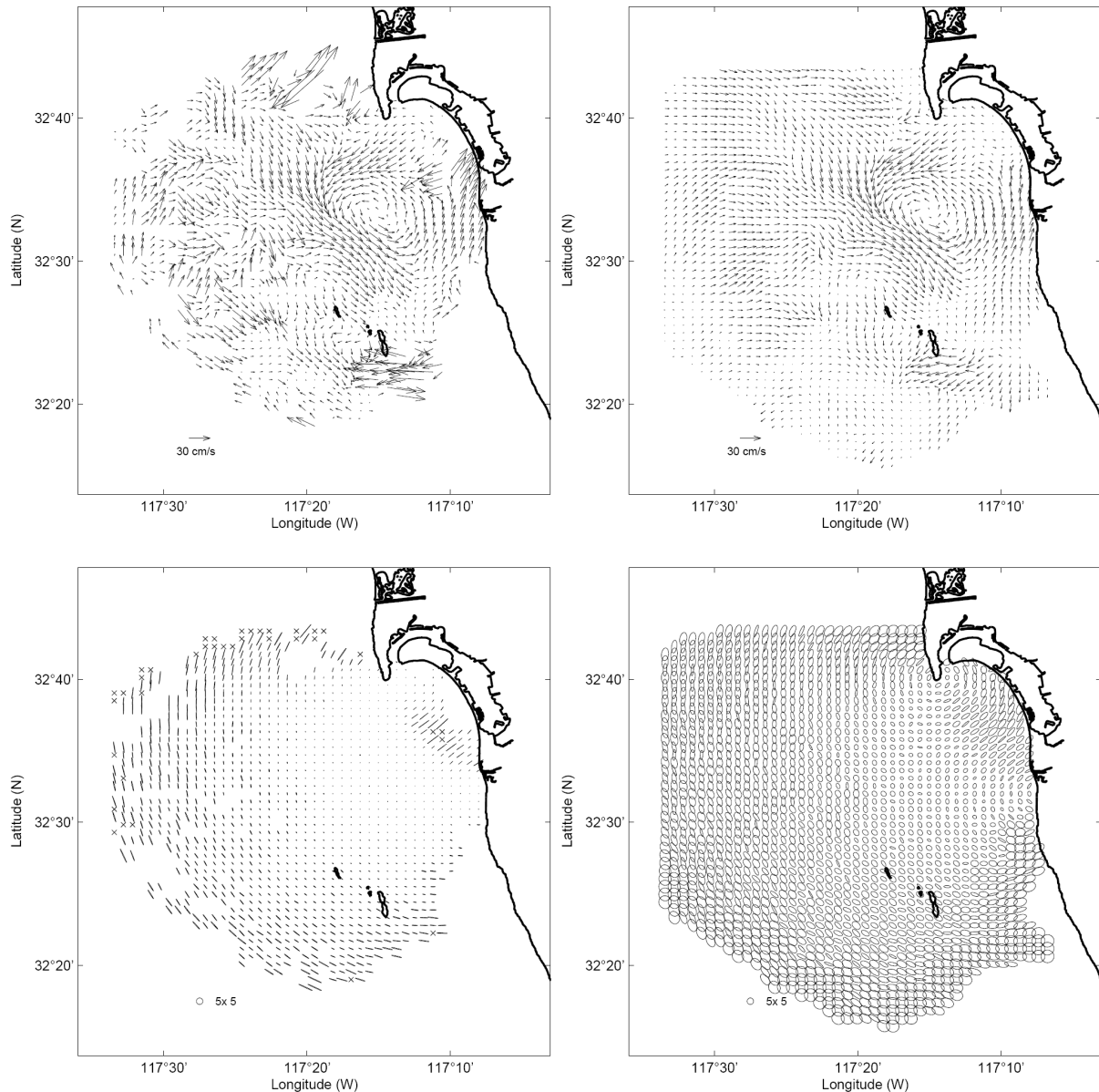


Figure 3: An example of the surface current vector for UWLS and OI and a posteriori uncertainty ellipses normalized by the observational error variance: UWLS (top left), OI (top right), UWLS normalized uncertainty (ϕ) (bottom left), OI normalized uncertainty (ϕ) (bottom right) for San Diego, California region.

Summary of mid-Atlantic development and use of HF radar for search and rescue

The USCG, for its SAR mission, responds to over 28,000 incidents with over 5,000 lives saved each year. The Search and Rescue Optimal Planning System (SAROPS) is the tool used to respond to these incidents. The effectiveness of SAROPS to define search areas depends critically on the observed real-time and forecasted surface current data that is delivered through their Environmental Data Server (EDS). The USCG SAR operators are trained in SAROPS and educated in modern ocean observation and regional current conditions.

High frequency radars were first operated in the Mid-Atlantic beginning in 1998. Today there are thirty five systems operated by eight different universities under the Mid Atlantic Regional Association Coastal Ocean Observing System (MARACOOS). The USCG Office of Search and Rescue and MARACOOS partners first demonstrated the effectiveness of measured surface currents in aiding search and rescue planning in 1998 (Figure 4). A series of projects then investigated the effectiveness of HF radar currents in SAR planning first using the 25 MHz network operated by the University of Connecticut and University of Rhode Island (Ullman et al., 2003) then expanding to use the long range network operated by Rutgers University (O'Donnell et al., 2005). This set the stage for the initiation of the MARACOOS effort in 2007 (Roarty et al., 2010). Maritime safety has been the highest priority theme within MARACOOS during its initial years.

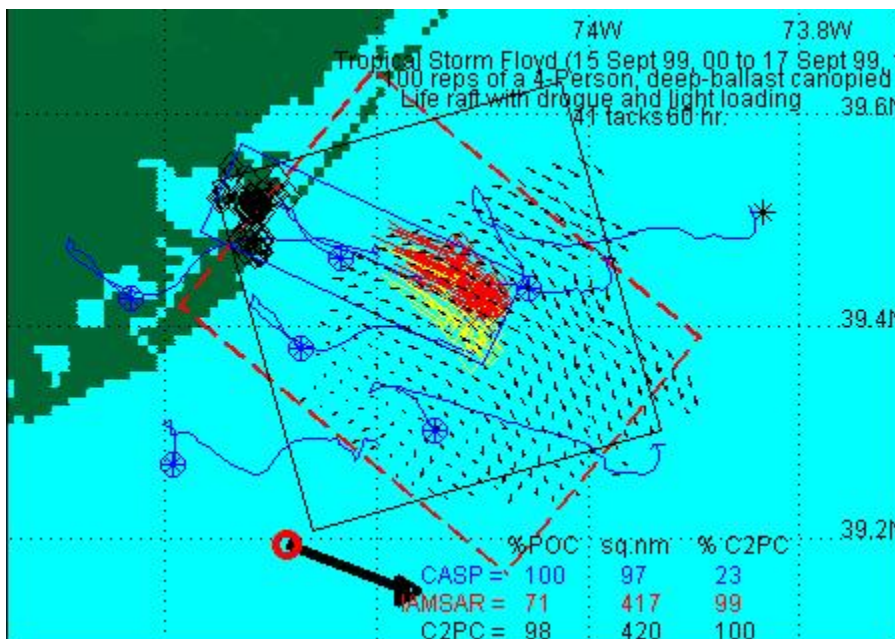


Figure 4: Graphic showing that the use of a field of surface current measurements can reduce the search area by a factor of 4 over a point measurement.

The USCG Office of Search and Rescue and MARACOOS have jointly demonstrated that surface current maps improve the effectiveness of SAROPS. In a simulated search case, using a USCG surface drifter released south of Long Island, the USCG used surface currents from an operational HYCOM model and the MARACOOS HF radar respectively with their SAROPS. The HF radar surface current-derived search area (Figure 5, right) was (a) centered on the drifter and (b) 3 times smaller than that derived from the HYCOM simulation. Thus, in Spring 2009, HF radar surface current data was installed on the USCG EDS for use as an operational component of SAROPS, an important first step toward a national capability. The USCG estimates that 50 additional lives will be saved each year after the national implementation of the HF radar surface current network. The indirect benefit is that USCG assets, which are typically redirected to SAR missions, will spend more time on their law enforcement and homeland security missions.

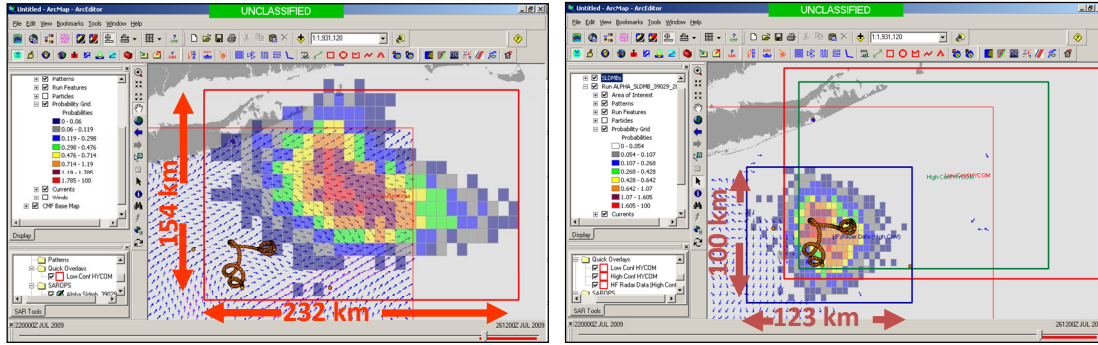


Figure 5: SAROPS search area using HYCOM model (left) and HF Radar data (right). The 4 day drifter path (brown inverted “V”) is shown.

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