U.S. Coast Guard Research and Development Center

1082 Shennecossett Road, Groton, CT 06340-6048

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USE OF COASTAL OCEAN DYNAMICS APPLICATION RADAR (CODAR) TECHNOLOGY IN U.S. COAST GUARD SEARCH AND RESCUE PLANNING

FINAL REPORT
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Marc B. Mandler, Ph.D.
Technical Director
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6048

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The R&D Center's technical point of contact is Mr. Art Allen, 860-441-2747, email: aallen@rdc.uscg.mil.

16. Abstract (MAXIMUM 200 WORDS)

This project looked at CODAR technology with the objective of providing accurate and reliable surface current data as a primary input into the SAR planning process. The two key products developed in this project include a Short Term Predictive System (STPS) for predicting surface currents based on historical CODAR current measurements, and an Interactive Web Site to facilitate access to CODAR current data and demonstrate applicability to SAR planning.

Drift trajectories that can be obtained using these products were compared with actual trajectories of Self-Locating Datum Marker Buoys (SLDMB) to assess and evaluate the applicability of CODAR technology to Coast Guard SAR planning relative to currently used environmental data sources.

Comparison of SLDMB trajectory predictions with actual SLDMB trajectories has shown that CODAR currents and STPS-predicted currents are clearly superior to National Oceanographic and Atmospheric Administration (NOAA) tidal current predictions for the purpose of predicting drift trajectories in near-coastal applications.

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EXECUTIVE SUMMARY

CODAR is a shore-based high-frequency (HF) surface radar system that can be used to measure surface currents up to 200 km from shore. First developed in the 1960s, it was difficult to run and maintain. However, with the advent of the Internet and high-speed computers, processing of the extensive data associated with CODAR and coordination of several installations required for large-scale coverage are now possible.

Coastal Ocean Dynamics Application Radar (CODAR) represents a mature technology that has been available for use since the 1960s. The number of operational CODAR sites is on the increase, due partly to recent advances in broadband data communication. The rapid rate of CODAR growth has precipitated another look at how CODAR data can be employed for Search and Rescue (SAR) planning.

This project looked at CODAR technology, where it is, and where it is going, with the objective of providing accurate and reliable surface current data as a primary input into the SAR planning process. The two key products developed in this project include a Short Term Predictive System (STPS) for predicting surface currents based on historical CODAR current measurements and an Interactive Web Site to facilitate access to CODAR current data and demonstrate applicability to SAR planning.

Drift trajectories that can be obtained using these products were compared with actual trajectories of Self-Locating Datum Marker Buoys (SLDMB) to assess and evaluate the applicability of CODAR technology to Coast Guard SAR planning relative to currently used environmental data sources.

Based on these investigations, an assessment has been made regarding the applicability of CODAR data to SAR planning efforts, and specific recommendations are presented to advance the use of CODAR data in SAR planning.

Conclusions

Current Coast Guard SAR planning tools rely on empirical analyses of surface current observations and are severely limited by the fact that current observations in the coastal ocean are sparse. An opportunity exists to capitalize on the many CODAR systems that are being made operational nationwide and to improve the quality of the environmental data the Coast Guard SAR planning process relies upon, as supported by the following conclusions presented in this report:

- Uninterrupted coverage will soon be available for the entire Northeast coast by both short-range and long-range CODAR systems. As a result, surface current vector data will be widely available at temporal and spatial resolutions superior to data currently used by the Coast Guard.
- Motivation for extensive CODAR system deployment is being driven by organizational needs outside the Coast Guard; consequently, coverage sufficient for Coast Guard use will be developed with minimal direct investment by the Coast Guard.

- Comparison of SLDMB trajectory predictions with actual SLDMB trajectories has shown that CODAR currents and STPS-predicted currents are clearly superior to National Oceanographic and Atmospheric Administration (NOAA) tidal current predictions for the purpose of predicting drift trajectories in near-coastal applications.

- Although the STPS-predicted currents are superior to the NOAA tidal current predictions for trajectory prediction, in their present immature state they are still significantly worse than the actual CODAR observations.

While CODAR data is demonstrably superior to data currently used by the Coast Guard, it is not currently available by accessing a single source. To be effectively employed by Coast Guard planning tools, a single data source of CODAR-based environmental data is required to deliver the most accurate environmental data that can be derived from available sources. Many of the issues addressed in this project remain unresolved, and further study is needed to effectively characterize and correlate the data quality available from the CODAR sources coming on-line.

Recommendations

Continued analysis of CODAR data, predictive capabilities, and access methods is recommended, based on the potential improvement to be gained from the higher quality data that can be made available. Specific areas for future investigation include:

- **CODAR Data Analysis –** To develop a better understanding of CODAR data and improve data product accuracy, further analysis and comparison of the deployed SLDMB data with the measured and predicted CODAR data is required. Include a systematic comparison of SLDMB and CODAR velocities to better understand inherent uncertainties and their impact on search area determination.
- **STPS Algorithm Improvements –** To advance the STPS algorithm and improve forecasting accuracy, a second-generation STPS algorithm needs to be developed that integrates wind forecast data. Base development on an analysis of how wind measurements are correlated with CODAR measured currents, and modify the current Gauss-Markov method to include those effects.
- **Interactive Web Site Improvements –** To demonstrate data availability from multiple CODAR sites and establish a method for data aggregation within and between adjacent CODAR regions, the coverage of the Web Site interface needs to be expanded to include components from other CODAR sites, and the solutions enhanced to provide Monte Carlo-style calculation of trajectories. Include solution implementation improvements based on the understanding gained from further CODAR data analysis.
- **Evaluate Operational Impact of CODAR Data –** To demonstrate potential SAR planning improvements and obtain feedback necessary to integrate CODAR data into operational search plans, an operational demonstration using the Interactive Web Site is recommended to coincide with the 2004 SAR season.

The Coast Guard is in the process of developing improved tools for SAR planning that will incorporate the most promising drift and search area methods that have been investigated. A direct link should be established between follow-on tasking arising from these recommendations and SAR planning tool development efforts.

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LIST OF ABBREVIATIONS AND ACRONYMS

BIS	Block Island Sound
CASP	Computer Assisted Search Planning
CG-SDDS	U.S. Coast Guard Software Development and Documentation Standards
Coast Guard	U.S. Coast Guard
CODAR	Coastal Ocean Dynamics Application Radar
CODAR CSDD	CODAR Short Term Predictive System and Interactive Web Site CSDD
CODAR Region	A geographic area covered by multiple coordinated CODAR sites and for which vector flow data files are made available
CODAR Site	A specific installation location consisting of a CODAR transmitter and CODAR receiver, plus additional telemetry electronics to transmit measured data to the central repository for the region of which the site is a member
CODE	Coastal Ocean Dynamics Experiment
CSDD	Consolidated Software Development Document
Drifters	Davis Drifters
FRONT	Front Resolving Observational Network with Telemetry
G-OPR	U.S. Coast Guard Office of Search and Rescue
HF	High Frequency
LKP	Last Known Position
MOTD	Coast Guard R&D Center Maritime Operations Technology Division
MSI	MicroSystems Integration, Inc.
MATLAB	Modeling, Simulation, Visualization, and Analysis Software Suite published by The MathWorks, Inc.
NEOS	Northeast Observing System
NJS	New Jersey Shelf
NOAA	National Oceanographic and Atmospheric Administration
NOPP	National Oceanographic Partnership Program
OSC	Operations Systems Center
R&DC	U.S. Coast Guard Research and Development Center
RDT&E	Research, Development, Test, and Evaluation
RMS	Root Mean Square
SAR	Search and Rescue

LIST OF ABBREVIATIONS AND ACRONYMS (cont'd)

SLDMB	Self-Locating Datum Marker Buoy
SME	Subject Matter Expert
STPS	Short Term Predictive System
UConn	University of Connecticut
URI	University of Rhode Island
XML	Extensible Markup Language

1. INTRODUCTION

This document summarizes the results from and lessons learned during the Coastal Ocean Dynamics Application Radar (CODAR) Short Term Predictive System and Interactive Web Site Project sponsored by the U.S. Coast Guard Research & Development Center (R&DC).

1.1 Scope

This project involved the development and analysis of methods for predicting target drift trajectories in near-coastal regions using CODAR technology. Methods employed included various simulations of target motion based on current fields measured using CODAR technology, as well as the development of a short-term predictive capability to project current field estimates up to 24 hours in the future. A Coast Guard-wide/World Wide Web interface was also developed during this project to facilitate the use of both measured and predictive CODAR data with Coast Guard search planning tools and processes.

As the Program Manager for the Search and Rescue (SAR) mission in the Coast Guard, Commandant (G-OPR) is a key stakeholder in the outcome of this project. The Operations Systems Center (OSC) is also a stakeholder, since they host the Computer Aided Search Planning (CASP) computer program, the primary tool used by SAR planners for offshore SAR cases. The R&DC is a stakeholder due to their past and current involvement with CODAR- and SAR-related drift prediction methodologies.

The primary project objective is to provide accurate and reliable surface current data projected up to 24 hours into the future to assist SAR planners in determining the total water current as a principal input into the SAR planning process. The two key products developed are the Short Term Predictive System (STPS) and the Interactive Web Site. Detailed development documentation for the STPS and Interactive Web Site is provided in a Consolidated Software Development Document (CSDD), which follows the format prescribed in U.S. Coast Guard Software Development and Documentation Standards (CG-SDDS) (Commandant Instruction 5234.44). The CODAR Short Term Predictive System and Interactive Web Site CSDD (CODAR CSDD) was completed incrementally in accordance with the project milestones and published as a separate document.

The final task in this project involved the comparison and analysis of drift trajectories that can be obtained using these products with actual trajectories of Self-Locating Datum Marker Buoys (SLDMB). This task was designed to assess and evaluate the applicability of CODAR technology to Coast Guard SAR planning relative to currently utilized environmental data sources.

In addition to the R&DC, the project team consists of MicroSystems Integration, Inc. (MSI), and the University of Connecticut (UConn) Department of Marine Sciences. UConn also leads a multi-institutional interdisciplinary project sponsored by the National Oceanographic Partnership Program (NOPP) to measure physical and biological properties in the water column of Block Island Sound. UConn is teamed with the University of Rhode Island (URI) and CODAR Ocean Systems, Ltd., and others in that effort. Data and resources developed through that project have been made available to this project through the MSI – UConn teaming agreement.

1.2 Background

CODAR is a shore-based high-frequency (HF) surface radar system that can be used to measure surface currents up to 200 km from shore. First developed in the 1960s, it was difficult to run and maintain. However, with the advent of the Internet and high-speed computers, processing of the extensive data associated with CODAR and coordination of several installations required for large-scale coverage are now possible.

Recently, the R&DC has been monitoring the redevelopment of CODAR through academic leaders such as the University of Connecticut – Department of Marine Sciences, Rutgers University, Naval Postgraduate School (REINAS project), University of California – Santa Barbara, and NOPP projects with Oregon State University. Additionally, the R&DC has worked closely with University of Connecticut – Department of Marine Sciences in the NOPP project, of which CODAR is a significant segment. Through these efforts, it is apparent that the CODAR system can be instrumental in assisting the Coast Guard in better understanding ocean surface currents in coastal zones. Given these advancements, the R&DC believes that technology will allow for the creation of an effective coastal prediction system aimed at assisting SAR planners in finding mariners in distress. As nearly 80 percent of all Coast Guard SAR cases occur within the near coastal region, an effective short-term predictive system (STPS) using CODAR is likely to have a significant impact on current Coast Guard SAR planning processes.

A current research, development, test, and evaluation (RDT&E) program at the Coast Guard R&DC involves use of CODAR data. Available CODAR data is being evaluated to determine if it can help improve Coast Guard mission effectiveness and efficiency in carrying out SAR cases by providing real-time surface current data.

1.3 Document Overview

This document summarizes CODAR project activities and provides the basis for determining the need for and direction of continued work in this area. The document is organized into the following four sections and two appendices:

- **Section 1: Introduction** – Defines the scope of this effort and provides background information on the project objectives and CODAR technology.
- **Section 2: Approach** – Provides an overview that identifies the tasking undertaken to achieve project objectives. A more detailed discussion of the development efforts and their milestones is provided in the CODAR CSDD.
- **Section 3: CODAR Search and Rescue Applications** – Discusses the application of CODAR, in concert with predictive methodologies, to the SAR mission.
- **Section 4: Conclusions and Recommendations** – Presents overall project conclusions and recommendations related to future research, improvements, and implementation activities.
- **Section 5: References** – Lists the supporting materials used to prepare this report.

2. APPROACH

The CODAR project included development of two software components and an analysis of the potential benefit of using CODAR-based environmental data sources over current data sources. A demonstration of the final, integrated product originally planned for this project was canceled and replaced with a detailed analysis of CODAR and STPS errors through comparison of predicted and actual drift trajectories. The following discussion describes the rationale and tasking undertaken in this project. A more detailed discussion of the development effort, which provides a process overview that highlights how user needs were discovered as well as a formal description of the requirements and design characteristics, is provided in the CODAR CSDD.

2.1 CODAR STPS Model

The CODAR STPS model has two major components: (1) development and implementation of an algorithm to extrapolate CODAR current estimates into the future and (2) development of an interface that allows Coast Guard personnel to access and exploit the predictions for their mission.

A workshop was conducted during the STPS Technical Download Meeting to foster interaction between project members and Coast Guard Subject Matter Experts (SMEs). The workshop was tailored to provide SMEs with an opportunity to identify existing Coast Guard SAR mission requirements and to review applications and initiatives under development. The workshop's goals were to clearly identify user needs and wants and to understand how users see CODAR-based current predictions improving their operational effectiveness.

The CODAR STPS Plan was developed to describe the prediction approach and methodology, describe how surface current field data is accessed, and define all required interfaces. A data-based model was selected to predict surface circulation, because it results in a site-independent STPS algorithm. Design requirements identified in the CODAR STPS Plan were finalized at the Initial Technical Review Meeting.

The STPS algorithm was developed in two stages. A straightforward implementation was developed first and was made available to support development of the Web site. The simplified STPS algorithm provides realistic predictions for use in developing the user interface. A second, more sophisticated algorithm was developed to support final integration prior to Web site beta testing. While the techniques to make the forecasts are different, the data format is the same for both implementations, and the Web site operates in the same way with both algorithms.

Following CODAR STPS algorithm implementation, an error analysis was developed using available environmental data.

2.2 CODAR Data Extraction Web Site

The CODAR Data Extraction Web Site serves as the integration focus for the functionality developed in this project. Web site user interface design commenced on finalization of a format for exchanging data with the STPS model. Conceptual user interfaces were presented for SME review during the Technical Download meeting. The workshop was tailored to give SMEs an opportunity to identify and prioritize issues affecting their area of expertise and to provide feedback regarding the developing interfaces. The workshop goals were to prioritize CODAR

Data Extraction Web Site user interface requirements and to identify relative benefits of any remaining alternatives within the developing Web site architecture.

The CODAR Data Extraction Web Site Plan was developed to describe the overall architecture of the CODAR STPS Capability and Web Site. The plan describes how each requirement will be met and defines all required interfaces. The CODAR Data Extraction Web Site was developed and hosted on a dedicated server using software products available via existing Coast Guard licensing and compatible with Coast Guard server requirements. Design requirements identified in the CODAR Data Extraction Web Site Plan were finalized at the Initial Web Site Technical Review meeting.

Following CODAR Data Extraction Web Site development, the site was made available to the R&DC for a beta-test period of 30 days. During the beta-test period, the user interface was exercised to ensure that the inherent process flow closely matches the thought process of the intended users. Unanticipated user inputs were also identified, and user input validation was enhanced to ensure data consistency. The completed Web site remained operational throughout the project to support development of presentation materials.

2.3 Operational Demonstration

An Operational Demonstration was initially planned for this project to demonstrate the use of CODAR-based environmental data to predict target motion in near-coastal applications. During the execution of the development tasks, it became clear that more study was required to understand the limitations regarding how accurately target motion can be predicted. Consequently, the Operational Demonstration was canceled and replaced by tasking to compare CODAR, CODAR STPS, and National Oceanographic and Atmospheric Administration (NOAA) based trajectory predictions with actual trajectories reported from SLDMBS.

2.4 Comparison of Predicted and Actual Trajectories

Trajectories obtained from SLDMBs deployed in two areas covered by CODAR installations were compared with predicted target trajectories based on CODAR flow fields, CODAR STPS predicted flow fields, and NOAA published tidal current information. SLDMBs were deployed in Block Island Sound (BIS) within the coverage zone of the Front-Resolving Observational Network with Telemetry (FRONT) standard-range CODAR system operated by the University of Rhode Island, and off the New Jersey Shelf (NJS) within the coverage region of the Rutgers University long-range CODAR system.

The time series of SLDMB reported positions provided a basis for comparison with time series generated using measured CODAR current fields, STPS predicted current fields based on CODAR data, and NOAA published tidal currents. An analysis of the results of those comparisons is provided in Section 3.5: Predictability of Target Trajectories Using CODAR and STPS Current Fields.

3. CODAR SEARCH AND RESCUE APPLICATIONS

The objective of this project was to show how current velocity field data based on CODAR observations can be used effectively for SAR planning. Using CODAR technology to provide spatially distributed environmental data in real time can address well-known limitations with environmental data currently being employed. These limitations result in conservatively large search areas.

A method of extending the data available from CODAR to provide predictions 24 hours into the future was developed and linked to a Web site that can be used to retrieve current field data, either historical or predicted, based on user request. Graphical display of target trajectory predictions illustrated the potential applicability, and analyses were performed that showed the potential improvement to SAR planning to be realized using CODAR-based data.

3.1 Coastal Zone Search and Rescue Mission Needs

One aspect of SAR planning is to determine the area where a target has drifted since the last known position (LKP) of the target. Reliable current estimates on which to base a drift prediction have, until recently, only been available at a few specific locations. From a practical standpoint, drift predictions have been based on current data from the closest available measurement location, and the currents have been considered uniform throughout the area of interest.

The use of such data is generally considered not very accurate for near-coastal SAR cases for the following reasons:

- Near-coastal current fields are spatially diverse, especially near prominent land features or significant subsurface bathymetry.
- Available current estimates are sparse; the distance between where the target is drifting and the source of data being employed is large enough that differences in current strength and direction can be significant.

Consequently, trajectory predictions are anticipated to have large errors, and search areas derived from them are conservatively estimated.

The spatial complexity of near-coastal currents is shown in Figure 1: Complex Coastal Current Fields, which illustrates the average daily current flow in and around Block Island Sound (BIS). The current field depicted was based on data collected from the BIS CODAR region operated by the University of Rhode Island (URI).

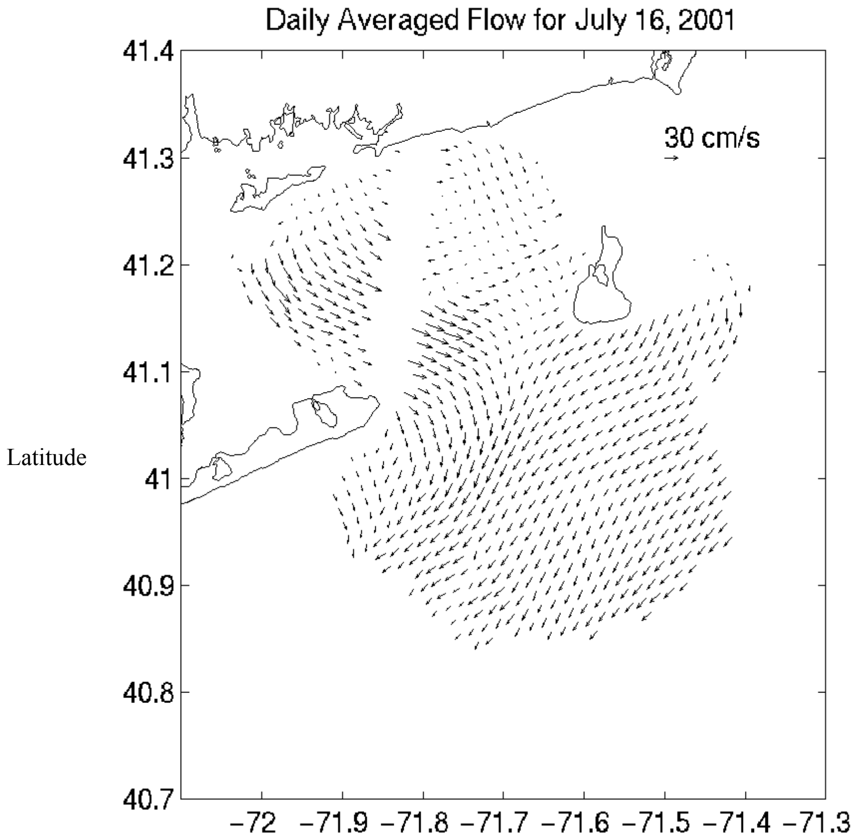


Figure 1: Complex Coastal Current Fields.

While current data in use by the Coast Guard does not exhibit such spatial diversity, algorithms exist that can use such spatially defined data; these have already been explored for use in SAR planning. The Coast Guard is about to undertake an effort to develop improved tools for SAR planning that will incorporate the most promising drift and search area methods that have been investigated.

The opportunity exists to capitalize on CODAR technology to support that development effort. To be used effectively, a single data source of CODAR-based environmental data should be established that reliably delivers the best quality environmental data that can be derived from available sources. Delivered data products must be in an acceptable format and must not require oceanographic training for the operator to interpret and use successfully.

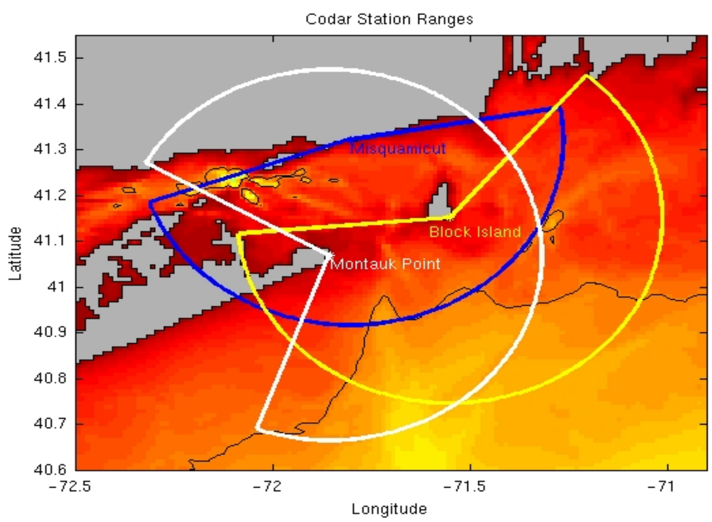
3.2 CODAR Technology

The CODAR system measures the ocean surface current using the Doppler principle. Two antennas (a transmitter and a receiver) are placed on land as close to the shoreline as possible. The transmitter sends out an electromagnetic signal with a very precise frequency (in the radio part of the spectrum). Because seawater is nearly a perfect conductor for these frequencies, the electromagnetic signal is reflected off the ocean surface and scattered in all directions. A fraction of the original signal is scattered back to the source and is recorded by the receiver. The majority of the back-scattered signal has been reflected by ocean waves of a very precise wavelength (exactly one-half the wavelength of the transmitted radio wave). Because the waves are moving relative to the antenna, the frequency of the reflected signal is changed slightly due to the Doppler effect. By measuring this Doppler shift, the speed of these ocean waves relative to the receiving antenna can be determined.

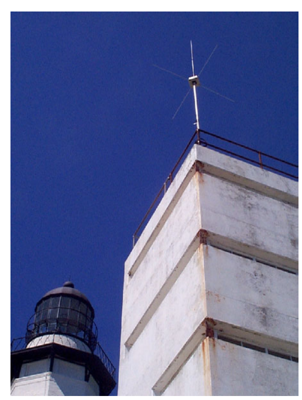
Ocean waves can be thought of as propagating on top of a moving water surface. The speed of the waves relative to the water surface is precisely known from theory. By subtracting this known value from the measured speed, the speed of the water (the current) upon which the waves are moving can be estimated.

Since the system can only measure the speed of the ocean current directly toward or away from the site, one station cannot provide a complete determination of the speed and direction of the current. Therefore multiple stations, each consisting of pairs of antennas, are placed so that they can project signals over the same location and make independent measurements. At least two stations with nonparallel radials are required to accurately resolve the radial velocity measurements into a field of composite directional current vectors.

CODAR regions providing data for this project were all constructed prior to the initiation of this project, under various funding. The primary CODAR region used was created as part of a multi-institutional interdisciplinary project funded through the National Oceanographic Partnership Program (NOPP). That region covers Block Island Sound and integrates CODAR data from three physical sites. Figure 2: Block Island Sound CODAR Installation illustrates the geographical coverage of each antenna array and shows the actual transmit and receive antennas at the Montauk Point CODAR site.



Transmit Antenna



Receive Antenna

Figure 2: Block Island Sound CODAR Installation.

This CODAR region is part of the Front-Resolving Observational Network with Telemetry (FRONT), further information about FRONT and CODAR is provided on their Web site (www.nopp.uconn.edu).

Internet and high-speed computers have now made the communication and processing of extensive data associated with CODAR more economical. As a result, many other CODAR installations are being developed and, as Figure 3: Northeast Observing System (NEOS) shows, CODAR installations will soon be able to provide uninterrupted coverage of the entire Northeast coast. These, and other installations nationwide, are integral to evolving coastal ocean observatory programs and are being funded independently from Coast Guard sources.

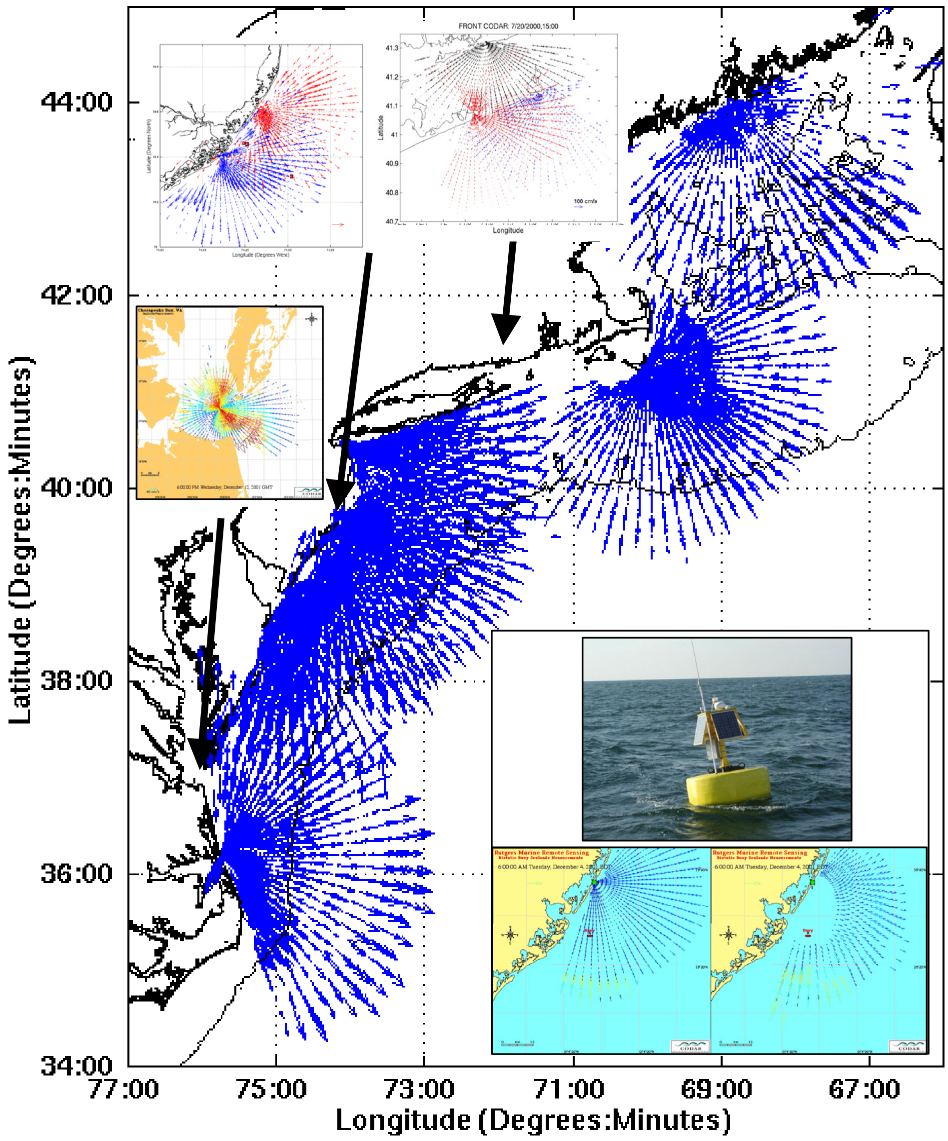


Figure 3: Northeast Observing System (NEOS).

Currently, operational CODAR installations routinely provide surface current vector files on an hourly to three-hour basis. Data extraction from such archives is available in near real time and includes significant historical depth.

3.3 Short Term Predictive System

To be able to exploit CODAR to predict drifting target trajectories, a means to predict current fields from CODAR measurements was developed. There are at least three approaches to developing a Short Term Prediction System (STPS) that will provide real-time forecasts for the near-surface circulation in a limited area of the coastal ocean:

1. An empirical analysis of surface current observations and their history
2. A mathematical model of the dynamics forced by wind forecasts and shelf-edge tide estimates
3. Using an objective combination of the first two approaches (often termed a data assimilating model)

Current Coast Guard search planning tools are based on the first approach but are severely limited by the fact that current observations in the coastal ocean are sparse. The availability of CODAR observations of near-surface currents will lead directly to improvements in search planning tools.

Exploiting theoretical ideas, the second approach also has substantial advantages. However, since the coastal ocean circulation is very sensitive to the local bathymetry and coastline geometry, including dynamics in the STPS will make the product site-specific. Substantial effort would be required to transfer it from the area of its development to other coastal ocean sites. Further, the costs of the computing technology and technical support required for the acquisition, operation, and maintenance of an operational dynamic model would be a significant and ongoing expense.

Since it is not clear at this time that the inclusion of dynamics will substantially improve the short-term accuracy of a data-based model in predicting surface circulation, the conclusion is that the development costs and restrictions associated with including dynamics in the STPS are unwarranted in the initial stages of its development. It is believed that a combination of theoretical models and observations – the third approach – will eventually provide the best solution trade-off between accuracy and applicability.

The design of the STPS for surface currents in CODAR coverage areas is based on an empirical decomposition of the currents into three components. In most of the coastal ocean there is a strong component due to tides, a weaker and more slowly varying component driven by winds, and a persistent motion associated with ocean density variations and very low frequency waves. The latter two components are referred to as the nontidal current. The tidal part of the motion is perfectly periodic and, therefore, easy to forecast. The circulation due to winds is more difficult to predict, since the future wind is uncertain. It can be large, however, and is critically important.

The relative importance of the different components of the surface current varies from location to location; therefore, so does the predictability. To demonstrate this, currents from two locations within the FRONT CODAR region are compared. The three FRONT CODAR sites, shown in Figure 4: URI/UConn CODAR Coverage Region and designated Block Island (BISL), Misquamicut Beach (MISQ), and Montauk Point (MNTK), provide hourly coverage of surface currents within an approximately 50 km by 50 km region. Two CODAR grid points are identified in this figure: "Station 1," located near the mouth of Block Island Sound, and "Station 2," about 15 km offshore.

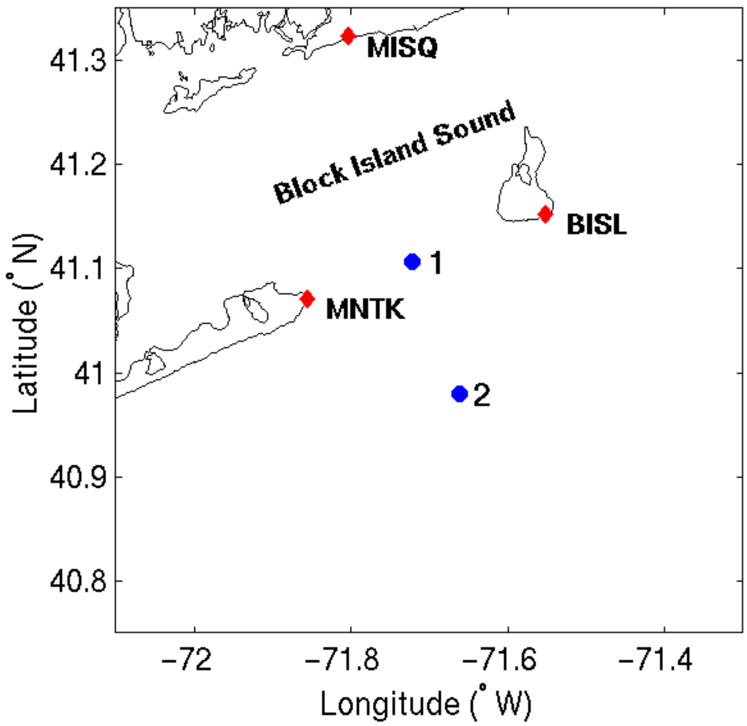


Figure 4: URI/UConn CODAR Coverage Region.

The time series of currents from the two CODAR grid points are presented in Figure 5: CODAR-derived Surface Current Time Series During November 2002. The observed currents cover a one-month period, represented along the x-axis in each of the plots in the figure. The top plots (a, b) show the east component of the current at each station. The middle plots (c, d) show the low-pass filtered currents. Low-pass filters remove higher frequency components and only display current components with a period greater than 24 hours. The bottom plots (e, f) depict the difference between the observed and low-pass filtered currents, which approximately represent the tidal currents. The nontidal current fluctuations, due predominantly to wind forcing, are visually correlated at the two sites, with slightly higher amplitude at the offshore site. Tidal currents are much stronger at the inshore site, with current amplitude of approximately 40 cm/s compared with 10 cm/s offshore.

The STPS is based on the above decomposition of the flow into tidal and nontidal parts. A separate prediction of each of these components is made at every grid point, and the current prediction is then the sum of the predicted tidal and nontidal currents. Predictions are produced on an hourly basis and extend for 25 hours into the future. A detailed discussion of the tidal and nontidal component predictions is described in the CODAR CSDD.

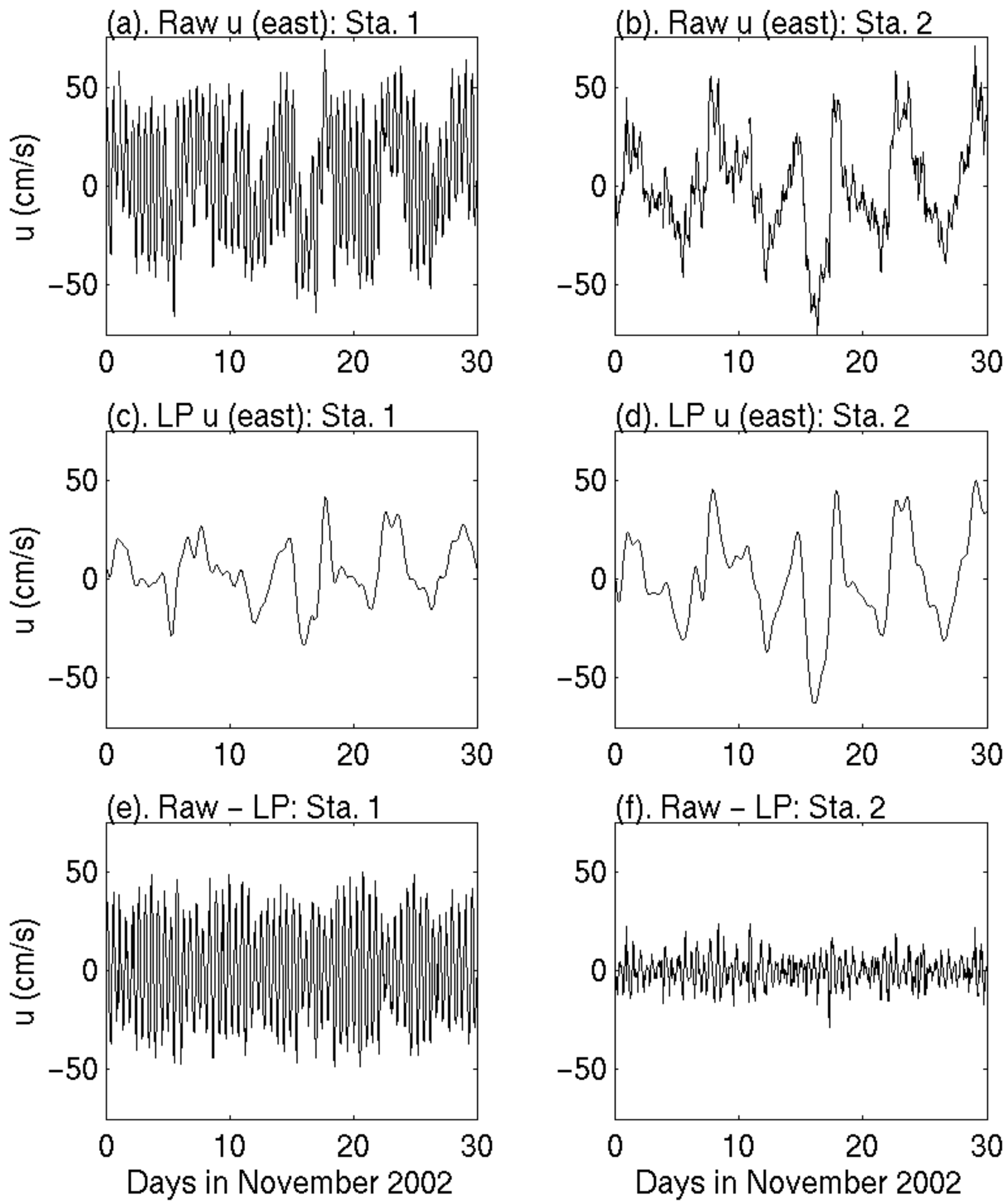


Figure 5: CODAR-derived Surface Current Time Series During November 2002.

The STPS is based on the independent prediction of the tidal and nontidal surface current components. Tidal currents are predicted using harmonic constituents derived from a one-month record of CODAR surface currents. Two methods for predicting the nontidal component were tested: hedging and Gauss-Markov estimation. The Gauss-Markov method was clearly superior at all forecast lags up to 25 hours, the maximum lag that was tested. Analysis of the combined – tidal plus Gauss-Markov nontidal – STPS predictions over a one-month period gives estimates of the region-averaged prediction error of 9 to 18 cm/s for the eastward component and 7 to 13 cm/s for the northward component. The range of prediction errors reflects the increase in prediction error with forecast lag.

A key component of the STPS is the estimation, at the time of prediction, of the uncertainties associated with the forecast velocities. The magnitudes of the predicted uncertainties are consistent with the computed root mean square (RMS) differences and the estimated uncertainties in the observations themselves. This leads to the conclusion that the forecast uncertainties can be reliably used to characterize the probable errors in the prediction. The forecast uncertainties will be important in the Monte Carlo-style calculation of trajectories that is envisioned for the next phase of this project.

The correlation of observation/prediction differences with wind, which is known to be the major forcing function for nontidal fluctuations in the FRONT region, is somewhat surprising. It suggests that the relative weight placed on the data contributing to the prediction is not accurate. This can result from incorrect characterization of either the observational errors in the velocity components or the data autocovariance functions. The observational errors are estimated by assuming that the uncertainty in the radial velocity from a given site is spatially and temporally constant, which has yet to be verified for the CODAR system. The autocovariance functions used in the implementation of the Gauss-Markov estimation procedure are averaged spatially over the CODAR domain and are then scaled by the actual data variance at each grid point. This spatial averaging is done to produce smoother autocovariance functions, the use of which helps reduce the incidence of wild predictions at grid points with frequent data gaps. However, there is clearly some spatial structure present in the autocovariance functions, and its neglect can lead to misrepresentation of the data covariance in some locations in the region. Further work is necessary to determine whether the use of more robust autocovariance functions derived from historical data records of, for instance, several months will produce more accurate predictions.

Although more work is necessary to confirm this point, preliminary work on the prediction methodology carried out using CODAR data from August 2001 resulted in somewhat lower prediction error during that time period as compared with the December 2002 period presented in this report. As the accuracy of the tidal prediction is unlikely to vary in a systematic manner over the seasons, this suggests that the nontidal predictability will be reduced in winter. This may be due to increased nontidal (wind-driven) current fluctuations caused by wintertime wind intensification.

3.4 Interactive Web Site

Current SAR planning uses environmental data to help predict the probable location of a target. Environmental data is retrieved from various sources, including the U.S. Navy and NOAA. It is anticipated that future CODAR regions along the U.S. coastline will be developed and maintained by multiple organizations with specific interests in certain geographic regions. Each region will operate autonomously, based on the site sponsor's program goals and funding. Coast Guard access to CODAR data can be accomplished either on a region-by-region basis or through a central CODAR data clearinghouse.

It is the intent of this development to demonstrate how CODAR data from multiple sources can be made available for Coast Guard SAR planning, using a central clearinghouse to select and authenticate data suitable for Coast Guard use. A data flow diagram for this concept is shown in Figure 6: Conceptual Overview, which identifies four distinct functions:

1. The multiple regions shown represent different CODAR regions that currently exist or may be developed along the coastline in the future. The Block Island Sound CODAR region used

in this project represents one possible region.

2. A national clearinghouse is shown, where data from each CODAR region is retrieved and where data quality is evaluated and maintained. One alternative is to host the STPS model being developed and its coefficients at the national clearinghouse as shown, subject to the same data quality controls.
3. A central application determines from which geographic region data is required, based on requests from user applications, and also determines whether to retrieve data from the central STPS clearinghouse or directly from the selected CODAR regions. Geographic region selection is determined from the area specified in the user's request. The data source is determined based on the time frame for which the user is requesting data and whether that data is historical or derived from the STPS predictions.
4. An end user application is required to format and/or process data appropriate for the end user's needs. Current end user applications include Computer Assisted Search Planning (CASP) and the Automated Manual Method. Other end user applications are under consideration.

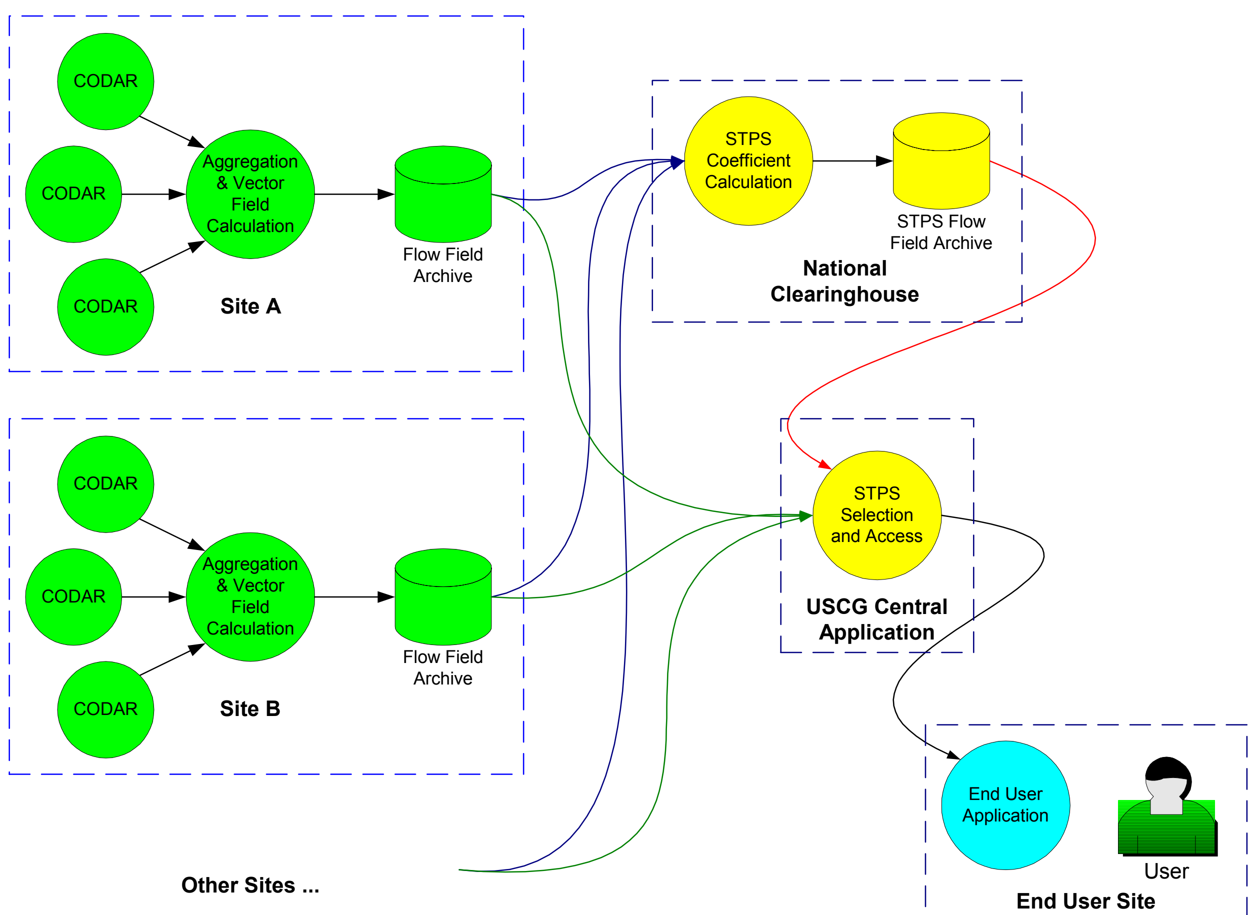


Figure 6: Conceptual Overview.

A modified version of the overall concept was developed to facilitate rapid development of demonstrable capability. A complete description of the implemented concept, including an operator's manual, can be found in the CODAR CSDD. This software product implements all required components using a single CODAR region for input and includes provisions for authenticating users, performing data downloads, and computing target drift solutions using either of two solution methods.

The functional components shown in Figure 7: CODAR Functional Components identify the basic Web site capabilities. Each of the three data displays is based on selection and extraction of data from the STPS predictions and/or from historical flow fields as appropriate to the intended purpose. Output data is provided in tabular form, and the transmitted Web pages also contain embedded XML data that can be imported to other analysis tools.

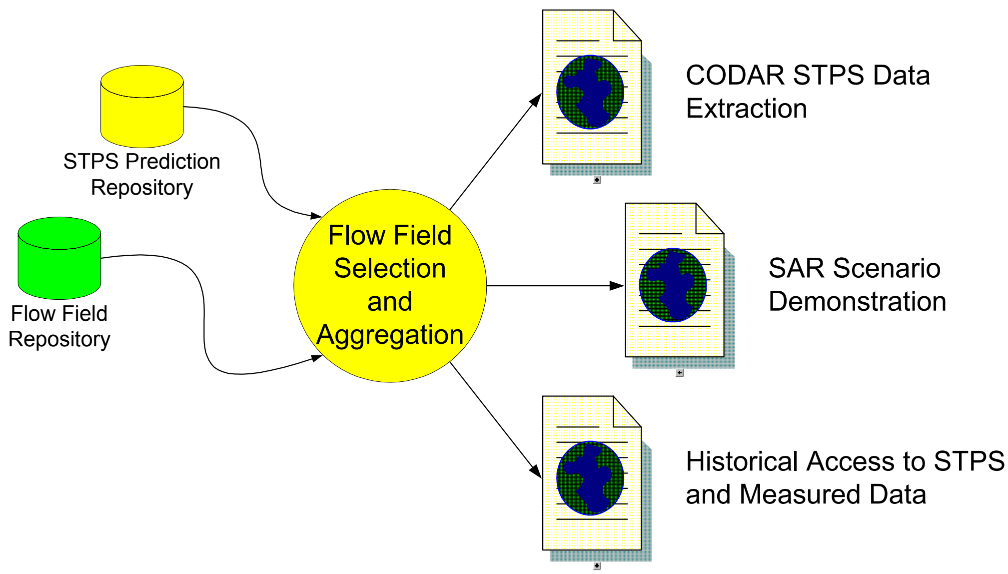


Figure 7: CODAR Functional Components.

In addition to the download capabilities provided in a tabular form, a graphical display is provided based on the estimated trajectories developed from the solution pages. Figure 8: Graphical Trajectory Solution Display shows an example solution page and illustrates the Web site capability to provide readily understandable results based on application of CODAR data.

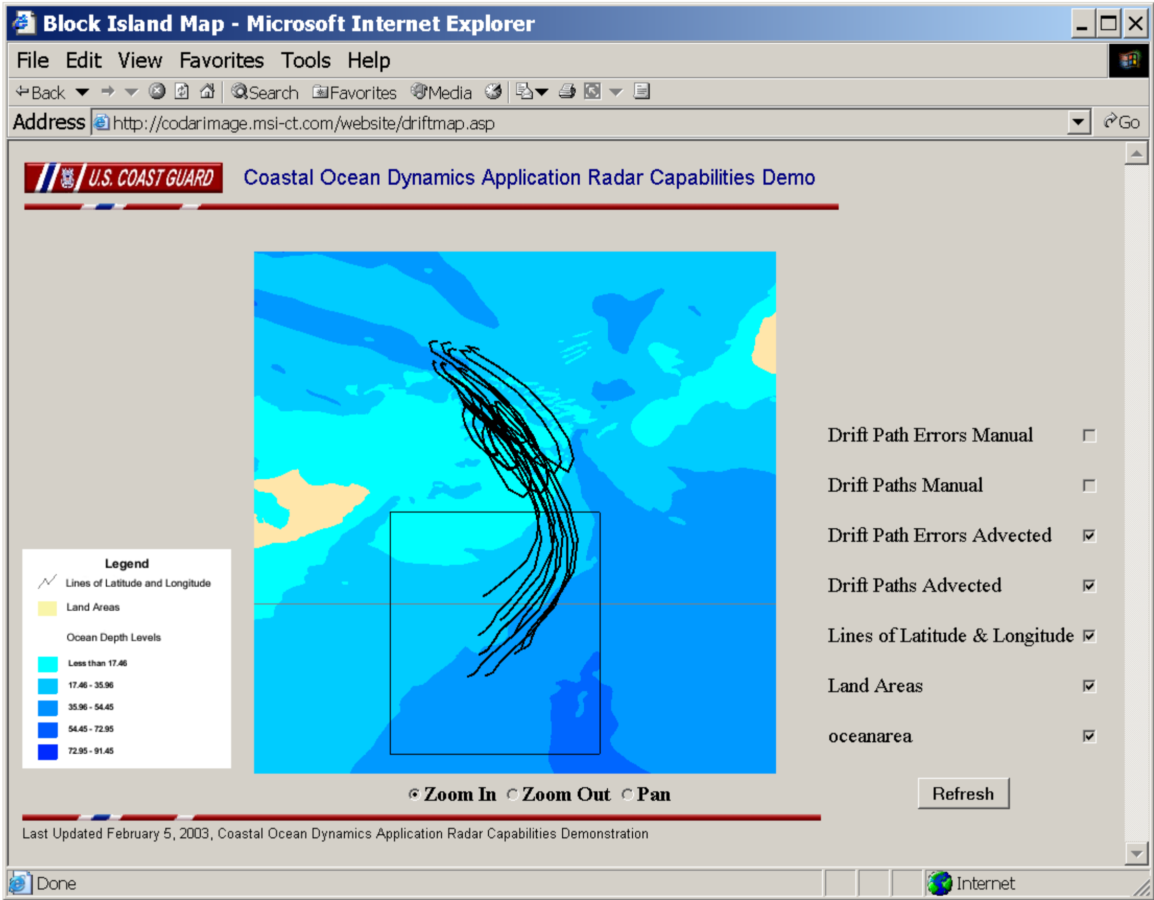


Figure 8: Graphical Trajectory Solution Display.

The solution shown was based on multiple trajectories, each started from random positions within an initial position envelope. The resulting trajectory computation is based on either historical CODAR measurements or STPS predictions, depending on whether the solution includes future drift predictions. An algorithm built into the data extraction process selects the best current vectors to use based on whether historical or predicted vectors are available and which vectors from which CODAR site are the closest to the point of interest. Additional work is required to refine the selection process in the face of multiple data sources and to assess the processing required to support full Monte Carlo-style calculation of trajectories and determine if such calculations can be done in an interactive environment.

3.5 Predictability of Target Trajectories Using CODAR and STPS Current Fields

The utility of CODAR surface current data in support of SAR planning depends on the ability to predict the trajectories of drifting objects using these currents. The purpose of the analysis presented here is to quantitatively assess this predictability by comparing trajectory predictions with actual SLDMB trajectories. Specifically, trajectory predictions using observed CODAR currents and currents derived from the STPS were compared with those computed using NOAA tidal current predictions. Present Coast Guard operations use the NOAA currents in many situations to assess drift for SAR planning purposes. The results presented here demonstrate that the underlying assumption behind the use of the NOAA currents, namely that the surface current is spatially uniform, are often unjustified and that trajectory predictions resulting from their use can be severely in error.

3.5.1 U.S. Coast Guard SLDMB Deployments

SLDMBs, shown in Figure 9: Self-Locating Datum Marker Buoy, are air-deployable 7/10th sized Davis/Coastal Ocean Dynamics Experiment (CODE) (Davis, 1985) surface drifters that report Global Positioning System (GPS) derived positions every half hour through the Argos satellite system.

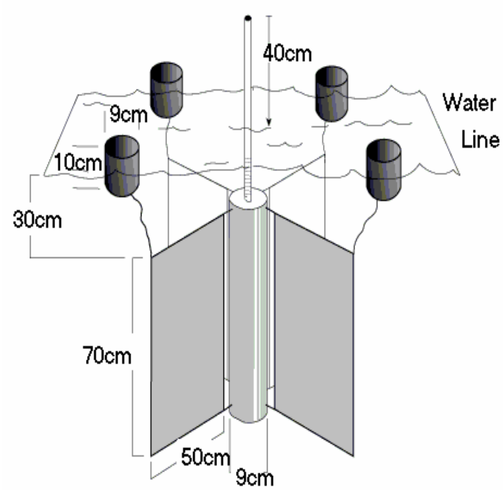


Figure 9: Self-Locating Datum Marker Buoy.

Several SLDMBs were deployed in December 2002 and March 2003 in order to develop a number of drift trajectories that can be used for comparison, as shown in Figure 10: December 2002 and March 2003 SLDMB Deployments. The location of the first good data point received from each SLDMB is denoted by the black dots, and the blue lines represent their trajectories. The coverage zones of the URI standard-range and the Rutgers long-range CODAR systems are also shown, depicted by the magenta dashed lines; the locations at which NOAA tidal predictions were obtained are indicated as red dots.

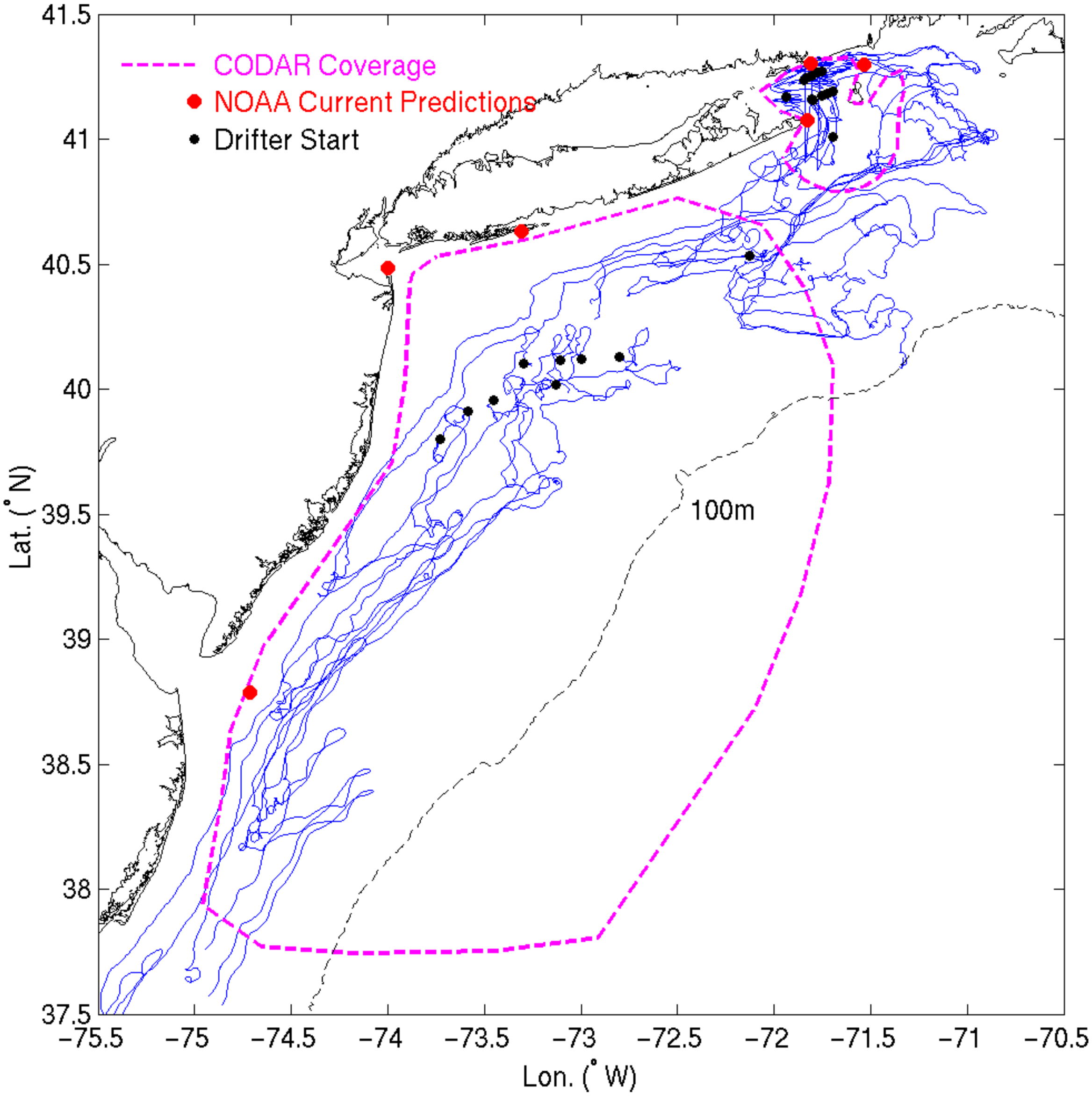


Figure 10: December 2002 and March 2003 SLDMB Deployments.

The Coast Guard, in cooperation with the University of Connecticut, deployed 10 SLDMBs in Block Island Sound during December 2002. This region is within the coverage zone of the University of Rhode Island's standard-range CODAR system. Several of these drifters were recovered as they exited the zone and were redeployed; one failed to return useful data. Subsequently, in March 2003 the Coast Guard deployed via aircraft 12 additional SLDMBs. Eight of these were deployed off the New Jersey coast within the coverage region of the Rutgers University long-range CODAR system and the remainder deployed in Block Island Sound. The drifters reported their positions at half-hour intervals on the hour and half hour. The time series of drifter position were decimated to hourly intervals to match the hourly and three-hour sampling of the CODAR systems.

Each SLDMB track was broken up into a series of 24-hour segments that were treated as independent trajectories in the statistical analysis. The start times of the segments were offset by six hours. Thus, the first trajectory for a given SLDMB starts at the time of the first good position (t_0) with subsequent trajectories starting at t_0+6 hr, t_0+12 hr, etc.

3.5.2 SLDMB Trajectory Prediction

Given the initial position, the path of an SLDMB can be computed if the current velocity field is known. Over a small time step (Δt) of one to three hours the rate of change of the drifter position is given by:

$$\frac{\Delta \mathbf{x}_p}{\Delta t} = \mathbf{u}(\mathbf{x}_p, t), \qquad \textit{(Equation 1)}$$

where $\mathbf{x}_p$ is the SLDMB position, t is time, and $\mathbf{u}(\mathbf{x}_p,t)$ is the velocity at the SLDMB location. Equation 1 relates the time rate of change of position to the velocity. Multiplying equation 1 by Δt allows computation of the change in SLDMB position over the time step, and thus a trajectory can be traced out by summing the changes in position over a number of time steps.

The important point to recognize is that the velocity in equation 1 is the velocity at the SLDMB location. The assumption that the velocity is invariant with position may be acceptable at certain locations and times, but as the sample CODAR current field shown below illustrates, this is often not the case. The trajectory comparisons in this report demonstrate that severe errors in trajectory predictions can result from the use of a constant velocity in equation 1.

A simple second-order predictor-corrector scheme (Press, et al., 1992) was used to solve equation 1. A fourth-order Runge-Kutta method (Press, et al., 1992) was also tested and was found to produce essentially identical trajectories. When velocity data from CODAR or the STPS is used for a trajectory integration using equation 1, the velocity must be interpolated to the SLDMB location $\mathbf{x}_p$. A nearest neighbor averaging scheme was used whereby the velocities at the closest four gridpoints are weighted inversely as the square of the distance from the SLDMB location. This is a robust method in the sense that it will provide an interpolated velocity at locations outside the CODAR/STPS domain. It will, however, produce uneven results when applied, for instance, close to topographic promontories where the closest gridpoints lie on opposite sites of the promontory. This situation was seldom encountered in the cases simulated in this report.

3.5.3 Trajectory Predictions

Three sources of surface current data were used for the prediction of SLDMB trajectories. The first of these was NOAA tidal current predictions, which were obtained at the locations shown in Figure 10: December 2002 and March 2003 SLDMB Deployments using the program Tides and Currents for Windows (version 2.5b). For a given trajectory segment, the NOAA current at the station closest to the starting point was used to represent the current experienced by the SLDMB. The second source was the CODAR observations, which were available on an hourly basis in the Block Island Sound (BIS) region and one observation every three hours in the New Jersey Shelf (NJS) region. The CODAR currents in the BIS region and the NJS region are produced on 1.5

km grid and 6 km grid, respectively. For the BIS region, hourly current predictions from the STPS system were used.

An example of 24-hour trajectories predicted using NOAA tidal currents, assumed not to vary with location, and CODAR-derived surface currents are shown in Figure 11: Sample Trajectory Predictions. The top panel displays a 24-hour trajectory ending at 00:00 on 17 December 2002 of an SLDMB in black. The trajectories predicted using NOAA tidal currents from a station just southwest of the starting point and using the CODAR currents are shown respectively in red and blue. The open circles denote the final position of the real and simulated SLDMBs. The CODAR current map at the end of the prediction interval is also plotted. The bottom panel shows the differences between the actual SLDMB trajectory and the predicted trajectories as a function of time over the 24-hour period. Separation between the SLDMB and the CODAR predicted trajectory is shown in blue, and separation between the SLDMB and the NOAA predicted trajectory is shown in red.

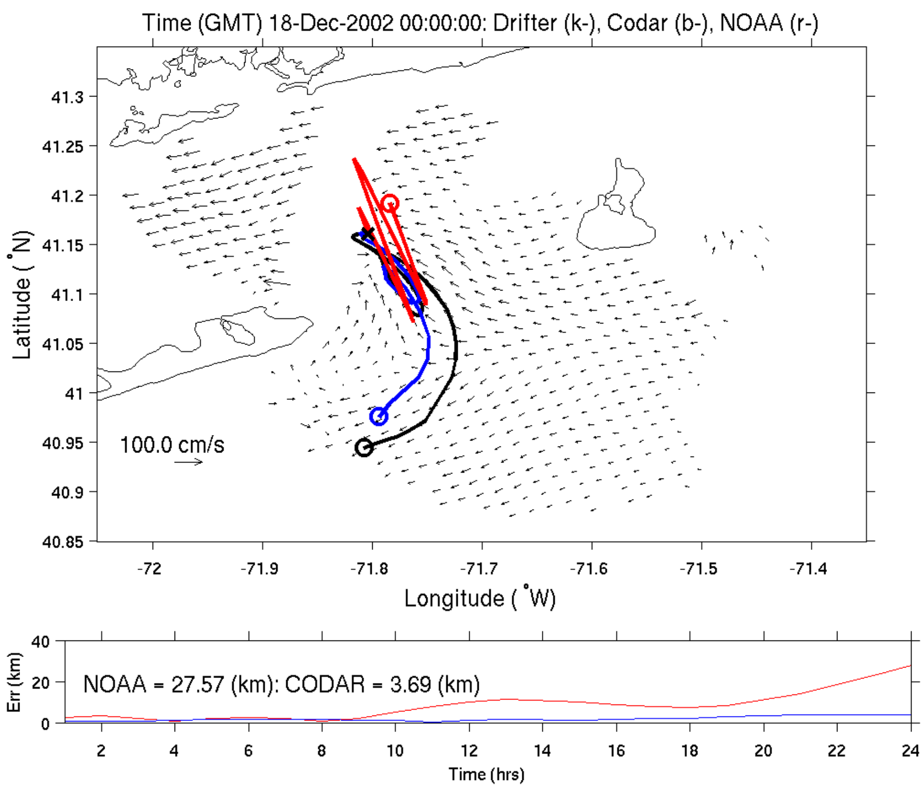


Figure 11: Sample Trajectory Predictions.

In this case, the trajectory predicted using the NOAA currents is severely in error, with a separation of approximately 25 km after 24 hours, while the trajectory predicted using the CODAR currents is in reasonable agreement with the SLDMB trajectory. The surface velocity field at the end of the 24 hours, also shown in Figure 11: Sample Trajectory Predictions, suggests that the reason for this discrepancy is the rapid spatial variability of the velocity field, a feature that is not captured using the single-point NOAA currents.

3.5.3.1 Trajectory Error Statistics

As described above, each SLDMB trajectory was broken up into a number of overlapping 24-hour segments, each of which was treated as an independent trajectory. For each segment, trajectory predictions were made, starting at the initial point of the segment, using surface currents from the different sources. At each time step, the separation between the actual and predicted SLDMB positions was computed and stored. The resulting database of separation versus time was used to produce histograms of separation at different times. From the histograms, the separation value was extracted that was greater than or equal to 95 percent of the separations, the 95th percentile value. This measure of the separation is shown as a time series over the 24 hours of the trajectory prediction.

Figure 12: Block Island Region Trajectory Error Histograms shows histograms of separation between SLDMB position and predicted SLDMB position for SLDMBs within the Block Island region. The three columns present histograms for the different prediction current sources; the left column used measured CODAR current, the center column used STPS predicted current, and the right column used NOAA tidal current predictions. Each row presents histograms for the separation errors at prediction times of 3, 6, 12, and 24 hours after the initial position.

For the Block Island region, the histogram plots clearly show the superiority of CODAR-derived currents for SLDMB prediction. The histograms for trajectories calculated using CODAR observations and STPS predictions are skewed significantly to lower separations compared with the histogram for the trajectories calculated using NOAA currents. For example, at an elapsed time of three hours, the CODAR and STPS predicted positions are always within 10 km of the actual SLDMB position, whereas a significant number of the NOAA predictions are in error by 10 to 20 km. The results at longer time intervals are similar, and at 24 hours most of the CODAR and STPS predicted positions are within 20 km of the SLDMB position. At this time lag, the positions using the NOAA currents are in error by more than 20 km in almost 50 percent of the cases.

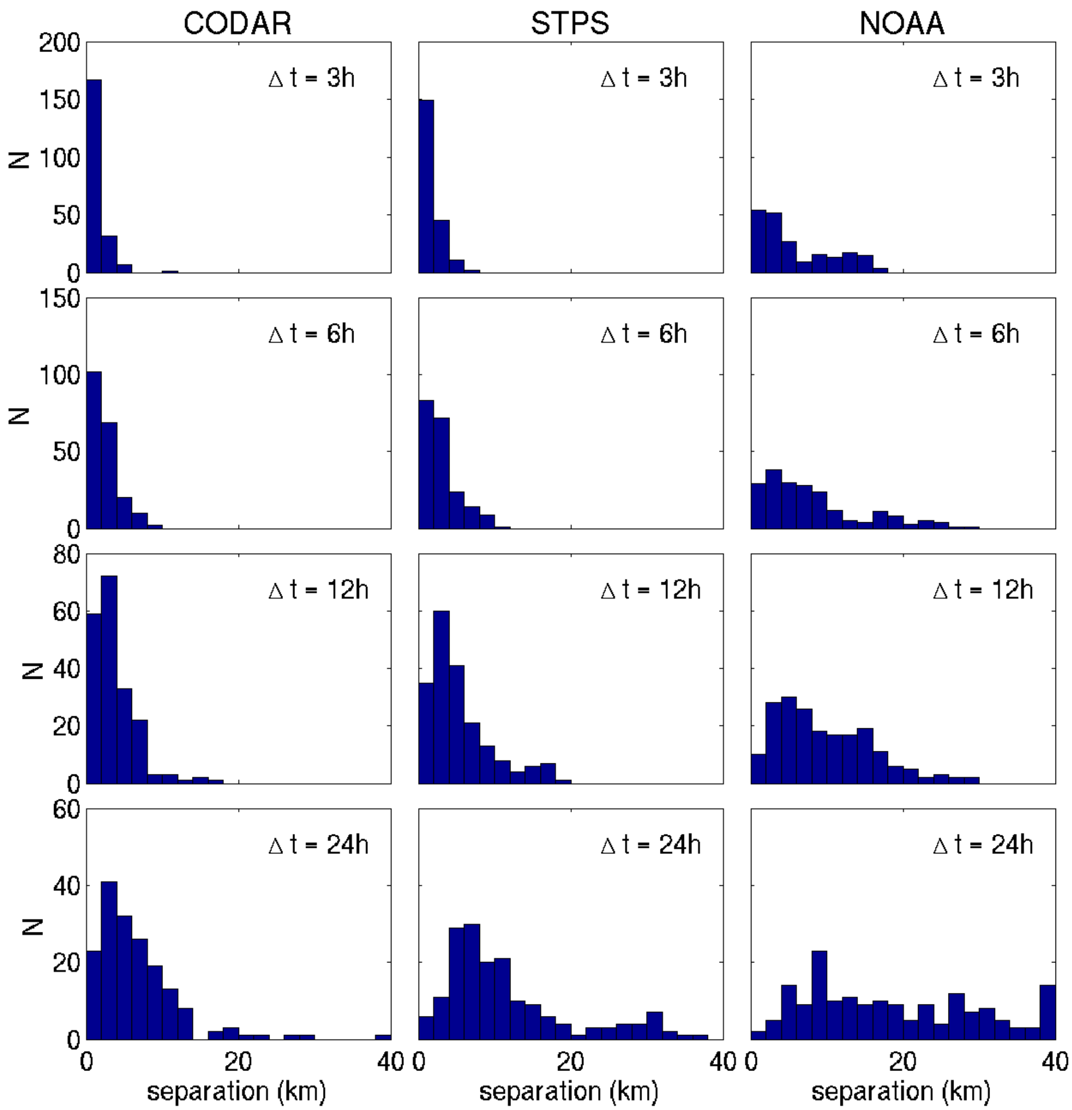


Figure 12: Block Island Region Trajectory Error Histograms.

Separation between SLDMB position and the predicted position is shown in Figure 13: Block Island Region 95th Percentile Separation as a function of time for SLDMBs within the Block Island region. The separation shown is the 95th percentile value. The three curves show the separation for each of the three current sources; the CODAR-based separation is shown in green, the STPS-based separation is shown in blue, and the NOAA tidal current-based separation is shown in red.

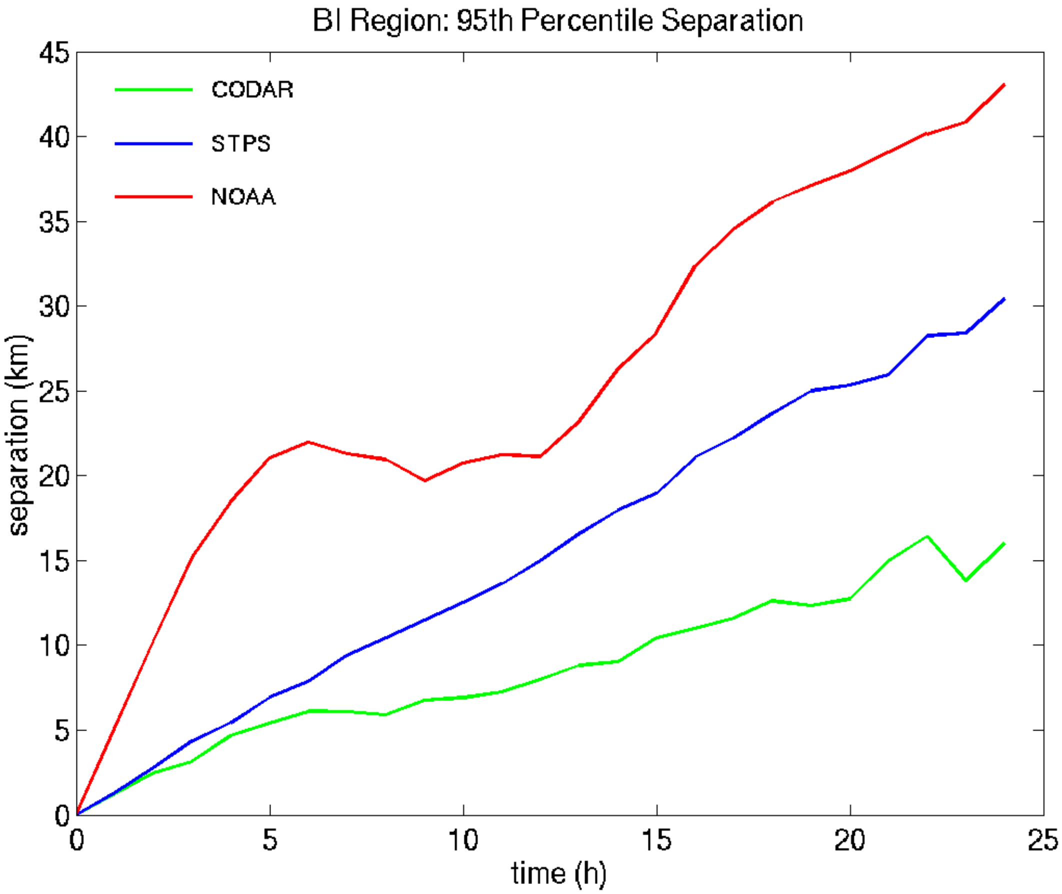


Figure 13: Block Island Region 95th Percentile Separation.

The increase with time of the prediction errors is more clearly seen in the time series of the 95th percentile separation shown in Figure 13: Block Island Region 95th Percentile Separation. At all times, predictions made using observed CODAR currents are the best and those made using NOAA currents are the worst, with trajectories predicted using the STPS currents intermediate in accuracy. The 95th percentile separation value increases monotonically for the CODAR and STPS predictions with values at 24 hours of 15 and 30 km, respectively. Using NOAA currents, the separation decreases slightly between about 6 and 12 hours before rising again to a 24-hour value of 40 to 45 km. This decrease at intermediate times is because the NOAA currents are strongly tidal, with a period of 12.4 hours. If applied in a region where tidal currents are actually weak (Station 2 in Figure 4: URI/UConn CODAR Coverage Region for example), the SLDMB trajectory predicted using NOAA tidal currents will execute a large oscillation with this period, whereas the actual SLDMB will move slowly more or less in one direction. At the end of 12.4 hours in this case, the predicted SLDMB trajectory will be roughly back at its starting point and thus closer to the actual SLDMB position.

The statistics of the trajectory comparisons for the SLDMBs within the New Jersey Shelf region are qualitatively similar to those of the Block Island region. (STPS predictions were not produced for this region.) Figure 14: New Jersey Shelf Region Trajectory Error Histograms shows histograms of separation between SLDMB position and predicted SLDMB position for

SLDMBs within the New Jersey Shelf region. The two columns present histograms for the different prediction current sources; the left column used measured CODAR current, and the right column used NOAA tidal current predictions. Each row presents histograms for the separation errors at prediction times of 3, 6, 12, and 24 hours after the initial position.

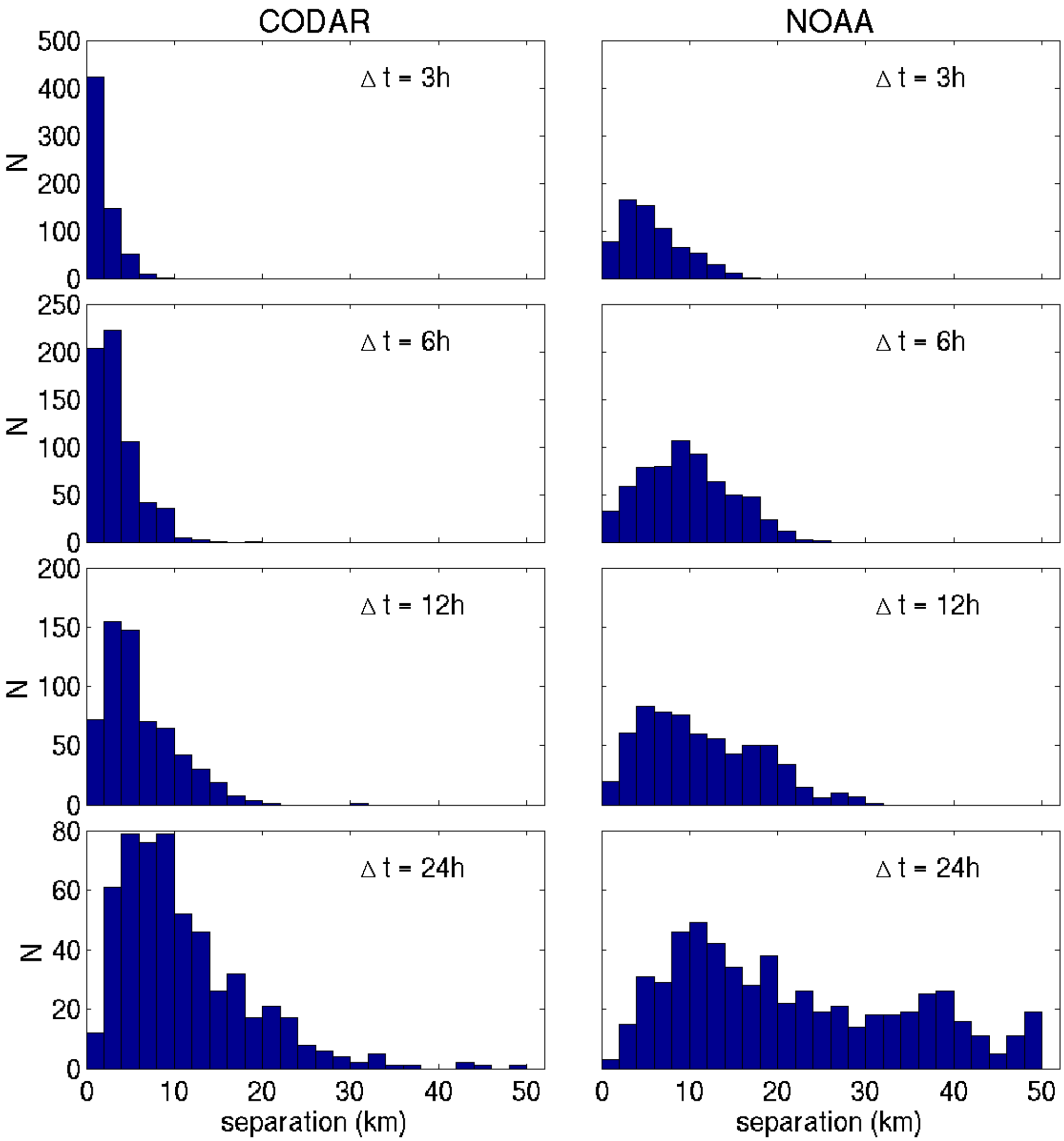


Figure 14: New Jersey Shelf Region Trajectory Error Histograms.

The histograms, skewed toward low separation for the CODAR case, again show the clear superiority of CODAR currents for predicting drift. At 24 hours, most of the CODAR-predicted positions are within 25 km. At this lag, using the NOAA currents, prediction errors are almost as likely to be greater than 25 km than less than 25 km.

The 95th percentile value of the separation between SLDMB position and the predicted position is shown in Figure 15: New Jersey Shelf Region 95th Percentile Separation as a function of time for SLDMBs within the New Jersey Shelf region. The two curves show the separation based on CODAR currents in green and the separation based on NOAA tidal currents in red. The 95th percentile separation after 24 hours is approximately 25 km using CODAR currents and roughly 45 km using the NOAA currents.

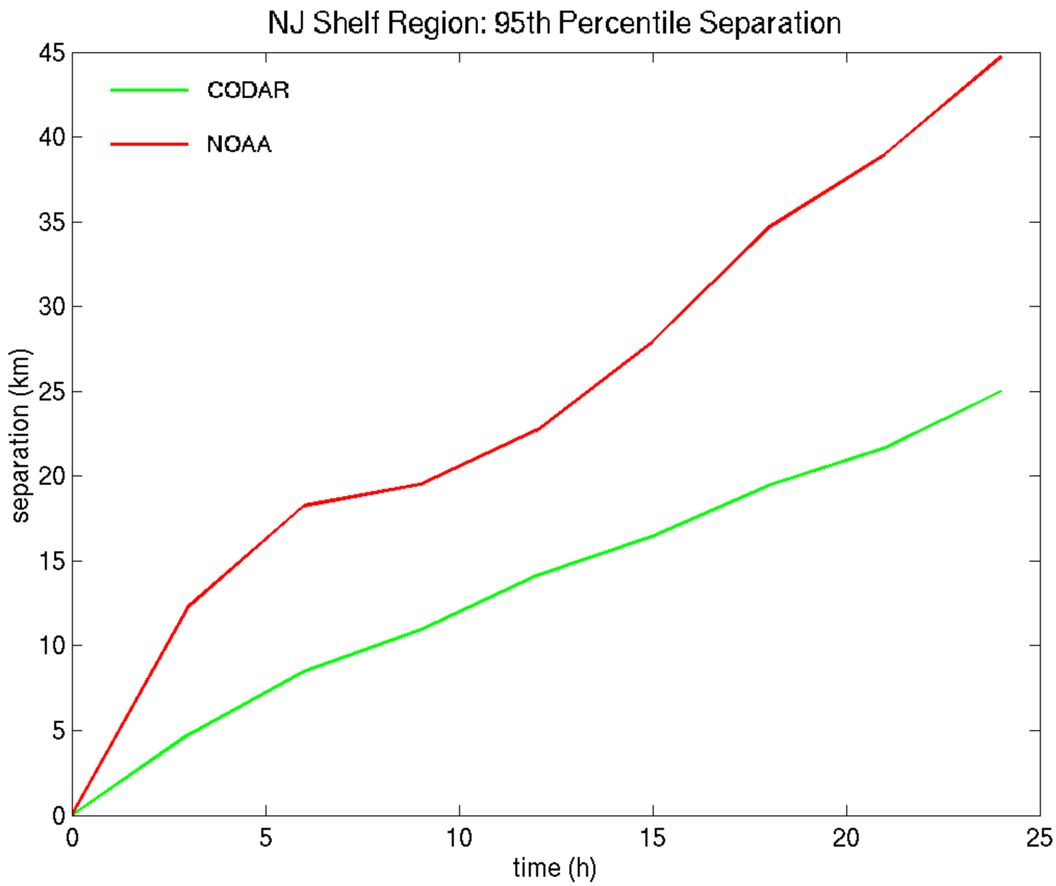


Figure 15: New Jersey Shelf Region 95th Percentile Separation.

3.5.3.2 Trajectory Errors versus Wind

CODE-type drifters, like the Coast Guard SLDMBs, exhibit negligible windage effects. This was investigated by comparing SLDMB prediction errors in the Block Island region with winds measured at a nearby NOAA buoy (44017). The separation between predicted and actual SLDMB position after 24 hours was plotted versus the mean wind magnitude over the 24-hour prediction interval, as shown in Figure 16: Block Island Region 24-hour Separation versus Wind. The three panels show, from top to bottom, the comparisons of wind speed to separation for predictions using CODAR, STPS, and NOAA currents.

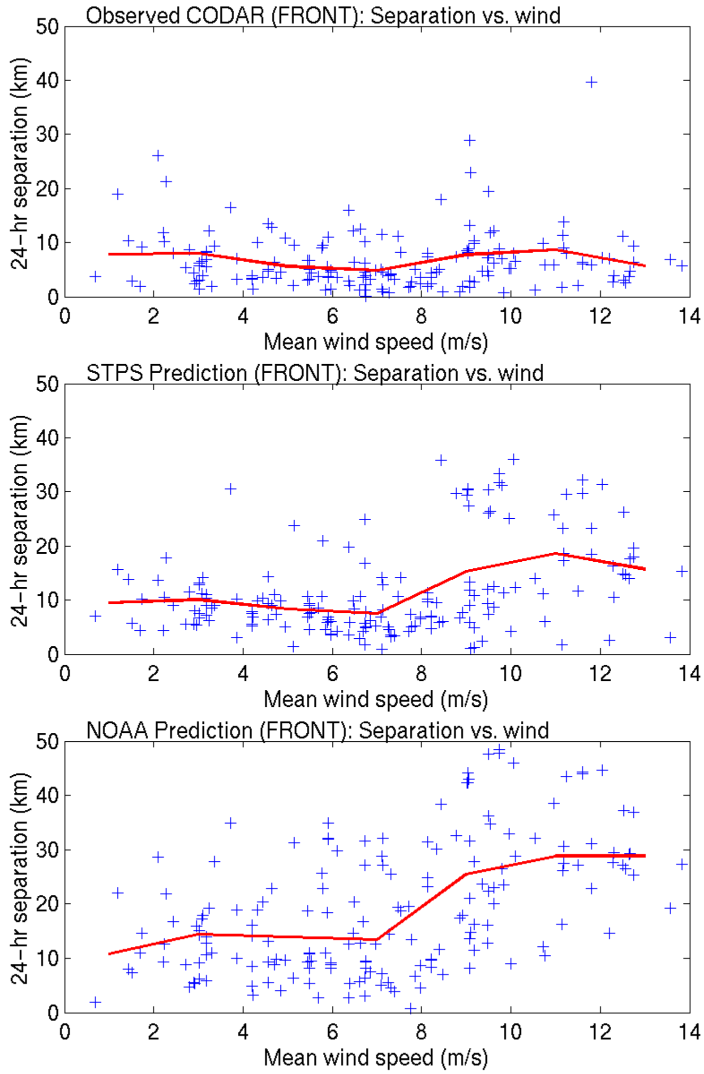


Figure 16: Block Island Region 24-hour Separation versus Wind.

The first comparison shows that prediction errors using observed CODAR currents for the prediction were not correlated with the wind. Because the CODAR currents contain the real wind-driven component, which is known from prior unpublished work to be large, this confirms that the SLDMBs are not experiencing significant windage. In contrast, the predictions using STPS and NOAA currents tend to be more seriously in error under high-wind conditions. This is not surprising for the NOAA currents, as they do not contain a wind-driven component. In the case of STPS currents, for which the dependence on wind is weaker than for the NOAA currents, this result indicates that the STPS prediction methodology fails to fully capture the wind-driven velocity.

3.5.3.3 Prediction Uncertainties and Search Areas

SAR planning involves the determination of a search area. Effective search area determination identifies an area where the target is likely to be found and provides a measure of the confidence in that determination. For a predicted trajectory to be useful in SAR planning, the uncertainty in the trajectory must be assessed. This analysis is presented below for the case in which CODAR-observed currents are used in the trajectory computation. In an actual SAR case, the uncertainty in the final SLDMB position is partly due to poorly known initial location and time of SLDMB release and partly due to uncertainties in the current field used to make trajectory predictions. The latter of these uncertainties was assessed using a Monte Carlo approach developed using MATLAB, a common modeling tool. Individual trajectories, from 100 to 1,000, were computed for each actual SLDMB trajectory. The individual computed trajectories differ because the CODAR velocity field is assumed to have a known uncertainty, and the velocity at each time step in the application of equation 1 is perturbed randomly by this amount. The region enclosing the final positions of all trajectories can be taken as a measure of the size of a potential search area. For a successful prediction, this region should contain the final position of the actual SLDMB.

The size of the search area depends on the uncertainty in the current velocity field. For the purpose of this analysis, the uncertainty was assumed to be spatially uniform. The errors in the eastward and northward components were assumed to be independent and Gaussian, with standard deviation of 15 or 20 cm/s. Examples of Monte Carlo simulations of SLDMB trajectories in the Block Island region are shown in Figure 17: Simulations of SLDMB Trajectories. In each panel, the blue line shows the actual SLDMB trajectory, the green lines delineate 100 SLDMB tracks simulated using CODAR currents with an assumed standard error of 20 cm/s, and the red dots are the endpoints of the simulated trajectories. The black box encloses all the final positions.

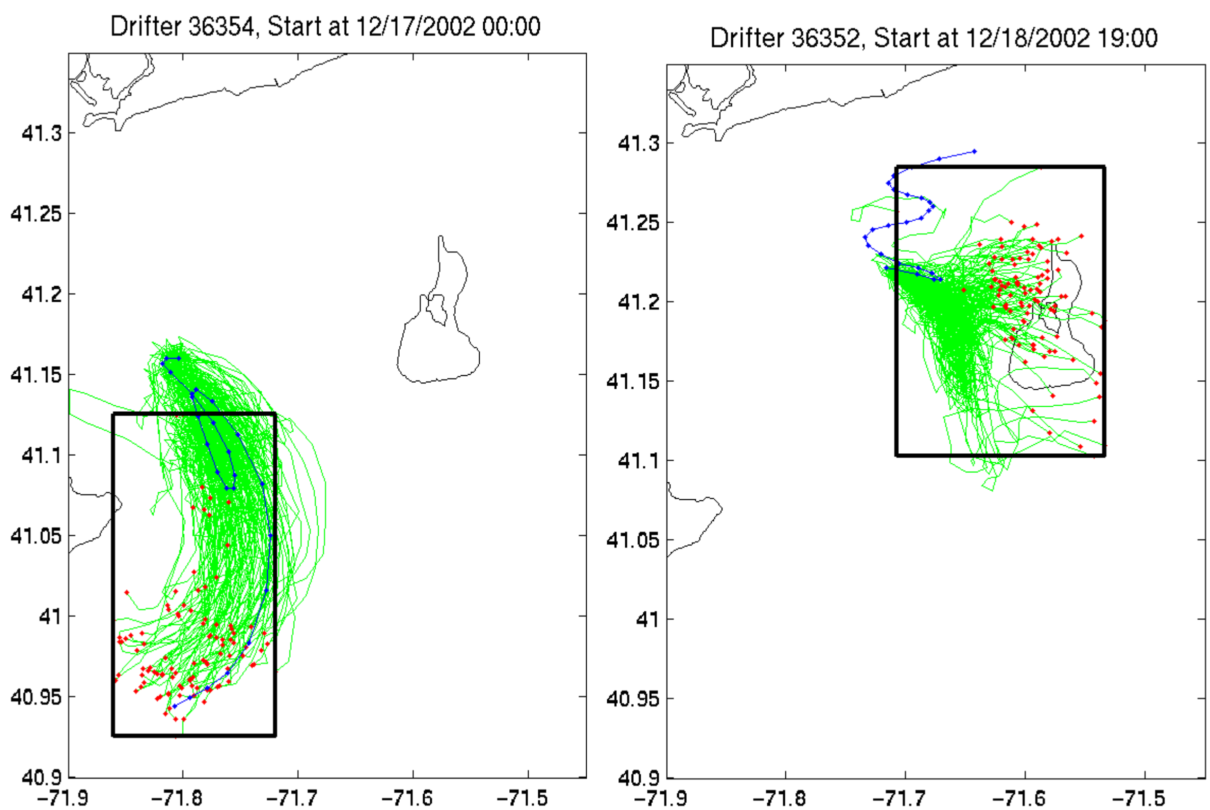


Figure 17: Simulations of SLDMB Trajectories.

The left panel shows a case that is defined to be a successful prediction; where the box enclosing the final positions of the 100 trajectories encloses the final position of the SLDMB. The case shown in the right panel is defined as a failure, since the final SLDMB position falls outside the box. In this case, it is clear that the assumption of a constant random velocity error is not correct. The CODAR velocity in this region during this time period appears to be biased toward eastward velocities, whereas the SLDMB experiences a more northerly drift.

An ensemble of trajectories, as in the examples shown in Figure 17: Simulations of SLDMB Trajectories was computed for each trajectory segment in the Block Island and New Jersey Shelf regions. The computation was limited to those trajectories that started and ended within an individual CODAR region. Table 1: Monte Carlo Simulation Results shows statistics for Monte Carlo simulations of drift trajectories with an assumed, spatially uniform velocity error. A successful prediction was defined as a case in which the box enclosing all final positions enclosed the SLDMB final position for a particular trajectory segment. A failure was defined as where the box did not enclose the final SLDMB position. For the Block Island region, the computation was performed using velocity errors of 15 and 20 cm/s. It was also repeated using 1,000 trajectories in order to test the effect of the number of trials on the size of the box enclosing the final positions.

Table 1: Monte Carlo Simulation Results.

Region	Velocity Error (Cm/S)	N Trials	N Success	N Failure	% Success
BIS	15	100	96	44	69
BIS	20	100	112	28	80
BIS	20	1,000	127	13	91
NJS	15	100	355	346	51
NJS	20	100	467	234	67
NJS	20	1,000	547	154	78

Using a velocity error of 15 cm/s with 100 trials results in success rates of 69 percent for the Block Island region and 51 percent for the New Jersey Shelf region. Increasing the error to 20 cm/s gives 80 and 67 percent success rates, respectively, suggesting that 20 cm/s is a more realistic estimate of the velocity error. As expected, the experiments with 1,000 trials produced larger boxes. In the Block Island region for 1,000 trials, the success rate increased to 91 percent; in the New Jersey Shelf region, it increased to 78 percent.

4. CONCLUSIONS AND RECOMMENDATIONS

CODAR represents a mature technology that has been available for use since the 1960s. The number of operational CODAR sites is on the increase, due partly to recent advances in broadband data communication. The rapid rate of CODAR growth has precipitated another look at how CODAR data can be employed for SAR planning.

This project looked at CODAR technology, where it is, and where it is going. The project then looked at some of the challenges associated with using CODAR for SAR planning and investigated how to address those challenges. The challenges identified included:

- Accessing and using CODAR data from different sources
- Assessing how well CODAR-based environmental data will perform when calculating drift trajectories
- Using historical CODAR-based environmental data to project future environments, which will be used to predict future drift trajectories

Based on these investigations, an assessment has been made regarding the applicability of CODAR data to SAR planning efforts. Specific recommendations are presented in Section 4.2: Recommendations to advance the use of CODAR data in SAR planning.

4.1 Conclusions

Current Coast Guard SAR planning tools rely on empirical analyses of surface current observations and are limited by the scarcity of current observations in the coastal ocean. An opportunity exists to capitalize on the many CODAR systems that are being made operational nationwide and to improve the quality of the environmental data that the Coast Guard SAR planning process relies upon.

Information collected about current and planned CODAR installations shows that uninterrupted coverage of the entire Northeast coast by both short-range and long-range CODAR systems will soon be available. Motivation for these CODAR systems is being driven by organizational needs outside the Coast Guard and do not require Coast Guard funding. As a result, surface current vector data at a temporal and spatial resolutions superior to data currently used by the Coast Guard can be accessed with minimal investment.

Comparison of SLDMB trajectory predictions with actual SLDMB trajectories shows that CODAR currents and STPS-predicted currents are clearly superior to NOAA tidal current predictions for the purpose of predicting drift trajectories. NOAA tidal current prediction do not contain a wind-driven component but are purely tidal with a very small residual mean; thus, trajectories using NOAA tidal current prediction suffer from more serious errors under high-wind conditions. A more significant problem with NOAA tidal current predictions is the assumption underlying their use in predicting trajectories – i.e., that the current throughout an area of interest is the same as the current at the nearest NOAA prediction site. Examination of individual CODAR current maps, for example Figure 11: Sample Trajectory Predictions, shows that this is not the case.

Although the STPS-predicted currents are superior to the NOAA tidal current predictions for trajectory prediction, they are significantly worse than the actual CODAR observations. The fact that final position errors using STPS-predicted currents are higher under high-wind conditions suggests that this deficiency is due, at least in part, to an inability to capture the true wind-driven current. Unpublished work by UConn shows that the CODAR currents are strongly correlated with the local wind. This indicates that better current predictions will be produced if accurate wind forecasts are available. The STPS algorithm using the Gauss-Markov method can be modified so that predicted currents are a function not only of the past history of the currents but also of the predicted wind.

For use in an operational context, an understanding of the uncertainty in a trajectory prediction is required. In performing the Monte Carlo simulations described in Section 3.5.3.3: Prediction Uncertainties and Search Areas, a known velocity uncertainty was assumed. Using a velocity error of 20 cm/s, the envelope of trajectory final positions enclosed the actual final SLDMB position 90 percent of the time for the Block Island region and somewhat less in the New Jersey shelf. This indicates that the error associated with currents from the New Jersey shelf long-range CODAR is higher than that for the standard-range CODAR in the Block Island region. This can be tested by systematically comparing SLDMB velocities, computed by differencing sequential SLDMB positions, with CODAR velocities. Systematic testing will provide a check on the estimated uncertainty and provide insight into whether the CODAR errors are spatially uniform or vary with position.

While CODAR data is demonstrably superior to data currently used by the Coast Guard, it is not currently available by accessing a single source, and the quality of data from different CODAR systems has not been verified. To be effectively employed by Coast Guard planning tools, a single data source of CODAR-based environmental data is required that will deliver the best quality environmental data that can be derived from available sources. Several steps have been taken to characterize available CODAR data and to establish the groundwork for using CODAR data in SAR planning tasks. Further study is necessary to effectively characterize and correlate the quality of the data available from the many CODAR sources coming on-line and to streamline the process of integrating that data into Coast Guard SAR planning tools.

4.2 Recommendations

Continued analysis of CODAR data, predictive capabilities, and access methods is recommended, based on the potential improvement to be gained from the higher quality data that can be made available. Specific areas for future investigation include:

- **CODAR Data Analysis –** To develop a better understanding of CODAR data and improve data product accuracy, further analysis and comparison of the deployed SLDMB data with the measured and predicted CODAR data is required. This should include a systematic comparison of SLDMB and CODAR velocities to better understand inherent uncertainties and their impact on search area determination.
- **STPS Algorithm Improvements –** To advance the STPS algorithm and improve forecasting accuracy, a second-generation STPS algorithm needs to be developed that integrates wind forecast data. Base development on an analysis of how wind measurements are correlated with CODAR measured currents, and modify the current Gauss-Markov method to include those effects.
- **Interactive Web Site Improvements –** To demonstrate data availability from multiple

CODAR sites and establish a method for data aggregation within and between adjacent CODAR regions, the coverage of the Web site interface needs to be expanded to include components from other CODAR sites, and the solutions enhanced to provide Monte Carlo-style calculation of trajectories. Include solution implementation improvements based on the understanding gained from further CODAR data analysis.

- **Evaluate Operational Impact of CODAR Data –** To demonstrate potential SAR planning improvements and obtain feedback necessary to integrate CODAR data into operational search plans, an operational demonstration using the Interactive Web Site is recommended to coincide with the 2004 SAR season.

The Coast Guard is in the process of developing improved tools for SAR planning that will incorporate the most promising drift and search area methods that have been investigated. A direct link should be established between follow-on tasking arising from these recommendations and SAR planning tool development efforts.

5. REFERENCES

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