# The Stevens Integrated Observation and Prediction System: Enhancement through New Sensors and Data Assimilation Techniques

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## LONG-TERM GOALS

The long-term goal of the project is to develop an advanced, integrated system of oceanographic, meteorological, and vessel surveillance sensors and littoral ocean forecasting models to allow for the real-time observation and nowcast/forecast of ocean, weather, and environmental conditions throughout the Hudson-Raritan Estuary and the Atlantic Ocean shoreline of the State of New Jersey. The observation and modeling systems are linked in a unique fashion, whereby the model forecast systems are enhanced by data assimilation, and the observing systems are enhanced by model-directed observations and model-assisted data interpolation.

## OBJECTIVES

During the year under report, the objective was to enhance and expand an existing observing and forecasting system of the Hudson Raritan Estuary that is used to support both safe navigation and port security. Primary objectives of the past year's effort included the expansion to include the Atlantic Ocean coastline of New Jersey, the creation of a very high-resolution model grid for the Hudson-Raritan Estuary, the addition of a forecast model for wind wave generation & transformation, the incorporation of an HF RADAR system to provide synoptic measurements of surface currents in the Lower Harbor, improved wireless data transmission, and the development of model assimilation schemes and model-assisted data interpolation and graphics.

## APPROACH

The observing system development is being coordinated by M. Bruno. This effort includes the development and deployment of ocean and weather sensors, including land-based salinity, temperature, turbidity, water level, current, and weather monitoring sensors at locations throughout the Hudson-Raritan Estuary and along the New Jersey Atlantic Ocean shoreline; an HF RADAR system in the Lower Harbor; and several vessel-based salinity and temperature sensors. The HF RADAR system is a joint effort with a separately-funded group at the Rutgers University Institute for Marine and Coastal Sciences.

The model forecast system is being coordinated by A. Blumberg. This effort includes the development of a very high-resolution, 3-D model of the entire Hudson-Raritan Estuary, Long Island Sound, and the

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New Jersey and Long Island coastal ocean, linked at the ocean boundary to a model of the New York Bight. The model is centered on the use of a high resolution application of the Princeton Ocean Model (Blumberg and Mellor, 1987). Water surface elevation and three-dimensional fields of currents, temperature, salinity, and water turbulence are calculated in response to meteorological conditions, freshwater inflows, tides, temperature and salinity at the open boundaries. Recent efforts have included the implementation of the high-resolution grid, and the incorporation of a wind wave generation and transformation model. The high-resolution (approximately 1 km) wave forecasting model is based on the NOAA Great Lakes Environmental Research Laboratory model (GLERL model, Donelan, 1977; Schwab, et al, 1984), a two-dimensional, parametric, dynamic model of wind-growth, propagation, and decay, modified to accept open boundary forcing through specification of significant wave height at the ocean boundary. The modified GLERL model has been incorporated into the 3D, curvilinear, Princeton Ocean Model framework.

Wind forcing is provided from forecasted wind fields derived from the NOAA/NWS/National Centers for Environmental Prediction (NCEP) North American Mesoscale (NAM) Weather Research and Forecasting Model (WRF), optimally interpolated to the high-resolution grid. Before June 20, 2006, when the NCEP NAM-WRF model became operational, wind forcing was provided by NOAA/NWS/NCEP's North American 12km Eta model, on the same grid. Open ocean boundary forcing to the coastal wave model is derived through optimal interpolation of forecasted wave conditions provided from the NOAA Western North Atlantic (WNA) WaveWatch III (WWIII) model at 15min resolution.

The daily prediction system is scheduled to simulate 72 hours - 24 hours in the past (the hindcast mode) and then 48 hours into the future (the forecast mode). The hindcast part of the cycle uses observed (not forecasted) forcing functions and a file is written out that forms the basis (initial conditions) for the next cycle.

Note: other key Stevens faculty and staff members involved in this effort include:
Nickitas Georgas - PhD student, high resolution circulation and wave modeling
Thomas Herrington - Associate Professor, coastal observations and analysis
Jeremy Turner, Research Engineer - field operations supervisor
Dov Kruger - PhD student, model optimization and data visualization
Don Chelsely, Research Engineer - programmer and data telemetry
Dave Runnels, Research Engineer - data base manager and web designer

## WORK COMPLETED

The work completed includes:

<u>Observing System</u>
The overall system design, capabilities, and data and forecast products can be found in Bruno et. al. (2006). Here we describe the estuary and coastal components of the system.

*Estuary*
Real-time oceanographic and weather information within the Estuary is obtained using various sensors placed at strategic locations; see Figure 1 for station locations. The network sensors, all of which provide their data in real-time, include:

- 8 shore-based salinity, temperature, turbidity, and water level sensors
- 2 moored platforms containing salinity, temperature, turbidity, and pressure sensors
- 2 Acoustic Doppler Current Profilers (ADCPs)
- Vessel-based conductivity, temperature, and dissolved oxygen sensors
- 6 weather stations providing continuous observations of local meteorological conditions
- A CODAR (HF RADAR) system located on the southeast shore of Staten Island (see Figure 1) that works in combination with two Rutgers University CODAR systems to provide the coverage necessary to enable surface current and wave measurements across much of the lower Harbor.

Newly expanded wireless data transmission capabilities have significantly improved data transmission rates and reliability. Issues such as wireless security and integrity have been addressed. Discussions with data users, including US Coast Guard Sector New York and the marine transportation industry, have led to improved web site data delivery, including new graphics that employ the model nowcasts to create color-coded maps of ocean properties from the discrete sensor data.

*Coastline (littoral)*
Real-time oceanographic and weather information along the Atlantic Ocean shoreline is obtained at several locations; see Figure 2 for station locations. The sensor design and network configuration are described in Bruno, et. al. (2001). The network sensors, all of which provide their data in real-time, include:

- 4 shore-based wave, water level, and water temperature sensors
- 5 weather stations providing continuous observations of local meteorological conditions
- 4 locations providing digital photos of the nearshore region

Prediction System

The prediction system is fully operational, and provides 72 hour simulations - 24 hours in the past (the hindcast mode) and 48 hours into the future (the forecast mode). The nowcast is obtained at the conclusion of the hindcast part of the cycle and a file is written out which forms the basis for the next cycle. The forecast simulations are performed using forecasted forcing functions except for the river flows, which are based on daily persistence. The modeling system saves the proper hydrodynamic information for a restart. A smooth and seamless execution occurs to start the next cycle, which is scheduled to start 24 hours later. Three-dimensional fields of salinity, temperature, and currents and two dimensional fields of water level, significant wave height, period and direction are archived every 30 minutes. Figure 3 illustrates the new high-resolution grid.

The coastal wave model has been continuously operational since May 15, 2006, each day producing 48-hr graphical forecasts for significant wave height, wave direction, and wave period. Figure 4 illustrates the 1 km grid used for the wave model, a well as the gridpoints for the surface wind input and the locations of open ocean boundary forcing data.

Both the observations and the model forecasts are distributed in near real-time to the public via the Stevens web site, using user-friendly graphical interfaces. For the coastal observations, go to http://cmn.dl.stevens-tech.edu/. For the Estuary observations and all forecasts, go to http://hudson.dl.stevens-tech.edu/NYHOPS/ (for forecasts, choose *Go to Forecasts* on the upper right hand corner of the NYHOPS website, and then choose from the dropdown menu). Time histories at all measuring points, as well as archived records, are available via the web site. The mobile (vessel-based) observations are accessed by choosing *Mobile Stations* on the upper right hand corner of the NYHOPS website.

## RESULTS

The integration of the observing system and the modeling system has significantly improved the performance of both. The forecast estimate of present conditions is improved by using the observations, which are continually available in real-time throughout the forecast period. The observation system employs the model to facilitate the creation of color-coded data “maps” for each measured parameter. Every 30 minutes a map of “Present Conditions” is prepared by assimilating all of the available data for that 30 minute period with the appropriate forecast. An objective optimal interpolation technique is used to create the assimilated distribution. In addition to being posted to the Internet, these distributions are saved for use with the next cycle of the prediction system. Figure 5 illustrates “Present Conditions” of surface salinity in the Estuary for 23 September, 2006.  Figure 6 illustrates the forecasted wave conditions on 27 June, 2006.

With a view toward developing the ability to assimilate HF RADAR data into the Estuary circulation model, we continue to conduct field validation experiments to assess the skill of the joint Rutgers-Stevens CODAR system in providing high-resolution measurements of the surface currents in the Lower Harbor. Of particular interest is the connection of the Estuary to the Atlantic Ocean via the Sandy Hook – Rockaway Transect. Figure 7 provides a comparison of the NYHOPS surface current model forecast with CODAR measurements on August 24, 2006.

The vessel-based sensors have been operating for more than one year, primarily using the sightseeing sailing ship Pioneer, which is based at the South Street Seaport Museum on the East River in Lower Manhattan. The vessel transmits (via cellular wireless) real-time measurements of near-surface (1-meter) salinity, temperature, and dissolved oxygen. Figure 8 illustrates the real-time measurements of near-surface temperature along the route as the Pioneer was underway on September 23, 2006, from approximately 0900 to 1645 EDT.

## IMPACT/APPLICATIONS

The work presented here provides a major step forward to the operational (two-way) coupling of real-time ocean and weather observation systems with a modeling system. The coupled system has also served as a valuable vehicle to enable the development of reliable, operational fixed and vessel-based observation systems. NYHOPS provides a wealth of real-time data and accurate forecasts in the waters of New York and New Jersey. This information is now available to serve the maritime user community in the same way that weather forecasting has served the on-land population. All of the data is available over the Internet 24 hours a day by means of weather forecast-like maps that can be used effectively by Harbor pilots, sailors, power boaters, swimmers, and fishermen as well as port security officials and emergency management personnel.

The observational network and modeling system are parts of the integrated, sustained ocean observing system envisioned by the National Oceanographic Partnership Program (NOPP), under the OCEAN.US office, and the Integrated Ocean Observing System (IOOS).  The PI’s have been active participants in the leadership of the Mid-Atlantic Coastal Ocean Observing Regional Association (MACOORA), now designated as a formal Regional Association under the IOOS program.

**RELATED PROJECTS**

None

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**HONORS/AWARDS/PRIZES**

Alan F. Blumberg, Stevens Institute of Technology, Elected Fellow, American Society of Civil Engineering.

Alan F. Blumberg, Stevens Institute of Technology, Appointed to the Science Advisory Board (SAB), U.S. Environmental Protection Agency.

Michael S. Bruno, Stevens Institute of Technology, Elected Fellow, American Society of Civil Engineering.

Michael S. Bruno, Stevens Institute of Technology, appointed member Marine Environmental Committee, Transportation Research Board.

Nickitas Georgas, Stevens Institute of Technology, 2006 American Shore and Beach Preservation Association Educational Award.


***Figure 1. Location of sensors in the NYHOPS sensor network. Several sensors are owned and maintained by partners NOAA/NOS and Rutgers University. Supplementing this network are real-time continuous observations from vessels operating in the Harbor.***

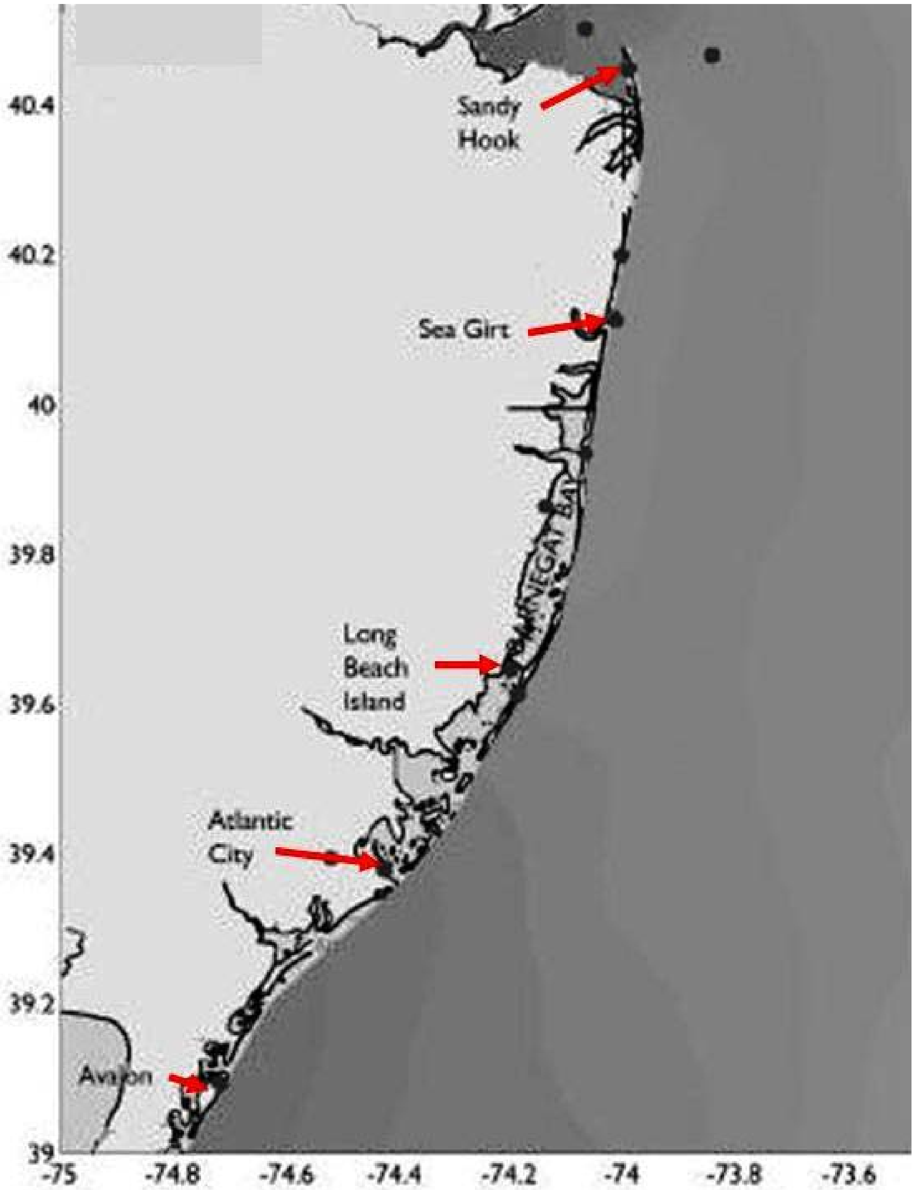


***Figure 2. Location of ocean and weather stations along the Atlantic Ocean shoreline of New Jersey.***

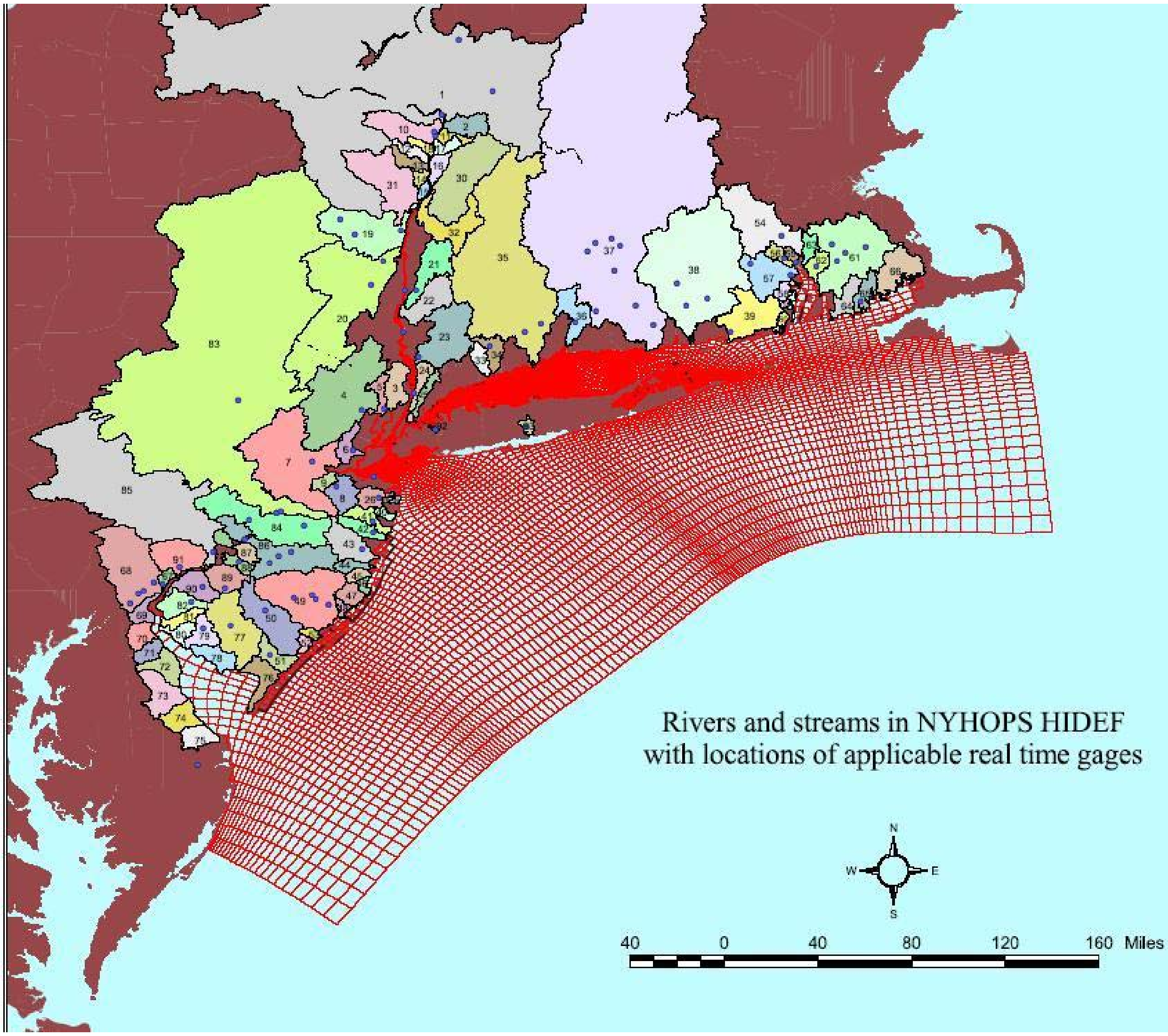


***Figure 3. High-resolution model grid, including tributary watersheds***

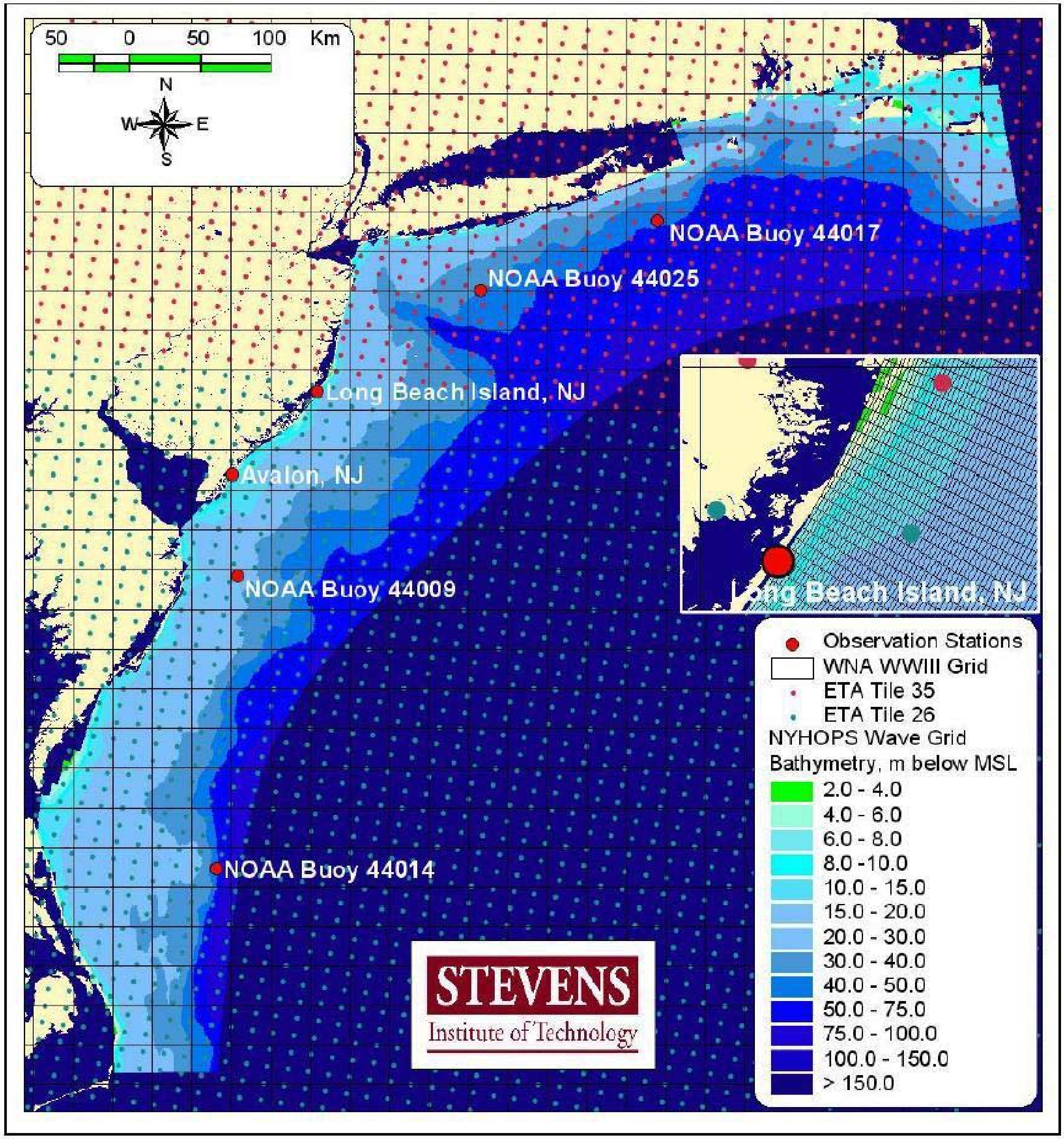


***Figure 4. The NYHOPS Coastal Wave Modeling system. Bathymetry (m below Mean Sea Level), resolution (~1km), Surface (ETA and WRF wind) and Open Ocean (WNA WaveWatch III) boundary forcing sources, and CMN southern NJ observation stations.***

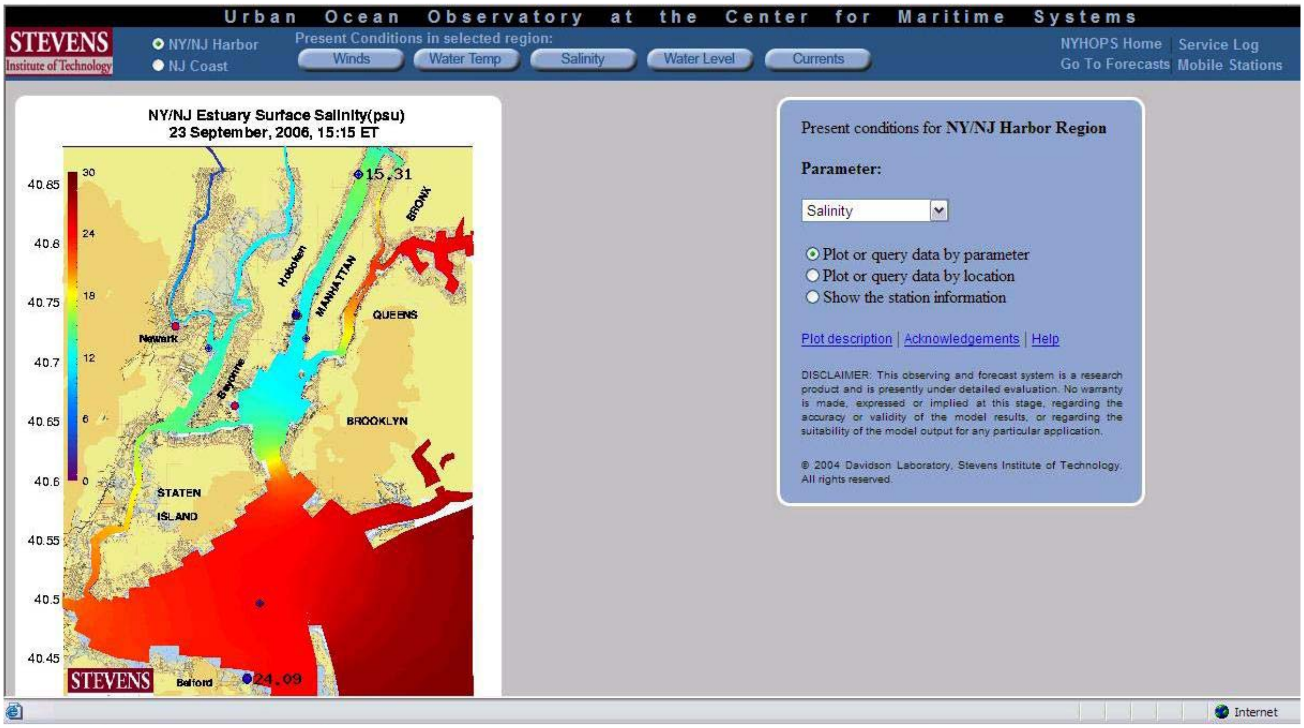


***Figure 5. Screen capture of the NYHOPS website, showing the surface salinity in the Estuary subdomain on 23 September, 2006. The spatial distribution is created using real-time data from the sensor network, the forecasted field that is available every 30 minutes, and an objective interpolation technique. The dots represent the locations of the sensors.***

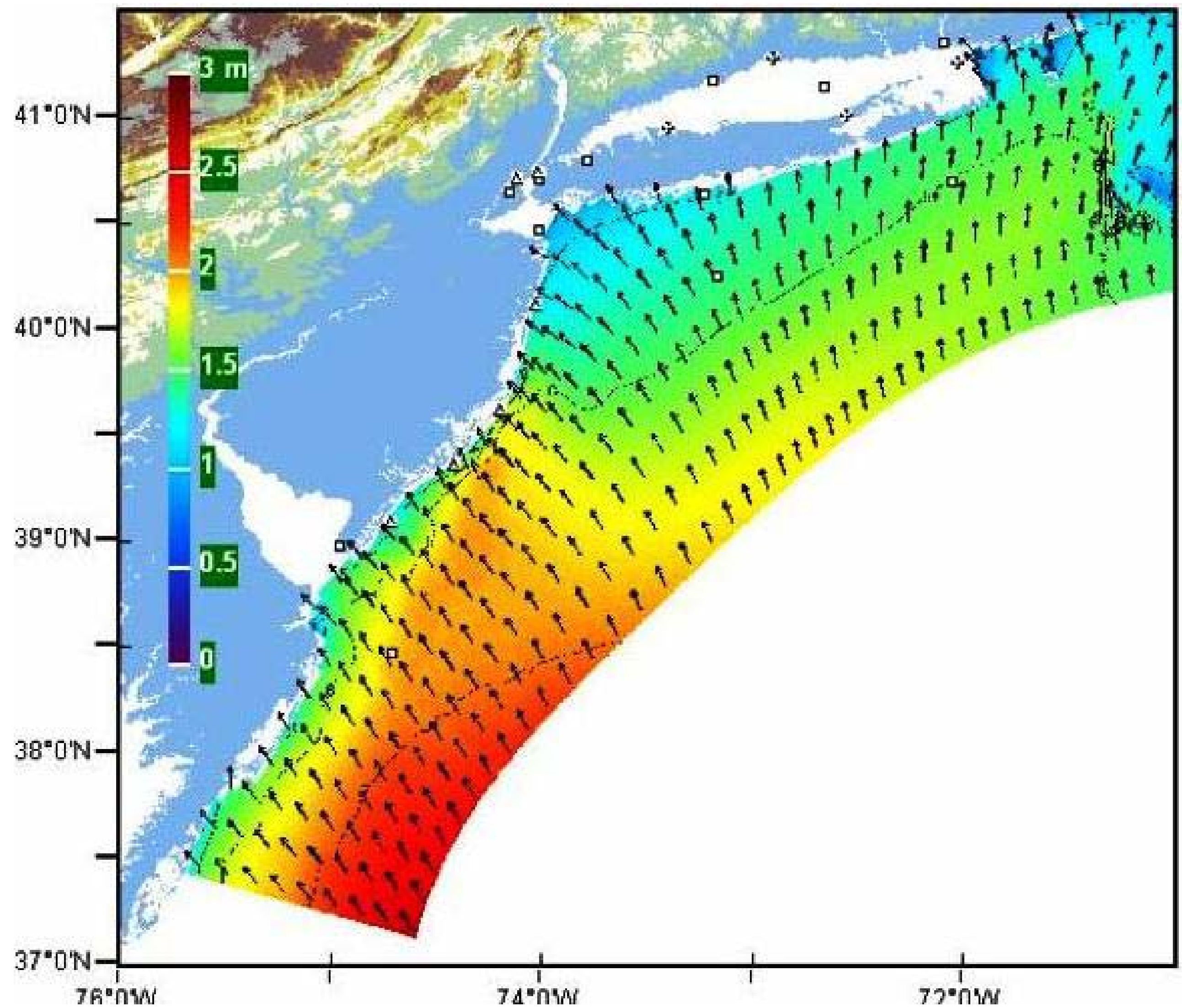


***Figure 6. Predicted waves for June 27, 2006 13:00-14:00 EDT. This is a composite representation of the hourly-averaged wave field. The color map depicts significant wave height ranging from 3m offshore to 1m nearshore; Line contours show wave period ranging from 7sec offshore to 4sec nearshore; Arrows show mean wave direction.***

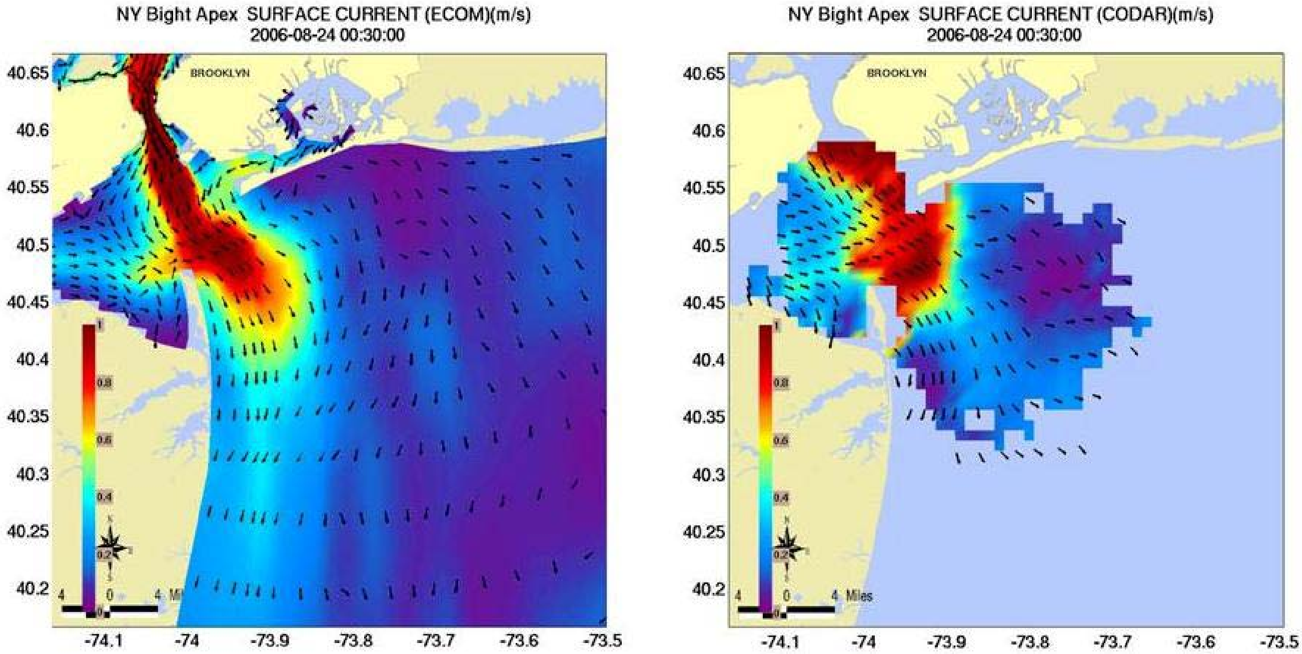


*Figure 7. Comparison of NYHOPS surface current forecast (m/s) (left) with HF RADAR measurement (right) on August 24, 2006.*

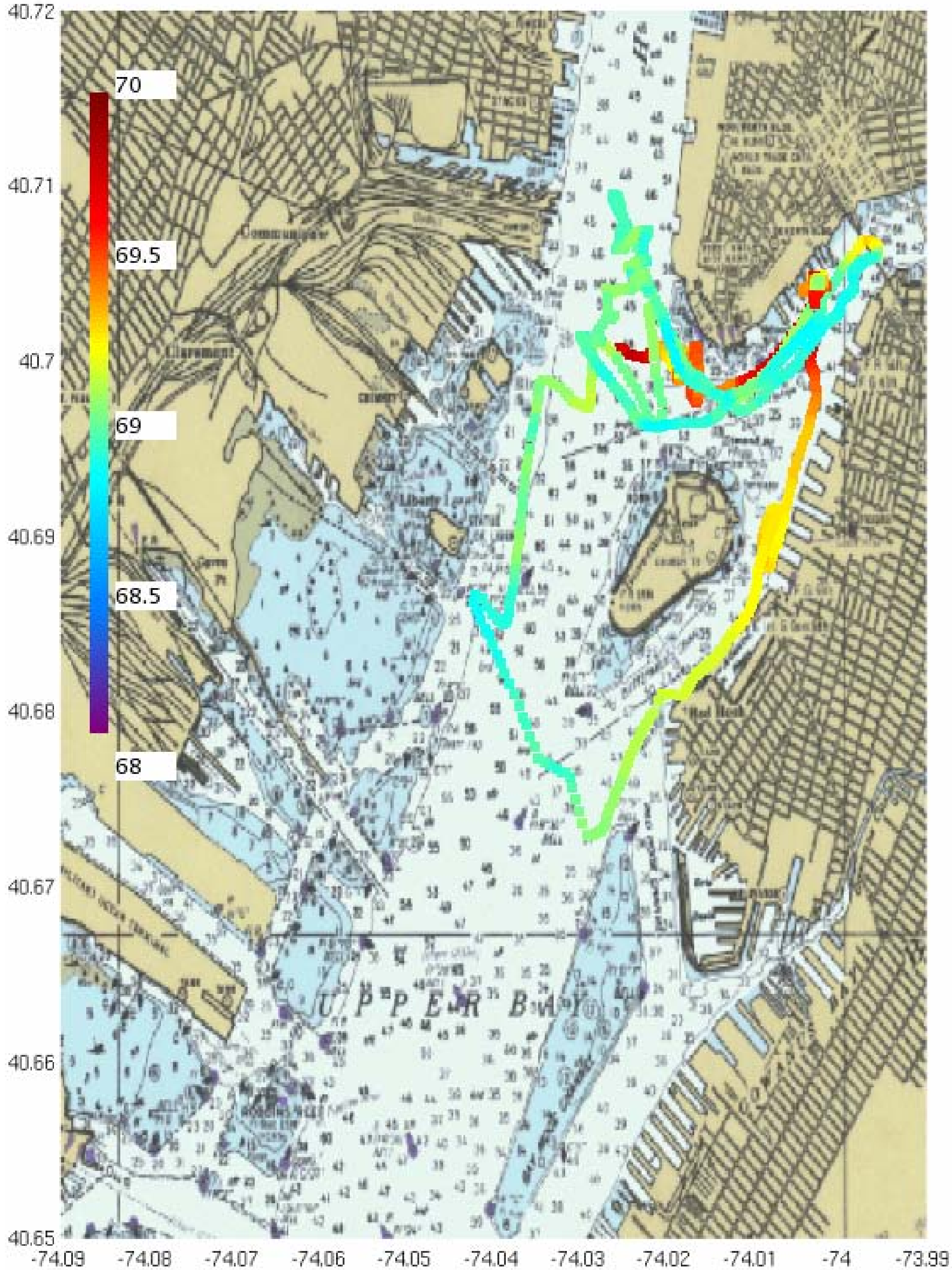


***Figure 8. Real-time measurements of near-surface temperature along the route of the instrumented vessel Pioneer on September 23, 2006 from approximately 0900 to 1645 EDT.***