Real-Time Coastal Monitoring and Prediction for Operations and Research

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Introduction: The coastal ocean is often characterized by vigorous, swiftly evolving fronts and eddies. These features bound waters of different characteristics and can have a high impact on operations and sensor performance. However, their complex dynamics make monitoring and prediction challenging. These features and other environmental conditions must be identified or forecast in near real time so that sampling can be designed to study them and operations can be modified to optimize performance based on their impact. This topic was one of the main research thrusts of a recent Joint Research Project (JRP) between the Naval Research Laboratory (NRL) and the NATO Undersea Research Centre (NURC). In the framework of this JRP, an international, collaborative research effort was developed involving more than 20 different research groups from seven countries. The research focused on winter and summer experiments in the central Adriatic Sea, an archetypal coastal area for fronts and eddies. NRL, in collaboration with the other institutions, implemented and tested a complete, real-time, coastal monitoring and prediction system during three "Dynamics of the Adriatic in Real-Time" (DART) cruises. Here we describe some tangible results and implications of the real-time monitoring and prediction thrust of this work.

Real-Time Coastal Monitoring: For the DART experiments, a near-real-time, in situ measurement and reporting system was used for adaptive sampling, forecast validation, and demonstration of real-time operational capabilities. The system consisted of satellite remote sensing products, surface drifting floats, and new Shallow-water Environmental Profiler in Trawl-resistant Real-time (SEPTR) configuration moorings. The SEPTRs sit on the ocean bottom with a shape and weight distribution (lower left panel of Fig. 4) designed to resist damage from fishing equipment. A profile is made by a buoy from the SEPTR base to the ocean surface at programmable intervals to transmit previous measurements and then make new measurements throughout the water column while returning to the protective SEPTR base. The SEPTR technology enabled near-real-time monitoring of waves and profiles of ocean velocity, temperature, salinity, and optics in a heavily fished frontal zone.

All the real-time data were collected, processed, and posted to password-protected NURC ftp and web sites accessible to scientists both at land-based laboratories and aboard the NURC ship with a high bandwidth satellite link. In particular, during the first summer cruise, graphics (e.g., Fig. 4) from three SEPTRs were prominently featured on the experiment web page and updated every measurement cycle (6 hours) showing the last 48 hours of transmitted velocity, sound speed, density, temperature, and salinity profiles. Multiple SEPTR moorings made it possible to track significant mixed-layer depth changes both in time and space.

The real-time measurements successfully improved scientific sampling during the research cruises. Examples include the NURC real-time processing of Advanced Very High Resolution Radiometer sea surface temperature (SST) and Moderate Resolution Imaging Spectroradiometer (MODIS) thermal and ocean-color images used during the winter cruise to identify a rapidly evolving frontal filament for focused sampling. Also, the automatic ftp posting of processed MODIS Terra (AM Orbit) and AQUA (PM Orbit) SST and chlorophyll concentration images by NRL was used to identify several different eddy and current meander events and verify numerical model predictions. In another example, the transmitted velocity data from a SEPTR showed a clear daily pattern of high and low vertical shear caused by the interaction of a mean current and an inertial oscillation, which was an environmental consideration for microstructure turbulence measurements.

Real-Time Coastal Prediction: The second component of the real-time-support thrust of the DART experiments was the implementation, use, and validation of a wide variety of meteorological, ocean, and wave prediction systems (more than a dozen were used). The products most used for real-time support were from the Navy Coastal Ocean Model (NCOM) and the Simulating WAves Nearshore (SWAN) model run by NRL; the Limited Area Model Italy (LAMI) meteorological model, the Adriatic Regional Ocean Modeling System (AdriaROMS), and the SWAN model run by the HydroMeteorological Service of the Regional Agency for Environmental Prevention in Emilia-Romagna (ARPA-SIM); and the Aire Limitée Adaptation Dynamique développement InterNational (ALADIN) meteorological model run by the Croatian Meteorological and Hydrological Service (CMHS). All these tools provided daily nowcasts and forecasts of the

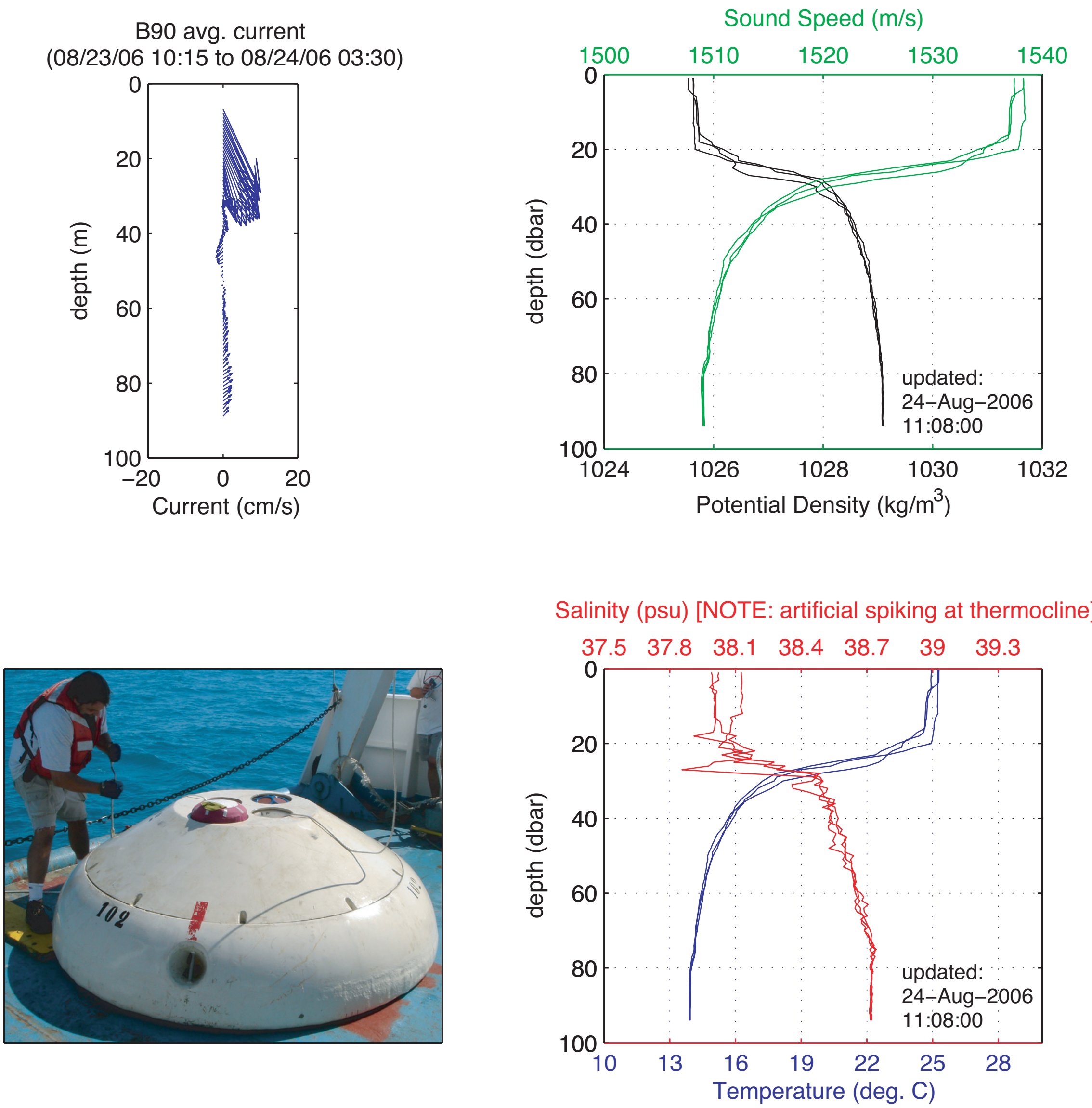

FIGURE 4
A SEPTR mooring and examples of near-real-time data display. Upper left panel and both right panels show the most recent 48 hours of measured and transmitted profiles of ocean velocity, temperature, salinity, density, and sound speed from one SEPTR as of August 24, 2006, 11:08 UTC, in the same form as displayed on the experiment web page. Lower left shows the SEPTR in its trawl-resistant configuration as used on the ocean bottom.

environmental state of the central Adriatic and were used for both short- and long-term planning.

Figure 5 shows an example of the scientific benefit of having accurate forecasts from numerical ocean and meteorological models. Cruise sampling was redesigned to verify the existence and capture the evolution of the predicted (boxed in red) northern anticyclone in this 48-hour ALADIN surface wind and NCOM ocean current and temperature prediction graphic (left panel of Fig. 5). The SEPTRs indeed showed anticyclonic turning (right panel of Fig. 5) and the high-resolution, in situ sampling suggested the presence of colder offshore water being advected onshore as predicted. In a similar event (not shown), a summer cruise measured a major meander of the coastal current system based on NCOM and AdriaROMS ocean forecasts.

During storm conditions, high-resolution wind and wave forecasts are essential for planning ship operations that are sensitive to sea state. During the final mooring recovery stage of the cruises, 48-hour wave forecasts were provided to the ship for each mooring of interest from the ARPA-SIM runs of LAMI and SWAN (Fig. 6, upper panel). Based on this figure, the ship was redirected to arrive at mooring B50 near forecast hour 27 to take advantage of the predicted short-duration lull in wave activity. As shown by the NRL-run SWAN model in the lower panel, the spatial variability in the forecast for this event was as important as the temporal variability.

Conclusions: The DART experiments showed the power and importance of reporting measurements and providing environmental forecasts to ships in near real time. Without these, the experiments would have been less successful, as many of the frontal events that were the focus of the research effort would have been missed. For operations, high-resolution predictive systems and new, in situ measurement systems can accurately quantify sound speed variations and other environmental impacts in complex frontal regions.

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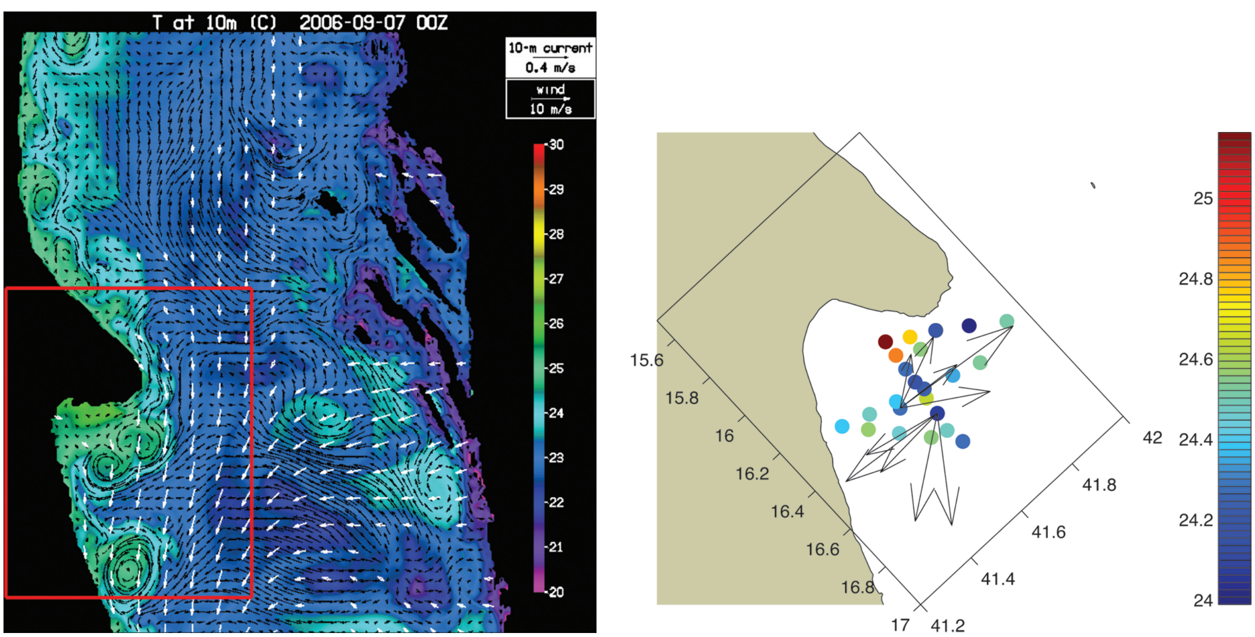

FIGURE 5
Forecast and adaptively sampled environmental conditions. Left panel is NCOM-predicted temperature (color) and ocean currents (black arrows) at 10 m depth and ALADIN surface winds (white arrows) on September 7, 2006, 00 UTC, forecast 48 hours earlier. Twenty-six hours of conductivity, temperature, and depth (CTD) data were collected from a ship (10-m temperature data shown as colored dots in the right panel) starting on September 8, 2006, 18 UTC, and two SEPTRs measured CTD data (10-m temperature data also shown) and velocities (10-m values are black arrows, right panel).

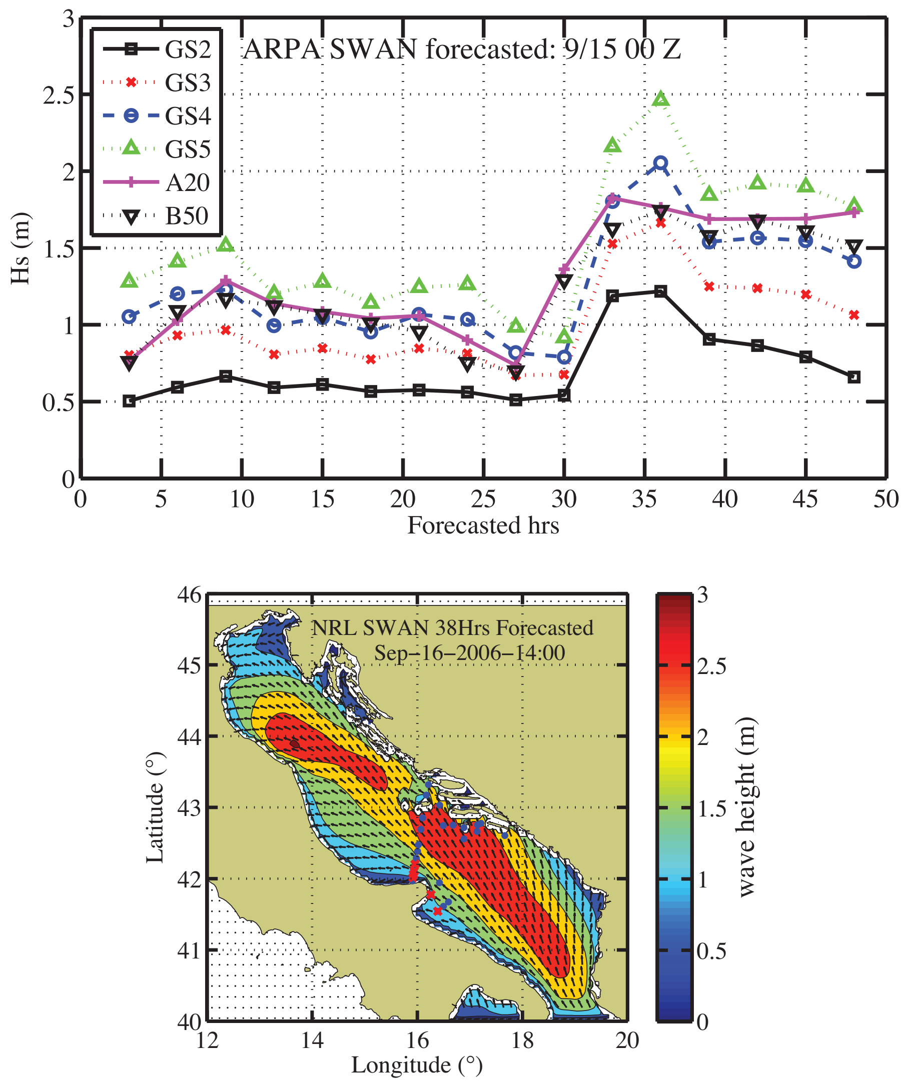

FIGURE 6

Temporal focused graphic of wave forecasts used for operation planning and the spatial pattern of waves near the storm maximum. Upper panel is forecast of significant wave height at several mooring locations during the forecast cycle starting at September 15, 2006, 00 UTC, from the ARPA-SIM SWAN run. Lower panel is NRL SWAN forecast significant wave height and mean wave direction at hour 38 for the entire Adriatic.