

## A National Oceanographic Partnership Program Award

### ***Front Resolving Observational Network with Telemetry (FRONT)***

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### Long-Term Goals

The **Front Resolving Observational Network with Telemetry (FRONT)** experiment is designed to evaluate the feasibility of making useful coastal ocean forecasts with a coarse array of instruments that telemeter data in near-real time for use in an assimilative numerical model. Direct observations are used to evaluate the model predictions.

### Objectives

The FRONT site is a portion of continental shelf south of the eastern end of Long Island, New York (Figure 1a). Historical observations indicate that variable bathymetry and strong tides interact with energetic wind- and buoyancy-forced motions to produce recurring fronts. Our objective is to develop and test the observation system in this complex dynamical regime. Technical objectives include coordination and telemetry of real-time data streams from a combination of in situ instruments; the development of an assimilative model to provide operational forecasts; and the development of technology and procedures for acquisition of multi-scale observations to evaluate the model.

### Approach

Data telemetry and instrument control will be accomplished with an acoustic underwater communications network that interfaces with buoy-mounted cellular modems to connect the insitu instruments to the terrestrial internet. The network features multiple acoustic modems connected in a topology that can tolerate failure or loss of individual elements. Figure 1c shows the topology used in the spring of 2002. The data is assimilated using the generalized inverse method to compute non-tidal adjustments to the sea level at the open boundaries of the model domain. These are then used, with wind and satellite-derived surface temperature observations to force the three dimensional, non-hydrostatic model known as MITgcm. The predictions of the model are evaluated by comparison to ship survey data.

Work Completed

The FRONT Observation System modeling capability was completed in the spring 2002. The model domain is shown in Figure 1(a) with an example of the surface salinity distribution in Figure 1(b). This package consists of a set of matlab scripts, driven by a single driving routine that, based on dates of desired state variable estimates, (1) determines model initializations, (2) generates forcing files (tidal, wind, sea-surface height), (3) runs initial forward model, (4) calculates initial model-data statistics, (5) drives inverse calculation, (6) reruns forward model with improved boundary forcing fields, and (7) generates final model-data statistics. Linking each of these processes and their output allows the observatory to function in a nearly automated fashion and with minimal operator intervention. In addition, it also unifies model termination and restart and thus enables simple estimation of sequential periods.

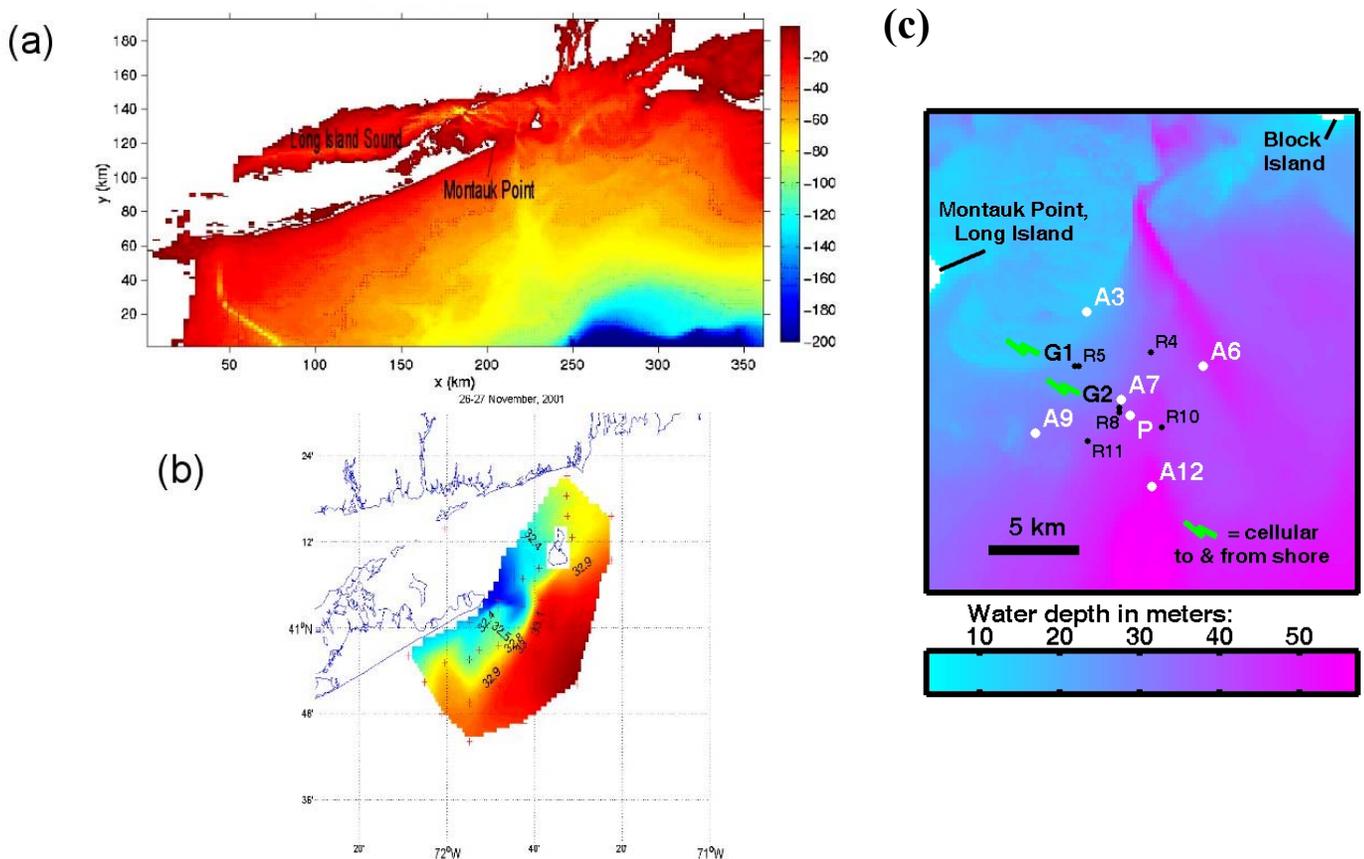


Figure 1: Two different magnifications of the FRONT site. (a) the model domain with the bathymetry color contoured; (b) the surface salinity in the study area in the fall of 2001; and (c) the location of five ADCPs (white) and the acoustic-cell gateways to the landbased internet [graphic: (a) A map showing the bathymetry of Long Island Sound and the adjacent shelf; (b) a map of the surface salinity between Long Island and Block Island showing a 1 PSU jump across the front tending southwest from Block Island; (c) a color shaded representation of the bathymetry in the area of the moored array with the location of the ADCPs and the acoustic to cell data gateway.]

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We conducted three major deployments of the 10 km by 10 km moored ADCP array during fall, winter and spring. The acoustic communication network demonstrated adaptive re-routing of data through multiple nodes, as well as modification of instrument sampling parameters, in real time from shore. Data were posted on the FRONT Web site in real-time and statistics detailing the performance of the subsurface acoustic communications were collected.

During the moored array deployments we conducted nine large scale surveys of the hydrography and circulation and nine fine scale surveys. Surveys have revealed detailed structure of frontal boundaries ~100 m wide (Figure 2). The NUWC turbulence measuring REMUS AUV was deployed during many of the small scale surveys.

### Results

We operationally tested the complete observatory system during a 10-week period from March 28 to June 8, 2002. The demonstration was divided into 3 segments: 3 weeks of forward model spinup; 3.5 weeks of data-based hindcasts; and 4 weeks of near-real time, data-based hindcast/forecasts. Observatory estimates were based on 7 day model integrations using 3.5 days of data from 2 moored ADCPs transmitting through the submarine acoustic network. Thus 7-day integrations consisted of 3.5 day hindcasts, and 3.5 day forecasts. Estimates of surface velocities as well as salinity and temperature were available in near-real time on our web site. This test generated a substantial amount of data that is currently undergoing analysis. The initial comparison of the model fields and surveys is encouraging.

Observation with a towed array, the URI ACROBAT and the NUWC turbulence measuring REMUS AUV were obtained at several fronts. Figure 2 shows the salinity structure of a front in the area of the moored array and the accompanying across-front velocity component. The horizontal scale of this front is less than 100m. Over this distance the velocity component changes by almost 50 cm/s. The structure suggests rapid downwelling and strong vertical accelerations.

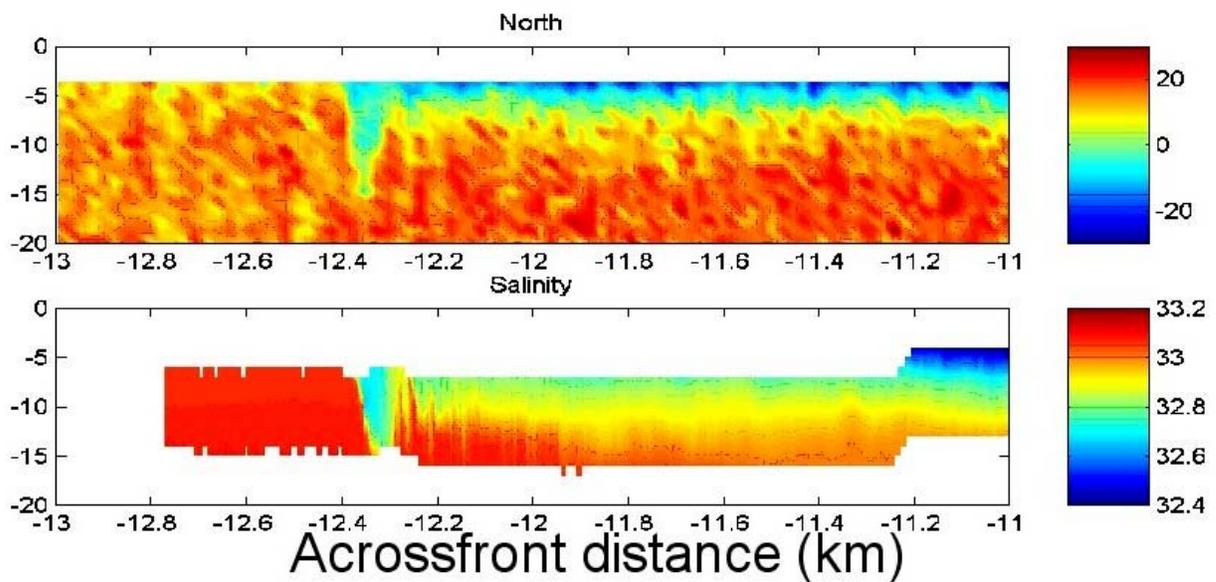


Figure 2: The fine-scale, across-front structure of a front measured with a short toad array and a 600 kHz ADCP. The upper frame shows the north component of velocity and the lower frame the salinity.

[graphic: (a) A two km vertical section of the north component of velocity showing a southward flow of 20cm/s near the surface and a northward flow of 0 cm/s below 7m, and (b) the corresponding salinity section with a large vertical gradient at approximately 10m. Both figures indicate a 100m wide frontal zone. ]

### Impact and applications

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This project has demonstrated that a fairly inexpensive, re-locatable, array of current meters with a subsurface wireless telemetry network that is robust to physical interference and can be deployed to provide data to shore. In conjunction with archived hydrography, the telemetered data can be incorporated in a data-assimilative numerical model to realistically simulate the environment in an operational mode for tactical naval applications. The model is effective in predicting currents, salinity and temperature. The telemetry technology could also be exploited to deliver data from monitoring networks to shore without the expense or disruption to the environment associated with cables.

The FRONT experiment schedule includes planned outages during which the fielded network may be used by SSC-SD to test prototype deployable sensors for surveillance, and other autonomous undersea devices, including mobile network nodes such as autonomous underwater vehicles (AUVs). The concomitant knowledge of the ocean structure provided by the FRONT system will allow SSC-SD to diagnose the relationships between network performance and the environment.

FRONT is a non-military application of the US Navy's Seaweb program for critical future Navy applications such as littoral ASW and autonomous operations. During the June 2001 Fleet Battle Experiment India (FBE-I), many of the Seaweb refinements implemented for FRONT were successfully demonstrated in conjunction with two prototype DADS sensors networked with an ashore ASW command center and a submerged US Navy fast-attack submarine.

### Economic Development

- The development of the "telesonar" acoustic modem technology by Benthos (formerly Datasonics) has been accelerated by their ability to test the equipment in the FRONT environment.
- Modifications to RD Instruments' ADCP firmware have been developed, implemented and tested that enable ADCPs to communicate efficiently with acoustic modems. This product improvement is now in use by other researchers
- Seasciences development of the control system and wing design for their Acrobat towed-undulating sensor platform has also benefited by its use in the FRONT project by the URI partners.
- This project has raised questions about the spatial structure of errors in CODAR estimates of the surface current data that will likely lead to improvement in the technology.

### Science Education and Communication

The FRONT project has supported the education of four graduate students and provided data with which they can advance their research. It has also provided valuable at-sea experience for four undergraduates at the University of Connecticut. In addition, FRONT has contributed to the funding of a DOD DURIP for a new generation turbulence AUV (with UMass-Dartmouth).

### Consideration for Excellence in Partnering Award

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1. **Ocean Sector Diversity:** The participants in the FRONT Project represent the complete spectrum of organizations involved in Ocean Sciences, from academic research institutions to government agencies and both small and large private companies. The leading academic sector partners in the FRONT Experiment include two large state universities (Connecticut and Rhode Island), a leading private university (Massachusetts Institute of Technology), and the Woods Hole Oceanographic Institution. The capabilities of these partners were augmented by groups from two U.S. Navy labs, the Space and Naval Warfare Systems Center (SPAWAR), and the Naval Underwater Warfare Center (NUWC), and the U.S. Coast Guard Research and Development Center (USCGRDC). Spanning the organizational divide between the state and federal agencies, NOAA's National Undersea Research Program (NURP) at UConn, participated in the FRONT team from the outset and became essential to overcoming operational difficulties. Two private sector partners were integral to the project from the beginning, Benthos (formerly Datasonics), and CODAR Ocean Sensors. Sun Microsystems joined the team early in the project by contributing two leading-edge parallel computers to the modeling team at UConn. And SeaSciences, a small Rhode Island Company, was entrained in the project during the field work to further develop the control system for their tow-body, the Acrobat.

Though not formally a partner in the FRONT project, Philip Bogden's role in assembling the FRONT team, the coordination and motivation of the initial phases of the project, the engagement of SUN Microsystems, and the development of the code to assimilate current observations were all crucial contributions to the project.

2. **Partner Involvement:** UConn leads the modeling team with support from the original developers, the partners at MIT. The forecast experiments were substantially assisted by the computing facilities contributed by SUN Microsystems. The moored in-situ observation campaigns were also coordinated at UConn with innovative contributions from the Woods Hole partners and substantial support for ROV operations from NURC. The NURC contacts with local fishing groups also proved valuable in cooperatively locating moored equipment. The URI team led the remote sensing of ocean color, temperature and surface currents in collaboration with CODAR Ocean Sensors. The data-telemetry technology development and testing was collaboration between SPAWAR, UConn, and Benthos with support from RD Instruments. The support of the USCGRDC was to gaining access to the Coast Guard navigational aid off Montauk Point for the acoustic modem-cell phone data link to the moored array, and also to the Coast Guard facilities at Montauk Point and Block Island for the deployment of CODAR stations. The ship surveys of the hydrography and circulation in the study area to evaluate the model predictions were conducted by the UConn and URI teams. The studies of the fine scale variability and turbulent fluxes were a close collaboration between NUWC, URI and UConn partners and supported by the SeaSciences.

3. **Matching Contributions:** The institutions involved in this project contracted to contribute a total of \$4,212,102. In addition, the Sun Microsystem's donation of computing facilities added at least another million dollars to the resources available to the project. The matching funds include partial salary support for the investigators and student. In addition UConn and URI invested their funds in computing machinery, current meters, moored CTD profilers, acoustic modems, ship survey equipment, and the Block Island Sound CODAR network.

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**4. Partner Long-Term Commitment:** The long term commitment of the partners to the FRONT project is substantiated by their investment of institutional resources in the observatory infra-structure (current meters, moored CTD profilers, acoustic modems, towed instruments and CODAR). The individual PI's have also demonstrated their commitment by authoring proposals and generating support for additional work in the area that exploits the FRONT project infrastructure. Several proposals are pending but payoff from the FRONT investments include:

- Codiga's Connecticut Sea Grant funded collaborative project with the State University of New York at Stony Brook (SUNYSB) to Long Island Sound and instrument a cross-ound erry to measure salinity, temperature and the water velocity profile along its regular track;
- Edwards and Kremer's EPA funded project to expand the FRONT model into Long Island Sound.
- O'Donnell, Ullman and Edwards Coast Guard funded project in collaboration with Microsystems Integration Inc. (a small private company) to exploit CODAR observations in search and rescue applications.

**Success in Project Objectives:** The FRONT project had two major objectives supported by the NOPP: (A) the development of a now/forecast model based on the MITGCM that assimilates telemetered data from a sparse array of instruments; and (B) acquire data with which to evaluate the skill of the model in representing nature with particular emphasis on the frontal structures.

The first objective was divided into several tasks associated with the development of the in-situ instrument deployment hardware that was robust and could survive fishing gear, the implementation of an underwater acoustic internet for data telemetry to shore and the development of numerical model with techniques that would allow data assimilation. All of these tasks have been spectacularly successful. Despite the challenges of fishermen, bad weather and vigorous tides, the practicality of underwater acoustic data telemetry network in a shallow inner shelf area has been demonstrated. The public-private partnership between SPAWAR, UConn and Benthos has been particularly effective. Descriptions of the hardware and the preliminary network performance have been published (Codiga et al., 2000; Porta et al., 2001; Codiga et al., 2003). Edwards et al. (2003a and b), have prepared two manuscripts describing the model developments and the physical processes in the FRONT domain. In addition, a Master's thesis at UConn (Rear, 2003) describing the tides in the study area has been completed and prepared for publication. The moored array deployments have generated extensive ADCP records. A summary of the observations and the data files are available on the project website (Codiga and Houk, 2002). In the spring of 2002, the partners' efforts culminated in a two month period in which current data from five ADCPs was telemetered to shore in near-realtime and assimilated in the MITCGM to produce seven day forecasts.

The second objective has also been successful. Ten surveys of the large scale variability of the circulation have resolved the seasonal differences. In addition, an analysis of the CODAR surface current observations (Ullman and Codiga, 2003) has demonstrated substantial seasonal variability in the inner shelf circulation and linked it to the seasonal variability in the horizontal temperature gradient. The fine scale observations using the NUWC AUV, the URI Acrobat and the UConn towed array have revealed completely unresolved structure. An initial comparison of

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the model results to the hydrographic fields at both large and fine scale is encouraging. It is clear that the data assimilation improves the representation of the front. A thorough comparison and evaluation is still underway, we expect that the project will guide further investigation of the role of non-hydrostatic effects on the inner shelf and estuarine outflows.

### Publications

Codiga, D. L., J. A. Rice, and P. S. Bogden (2000). Real-time delivery of subsurface coastal circulation measurements from distributed instruments using networked acoustic modems. Proc. MTS/IEEE Oceans 2000, 1, 575-582.

Codiga, D.L. and A.E. Houk (2002). Current profile timeseries from the FRONT moored array. Technical Report, Department of Marine Sciences, University of Connecticut, 19 pp. <http://nopp.uconn.edu>.

Codiga, D.L., J.A. Rice, and P.S. Baxley (2003). Networked acoustic modems for real-time data delivery from distributed moorings in the coastal ocean: initial system development and performance. J. Atmos. and Oceanic Tech (submitted).

Codiga, D.L. and L.V. Rear (2003). Observed tidal currents outside Block Island Sound: Effects of estuarine outflow, stratification, and friction. In preparation for JGR-Oceans.

Edwards, C.E., T.A. Fake and P.S. Bogden (2003). A numerical model investigation of spring-summer frontogenesis at the mouth of Block Island Sound. (In prep).

Edwards, C.E., T.A. Fake, D. L. Codiga and P.S. Bogden (2003). Combining ADCP records with a GCM using a linear depth-averaged inverse model: the effect of low frequency motions on fronts near Block Island Sound. (In prep)

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Porta, D., J. Rice, and D. Codiga (2001). Acoustic modem multi-access networking for data acquisition. Sea Technology, 42(5), 10-14.

Rear, L. V. (2002). Observations of tidal current and stratification profiles on the continental shelf outside Block Island Sound. M.S. Thesis, Department of Marine Sciences, University of Connecticut, 64 pp.

Ullman, D.S. and D.L. Codiga (2003). Seasonal variation of a coastal jet in the Long Island Sound outflow region based on HF radar and Doppler current observations. Journal of Geophysical Research – Oceans (submitted)