

Real-Time Observations of a Coastal Upwelling Event Using Innovative Technologies

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LONG-TERM GOALS

The long term goals of this project are to develop a measuring capability for tracking and forecasting the development and decay of coastal upwelling circulations. A suite of real-time, remotely sensing instruments will input to a 3-D, data assimilating numerical model, which will support both circulation and ecosystem (e.g., bioluminescence potential) predictions.

OBJECTIVES

The objectives of this program are to demonstrate the utility of aircraft-derived sea surface temperature (SST) maps, together with HF radar-derived surface velocity maps, in tracking coastal upwelling fronts. These data should be useful in guiding at-sea measurements and in constraining numerical circulation models. Additional objectives include demonstration of real-time acoustic telemetry of velocity profiles from a bottom-mounted ADCP, which should provide critical subsurface data.

APPROACH

The approach taken has been to extend the unique suite of oceanographic and atmospheric sensors in and around Monterey Bay by flying additional sensors onboard a small airplane, and by deploying a newly developed acoustic telemetry system with an ADCP in a trawl resistant bottom mount (TRBM), during a period when the Office of Naval Research (ONR) and the Monterey Bay Aquarium Research Institute (MBARI) were sponsoring a multi-ship field program. The extended measurements complemented a three-site High Frequency (HF) radar network and three deep-ocean moorings already in place around Monterey Bay. A fourth mooring, the NPS Flux Buoy, was deployed within Monterey Bay during the course of the intensive field measurements, which took place in August 2000. An extensive modeling effort led by I. Shulman of the Univ. of S. Mississippi has taken place in parallel with these data-based efforts. (Model results are reported separately by Dr. Shulman.)

WORK COMPLETED

The field measurements were successfully completed in August 2000. Data analysis and preliminary data assimilation tests have been conducted in the ensuing year. The field effort was highly successful in each of the four areas targeted during the August campaign: 1) repeated aerial SST and wind mapping, 2) real-time acoustic telemetry of bottom-mounted ADCP data, 3) real-time surface velocity

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mapping from multiple HF radar sites, and 4) enhanced moored observations of surface winds. Because these data built on the observations in place for the Innovative Coastal-Ocean Observing Network (ICON) project, the focus was on the aircraft- and TRBM-based data. Photographs of the support aircraft, Flux Buoy, and the TRBM are shown in Figure 1.



Figure 1. Photographs showing (clockwise from left) NPS Flux Buoy, twin-engine Navajo aircraft operated by SPAWAR and Gibbs Flight Center, Radio and acoustic telemetry mooring, and TRBM with ADCP and acoustic modem.

Thirteen aircraft surveys of Monterey Bay were conducted during the period 17-31 August 2000 (see: http://www.oc.nps.navy.mil/~icon/collaborations/muse_flights). Velocity profiles over a 90 m water column in the northern portion of Monterey Bay were also obtained from an ADCP with acoustic telemetry capabilities during that period, while the NPS Flux Buoy was deployed in the eastern portion of the Bay. The aerial surveys provide an unprecedented time history of SST and winds during the period, which illustrate a complete cycle from strong upwelling circulation to onshore migration during relaxation/downwelling wind conditions. The aircraft data were collected from an altitude of 130m, which was below a thick stratus layer on most occasions. For comparison, only one useable SST map was obtained during the two-week flight period from satellite-based sensors.

RESULTS

The results of the data collection and analyses have been to provide a clear description of ocean currents and temperatures during the August 2000 field experiment. In addition, a dramatic set of wind maps were collected from the aircraft that show small-scale structures, including wind jets that correlate directly with current jets along the upwelling front. One such feature was observed on 17 August 2000 when strong, upwelling favorable winds formed a narrow jet across the mouth of Monterey Bay whose scales matched the narrow and cold ocean current in the same location. The SST feature and associated HF radar-derived surface currents are shown in Figure 2 along with the aircraft

trajectory, which was typical of the 13 separate flights, and the TRBM location. Subsequent SST maps showed the ocean response to weakened winds, which involved onshore movement of warm water, disappearance of the wind jet, and weakening of the upwelling jet.

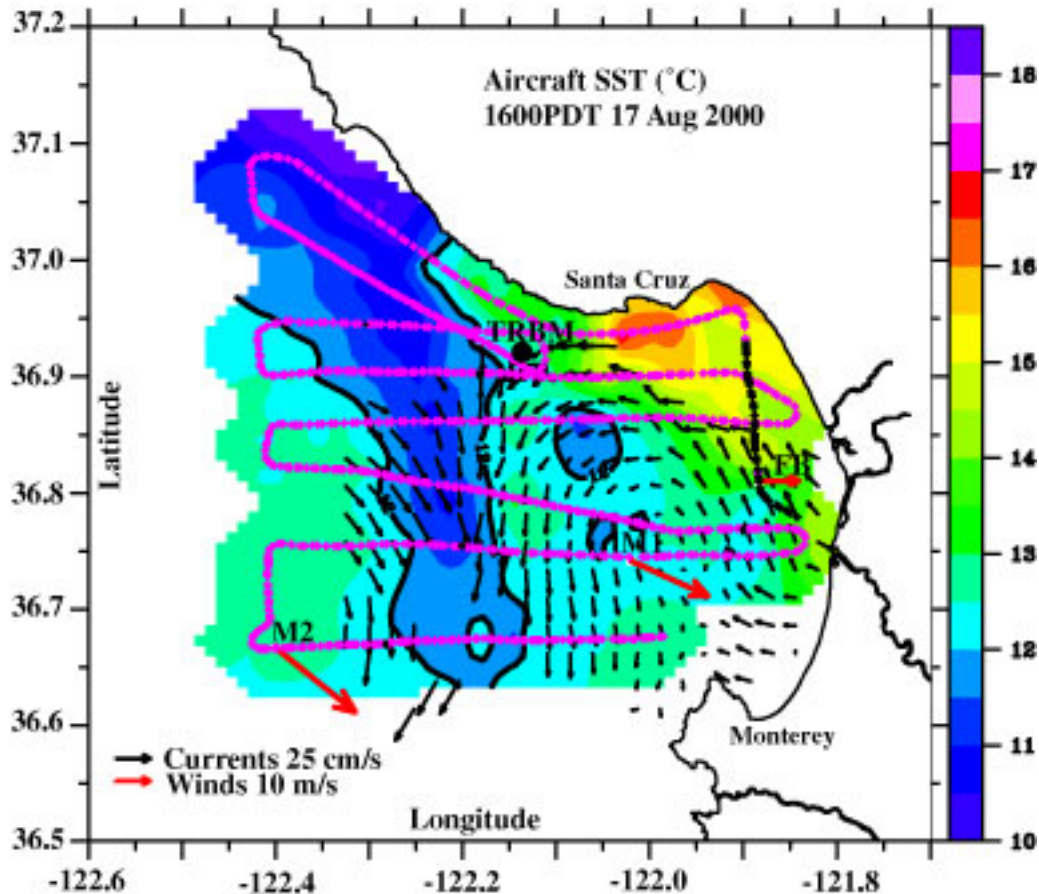


Figure 2. SST on 17 August measured under the aircraft flight path (purple lines) from an altitude of 130 m with a downward-looking radiometer. Surface wind vectors at MBARI(M1 and M2) and NPS (FB) moorings are shown along with HF radar-derived daily averaged surface velocity. Subsurface velocity data were collected from an upward-looking ADCP at the site marked TRBM. [Figure shows a 10 km-wide cold band of 10-11 °C surface temperature across the mouth of Monterey Bay. Inside the Bay, temperatures range from 12-17 °C. Surface velocity shows cyclonic flow and wind stations show along-coast flow from NW to SE.]

Air temperatures, dew point, and wind velocities measured by the aircraft on 17 August showed a tongue of warm and dry air that mapped precisely onto the cold SST feature in Figure 2. Clearly, atmosphere-ocean coupling exists on these small, ~10 km, coastal scales during upwelling-favorable wind conditions. The wind jet, coupled with the relative shelter of Monterey Bay, produced significant positive wind stress curl, a feature that is seldom incorporated in wind models. For ICON and related projects, however, NRL has initiated a COAMPS reanalysis project that covers this region with 9 km horizontal resolution. Winds mapped by the aircraft and predicted by COAMPS are shown in Figure 3 along with values of the wind stress curl. Model winds miss the narrow jet across the mouth of the Bay, but they include the sheltering inside the Bay and the positive curl.

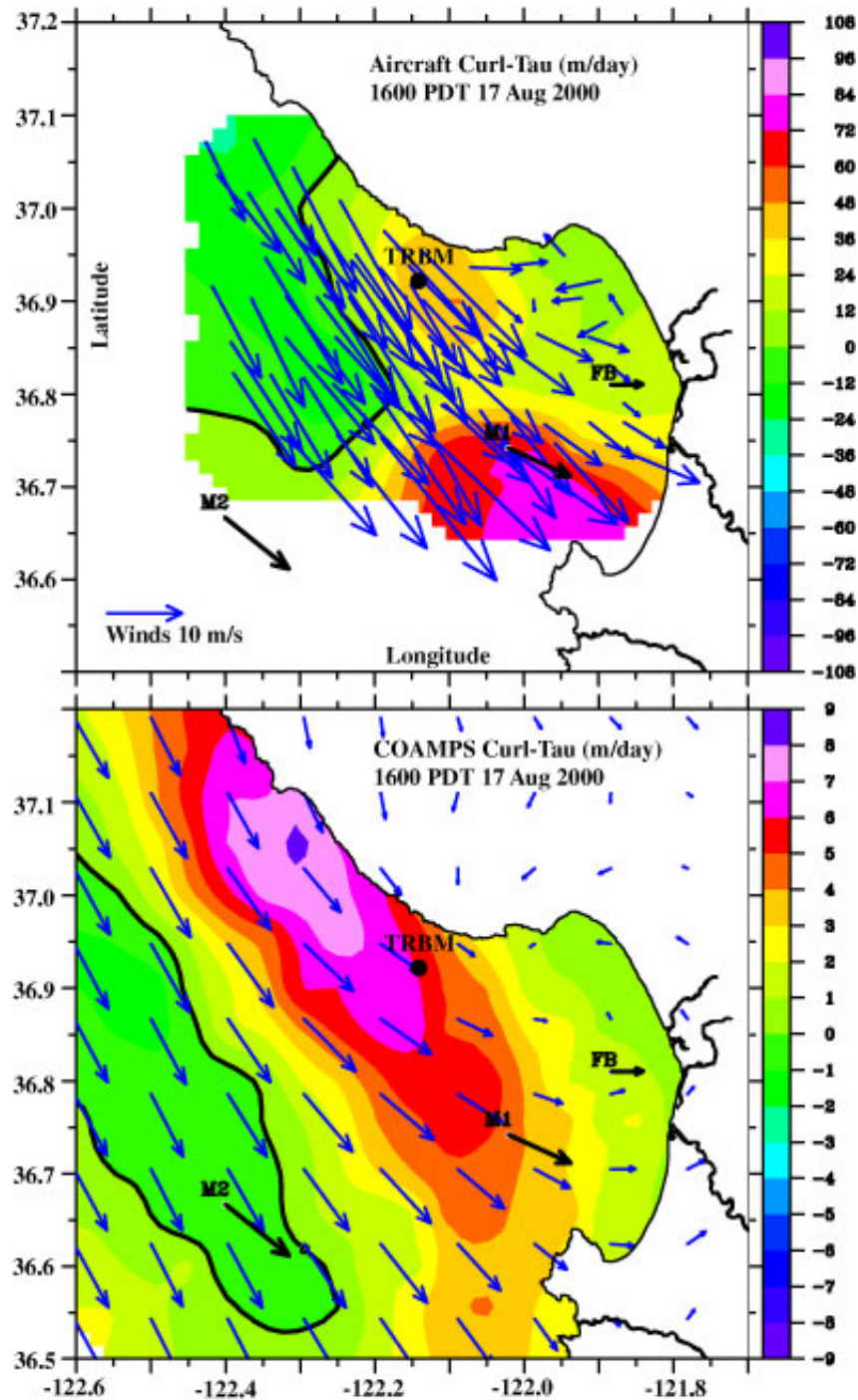


Figure 3. Aircraft winds at 130 m and COAMPS model surface winds together with observed surface winds at the mooring sites and computed wind stress curl. [Upper panel shows northwesterly aircraft winds around 15 m/sec outside the Bay with weaker winds around 5 m/sec inside the bay. Lower panel shows a similar pattern from COAMPS model surface winds. Positive curl around 30 m/day and 6 m/day exist over Monterey Bay for aircraft and COAMPS winds, respectively.]

Velocity profiles from the TRBM site exhibited mean flow to the northwest, out of Monterey Bay. At higher frequencies, the data also exposed the presence of large, non-linear internal waves resembling solitary wave packets. Timing between soliton packets was variable, suggesting multiple generation sites. Although short-lived, horizontal and vertical velocities associated with the packets are strong enough to affect AUV performance and alias section data. Bottom pressure (sea level) and mid-column vertical velocity fluctuations are shown in Figure 4 during a portion of the two-week record. It is worth noting that stable instrument mounts, such as the TRBM, are required to be able to measure vertical velocity.

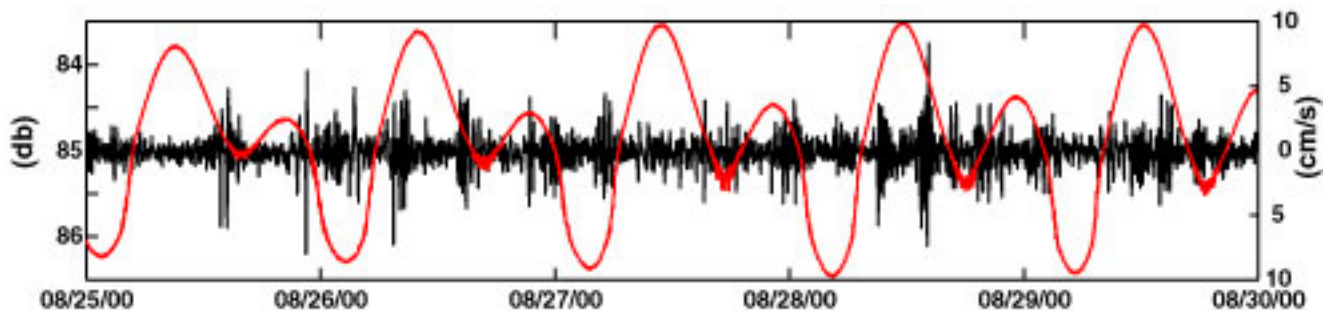


Figure 4. Bottom pressure (red) and 39 m vertical velocity at the TRBM site. [Figure shows semi-diurnal sea level fluctuations superimposed on a record of vertical velocity, which is dominated by packets of reversing velocities with magnitudes of plus or minus 5 cm/sec existing for several minutes at a time. Individual packets are separated by 4 to 16 hours.]

IMPACT/APPLICATIONS

The likely impacts of these observations will be the increased use of coastal SST and wind mapping with small aircraft and increased use of acoustic telemetry.

TRANSITIONS

The transition opportunities are in the area of rapid environmental assessment (REA) with increased use of aircraft, acoustic telemetry, and HF radar. These advances will also directly impact circulation models making them better-equipped to produce nowcasts and forecasts in the coastal ocean.

RELATED PROJECTS

This project is closely related to ONR programs N00014-97-1-0171 (Shulman) and N00014-98WR-30170, N00014-99WR-30118, and N00014-00WR-20160 (ICON). The August 2000 field program coincided with the ONR Autonomous Ocean Sampling Network (AOSN) program and the MBARI MUSE program (<http://www.mbari.org/MUSE>).

PUBLICATIONS

Paduan, J. D., M. Cook, D. M. Fernandez, C. Whelan, I. Shulman and C.-R. Wu, 2001: Statistics and data assimilation results from long-term HF radar-derived surface currents around Monterey Bay, California. Proceeding, 1st Radiowave Oceanography Workshop (ROW1), 7-9 April, 2001, Timberline Lodge, Mt. Hood, OR, 8 pp.

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