The Prediction of Wind-Driven Coastal Circulation

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Industrial Partners: J. Svejkovsky (Ocean Imaging), D. Barrick and B. Lipa (CODAR)

LONG-TERM GOAL

To develop forecast systems for wind-driven coastal ocean flow fields.

OBJECTIVES

To understand the dynamics of, and to build a predictive capability for, wind-driven mesoscale oceanographic processes (2-50 km horizontal space scales, 2-10 day time scales) over the continental shelf as influenced by temporal and spatial variability of the atmospheric forcing, by spatial variability of the continental margin, and by internal mixing related to small-scale turbulence. The ocean features of interest include energetic alongshore coastal jets, upwelling and downwelling fronts, and eddies.

APPROACH

This National Oceanographic Partnership Program project combines modeling, data assimilation and an observational program off Oregon. A high-resolution, three-dimensional coastal ocean circulation model (POM - Princeton Ocean Model) is being applied to an Oregon coastal region for direct simulations, data assimilation and process studies. The ocean model is being forced initially by observed winds and heat flux and the results compared with observations. Eventually, the ocean model will be driven by fluxes from a high-resolution coastal atmospheric model. Data assimilation techniques that test models against data in a scientifically rigorous fashion are being developed.

The observational program includes long-term measurements from the OSU Coastal Radar System presently deployed near Newport. During summer 1999, NOAA ETL partners expanded the land-based radar coverage (J. Harlan) and obtained vertical wind profiles using an upward-looking RASS profiler on the coast (J. Wilczak). Satellite-sensed sea surface temperature and roughness are being made

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available by Ocean Imaging (J. Svejkovsky). Bi-weekly hydrographic and zooplankton sampling was conducted off Newport by NOAA NMFS (W. Peterson). CODAR Ocean Sensors (D. Barrick, B. Lipa) worked on testing the feasibility of improving the direction-finding capabilities of their standard SeaSonde antenna by including up to four additional whip antennae.

Additional measurements by OSU PIs included bi-weekly hydrographic and velocity sampling off Newport using a small research vessel. During May to August 1999, three moorings equipped with current, temperature and conductivity sensors throughout the water column were deployed and successfully recovered off Newport. One of the moorings measured surface winds, pressure, air temperature and solar insolation, and telemetered those data to shore. During July and August, atmospheric soundings were made at Newport on selected days. A three-week cruise aboard the R/V Wecoma was made during July 1999. High-resolution hydrographic, bio-optical, velocity and microstructure data were collected in a region near Newport encompassing the coverage of the land-based radar.

WORK COMPLETED

Modeling and data assimilation studies of coastal oceanic and atmospheric circulation off Oregon are proceeding on several fronts. Atmospheric forecasts are being made regularly with a regional, high-resolution atmospheric model, the Univ. of Oklahoma's Advanced Regional Prediction System (ARPS) (see http://ca.ENGR.ORST.EDU/~barboup/Coast1.html). This nonhydrostatic, mesoscale atmospheric model is initialized and forced with the NCEP Eta model operational forecast and analysis. Model forecasts and forecast statistics are being compared with meteorological observations including moored and coastal surface meteorological stations and RASS profiler data.

Time-dependent, three-dimensional ocean circulation on the continental shelf off Oregon in the region from 41.7 to 47N is being studied using the Blumberg-Mellor, finite-difference, hydrostatic primitive equation model. A limited-area, high-resolution curvilinear grid (< 1.5 km horizontal spacing, 30 vertical sigma levels) with realistic Oregon bottom topography and coastline is used. The grid extends 600 km alongshore and 250 km offshore and contains three open boundaries. The response of the coastal ocean during summer upwelling conditions to forcing by observed wind stress and heat flux is examined for the historic 1973 CUE-2 period and for the OSU NOPP intensive observational period May-August 1999. Work involving forcing this ocean model with surface fields from the mesoscale coastal atmospheric model has been initiated.

Progress has been made on developing a method by which radar-derived surface velocity measurements can be assimilated into coastal ocean models. One aim is to determine how much information about sub-surface fields can be obtained from knowledge of the surface currents. POM is utilized in a high-resolution domain with Oregon continental shelf and slope topography. A series of model-data comparisons indicates that the model is capable of reproducing a substantial fraction of the observed surface and sub-surface velocity variance. An ensemble of summer simulations for 18 different years, forced with observed winds, was used to estimate the non-homogeneous, non-isotropic and non-stationary forecast error covariances for use in sub-optimal, sequential data assimilation schemes such as the Physical-space Statistical Analysis Scheme (PSAS). A series of identical-twin experiments and initial assimilation experiments with CODAR data have been completed.

Data from Oregon State University's land-based HF radar have been collected continuously since November 1997 (see http://www-currents.oce.orst.edu/seasonde). Near-surface currents measured by a mid-shelf upward-looking ADCP and those from the HF radar are highly correlated for subtidal motions (0.84, 0.94 for eastward, northward components respectively) with standard deviations of the differences of about 0.10 m/s in each component.

From May-Sep 1999, hydrographic and velocity sections were obtained in the center of the OSU NOPP study region by towing a small undulating vehicle (Guildline "Minibat") from the 37-foot R/V Sacajawea which was also equipped with a hull-mounted ADP (250 kHz Sontek). Fifteen cross-shelf sections of T, S, fluorescence and light transmission along the Newport Hydrographic (NH) line (44 39.1' N) between the 8 and 100-m isobaths were made at roughly two-week intervals (http://eccles.oce.orst.edu/jay/minibat/home.html).

A set of repeated three-dimensional hydrographic, velocity and bio-optical surveys over the central Oregon continental shelf and slope was obtained during July 1999. The thermohaline fields were measured using the towed undulating vehicle SeaSoar equipped with a CTD and a nine-wavelength light absorption and attenuation instrument (ac-9). Approximately 12,000 profiles were collected during the cruise. Velocity was measured with a 150-kHz shipboard ADCP. The optical measurements are used to estimate chlorophyll, sediment and dissolved organic matter concentrations. Turbulence profiles were obtained during the cruise from a cross-shelf section along the mooring array off Newport. Approximately 1400 profiles of T, S, kinetic energy and temperature dissipation rates, and light backscatter were collected with the OSU Chameleon profiler.

Ocean Imaging (J. Svejkovsky) is developing methods to extract information from Synthetic Aperture Radar (SAR) imagery related to current boundaries, and to use that information in conjunction with AVHRR imagery to study coastal ocean dynamics. SAR penetrates most cloud cover and is of higher spatial resolution (20-100 m) than SST imagery. SAR data has been included in a time series of 1-km resolution SST imagery to study mesoscale upwelling. The remotely sensed data are being compared with available shipboard and land-based radar data as well as with model fields.

NOAA NMFS scientists (W. Peterson) continued to sample the NH line at biweekly intervals between 1 and 15 miles from shore, an effort which began in 1996. At each station a CTD cast was made, secchi depths were determined, surface water samples were collected for nutrients and chlorophyll, and two zooplankton tows were made. The NH line was sampled 23 times during the Oct 98-Sept 99 study period, including five times during the intensive field survey in July 1999.

RESULTS

A comparison of atmospheric model forecasts and observed winds is shown in Figure 1, where vertical profiles of the mean and standard deviation of the cross-shore and alongshore winds for summer (Jun-Aug) 1999 are displayed. The model captures the dominant vertical structure and amplitude of the mean and variable winds in the lower atmosphere.

For the coastal ocean model, comparisons of mean values and standard deviations of the observed and modeled alongshore velocity (v) during the 1973 experiment show that mean values are reasonably close with similar spatial structures. The model standard deviations are generally somewhat smaller than the observed, but show a similar increase toward the coast. Correlation coefficients between observed and modeled alongshore velocity are higher near the bottom than at mid-depth. Space-lagged correlation coefficients for modeled alongshore and cross-shelf (u) velocity show large correlation scales for v and short correlation scales for u, similar to those found in the observations. Preliminary model runs for summer 1999, forced with wind stress and heat flux observed from the OSU NOPP mooring, show the behavior of time-dependent upwelling (Figure 2). For comparison, an example of a daily averaged HF radar-derived surface velocity map is also shown.

Six maps of the hydrographic, velocity and bio-optical fields from about the 50-m isobath (5 km offshore) to out over the continental slope and ranging from 50-130 km alongshore were made (Figure 2). Throughout the month, subsurface isopycnals were tilted up toward the coast consistent with seasonal upwelling. The surface layer (0-20m) showed a great deal more temporal variability as warm, fresh water moved cross-shelf in response to wind forcing. The upwelling front and alongshore jet interacted with two submarine banks, Stonewall and Heceta. Heceta Bank has a strong influence, directing the alongshore flow and the material it contains offshore at the southern end of the Bank. Turbulence in the bottom boundary layer occurred broadly, although intermittently, over the shelf and was correlated with bumps in the bottom topography. Mid-depth turbulence often occured in the vicinity of these bumps, but was also observed at the sheared interface below the coastal jet and in association with a near-surface pulse of onshore current.

Ocean Imaging coordinated the collection of CTD data over the Oregon shelf and slope from tuna fishing boats during the OSU NOPP field season. This activity augments the OSU NOPP observational data set and demonstrates a partnership between academia and private industry.

The bi-weekly NOAA NMFS sampling off Newport showed that 1999 was characterized by a strong, extended upwelling season beginning in April and continuing through September. During 1999, the zooplankton community was composed solely of cold water species of subarctic origin. This contrasts with previous years since at least 1996 when the zooplankton community off Oregon was composed of a mixture of species of subarctic origin along with species with transition zone and central/southern California origins. Thus, in 1999 the extended weak El Niño conditions that have persisted off Oregon since 1992 came to an end. The NOAA NMFS partner's research is producing a long time series of data on nutrients (N), phytoplankton (P) and zooplankton (Z) that can be used to calibrate an NPZ ecosystem model which is being added to the coastal physical model under CoOP support.

IMPACT/APPLICATIONS

A verified predictive capability for wind-driven coastal circulation based on remotely sensed data and a minimum of in situ data would be of great use for navigation, search and rescue, pollutant transport and ecosystem studies since much of the world's coastal oceans are wind driven.

TRANSITIONS

Optical data from the July 1999 cruise are being used by S. Pegau in the ONR HyCODE ARI.

RELATED PROJECTS

Some aspects of the ocean modeling and data assimilation studies are jointly funded by NSF Grant OCE-9711481 (CoOP) and by ONR Grants N00014-98-1-0043 and N00014-94-1-0926. The OSU NOPP atmospheric PIs collaborated with and supported the remote sensing, aircraft and modeling efforts of M. Wetzel (DRI, Reno), G. Vali (U. Wyoming) and W. Thompson (NRL Monterey) associated with the COSAT experiment off the Oregon coast during August 1999.

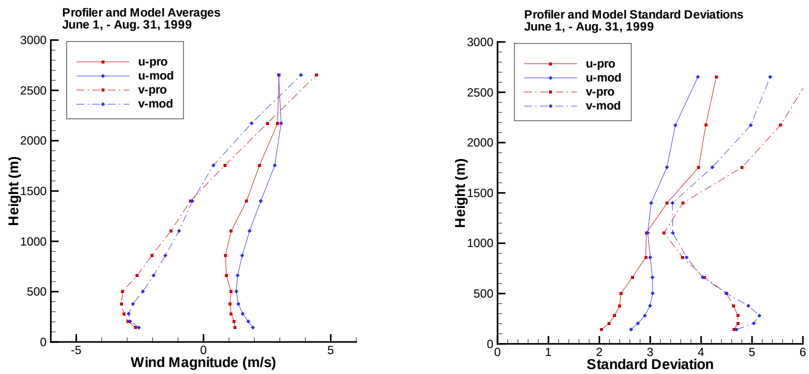

Figure 1. Comparison of mesoscale atmospheric model and RASS profiler winds at Newport, OR.

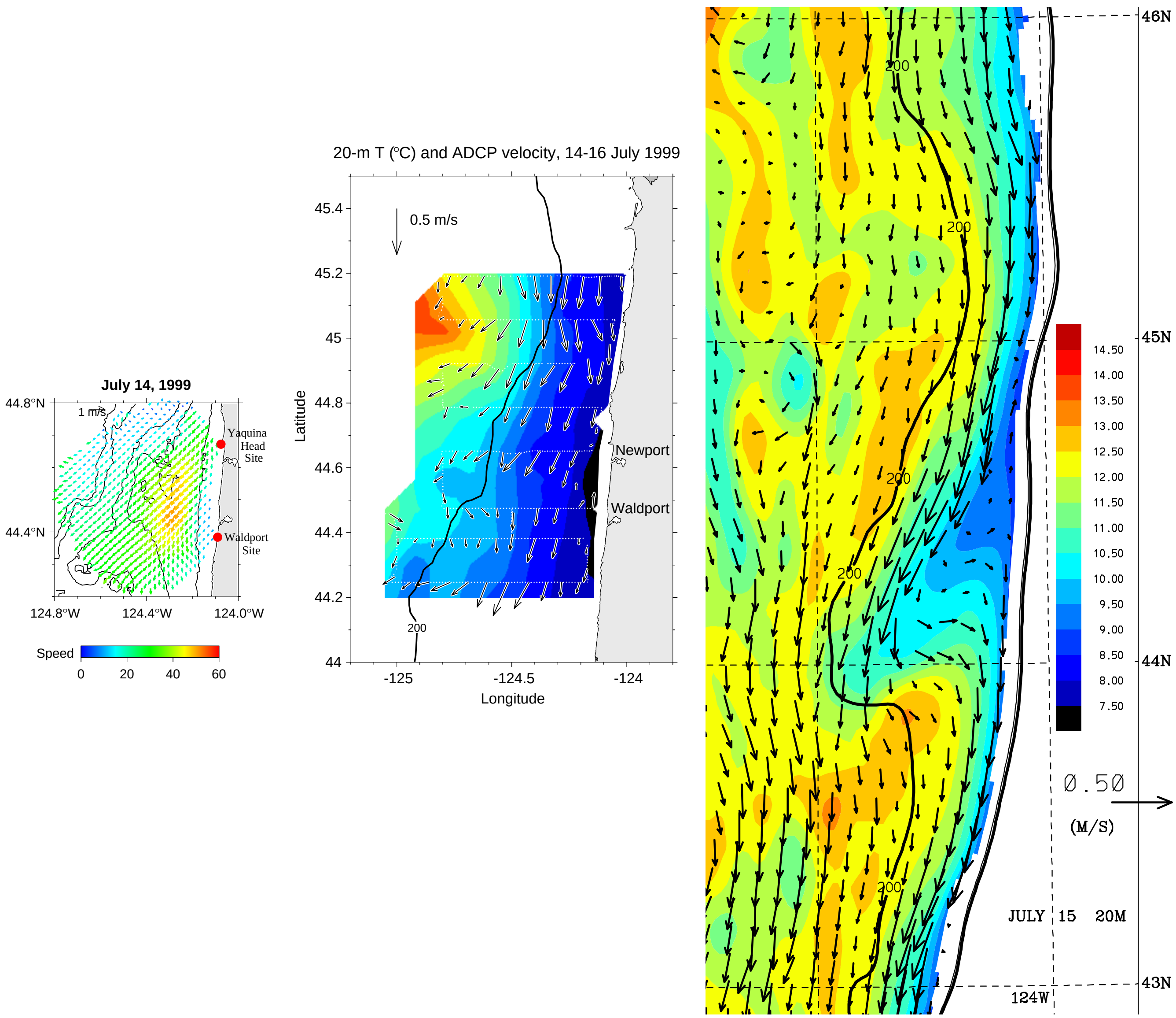

Figure 2. Maps of 20-m temperature and velocity as measured from the R/V Wecoma during 14-16 July 1999, surface velocity from land-based coastal radar averaged over 14 July, and 20-m temperature and currents from a coastal circulation model.

PUBLICATIONS

Allen, J. S., J. A. Barth and P. M. Kosro, 1999. The prediction of wind-driven coastal circulation. American Society of Limnology and Oceanography Aquatic Sciences Meeting, Santa Fe, NM, February 1999, 12-13.

Austin, J. A., J. A. Barth, P. M. Kosro and S. D. Pierce, 1999. Small-boat hydrographic surveys of the Oregon inner shelf, summer 1999. Eastern Pacific Ocean Conference, Stanford Sierra Camp, CA, September 1999.

Barth, J. A., P. M. Kosro, J. A. Austin and S. D. Pierce, 1999. Three-dimensional hydrographic and velocity fields over the Oregon shelf during time-dependent upwelling. Eastern Pacific Ocean Conference, Stanford Sierra Camp, CA, September 1999.

Barbour, P., S. Bielli, R. Samelson, E. Skyllingstad and J. Wilczak, 1999. Atmospheric forcing during the 1999 Oregon upwelling season. Eastern Pacific Ocean Conference, Stanford Sierra Camp, CA, September 1999.

Gan, J. and J. S. Allen, 1999. Variability of upwelling circulation on the Oregon continental shelf: Simulations and comparisons with observations. Eastern Pacific Ocean Conference, Stanford Sierra Camp, CA, September 1999.

Kurapov, A. L., J. S. Allen, R. N. Miller and G. D. Egbert, 1999. Generalized inverse for baroclinic coastal flows. Eastern Pacific Ocean Conference, Stanford Sierra Camp, CA, September 1999.

Oke, P. R., R. N. Miller, J. S. Allen, G. D. Egbert and P. M. Kosro, 1999. Assimilation of CODAR data into a primitive equation coastal ocean model. Eastern Pacific Ocean Conference, Stanford Sierra Camp, CA, September 1999.

Pegau, W. S., J. A. Barth and P. M. Kosro, 1999. Optical variability off the Oregon coast. Eastern Pacific Ocean Conference, Stanford Sierra Camp, CA, September 1999.

Pierce, S. D., P. M. Kosro and J. A. Barth, 1999. Tidal velocity structure off the central Oregon coast. Eastern Pacific Ocean Conference, Stanford Sierra Camp, CA, September 1999.

Samelson, R., 1999. OSU coastal ocean NOPP 1999: A look ahead. Pacific Northwest Weather Workshop, Seattle, WA, February 1999.

Svejkovsky, J., 1999. Physical and biological observations of small-scale currents in nearshore waters using Synthetic Aperture Radar satellite imagery. Eastern Pacific Ocean Conference, Stanford Sierra Camp, CA, September 1999.