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

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Grant Number: N00014-97-1-0171
http://www.coam.usm.edu/ICON

LONG-TERM GOALS

The long-term objective is to contribute to the development of the components of limited area, open boundary, coastal nowcast/forecast systems that will resolve the time and length scales of the relevant ocean dynamics in shallow coastal environments.

OBJECTIVES

Specific objectives for this year were:

1) to evaluate the capability of a high-resolution model to track major features in an upwelling system while constrained by the available measurement suite and nested within the regional model.

2) to investigate the utility of the circulation model and advective-diffusive tracer model for a short-term (2-3 days) bioluminescence potential (BL) predictions.

APPROACH

The approach is based on modeling experiments with the fine-resolution model of the Monterey Bay Area (named ICON model due to NOPP sponsored project "Innovative Coastal-Ocean Observing Network" (ICON) and with a finer-resolution sub model of the ICON model (frsICON around the upwelling front at the north of the Monterey Bay).

Major elements of the ICON model (Shulman et al., 2002a, Shulman et al., 2002b, Shulman et al., 2000) are the same as those used by the Navy's prediction systems: the Princeton Ocean Model (POM)-based ICON ocean model is coupled to a larger-scale version of the Pacific West Coast (PWC) model of the NRLSSC (the PWC itself is embedded within a global model); the ICON model is forced with products from the high-resolution, state-of-the-art Navy atmospheric models NOGAPS and COAMPS; the model is capable of assimilating HF radar derived surface currents and MCSST data.

The frsICON model grid (Shulman et al., 2002c) has a variable resolution in the horizontal, with a finer resolution (500-600 m) around the upwelling front in the northern part of the Monterey Bay telescoping to coarser resolution (1.5 km) in the outer portion of the domain. On the open boundaries, the frsICON model is one-way coupled to the ICON model. The frsICON model is forced with atmospheric products from 9 km resolution COAMPS model predictions. In addition, the frsICON model assimilates CODAR-derived surface currents.

The short-term BL forecasts are conducted by assimilating limited BL observations into an advective-diffusive tracer model with the velocities and diffusivities from a nested, data assimilating coastal circulation model such as ICON or frsICON.

Research has been conducted in collaboration with Drs. J.D. Paduan, L.K. Rosenfeld, S.R. Ramp, and C.A. Collins of NPS, D. McGillicuddy of WHOI, and S. Haddock of MBARI. Dr. J. Kindle's group at NRL provided atmospheric products from COAMPS 9 km predictions and outputs from the larger-scale Pacific West Coast model for the ICON model atmospheric and open-boundary conditions.

WORK COMPLETED

A large number of parallel runs that utilize a variety of atmospheric and boundary forcing functions were created for 1999 and 2000. These runs, outlined in Table 1, form the basis for most of the model-model and model-data comparisons analyzing the model predictions' sensitivity to atmospheric forcing, open-boundary conditions, grid resolution, and data assimilation.

Table 1.

ICON Model Runs in 1999				
Run #	Wind Forcing*	Surface-Heat Forcing**	Open-Boundary Forcing***	CODAR Assimilation
1	NOGAPS	None	PWC0.0	None
2	NOGAPS	MCSST	PWC0.0	None
3	COAMPS	None	PWC0.0	None
4	COAMPS	MCSST	PWC0.0	None
5	COAMPS	COAMPS	PWC0.0	None
6	COAMPS	None	PWC2.1	None
7	COAMPS	COAMPS	PWC2.1	None
8	NOGAPS	None	PWC0.0	Yes ****
9	COAMPS	None	PWC0.0	Yes ****
ICON Model Runs in 2000 (January 1 – October 1)				
10	COAMPS	COAMPS	PWC10.9	No
11	COAMPS	COAMPS	PWC10.9	Yes ****

* 9 km resolution COAMPS used.
** MCSST surface temperatures always assimilated into PWC but only assimilated in ICON model where indicated.
*** PWC0.0 is forced with NOGAPS wind; PWC2.1 and PWC10.9 are forced with 27 km, operational COAMPS wind in 1999 and 2000 respectively.
**** Runs 8, 9, and 11 were done with the use of several CODAR data assimilation schemes.

The impact of CODAR data assimilation on the ICON model predictions has been evaluated. Results from bioluminescence predictability experiments were analyzed and corresponding paper was submitted (Shulman et al., 2002c).

RESULTS

Analysis of the ICON model runs (Table 1) showed that high-resolution atmospheric forcing (COAMPS wind and heat fluxes), as well as accurate open-boundary conditions (regional PWC is also forced with COAMPS), are critical for the model accuracy in representation of upwelling plumes and their interaction with the California Current system. High resolution wind forcing created strong upwelling signatures in the ICON model, and the model better captured the influence of the complex coastline and topography structure.

In run 7 (Table 1), the ICON model simulations reproduce upwelling filaments originating at Ano Nuevo and Pt. Sur areas. These upwelling filaments form and decay with realistic space and time scales. The model run reproduced a meandering front between the cooler upwelled water and the warmer water of the California Current, as well as the narrow pole ward-flowing California Undercurrent. The inclusion of high-resolution surface heat fluxes from COAMPS predictions is important for accurate prediction of the mixed layer shallowing during the summer.

At the same time, the comparisons between observations and model results show that, even with high-resolution atmospheric forcing, the model captures the "essence," but not the "details," of the observed variability. However, the assimilation of observations usually helps to correct this situation. Comparisons of the statistical properties of the CODAR data and the observed wind (Paduan et. al, 2001) indicate a strong correlation between the dominant alongshore, upwelling-favoring wind forcing and CODAR surface currents. Because the wind stress is probably a significant source of errors in the model solutions, the idea of using CODAR data for correction of the surface model wind forcing looks promising. Different CODAR data assimilation schemes based on the idea of correcting the model wind forcing are compared and judged based on the correlation between the ICON model and ADCP currents at the M1 and M2 moorings in simulations during 1999 and 2000.

Analysis of two-dimensional maps of complex correlation (according to Kundu, 1976) between model-predicted and ADCP currents indicates that for the model run without assimilation (Fig. 1, left), the M2 mooring is positioned in the area between the low and high areas of the correlation. The run without assimilation also shows areas of high correlation between M2 and model currents northwest of the M2 location. This indicates the presence of a spatial and temporal shift between model and observed features. We can speculate about the many reasons for this: inaccuracies in bathymetry, atmospheric forcing, etc. However, the model run with assimilation (Fig. 1, right) show a higher correlation between model and ADCP observations, and higher correlation in the northeast direction from M2. This is in agreement with the correlation map between the CODAR currents and the M2 surface bin. Therefore, the impact of CODAR data assimilation results in the reduction of the spatial and temporal shifts present in model comparisons with ADCP observations. Also, with CODAR surface current data assimilation, the ICON model consistently tracks eddy-like features within the domain.

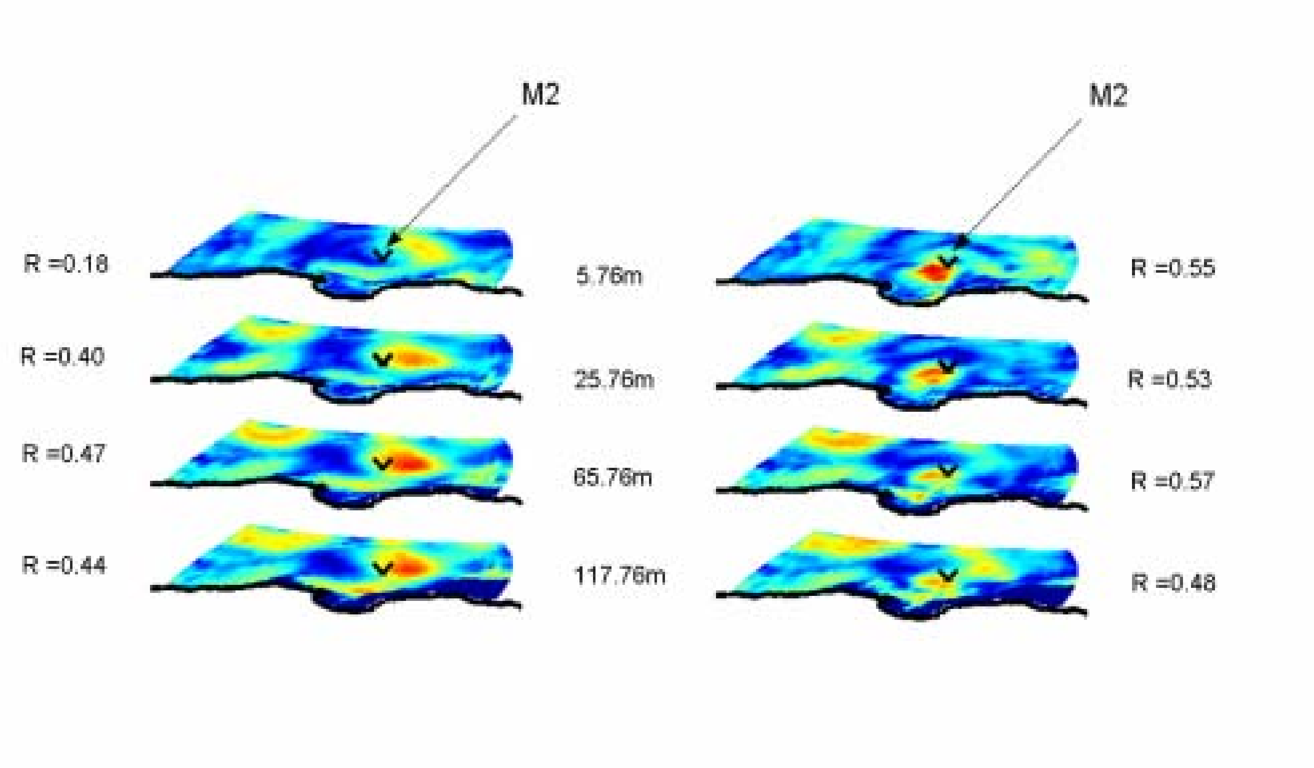

Figure 1. Magnitudes of complex-correlation coefficients between the M2 mooring and model-predicted currents at four ADCP bins (for model run without assimilation (left plot) the M2 mooring is positioned in the area between the low and high areas of the correlation. The run without assimilation also show areas of high correlation between M2 and model currents northwest of the M2 location. However, the model run with assimilation (right plot) show a higher correlation between model and ADCP observations, and higher correlation in the northeast direction from M2. This is in agreement with the correlation map between the CODAR currents and the M2 surface bin).

Two cross-shore surveys of bioluminescence data conducted at two locations were used in BL predictability numerical experiments (Shulman et al., 2002c). The first cross-shore section was taken on the 242nd calendar day of 2000 to the north of the Bay (section AA as noted below), and the second cross-shore was taken inside the Bay on the 245th calendar day of 2000 (section BB as noted below). Analysis of ICON and frsICON model outputs indicates the development of strong currents offshore directed to the south-southeast, and a coastal jet flowing along the coast to the northwest. These conditions correspond to the observed wind reversal from upwelling to downwelling favorable during 242-245days. As a result of these hydrodynamic conditions, water masses to the north of the Bay tend to be entrained into the southeastward flow offshore. This suggests that during days 242-245 water masses at section BB inside of the Bay were not formed from water masses at section AA outside of the Bay. Therefore, observations of BL collected on day 242 outside of the Bay will provide little information for BL predictability inside the Bay at 245th day. On the other hand, section BB feeds into a northward-flowing current at the mouth of Monterey Bay. Thus, this suggests that water masses inside the Bay will reach the section AA outside of the Bay, and it tells us that during days 242-245, sampling of BL intensity inside the Bay plays an important role in BL predictability at section AA outside of the Bay. These conclusions were supported by conducted particle tracking experiments as well as data assimilating experiments with the tracer model. In addition, numerical experiments show that that the BL maximum is located in the highly sheared frontal area where there is a reversal of flow direction. Overall, these results demonstrated the strong utility of the circulation model in predicting the location and intensity of the BL maximum over a 72-hour period, and over distances of 25-35 km.

IMPACT/APPLICATIONS

In situations where it is difficult to obtain extensive data sets to validate numerical models and techniques in areas of strategic importance, our development and testing of coupling and data assimilation techniques, together with extensive observational programs in and around the Monterey Bay Area, allow continued development of techniques for data assimilation, atmospheric forcing, and coupling between models.

TRANSITIONS

Circulation fields from the ICON and frsICON models have been used in predictions of the bioluminescence potential and for understanding high-resolution observations within the framework of a joint effort by ICON, Autonomous Ocean Sampling Network (AOSN), and MOOS (MBARI Ocean Observing System) Upper-Water-Column Science Experiment (MUSE).

ICON model outputs for June-August of 1999 and 2000 will be used by AOSN II group for testing optimal sampling schemes and for optimizing the trajectories and control theory used for AUVs.

RELATED PROJECTS

ONR’s “Autonomous Ocean Sampling Network II (AOSN II) Experiment”.
Coordination with a joint effort of the Harvard, MBARI, WHOI, NPS, Princeton, CalTech, JPL, NRL, and USM groups in designing and building an Adaptive Coupled Observation/Modeling Prediction System in the Monterey Bay.

ONR’s "High-Resolution Measurements of Coastal Bioluminescence; Improving short-term predictability across seasons" at MBARI.
Modeling activities will be undertaken in conjunction with the high-resolution bioluminescence observational program being conducted by Dr. Haddock in the Monterey Bay area.

NOPP’s "An Innovative Coastal-Ocean Observing Network (ICON),"NOMP’s and ONR’s "Autonomous Ocean Sampling Network (AOSN),” and MBARI’s "Upper-Water-Column Science Experiment (MUSE).”
Modeling is conducted in coordination with a joint effort of the ICON/AOSN/MUSE projects.

NRL’s "Coupled Biophysical-dynamics Across the Littoral Transition (CoBALT).”
CoBALT PWC predictions and COAMPS products are used for open-boundary and surface forcing in the Monterey Bay area models (ICON and frsICON models).

Collaboration with Dr. Kirwan's group from Univ. of Delaware on application of Normal Mode Analysis in data assimilation.

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PUBLICATIONS

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