An Innovative Coastal-Ocean Observing Network (ICON)

Jeffrey D. Paduan
Steven R. Ramp, Leslie K. Rosenfeld, Curtis A. Collins, Ching-Sang Chiu, Newell Garfield
Department of Oceanography, Code OC/Pd, Naval Postgraduate School
Monterey, CA 93943
phone: (831) 656-3350; fax: (831) 656-2712; email: paduan@nps.navy.mil

Francisco P. Chavez
Monterey Bay Aquarium Research Institute
7700 Sandholdt Road
Moss Landing, CA 95039
phone: (831) 775-1709; fax: (831) 775-1620; email: chfr@mbari.org

Igor Shulman
Institute of Marine Sciences, University of Southern Mississippi
Stennis Space Center, MS 39529
phone: (228) 688-3403; fax: (228) 688-7072; email: shulman@coam.usm.edu

John F. Vesecky
Atmospheric, Oceanic, & Space Sciences, University of Michigan
Ann Arbor, MI 48109
phone: (734) 764-5151; fax: (734) 764-5137; email: jfv@engin.umich.edu

Daniel M. Fernandez
Institute of Earth Systems Science & Policy, California State University Monterey Bay
Seaside, CA 93955
phone: (831) 582-3786; fax: 582-4122; email: daniel_fernandez@monterey.edu

John C. Kindle
Oceanography Division, Naval Research Laboratory
Stennis Space Center, MS 39529
phone: (228) 688-4118; fax: (228) 688-4759; email: kindle@nrlssc.navy.mil

Robert Maffione
HOBI Labs
56 Penny Lane, Suite 104, Watsonville, CA 95076
(831) 768-0680; fax: (831) 768-0681; email: hobilabs@hobilabs.com

Donald Barrick
1000 Freemont Ave, Suite K, Los Altos, CA 94024
phone: (408) 773-8240; fax: (408) 773-0514; email: don@codaros.com

Document #s: N00014-98WR-30170, N00014-99WR-30118, N0001400WR20160, and
N0001498WX30418; Grant # N00014-98-1-0870
http://www.oc.nps.navy.mil/~icon/

LONG-TERM GOALS

The Innovative Coastal-Ocean Observing Network (ICON) is a partnership of government, academic, and industrial entities funded by the National Ocean Partnership Program (NOPP). Its goal is to bring together modern measurement technologies, to develop new technologies, and to integrate them within a data assimilating coastal ocean circulation model.

OBJECTIVES

The objectives of the project are to evaluate the several real-time observing systems as components of future coastal monitoring networks as well as sources for data-assimilating numerical models.

APPROACH

The approach taken in this project is to build on existing partnerships and observing systems around the Monterey Bay region by providing coordination, additional instrumentation, and a focus on evaluating the impact of the various measurements on the validation and forcing of a coastal circulation model. The major components of the observing network include 1) surface current maps from shore-based high frequency (HF) radar installations, 2) subsurface currents, temperature, salinity, and bio-optical properties plus surface meteorological properties from several deep-ocean moorings, 3) sea surface temperature and color from satellites, and 4) along-track temperature and temperature variances from two acoustic tomography slices through the region. These data sets each involve real-time data telemetry. They are also being used as either validation or assimilation sources for a nested, primitive equation numerical model designed to track the evolution of mesoscale filaments and eddies.

WORK COMPLETED

Additional HF radar stations were deployed south of Monterey Bay, moored observations were retrieved from five offshore sites, and acoustic travel times were collected from one along-shore and one cross-shore tomography section. The mooring locations, HF radar sites, and a sample HF radar data set are shown in Figure 1. Of particular note are expanded HF radar locations at Granite Canyon and Pt. Sur and the M4 mooring location, which returned exceptionally good oceanographic, atmospheric, and bio-optical data for the entire period of its deployment from August 1999 into September 2000. Shorter-term deployments of the NPS FLUX buoy and of a bottom-mounted ADCP with acoustic telemetry were made in August 2000 in conjunction with the ONR/AOSN field campaign. Also during that campaign, thirteen separate synoptic surveys of sea surface temperature, air temperature, and winds were made from an instrumented aircraft.

The numerical model was spun up from 1995 using NOGAPS wind forcing and lateral boundary conditions from the NRL Pacific West Coast (PWC) model, which itself is nested within the NRL 1/4 degree, global layered model. Multiple runs of the ICON model for the period 1999 have been conducted to evaluate the role of wind forcing (NOGAPS vs. COAMPS), the effectiveness of various data assimilation techniques, and the sensitivity to surface heat fluxes. In addition, a triply nested model grid was generated for the Monterey Bay region to be used to investigate specific case studies of upwelling fronts and filaments sampled during the AOSN field campaign.

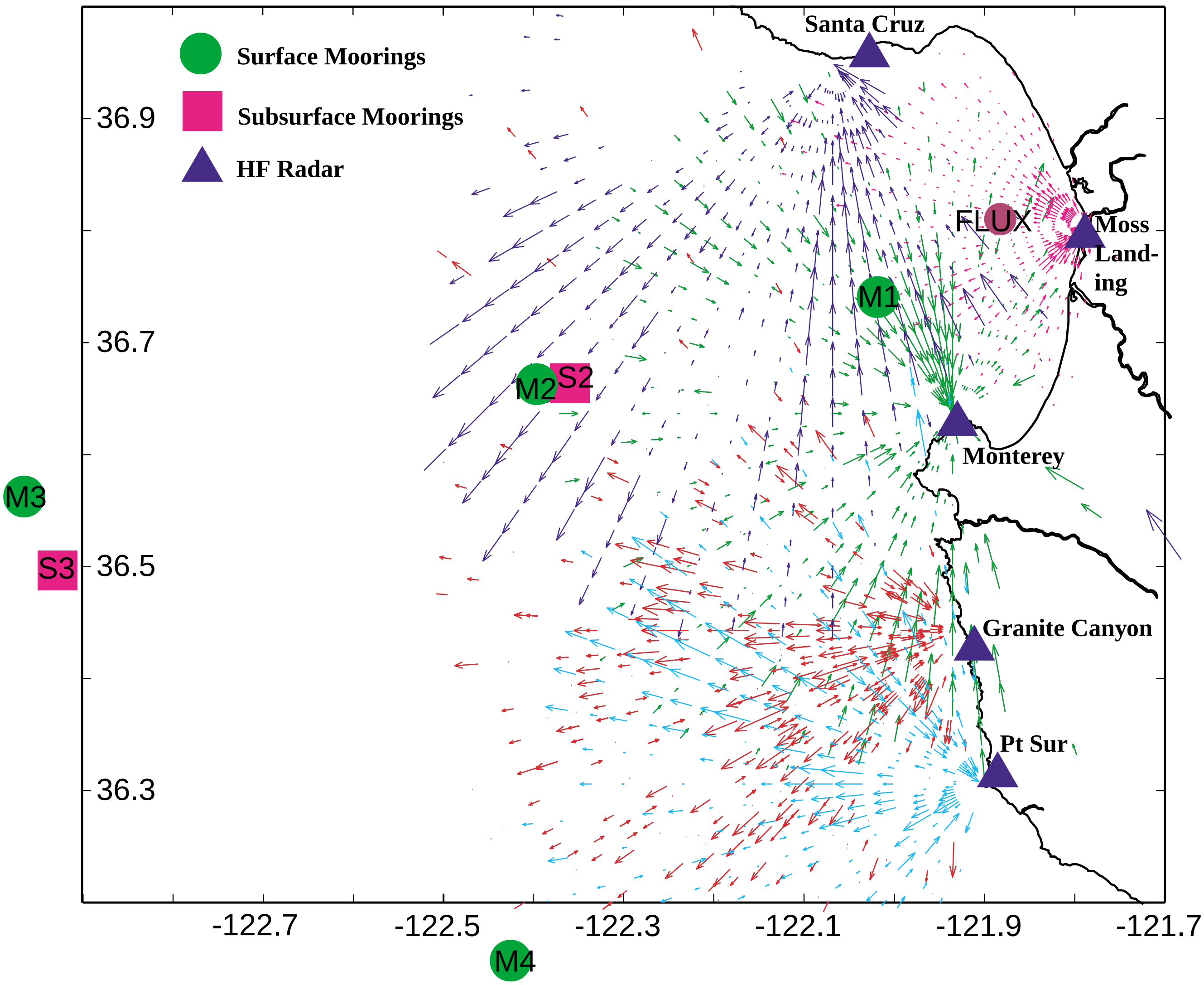

Figure 1. ICON Mooring and radar locations presented with the first five-site HF radar data set collected on 20 January 2000. Note that these single-component, radial currents must still be combined to produce a vector current map in the regions of overlap.

RESULTS

The HF radar data in Figure 1 illustrate the results of the expanded HF radar network. Data from the entire network is available beginning January 2000. Analyses to date have, however, utilized surface current maps from the three sites around Monterey Bay. Model results, with and without assimilation of the HF radar-derived currents, have been compared to temperatures, salinities, and velocities at the mooring sites. In addition, a systematic comparison has been initiated to evaluate the surface heat flux parameters output by the high-resolution (9 km) COAMPS atmospheric model against time series measurements from the mooring sites.

As an example of the model performance and types of comparisons that have been conducted, Figure 2 shows subsurface temperatures for all of 1999 at the M1 mooring location from observations and from the numerical model. Statistical comparisons of the same data are presented in Table 1 for the base run with NOGAPS wind forcing and no heat flux forcing and for a run in which surface heat fluxes were incorporated through the assimilation of the composite MCSST data.

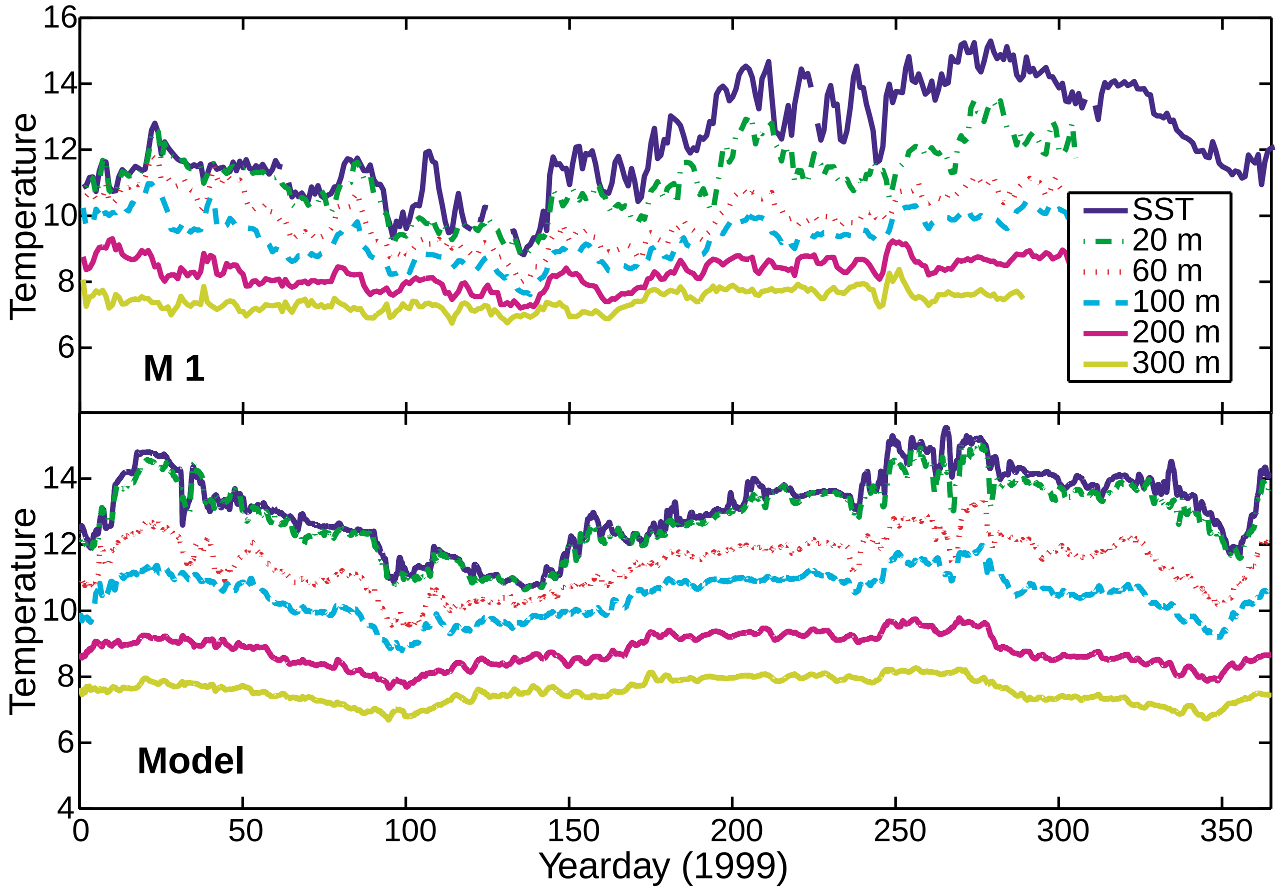

Figure 2. Daily averaged temperatures at the M1 mooring site from observations and from the ICON model forced with NOGAPS winds and regional-scale (PWC) boundary conditions.

The model performance is quite good at seasonal time scales, which is a validation of the one-way nesting because these variations are successfully tracked by the PWC regional-scale model. At higher frequencies, the model does not reproduce the observed level of variability. Other problems are visible near the surface where the model mixed layers are too deep in summer and too shallow in winter, which is certainly a reflection of the lack of heat flux forcing. This problem is mitigated to some degree by assimilation of MCSST data at the surface (Table 1).

Table 1. Model versus observed temperature statistics (˚C) at the M1 mooring site for 1999.

Depth (m)	σ_{obs}	σ_{mod}	σ_{mod} with MCSST	RMS difference	RMS diff. with MCSST
0	1.52	1.12	1.16	1.33	1.05
20	1.03	1.12	1.07	1.85	1.72
60	0.81	0.83	0.83	1.59	1.58
100	0.70	0.69	0.66	1.28	1.23
200	0.46	0.47	0.46	0.72	0.63
300	0.30	0.35	0.35	0.38	0.35

Assimilation of velocity data from low-pass-filtered HF radar data has been tested using the machinery of Physical-Space Statistical Analysis System (PSAS) and spatial error covariances based on seasonal statistics from the HF radar data (see Shulman et al., 2000ab). Despite the surface-only nature of the assimilation (no vertical projection was made during the assimilation), divergences in the correction fields imposed by the observed velocity patterns quickly penetrate to the main thermocline. This is illustrated in Figure 3, which gives an example of the model currents at 75m with and without data assimilation. The changes at 75m are significant and, in addition, the limited-area corrections can be seen to have an effect outside the spatial range of the actual data.

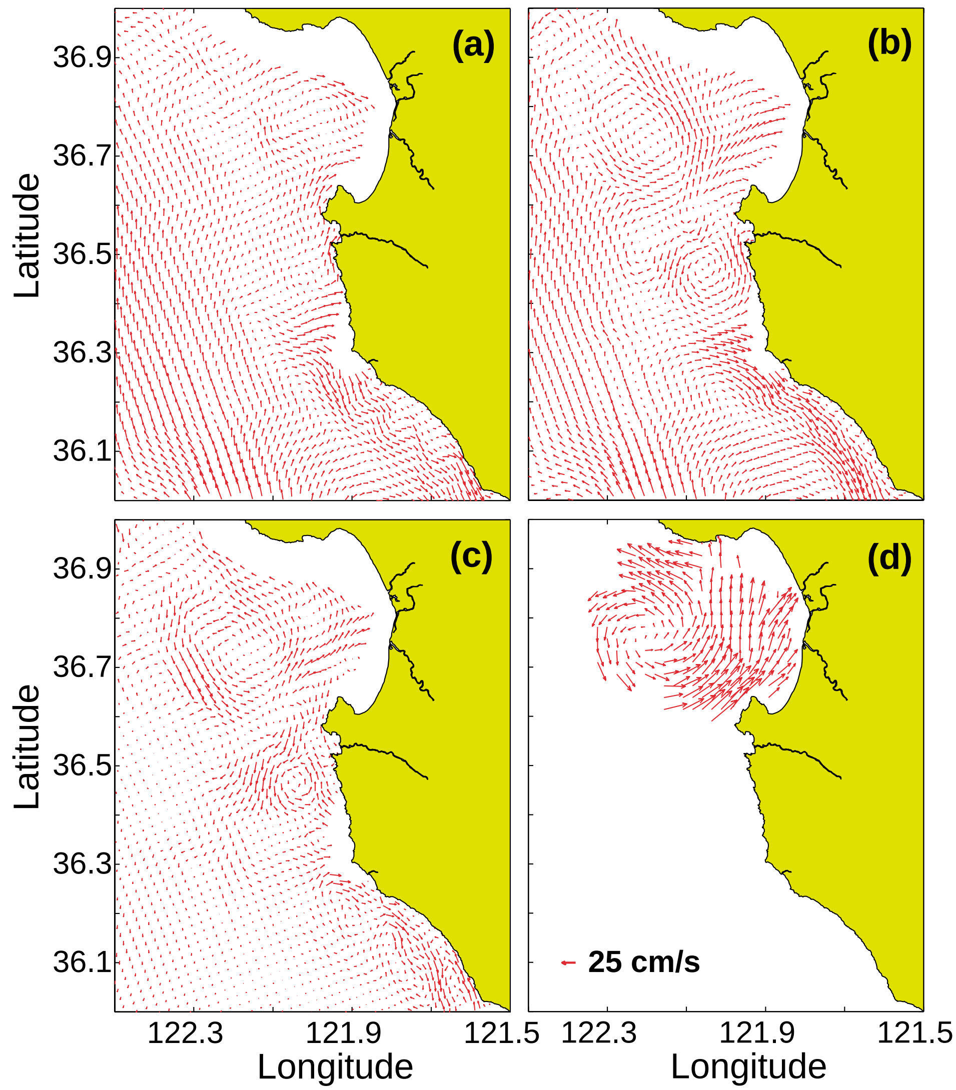

Figure 3. ICON model results at 75m depth on 15 August 1995 with only (NOGAPS) wind forcing (a) and with the addition of HF radar-derived surface current assimilation (b). The model difference at 75 m depth with and without assimilation (c) and the most recent HF radar-derived surface current map (d) are also shown.

Long-term velocity comparisons at the M1 mooring location illustrate the effect of surface velocity data assimilation as a function of depth. Correlations of observed and modeled cross-shore (u) and along-shore (v) velocities are shown in Figure 4 as a function of depth with and without data assimilation. The figure shows largely improved results down to 150m for the dominant along-shore currents when data assimilation is employed. The results are not all good as the correlation with weaker cross-shore currents is reduced in the region of the thermocline with data assimilation.

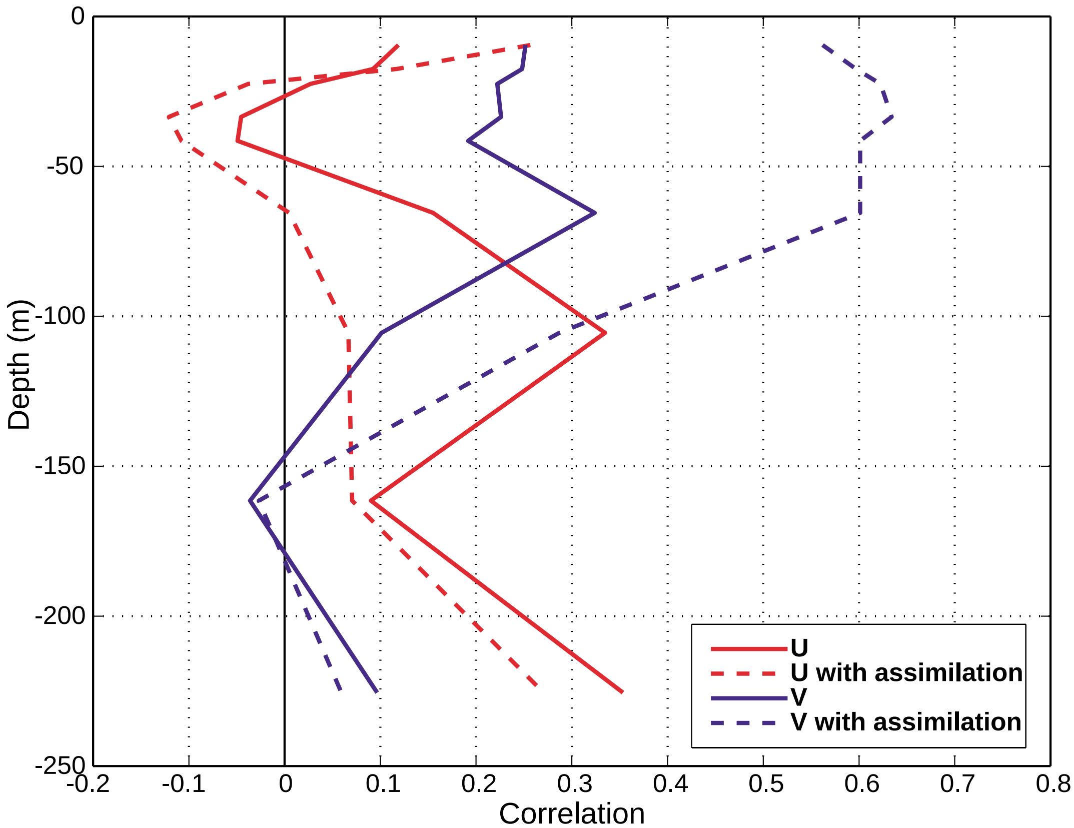

Figure 4. Modeled vs. observed currents at M1 in 1995.

IMPACT/APPLICATIONS

The likely impacts of this project include improved real-time communication, processing, and display of coastal ocean data along with improved algorithms for assimilating that data into numerical models.

TRANSITIONS

The transition opportunities are related to improved coastal nowcast and forecast systems.

RELATED PROJECTS

This project is closely related to other NOPP efforts focusing on data assimilation and coastal ocean modeling. The ONR-sponsored project of Ly and Paduan (N00014-00-WR20098) to observe and model surface waves in Monterey Bay is a direct extension of the ICON efforts. Also, related efforts can be found in the separate modeling program of Shulman (N00014-97-1-0171). ICON is closely linked to the Autonomous Ocean Sampling Network (AOSN) project whose field program, along with a campaign sponsored by the Monterey Bay Aquarium Research Institute called MUSE, was conducted in Monterey Bay in August 2000.

PUBLICATIONS

Barrick, D., R. Cheng, N. Garfield, J. Paduan, P. Lilleboe, J. Gartner, and L. Pederson, 2000: Toward bay/harbor circulation model improvement incorporating HF radar data based on SeaSonde deployments on San Francisco Bay. Proceedings, IEEE Oceans-2000, 5 pp.

Paduan, J.D., L.K. Rosenfeld, S.R. Ramp, F. Chavez, C.S. Chiu, and C.A. Collins, 1999: Development and maintenance of the ICON observing system in Monterey Bay. Proceedings, Third Conference on Coastal Atmospheric and Oceanic Prediction and Processes, New Orleans, LA, 3-5 November.

Shulman, I., C.-R. Wu, J.K. Lewis, J.D. Paduan, L.K. Rosenfeld, S.R. Ramp, M.S. Cook, J.C. Kindle, and D.-S. Ko, 2000a: Development of the high resolution, data assimilating numerical model of the Monterey Bay. In Spaulding, M.L. and H. Lee Butler (Ed.), Estuarine and Coastal Modeling, 980-994.

Shulman, I., C.-R. Wu, J.K. Lewis, J.D. Paduan, L.K. Rosenfeld, J.C. Kindle, S.R. Ramp, and C.A. Collins, 2000b: High resolution modeling and data assimilation in the Monterey Bay area. Continental Shelf Research, submitted.