A National Oceanographic Partnership Program Award

Innovative Coastal-Ocean Observing Network (ICON) Renewal

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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 was to build on existing partnerships and observing systems around the Monterey Bay region. The major components of the observing network included 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 involved real-time data telemetry. They were also used as either validation or assimilation sources for a nested, primitive equation numerical model. The ICON P.I. group and their respective areas of research are listed in Table 1.

Table 1. ICON Partner Institutions and Primary Responsibilities

Naval Postgraduate School (NPS; J. Paduan, C. Collins, L. Rosenfeld, S. Ramp, C.-S. Chiu)	Project management; Moored, HF Radar, Ship, and Acoustic Tomography Observations
Univ. of Michigan (J. Vesecky*)	HF Radar Construction
Calif. State Univ. Monterey Bay (D. Fernandez)	HF Radar Observations
Univ. of Southern Mississippi (I. Shulman)	Circulation Modeling and Data Assimilation
Naval Research Laboratory (J. Kindle)	Regional Modeling; Bio-Physical Modeling

HOBI Labs, Watsonville, CA (R. Maffione)	Moored Optics Sensors, Bio-Physical Modeling
Monterey Bay Aquarium Res. Inst. (F. Chavez)	Mooring Construction, Bio-Physical Modeling
Codar Ocean Sensors, Los Altos, CA (D. Barrick)	HF Radar Maintenance and Algorithms

*now at: University of California Santa Cruz

Work Completed

This project utilized two types of HF radar systems: the commercially available CODAR/SeaSonde unit and the Mutli-Frequency Coastal Radar (MCR). The latter is under development by partner J. Vesecky. The MCR is unique in its ability to transmit and receive backscatter signals on four frequencies simultaneously within the HF band. In principle, this provides for the possibility to measure velocity shear very near the ocean surface (within 1-2 m). MCR improvements were incorporated in this project with the construction of the third experimental system (SN3), including: 1) a capability for recording engineering housekeeping data, 2) a new VSWR protection circuit, 3) improved temperature stability of the receiver's gain control function, and 4) modifications to the transmitter modulator to improve linearity and reduce distortion. With the deployment of the SN3 MCR system at Granite Canyon south of Monterey Bay and the deployment of a new SeaSonde unit on Pt Sur further south, the surface velocity mapping capability was extended beyond Monterey Bay to include the upwelling center offshore Pt Sur. Extensive comparisons of radial current data from co-located SeaSonde and MCR units at Santa Cruz and Moss Landing in Monterey Bay were conducted by the HF radar team and presented at the 2nd International Radiowave Oceanography Workshop (ROW-2) in Landeda, France in April. Data from the independent HF radar systems agree well with RMS differences on the order 10 cm/sec, which is comparable to the radar-to-mooring agreement found by other investigators.

Data from the HF Radar network was collected and processed along with bio-physical data from four deep-ocean mooring sites and one, shorter-term, meteorological turbulence measurement site. In addition, acoustic data collected at the SOSUS array listening station offshore Pt Sur. was processed for travel time variations from two sources on Davidson Seamount and Pioneer Seamount to the West and North, respectively. Revisions to the forward-problem ray tracing between Davidson Seamount and Pt Sur were completed within the M.S. thesis work of D. Neander along with initial computations of the tomographic inverse.

Results

Publication efforts are ongoing, but a number of results have been obtained and promulgated with regard to surface velocity maps from HF radar and their use with nested, data assimilating circulation models. Some of these results from the past year are highlighted here beginning with the description of the primary mode of variability in both the HF radar-derived currents and the wind-forced circulation model.

Surface current output from the nested, high-resolution circulation model run by I. Shulman (USM) was subsampled at the locations of the HF radar data within Monterey Bay for the purpose of computing comparable Empirical Orthogonal Function (EOF) representations of the velocity variability. In this case, both observed and modeled surface currents are dominated by along-coast flow across the mouth of Monterey Bay. Very similar patterns emerged in the data and model results for the most dominant mode (Figure 1). In both cases, that mode accounted for, approximately, 50% of the variance, while the second mode dropped to about 15% of the variance in the year-long sub-tidal-period velocity records.

In the Monterey Bay region, the primary velocity variance is related to the dominant alongshore wind variations, which flip between upwelling favorable and downwelling favorable during most of the year. The temporal amplitude of the HF radar-derived first velocity mode is highly correlated with this alongshore wind component (Figure 2). A similar correlation (not shown) can be demonstrated for the wind-forced model results prior to the use of data assimilation to incorporate HF radar measurements.

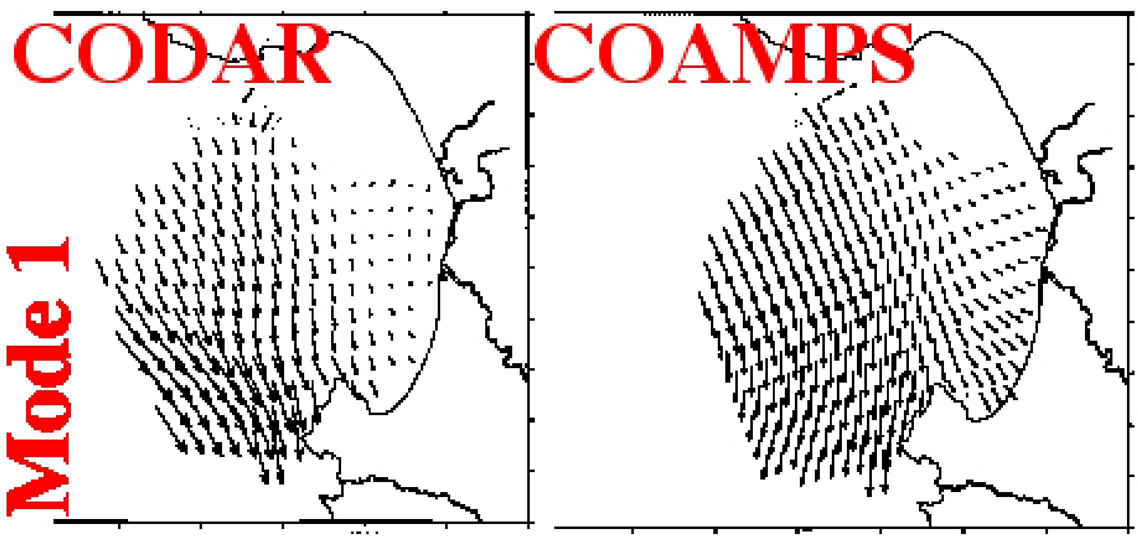

Figure 1. First spatial velocity mode for 1999 over the domain of the Monterey Bay HF radar coverage for the radar-based observations (CODAR) and for numerical model runs using high resolution (9 km; COAMPS) wind product. Note: low resolution (100 km; NOGAPS) forcing produced a similar first-mode pattern but different patterns at higher modes. Also note that, for scale, it is 40 km across the mouth of Monterey Bay.

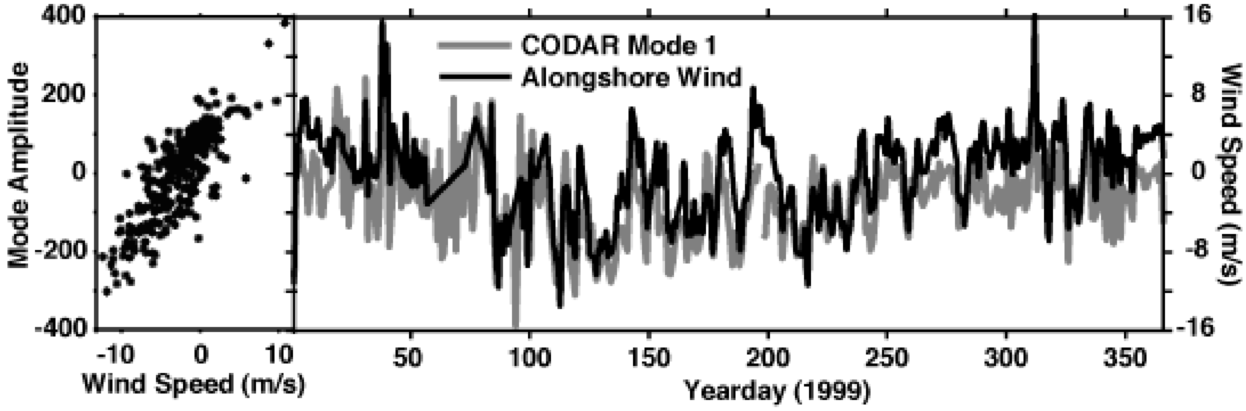

Figure 2. Alongshore component of wind at the M1 mooring near the center of Monterey Bay and the mode 1 amplitude for the radar-derived (CODAR) surface velocity fields as a scatter plot (left panel) and versus time (right panel).

The high degree of "success" achieved by the model with regard to the energetic, wind-driven surface current reversals did not translate into high skill with regard to the positioning of mesoscale fronts and eddies within the model domain. An important result of the model-to-mooring data comparisons undertaken is the fact that the nested, wind-forced circulation model may produce realistic features that are imprecisely located, which led to deceptively low skill scores with single-point comparisons. When, instead, model currents throughout the domain were correlated with observed currents, high correlation results were obtained offset in space from the mooring location by just a few kilometers (Figure 3).

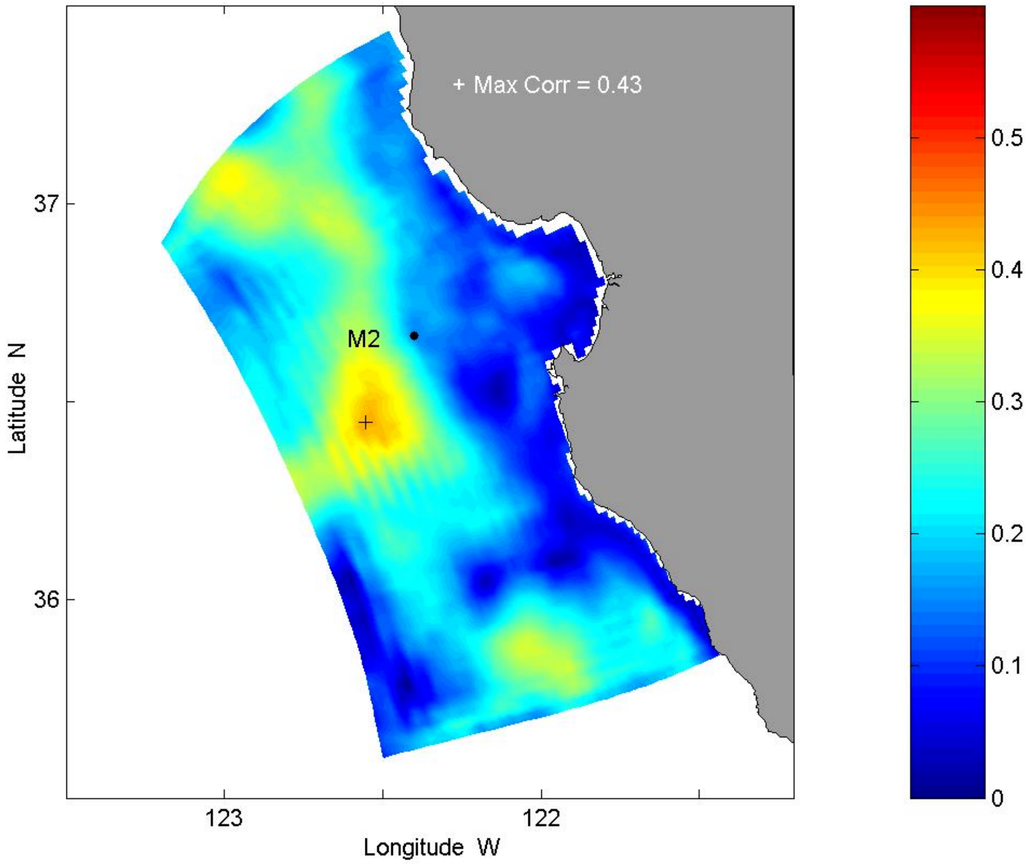

Figure 3. Magnitude of the complex surface velocity correlation for 1999 between ICON model output and observed currents at the M2 mooring site outside Monterey Bay. Values at the mooring location are low (~0.10), but there is a much higher peak value (0.43) about 20 km to the southwest.

The coastal modeling and observation results from ICON strongly suggest a role for data assimilation in the improvement of model nowcasts and forecasts. The observed larger scales are included in the model simulations and smaller scales are represented but offset in space. Preliminary results are available from work to use surface current maps from the HF radar network as a data assimilation source for the ICON model. In this highly complex domain where the offshore boundary reaches depths exceeding 3000 m and the interior includes the Monterey Bay and the topography of the Monterey Submarine Canyon, it is not expected that a significant correlation exists between surface currents and the state variables throughout the model domain. As an alternative to the development of such a 3-D data (and error) covariance matrix, we have investigated the "effective depth" achieved when observed currents are assimilated only into the surface, or near-surface, model level(s). At the heart of the surface assimilation technique is a truncated Kalman filter (PSAS) that utilizes observed data-data horizontal covariance scales computed monthly from the historical HF radar data set. Those scales have small seasonal variations, but mostly show alongshore (cross shore) decorrelation scales around 12 km (8 km).

The results of ocean current assimilation into the mixed layer levels of the ICON model provide encouragement that these data may improve open-coast circulation models down to depths of around 100 m (Figure 4). Work is ongoing to document the physical mechanisms by which favorable adjustments are made to the model currents below the level of direct assimilation. Presumably, this occurs due to divergences in the correction field, which shows the utility of 2-D velocity maps available only from HF radar systems.

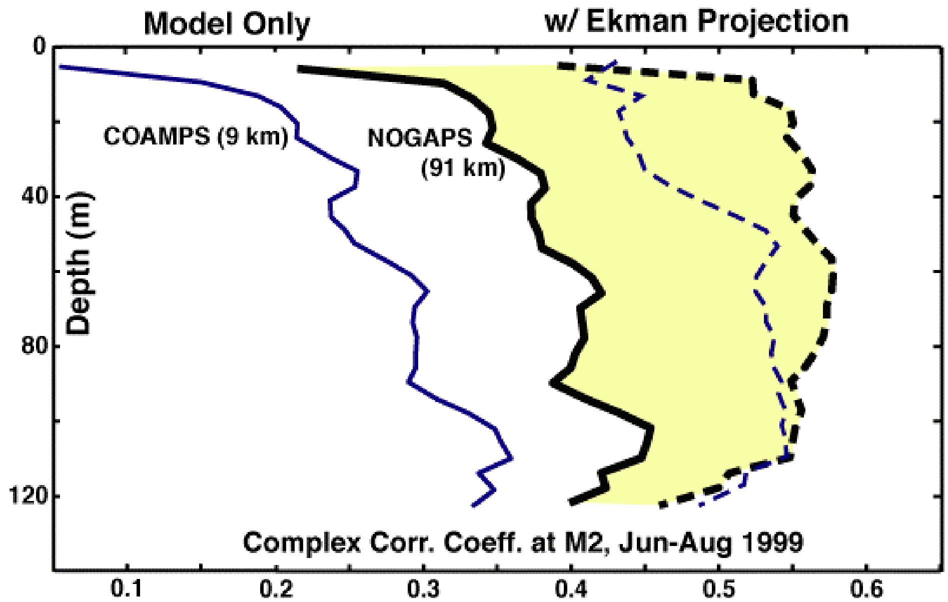

Figure 4. Amplitude of the Summer 1999 complex velocity correlation between ICON model output and observations as a function of depth from the surface to 120 m at the M2 mooring site, which is just outside the footprint of the HF radar data in Monterey Bay. Results are included for model simulations forced by low resolution (100 km; NOGAPS) and high resolution (9 km; COAMPS) winds both with and without assimilation of HF radar-derived surface currents. The assimilation significantly improves the correlations down to depths around 100 m.

Impact and Applications

National Security

This project has developed improved techniques for real-time assessment of the velocities and temperatures of the coastal ocean. Importantly, these techniques have also been integrated into a numerical modeling framework. In the future, these model-data systems will provide the nowcasts and forecasts used to plan marine operations, and to react to potential hazards delivered to or via the coastal ocean.

Economic Development

The most significant impacts of the research and development conducted in this project are likely to be felt in the area of marine weather forecasts for the coastal ocean region. This will include weather forecasts and also the emerging area of real-time ocean forecasts for currents, waves, and temperatures. Improved ocean forecasts, and improved access to these forecasts, will increase the efficiency and safety of both commercial and recreational activities in the coastal ocean.

Quality of Life

The observing and prediction systems under development in this project will directly improve the access of the public and resource managers to real-time and archival descriptions of the physical conditions in the coastal ocean. Improved mitigation of hazardous spills is one direct consequence. Better weather forecasts for recreational boaters is another quality-of-life factor that will be improved.

Science Education and Communication

This project will most likely impact the science education and outreach communities through improved access to real-time and archived environmental data and analyses. Our experience has shown that local educators are very interested in the incorporation of environmental data from their own area into their science classrooms. To be successful in this regard requires reliable and easy-to-interpret displays of data and model fields from the coastal ocean environment, which is a central goal of this project.

Transitions

For the four NOPP evaluation factors below, please describe how the results (hardware, software, knowledge) are being utilized by others. Transition is taken to mean, "products which are being incorporated into more developmental (or operational) programs or have already been incorporated in other's plans."

National Security

A significant transition activity of this project has been to support new Navy research projects in Monterey Bay that are testing models and autonomous vehicles. A series of experiments have been scheduled that explicitly take advantage (and rely upon) the network of HF radars and moorings that were put in place during this project, along with modeling system that was developed. Tests include the further evaluation of data assimilating model capabilities and the ability of the overall system to detect and predict distributions of bioluminescence, which can be a major factor in Navy operations in the coastal ocean.

Economic Development

The observation and modeling system that was put in place during this project has been taken on as the prototype for an expanded forecast system that would integrate marine and agricultural forecasts in Monterey Bay and the adjacent Salinas Valley in support of fishermen and farmers.

Quality of Life

The most significant transition in this area is likely to be the expansion of coastal monitoring efforts and capabilities within the Monterey Bay National Marine Sanctuary based on the observations and modeling framework that was developed in this project.

Consideration for Excellence in Partnering Award

Ocean Sector Diversity: The partners in this project were diverse. The central institution was the Naval Postgraduate School (NPS), which is an academic institution with strong ties to the federal system and, especially, to the technical requirements of the Navy. The private research partners, the Monterey Bay Aquarium Research Institute (MBARI), Codar Ocean Sensors, Ltd.

(COS), and Hobi Labs (HOBI) each made very large contributions. Researchers at the University of Michigan (UM), California State University Monterey Bay (CSUMB), the University of Southern Mississippi (USM), and the Naval Research Laboratory at Stennis Space Center were also full partners, despite their geographic separation from the field site in Monterey Bay.

Partner Involvement: Within NPS, researchers were involved with project management, HF radar data processing, ship surveys, mooring deployments and data processing, and acoustic tomography among other things. At MBARI, partners built and deployed the deep-ocean moorings used in this project. UM scientists built and deployed a new multi-frequency HF radar system during the project. USM and NRL scientists conducted nested ocean model simulations of the entire California Current System with high resolution grids centered on Monterey Bay. USM and NPS scientists also worked closely on developing and testing algorithms to assimilate data from the HF radar network into the numerical model, which also required coordination with other NPS researchers and with MBARI researchers to obtain and interpret mooring data that was used as independent validation of the model improvements related to data assimilation. At HOBI, engineers constructed new hyperspectral ocean color instruments that were first deployed on the mooring that was specially constructed for this project. (Now those instruments are a part of the HOBI commercial product line.) COS completely rebuilt one of their commercial CODAR/SeaSonde HF radar systems to fit into a small enclosure that was successfully mounted high on a rock at the remote Point Sur lighthouse location in support of this project. (COS has used that results on many occasions to demonstrate to new customers the extreme versatility of their particular HF radar system implementation.) The P.I. from CSUMB was involved with HF radar algorithm development. CSUMB also was the source of two undergraduate students that became critical members of the research team.

Matching Contributions: There were many significant matching contributions in this project. The largest was probably the MBARI mooring program. This project paid for the hardware needed to construct a fourth deep-ocean mooring in the Monterey area, but the MBARI program built the mooring and, at the same time, continued to maintain three other moorings in the region, including real-time radio communications. The MBARI mooring program itself was estimated to cost over 0.5M per year during the period of this project. The construction efforts of COS and HOBI described above were also matching fund efforts that were not directly paid for by this project. In the modeling arena, the large (>$1M) CoBALT project at NRL was essential to this project because it sponsored the regional modeling efforts that were required to run the nested, high-resolution Monterey Bay grids. After funding for this project was secured, USM agreed to fund a full post-doc position for one year to work with the P.I. at USM. Finally, a significant amount of field equipment and faculty time was provided by NPS during this project. NPS also sponsored 1/2 of a post-doc position related to this project and that position was filled by a researcher from Ensenada, Mexico.

Partner Long-Term Commitment: After one year, all of the partners are still involved in continuing efforts related to this project. MBARI, for example, has expanded their mooring program and is beginning a very ambitious cabled observatory program in Monterey Bay with matching funds from NSF. COS has continued to sponsor its contributions to the Monterey Bay HF radar network and they have become involved with a number of other programs in the region related to expanding the use of HF radars. NRL has renewed the regional numerical modeling efforts begun under the CoBALT program.

Success in Project Objectives: The central goal of this project was a scientific one: to determine what suite of coastal ocean measurements and models are needed to track the week-to-week variations of the mesoscale filaments and eddies driven by upwelling processes around Monterey Bay? That science goal, of course, has a clearly pragmatic objective embedded within it to determine what is needed to maintain a useful network of coastal observations and model simulations. On the scientific front, we have certainly shown that the combination of HF radars, moorings, and models that we implemented can track the critical variations between upwelling and downwelling conditions in this area. A lot of effort went into evaluating the high resolution model with and without data assimilation and a few surprising results were obtained. Namely, we know now that nesting within a very good region model is essential for this type of coastal model. We found the Monterey Bay model domain was affected equally by the baroclinic boundary conditions supplied at the boundary by the regional model and the local wind forcing. With regard to the wind forcing, this project demonstrated significant differences in the model outcomes depending on the resolution of the atmospheric model used to force the ocean model. Further, important errors in the way the Navy COAMPS model was archived at the highest resolution were uncovered and corrected as a result of this project. Realistically, the true success of this project will be measured by whether or not an operational observing system emerges for the central California region. Several follow-on projects have already taken place with funding from NOPP, Navy, and NOAA, but these projects still rely heavily on the research benefits to justify them. If new projects, such as the initiative called CCEPI that hopes to help fishermen and farmers be more productive, are successful, then this initial NOPP project will have been extremely successful.

Related Projects

This project interfaces directly with the many Monterey Bay-area programs, including: HF Radar Measurements of Ocean Surface Currents and Winds (J. Vesecky; Award Number N00014-99-1-0174), the NOPP project entitled Simulations of Coastal Ocean Physics and Ecosystems (SCOPE; P.I. F. Chavez.), the Autonomous Ocean Sampling Network (AOSN) project entitled Aerial Surveys of the Ocean and Atmosphere off Central California (Document numbers N0001401WR20317 and N0001402WR20393), NOAA's Center for Integrated Marine Technology (UC Santa Cruz), and NOAA's Sanctuary Integrated Monitoring Network (SIMoN).

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