Autonomous Ocean Sampling Network II (AOSN-II): System Engineering and Project Coordination

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LONG-TERM GOALS

The long-term goals of this project are defined in its charter:

"We are designing and building an adaptive coupled observation/modeling system.

- The system will use oceanographic models to assimilate data from a variety of platforms and sensors into synoptic views of oceanographic fields and fluxes.
- The system will adapt deployment of mobile assets to improve performance and optimize detection and measurement of fields and features of particular interest.
- The system should be sustainable in its operation, and capable of being readily relocated, in its final form.

We will test performance of the system in a quantitative fashion. We will use the results of those tests to guide research and development to improve system performance.
Components of the system are the subject of individual research programs. We will structure the program to facilitate those research efforts, with a view to improving system performance, and capture the most mature aspects for building the adaptive coupled observation/modeling system.
We will develop the system incrementally, coupling proof and test of the system to specific scientific objectives."
The work described below is the product of a collaboration of research efforts that are discussed more fully in separate annual reports (see list of related projects).

OBJECTIVES

The objective of this year's effort was to assemble components, each the result of many years of independent research conducted within the collaborating institutions, into an Adaptive Coupled Observation /Modeling Prediction System (Fig. 1). The system provides detailed synoptic field estimates, obtainable in no other way. The long-term objective of this is to make possible the rapid advancement of interdisciplinary ocean science and to enable powerful new methods for efficient ocean management and maritime operations. This year's effort employed the AOSN system to study the upwelling of nutrient rich water near Pt Año Nuevo and its advection across the Monterey Bay. The upwelling is driven by strong northwesterly coastal winds. Physical, chemical, and biological aspects of this upwelling process were studied. System performance was tested both qualitatively and quantitatively during the experiment and will continue throughout the year. Results of these tests will be used to guide research and development to improve System performance.

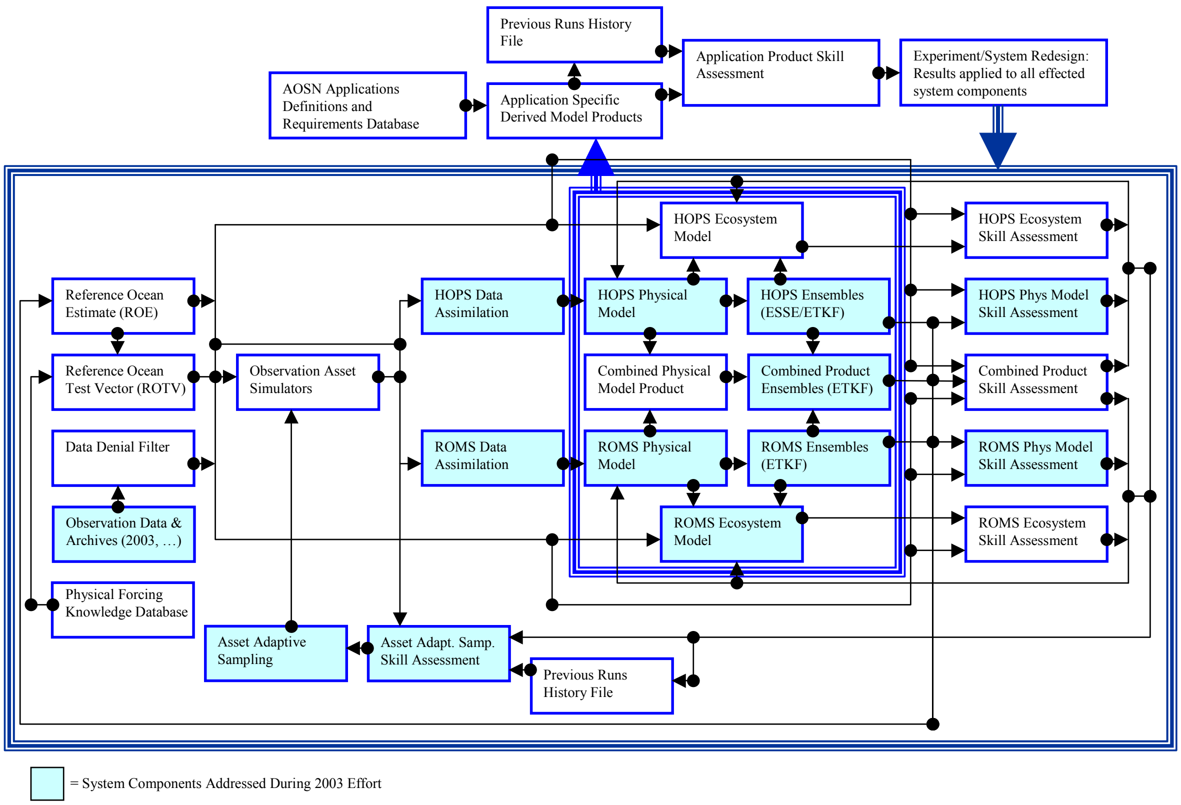


Figure 1: AOSN System Diagram

APPROACH

The Autonomous Ocean Sampling Network (AOSN) project brings together sophisticated new robotic vehicles with advanced ocean models to improve our ability to observe and predict the ocean. The development activity is coupled with science-driven experiments chosen to focus technology development and to convincingly demonstrate new capabilities. The first field program demonstrating the coupled observation/modeling system of the AOSN II effort was run in Monterey Bay from mid July to early September 2003.

The operational system includes data collection by smart and adaptive platforms and sensors that relay information to a shore in near real-time (hours) where it is assimilated into numerical models. The model output helps visualize the four-dimensional fields and predict future conditions. Observations are provided by a variety of remote sensing and in situ assets. Data from these assets was communicated to shore, usually by Iridium satellite communications, where it is placed in a central repository that can be accessed via the Internet by modeling groups and other collaborators. Key to our approach is the development of adaptive sampling control strategies to command our mobile vehicles to places where their data will be most useful. Meetings of the Real-Time Operational Committee occurred every other day during the experiment, and provided a forum for reviewing progress against objectives, observational results, model output, and planning subsequent observations.

Graphical observation data products and modeling results were placed on open project web sites in real-time.

WORK COMPLETED

Field experiment activities began the week of 14 July when the WHOI and SIO glider teams arrived to start in-sea testing. The AOSN field experiment formally commenced when the RV Pt. Sur left port on 2 August for the first of three hydrography cruises and finished when the RV Pt. Sur returned to port from the last of the hydrography cruises on 7 September. All assets (Fig 2, and AOSN Asset List 2003) were deployed on schedule without incident, and with very few minor exceptions operated reliably throughout the experiment. The weather cooperated beyond our hopes. It permitted us to start the field experiment during a wind relaxation period, then provided strong upwelling favorable winds and significant upwelling that was advected across the Monterey Bay. These winds relaxed in late August causing the Upwelling Center to dissipate. Conditions returned to upwelling favorable winds and upwelling conditions toward the end of the experiment.

Data was captured throughout the field experiment to data servers at MBARI, Harvard, and JPL and was assimilated in real-time into the HOPS and ROMS models. The models provided forecast products for review during "Real-Time Operations Committee" (RTOC) meetings that were held throughout the field experiment. Visualization products for the observation assets were also prepared, as were skill metrics products and weather reports. All were presented during the RTOC meetings. RTOC meetings were held daily at first and then every other day throughout the remainder of the field experiment. It was during these meetings that results were discussed, model needs were recognized, and Adaptive Sampling plans were made. Gliders were then reprogrammed with new mission data and other assets were redeployed based on decisions made during the RTOC meeting. All presentations were captured and archived and can be viewed at the MBARI website (MBARI AOSN website) or the Harvard website (Harvard AOSN website).

Coordination of the AOSN project was achieved through meetings and workshops held at MBARI (), Princeton (12 Nov. 2002), Harvard (13 Nov. 2002, and 21 March 2003), and ONR (9 Jan. 2003), by weekly "Real-Time Operations Process" telecons and bi-weekly "Executive Team" telecons, by countless emails whose distribution was facilitated by the establishment of email discussion lists, and by many face to face and telephone conversations between individuals. Through these coordination efforts, the AOSN Team developed a series of field experiment objectives and a plan for the Monterey Bay 2003 field program.

RESULTS

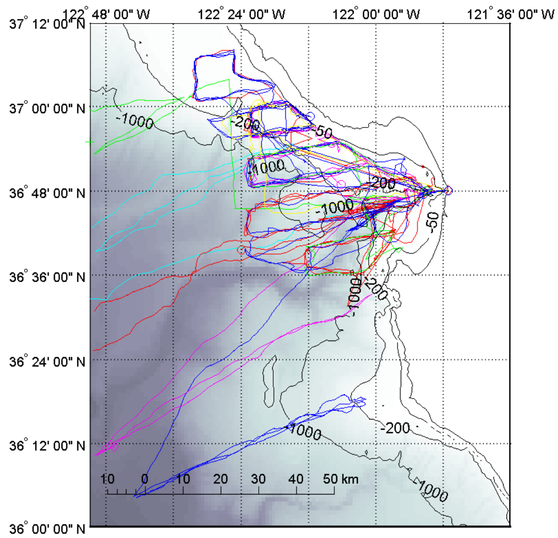
The 2002/2003 AOSN efforts, culminating in the 2003 field experiment, were a great success. Over 21 different autonomous robotic systems, three ships, an aircraft, CODAR, drifters, floats, and numerous fixed (moored) observation assets were used the field program to produce an unprecedented data set of upwelling processes in the vicinity of Monterey Bay. Figure 1 below illustrates a selected set of the many observation assets successfully recruited into the AOSN effort and deployed and operated during the 2003 field experiment.

Figure 2: Selected Observation Assets

A series of reports summarize progress in defining the AOSN System, starting with "AOSN II System Performance Goals and Metrics" (Bellingham and Robinson) were developed. Subsequent reports determined the observation assets required ("Observation Plan for July-September AOSN-II Experiment", Chavez), the model products required ("Integration of HOPS and ROMS During and Beyond the 2003 August AOSN-II Experiment", Lermusiaux and Chao), and the skill metrics with which to study the results ("AOSN II System Goals and Performance Metrics", Davis, Bellingham, Chandler, Chavez, Leonard, and Robinson) and ("Correlations for Measuring Skill" Davis).

Operations for the AOSN field program were staged from MBARI, and supported by MBARI personnel. Central to the success of the field experiment was the establishment of an effective control room. A large, isolated space was carved out at MBARI and equipped with office equipment, computers, networking gear, projection displays, plotters, printers, and communications tools. Special software tools were written to facilitate the management of data during the hectic hour-to-hour operation of the field experiment from within the control room. Figure 3 shows an example of the asset-tracking tool developed by the Princeton Team that was projected continuously within the control room and proved an invaluable asset at keeping all involved up-to-data on asset deployments. Figure 4 shows an example of the many visualization tools developed to provide a real-time look at observed data. These were posted on an open web site as they were produced (MBARI AOSN Website).

MBARI conducted a total of 16 AUV surveys with the Dorado AUV operated off of the RV Zephyr in support of the Haddock Bioluminescence studies and the Chavez CTD studies. Figure 4 provides a sample Dorado dataset.



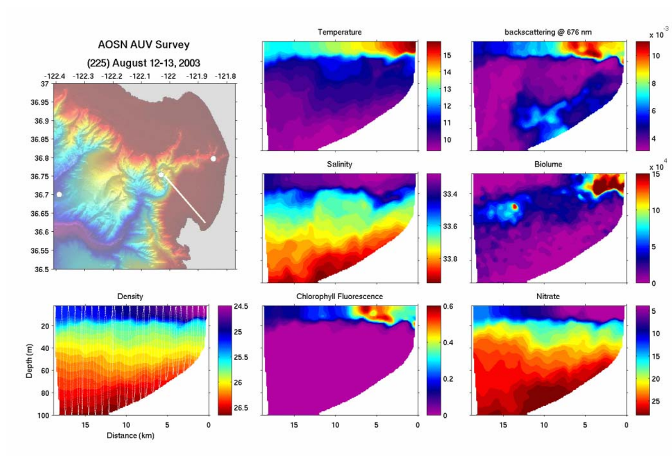


Figure 3: WHOI and SIO Glider Tracks ***Figure 4: Dorado AUV Observation Data***

Assessing model skill was accomplished, in part, using the tools shown in figure 5 below. This tool interpolates 4D model product data to the observation asset grid (lat, lon, depth, and time), and then displays the results next to the observation data using the identical data processing and display tools. Early skill metrics are calculated and displayed in the form of the Horizontal Tempered Correlation Coefficient described fully in ("Correlations for Measuring Skill", Davis).

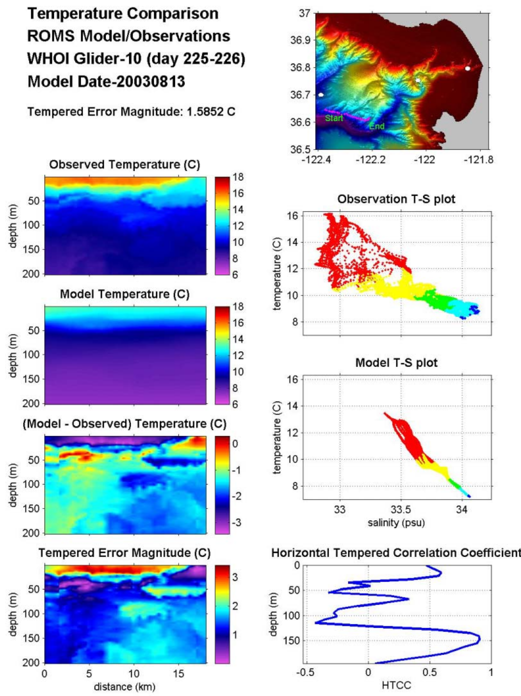


Figure 5 - Model Observation Comparisons and Skill Metics Calculations

IMPACT/APPLICATIONS

The AOSN System has the potential to provide 3-5 day forecasts of important oceanographic physical, chemical, and biological events using continuously deployed autonomous assets coupled with models. Use of adaptive coupled observation/modeling oceanographic prediction systems may someday be as commonplace as the use of atmospheric models and will perhaps have even greater impact on science due to their ability to reveal events difficult to observe in any other way. The AOSN-II project and experiments represent the first attempt to fully integrate major components of an adaptive coupled observation/modeling prediction system into an engineered system. The use of multiple vehicles allows synoptic surveys that would otherwise be prohibitively expensive.

TRANSITIONS

We are actively working with the Naval Oceanographic Office to identify promising technology transitions, and develop transition plans. Perhaps most important, the work creates mobile platforms and supporting systems for extended deployment in remote (and not so remote) locations. Many Navy missions, including tactical oceanography, mine counter measures, covert surveillance, and anti-submarine warfare will benefit from the developed technology.

This project serves as a technology demonstrator to prove concepts and methods for a sustainable, relocatable Integrated Ocean Observing System (IOOS). Many elements of the observational systems used in the program are already in the process of commercialization.

RELATED PROJECTS

This program is the lead element of an ONR effort collaboratively linked with the following ONR funded efforts:

“Implementing FORMS (Feature oriented regional modeling system) for the Monterey Bay forecasting system using HOPS and ROMS”, Avijit Gangopadhyay, N0001410206

“Development of a Monterey Bay Forecasting System Using The Regional Ocean Modeling System (ROMS)”, Yi Chao, N000140310208

“Adaptive sampling during AOSNII”, PI: S. J. Majumdar, N000140310559

“Deep Autonomous Gliders for the "Autonomous Ocean Sampling Network II' Experiment”, Russ E. Davis, Jeffrey T. Sherman, N000140311049

“Coastal Bioluminescence: Measurement and Prediction”, J.F. Case, N000149710424, Grant Supplement, Mod. 13

“Aerial Surveys of the Atmosphere and Ocean off Central California”, S. R. Ramp, J. D. Paudan, W. Nuss, and C. A. Collins, N0001403WR20002, N0001403WR20006

“Hyperspectral Radiometer for Airborne Deployment” S. Ramp, N0001403WR20209
“High-Resolution Measurement of Coastal Bioluminescence: II. Improving short-term predictability across seasons”, Steven Haddock, N000140010842

“QUANTIFICATION OF LITTORAL BIOLUMINESCENCE STRUCTURE AND INDUCED WATER LEAVING RADIANCE”, Mark Moline, N000140310341

“Use of a Circulation Model to Enhance Predictability of Bioluminescence in the Coastal Ocean”, Igor Shulman, Naval Research Laboratory, Grant Number: N0001403WX20882 and –20819, Leslie Rosenfeld and Jeffrey Paduan, NPS, Grant Number: N0001403WR20009, Dennis McGillicuddy, N000140210853

“Participation in AOSN II”, A. Healey, N0001403WR20063

“Autonomous Ocean Sampling Network II (AOSN II): System Engineering and Project Coordination”, J. G. Bellingham and P. Chandler, N000140210856

1. “Underwater Glider Networks and Adaptive Ocean Sampling”, Naomi Leonard, Clarence Rowley, and Jerrold Marsden, N000140210826
2. “Underwater Glider Dynamics and Control”, Leonard (PI), N000140210861
3. “Autonomous Ocean Sampling Network II: Assessing the Large Scale Hydrography of the Central California Coast”, Margaret A. McManus and Francisco Chavez, N000140310267
4. “An Autonomous Glider Network for the Monterey Bay Predictive Skill Experiment / AOSN-II”, David M. Fratantoni, N000140210846
5. “Instrumentation in support of autonomous glider operations”, David M. Fratantoni, N000140310736

6. “Glider communication and sensor enhancements in support of AOSN”, David M. Fratantoni, N000140210846
7. “Development of a Regional Coastal and Open Ocean Forecast System:
8. Harvard Ocean Prediction System (HOPS)” (Included under this are "Quantitative Interdisciplinary Adaptive Sampling OSSEs for Monterey Bay and the California Current System - AOSN-II" and "Adaptive Sampling OSSEs for Monterey Bay and the California Current System - AOSN-II"). A.R. Robinson, N000149710239
9. “Monterey Bay Sampling”, Craig Bishop, N0001403WX20009
10. “Developing of a Monterey Bay Forecasting System Using the Regional Ocean Modeling System (ROMS)”, James C. McWilliams, N000140210236, Fei Chai, N000140310208

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AOSN II System Goals and Performance Metrics”, Davis, Bellingham, Chandler, Chavez, Leonard, and Robinson, http://www.mbari.org/aosn/Documents/GoalsMetrics5_2003May11.pdf

“Correlations for Measuring Skill” Davis), http://www.mbari.org/aosn/Documents

“AOSN RTOC Summary 3 Sept 2003”, http://www.mbari.org/aosn/Documents

“AOSN Asset List 2003”, http://www.mbari.org/news/news_releases/2003/aosn_assets/bellingham-aosn-assets.html

PUBLICATIONS

The great success of the AOSN field experiment and the value of the synoptic dataset it generated are being captured by AOSN Team members within a large number of presentations and publications that are currently in process. These will be fully documented in the next annual report.