CENTER FOR INTEGRATED MARINE TECHNOLOGIES

A continuation proposal submitted by the
Center for Integrated Marine Technologies
University of California, Santa Cruz

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INTRODUCTION

With increasing human populations, demands on coastal resources are increasing, leading to dramatic changes in coastal ecosystems. Because we rely on the ocean for food, commerce, mineral, and energy resources, as well as for recreation, it is critical that we develop conservation and management strategies that facilitate the sustainable use of marine resources while minimizing impacts on natural systems. A major impediment to achieving this has been a lack of an integrated understanding of the basic processes governing coastal ocean ecosystems.

In an effort to develop this understanding, Congress directed the U.S. marine science community to develop a sustained and integrated ocean observing system (IOOS) that rapidly and systematically acquires and disseminates data and data products to serve the critical and expanding needs of environmental protection, public health, industry, education, research, and recreation. For the coastal U.S., the ideal integrated coastal ocean observing system (ICOOS) is one that: 1) is based on sound science and modern technologies, 2) provides timely access to data, and 3) makes effective use of existing resources, knowledge, and expertise (Malone 2001). Malone (2001) proposed that an ICOOS initially develop through the establishment of regional proof-of-concept pilot projects that incorporate existing programs and new initiatives into a coordinated and integrated system. Starting in 2002, the Coastal Observation Technology System (COTS) project funded the Center for Integrated Marine Technologies (CIMT) to develop one of several model demonstrations of regional coastal ocean observing systems based on combined knowledge, expertise, and efforts.

CIMT has sought to develop a comprehensive understanding of how ocean dynamics affect marine resources by addressing three main limitations to an integrated coastal ocean observation system: 1) the development of new technologies to measure key components in the system, 2) the integration of diverse data sets across disciplines and programs, and 3) incompatibilities in temporal and spatial resolution of data sets. A well-integrated interdisciplinary approach offers the only prospect of truly providing predictions regarding present and future effects of human activities on marine ecosystems. We have assembled a group of physical, biological, and geochemical oceanographers, ecologists, resources managers, and remote sensing experts, together with instrumentation and networking engineers who are working synergistically to develop an integrated regional coastal ocean observation system. Our unified goal is to create a well-integrated pilot system that will provide novel insights and critical data about the functioning of the California coastal upwelling ecosystem.

By creating a Center for Integrated Marine Technologies (CIMT), we are explicitly linking new technologies across disciplines of marine science to address key questions for environmental protection, public health, industry, education, research, and recreation. This Center provides the structure for an innovative new approach to understanding how key marine resources respond to short and long-term changes in physical oceanographic processes such as El Niño events, decadal oscillations, and long-term climate change. CIMT combines emerging technological and data integration approaches to determine the processes underlying the dynamics of coastal upwelling ecosystems, and to investigate the critical linkages between:

- *Detailed physical oceanographic measurements of upwelling intensity and surface currents with*
- *Assessment of the availability of critical nutrients, to determine the extent to which these may be used to predict*
- *The distribution, abundance and species composition of phytoplankton and zooplankton, and*
- *The distribution, abundance and species composition of top-level consumers including fish, sea lions, seabirds, sea turtles, and whales.*

The CIMT efforts are focused on the Monterey Bay region of the Monterey Bay National Marine Sanctuary (MBNMS) – from Pt. Año Nuevo on the North to Pt. Lobos on the South out to 122°05' west longitude. This region roughly encompasses the effects of the Davenport/Año Nuevo upwelling region (Rosenfeld et al. 1994). Monterey Bay is an ideal location for the development of a pilot regional ICOOS. Presently, there are more than 20 federal, state, and private academic, research, and resource management agencies and institutions actively involved in studying, measuring, and monitoring the waters in and around Monterey Bay and the MBNMS on an ongoing basis. A number of these institutions have been collectively developing, maintaining, and operating a coastal observing system in Monterey Bay and the surrounding region, delivering data in near real-time, for almost 15 years (Appendix A). These efforts are becoming increasingly interdisciplinary and multi-institutional.

The California Upwelling Ecosystem

California's National Marine Sanctuaries (Cordell Bank, Gulf of the Farallones, Monterey Bay and Channel Islands) are situated in one of four major global coastal upwelling regions. Coastal marine ecosystems are the world's most productive - producing nearly 95% of the annual global production of marine biomass (Sherman 1991). While they represent only 0.1% of the ocean surface area, upwelling regions account for more than 21% of the world's fisheries landings (Parrish et al. 1983). In 1996, for example, the landings of commercial fisheries in the California upwelling region totaled 208,440 metric tons, with a wholesale value of $215.3 million (2003 dollars-CalCOFI 1997). Despite the ecological and economic importance of coastal upwelling centers, we still have only a rudimentary understanding of how coastal upwelling fuels the engines of productivity associated with them. Progress in understanding the dynamics of upwelling centers and their associated ecological communities has been hindered as disparate disciplines have failed to coordinate use of new technologies in interdisciplinary studies of upwelling processes.

Understanding the strength of these linkages and the factors that contribute to their variability provides us with the foundation of knowledge needed to predict the impacts of climatic change and human activities on coastal productivity. Developing and integrating the new technologies accomplish this and will serve as a model for ocean observing in all U.S. coastal regions. Along the California coastline, upwelling occurs during periods of strong northwesterly winds and is most intense in late spring and early summer (reviewed by Barber and Smith 1981, McGowan et al. 1996), producing a band of cold water along the coast (Figure 1). This band is typically tens of km wide and separated from offshore warmer water by a series of highly variable jets, plumes and eddies (Strub et al. 1991). Upwelled water infuses surface waters with essential macronutrients such as nitrate, phosphate, and silicic acid, and this often leads to blooms of phytoplankton, forming the foundation of food chains that support coastal fisheries, seabirds and marine mammals.

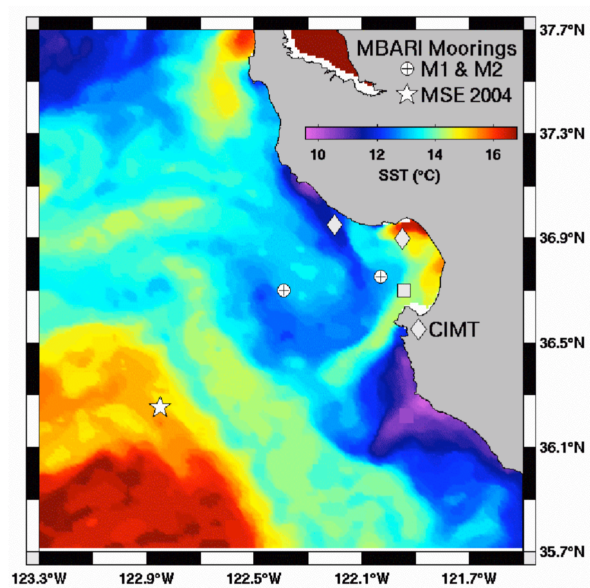

Figure 1. Satellite imagery of sea surface temperature in central CA. Note the cool, upwelled water along the shoreline and locations of M1 and M2 moorings (circles).

The Monterey Bay Upwelling Region

Monterey Bay oceanography is strongly influenced by this persistent upwelling plume (Pennington and Chavez, 2000; Rosenfeld et al., 1994). During the spring and summer upwelling period, satellite imagery indicates cold surface water originates north of Monterey Bay near Davenport and advects southwards across the mouth of the Monterey Bay as an upwelling plume (see prior CIMT reports for an extensive review). During fall and winter, surface currents are northward both within Monterey Bay (Breaker and Broenkow 1994) and across its mouth (Paduan and Rosenfeld 1996). At this time the upwelling plume is absent and the spatial distributions of surface temperature, salinity, primary production and chlorophyll are more uniform relative to the upwelling season. Recent studies have demonstrated that the supply of iron, a key micronutrient necessary for plant growth, plays a critical role in controlling phytoplankton blooms (Hutchins and Bruland 1998, Hutchins et al. 1998). When coastal upwelling occurs in the spring, iron from the shelf sediments is entrained in upwelled water along with elevated concentrations of nitrate and silicic acid (Bruland et al. 2001). Southward currents result in the enormous productivity of this region being swept into Monterey Bay (Kudela and Dugdale 2000, Kudela and Chavez 2002).

Climatic Impacts on Upwelling Centers

Adding further complexity to coastal productivity are the influences of climatic events occurring interannually (El Niño/La Niña) and interdecadally (climatic regime shifts). Declines in upwelling, potentially linked to human activities, led to changes in productivity along the West Coast of North America beginning in 1977 (McGowan et al. 1998). However, a strong reversal, associated with multidecadal changes, occurred in the late 1990s (Chavez et al., 2003), making it clear that we need to understand the natural system before we can assess human impacts. Unfortunately, our ability to predict the potential impacts of these events is poor. For example, during the 1997/98 El Niño event, productivity was generally low in the Eastern Pacific. However, weak upwelling very close to the central California coastline fueled moderate levels of primary production (Kudela and Chavez 2000, 2002; Chavez et al. 2002). Seabirds and marine mammals that normally range far offshore responded to this climate-induced inshore shift in productivity and were concentrated in very nearshore waters (Benson et al. 2002). In contrast, other animals that rely on the productivity of upwelling centers, such as squid, experienced dramatic declines and fishery collapse. Combined, these new insights indicate phytoplankton production and the distribution and abundance of animals from zooplankton to fish, squid, seabirds and whales may be determined by complex interactions among climatic events, riverine input of iron, and wind-driven coastal upwelling of nutrients.

The strategy of CIMT is to create a regional model of a Regional Ocean Observation System that links remotely-sensed, ship-based, mooring-based, and land-based data sets using an innovative database system. Our goal is to provide critical information on coastal processes to research, resource management, recreation, commerce, and military users in relevant, easily accessed, and timely web-based formats. In the following pages, the major components of CIMT are discussed in terms of activities to date and specific plans for actions during year three.

REMOTE SENSING MEASUREMENTS

CIMT Remote Sensing activities focus on providing data from satellite, airborne, shore-based, and autonomous sources, including marine mammal tagging, and, through collaboration with other programs (e.g. MBARI, the Autonomous Ocean Sampling Network II: AOSN II), AUVs and towed vehicles. The goal of the remote sensing group is to characterize the large-scale environment in which both the CIMT program and the MBNMS are embedded. This includes characterization of physical features (~1 km resolution) such as the presence/absence of frontal fields, and the spatial/temporal coupling of physical and biological properties. These data are provided to other groups, particularly the shipboard component, for integration into their products. In addition, they are used separately for regionally tuned models to estimate primary production and new primary production (e.g. export production). With the proposed development of an enhanced modeling component in Year 3 of CIMT, we anticipate working closely with that group (which was formerly included under the Remote Sensing administrative component) to provide model input and validation.

The remote sensing component may be described in three sections:

- Operational satellite products closely linked to national programs
- Regional efforts including airborne overflights, shore-based HF radar systems, and in situ ground-truthing activities
- Developmental efforts including marine mammal tagging

Operational satellite products

A core component of any existing or future Ocean Observing System (OOS) structure is the development of "backbone" components such as remote sensing. Through Year 2, the CIMT program has been maintaining and processing satellite data regionally. The Monterey Bay Aquarium Research Institute (MBARI) is the real-time license holder for capture of HRPT images from the SeaWiFS satellite on the west coast. AVHRR data are available from the west coast CoastWatch node, which recently relocated to the Pacific Fisheries Environmental Lab. MODIS data are available via the Goddard DAAC, as well as from Oregon State University. In collaboration with Dave Foley (CoastWatch) and the Sea Space Corporation, we have also been evaluating near real time data from the Indian Ocean Satellite (OCM), which has 300-meter resolution data similar to SeaWiFS ocean color (Figure 2).

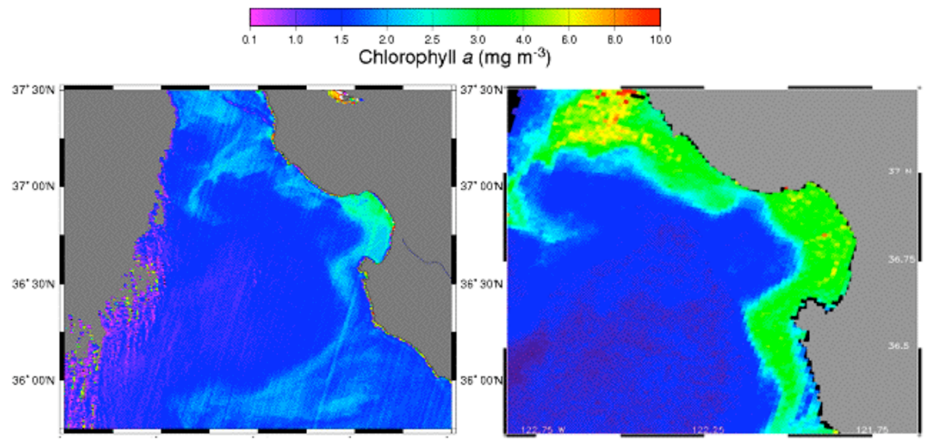

Figure 2. OCM satellite data (left panel) courtesy of Dave Foley (CoastWatch) and Sea Space Incorporated, which provides ca. 300 m resolution, compared to SeaWiFS (right panel) with 1 km resolution, for the same day (19 September 2003).

During the first two years of this project, we have focused on disseminating the remote sensing products by setting up an automated processing and archiving facility, and we currently make products available in near-real time at the CIMT Remote Sensing web page, http://oceandatacenter.ucsc.edu. In preparation for the development of a National OOS, we have been working on reducing the redundancies associated with these efforts; for example, both we and PFEL archive and disseminate ocean color and temperature data, and all of these data are also available from national archives such as the SAA (NOAA) and the Goddard DAAC (NASA). Beginning in year 2 and as a core proposed activity for year 3, we are establishing collaborations with several of these groups to set up a virtual distributed network which will streamline the processing and archiving of these data. CIMT will reallocate resources to become a regional distribution hub for data processed by other organizations, allowing us to focus on value-added products. Ongoing or in-development collaborations include:

- *NOAA*: NOAA has tasked Dr. Richard Stumpf with archiving and distributing ocean color data for the US coast, and the national Sanctuary programs. Through our collaboration with Dr. Stumpf, we will serve as a regional data portal for NOAA-processed ocean color products (radiance fields, chlorophyll, statistical products such as annual means). In addition we are working with Dr. Stumpf to develop regional (west coast) research products such as HAB detection algorithms into operational products.

- *PFEL/CoastWatch/Sea Space*: Dave Foley and Mike Laurs have been providing us with both AVHRR and OCM data. The CIMT Remote Sensing Group has been working with them to interpret these data with the goal of incorporating these data into our virtual distribution system.
- *NASA*: We have set up a daily ftp-transfer system for SeaWiFS and MODIS (Terra and Aqua) chlorophyll products, courtesy of Dr. Gene Feldman (GSFC). These are staged by NASA as available (in real time) and incorporated into our virtual distributed archive.
- *UCSC*: In year 2 we are evaluating the ArcGIS package (ESRI) as a convenient and public-friendly web interface to the data; this system is already being used by the CI-CORE (Center for Integrative Coastal Observation, Research and Education) program for their remote sensing data distribution (http://www.marine.calpoly.edu/cicore/data/hyperspectral/default.shtml).

Regional efforts

A unique remote sensing monitoring program is underway in cooperation with the ONR AOSN-II program that utilizes low-level aircraft surveys of the region covering much of the MBNMS. The surveys are being conducted ca. every two weeks, and return maps of sea surface temperature, ocean color, and winds, often from underneath the persistent stratus (Figure 3), as well as several other atmospheric variables. Two cross-shore vertical sections to 4000 feet during each flight provide three-dimensional data on the marine atmospheric boundary layer. During 2003, we collected a total of 40 hyperspectral (ocean color) airborne maps of the Monterey Bay (e.g., Figure 4). The

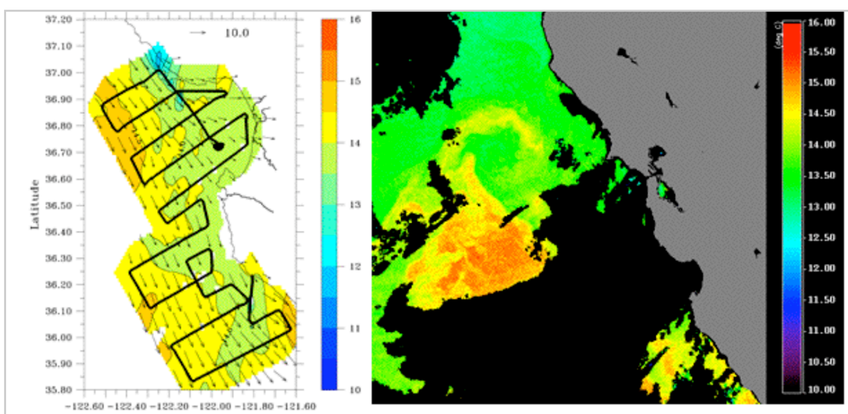

Figure 3. Sea surface temperature from AVHRR (NOAA CoastWatch, left) and the CIRPAS radiometer and wind vectors (right), demonstrating the superior resolution and cloud-cover capabilities of airborne imagery, versus the synoptic scale provided from satellites.

sequence of simultaneous temperature and color maps being collected will provide the context for in-water CIMT surveys. Survey results are available on line at: http://www.oc.nps. navy.mil/~teanders. We are also coordinating with CI-CORE to fully utilize the PHILLS2 hyperspectral data. Planned efforts for Year 3 include joint calibration/validation, intercomparisons of the sensors, and standardized data collection policies (see below).

Although covered in greater detail in the shipboard section, we have also instrumented the *R/V John Martin* with an underway fluorometer, and added a passive 7-channel radiometer package and active 2-channel backscatter instrument to the CTD profiler for verification of the satellite and airborne data. At this time, we are in the process of purchasing a newly designed hyperspectral groundtruth package designed by Satlantic Inc. to the specifications of a consortium of investigators, including CIMT and CI-CORE. We have been and will continue to utilize cruises of opportunity and CIMT activities to calibrate/validate the various sensors and packages independent of the remote sensing. For example, in October 2003 we utilized the *R/V Point Sur* to field test the marine mammal CT and light tags in comparison to larger CTD and radiometric packages. For Year 3, these activities will be expanded to include cross-calibration of the mooring instruments during the CIMT shipboard cruises.

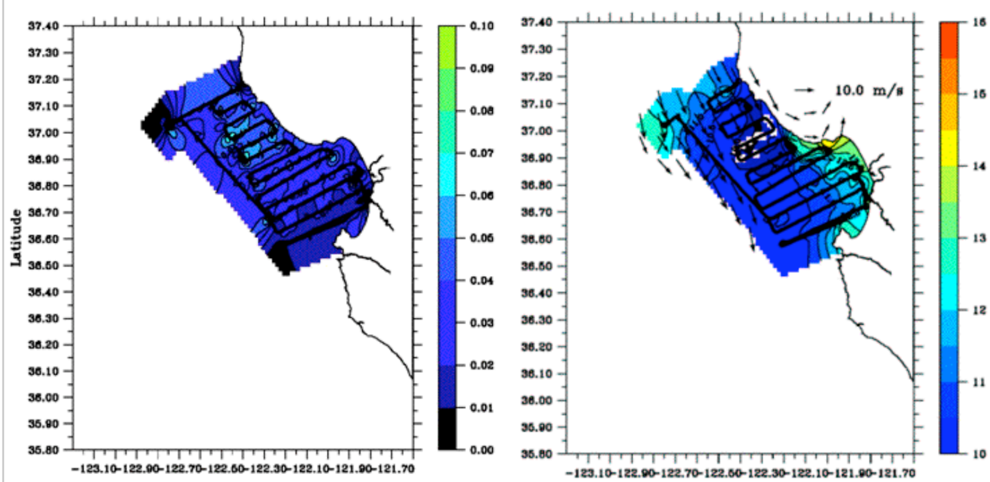

Figure 4. Hyperspectral ocean color showing relative chlorophyll fluorescence (right) and sea surface temperature overlayed with wind speed (left) from an airborne overflight on May 27, 2003.

Developmental efforts

An important value-added contribution from CIMT is the development and validation of regional or experimental data sets. There are numerous non-standard (or research) products available from remote sensing that are not routinely disseminated to the public. For Year 2, we explored the applicability of some of these products, including the use of the 250 μm (terrestrial) bands on MODIS for mapping near-shore sediments, functional group identification of phytoplankton assemblages (e.g. diatoms vs. dinoflagellates) from hyperspectral data (Dierssen et al., 2004), and correlative relationships between remotely sensed backscatter, chlorophyll, and bio-available iron (Kudela et al., 2002). The availability of frequent cruises and ancillary ground-truth data make this CIMT project an ideal venue for such development. For year 3, we propose to continue this in close collaboration with our partners to transition successful experimental products to more operational results.

On the hardware side, we continued our work with the marine mammal group to evaluate the use of tags on California sea lions, similar to the much larger scale work that has been done with elephant seals (Boehlert et al., 2001). During Year 2, we successfully deployed 22 SRDL (Satellite Relay Data Loggers) on California sea lions. These tags transmit water column temperature profiles from free-ranging California sea lions. This technology is very promising with the first 4 tags having transmitted 417 temperature profiles with a max depth of 387m (1.7-3.3 profiles per tag day). An example of temperature profile and the depth range are provided in Figure 5. In year 3 we will deploy a newly designed SRDL developed with funding from ONR that will provide salinity as well as temperature data (Figure 5). During year 3 we would like to test and then deploy 12 of these CTD tags on California sea lions.

We have also extended the use of sea lions as sensing platforms with the deployment of archival light-sensing tags on 8 California sea lions. These data could provide another high-resolution, 2-D dataset of water quality and chlorophyll biomass (using attenuation as a proxy). While highly exploratory, funding for this component is minimal and provides a unique and valuable dataset complementary to the large-scale remote sensing. ONR-NOPP and the Packard Foundation are supporting the development of the CTD and GPS tags for use with marine mammals. In year 3 we hope to further test and evaluate

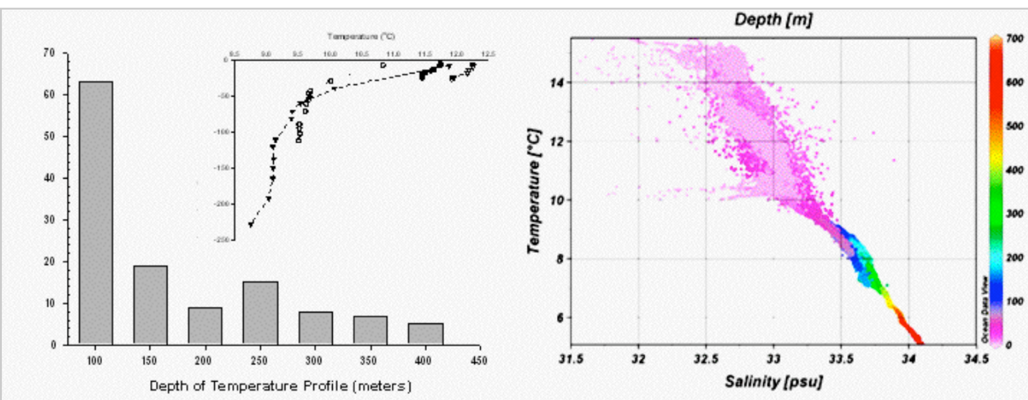

Figure 5. Depth histogram plot (left) for the first 4 SRDL temperature tags deployed on California sea lions. The inset shows 4 representative profiles. Right: Temperature, Salinity, Depth plot from the new CTD tag deployed on a northern elephant seal in Monterey Bay.

these technologies by using juvenile elephant seals that will be transported and released at strategic locations around Monterey Bay.

SHORE-BASED MEASUREMENTS OF SURFACE CURRENTS (HF Radar)

Real-time maps of coastal ocean surface currents from High Frequency (HF) radar backscatter instruments are a critical component of CIMT and the observational database in the Monterey Bay region. These instruments are central components of many other existing and developing coastal ocean observing systems. Monterey Bay and CIMT researchers have been, and continue to be, at the forefront of these developments. Although HF radar current mapping has been possible for many years, only recently has it become timely and reliable enough to be used outside the research arena.

In the first phase of CIMT, effort was focused on increasing the number of HF radar sites around Monterey Bay and on establishing real-time communications to each site. This involved developing wireless Internet links and the creation of automated scripts for the continuous flow of data. At this stage, programs run each hour at NPS that are responsible for downloading radial current observations from the individual sites, combine them into a single, best-fit vector map, and ship the vector map to CIMT partners at several locations. Excellent coverage is achieved from the four HF radar sites around Monterey Bay proper. However, even with the best case scenario, spatial gaps are to be expected in the coverage from these instruments, making the production of automatic velocity-based products difficult. To fill these gaps we have collaborated with the University of Delaware to develop an integrated real-time normal mode analysis to supply a fixed grid data set. This has allowed us to supply real-time hourly updated surface trajectory animations.

An example of these hourly surface velocity maps is shown in Figure 6. These products are available through the CIMT web site or directly at: http://Newark.cms.udel.edu/~brucel/realtimnemaps. We will compare our circulation model results as one of the critical research and development areas during the next phase of CIMT. In addition, the use of surface velocity maps as data assimilation sources to the coastal ocean model will be investigated in collaboration with modeling partners at UCLA, JPL, and NRL-Stennis.

We will also expand the coastal ocean area covered by the HF radar network to the south and north during the next phase for CIMT. A new satellite Internet downlink along the Big Sur coastline will allow the coverage to be extended from the Monterey Peninsula south to Pt Sur. Two new systems being purchased with ONR funds will expand coverage north of Santa Cruz to the area around the critical upwelling center offshore Pt Año Nuevo. Collectively these developments will expand our coverage to ~160 km of coastline.

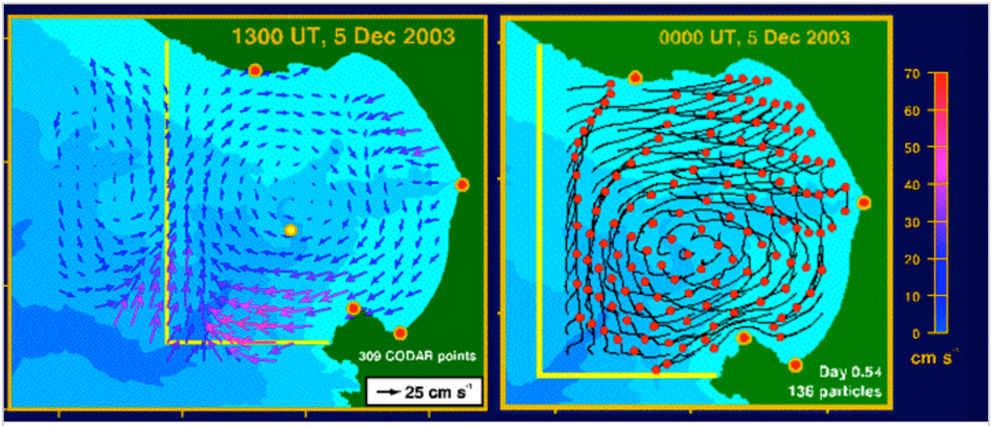

Figure 6. Example of real-time hourly surface current map from the four-site HF radar network (left) showing radar locations (symbols) and the present extent of the real-time normal mode analysis (box). Animations of the surface particle trajectories over the previous 24 hours within the normal mode analysis domain (right) are automatically generated and posted each hour along with the instantaneous and daily averaged current maps.

In addition to expansion of the real-time HF radar coverage, model validation, and model data assimilation, other activities include research into the use of simultaneous multiple frequency backscatter to deduce near-surface velocity shear and vector winds. During the next phase of CIMT the Surface Current Measurement Group will:

- Supply quality-controlled surface current data for Monterey Bay in near-real time for display and dissemination on the CIMT website. This includes the reinstallation of a multifrequency HF radar unit at Moss Landing and renovation of HF radars at Long Marine Laboratory.
- Deploy and integrate new multifrequency Codar systems to supplement existing multifrequency HF radars.
- Develop and implement techniques for mapping the wind field.
- Investigate methods for data assimilation into numerical ocean circulation models.
- Investigate techniques for detection and tracking of ships and small boats.

MOORING-BASED MEASUREMENTS

Continuous monitoring from moorings is essential for any ICOOS in order to understand regional variability and provide context for process studies that occur over more limited periods. MBARI has demonstrated the utility of such a program, with nearly continuous data over the last 13 years from a series of offshore moorings in Monterey Bay (M1 and M2).

Year 2 Accomplishments

During Year 2 CIMT and MBARI have supported instrument controller and telemetry development, and the construction of a next-generation "smart" mooring, to be deployed at the end of Year 2. This design supplies significantly more power for data collection and communication than other similar moorings. Radio based communications between shore and the mooring enable instrument query, control, event detection, and response. Using the existing MBARI moorings, we have supported the deployment of a new generation of a hydroacoustic instrument for monitoring zooplankton and fish at the M1 site (Figure 1). A passive acoustic system for detecting marine mammal vocal activity has been developed and tested by the Bioacoustics Laboratory, Cornell University (see system description below). This 4-element array will be deployed in Monterey Bay mid-March 2004, prior to the arrival of foraging whales in Monterey Bay (typically April/May). The array will provide a relative measure of large whale abundance in the Bay, as well as whale location associated with spatial patterns in prey distribution measured by the shipboard survey group.

Year 3 Goals

Deployment of nearshore mooring: Typically, once upwelled water enters Monterey Bay, currents slow and the water column becomes stratified. This leads to optimal conditions for phytoplankton growth that can result in dominance by algal species (either pennate diatoms or dinoflagellates) that produce toxins harmful to humans. The present M1 and M2 moorings (Figure 1), supported by MBARI, provide important references for long term monitoring of Monterey Bay and the contiguous waters of the California Current. However, these phytoplankton blooms are not well captured by the current mooring locations. In year 3 we will deploy and additional mooring, M0.5, at a location where blooms reach their maximum levels. This mooring will utilize the "smart" mooring technology and will target bloom formation inside Monterey Bay. Collectively, these moorings will allow Monterey Bay to serve as a useful microcosm for the California coastal upwelling system. The moorings are equipped with meteorological, physical, chemical and biological sensors allowing scientists to follow and understand the relationships between atmospheric forcing and biological responses.

Environmental sample processor: Molecular probes are useful tools for identifying water borne microorganisms and the substances they produce, even when those targets are very dilute and embedded in a taxonomically complex and organic-rich matrix. Application of such technology outside of a laboratory poses many technological challenges, particularly if unattended, real-time synoptic analysis of multiple locations for extended periods of time is desired. The Environmental Sample Processor (ESP) is a novel instrument developed in an effort to overcome these challenges (Scholin et al. 1998; http://www.mbari.org/microbial/ESP). The ESP was designed to collect discrete subsurface water samples remotely, concentrate microorganisms, and automate application of DNA (or other) molecular probes to enable identification and quantification of particular species captured. Results of DNA probe array assays are transmitted in real-time via radio modem to shore for processing, interpretation and dissemination. The ESP also archives discrete samples for nucleic acid, microscopic and toxin analyses for validating real-time data from the probe arrays as well as facilitating other analyses in the laboratory (such as construction of gene libraries).

Development of instruments that enable long term, unattended application of molecular probes *in situ* offers an exceptionally novel approach for detecting water borne microbes as well as the genes they harbor and express. In a step toward reaching this goal, we will deploy the existing "first generation" ESP near the CIMT M0.5mooring during August, September and October '04. Probes for a variety of invertebrate larvae (e.g., mussel, barnacle), several species of harmful algae (e.g., *Pseudo-nitzschia australis*, *Alexandrium catenella*, *Heterosigma akashiwo*) and groups of archea and eubacteria (e.g., group I and II Archea, *Cytophaga*, *Rosebacter*, etc.) are available for this purpose. Results of this work will facilitate development of the "second generation" ESP (NSF OCE-0314222), with the objective of integrating that device onto the CIMT mooring itself once it becomes available ('05-'06).

Active hydroacoustic system: In collaboration with Dr. David Demer, NOAA/Southwest Fisheries Science Center, we have developed, tested and deployed a 120 kHz active hydroacoustic system on the MBARI M1 mooring. This system provides hourly measurement of acoustic backscatter of zooplankton and fish, in conjunction with an ongoing suite of physical and biological oceanographic data on the M1 mooring. During year 3 we will develop a twin active acoustic system for deployment on the M1 mooring during the annual system overhaul. A duplicate system assures continuous collection of data on higher trophic level sound scattering zooplankton and fish.

Passive acoustic system: Using technology recently developed by the Bioacoustics Laboratory at Cornell University, we have developed and tested a bottom-mounted passive acoustic system for monitoring patterns in the abundance and ecology of apex predators such as large whales in the Monterey Bay study area. The system consists of a continuously recording passive hydrophone system mounted on a mooring. Previous studies have shown that whale vocal behavior is an accurate index of whale abundance (Croll et al. 2001), and a pilot study conducted in Monterey Bay in 2000 demonstrated that this tool can be used to correlate whale abundance patterns with biotic and abiotic factors. By adding this new and innovative way to monitor apex predator populations (through sound), we will greatly expand the temporal resolution of the CIMT Monterey Bay marine mammal data set. In addition, this system will establish a reliable near-shore acoustic monitoring system that can be used as a means of monitoring potential Homeland threats to the nearshore coastal zone.

Comparison of continuous vertical profiling from moorings: MBARI and UCSC own three vertical profiling mooring systems. Two of the three are commercial units (SeaHorse manufactured by Brooke Ocean Technology). The third, known as MVP (MBARI Vertical Profiler), was designed and built at MBARI. Each has strengths and weaknesses. During the next year we will evaluate these mooring systems at the M0.5 site. Figure 7 shows a 2-week SeaHorse deployment at M0.5 during August 2003.

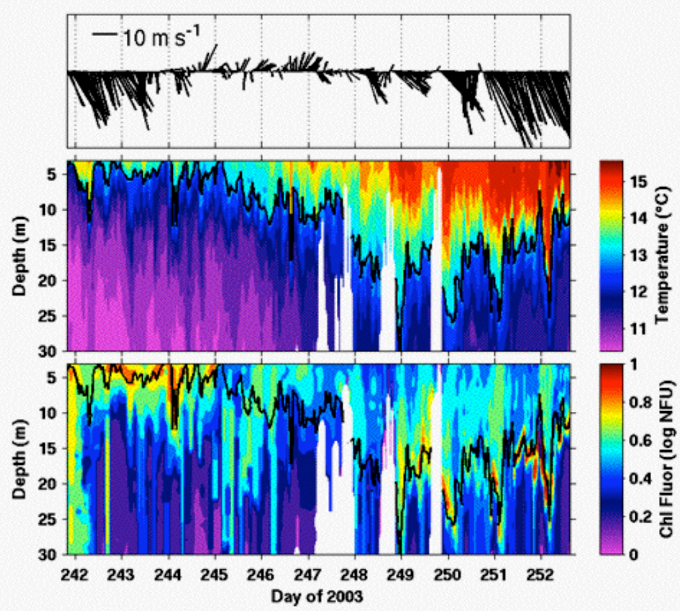

Figure 7 a) Wind time series from NDBC data buoy. b) Temperature data from 2-week SeaHorse deployment at M 0.5 site during August 2003. c) Fluorometry data from 2-week SeaHorse deployment at M 0.5 site during August 2003.

SHIP-BASED MEASUREMENTS

Success of ship-based measurements relies upon the simultaneous measurement of physical and chemical oceanographic processes; primary productivity and phytoplankton community structure; zooplankton abundance, distribution, and composition; and seabird, whale and sea turtle distribution and abundance within the Monterey Bay upwelling area. Surveys are conducted monthly utilizing existing grids of transects (ranging 8–19 km in length) spaced ~5 km apart (Figure 8). Ongoing sampling programs have been conducted within Monterey Bay since 1996 as part of a broad scale survey of physical oceanography, primary production, zooplankton and predator dynamics within these areas. These surveys provide synoptic data sets of the Monterey Bay region that serve to: 1) groundtruth remotely sensed data, 2) improve data analysis algorithms for remotely sensed data, 3) provide detailed information on vertical temperature, salinity, light transmission, and currents, 4) provide detailed information on the distribution and abundance of primary producers, 5) provide detailed information on the distribution of species that generate harmful algal blooms, 6) provide detailed information on the vertical and horizontal distribution of zooplankton and schooling fish, 7) characterize phytoplankton and zooplankton community composition, 8) provide detailed information on the distribution and abundance of seabirds, sea turtles, and marine mammals.

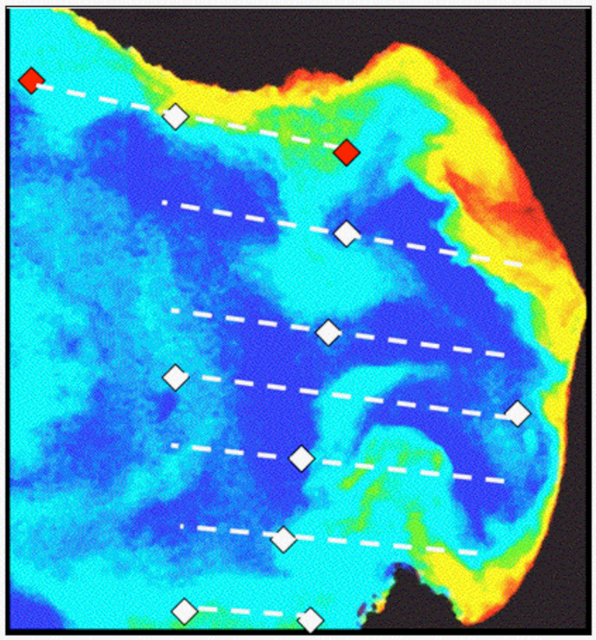

Figure 8. CIMT Ship-based survey track lines and hydrographic stations, Monterey Bay

Year 2 Accomplishments

- Nine shipboard surveys were successfully completed during 2003.
- *Underway data collection:*
  - *Sea surface temperature*
  - *Subsurface currents - acoustic doppler current profiler*

    - *Surface fluorescence and backscatter*
    - *Colored dissolved organic matter*
    - *Zooplankton backscatter at 38, 120, and 200 kHz*
- *Hydrographic station data collection:*
    - *Conductivity*
    - *Temperature*
    - *Fluorescence*
    - *Nutrients*
    - *Size fractionated chlorophyll*
    - *Discrete bottle measurements*: (total suspended solids, biogenic and lithogenic silica, CHN, and absorption spectra)
    - *Beam attenuation, backscatter, CDOM, and passive light at 7 channels*
    - *Semi-quantitative microscopic identification of the phytoplankton community*
    - *Quantitative diagnosis of toxic phytoplankton species using molecular probes*:
    - *Measurements of domoic acid*
- *Zooplankton net sampling*: Net samples are collected; volume displacement measured, and community composition characterized
- *Marine mammal and seabird distribution and abundance*: Data collected using standard National Marine Fisheries Service/NOAA techniques.

Goals for Year 3

Our goals for year 3 include:

- Maintain ongoing monthly shipboard survey data set
- Install and test 38kHz split-beam hydroacoustic system
- Improve data quality assurance and checking.
- Provide ground-truth data for quality assurance of remotely-sensed data
- Provide species identification and synoptic coverage of phytoplankton community for testing of ESP system (see Mooring section)

APEX PREDATOR MEASUREMENTS

This portion of the CIMT project will establish the relationship between remote and directly sensed physical and biological oceanographic variables and the distribution and movement of apex predators. In the short-term, it will provide us with an understanding of the location and dynamics of apex predator foraging habitat; ultimately, it will provide a basis from which to predict the effects of the climate variability on the dynamics of apex predator distribution and abundance patterns – a key goal of resource managers.

Year 1-2 Accomplishments:

- *Fabrication and deployment of capture cage*

- *Deployment of Satellite Data Relay Loggers on 22 adult male California sea lions Deployment of satellite tags on 2 blue whales and 4 humpback whales*
- *Deployment of 10 archival dive recorders on blue whales concurrent with ship-based survey data sets*

Year 3 goals:

As described in Remote Sensing, we have modified the SDRL to provide salinity as well as temperature data. In collaboration with the TOPP program we plan to continue satellite tagging efforts with blue and humpback whales. This will provide a larger context for movements of individual whales. We will also expand our archival tagging efforts to elucidate the relationship between oceanographic patterns, prey patches, and whale diving behavior.

DATA ARCHIVING and DISSEMINATION NETWORK

The overarching goal of the CIMT database group is to develop a data archive and retrieval system for the purpose of acquiring and archiving historical and real-time data sets collected from oceanographic surveys and autonomous instrumentation. This system is designed to identify data from both CIMT (locally) and non-CIMT programs (remotely) within the MBNMS through the cataloging of FGDC metadata common to both types of data sets. These data will be available to a variety of potential users including local user groups and residents, educators, governmental decision makers, in addition to the oceanographic and atmospheric scientific communities. The core component of the data dissemination system is the relational database, from which data are both retrieved by users and submitted by properly configured autonomous instruments and project principal investigators.

The Relational Database

We have developed a MySQL relational database with data submission and retrieval capabilities (Figure 9) that contains information collected by investigators in the CIMT program. The database includes data from monthly shipboard surveys, and will include data from the CIMT mooring after it has been deployed. Multiple interfaces have been designed to accommodate the varied interests of users through the creation of specialized web pages, tailored to provide the best combination of speed and efficiency with general web experience. Data retrieval options from the web site include on-line visualization of the data and direct download in a variety of formats, including Microsoft Excel worksheets as well as COARDS compliant netCDF files and ASCII text files. To achieve the highest level of usability, we have adopted FGDC metadata formatting standards that are applied to all data sets. In year 3, we will optimize this database. Optimization occurs after the database has been developed; it requires user and data flow feedback as well as machine generated statistics, including database queries performed and the length of time to perform them. These statistics are gathered and summarized as dynamically generated content on the CIMT website.

Interfacing CIMT and Other Data Servers Within the MBNMS

We have developed the capability to interface between the CIMT database and other data servers within the MBNMS. We have taken advantage of the Open-source Project for a Network Data Access Protocol (OPeNDAP, formerly DODS) software. OPeNDAP is a set of platform independent software responsible for negotiating data requests by providing that data across the internet without the need for translation or conversion.

In year 3, we propose to distribute our data to other Regional Ocean Observing Systems (ROOS). We are presently participating in the NORLC Interoperability demonstration, which tests data transmission methods between ROOS's. The method of interface involves dynamic creation of OGC standards complaint XML files, which are delivered to a remote site (NOAA CSC) and assembled within MapServer. We will use what we learn from the Interoperability demonstration to automate the interface between CIMT and other ROOS's.

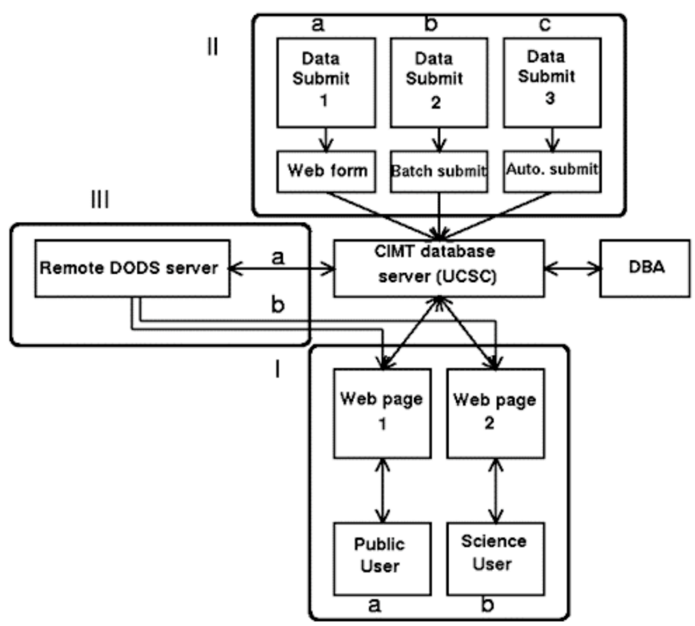

Figure 9. Schematic of the CIMT database system. Three forms of submission of data to the database are supported: single-session data upload of data (IIa) where database tables are updated and files submitted via web applications and forms; batch submission (IIb) where multiple files are transferred to a queue until best handled by the database; and autonomous submission (IIc) where autonomous instruments such as moorings relay information to the database. This allows for the submission of raw, unprocessed data directly to the database. Data retrieval includes the option to format data as Microsoft Excel worksheets. Metadata conform to FGDC formatting standards.

Interfacing CIMT and Satellite Data

We are developing the ability to interface data from the CIMT database with data from the Remote Sensing group, which are stored in a pre-existing, web-accessible database. During Year 2, we have been moving this pre-existing database to a MySQL and OPeNDAP client/server system, to make it compatible with the existing CIMT database. As demand for these products has increased with the evolution of CIMT, we propose to restructure the handling and analysis of these data streams. Unprocessed remote sensing data can easily overwhelm traditional database and storage systems, as hundreds of gigabytes of data are generated per year. For the most efficient handling and analysis of these data streams we will develop programming and hardware support to work with the database and visualization teams, and provide day-to-day handling of the remote sensing data. As described in the Remote Sensing section, we have also been establishing a virtual processing system so that other groups (e.g. NOAA, NASA) will handle much of the raw data assimilation, greatly reducing the data handling issues for CIMT. By the end of Year 2, the new Remote Sensing database will be online, with these partnerships in place. For Year 3 we propose to integrate the two databases and ensure that end users can access all of these data from a common portal.

A Partnership with CI-CORE

We have developed the CIMT website in affiliation with CI-CORE, which is also funded by COTS. We have contracted with Dr. Dale Robinson, who specializes in web design for scientific programs, to develop a web presence for CIMT (http://cimt.ucsc.edu/). Dr. Robinson is also involved with the CI-CORE program, and we are maintaining a similar look and feel, as well as interchangeable data formats, so that the CIMT and CI-CORE programs are complementary. The second iteration of the CIMT web site is in progress, and will be completed mid-February. This new page is almost entirely dynamic and tightly integrated with the database. New components in this iteration include:

- Data displaying methods tested in the Interoperability demo.
- An already developed user registration section.
- A webserver and database server statistics screen for evaluation of web site performance.
- Incorporation of community approved FGDC metadata templates to ensure completeness of submitted data sets.
- Creation of sensor-specific parsing scripts to facilitate data set submission.

- High-level search capabilities in 5-D (lat, long, depth, time, and parameter).
- A method of alerting registered users to new/altered datasets.

MODELING

Although Monterey Bay's productive ecosystem derives ultimately from the wind stress-driven upwelling circulation common to many eastern boundary coastal environments, the contour of the coast and complex canyon bathymetry substantially alter and complicate the resulting flow. For example, upwelling along our coast exhibits substantial spatial variability. During upwelling favorable wind periods, observations reveal a cold tongue extending southward across the bay from the upwelling center at point Año Nuevo. How this nutrient-rich water contributes to the bay productivity relative to more locally driven upwelling remains an open question. Monterey Bay exhibits motion at several scales, but at the largest is a competition between a residence-prolonging cyclonic eddy circulation with intermittent flushing from open ocean forcing. Understanding the role of the physical circulation at this and smaller scales on net biological productivity, and in turn marine mammals, represents one central scientific goal.

Two years of CIMT monitoring has produced a sizeable dataset providing spatial and temporal distributions for a wide range of physical, biological, and chemical variables. This extensive dataset provides a unique opportunity to investigate the connection between the physical environment and the observed biological fields. An important and timely step in this process is the development and analysis of a physical model of Monterey Bay that can be used both to place collected field data into context and also as a tool for process study. Fortunately for CIMT, Monterey Bay has been the focus of several independently funded modeling efforts. Three recent or ongoing projects are the ICON project, the SCOPE project, and AOSN II (see appendix for web links). CIMT can leverage this previous and extensive experience to rapidly establish a local modeling capability.

Evaluations over the past year of the models currently being run in Monterey Bay have led us to the conclusion that a more formal collaboration with the Jet Propulsion Laboratory's (JPL) implementation of the Regional Ocean Modeling System (ROMS) (http://ourocean.jpl.nasa.gov/) is the best path for CIMT to follow in the coming year. The August 2003 AOSN II experiment has shown that ROMS can assimilate a number of types of data that CIMT can supply. ROMS also has a biological component coupled with the circulation model. Additionally, Dr. Yi Chao, the JPL ROMS PI, is excited about working with CIMT, and we can take advantage of the added synergism with two recently funded NASA projects (Chao and Chavez), and the prospect of continuing AOSN experiments. The first NASA project (R.T. Barber PI) focuses on large scale Pacific climate variability and its impact on marine ecosystems. The second project (J. McWilliams PI) focuses on simulating the carbon cycle off the west coast of North America. Chao has a long-standing collaboration with McWilliams' group at JPL, which is at the forefront of model development and has an emphasis on the California Current, so as new model developments occur, they will be transitioned to the JPL model.

Since early 2003, JPL has been running a 15 km resolution West Coast domain and a 5 km resolution central California domain, with embedded ecosystem components, in real-time using the Navy's Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS), or a blended COAMPS / Quikscat product for forcing, with satellite SSH and SST assimilation. During the AOSN II experiment, they ran a triply-nested (1.5/5/15 km) model with the inner nest over Monterey Bay, but without the ecosystem part. This configuration included a 3-D variational data assimilation capability in which observations of temperature and salinity were incorporated daily into the model fields and constrained model evolution. We propose that CIMT contribute towards the re-implementation of the triply nested version. In conjunction with the NASA-funded projects, we hope JPL can add the ecosystem code to this. In addition, CIMT will supply temperature and salinity data for assimilation into the model, and JPL will supply all model output for use by CIMT investigators.

While this capability is ready to be incorporated into the CIMT framework, actually adding the model capability to CIMT requires local effort: 1) hydrographic, overflight, and potentially marine mammal-derived datasets must be bundled appropriately for model assimilation, 2) model fields must be incorporated into the CIMT database system to become useful to CIMT researchers and, 3) developing model-data intercomparisons are essential to assess model output. Although the modeling system must still mature in important ways for CIMT (e.g., adding tidal forcing, or more realistic bathymetry), we do not propose any substantial effort toward model development of this type at this time.

We believe it is critical to characterize and interpret the physical circulation during periods of interesting CIMT collections. We propose supporting one postdoctoral researcher who would perform such analysis, contributing to the integration of CIMT activities. Possible directions this individual could pursue include (a) distinguishing within the observed and modeled fields periods of upwelling, relaxation, as well as those of intense open ocean forcing,

(b) exploring the physically driven time-scales associated with the upwelling circulation from both the upwelling center, Año Nuevo, as well as within Monterey Bay, (c) quantifying horizontal dispersion time-scales within the bay, and (d) understanding flow/canyon interactions. This sort of analysis would be complementary to many ongoing CIMT efforts, and provide a bridge between the biological and chemical observations and the physical environment.

Finally, central to CIMT is understanding how atmospheric forcing and ocean physics influence the concentration of keystone species such as krill, anchovies and sardines, which provide food for seabird populations and marine mammals. Numerical models for basic phytoplankton and zooplankton have been developed and implemented within the ROMS model. What are lacking however are quantitative models for the keystone species, seabirds and marine mammals. The first step in this direction requires synthesis of data collected to date and development of first-order equations relating the physical environment and the basic ecosystem (phytoplankton and zooplankton) to the higher trophic levels. We propose supporting a postdoctoral fellow to perform the synthesis and model development.

PUBLIC OUTREACH AND ACCESSIBILITY

A critical scientific and management focus within MBNMS continues to be the ability to provide information in a timely manner and an accessible format to a broad and interested coastal constituency. One of the primary goals of the Sanctuary Integrated Monitoring Network (SIMoN: http://www.mbnms-simon.org) is to rapidly disseminate monitoring information to a broad array of stakeholders and end users. The SIMoN website has been developed and is now operational. Evidence for the regional interest in this type of information is provided by the 350,000 hits the site received in its first six weeks of existence. Coastal ocean monitoring data are most useful when readily available and provided in a timely and relevant format to managers and decision makers, the research community, educators and various public interest and user groups, and the general public. One key to long-term support of a comprehensive monitoring program is the effective communication of information and regular use of that information by a wide range of stakeholders. Creating an effective program requires input from these stakeholders as part of an iterative process. An additional requirement is that the diverse types of information being collected are presented in a visually understandable and usable format. This is a key component of CIMT's outreach program.

Year 2 Accomplishments

Dr. Steve Lonhart, a scientist for SIMoN at the MBNMS, canvassed several groups identified by Sanctuary staff as potential end-users of CIMT data products. These contacts include members of the local fishing community, a Sanctuary Advisory Council representative of the local sport fishing community, all of the local harbormasters, and environmental groups. From these contacts we have developed a list of priority data and visualizations tools.

Year 3 Goals

- Increase outreach efforts to potential users of the CIMT web site.
- Assist in the development of a web page that is effective for public use of CIMT information.
- Identify gaps of knowledge that if filled would benefit stakeholders.□

To assist in this goal, CIMT has hired (start date of January 2004) a full-time marine research/outreach coordinator to serve as a liaison between CIMT and the user community. This outreach specialist will train users and receive input on how well beta versions of the CIMT web site meet the needs of other scientists, resource managers, educators, and the public. There will also be a number of training or demonstration workshops that will convene at specific locations and draw different user groups. In addition, the outreach specialist will convene regular meetings with CIMT technical staff and PIs to present the needs of stakeholders and to work with technical staff to develop the most effective web design and user interface. This feedback loop is a critical component that will allow CIMT researchers to modify their products in response to the needs of the user community. The outreach specialist will work with CIMT and SIMoN to design an outreach brochure and/or other documents about CIMT and its opportunities for information sharing and collaborative research. In addition to presenting information to stakeholders, the outreach specialist will be exposed at these meetings to non-CIMT data and information that can be added to the web site. By identifying overlooked data sets and presenting other gaps of information to CIMT, the outreach specialist will increase collaborative efforts between CIMT and other programs, as well as make the CIMT program more comprehensive in scope.

HOMELAND SECURITY

As an integrated coastal ocean observation system, CIMT provides several potential benefits to homeland security. These include:

- Detailed information on nearshore currents, which is essential to model the fate of toxins/harmful chemicals introduced into the coastal environment
- Data on natural transport (e.g. sediment, iron, plankton) and toxin (e.g. harmful algal bloom) events. These serve as the background against which man-made events must be detected
- Proof-of-concept of the use of low-cost coastal HF radar to detect the movements of small vessels in the coastal zone, including the assessment of multifrequency and bi-static techniques.
- Passive low-frequency acoustic data that can be used to measure background noise levels against which large vessel movements can be detected.
- Enhanced coastal surveillance capability with an integrated data management and visualization system capable of 3D representation of the coastal marine environment.

TRANSITION STRATEGY

CIMT, as a pilot project for IOOS, is mindful of the need to define pathways by which the regional ocean observing system can transition to being "operational." A number of the elements in CIMT have been in near-continuous operation for several years now. As we think about transitioning these systems to operational status (to be overseen on a daily basis by people who are not necessarily the system developers) we need to formalize these lessons learned and resource requirements. In large part, we can do this now for the HF radars, surface moorings, satellite data and cruises. Specifically, we will write requirements in terms of labor (both time and expertise), dollars, and ship time needed to support these elements (on an annual basis, by cruise, or by mooring deployment) once they are established, and we will specify the labor and equipment (with today's costs) needed to extend these arrays (per HF radar, per mooring etc.). We will also identify the problems encountered and the lessons learned. One benefit is that it will let us, and others, do cost comparative analyses of different methodologies to achieve the same result. For instance, what is the cost of sending someone to sea once a week to measure (iron, nitrate, HABS etc) vs. deploying an automated system on a mooring? How long will it take to recoup the development costs? In implementing the IOOS, there will be trade-offs to be made, and it will be necessary to have hard numbers in hand to make those decisions.

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APPENDIX A EXISTING COASTAL OBSERVING PROJECTS WITHIN THE MONTEREY BAY AND MONTEREY BAY NATIONAL MARINE SANCTUARY AREA

ACT: The Alliance for Coastal Technologies is one of the NOAA-sponsored COTS programs, as is CIMT. ACT is interested in developing and applying sensor technologies for monitoring coastal environments. MLML and MBARI together are one of the 5 partner institutions, and the only ones on the West Coast. http://www.actonline.ws/.

AOSN: The Autonomous Ocean Sampling Network is a Navy-funded effort to develop a real-time adaptive and predictive observational/modeling system. The development of this system, which relies heavily on autonomous mobile assets, will be carried out in Monterey Bay and contiguous waters of the California Current during 2003 and 2004. It involves on the order of 10 US institutions. e.g., http://www.mbari.org/aosn, http://ourocean.jpl.nasa.gov/ and http://people.deas.harvard.edu/~leslie/AOSNII/

CI-CORE: Also with NOAA COTS funding, the California State University (CSU) has established the Center for Integrative Coastal Observation, Research and Education. The CI-CORE observatory, to be distributed along the entire 1200 miles of California coastline will help address a variety of challenges to coastal environmental quality, including watershed alteration, shoreline erosion, chemical contamination of food webs, depletion of fish stocks, toxic plankton blooms, marine-borne pathogens, and the rapid invasion of coastal and estuarine waters by non-indigenous species.

ICON: The Innovative Coastal-Ocean Observing Network was established with 2-year funding from NOPP in FY98. Eight partner institutions were involved. At its peak in 1999-2000, it included 4 moorings telemetering surface and subsurface meteorological, bio-optical, and physical oceanographic measurements in near real-time; acoustic tomography; satellite remote sensing of sea surface temperature and color; land-based HF radars measuring surface currents; shipboard surveys of physical, chemical and biological properties, and high-resolution retrospective numerical modeling. http://www.oc.nps.navy.mil/~icon/.

MBARI: The Monterey Bay Aquarium Research Institute (MBARI) has continuously maintained between 2 moorings in, and outside of, Monterey Bay supporting a variety of sensors for measuring bio-optical, physical, and meteorological variables. These data are reported to shore via packet radio within one hour of being collected. A ship-based time series complements the mooring measurements. This time series is unique among coastal environments in that it provides 15 years of continuous biogeochemical and ecological data. More recently Autonomous Underwater Vehicles have been integrated into the time series. MBARI and the Naval Postgraduate School (NPS) have been making biological, chemical and physical measurements quarterly along CalCOFI line 67. http://www.mbari.org/.

MARS: The Monterey Accelerated Research System has been recently funded by NSF to deploy an underwater cable with power and high bandwidth communication for instrument testing and scientific research in deep ocean waters. The cable will be deployed in Monterey Bay and serve as a national community resource. The installation, to be carried out in 2005, involves 10 US institutions.

NEOCO: The Network for Environmental Observations of the Coastal Ocean, a monitoring effort sponsored by the University of California for two years, is based on instrument packages deployed on piers extending over about 700 miles of California coastline from La Jolla to Bodega Head. UCSC is one of the 7 participating campuses in this newly established program. http://www.es.ucsc.edu/~neoco/.

NPS: The Naval Postgraduate School is the lead institution in ICON, and is a partner in AOSN and SCOPE. In addition, NPS maintains and operates a nearshore observatory in Monterey and a network of HF radars around the bay for surface current measurements. http://www.oc.nps.navy.mil/.

PISCO: Funded by The David and Lucile Packard Foundation, the Partnership for Interdisciplinary Studies of Coastal Oceans is a research consortium involving marine scientists from four universities along the U.S. West Coast, including UCSC and HMS (Stanford University) on Monterey Bay. PISCO focuses on understanding the nearshore ecosystems of the West Coast by integrating long-term monitoring of ecological and oceanographic processes at dozens of coastal sites with experimental work in the lab and field. PISCO's findings are applied to issues of ocean conservation and management, and are shared through public outreach and student training programs. http://piscoweb.org/index.html.

SCOPE: The Simulations of Coastal Ocean Physics and Ecosystems program received 3-year funding from NOPP starting in FY00, and includes some of the same partners as ICON. The goal is to model the coastal upwelling ecosystem within the Monterey Bay National Marine Sanctuary (MBNMS) with high spatial and temporal resolution. The model includes the interconnected physical, chemical, and biological processes, and is capable of assimilating data from satellites and *in-situ* sensors. http://www.mbari.org/bog/nopp.

SIMoN: The Sanctuary Integrated Monitoring Network was recently established by the MBNMS as a fundamental element of the Sanctuary's conservation and management plan. SIMoN was designed in partnership with the regional science and management communities to identify and track natural and human induced changes to the Sanctuary. SIMoN's specific goals include: integrating existing monitoring conducted in the MBNMS; initiation of basic surveys or characterizations of all habitats and regions of the MBNMS; establishment of a series of long-term monitoring efforts to fill in critical gaps; initiation of specific, question-driven monitoring efforts with fixed durations, and providing timely and pertinent information to managers and decision makers, the research community, and the general public. It is viewed as a model system for the other marine sanctuaries. The SIMoN web site will serve as a portal for many end products of the CIMT data integration and visualization efforts. http://www.mbnms-simon.org/.

UCSC/MLML: University of California, Santa Cruz (UCSC) and California State University's Moss Landing Marine Laboratories (MLML) have been conducting multidisciplinary surveys in Monterey Bay on a monthly basis. Seven tracklines cover the entire Bay, concentrating in the region of the Monterey Canyon. Measurements include: surface and subsurface temperature; macro-(N, P, Si) and micronutrient (Fe, Al) distribution and abundance; sea surface chlorophyll; phytoplankton community structure; zooplankton abundance, distribution and community structure; schooling fish distribution and relative abundance; and seabird, marine mammal, and sea turtle distribution and abundance.