Title

Coastal Ocean Observing System Elements for the Southern California Bight and Santa Monica Bay

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COASTAL OCEAN OBSERVING SYSTEM ELEMENTS FOR THE SOUTHERN CALIFORNIA BIGHT AND SANTA MONICA BAY

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Abstract

We received funding from UCMC in order to establish, maintain and augment the sensors for UCLA's oceanographic mooring in Santa Monica Bay; to sample the water quality within the surrounding region; and to interpret the measurements in combination with satellite remote sensing and three-dimensional, fine-scale simulations of the local region. We met these goals by successfully launching the mooring in June of 2001 and maintaining it until August 2003, when we pulled it for servicing. After a major overhaul, the mooring was relaunched in February 2005. All observational data are made available to the public in near real time via a dedicated website (http://www.ioe.ucla.edu/MUCLA/) that includes an interactive web-based data interface. Furthermore, we have started and maintained bi-weekly shipboard surveys of the surrounding waters as well as instituted regular collection of satellite data in order to place the observations at the mooring in a large-scale context. Our continuous observations reveal a very dynamic system with the power of the physical variability concentrated on diurnal and 10-20 day timescales, while the biological variability is dominated by episodic and shorted lived events, of which we were able to capture an extraordinary one in March of 2002. Such variability is typically missed by a shipboard only based observing system, highlighting the importance of continuous observations. UCMC's funding of our mooring operation and the ancillary projects was crucial for establishing such expertise at UCLA, and has made it possible for us to participate as a full partner in the emerging Southern California Coastal Ocean Observing System framework. Several publications analyzing the results have been written, and we anticipate several more, particularly given the increase in the value of these observations as the timeseries increases in its duration.

Progress Report

In late June 2001 a modified PROTEUS-type mooring [*Chavez et al.*, 1994] (Figure 1) was deployed at 33° 56' N, 118°43' W inside Santa Monica Bay at the edge of the continental shelf in about 500 m of waters. This mooring forms the centerpiece of the Santa Monica Bay Observatory (SMBO), which is now part of the Southern California Coastal Ocean Observing System (SCCOOS). The mooring was pulled out of the water in August 2003, completely serviced and overhauled, and redeployed in early February 2005 at the same location.

The SMBO Mooring is a near-realtime interdisciplinary mooring that combines meteorological observations with surface and upper ocean physical and biological measurements, and uses an Ocean Acquisition System for Interdisciplinary Science (OASIS) System to log and transmit the data via packet radio to a receiving station located on the UCLA campus. Most measurements are taken approximately every ten minutes and are then stored by the OASIS system until an hourly download to the campus receiving station is achieved. All data are made available to the public within one day of collection at (http://www.ioe.ucla.edu/MUCLA/). A web-based data interface (based on the Live Access Server software that allows any user to interactively generate customized plots and to download and manipulate the mooring data has also been installed.

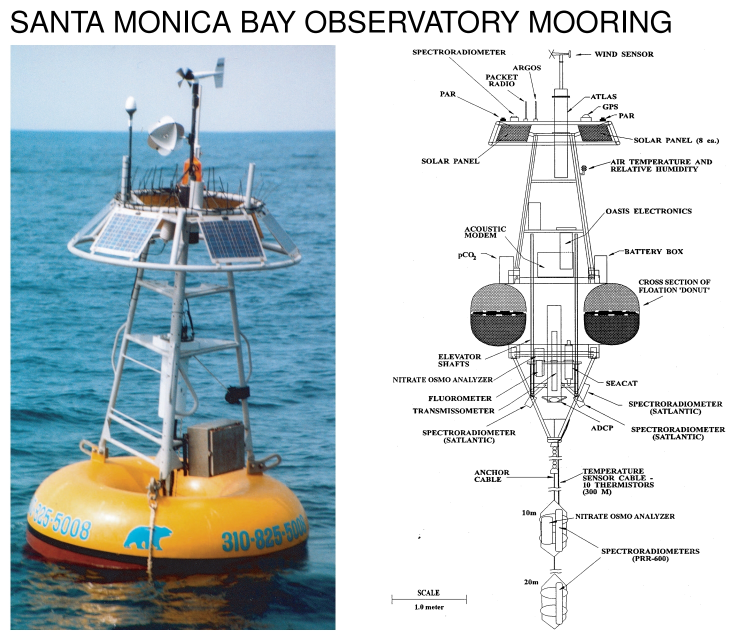

Figure 1: Photo and schematic drawing of the SMBO mooring deployed at 33° 56' N, 118°43' W.

Table 1 shows a summary of the devices and sensors that are deployed on the SMBO mooring as well as their sampling intervals and their dates of operation. Figure 1 shows a photo and a schematic sketch of the mooring. The mooring was designed and built for UCLA by the Monterey Bay Aquarium Research Institute (MBARI) following the design and procedures of their own mooring program in Monterey Bay [*Chavez et al.*, 1994]. Details for the mooring design and the OASIS system can be found in the latter publication.

The data gathered over the more than two year deployment reveal great richness in the physical, biological, and chemical variability of the upper ocean and lower atmosphere. Among the many scales of temporal variability that we have been able to observe, we limit our description here to two: the diurnal time-scale, and the more stochastic time-scale of episodic events.

Diurnal cycle

Over the entire record, the strongest variability is found in the diurnal cycle, with day-night sea surface temperature (SST) contrasts often exceeding 2°C [*Leinweber et al.*, 2005]. These fluctuations are larger than what can be explained by local heating and cooling, particularly when considering that air temperature remains very close to SST. Furthermore, this mechanism also cannot explain the accompanying diurnal sea surface salinity (SSS) changes. Our research to date suggests that these

Table 1: Summary of sensors and devices installed on the Santa Monica Bay Observatory Mooring during (i) the June 2001 to June 2003 deployment and (ii) during the ongoing deployment (February 2005-).

Device or Sensor[b]	Manufacturer[b]	Measured Properties	Sample Interval (min)	Sensor location	Dates of operation
ADCP (300 kHz)	RDI	Acoustic backscatter currents	30	ca 0.5m (0-120m, 4m bins)	06/01-04/02; 03/05 -
CTD (SEACAT)	SeaBird	Conductivity, Temperature, Pressure	10	ca 0.5 m	06/01-06/03; 02/05 -
Fluorometer	WET Labs	Chlorophyll fluorescence	10	ca 0.5 m	06/01-05/03; 02/05 -
Transmissometer	WET Labs	Optical clarity	10	ca 0.5 m	06/01-06/03; 02/05 -
CT(D)	SeaBird	Conductivity, Temperature, (Pressure)	10	10(p), 20(p), 30m 40, 50(p), 60m 70, 80, 90, 100m(p)	06/01-04/02; 02/05 -
ATLAS	PMEL	Air temperature & pressure, windspeed & direction	10	Air	06/01-06/03; 02/05 -
GPS	Magellan	Latitude, Longitude	10	Air	06/01-06/03; 02/05 -
OASIS	MBARI	Data acquisition, telemetry	n/a		06/01-06/03; 02/05 -
Packet radio	PacComm/ Motorola	Telemetry	60		06/01-06/03; 02/05 -
CO_2 analyzer (LI 192SA)	LICOR/ MBARI	Carbon dioxide	60	ca 0.5 m	multiple deployments 03/05-

a: ADCP: Acoustic Doppler Current Profiler; CTD: Conductivity, Temperature, Depth; GPS: Global Positioning System; OASIS: Ocean Acquisition System for Interdisciplinary Science
b: RDI: RD Instruments, San Diego, CA; PMEL: Pacific Marine Environmental Laboratory, Seattle, WA; SeaBird: Sea-Bird Electronics, Inc., Bellevue, WA; WET Labs: Philomath, OR; MBARI: Monterey Bay Aquarium Research Institute, Monterey Bay, CA.

fluctuations are caused by an interaction of the diurnal sea-breeze with the local horizontal structure of temperature and salinity. As the winds begin to increase in the morning hours, they typically shift from being southeasterly to being straight from the west. This leads to an Ekman transport of surface waters toward the southwest, which tends to push the often substantially warmer and slightly more saline waters from the inshore region around Pt. Dume toward our mooring. During the night, when winds are weaker and mostly blowing from the east, this watermass gets replaced with the cooler, less saline waters representative of the open Santa Monica Bay.

We find also substantial inter-daily variations of the diurnal cycle and its ensuing mass flux as well as indications of inertial currents in a diurnal forced response, possibly of large horizontal scale. Such variability is typically missed by shipboard based observations or satellite altimetry, and highlights the need for continuous observations from a mooring.

The diurnal cycle emerges also as a very dominant mode of variability in our observations of the partial pressure of CO_2 in seawater, with substantial consequences for the exchange of CO_2 across the air-sea interface [*Leinweber et al.*, 2005]. Our preliminary analyses show that only about half of the diurnal cycle is driven by the daily cycle of heating and cooling, but that the daily changes in the net uptake of CO_2 by phytoplankton (sum of photosynthesis and respiration) are at least equally important in explaining the diurnal cycle. Another surprising finding is the large diurnal variation in atmospheric pCO_2, caused primarily by the presence or absence of fossil-fuel polluted air from the city of Los Angeles.

March 2002 upwelling event

Upwelling in the central SCB region is episodic and tends to occur in late winter and early spring [*Eppley*, 1992], while throughout the rest of the year, the upper ocean tends to be well stratified. As a consequence, chlorophyll levels in SCB are generally low, but reach intermittently very high values. An analysis of SeaWiFS derived satellite chlorophyll for the Santa Monica/San Pedro Bay area [*Nezlin and Li*, 2003] reveals a median concentration from September 1997 to May of 2003 of about 0.5 mg Chl m^{-3}, but nearly every year large blooms develops sometimes between March and May with chlorophyll concentrations reaching well above 5 mg Chl m^{-3}. In March of 2002, the highest chlorophyll concentrations were detected with concentrations reaching nearly 12 mg Chl m^{-3}.

One might argue that the satellite based time-series is biased because of lack of observations during critical times in late spring and early summer as a result of frequent cloud cover in the SCB area. However, our in-situ observations of fluorescence from the mooring support the conclusions drawn from the satellite analyses, also suggesting low chlorophyll levels throughout the year, but punctuated by episodic blooms (Figure 2).

The episodic nature of these blooms poses many interesting questions and challenges (see *Gruber et al.* [2005]). Although coastal upwelling can be suspected to be the main mechanisms that lead to these episodic blooms, to our knowledge, there have been so far no in situ studies that clearly demonstrated this link within the Southern California Bight. Alternative interpretations of the cause of these blooms are (i) entrainment of nutrient rich sub-surface waters by convection, driven by buoyancy loss at the surface and enhanced turbulent mixing by high winds, and (ii) upwelling associated with the passage of frontal structures and eddies.

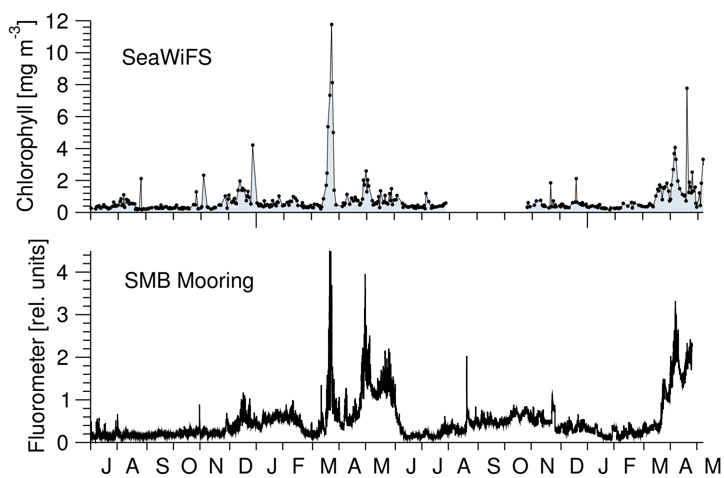

Figure 2: Timeseries of phytoplankton abundance in Santa Monica Bay from June 2001 to May 2003. (a) Timeseries of median chlorophyll observed by the SeaWiFS sensor for the Santa Monica and San Pedro Bays. (b) Timeseries of fluorescence as measured on the Santa Monica Bay Observatory Mooring inside Santa Monica Bay. From *Gruber et al.* [2005].

If the blooms are indeed a consequence of upwelling, a second puzzle emerges. As seen in Figure 3, conditions very similar to those seen in March 2002 and March 2003 prevailed in December of 2001 and 2002 in Santa Monica Bay with upwelling favorable winds persisting for several days. Yet, oceanic phytoplankton showed only a minor response, while in the major bloom episodes in March 2002 and 2003, where upwelling favorable conditions were only marginally stronger, phytoplankton abundance increased in response by more than one order of magnitude. It therefore appears that within SCB, the coupled physical/biological system exhibits a highly nonlinear response to wind forcing.

Given the episodicity and rareness of these blooms, the lack of in situ observations of these phenomena does not come as a surprise. At the bi-weekly sampling interval adopted, for example, by the Plumes and Blooms project in the Santa Barbara Channel [*Toole and Siegel*, 2001], it takes almost three years before one of these bloom events are encountered by chance. And if encountered, there is little information available about what happened before and how the event might unfold thereafter. As a consequence, our understanding of the detailed evolution of upwelling events and how this evolution is shaped by physical/biological interactions is limited.

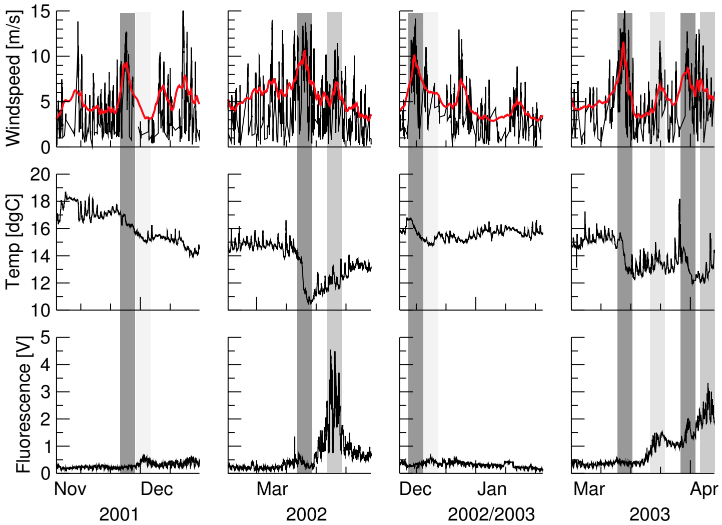

Figure 3: Suite of one-month timeseries plots of upwelling favorable windstress and oceanic response. The four periods are 01 Nov 2001 to 31 Dec 2001; March 01, 2003 to March 31, 2002; Dec 10, 2002 to Jan 10, 2003; and March 05, 2003 to April 05, 2003. (a) Timeseries of alongshore windstress for Santa Monica Bay computed from the SMBO windsspeed observations; (b) timeseries of near-surface temperature at the SMBO mooring, and (c) timeseries of near-surface fluorescence at the SMBO mooring. The gray bands indicate upwelling favorable conditions. From *Gruber et al.* [2005].

Gruber et al. [2005] analyzed the dynamics of the March 2002 event, with a focus on the intricate interactions between the physical processes that drive such events and the biological responses. They demonstrated that the bloom event in March 2002 was the result of a strong wind event that lasted long enough to result in a full oceanic response, a result supported by the hindcast simulations of *Capet et al.* [2004]. Furthermore, this wind event occurred near the time of minimum SST, i.e. minimum vertical stability. This caused a strong upwelling with an outcropping of water masses near the mooring site that are usually located at depths of 100 m or more (see Figure 4). The outcropping of these deep waters exposed very high nutrient concentrations to the surface. After the actual upwelling started to relax, the newly injected nutrients led to a massive phytoplankton bloom, with a a more than one order of magnitude increase of phytoplankton biomass in a few days. A closer inspection of the satellite images and our concurrent modeling results show, however, that a substantial fraction of this rapid increase is not due to local growth, but the advection of waters that have upwelled to the northwest earlier, giving phytoplankton enough time to fully respond to the new input of nutrients (see also *Frenzel et al.*, 2004).

The significance of the March 2002 event in Santa Monica Bay is enhanced by the simultaneous observations of a bloom of the diatom *Pseudo-nitzschia spp.*. This harmful algae produces domoic acid, a neurotoxin, which leads to neurological dysfunctions in marine mammals and sometimes to their deaths [*Scholin et al.*, 2000]. A few weeks after the bloom in March of 2002, a large increase in the stranding of marine mammals was observed in the region, and was linked to domoic acid poisoning (Heal the Bay, Newsletter). Therefore a good understanding of the biological/physical coupling in such upwelling events also has benefits for understanding the dynamics of harmful algal blooms.

Impact of UCMC funding

The seed funding we received from UCMC to deploy, maintain, and enhance the multidisciplinary mooring in Santa Monica Bay was crucial to the success of this program. It also provided seed funding to start an ancillary shipboard based time-series program, whereby we sample the waters at the mooring site every two weeks for laboratory-based analyses of inorganic carbon parameters (dissolved inorganic carbon, total alkalinity), nutrients, chlorophyll, biogenic silica, and phytoplankton species composition (the latter in collaboration with Prof. R. F. Shipe) (see e.g. *Leinweber et al.* [2005]). One of the PI's was able to secure funding from the National Science Foundation to continue this

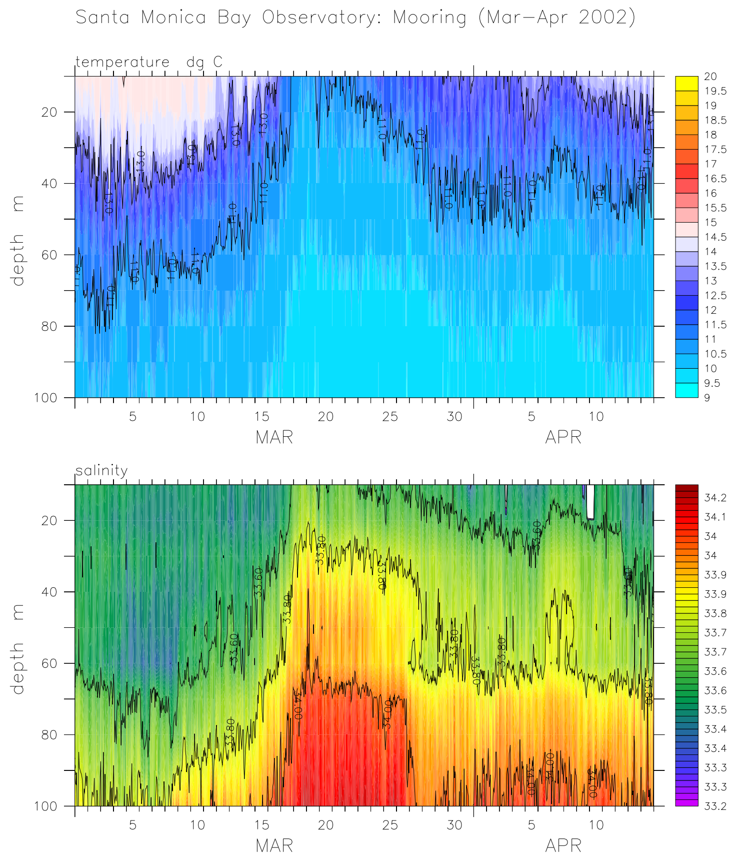

Figure 4: Time-depth section plots of (a) temperature in °C and (b) salinity as observed at SMBO from March to April 2002. From *Gruber et al.* [2005].

time-series program as well as shiptime to deploy and retrieve the mooring. Together with Prof. K. Stolzenbach, the two PIs also secured funding from NOAA to continue operating the mooring as part of the Southern California Coastal Ocean Observing System.

Publications

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Blaas, M., C. Dong, P. Marchesiello, J.C. McWilliams, and K.D. Stolzenbach, 2005: Sediment transport modeling on Southern Californian shelves. Part I: Model description and sensitivity experiments & Part II: Transport during synoptic events, in preparation.

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Gruber, N. The coastal carbon cycle challenge. Presented at Oregon State University, November 4, 2004.

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Plattner, G.-K., The coastal carbon cycle challenge. Presented at Scripps Insitution of Oceanography (Marine chem-geochem-geosciences seminar), San Diego/California, October 18, 2004.

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Plattner, G.-K., H. Frenzel, N. Gruber, A. Leinweber, and J. C. McWilliams, Changing winds and coastal carbon cycle: A case study for an upwelling region. Presented at SCOR conference "The ocean in a high CO_2 world", Paris/France, May 2004. (SCOR: UNESCO Scientific Committee on Oceanic Research)

1 Participants

- Nicolas Gruber, (PI) AOS and IGPP
- Jim McWilliams, (PI) AOS and IGPP
- Keith Stolzenbach, Civil & Env. Engineering
- Anita Leinweber, postdoctoral researcher, IGPP
- Levanto Schachter, marine technician, IoE
- Heather Coleman, research assistant, UCLA
- Andrew McDonnell, research assistant, UCLA
- Hartmut Frenzel, programmer, IGPP

Education and Public Outreach

The mooring and the other elements of the Santa Monica Bay Observatory have become important elements in undergraduate teaching at UCLA. We incorporated analyses of the data gathered by the observatory into three undergraduate classes at UCLA. These classes are AS103 (Physical Oceanography), AS105 (Introduction to Chemical Oceanography) and AS130 (Circulation of Santa Monica Basin), which are taught by Profs. C. Pasquero, N. Gruber and J. McWilliams. AS103 and AS130 make also use of UCLA's vessel *RV Sea World* for teaching purposes, and we have regularly organized the cruises around the mooring in order to foster interactions to the maximum extent possible. In addition, several term papers have been written by the students in AS130 on the basis of the data from the mooring.

We have just begun activities related to public outreach. We are in the process of completely overhauling our website and expanding it into a hub to cover all aspects of the Santa Monica Bay Observatory. In addition to the mooring data, we are planning to include satellite data, observations from the Santa Monica Pier sampled as part of the UCMC sponsored Coastal Environmental Observation Network, data from historical and recent hydrographic shipboard surveys, and model results from a high-resolution coastal model. This revamped website will also have specific portals for K1-12 teachers and students. The interaction with this latter group will greatly benefit from UCLA's long tradition in oceanographic teaching at primary and secondary schools, such as organized by the OceanGLOBE program operated by the UCLA Ocean Discovery Center.

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