MODELING OF AN UPWELLING EVENT AND ITS EFFECTS ON BIOGEOCHEMICAL CYCLES IN SANTA MONICA BAY, CALIFORNIA

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ABSTRACT

In March 2002, an unusually strong upwelling event with very low sea surface temperatures was observed throughout the Southern California Bight. About one week after the peak of the upwelling, very high concentrations of surface chlorophyll were measured by SeaWiFS. The upwelling was driven by persistently strong along-shore winds acting upon weakly stratified waters. The injection of new nutrients into the euphotic zone led to the highest surface chlorophyll concentrations recorded by SeaWiFS in Santa Monica Bay since September 1997. We have modeled this upwelling event with ROMS in a 4-level embedded configuration and an NPZD-type ecosystem/biogeochemical model. The model was forced with a blended wind product based on COAMPS results and QuikSCAT observations. The modeling results show the same patterns as the observations, both in temporal and spatial evolution of surface temperatures and chlorophyll concentrations. However, the magnitude of the upwelling and the ensuing phytoplankton bloom are underestimated.

MODEL SETUP

We have set up four grid levels with the AMR library (see Fig. 1). The parent grid (L0) has 20 km horizontal resolution and covers the entire region of the California Current System, which extends along the US west coast approximately from the Mexican to the Canadian border. The first child grid (L1; 6.6 km) covers the Southern California Bight. The second child grid (L2; 2.2 km) covers Santa Monica and San Pedro Bays and nearby regions. The third child grid (L3; 700 m) includes the immediate area of Santa Monica and San Pedro Bays.

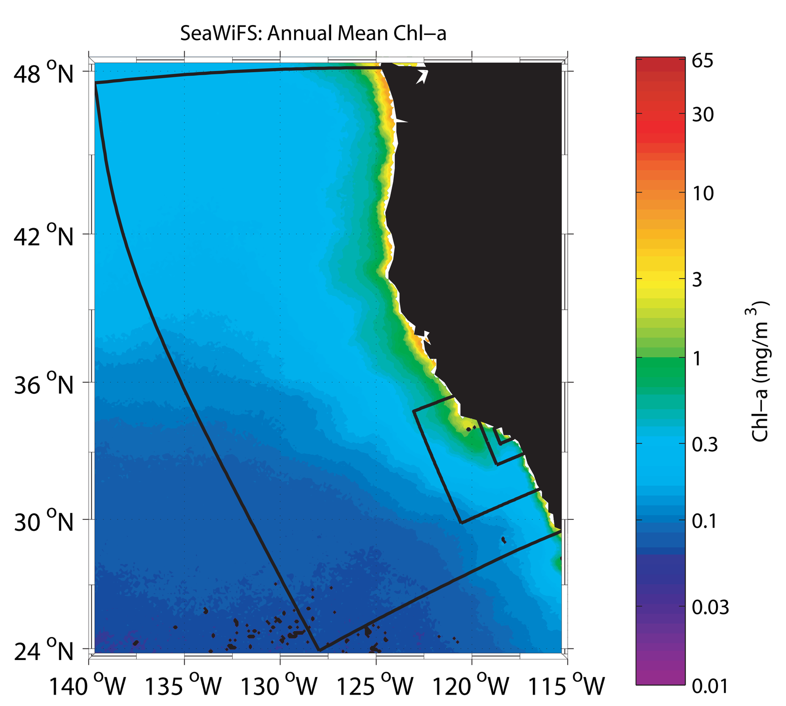

Figure 1: 4-level model domain with surface concentrations of chlorophyll *a* (detected by SeaWiFS) as background.

The real-time wind forcing fields with 12 h temporal resolution were created based on the blended wind product by Chao *et al.* (2003) with corrections near shore as discussed by Capet *et al.* (2004). The model was spun up at the 20 km resolution with COADS winds for 10 years. The resulting fields were used as initial conditions for the 4-level run with real-time winds. Temperature, salinity, and nitrate climatologies from the World Ocean Atlas 1998 were used as boundary conditions. All other biogeochemical components were set to 0 at the boundaries.

FLUX ANALYSIS

The ROMS NPZD model includes the capability of tracking the fluxes depicted in Fig. 2. As an example, Fig. 5 shows new production, i.e. growth of phytoplankton through uptake of NO_3, in the euphotic zone (its depth is defined by the 1% light level) at the peak of the bloom in Santa Monica Bay. The black line depicts the boundary of the study area for the budget calculations. Fig. 6 shows the development of new and regenerated (phytoplankton growth through uptake of NH_4) production through March 2002. Regenerated production is fairly constant with a slight rise after the peak of the upwelling, whereas new production increases significantly during the bloom phase. During the peak of the upwelling (until March 18), phytoplankton is transported laterally out of the Bay. At the end of the month there is some influx of phytoplankton into the area. Sinking and vertical advection play a minor role in the budget of phytoplankton. The standing stock of phytoplankton increases by 50 % through March. The budget is closed by grazing and the mortality of phytoplankton (not shown in Fig. 6).

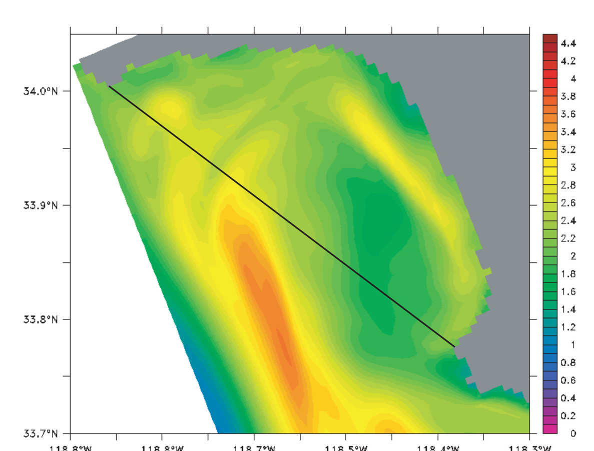

Figure 5: Averaged new production of phytoplankton from March 28 (noon) to March 30 (noon) in Santa Monica Bay (in units of mol N m^{-2} yr^{-1}).

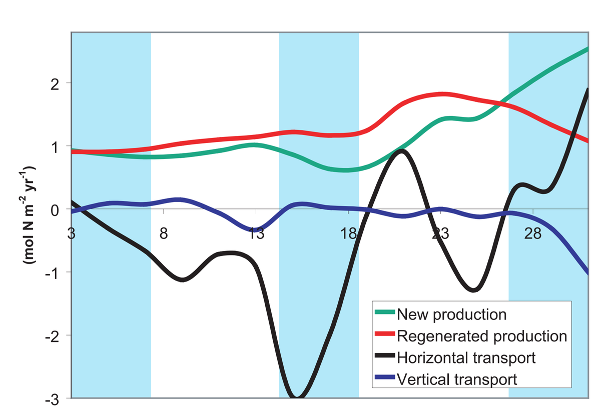

Figure 6: Budget analysis for phytoplankton during March 2002 in Santa Monica Bay.

In Fig. 7, three distinct phases (highlighted by blue boxes in Fig. 6) are compared with respect to the phytoplankton budget. The first phase (March 2-6) reflects "average" conditions without significant upwelling. New ("NP") and regenerated ("RP") production are almost equal, i.e. the f-ratio (fraction of new compared to total production) is 0.5; neither horizontal ("HT") nor vertical ("VT") transport play a role. During the peak of the upwelling (March 14-18), the f-ratio drops to 0.38, horizontal transport is a major loss term. At the peak of the bloom (March 28-April 1), the f-ratio rises to 0.66, an influx of phytoplankton contributes to the increased concentration of phytoplankton, and downwelling-induced vertical advection is a minor loss term.

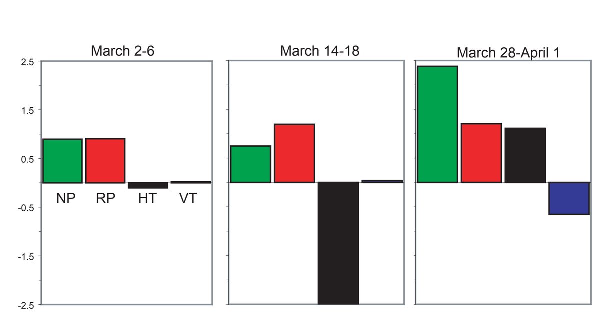

Figure 7: Comparison of budget terms during three distinct phases (in units of mol N m^{-2} yr^{-1}).

REFERENCES & CONTACT

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Capet *et al.* (2004): *Geophys. Res. Lett.*, **31**, L13311, doi:10.1029/2004GL020123
Chao *et al.* (2003): *Geophys. Res. Lett.*, **30**, 1013, doi:10.1029/2002GL015729
Gruber *et al.* (2004): *Deep-Sea Res. I*, in preparation
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THE BIOGEOCHEMICAL MODEL

We have coupled a standard NPZD (nutrient, phytoplankton, zooplankton, detritus) model with a single limiting nutrient (nitrogen) and diatom-like phytoplankton class (based on Moisan & Hofmann, 1996) to ROMS. The parameters of this ecosystem model have been tuned to upwelling conditions. Consequently, the model is quite successful in simulating the ecosystem dynamics in near-shore regions as discussed in this study, but underestimates chlorophyll concentrations in the more oligotrophic regions further offshore. This model is discussed in detail in Gruber *et al.* (2004).

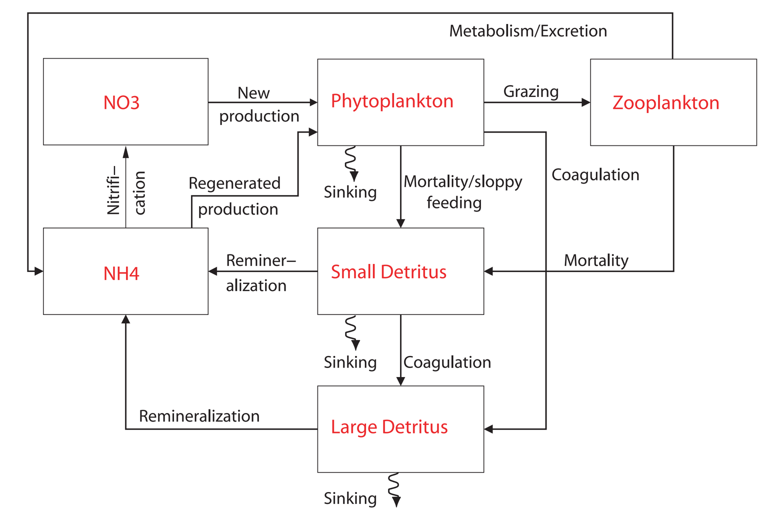

Figure 2: Schematic of the nitrogen pools and fluxes in the NPZD model that has been coupled to ROMS.

SEA SURFACE TEMPERATURE

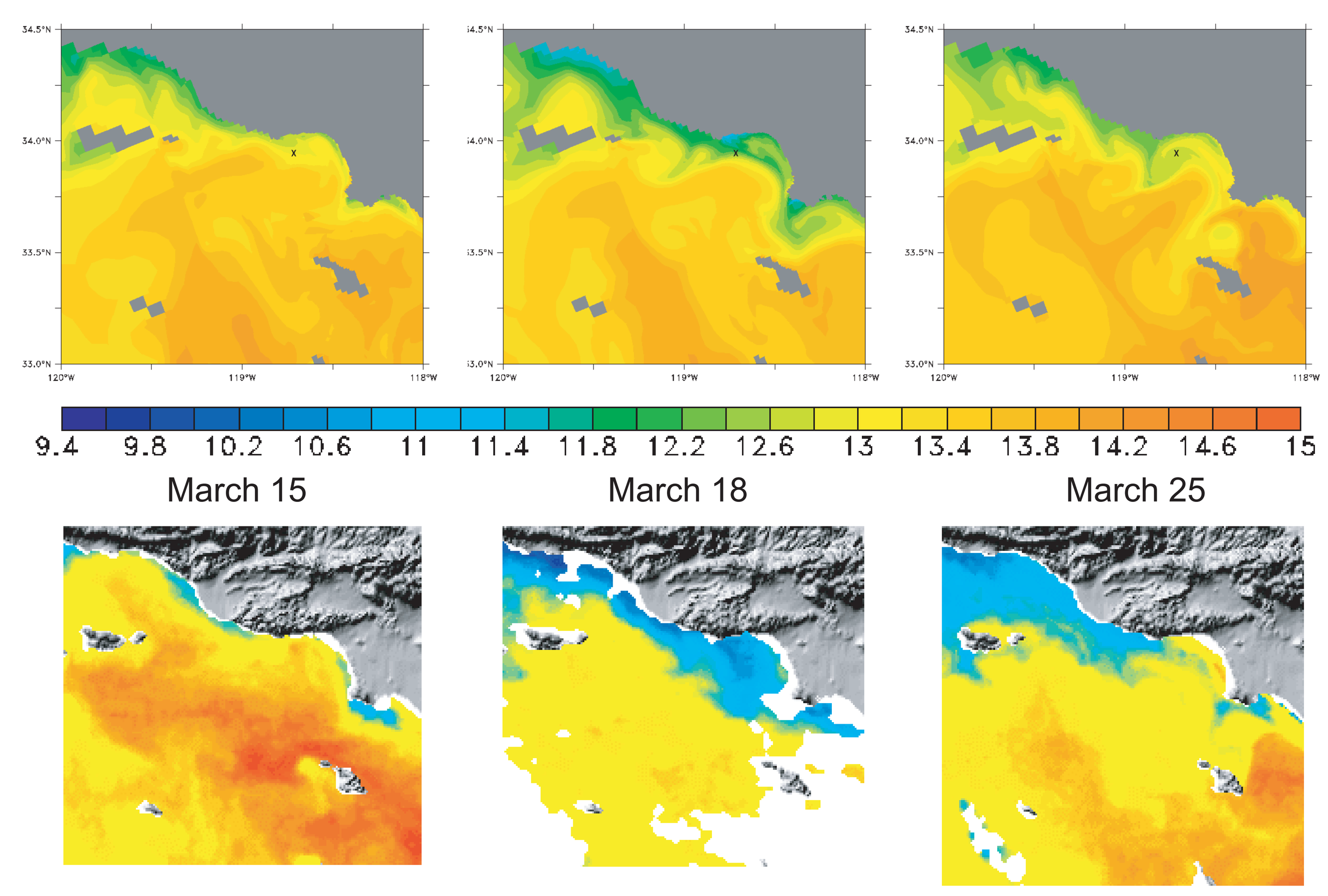

Figure 3: Sea surface temperature in and near Santa Monica Bay as modeled by ROMS (top row) and observed by AVHRR (bottom row) at three time steps: Before the upwelling started (March 15), at the peak of the upwelling (March 18), and during the relaxation phase after the upwelling (March 25). The modeled results correctly reflect the trend of the observations, while underestimating the magnitude of the cooling due to the upwelling.

SURFACE CHLOROPHYLL

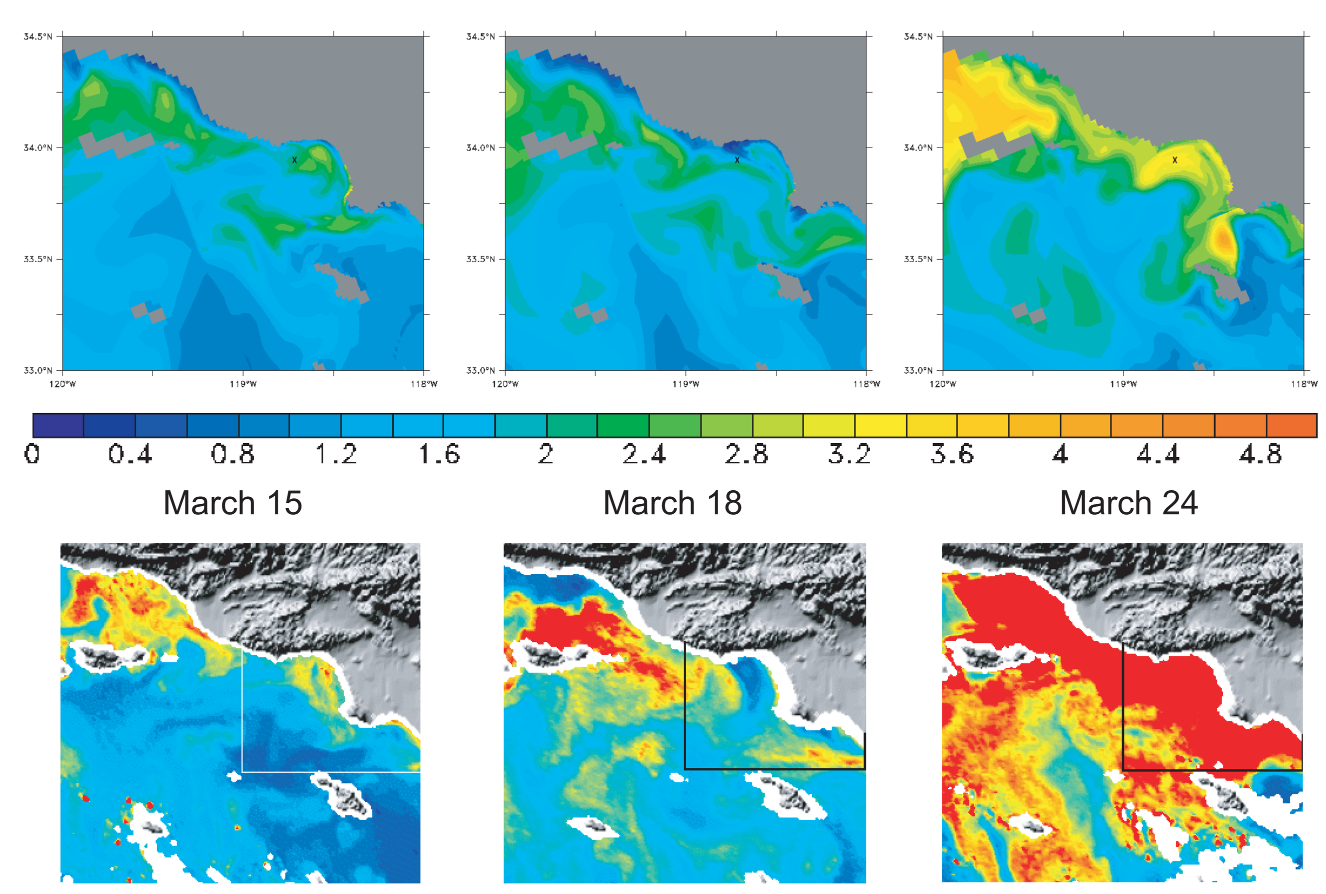

Figure 4: Surface chlorophyll *a* concentrations (in mg Chl-*a* m^{-3}) in and near Santa Monica Bay as modeled by ROMS (top row) and observed by SeaWiFS (bottom row) at three time steps: Before the upwelling started, at the peak of the upwelling, and during the phytoplankton bloom phase after the upwelling. The modeled results correctly reflect the trend of the observations, while underestimating the magnitude of the bloom following the upwelling.

RESULTS AND DISCUSSION

The ROMS model presented here was successful in simulating the general trends observed during the upwelling event in March 2002 in Santa Monica Bay. However, the magnitude of the upwelling was significantly underestimated: While the lowest surface temperature observed at the UCLA mooring at the entrance to the bay was 10.5°C, the modeled temperature at this point was 12.2°C. The discrepancy is most likely due to the wind forcing used in this model. A run with the original blended wind product failed to produce any upwelling (Capet *et al.*, 2004). With a near-shore correction intended to match the winds observed at the UCLA mooring, upwelling similar to the observations was simulated. However, the spatial and temporal resolution of the wind forcing is not enough to accurately reproduce the magnitude of the upwelling. There are two reasons for the lower concentrations of chlorophyll in the model than in the observations: Phytoplankton production is tied to the supply of upwelled nitrogen. Secondly, the parameters of the biogeochemical model used here were later found to underestimate the growth of phytoplankton.

We have also run a ROMS model with several modifications: A revised bathymetry for the L2 and L3 grids, a new wind product by Blaas and Dong derived from MM5 and ETA model results with a temporal resolution of 3 h, and a revised biogeochemical model. The highest resolution of the MM5 model was 6 km. This run failed to produce significant upwelling in Santa Monica Bay in March 2002. The complicated topography around the Bay (Santa Monica Mountains) and the fairly coarse resolution of the MM5 model are likely causes of this discrepancy. A reversal of the wind direction over the Bay is modeled with MM5 during the peak of the upwelling event. A further improved wind product with an MM5 model at 2 km resolution is in preparation, which may be able to reflect the actual winds over the Bay more accurately.