SEASONAL CARBON CYCLING IN SANTA MONICA BAY, SOUTHERN CALIFORNIA

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ABSTRACT
The ocean margins form the transition zone between terrestrial and open ocean areas and represent up to 30% of total ocean productivity, yet their role in the global carbon cycle is ill quantified. In order to address this issue, a bi-weekly time-series program was established in Santa Monica Bay in January 2003 to measure the seasonal evolution of the upper ocean carbon cycle at this coastal site. Our measurements reveal a strong seasonal cycle with an amplitude in salinity normalized dissolved inorganic carbon (DIC) reaching nearly 200 µmol/kg and pCO_2 changes of more than 200 µatm. The seasonal cycle of DIC is characterized by a maximum in late winter/early spring, which is caused by upwelling bringing high DIC concentrations from the upper thermocline during this time of the year. The concomitant supply of high levels of nutrients fuels an intense bloom, whose strength varies from year to year in response to large interannual variations in upwelling. In 2003 and 2004, substantial surface DIC decreases were observed under nitrate depleted conditions i) right after the occurrence of upwelling, and i) about three months after upwelling. This implies that during these times, either organic matter production occurred with a very high stoichiometric C:N ratio and/or an additional source of new nitrogen existed that supplied nitrogen without supplying DIC. The seasonal cycle of pCO_2 follows that of DIC with a late winter/early spring maximum, whose levels far exceed that of the atmosphere, and a summer-time minimum with undersaturated pCO_2 values. Annually, Santa Monica Bay acts as a weak to moderate sink for atmospheric CO_2. We suggest that this is mainly due to biological production and in part driven by the uptake of anthropogenic CO_2.

TIME-SERIES MEASUREMENTS
Time-series measurements of DIC and related parameters were initiated in January 2003 on a bi-weekly basis in the upper 300 m at the site of an interdisciplinary mooring in Santa Monica Bay (SMBO: 33°55.900 N, 118°42.937 W), Southern California. In addition, hourly pCO_2 measurements were collected in both atmosphere and near surface ocean over two periods between May 2002 and July 2003, resulting in over 100 diurnal pCO_2-cycles.

THE SEASONAL CARBON CYCLE IN SANTA MONICA BAY
In late winter/spring, wind events can lead to local upwelling. The concomitant increase in surface DIC turns this area into a source for atmospheric CO_2, with varying strength from year to year. In the winter/spring of 2003 a moderate to strong upwelling enriched surface waters in nutrients. DIC background concentration of about 2000 µmol/kg increased up to 2090 µmol/kg, turning the area into a source of atmospheric CO_2. In February 2004, upwelling favorable conditions only occurred for a short period of time and surface DIC concentrations did not exceed 2025 µmol/kg. In both years, the upwelling event was followed by a short period with a moderate to strong decrease in DIC due to both CO_2

outgassing and DIC uptake by phytoplankton, turning the area into a weak to moderate sink for atmospheric CO_2. This DIC drawdown is followed by a time when the system is close to equilibrium or slightly undersaturated in CO_2 with respect to the atmosphere. About three months after the upwelling events in 2003 and 2004, another strong surface DIC drawdown was observed, leading to moderate uptake of atmospheric CO_2. Annually, although Santa Monica Bay is influenced by upwelling, it acts as a weak to moderate sink for atmospheric CO_2. However, to explain the moderate to strong decrease in surface DIC right after the upwelling and three months after the upwelling, either the uptake of particles with a stoichiometric C:N ratio drastically higher than that of Redfield, and/or an additional source of new nitrogen is needed.

SEASONAL CARBON CYCLING AND PHYTOPLANKTON COMPOSITION

To investigate possible biological processes that alter surface DIC, we have compared the surface DIC values normalized to salinity (sDIC), nitrate, phosphate, and silicic acid concentration with the phytoplankton species composition (Fig. 1). In February 2004, the biologically induced drawdown after upwelling was about $\Delta sDIC \sim 40$ μmol/kg. Using the Redfield ratio, only about a third of this drawdown can be explained by the new input of nitrate due to upwelling. However, the spring bloom was dominated by the diatom *Pseudo-nitzschia*. For similar species, C:N ratios up to 24 have been reported [*Brzezinski*, 1995] and hence the observed DIC drawdown after the upwelling may be a result of their high C demand. In September/October 2003 and May 2004, surface DIC decreased despite nitrate depletion. In 2004, the species composition was dominated by diatoms, probably with a C:N ratio close to Redfield or less, i.e. these organisms cannot explain the observed drawdown in DIC. However, both in 2003 and 2004, DIC drawdowns occurred during times of low surface nitrate concentrations, high phosphate concentrations, high SST, and low wind speed, all conditions favorable for N_2 fixation. These DIC drawdowns were followed by toxic dinoflagellates forming red tides, which have been hypothesized to meet their N demand derived from recently fixed N_2 [e.g. *Minagawa and Wada*, 1986]. Hence, we suggest N_2 fixation as an explanation of the observed DIC drawdown as well as the occurrence of red tides in Santa Monica Bay.

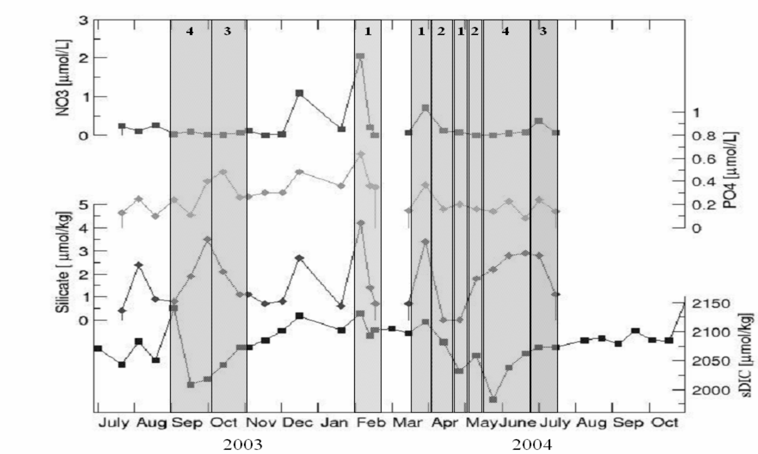

Fig. 1: Surface nitrate, phosphate, silicic acid and DIC concentrations from July 2003 until October 2004. Numbers in bars show dominant phytoplankton species: 1) *Pseudo- nitzschia*, 2) Diatoms, 3) Red tides (toxic algae), and 4) dinoflagellates, possible N_2 fixation.

REFERENCES

Brzezinski, M. A. (1985), The Si:C:N ratio of marine diatoms: interspecific variability and the effect of some environmental variables. *Journal of Phycology*, 21, pp. 347-357.

Minagawa, M., and E. Wada (1986), Nitrogen isotope ratios of red tide organisms in the East China Sea: A characterization of biological nitrogen fixation. *Marine Chemistry*, *19 (3)*, pp. 245-259.