A Field Study of Surface Nutrient Enrichment in the California Current

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LONG-TERM GOALS

My goal is to provide the baseline data needed to stimulate others to continue the investigation of surface enrichment of inorganic nutrients to better understand the cycling of nutrients and materials and physical mixing history of the surface layers of the ocean.

OBJECTIVES

Surface nutrient enrichment (SNE), a subtle and relatively infrequent increase of phosphate, silicate, nitrate and nitrite in the surface layer of the ocean, was first described by Haury et al. (1994) from historical data. The poor spatial, temporal and analytical resolution of the data made it difficult to accurately describe and explain the features. The fall 1996 survey cruise of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) formed the foundation of a field program to better describe the spatial and temporal (diel) variability in SNE. The routine CalCOFI observations provided the environmental context within which the measurements of surface enrichment were made. Ancillary programs provided additional contextual data (e.g., optics, phytoplankton pigments, and nutrient dynamics). The work provides the better description of surface nutrient enrichment needed to formulate rational hypotheses on its formation, maintenance and ecological significance.

APPROACH

The detailed description of surface nutrient enrichment augmented the standard CalCOFI sampling regime in three ways. (1) Increased vertical resolution: three extra depths in the upper 100 m were sampled at all stations; three special stations on Line 90 sampled 24 depths in the upper 25 m. (2) An automated analyzer (HRAA) with enhanced (2-5x) detection, accuracy and precision limits measured nutrient concentrations on some stations of Line 93 and all stations of Line 90. (3) Time series measurements: at Station 93.50, a drogue was followed for 24 hr while taking 24-bottle CTD casts (0-125 m) at 4 hr intervals; at Station 90.120, a fixed geographic position was occupied for 24 hr with similar sampling.

WORK COMPLETED

The fieldwork was carried out on CalCOFI cruise RR9610 (10 Oct to 2 Nov 1996). A total of 86 CTD casts for nutrients was taken over the standard sampling grid: these included 14 HRAA time-series and

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18 high vertical resolution casts. Early preliminary results have been published (Haury and Shulenberger, 1998). All the data have been published (SIO, 1998) and are available on the CalCOFI web site. A final manuscript describing the results is almost ready for submission.

RESULTS

Higher nutrient concentrations in near-surface waters (presence of subsurface minima) were detected at the following percentage of stations:

	Silicate	Phosphate	Nitrate	Nitrite
Standard analyzer	49%	46%	13%	2%
High Resolution	84%	76%	48%	10%

On stations where both methods were used, the standard analyzer did not detect enrichment at about one third of the stations where the HRAA did detect it.

Surface enrichment in silicate, phosphate and nitrate (nitrite enrichment was too rare for generalizations) occurred frequently in the near surface "well mixed layer" (i.e., where there was no density gradient). Less frequently, nutrients decreased in the density gradients at the base of the mixed layer and well into the pycnocline, resulting in an enriched mixed layer. These results suggest that two separate processes (or sets of processes) form what we have been calling SNE to date: 1) true near surface enrichment (SNE) in the mixed layer, and 2) deeper subsurface nutrient depletion (SSNR). SNE appears to be an in-situ process primarily driven by nutrient consumption and regeneration, while SSNR is either an in-situ or an advective feature (or both). No evidence was found for diel effects on either phenomenon, or that bubbles and Langmuir circulations have any important role in the creation or maintenance of enrichment.

A weak association between increasing wind speed and increasing frequency and thickness of surface enrichment in the mixed layer (SNE) has led to a hypothesis about its formation:

> SNE is formed when greater wind speeds break down thin layer structures (order 1 m vertical scale) in the mixed layer that are the site of intense biological activity (i.e., increased regeneration of nutrients). These structures, rarely sampled by discrete bottles, are dissipated by wind mixing in the surface layer and the resulting dispersion of nutrients results in higher apparent concentrations within the surface mixing portions of the mixed layer.

IMPACT/APPLICATION

The general phenomenon of surface nutrient enrichment appears to be a much more common feature of the upper layers of the ocean than previously believed. Elucidating the mechanisms forming surface enrichment and subsurface depletion will enhance our understanding of nutrient cycling and the role of physics in mediating it. This will form the basis for characterizing and delineating the causes and ecological significance of SNE and SSNR. Results from this study in the California Current will have application to oceanography in general, as surface nutrient enrichment occurs throughout the world ocean. Much (often most) of the nutrients usable by green plants occur in these shallow depths. This new information may have a significant impact on ocean modeling, since no model of upper ocean ecology either includes or produces these nutrient distributions.

TRANSITIONS

This work is fundamental biological oceanography; there are no immediate “transitions” to report. Ultimately it will help us understand and predict the fine-scale distributions of light and sound scatterers in the upper ocean.

RELATED PROJECTS

Results from ancillary programs carried out on CalCOFI 9610 are invaluable in interpreting our SNE data. Collaborations are with:

Greg Mitchell (SIO): Vertical bio-optical profiles; useful in hypothesis testing (e.g., photoinhibition, etc.).

Rick Reynolds (SIO postdoc): Fast Repetition Rate Fluorescence estimates of photosynthetic efficiency, etc. at several depths.

Ralf Goericke (SIO): Detailed pigment composition observations including vertical profiles (phytoplankton community structure).

Jackie Collier (Rensselaer Polytechnical Inst.): Phytoplankton community vertical structure using flow cytometry; profiles of ammonium and urea distributions and uptake rates.

REFERENCES

Haury, L.R., C.L. Fey and E. Shulenberger. 1994 Surface enrichment of inorganic nutrients in the North Pacific Ocean. Deep-Sea Research I, 41:1191-1205.

Haury, L. and E. Shulenberger. 1998. Surface nutrient enrichment in the California Current off Southern California: description and possible causes. Deep-Sea Research II, 45:1577-1601.

SIO. 1998. Physical, chemical and biological data, CalCOFI Cruises 9608 and 9610. SIO Ref. 98-11, 118 pp.

The data from CalCOFI Cruise 9610 are available on the Marine Life Research Group web site (http://www-mlrg.ucsd.edu/calcofi/).

PUBLICATIONS

Haury, L.R., C.L. Fey and E. Shulenberger. 1994 Surface enrichment of inorganic nutrients in the North Pacific Ocean. Deep-Sea Research I, 41:1191-1205.

Haury, L. and E. Shulenberger. 1998. Surface nutrient enrichment in the California Current off Southern California: description and possible causes. Deep-Sea Research II, 45:1577-1601