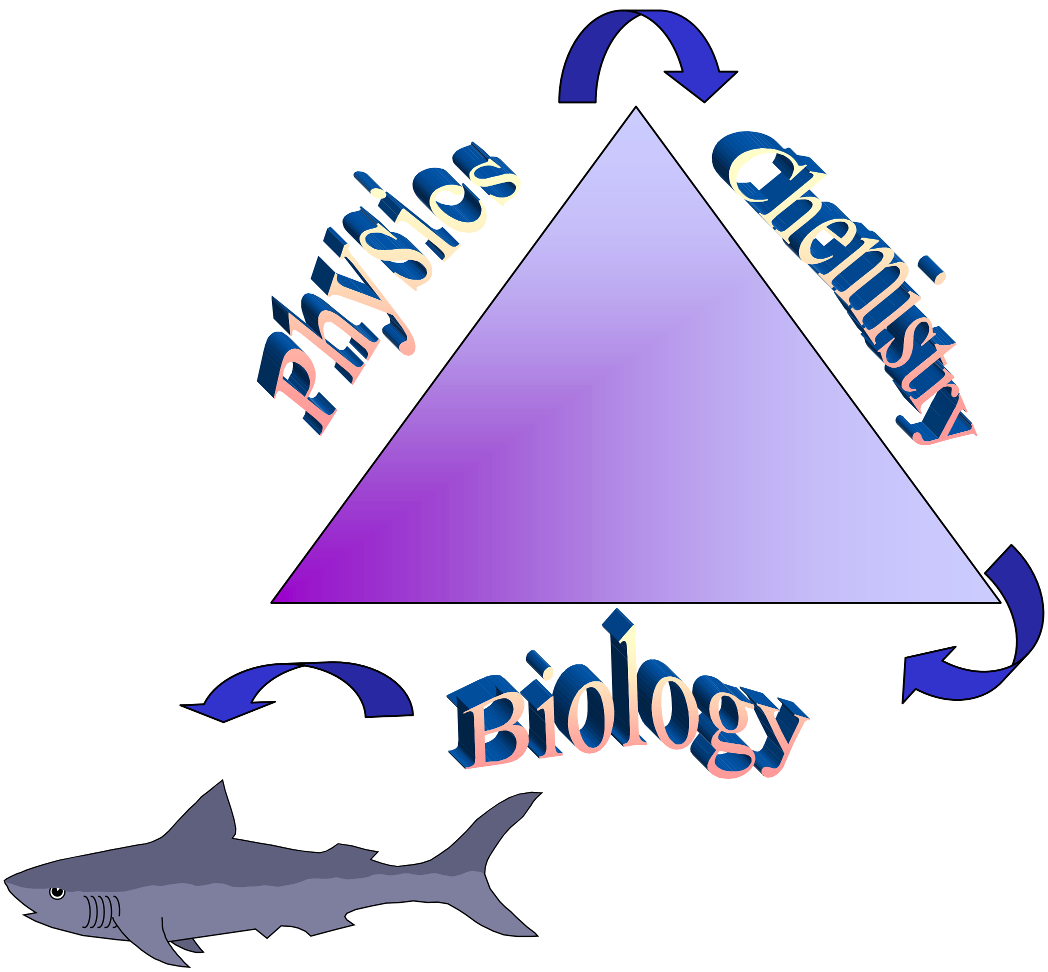
Compiling and Analyzing Nutrient Data on CalCOFI Line 67



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A. Introduction

In any water system, the physics of a system determines the chemical makeup of the water. Following the chemistry will come the biology appropriate to the system. This is the natural order, but like a triangle of properties, much can be determined about any of the other two fields through an examination of only one property regime. This has been a hallmark of the progress in oceanography and continues to be a valuable tool today.

The California coast has a complex and unique physical regime that provides a rich and varied biological array. The area off Monterey Bay, where this study is concentrated, undergoes three distinct physical periods each year. These are broadly defined as the upwelling period, the oceanic period and the Davidson period (Pennington and Chavez, 2000). During the upwelling period, which lasts from as early as late March to as late as the end of September, the coast is dominated by the upwelling of cool, nutrient rich water. This water is then transported offshore at the surface, bringing with it a wide array of photosynthetic life and enriching the food web off the coast. As the upwelling period ends, the oceanic period begins. This period, often known more for the absence of a particular phenomenon than anything else, can be as short as two months in length and heralds the change from the upwelling period to the Davidson period. During the oceanic period, the nutrient pump provided by the upwelling is shut down and there is a gradual increase in the temperature of the surface waters in the bay, along with a marked decrease in nutrients and primary productivity. The Davidson period, named for the Davidson current, is a winter phenomena that transfers water latitudinally along the coast rather than in the vertical. This is again a period of decreased biological productivity and nutrient load.

Of the many elements and compounds needed for an entire food web, Nitrate (NO_3), Silicate (SiO_4) and Phosphate (PO_4) are those most familiar. These three nutrients, often termed the macronutrients, are the easiest and most consistently tested for nutrients in ocean water. While there are micronutrients that can, and do, limit biological growth, this isn't generally the case in a coastal environment. Inputs to coastal areas via river discharge or from tides provide a rich array of micronutrients such as iron. In a coastal area there is also significant input of macronutrients, but the requirements of primary producers is such that silicate and phosphate demands are well met. While silicate can be a limiting nutrient in the open ocean, in coastal regions, especially in Monterey Bay, this has not been shown to be the case. Nitrate has been identified on numerous occasions throughout the history of oceanography to be the primary limiting macronutrient in coastal areas. This holds true for Monterey Bay as well (Pennington and Chavez, 2000).

B. Purpose

For this project, a snapshot of the nutrient profile along CalCOFI line 67 was to be examined. Aside from an idea of the biology that could be expected to follow this nutrient profile, something of the unique physical regime of Monterey Bay may also be seen in such a profile. While only one profile of intermittently taken samples would have been available for the February, 2001, Leg 1 cruise, the Monterey Bay Aquarium Research Institute (MBARI) has a detailed history of samples taken from many cruises along this line.

Instead of using the February data for Leg 1, two other cruises were used for this project. September 2000 and April 26-29, 2000 offered complete data sets for CalCOFI line 67 and were examined for Nitrate (NO3), Silicate (SiO4) and Phosphate (PO4). Due to the nitrate limitation previously discussed, the focus of this study was to accurately portray the nitrate profile along CalCOFI line 67 for both of these time periods. Comparison of the Phosphate and Silicate profiles with the Nitrate load was done as well. Information to be gleaned from this short study is a visual depiction of the offshore transport of nutrients at the beginning and the end of the upwelling season. Chlorophyll studies were completed in another study and the results are not included here.

C. Materials and Method

Samples of water were taken from Niskin bottles attached to the SeaBird 7 CTD aboard RV Pt. Sur. Samples were taken from the top 200 meters of the water column at regularly spaced intervals. Upon CTD retrieval, water from each depth was taken, sealed and then frozen aboard ship. Chemical analysis was carried out by MBARI and results forwarded in raw data format.

Preparation of the raw data included the separation of doubled data and organization of the data by depth and cast. Since the depths at which each bottle was released varied within the column and with regard to their final depth, as well as in the total number of bottles sampled, a linear interpolation was made of the data to give an even number of data points for MatLab matrix generation. Two types of “no data” points had to be dealt with in different manners.

The first type of “no data” point included those depths at which a sample was taken but no analysis of the nutrients was made. This type of error occurs when a bottle is overfilled and breaks upon freezing or when a bottle leaks. In these cases, if a data point

A	B	C		D	E	F
Central Point Missing				Depth of Last Bottle Too Shallow		
Depth (m)	NO3 µM/l	Interp		Depth (m)	NO3 µM/l	Interp .
0	0.16	0.16		0	4.06	4.06
-5	4.24	4.24		-10	3.22	3.64
-10	9.83	9.83		-15	5.3	3.22
-20	15.02	12.425		-25	10	5.3
-30	17.37	15.02		-35	14.91	7.65
-40	20.29	16.195		-40	16.11	10
-60	nan	17.37		-65	20.21	12.455
-80	20.96	18.83		-85	23.5	14.91
-100	22.41	20.29		-105	25.3	16.11
-150	24.63	20.37375		-150	28.74	16.93
-200	27.69	20.4575				17.75
		20.54125				18.57
		20.625				19.39
		20.70875				20.21
		20.7925				21.0325
		20.87625				21.855
		20.96				22.6775
		21.3225				23.5
		21.685				23.95
		22.0475				24.4
		22.41				24.85
		22.632				25.3
		22.854				25.6822
		23.076				26.0644
		23.298				26.4467
		23.52				26.8289
		23.742				27.2111
		23.964				27.5933
		24.186				27.9756
		24.408				28.3578
		24.63				28.74
		24.936				nan
		25.242				nan
		25.548				nan
		25.854				nan
		26.16				nan
		26.466				nan
		26.772				nan
		27.078				nan
		27.384				nan
		27.69				nan

Table 1.

existed at a depth above and below the missing data, the point was simply removed and a linear interpolation through the point was made, as shown in columns A, B and C of table one. Instances in which the last bottle sampled was at a depth less than 200 meters or the first bottle sampled was not at the surface, the interpolation was made as shown in columns D, E and F of Table 1. The presence of NaN signifies ‘not a number’ and is quite problematic for averaging many such profiles with time, but the nature of this project, which takes each profile on its own merit, eliminated the issue of accumulating NaN values within a matrix.

Once the data was organized and interpolated, it was checked using plots of the original data with the interpolated data to ensure that there was no change in the essential character of the data during interpolation (Figure 2).

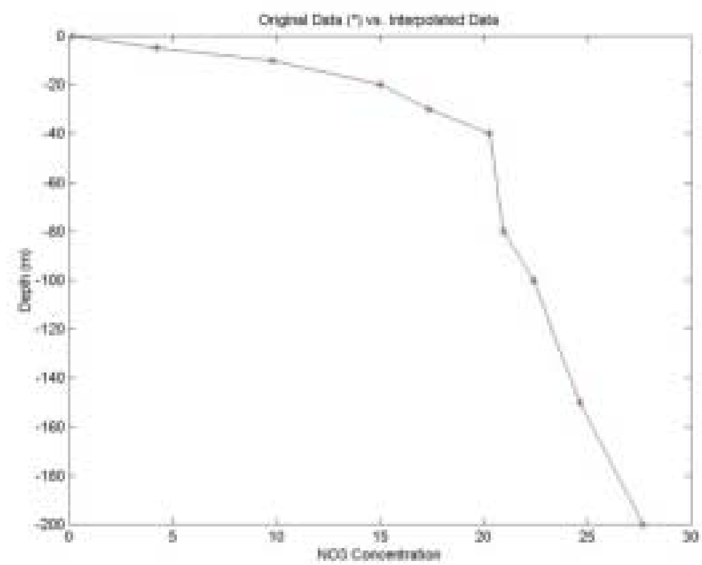

Figure 2. Plot of data points from original samples (red *) against the same data after linear interpolation was done (blue -).

Simple contour filled plots were then constructed for each nutrient for both data sets displaying the nutrients and temperature with depth going West to East using MatLab

(Figures 3-13). Programming code has been attached as Appendix A. Final displays were made by subtracting the Spring data from the Fall data showing difference contours (Figures 14-17).

D. Results and Discussion

Figures 3, 4 and 5 show nitrate, phosphate and silicate contours for the end of April

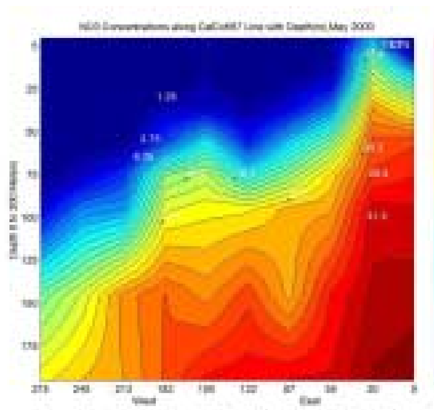

Figure 3.

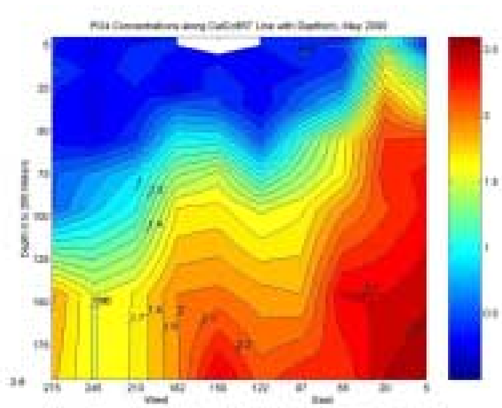

Figure 4.

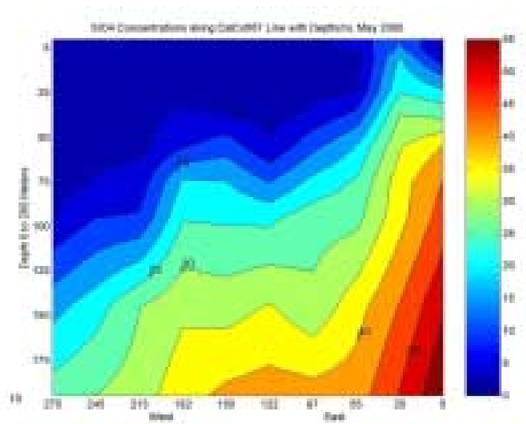

Figure 5.

Fig 3. Nitrate (NO3) concentrations in µM/l for Apr/May 2000. Fig 4. Phosphate (PO4) concentrations in µM/l. Fig 5 for Apr/May 2000. Silicate (SiO4) in µM/l for Apr/May 2000. In each graph the contours are graphed with distance in kilometers from the coast at 0 km on the x axis, with depth in meters on the y axis.

cruise. In each of the three contours, significant increases in the amount of nutrient present occur with increasing proximity to the coastline, which is represented at the far right of the graphs.

It is important to make the distinction that these were sampled at the end of April since the change in the upwelling between April and May is significant, with May have almost twice the upwelling in this location. A table from of averaged upwelling rates for the area is given in table 2 (Mason and Bakun, 1986).

36N 122W	Jan	Feb	Mar	Apr	May	June	July	August	Sept	Oct	Nov	Dec
1972	10	2	107	147	183	228	197	179	83	4	1	4
1973	-2	-28	123	208	260	267	295	250	111	43	17	0
1974	0	33	28	148	361	288	213	217	128	69	19	19
1975	27	10	55	156	271	287	266	201	152	71	57	23
1976	22	20	124	115	259	196	224	109	80	49	4	1
1977	2	34	141	153	138	232	247	173	85	67	41	-10
1978	-36	1	5	59	188	240	252	183	83	68	22	12
1979	-3	10	30	161	259	350	238	259	121	41	3	-9
1980	-1	-17	105	144	317	292	224	276	131	51	32	-7
1981	-20	5	56	189	333	289	250	252	159	42	0	3
1982	2	4	9	41	239	207	221	170	115	26	0	3
1983	-23	-16	4	35	187	269	223	116	74	30	11	2
1984	13	23	101	231	277	336	186	189	113	93	3	-3
1985	-1	51	88	150	228	199	202	180	94	74	28	-11
AVG	-0.71	9.429	69.71	138.4	250	262.9	231.3	196.7	109.2	52	17	1.929

Table 2. Averaged monthly upwelling index for several years for location closest to Monterey Bay. Location is 36N-122W. This is a position approximately 0.6 degrees latitude from the center of Monterey Bay.

From table 2, which shows upwelling values for the April to May transition of 138.4 to 250 cubic meters per second per 100 meters of coastline, it is reasonable to expect that a sharp increase in macronutrient concentration would be present in close proximity to the coastline. In all three figures, (Figs. 3,4, and 5), this is shown to be the case. In near perfect likeness, the values increase sharply between 5 and 20 kilometers offshore. This location corresponds to the area between stations C1 and 67-50 along CalCOFI line 67. A secondary increase is apparent in all three graphs at distances from 122 km to 213 km offshore. This corresponds to stations 67-65 to 67-80 along CalCOFI line 67. The change in bathymetry in that area as water approaches a sharp upslope corresponds to the location of that increase.

As a further test, temperature was graphically calculated for the line as well. If this increase in nutrients were upwelling related, then there should be a measurable decrease in temperature in these area, showing an opposing pattern to the nutrient graphic patterns. As shown in figure 6, this is the case. Both areas that displayed increased nutrient concentrations show marked decreases in temperature.

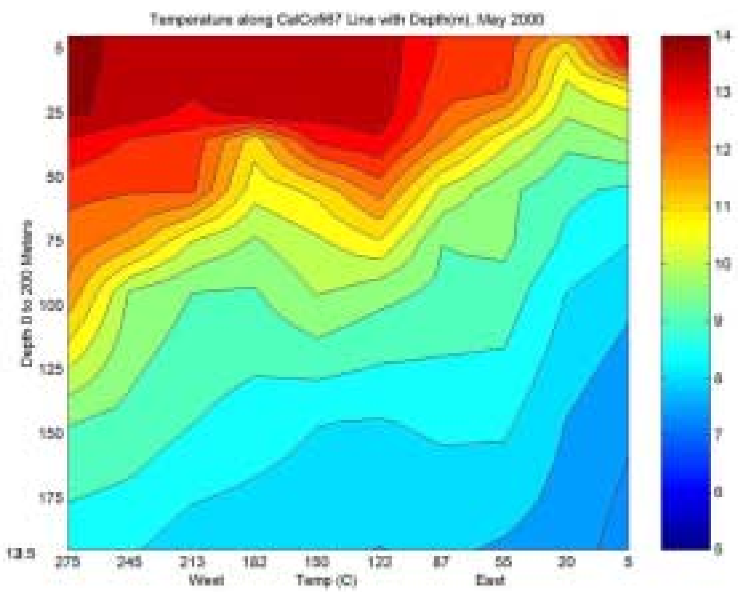

Figure 6. Temperature (°C) contoured with distance from shore (km) and depth (m) along the horizontal and vertical axis for Apr/May 2000.

Comparison of the averaged upwelling values for April/May with September indicate that there should as much as little the upwelling in September (Table 2). If this set of data follows the average, then significantly lesser nutrients should be found and logic suggests that the evidence of upwelling should be apparent at a further distance from shore as the forces behind the upwelling dissipate at the onset of the oceanic period. Examination of contours graphs for the nutrients in September do show this (Figs 7, 8, and 9).

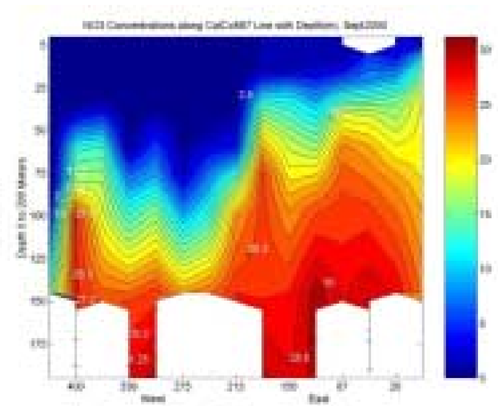

Figure 7.

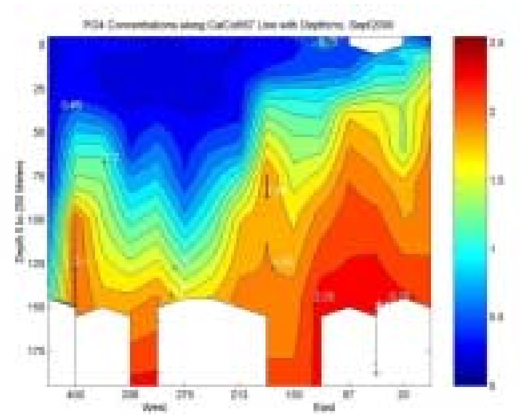

Figure 8.

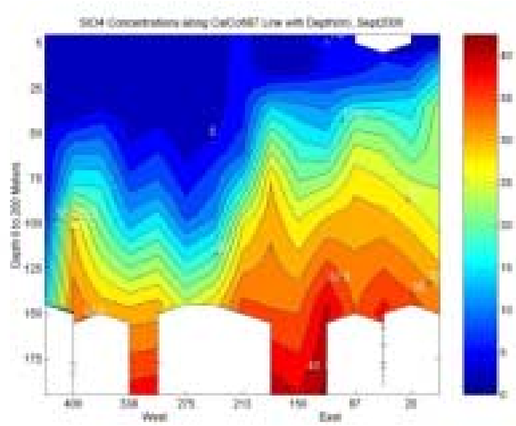

Figure 9.

Figure 7, 8 and 9. Nitrate (NO3), Phosphate (PO4) and Silicate (SiO4) in µM/l for September 2000. Horizontal axis is distance from shore in kilometers and vertical axis is depth in meters. Areas in white are areas in which no data exists.

It should be noted that the September data covers 150 kilometers greater distance from shore, giving an exaggerated view along the profile. When graphed to display only the same distance covered in the spring cruise, as shown in figures 10, 11 and 12, the comparison is more readily made.

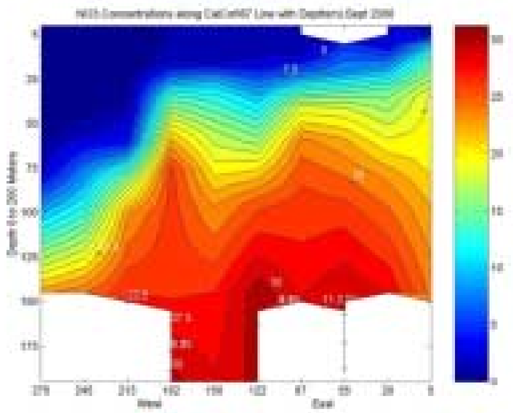

Figure 10.

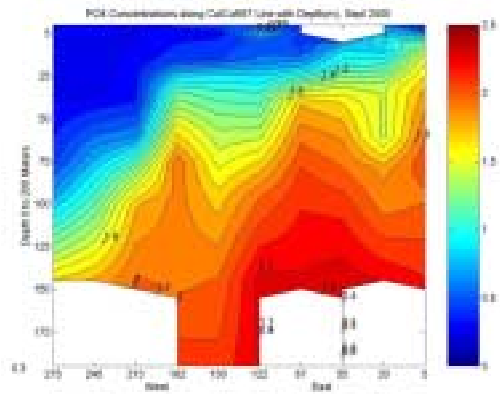

Figure 11.

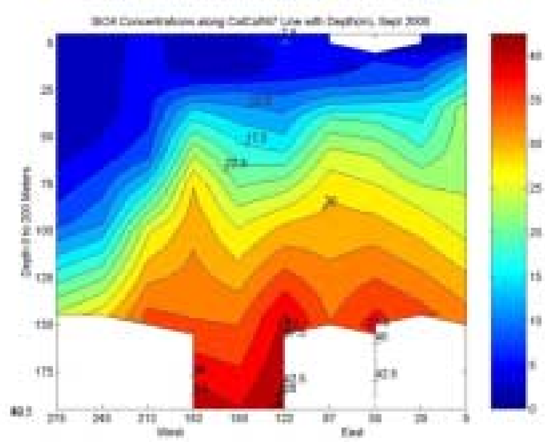

Figure 12.

Figure 10, 11 and 12 display nitrate (NO3), phosphate (PO4) and silicate (SiO4) for September 2000 for only the first 275 km of CalCOFI line 67. Each is plotted with the vertical axis showing depth in meters and the horizontal axis showing distance from shore in kilometers.

Examination of figures 10, 11 and 12 show the same similarities as seen in the graphs for the spring data. Each indicates increases in nutrient concentration coming from subsurface sources at specific locations. What is different are the locations at which the effect is observed and the amount of nutrients involved. For September, the location of the nutrient surge we might normally associate with upwelling is farther offshore than in spring. Overall concentrations of nutrients were lower, especially near shore. For both nitrate and silicate, there is a marked drop in the concentration at the stations closes to shore, though the phosphate shows an increase. Because of the limited number of samples, nothing conclusive can be drawn from that location. The smaller concentrations of nitrate and silicate throughout the profile remain the most striking feature. Silicate decreases of as much as 14 μM/l throughout the profile stand out.

Again, an examination of the temperature profile may prove helpful in determining what is occurring for this September profile (Figure 13).

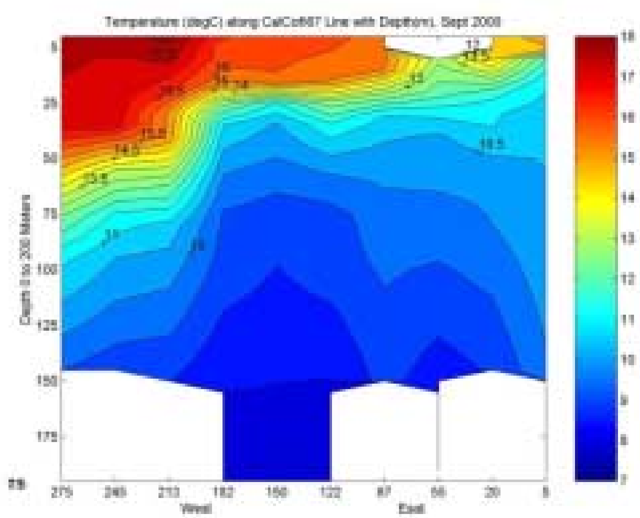

Figure 13. Temperature (°C) along CalCOFI line 67 for September 2000. Vertical axis is depth in meters and horizontal axis is distance from shore in kilometers.

Examination of the temperature and nutrient graphs for September shows that the increase in subsurface nutrients between 122 and 213 km is reflected in a concurrent decrease in temperature at the same location. The upwelling index for this location does show significant upwelling still present, though diminished from the spring and summer maximum, hence this profile carries out the supposition that increased nutrients are still being brought into the illuminated surface waters allowing increased photosynthetic processes to occur (Service, Rice and Chavez, 1998).

Secondary to the general likeness of the graphs is the representation of the near shore increase in temperature. This profile matches the profiles for nitrate and silicate, but not phosphate. There is no easy explanation for the increase in phosphate near shore considering that all other variables decrease, hence no suppositions will be made. Examination of the raw data shows that this increase in phosphate is due to a single increased value at 5 km offshore. Due to this, it isn't unreasonable to suggest that this may be a faulty data point. Without that data point the profile becomes much like the others for the September profile.

Also noted is the overall increase in temperatures for the September profile. Lowest temperatures increased from 5 to 7 degrees Celsius, while maximum temperatures near the surface increased nearly 4 degrees Celsius. Maximum temperatures for the spring profile reached 14 °C and for September reached 18 °C for the same 275 km profile. This is indicative of the summer surface warming and the decrease in upwelled waters reaching the surface.

Difference contour plots constructed by subtracting the spring data from the fall data illustrate the differences between the two profiles in overall concentration and in the location of the increases (Figs 14-17).

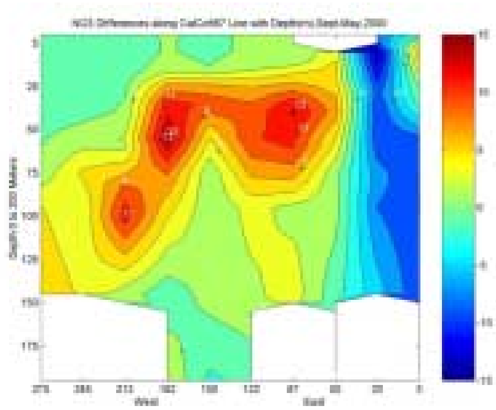

Fig 14.

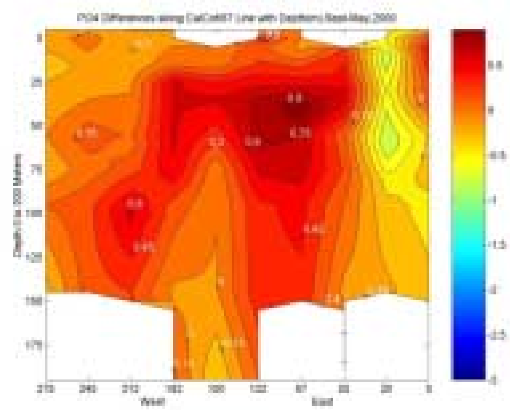

Fig 15.

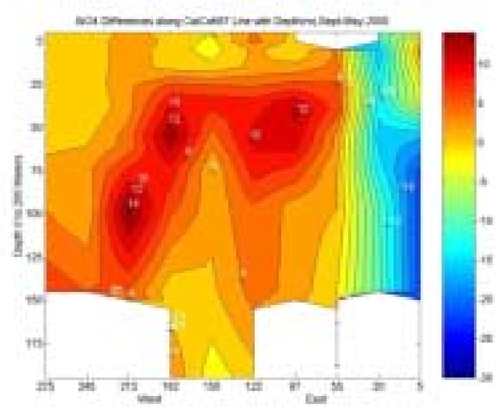

Fig 16.

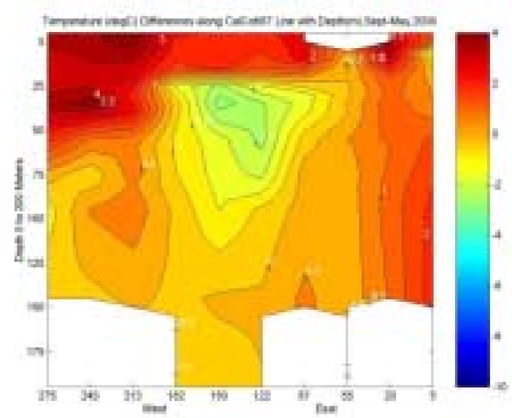

Fig 17.

Figures 14-17. Difference contours Nitrate (NO3), Phosphate (PO4), Silicate (SiO4) and Temperature (°C) along CalCOFI line 67. Vertical axis represents depth in meters and horizontal axis represents distance from shore in kilometers. Data from spring was subtracted from the fall data and the differences plotted.

Most striking about the difference contours is the similarity of them for all three nutrients and the complete opposition shown in the temperature profile. This is very consistent will an upwelling regime, in which cooler upwelled water is enriching the upper layers. In each of the nutrient difference contours there is a large negative difference in the near shore from 5 to 55 km offshore. This indicates that September has significantly less nutrient load at these locations than the April/May profile. Again, examination of the upwelling index proves that this is an expected result, though graphically it is far more noticeable. The temperature difference contour bears this out by showing an increase in temperature of up to 2.5 °C for the September profile in the same region, which is consistent with a decrease in upwelling.

Less illuminating is the striking increase in September nutrient load at 3 locations between 55 and 245 kilometers offshore. Of note is that all three of these locations are 100 meters or less in depth at their maximum values. One potential explanation for this lies in the lag time between nutrient availability and increased productivity (Wilkerson, et al., 2000). There is a lag in both time and space from the time in which upwelled water, containing high nutrient concentrations, is fully utilized and becomes depleted. During times of maximum upwelling, the area coinciding with those dramatic increases is cited as an “NO3 Deplete” area as rampant primary production takes place in the upwelled water and is transported, near the surface, offshore (Wilkerson, et al., 2000).

With a decrease in upwelling and a commiserate decrease in primary productivity, it is possible that there would be a virtual increase in nutrient load at the surface offshore. Predation of primary producers and the annual die off of primary producers at the end of the upwelling season would, in a normal year, be well underway during the time of this sampling. However, there is too little data to make anything other than minor speculations on the presence of these increased nutrient spots.

Perhaps most unusual is the temperature difference associated with the 3 locations. Directly in the center of the two most significant of the upper level increased nutrient locations, there is an area of significantly lower September temperatures. Were this an upwelling associated difference, it would be expected that colder temperatures would be found there as well. In this case, the two areas of increased nutrients straddle an area of lower temperature for the same time. Again, data from only two profiles isn't sufficient to make anything other that supposition on and so no conclusions can be drawn from it.

E. Conclusion

While physics remains the primary tool for explaining the physical regime in a coastal system, much can be learned about the physical processes occurring by examining the chemical and biological components of the system. In this study, data from two cruises, at opposite ends of the upwelling season, were examined for their nutrient concentrations. Comparison of the two profiles for the macronutrients of nitrate, phosphate and silicate, along with the temperature profiles, gave clear indications of the processes occurring during each time period.

During the end of April, the profiles gave the expected increases in nutrient load near the shore as the April/May upwelling began its annual maximum. For September, these profiles showed an expected decrease as the transition to the fall oceanic period began. Comparison with temperature profiles further bore this supposition out as nutrients were highly correlated with decreased temperatures.

Unexpectedly, the differences between the two profiles gave an unusual pattern in the illuminated waters offshore in which September values of nutrients were significantly higher than the spring values. Further, the temperature was decreased between the areas of increase, rather than the expected lower values. There is no easy explanation for this difference and nothing similar is noted in reference material read to date. However, it is less than reliable to base any supposition on the nature of this phenomenon on only two profiles, especially when no other physical or biological parameters were examined for this study.

Upwelling off the coast of Monterey Bay provides for a rich and varied biological regime that is host and benefactor to animals and humans. Simple examination of the nutrients is an inexpensive and rapid method for visualizing the state of the physical regime at any time. Nutrient and temperature contours provided for a quick understanding of the system that upwelling tables and indexes don't give. It further demonstrates that the year 2000 followed the timeline for upwelling with startling regularity, at least in character, even though no data on the exact amount were available. The creation of models that will correctly determine the amount of primary productivity that will be transported offshore during these upwelling periods depends heavily on acquiring accurate and extensive profiles in order to formulate the proper calculations. These profiles, and further, more time expansive, profiles are of value to that endeavor and to the student who needs to understand the system as a whole.

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