Estimating Primary Productivity in Central California Using SeaWiFS

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1. Introduction

Global climate change has been a topic of intense debate since the introduction of the global warming concept. Researchers continue to search for the answers through an understanding of environmental processes that already regulate global climate. Carbon Dioxide is a greenhouse gas known to be a significant contributor to anomalous warming. Its effects are countered by terrestrial and aquatic plant life, which use carbon dioxide in the process of photosynthesis. Researchers believe that primary producers, phytoplankton that make up the base of the oceans' food chain, are a Carbon Sink comparable to that of terrestrial plants, but knowledge of inter-annual variability is poor. Phytoplankton contain chlorophyll-a, one of the principal pigments of photosynthesis, and are known to absorb blue (443nm) and red (670nm) wavelengths and reflect green (550nm) wavelengths in the visible spectrum. Several studies are currently underway to quantify primary productivity via remote sensing and interpretation of ocean color. Measurements of the reflected wavelengths represent the concentration of chlorophyll-a in the ocean, and global coverage is attained.

The purpose of this study is to examine the accuracy of the Sea-viewing Wide Field of view Sensor (SeaWiFS), a satellite-mounted ocean color sensor, in a coastal environment. Comparisons will be made to in situ measurements of fluorescence, chlorophyll-a and primary productivity over three oceanic seasons: The spring and summer upwelling period, fall oceanic period, and Davidson current period. The upwelling period is typically characterized by high chlorophyll-a and primary productivity values, the oceanic period experiences varying degrees of primary productivity where occasional upwelling may still provide enough nutrients to support occasional blooms, while the Davidson current period is an annual minima (Pennington et al., 1999).

2. Sensors and Measurement Techniques

a. Fluorimeter

An Aquatracka III pulsed light, dual beam fluorimeter mounted on a Seabird Electronics CTD is used in this study. A fluorimeter emits light from a 5.5 Hz Xenon lamp at a 430nm wavelength. This wavelength excites chlorophyll-a molecules, which then emit at a wavelength of 685nm. A comparison between the intensity of the source and emitted light is representative of the chlorophyll-a concentration. An algorithm is applied within the Seabird processing software to the raw CTD fluorimeter data in order to provide realistic chlorophyll-a concentrations, however these values have been found to be misleading (Pennington, personal conversation). Therefore, raw fluorimeter readings are extracted directly from the CTD and regressed against in situ chlorophyll-a data. The fluorimeter readings are expected to be directly proportional to chlorophyll-a concentration.

b. SeaWiFS

SeaWiFS was launched in February 1997 as a follow on to the Coastal Zone Color Scanner, which ceased operations in 1986. The sensor is mounted on the SeaStar spacecraft, a polar orbiting satellite that can view every square kilometer of cloud-free ocean every 48 hours, making it an efficient and valuable tool on a global scale. SeaWiFS operates on six channels covering the visible spectrum and two near infrared (NIR) channels that are sensitive to aerosols. To derive ocean properties, path radiance must have a small and removable contribution. Three sources of path radiance are scatter by clouds (a non-removable source), scatter by molecules (known as Rayleigh scatter), and scatter by aerosol particles (as measured in the red and NIR channels). Algorithms applied to raw SeaWiFS data remove the contributions of path radiance and are extremely important since only 5-10% of the light seen at the satellite is reflected from within the ocean (NASA). Pigment or chlorophyll-a concentration will then be proportional to the ratio between the green (520nm) and blue (443nm) wavelengths.

c. Direct Chlorophyll and Primary Productivity

Water samples are first collected in the upper 200m of each station using a SeaBird CTD rosette sampler. It is necessary to measure the amount of chlorophyll directly at a given depth in order to have a benchmark against which to compare the fluorimeter and SeaWiFS data. This was accomplished using the Holm-Hansen Technique as described in Pennington 1999. Data is in units of milligrams per cubic meter.

Productivity experiments are then performed on those samples collected at six fixed depths, representing 100, 50, 30, 15, 5, 1, and 0.1% light penetration depth (LPD), which are estimated by secchi disk. For samples collected at night, the last daylight secchi depth is used (Michisaki, personal communication). The LPD's indicate the euphotic zone at a particular station, with the bottom of this zone being the 0.1% LPD. A direct measurement of primary productivity is made using radioactive Carbon 14 (14C). 14C is introduced into water samples from each predetermined LPD and incubated in a representative corresponding environment, created using nickel-cadmium screens that act as neutral density filters to reduce light intensity to the same level as that occurring at the same depth from which the sample was collected. After 24 h, the samples are filtered and soaked overnight with .5 N HCL to purge the filters of inorganic Carbon isotope. 14C uptake is then counted in milligrams of C per cubic meter per day, yielding an accurate spatial measurement of primary productivity.

3. Data

a. In Situ Data

Data were collected from one cruise along the California Cooperative Oceanic Fisheries Investigation (CalCOFI) line 67 aboard R/V Pt. Sur from 28 January to 1 February 2002, corresponding to the Davidson Current Season along the central California coast. A seaward flowing jet dominated the sampling area oceanic environment throughout the period and will be discussed later.

Ten stations of fluorimeter data and corresponding chlorophyll-a measurements are interpreted at depths of 5,10,20,30,40,60,80,100,150, and 200m. Regression between fluorimeter and chlorophyll-a measurements are made over the entire sampling depth, using raw fluorimeter voltage and chlorophyll-a measurements provided by the Monterey Bay Aquarium Research Institute (MBARI). Data analysis was accomplished using the same method as Witzleb, 2001 for the primary productivity data. If no productivity data existed at a standard depth, the productivity value representing the depth directly above the standard depth was averaged with the value below to produce an approximate value of 14C uptake. Depth integrated values of 14C uptake were determined by taking a sum of the values over the euphotic zone. Comparisons between 14C uptake, fluorimeter and chlorophyll measurements are made only over the corresponding euphotic zone depth.

b. Remote Sensing Data

Level two (L2) SeaWiFS imagery (post-calibration) from 4 FEB02 was retrieved directly form NASA through the NPS Remote Sensing Laboratory. An algorithm (slope=.001;intercept=32.0 - as provided in SeaDAS) is required in order to pull chlorophyll-a measurements directly from the imagery. Typically, composite images of the Monterey Bay area are needed due to the frequency of cloud cover. After geo-referencing the L2 image, the pixel value of the latitude and longitude corresponding to the first latitude and longitude value of each CTD cast is recorded. Pixel values are in milligrams per cubic meter and are compared directly to the in situ chlorophyll, fluorimeter and primary productivity measurements.

4. Analysis

a. Fluorimeter vs. Chlorophyll-a

A linear regression analysis was performed comparing the raw fluorimeter readings and chlorophyll-a measurements provided by MBARI. A correlation coefficient of .849287, a slope of 1.28369, and an R^2 value of .7213 was derived for the cruise time frame, falling in the Davidson current period. Data in Table 1 from Witzleb, 2001 is provided for comparison. The April data represents the spring and summer upwelling seasons and the September data represents the Oceanic period. The slopes of the linear regression show that chlorophyll concentrations tend to be on the order of twice the fluorimeter voltage output for these two time frames collectively.

	Correlation Coefficient	**Slope of the Linear Regression**
APR 2000	**.91874**	**.99032**
SEP 2000	**.93434**	**2.64361**
JAN 2002	**.84927**	**1.28369**

Table 1. Statistical analysis of in situ collected chlorophyll-a (mg/m^3) as the dependent variable and CTD/rosette mounted fluorimeter output (Volts) as the independent variable for three cruises conducted along CalCOFI line 67.

However, there is definite variation from season to season where the chlorophyll is on the order of 2.6 times the fluorimeter voltage at its most robust in the Oceanic period. A scatter plot (Figure 1) of chlorophyll-a vs. fluorimeter values, including data at all levels for January 2002, shows a definite correlation, with two noticeable outlying clusters of data points – one below the regression curve and one above.

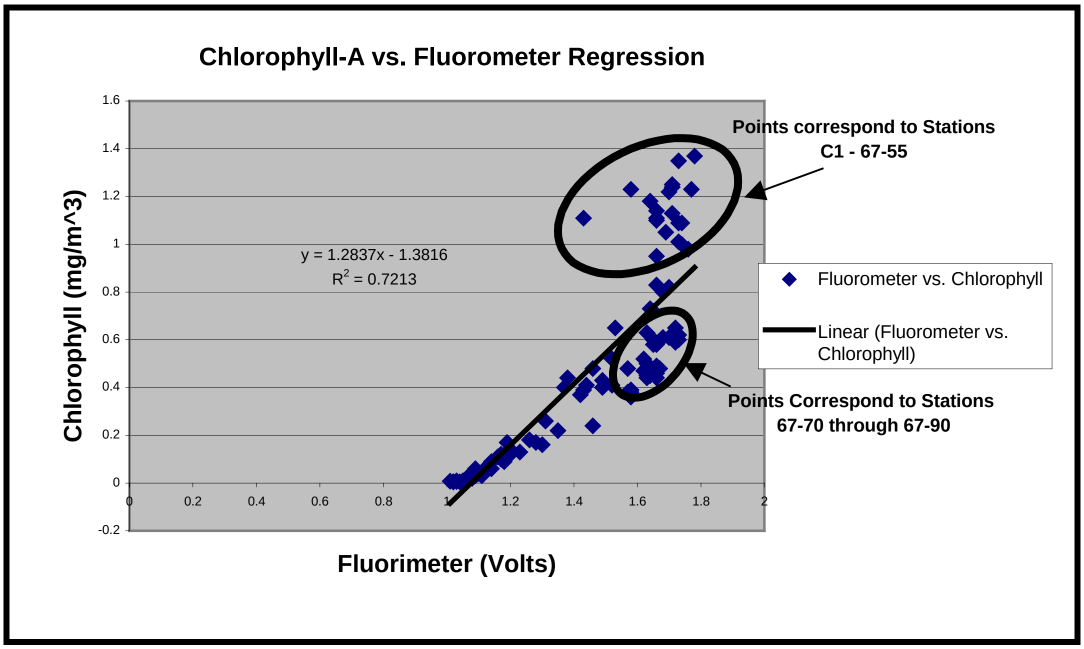

Figure 1. Scatterplot of chlorophyll-a concentration vs. fluorimeter output to 200m depth.

The cluster above the curve includes those data points in the euphotic zone at stations located prior to a frontal boundary located at approximately 123.5 deg W longitude as shown in Figure 2. The cluster below includes data points located in the euphotic zone at stations following the frontal boundary. This supports the suggestion that chlorophyll-a molecules engaged in the process of photosynthesis are less likely to fluoresce in response to the fluorimeter than chlorophyll-a molecules not engaged in photosynthesis, because the data points from below the euphotic zone correlate closely.

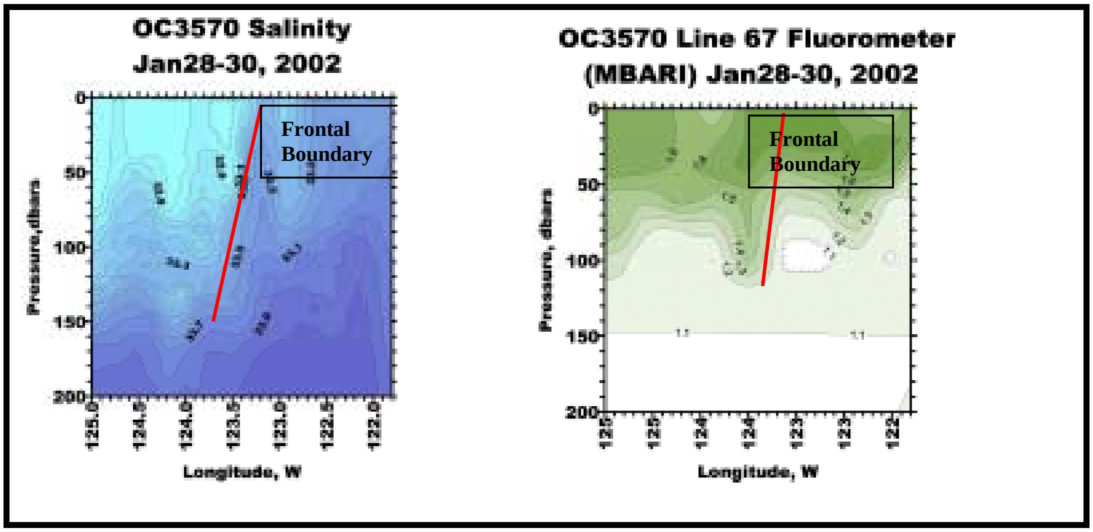

Figure 2. 200m data signatures of frontal boundary located at approximately 123.5 degrees W.

An additional point of interest is the relationship of the data to the regression curve and its location in relation to the frontal boundary. At the pre-frontal stations, there is, on average, over twice as much chlorophyll-a in the euphotic zone than at the post-frontal stations. Although there appears to be very little correlation between chlorophyll and fluorimeter values at the pre-frontal stations, a linear relationship remains for post-frontal chlorophyll-a values. This is believed to be a function of the increased depth of the euphotic zone (Fig. 3) at the post-frontal stations, which is a direct result of the lower chlorophyll-a concentrations (less chlorophyll-a, less phytoplankton, better water clarity).

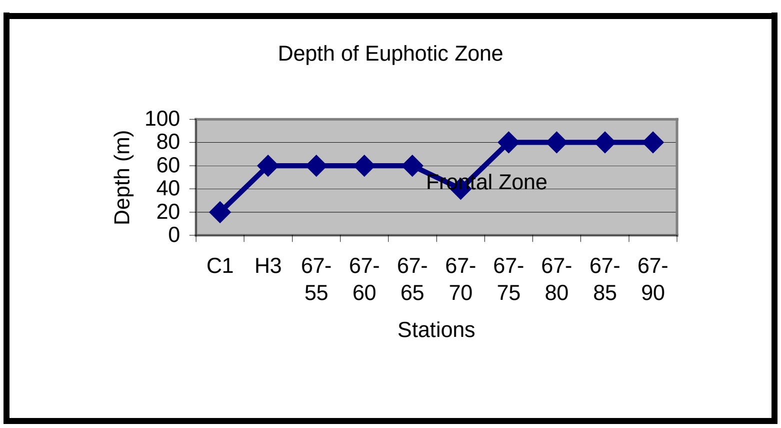

Figure 3. Euphotic Zone depth along CalCOFI line 67 for January 2002.

It is possible that at the greater depths, that despite amount of light penetration, chlorophyll-a molecules are less likely to photosynthesize and more likely to react to the fluorimeter.

b. Primary Productivity

Comparisons between the primary productivity (14C uptake), chlorophyll-a , and fluorimeter measurements are made only within the designated euphotic zone, as indicated in Figure 3. Since primary productivity and chlorophyll-a values are obtained from direct measurement, the values are expected to be closely representative of each other. Correlation coefficient data from Witzleb, 2001 and data from January 2002 are included in Table 2. The correlation coefficient of 14C uptake vs. chlorophyll-a agree well for the representative data of all three periods, as expected. However, the correlation coefficient of 14C uptake vs. fluorimeter for January are extremely poor, even in comparison to the April and September values. This is expected since fluorimeter values measure chlorophyll-a through a different process than that which occurs in photosynthesis. Since primary productivity is based on the rate of photosynthesis, a close correlation is not expected.

Correlation Coefficients:	Carbon Uptake vs Chlorophyll-a	Carbon Uptake vs. Fluorimeter Output
APR 2000	**.95961**	**.64701**
SEP 2000	**.95192**	**.93956**
JAN 2002	**.93632**	**.12937**

Table 2. Correlation of 14C uptake (dg/m^3/d) with in situ chlorophyll–a (mg/m^3) and fluorimeter output (volts).

c. SeaWiFS

A plume of relatively high-chlorophyll water can be seen flowing offshore late in the period in which this data is recorded (Figure 4). SeaWiFS coastal measurements are known to be inaccurate in the waters off Central California due to the fact that the processing algorithms are based on calibrations from a marine buoy moored in warm, tropical waters off the coast of Hawaii (MacFadyen, 1998). As denoted in Table 3, SeaWiFS correlation coefficients for January are very poor in comparison to April and September.

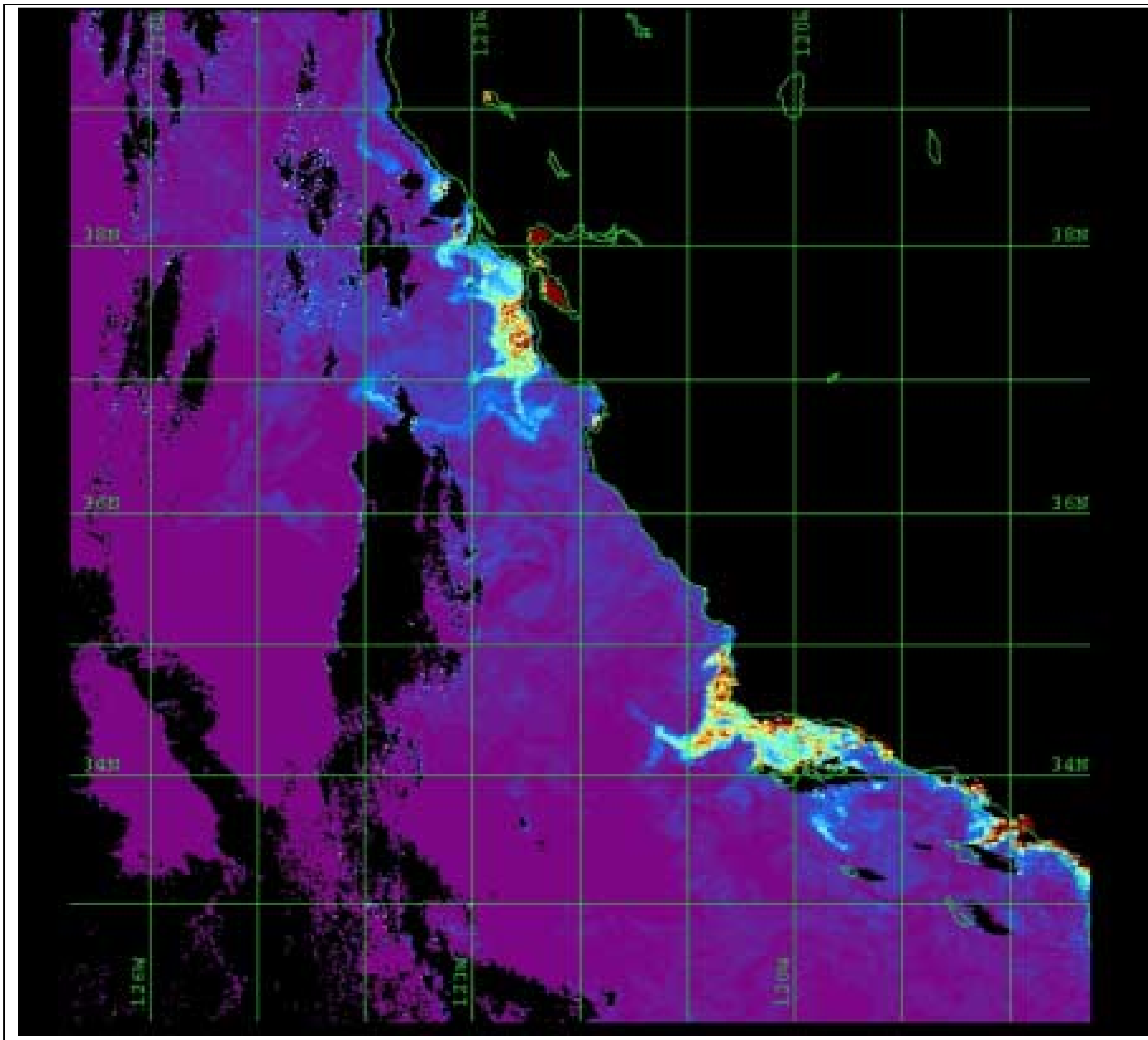

Figure 4. February 4 SeaWiFS imagery as derived from Level 2 file. Note the seaward flowing jet and hammerhead feature extending from Monterey Bay.

This may be due in part to the imagery analyzed. The offshore jet was being sheared apart at the time the measurements were recorded, whereas the jet was relatively strong on the dates the chlorophyll and primary productivity data were being recorded. Trends of chlorophyll-a overestimation by SeaWiFS are supported in the measurements over the first half of the line (out to approximately 60 km). Values are only slightly underestimated outside 100km. This is in contrast to MacFadyen, 1998 in which overestimation is most pronounced between 100km and 200km offshore in the November-April period.

Correlation Coefficient	SeaWiFS vs Chlorophyll-a	SeaWiFS vs. Fluorimeter Output	SeaWiFS vs. Carbon Uptake
APR 2000	**.87647**	**.60769**	**.95008**
SEP 2000	**.99511**	**.94317**	**.97214**
JAN 2002	**.63271**	**.69434**	**.77903**

Table 3. Correlation of SeaWiFS derived chlorophyll-a concentrations with 14C uptake (dg/m^3/d), in situ chlorophyll–a (mg/m^3), and fluorimeter output (volts).

5. Conclusions

Comparisons between chlorophyll-a and primary productivity were made in order to determine the accuracy of remotely sensed measurements off the central California coast during three oceanic periods: The spring and summer upwelling period, fall oceanic period, and Davidson current period. The upwelling period is typically characterized by high chlorophyll-a and primary productivity values, the oceanic period experiences varying degrees of primary productivity where occasional upwelling may still provide enough nutrients to support occasional blooms, while the Davidson current period is an annual minima (Pennington et al., 1999).

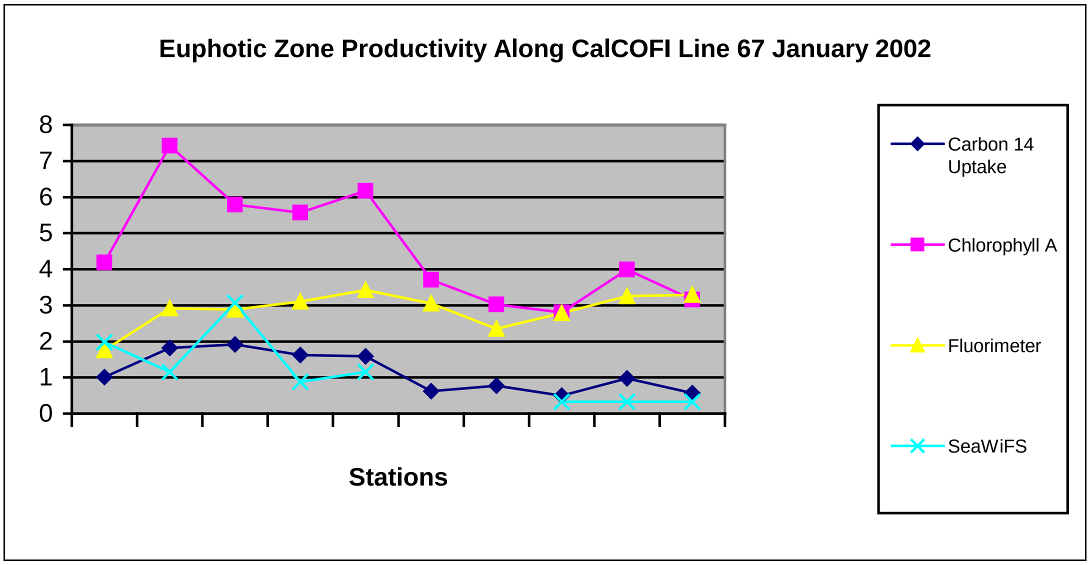

Figure 5. Data for all stations are displayed. Missing data points correspond to areas of cloud coverage. 14C uptake (dg C/m^3/d), chlorophyll-a (mg/m^3/d), fluorimeter (volts), SeaWiFS (mg/m^3/d).

Data analysis from the January 2002 cruise supports a correlation between remotely sensed chlorophyll-a concentrations and in situ measurements of chlorophyll and primary productivity, although not as strong as determined in April or September 2000. Relationships tend to support the findings of MacFadyen, 1998 in which it was determined that spatial and temporal distributions of chlorophyll-a concentrations may be identified, however, exact measurements are not currently accurate enough to be made on a global scale. Other factors affecting the outcome of the data relationship include lack of availability of SeaWiFS data during the precise cruise dates due to cloud coverage. A monthly composite of imagery, as used in Witzleb, 2001, may have improved the data correlation; however, because of the oceanic jet present during the corresponding cruise dates, the best imagery composite would have included that of 28-31January.

Seasonal variations of data correlation appear to be in agreement with MacFadyen, 1998, although more extensive data analysis needs to be completed to draw specific conclusions.

6. Future Research

The SeaWiFS project funds several research efforts aimed at identifying ways to overcome the remote sensing problem of atmospheric scattering, which tends to become a greater issue in inhabited coastal areas. One example includes research being conducted at the University of California, Santa Barbara. The above-water approach to estimating water-leaving radiance and remote-sensing reflectance is highly influenced by environmental factors. A model of the role of wind on the reflected sky radiance measured by an above-water sensor illustrates that, for clear-sky conditions and wind speeds greater than 5 m/s, determinations of water-leaving radiance at 490 nm are undercorrected by as much as 60% (Toole, et. al.). As more accurate and inclusive corrective algorithms are applied to raw, remotely sensed data, the magnitude and variability of chlorophyll and primary productivity will provide the oceanographic community with a better understanding of these important carbon sinks.

REFERENCES

MacFadyen, Amy 1998: *Modeling primary productivity from satellite-derived chlorophyll in the Monterey Bay region.* Monterey Bay Aquarium Research Institute. 19pp.

NASA, cited 2002: SeaWiFS Project. [Available on-line from http://seawifs.gsfc.nasa.gov/SEAWIFS.html]

Pennington, J. Timothy, F.P. Chavez,1999: Seasonal fluctuations of temperature, salinity, nitrate, chlorophyll and primary production at station H3/M1 over 1989-1996 in Monterey Bay, California. *Deep-Sea Research II*, **47**, 947-973.

Toole, DA, Siegel DA, Menzies DW, Neumann MJ, Smith RC, 2000: Remote-sensing reflectance determinations in the coastal ocean environment: impact of instrumental characteristics and environmental variability. *Applied Optics* **39**, (3) 456-469.

Witzleb, Robert W, 2001: *Phytoplankton productivity along CalCOFI line 67*. Naval Postgraduate School. 15 pp.