

Semi-Annual Progress Report
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Task Objectives

The objectives of the last six months were:

- Continue analysis of Hawaii Ocean Time-series (HOT) bio-optical mooring data,
- Continue analysis of bio-optical from JGOFS cruises in the Southern Ocean
- Participate in an interdisciplinary optics cruise off Oregon
- Maintain documentation of MOCEAN algorithms and software for use by MOCEAN and GLI teams
- Continue chemostat experiments on the relationship of fluorescence quantum yield to environmental factors.
- Continue to develop and expand browser-based information system for in situ bio-optical data

Work Accomplished

Analysis of Field Data from Hawaii

We continue to analyze bio-optical data collected at the Hawaii Ocean Time Series mooring. The HOT bio-optical mooring was recovered in November 1998. After retrieving the data, the sensor package was serviced and redeployed. We now have over 24 months of data. These are being analyzed as part of a larger study of mesoscale processes at this JGOFS time series site. A manuscript documenting the effects of mesoscale circulation on productivity (as revealed by sun-stimulated fluorescence) has been submitted to *Deep-Sea Research*.

In addition, Ricardo Letelier is funded as part of the SeaWiFS calibration/validation effort (through a subcontract from the University of Hawaii, Dr. John Porter), and he is collecting bio-optical and fluorescence data as part of the HOT activity. This will provide additional in situ measurements for MODIS validation. All of these data may be obtained at our Web site, <http://picasso.oce.orst.edu/users/jasmine/ORSOO>. The data have also been provided to the SIMBIOS project.

Analysis of Data from the Southern Ocean

We presented and discussed our results from the U.S. JGOFS Southern Ocean to the Principal Investigators Workshop in Knoxville, TN. We focused on the bio-optical moorings and drifters. A manuscript describing initial results has been submitted to a special issue of *Deep-Sea Research*. We briefly summarize these results below.

As the optical moorings relied on an upward-looking radiometer (i.e., measured downwelling irradiance), we needed to develop an algorithm to convert these measurements into phytoplankton chlorophyll concentrations. A comparison of SeaWiFS-derived chlorophyll from ship-derived chlorophyll showed that the SeaWiFS algorithms worked well in the Antarctic Polar Frontal Zone (Moore et al, submitted). Figure 1 shows the time series of SeaWiFS-derived chlorophyll for the mooring locations for days when it was clear over the moorings. The SeaWiFS data comes from both local area and global area coverage imagery. Note the strong spring bloom apparent around day 340 (early December 1997).

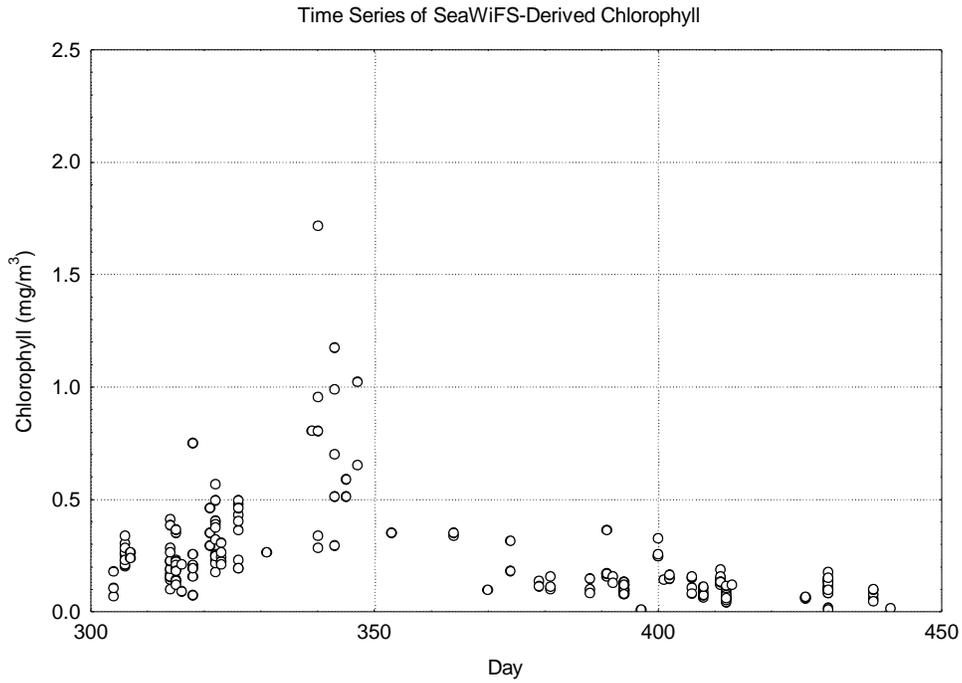


Figure 1. Time series of chlorophyll from SeaWiFS LAC and GAC imagery at the Polar Front mooring locations, 1997-1998.

We used a nonlinear least-squares routine to fit the downwelling radiances to chlorophyll as follows:

$$chl = a \times \left[\frac{E_d(443)}{E_d(555)} \right]^b$$

For our data, $a=0.52$ and $b=-0.544$. Figure 2 shows the regression between satellite-derived and mooring-derived chlorophyll.

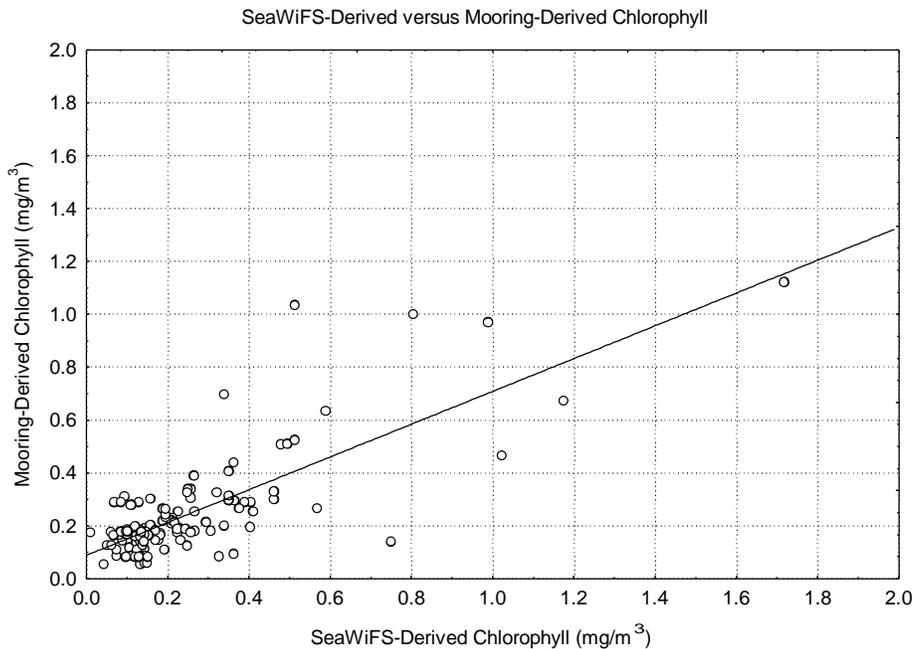


Figure 2. Comparison of SeaWiFS-derived and mooring-derived chlorophyll from the Antarctic Polar Frontal Zone bio-optical moorings.

Using Model II regression, the slope was 0.80 (± 0.08 at the 95% confidence interval) and the intercept was 0.04 (± 0.03 at the 95% confidence interval). A slope of less than 1.0 is likely an artifact of the small range of observed chlorophyll values. If we eliminate the one high chlorophyll value, the slope increased to 0.88 (± 0.10 at the 95% confidence interval).

Figure 3 shows the mooring-derived chlorophyll time series. The general pattern is similar between moorings: a pronounced spring bloom began in early December 1997, peaked in late December and then began to decay over the next month. We calculated sun-stimulated fluorescence per unit chlorophyll (F/C) to estimate the photoadaptive state of the phytoplankton community during this bloom event.

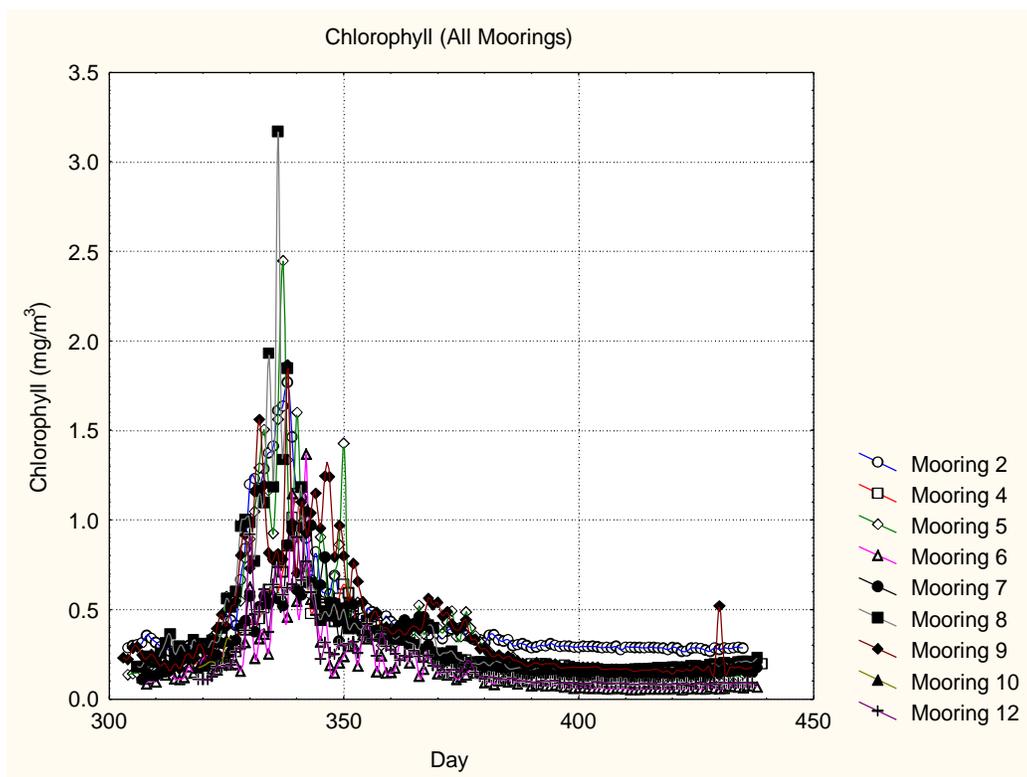


Figure 3. Time series of chlorophyll from the bio-optical moorings in the APFZ, 1997-1998.

Figure 4 shows the time series of F/C. As with the chlorophyll time series, there is a generally repeatable pattern at each mooring, but there was more variability. There is an increase in F/C just before the increase in chlorophyll. F/C then drops to a very low value. It remained low, even as chlorophyll concentrations began to decline. About one month after the peak in chlorophyll concentration, F/C began to increase at most of the moorings, especially moorings 4 and 7.

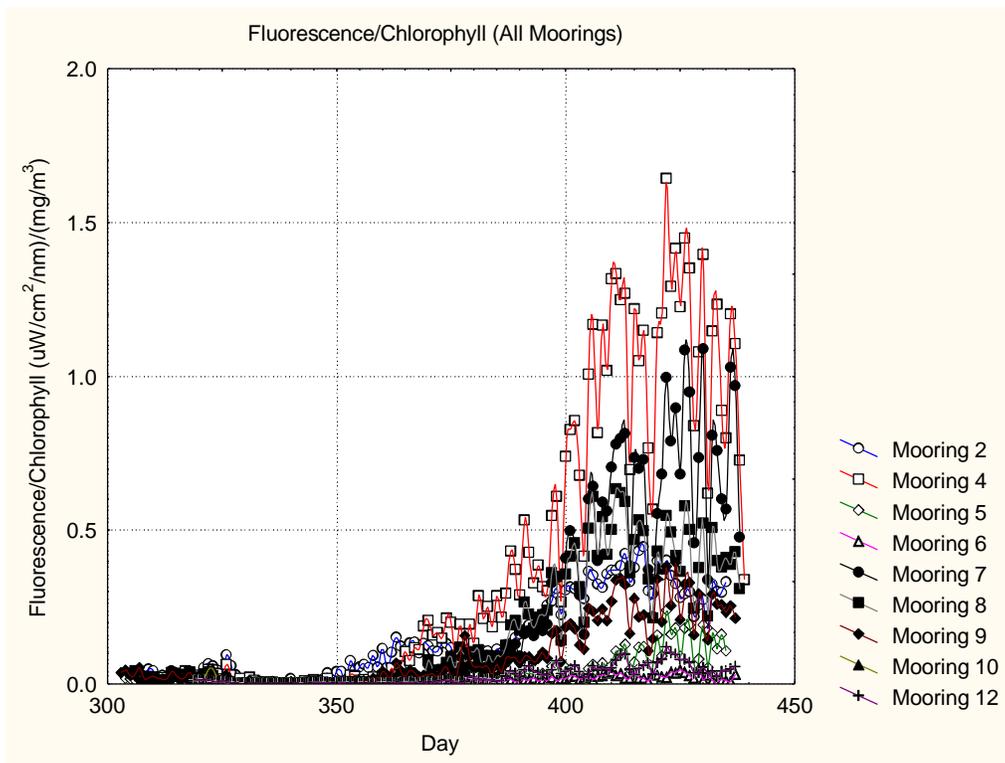


Figure 4. Time series of F/C from the bio-optical moorings, 1997-1998.

We interpret these results as follows. The initial bloom in chlorophyll is initiated by the sudden increase in stratification of the upper ocean in early December. This inhibits deep mixing, allowing phytoplankton to spend more time in the well-lit upper waters. The sudden change in the light environment also increase F/C, as phytoplankton are not photoadapted to this new regime. As the phytoplankton adapt, F/C drops rapidly, indicating high productivity. However, chlorophyll concentrations begin to decrease before F/C increases, suggesting that the light utilization properties of the phytoplankton were not under stress. Instead, phytoplankton were probably limited by a nutrient not involved in phytoplankton photosynthesis. As spring blooms in the Antarctic Polar Frontal Zone are generally dominated by diatoms, depletion of silicate is a likely cause for the collapse of the spring bloom. Silicate is not involved in phytoplankton energetics, unlike other nutrients. Eventually, F/C begins to increase, implying that the phytoplankton community began to be limited by a nutrient involved in photosynthesis. Since nitrate is always abundant in the APFZ, it is likely that the increase in F/C is related to iron limitation. Note that F/C increases the most in late summer, when stratification is the strongest.

We used cluster analysis to study spatial differences in the time series of chlorophyll and F/C. In general there were two communities (Figure 5): a southern cluster characterized by an intense bloom in chlorophyll which became iron-limited earlier than the northern cluster which had a less intense bloom. We suspect that these spatial patterns are related to the mesoscale circulation associated with the APFZ which provided sufficient silicate to the southern cluster whereas the northern cluster had lower silicate concentrations.

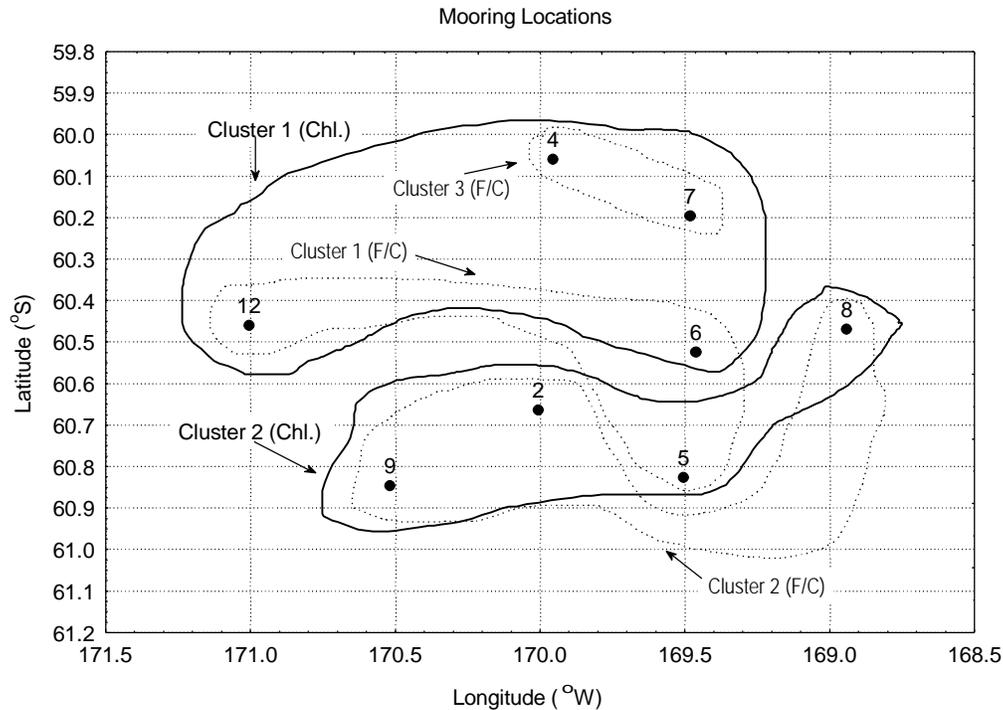


Figure 5. Results of cluster analysis of chlorophyll and F/C time series, showing the spatial relationships.

We deployed three clusters of drifters to study the convergence/divergence field associated with the PF. Two clusters were deployed in the first survey and a third cluster was deployed in the second APFZ survey. Two bio-optical drifters were deployed during the final APFZ process cruise. Most of the drifters survived several months as projected and traveled to the Mid-Pacific Rise where they were trapped in the rough topography of the Eltanin Fracture Zone. We are analyzing these drifters in comparison with the mooring time series. We have calculated vertical velocities based on the vorticity balance of coherent clusters of drifters. These results will be presented at an international oceanographic meeting in May 1999.

The Tethered Spectral Radiometer Buoy II was deployed at several stations during the APFZ cruises. Chlorophyll values were generally low, given the deep mixing present in the PF during early spring. The TSRB II values agreed quite well with chlorophyll extractions made from near-surface water samples. Sun-stimulated fluorescence was also measured, and these data are now being analyzed.

The Fast Repetition Rate (FRR) fluorometer was deployed during the second JGOFS survey to the Polar Front. Although the data were reasonable, there were several technical problems with the operation of the FRR fluorometer. Most notably, the underwater connectors and some elements of the software were poorly designed, resulting in some data loss. The fluorometer was shipped back to Chelsea Instruments in the United Kingdom and was replaced with an upgraded model. However, the data that were recovered look intriguing. To support analysis of the FRR data, over 400 samples were collected for detailed pigment analysis using HPLC.

All of the mooring, drifter, and TSRB data are available our Web site, <http://picasso.oce.orst.edu/users/jasmine/ORSOO>

Oregon Optics Cruise

We participated in a cruise in the coastal upwelling region off Oregon in September 1998. We deployed the new FRR fluorometer and the Satlantic TSRB-II. The FRR worked quite well this time, although there are some improvements in software that still need to be implemented. The TSRB was deployed several times, beginning before sunrise and ending after sunset. Photosynthetically-available radiation (PAR) was

estimated from the seven channels of downwelling irradiance measured by the TSRB II (Figure 6) This figure also shows the chlorophyll time series calculated using a SeaWiFS-style algorithm.

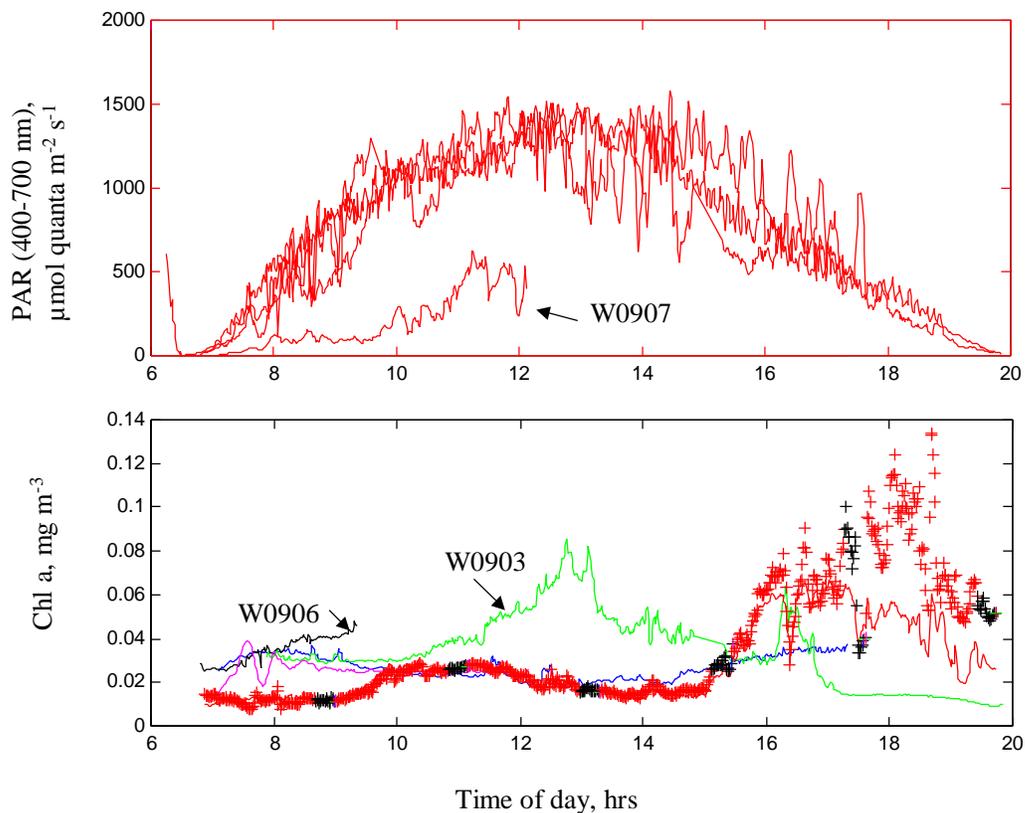
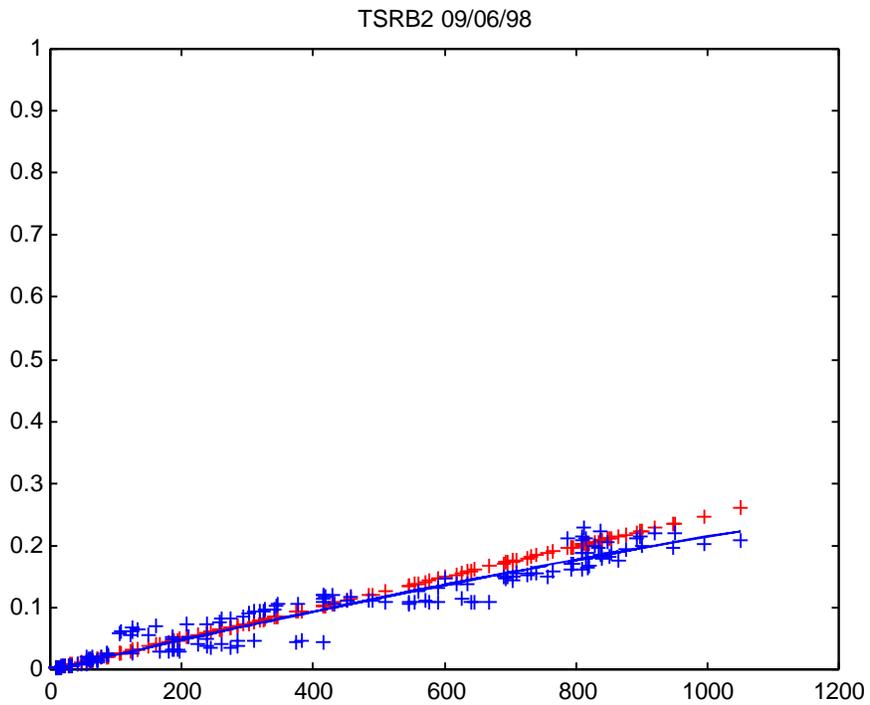
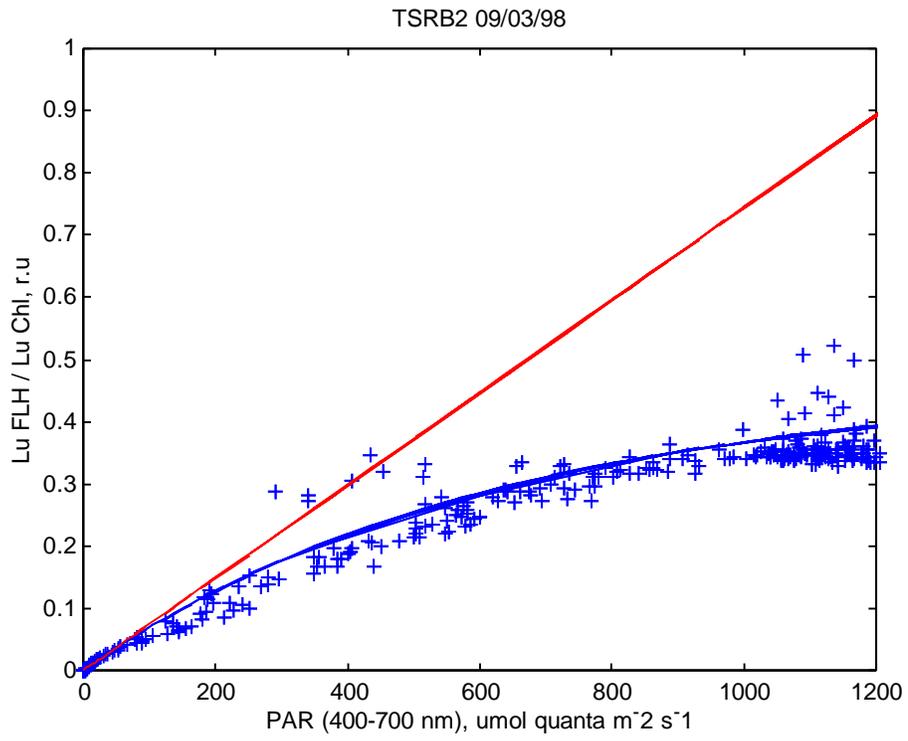


Figure 7. PAR and chlorophyll time series from several successive deployments of the TSRB II off Oregon.

Figure 8 shows three panels of fluorescence line height (FLH) per unit chlorophyll plotted versus PAR for three days: Sept 3, 6, and 7, 1998. For all three deployments FLH/chl is nearly linear with PAR until PAR exceeds 50-300 $\mu\text{mol quanta}/\text{m}^2\text{s}^1$. There are strong differences in the three deployments, especially on Sept. 7 (bottom panel). This deployment was done over the shelf break. As we noted in an earlier report (published in Letelier et al., 1997), the slope of these lines is proportional to the apparent quantum yield of fluorescence. The steeper the line, the higher the quantum yield of fluorescence, which is inversely related to the quantum yield of photosynthesis. This is consistent with an increase primary productivity observed in the region of active upwelling. Note the decrease in slope in the upwelling deployments (Sept 3 and 6), which may be the result of an increase in upwelling intensity over the three days.

These results differ from our previous work as we have access to a full suite of ocean physics, chemistry, and biology as part of this cruise.



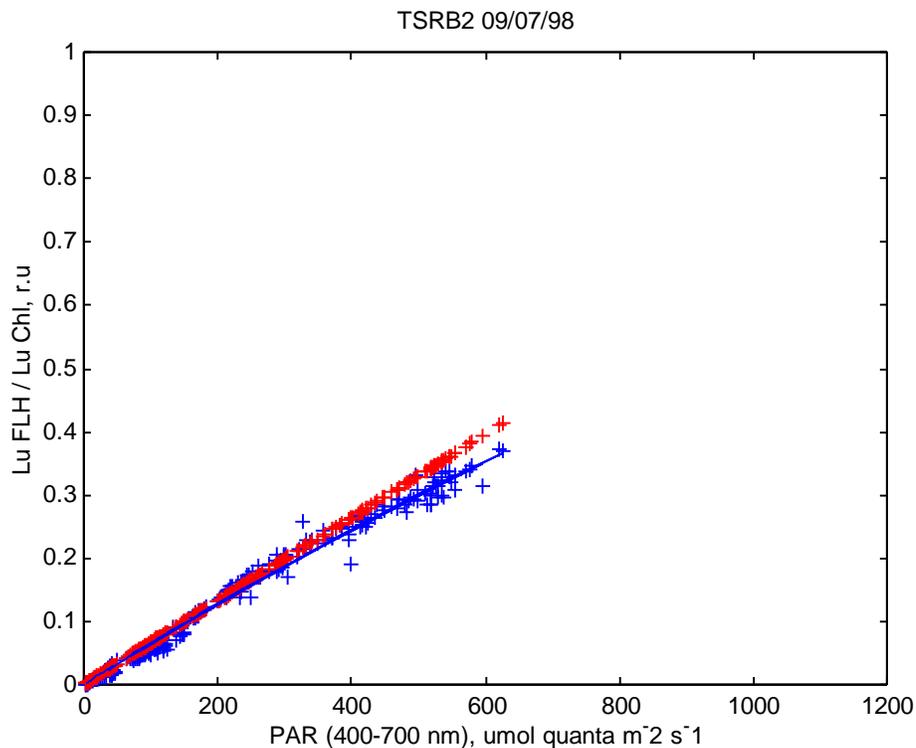


Figure 8. Regressions of FLH/chl versus PAR during three deployments of the TSRB II off Oregon.

Unfortunately, the TSRB II became wrapped around the propeller shaft of the research vessel during one of the deployments. The TSRB was severely damaged and is now being replaced. We also obtained several profiles using the Fast Repetition Rate fluorometer.

MOCEAN Algorithm Documentation

As part of our joint MODIS/GLI activities, we have developed a complete set of on-line documentation for the MODIS Ocean algorithms. This Web page can be accessed at <http://picasso.oce.orst.edu/users/jasmine/MODP/>. We have maintained this page in cooperation with the University of Miami. We distributed the Version 2 MODIS Ocean codes to the GLI team and to Dr. Jim Yoder, Univ. Rhode Island, and to researchers working on NPOESS.

Chemostat Experiments

In our last report, we discussed our chemostat experiments with sun-stimulated fluorescence. During photosynthesis, the sun-stimulated (also called passive or natural) fluorescence is a passive signal emitted by the photosystem that can be affected by changes in temperature, nutrient and light availability. Because variations in the amount of fluorescence emitted per unit light absorbed (fluorescence quantum yield) take place in response to changes in the energy distribution in the photosystem, we can expect these variations to be the first direct signal of biological response to physical and chemical changes.

Using a chemostat that allows the continuous monitoring of passive fluorescence and fluorescence quantum yield under nutrient, light and temperature controlled conditions, we are quantifying the time scales of the physiological response of phytoplankton (as manifested in the chlorophyll fluorescence) to environmental variability. This information is crucial for the development of models of coupled ocean physics and biology as well as for the design and analysis of next-generation in situ instrumentation which rely on passive sensing of phytoplankton.

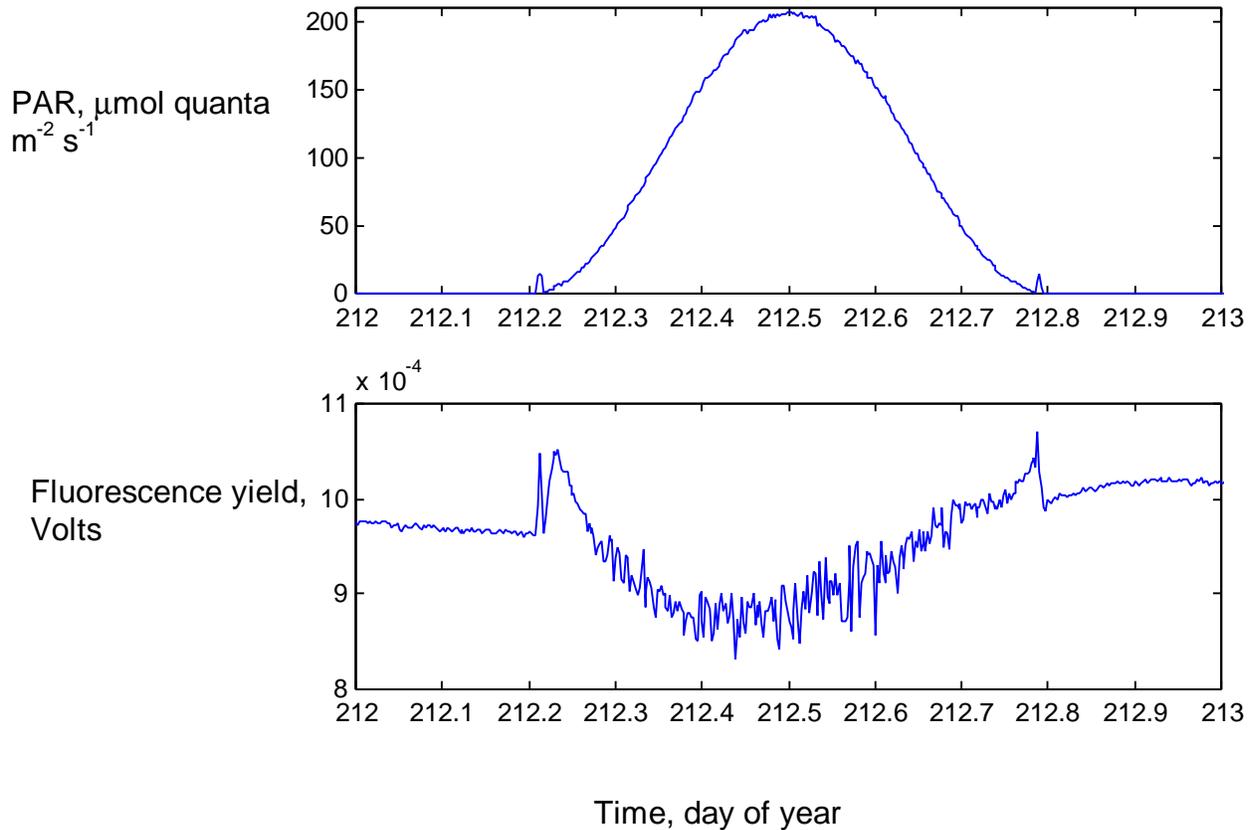


Figure 9. A sample run of the chemostat, showing PAR and fluorescence yield during a diel cycle.

Figure 9 shows a one-day cycle of PAR and fluorescence yield from the chemostat. We have added a computer control to the light source in order to provide a more realistic day light environment. The small peaks at the beginning and end of the daylight cycle are artifacts of the initial warm-up and turndown of the light source. Note the increase in fluorescence yield at the beginning and end of the “day,” part of the photoadaptive process. The mid-day depression is still under study, but it is probably related to photoadaptation of the reaction centers.

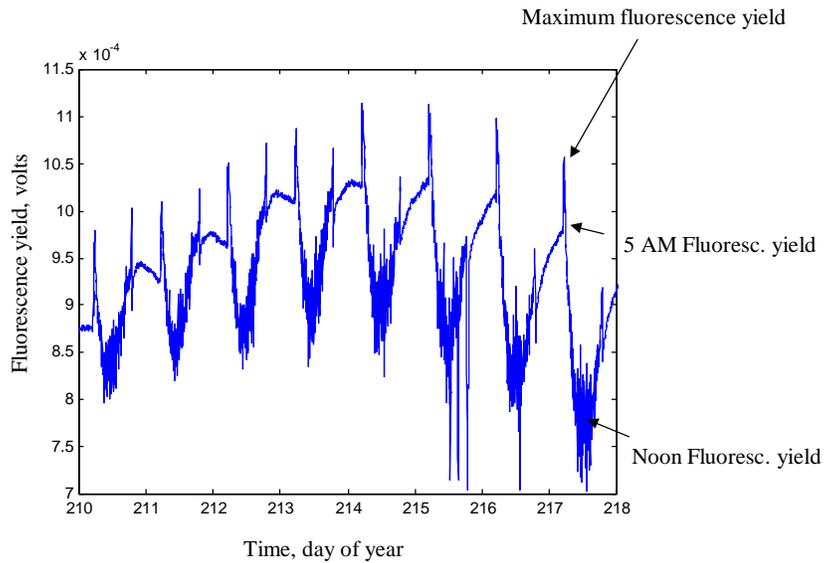


Figure 10. A one-week record of fluorescence yield from the chemostat.

These patterns are reproducible over many days and weeks, as shown in Figure 10. The are changes in the pattern, which we think are related to changes in the nutrient environment of the chemostat. Figure 11 shows a summary of the descriptive statistics shown in Figure 10.

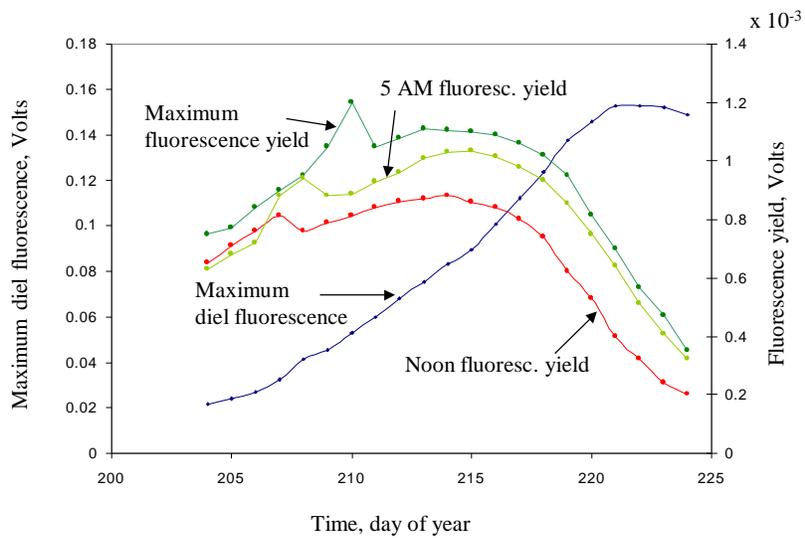


Figure 11. Time series of the descriptive statistics shown in Figure 10.

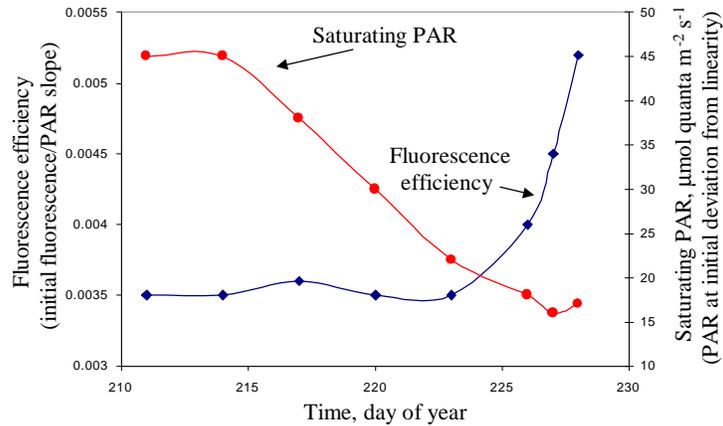


Figure 12. Time series of fluorescence efficiency and saturating photosynthetically-available radiation (PAR).

We used the information in Figure 10 to derive an estimate “fluorescence efficiency” which was based on the initial slope of fluorescence versus PAR at low light levels at the beginning of the “day.” We also estimated “saturating PAR” which we defined as the point where the fluorescence yield began to deviate from a linear function of PAR (see Figure 8, top panel). In the specific data set shown in Figure 12, we can see the phytoplankton culture adapt to a new nutrient regime.

The main objective during the first phase of our research is to evaluate the range of scales of variability that can be studied by monitoring phytoplankton sun stimulated fluorescence. The results from these studies will help in our interpretation of the scales of variability in phytoplankton fluorescence yield observed in pelagic environments.

Two major questions to be addressed during this phase are:

1. What are the time-lag response of fluorescence to changes in nutrient (nitrogen, phosphorus, and iron), light, and temperature regimes?
2. Is there a correspondence between the magnitude of the fluorescence response and the magnitude or type of environmental change?

Our last report showed the design of the chemostat. We have modified the computer control of the system and now have Windows and Matlab routines to access and process the data. A flow-through cell for the spectrophotometer and for the FRR fluorometer have also been built and installed. We modified the monochromator so that we can measure fluorescence action spectra. The entire optical system has now been calibrated, which required the development of an entirely new set of protocols. Lastly, we are evaluating a Hansatech oxygen evolution probe to measure photosynthetic activity.

EOSDIS Plans

We have continued our work on distributed objects frameworks for EOS data retrieval and analysis. This work was supported through a contract with the Raytheon ECS prototyping activity. Additional reports

may be found at <http://picasso.oce.orst.edu/users/mark> .

We have now put all of our California Current and Southern Ocean drifter on line. Mooring data from Hawai'i and the Southern Ocean are also available, as are the TSRB data sets from the Southern Ocean, Hawai'i, and the Oregon coast. These data can be accessed at <http://picasso.oce.orst.edu/users/jasmine/ORSOO> . We have also developed a set of Java components to link the data collection and control system for the chemostat with our data base.

Anticipated Future Actions

- Retrieve and redeploy bio-optical mooring in Hawaii and continue analysis of bio-optical data
- Analyze data from bio-optical moorings and drifters, TSRB II, and FRR in the Antarctic Polar Frontal Zone
- Analyze TSRB II data from the Oregon coast
- Continue chemostat experiments on the relationship of fluorescence quantum yield to environmental factors. Establish relationship between fluorescence quantum yield and photosynthetic parameters.
- Continue to develop and expand browser-based information system for in situ bio-optical data.

Problems and Solutions

The most significant concern remains the reduced ability of EOSDIS to deliver data products at launch. We are concerned that insufficient data will be delivered for algorithm validation as well as analysis in support of future EOS sensor designs. In particular, much of the quality assurance will depend on delivery of data over the network; there is little leadership within ESDIS on network design. With the push to PI processing, the network will increase in importance. Unless a coherent strategy is designed and implemented, it will be unlikely that we will meet our data delivery requirements.