Semi-Annual Progress Report

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MODIS Team Member, Contract # NAS5-31360

Task Objectives

The objectives of the last six months were:

- Complete analysis of bio-optical drifter from JGOFS cruises in the Southern Ocean
- Analyze data from MODIS validation cruise off California and Mexico and collect validation data off Oregon
- Complete chemostat experiments on the relationship of fluorescence quantum yield to environmental factors.
- Evaluate initial MODIS imagery from several regions of the world ocean
- Install MODIS Direct Broadcast facility
- Continue to develop and expand browser-based information system for in situ bio-optical data and MODIS imagery.

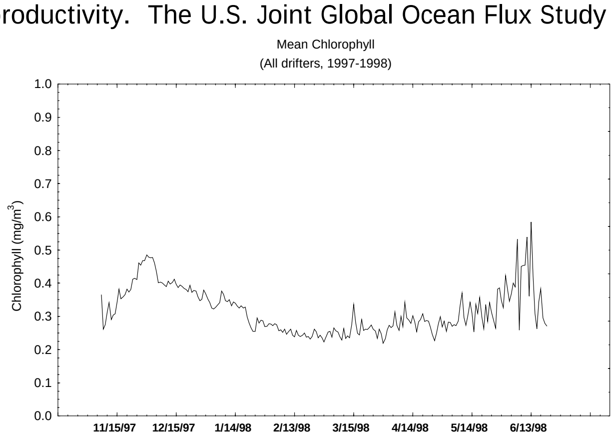
Work Accomplished

Analysis ofJGOFS bio-optical drifter data

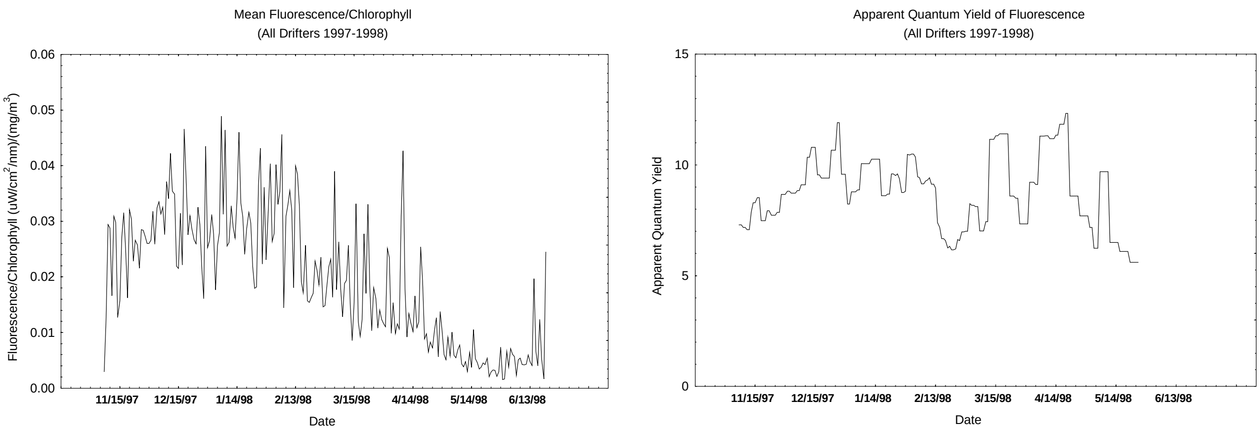
We presented our results from the U.S. JGOFS Southern Ocean in two invited talks at the AGU/ASLO Ocean Sciences meeting in January 2000. We also presented our results at the International Southern Ocean JGOFS meeting in Brest, France in July 2000 and will make another presentation at the German JGOFS Ocean Biogeochemistry meeting in September 2000.

All of the Southern Ocean mooring, drifter, and TSRB data are available on our Web site, http://picasso.oce.orst.edu/ORSOO

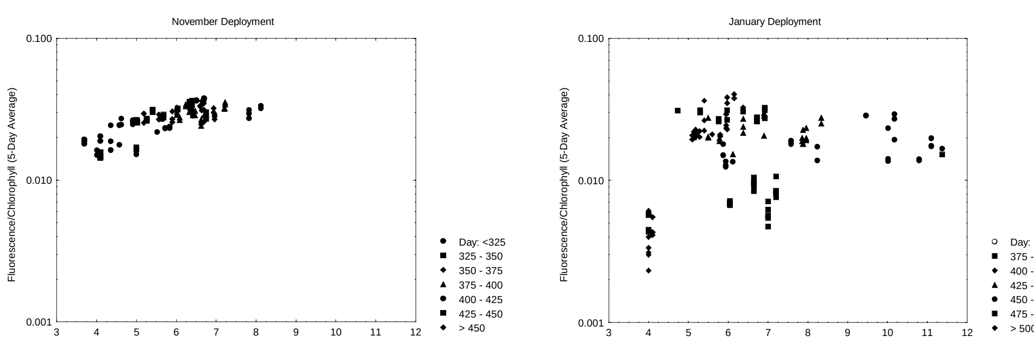
The Antarctic Polar Front is a complex set of meandering jets, which appear to support enhanced primary productivity. The U.S. Joint Global Ocean Flux Study (JGOFS) conducted a series of survey and process studies in part to study the processes regulating primary productivity in this high nutrient, low chlorophyll (HNLC) region. We deployed a set of surface velocity drifters, some of which were equipped with bio-optical sensors, to study the temporal and spatial scales of biological and physical processes in the Antarctic Polar Frontal Zone (APFZ). There were two primary sets of deployments: November 1997 before the spring bloom and January 1998 after the spring bloom. Some of the drifters in the November deployment were deployed in coherent clusters, thus allowing us to calculate vertical velocities. The November deployment also revealed a strong spring bloom (Fig. 1), which although it decreased over time, it persisted at somewhat higher values throughout the drifter deployment than the bloom observed at a fixed moored optical array.



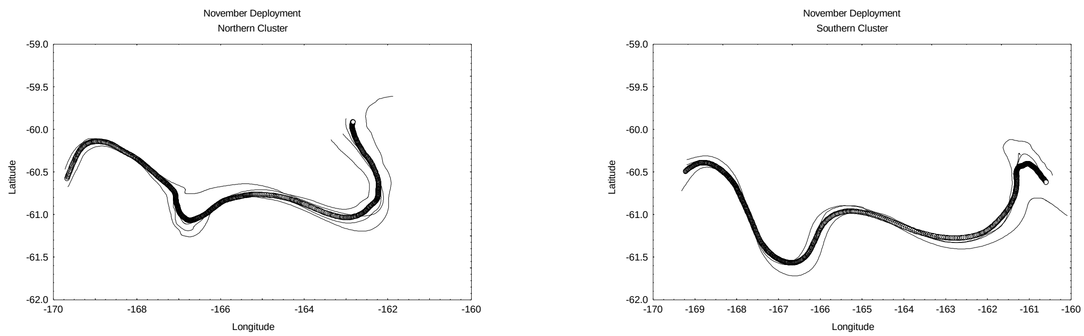
The increase late in the time series is a result of the two drifters that encountered the fracture zone. Higher chlorophyll values are often associated with topographic features in the Southern Ocean (e.g., Sullivan et al., 1993). An analysis of Sea-viewing Wide Field of View Sensor (SeaWiFS) ocean color imagery (Moore and Abbott, in press) shows enhanced chlorophyll concentrations wherever the ACC crosses over topographic features. This enhancement may be the result of enhanced eddy-induced mixing that results in higher nutrient concentrations. In the Udintsev Fracture Zone, several Southern Ocean fronts converge as the ACC passes over the Pacific/Antarctic Ridge (Moore et al., 1999).



The mean patterns of fluorescence/chlorophyll (F/C) and apparent quantum yield of fluorescence are shown in Figure 2. F/C (Fig. 2, left) began at a low value, and then increased, shortly after chlorophyll concentrations reached their maximum values in early December. F/C is generally high in January and February, decreasing in March and especially April. As noted above, the April time period was sampled by drifters that were in the vicinity of the Udintsev Fracture Zone. Apparent quantum yield of fluorescence (Fig. 2, right) showed a similar pattern, especially in December and late March/April. During the January/February time period, there was no clear relationship between F/C and apparent quantum yield. This difference is more apparent in Figure 3 which shows the relationship between F/C and apparent quantum yield from the November (Fig. 3, left) and January (Fig. 3, right) deployments. In general, we expect that F/C and apparent quantum yield should be positively correlated. Moreover, comparisons of F/C and C^{14} uptake showed an inverse relationship (Abbott et al., in press) at the bio-optical moorings. Therefore, the drifters likely observed high primary productivity in late November/early December, followed by a period of increasing photosynthetic stress. Productivity apparently increased again in late summer/early fall, especially as the drifters moved into the vicinity of the fracture zone.

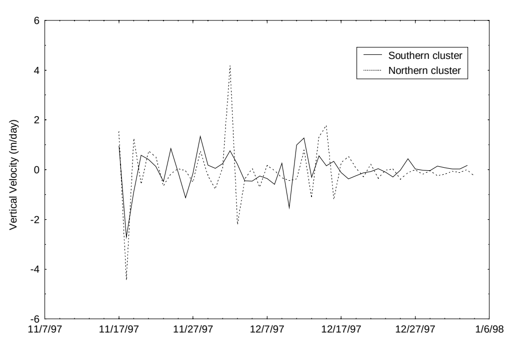


This simple pattern does not explain the shift in the relationship between F/C and apparent quantum yield of fluorescence during much of the summer. We compared the time series of daily PAR with chlorophyll, F/C, and the apparent quantum yield of fluorescence. The drifters in the November deployment all had a significant positive correlation between chlorophyll and PAR. In contrast, the drifters from the January deployment all had a negative correlation between chlorophyll and PAR, except for drifter 11 which was the southernmost drifter. For F/C, none of the November drifters were correlated with daily PAR except for the two northern drifters. However, nearly all of the January drifters showed a positive correlation between F/C and daily PAR. These results suggest that during November, the phytoplankton were primarily light-limited as chlorophyll concentrations increased with increased light availability. Moreover, the lack of correlation between F/C and PAR suggests that these populations were generally light-limited. That is, as PAR increased, the amount of fluorescence did not increase, implying that phytoplankton were able to utilize this increased PAR in photosynthesis. In contrast, the positive correlation between daily PAR and F/C and the negative correlation between chlorophyll and daily PAR in the January drifter records suggests that the phytoplankton were generally nutrient-limited. As PAR increased, phytoplankton fluorescence increased, implying that the phytoplankton were unable to use this increased PAR in photosynthesis.



During AESOPS, nine drifters grouped into a cluster for almost 15 days with eight of the drifters separating into two clusters for almost 50 days (Fig. 4). The large-scale coherent cluster consisted of 6 WOCE SVP and 3 bio-optical drifters. The north sub-cluster (Fig. 4, left) had one bio-optical drifter while the southern cluster (Fig. 4, right) had two bio-optical drifters. The trajectories of the drifters followed the Polar Front through two large meanders with upwelling upstream of the peaks and downwelling downstream of the troughs. The vertical velocities reached peak values of 4 m/day with typical values less than 1 m/day. Combining all nine drifters into a large cluster, the estimated vertical velocities are much smaller. However, the big cluster appeared to violate the assumption that the scale of the cluster is smaller than the scale of the flow field. Monitoring the ratio of the cluster length to square root of the cluster area, we find that both sub-clusters became elongated for the ten day period between day 340 (December 16, 1997) and day 350, when the estimates of the vertical velocity are unreliable.

We compared the vertical velocities for the sub-clusters with the biological variables: chlorophyll, F/C, apparent quantum yield of fluorescence, and chlorophyll accumulation rate. Although none of the overall correlations were significant for the overall series, there were time periods where there were consistent linear relationships between vertical velocity and F/C. For the three bio-optical drifters, there was a negative relationship between F/C and vertical velocity (Fig. 5) during the first 20 days of the deployment. After this period, there were no consistent relationships between any of the variables and vertical velocity. Although this may indicate that indeed there was no relationship, the relationship may not have been a simple linear function without any time lag in the response between the bio-optical properties and vertical velocity. Two processes could explain the initial relationship between F/C and vertical velocity. First, increased upward movement may have brought more nutrients (possibly iron, as nitrate was never limiting in this region) which would reduce F/C.

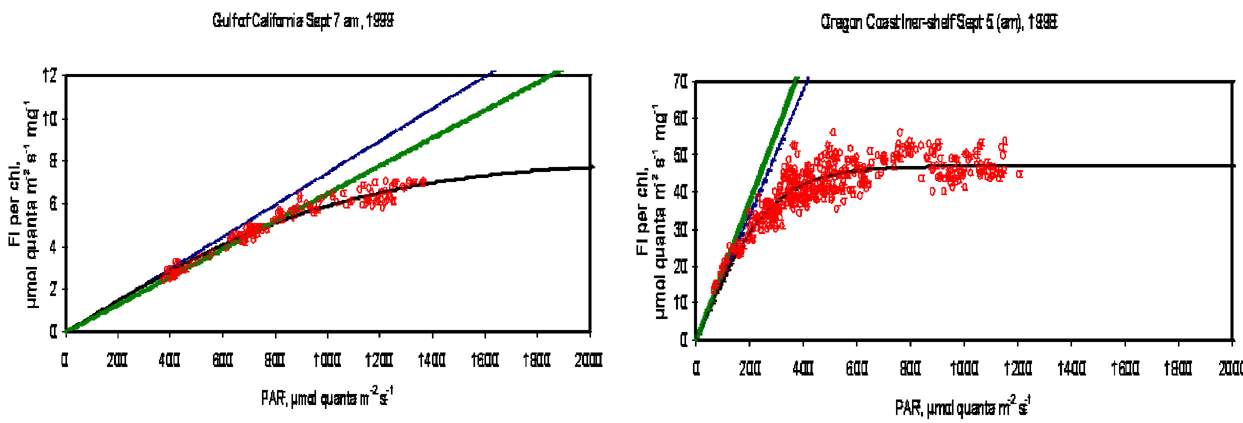


Second, upward motion would increase the amount of light available to the phytoplankton; if light limitation was important, this process would also reduce F/C. During this time period, chlorophyll increased substantially, whereas F/C remained relatively constant. Analysis of the entire suite of bio-optical drifters showed little correlation between daily PAR and F/C, suggesting that light limitation was important during the early part of the deployment as the chlorophyll bloom developed. Thus it appears that the impact of upward motions in the meandering jet is through their modification of light availability, rather than nutrients, at least in the initial phase of the spring bloom. The absence of a response of F/C to variations in vertical response later in the deployment could be the result of relatively low vertical velocities coupled with a deep nutricline (iron concentrations were generally low to depths of 200m in the APFZ; Measures and Vink, submitted). Vertical velocities were nearly zero in both sub-clusters beginning in late December (Fig. 5).

Analysis of the PAR and chlorophyll fluorescence records suggests that light availability dominated the early stages of the spring bloom, which was also proposed for the bio-optical moorings (Abbott et al., in press). Early in the development of the bloom, F/C was correlated with vertical velocity. Although increased nutrient availability associated with upwelling might also lower F/C, the overall correlation between PAR and chlorophyll suggests that the impact of upwelling was through its impact on light availability. The decline of the bloom could be the result of increasing nutrient stress. Vertical velocities calculated from coherent drifter clusters dropped to very small values in late December after the peak of the spring bloom.

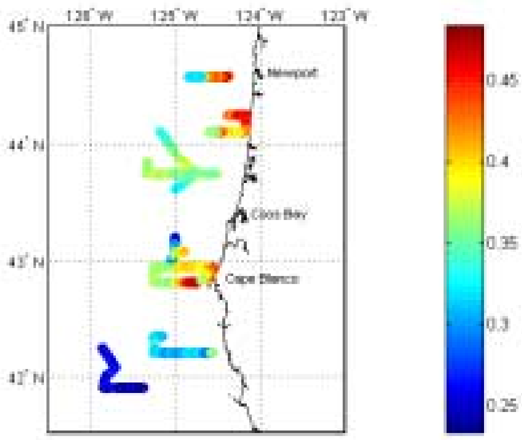
Validation Cruise

Before passive fluorescence can be used in remote sensing algorithms, we must understand the processes that alter the quantum yield of fluorescence (ϕ_F) in time and space. To this end, we used a Tethered Spectroradiometer Buoy II (TSRB II) from Satlantic, Inc. to make passive measurements of



phytoplankton fluorescence and chlorophyll as part of the MOCE-5 MODIS validation cruise off Baja California from September 1999 as well as over the inner shelf off Oregon in September 1998. Figure 6 shows passive fluorescence per unit chlorophyll as a function of photosynthetically available radiation (PAR). The time kinetics revealed by these measurements show how ϕ_F changes during the day and between regions of the ocean. We fit a hyperbolic tangent function to these data, analogous to a photosynthesis/irradiance curve. The slope of this function is proportional to the quantum yield of fluorescence, ϕ_F. The left panel (Gulf of California) has a lower initial slope (green line) than the measurements from the Oregon coast (right panel). Since ϕ_F is inversely proportional to the quantum yield of photosynthesis, the upwelling region of the Gulf of California is significantly more productive than the shelf region off Oregon, which was outside the upwelling zone. Note also that the maximum fluorescence/chlorophyll is significantly different as well. These data suggest that passive fluorescence/chlorophyll may provide valuable information regarding the photosynthetic state of the phytoplankton, which could then be used to improve satellite-based estimates of primary productivity. However, we must first develop a quantitative understanding of how ϕ_F varies as a function of environmental processes.

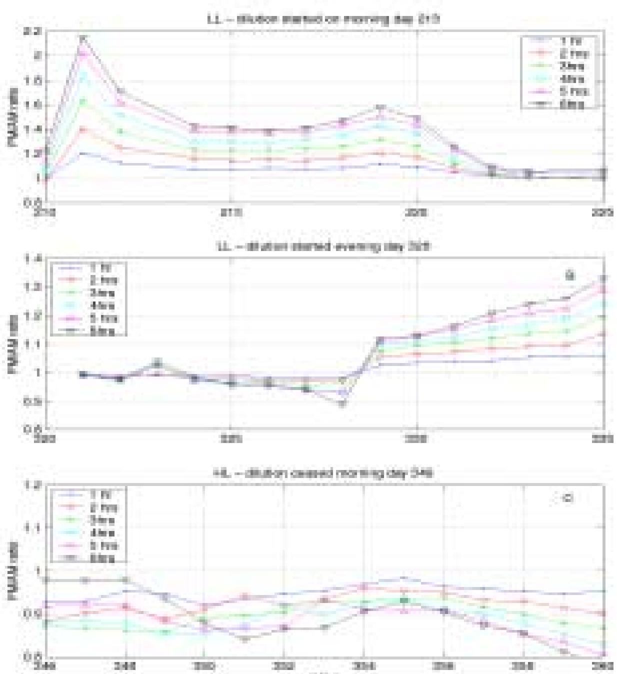
To study the processes affecting passive fluorescence in more detail, we have acquired data from a Fast Repetition Rate Fluorometer (FRRF). Concurrent measurements were made of physical, chemical, and biological properties at the same time and space scales. Figure 7 shows a map of variable fluorescence



from the FRRF (F_v/F_m) for the Oregon coast, collected at night in May 2000. High F_v/F_m corresponds to rapidly-growing phytoplankton, which can be seen nearshore in the upwelling regions. The ability to observe regions with highly variable fluorescence properties within a single MODIS image is a significant advantage, especially when these results can be correlated with changes in the physical, chemical, and biological properties of the water. We are continuing to make field measurements in conjunction with MODIS-derived fluorescence fields to determine these environmental controls on ϕ_F. Another cruise is just now being completed.

Chemostat Experiments

Both of these field data sets reveal large-scale changes in fluorescence characteristics that appear to be related to the photosynthetic state of the phytoplankton. However, many questions remain. Does the relationship between passive fluorescence and productivity vary in a predictable manner? Is the relationship consistent across the world ocean and across seasons? Can satellite remote sensing of passive fluorescence play a role in these models?

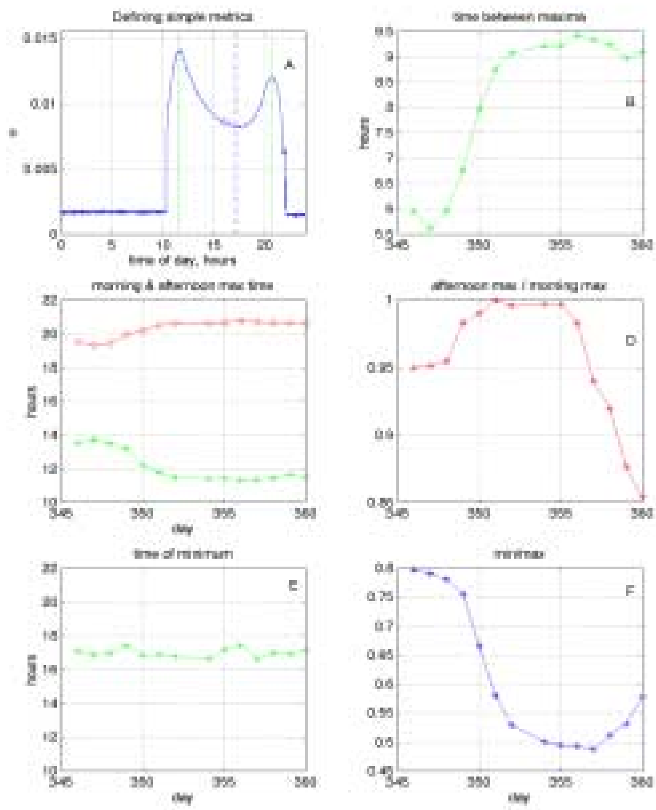


Our chemostat studies (Laney et al., submitted)are designed to bridge the gap between the large-scale field studies on environmental processes and passive fluorescence and the physiological processes that alter ϕ_F. We use the Gordon (1979) definition of the coefficient of fluorescence to express the natural fluorescence radiance normalized to the PAR irradiance and use a shorthand of his notation (Φ). Although the amplitude of Φ is primarily a function of chlorophyll biomass, in our culture experiments we have observed gradual changes in the diurnal character of Φ during periods of increasing or decreasing nitrate availability. We hypothesize that changes in Φ reflect physiological responses to the availability of nitrate and have devised simple metrics with which these responses can be examined. Φ varies mostly between morning and afternoon, and we first examined the ratio of afternoon to forenoon Φ during periods of variable cell-specific nitrate availability.

We calculated this PM/AM Φ ratio for six intervals centered on solar noon ranging from 0.5 to 3 hours before and after, corresponding to an interval between Φ samples of 1 to 6 hours (Figure 8). These ratios were calculated for Φ data collected during three experiments with the marine diatom *Thalassiosira weissflogii* (Bacillariophyceae) under conditions of different irradiance intensity and nitrate availability.

In the first panel, cells were introduced into a constantly diluted chemostat with low dilution rate under low light. As cell abundance increased and available nitrate per cell decreased, PM/AM was consistently above one (Figure 8a) and decreased to unity as chlorophyll biomass stabilizes and phytoplankton reached steady state growth. In the second panel, cells were introduced into a chemostat with zero dilution rate under low light conditions, which was increased to high dilution on day 328. PM/AM during this shift from gradual starvation to nitrate abundance is initially unity, and substantially increases with available nitrate (Figure 8b). In the third panel (Figure 8c), cells in a chemostat with high light experience a shut off in dilution on day 349. PM/AM throughout this period is consistently below unity but appears to contain no useful long term characteristics to recover the influence of nitrate availability in natural fluorescence.

In general, maximum spacing between forenoon and afternoon Φ samples increases the dynamic range of PM/AM and improved the utility of this parameter. However, that PM/AM does not capture any kinetics of nitrate starvation under HL is problematic for remote sensing purposes, where much data will be collected from latitudes where daily irradiance profiles are best characterized as "HL". The insensitivity of Φ under HL conditions may be because such a simple ratio may not be sophisticated enough to capture these kinetics. Six other quantitative metrics related to Φ were examined to take advantage of the complexity of diurnal Φ, and all are related to the amplitude and timing of the midday depression (Figure 9).

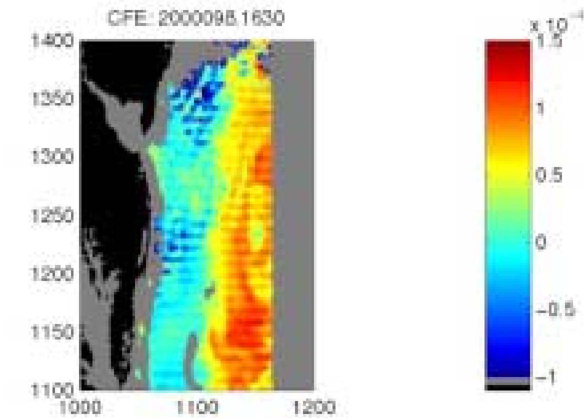


The first panel in Figure 9 shows how the various additional HL metrics are derived. All parameters are generated from either the magnitude or timing of the morning and afternoon Φ maxima (dashed lines) and the diurnal minima (dot-dashed line). Each of the remaining five panels shows the use of each metric on the natural fluorescence data shown in Figure 8c. The timing of the morning and afternoon maxima exhibit identifiable long term kinetics (Figure 9c), but the timing of the midday minimum is comparatively insensitive (Figure 9e). The time elapsed between maxima shows four distinct phases (Figure 9b) as do the ratio of PM to AM maxima (Figure 9d) and the ratio of diurnal minimum to maximum (Figure 9f). The identification of different kinetics in each of these simple metrics indicates that different physiological adaptations are being reflected in each.

Using such time series of Φ-derived metrics, ecological models can be applied to determine time constants, half-saturation times, changes in carrying capacity and so forth for each response. For example, our laboratory experiments to date indicate that changes in the amplitude of Φ normalized to chlorophyll biomass are very strongly correlated to changes in the amount of chlorophyll per cell under certain environmental and physiological conditions. Inverting this relationship, knowledge of the variability in chlorophyll biomass using independent techniques (e.g. absorption based models which are used in ocean color sensors) allows for the identification of variability in cell abundance based on measurement of Φ. Consequently, data such as that in Figure 9 may be interpreted as reflecting population based changes, and logistic models of resource limitation may be applied to determine how a phytoplankton population responds to shifts in nitrate availability. As more laboratory data are analyzed, further applications of such metrics may become apparent.

Early MODIS Imagery

Figure 10 shows an image of chlorophyll fluorescence efficiency (CFE) calculated from MODIS data. The image covers part of the western North Atlantic near the Chesapeake and Delaware Bays. CFE is based on fluorescence line height (FLH) which is an estimate the fluorescence-induced deviation from the baseline spectrum of water-leaving radiance (Gower et al., 1981) and the number of photons absorbed by phytoplankton (Carder, 1998). Aside from the striping visible in the MODIS imagery which is an artifact of the sensor and its associated Level 0/1 processing, we note that CFE is low in a narrow strip along the coast and higher in the waters farther offshore on the shelf. The corresponding chlorophyll image shows high chlorophyll in the narrow, low CFE strip, suggesting that this "high" chlorophyll water may contain non-fluorescent materials such as CDOM or that it is more productive.



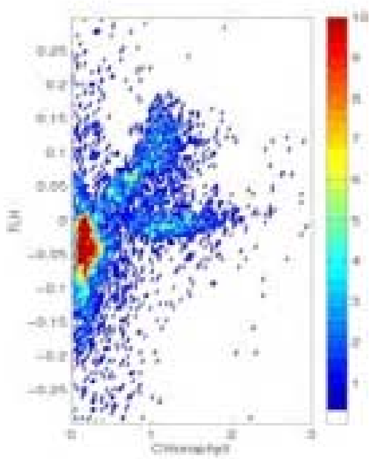


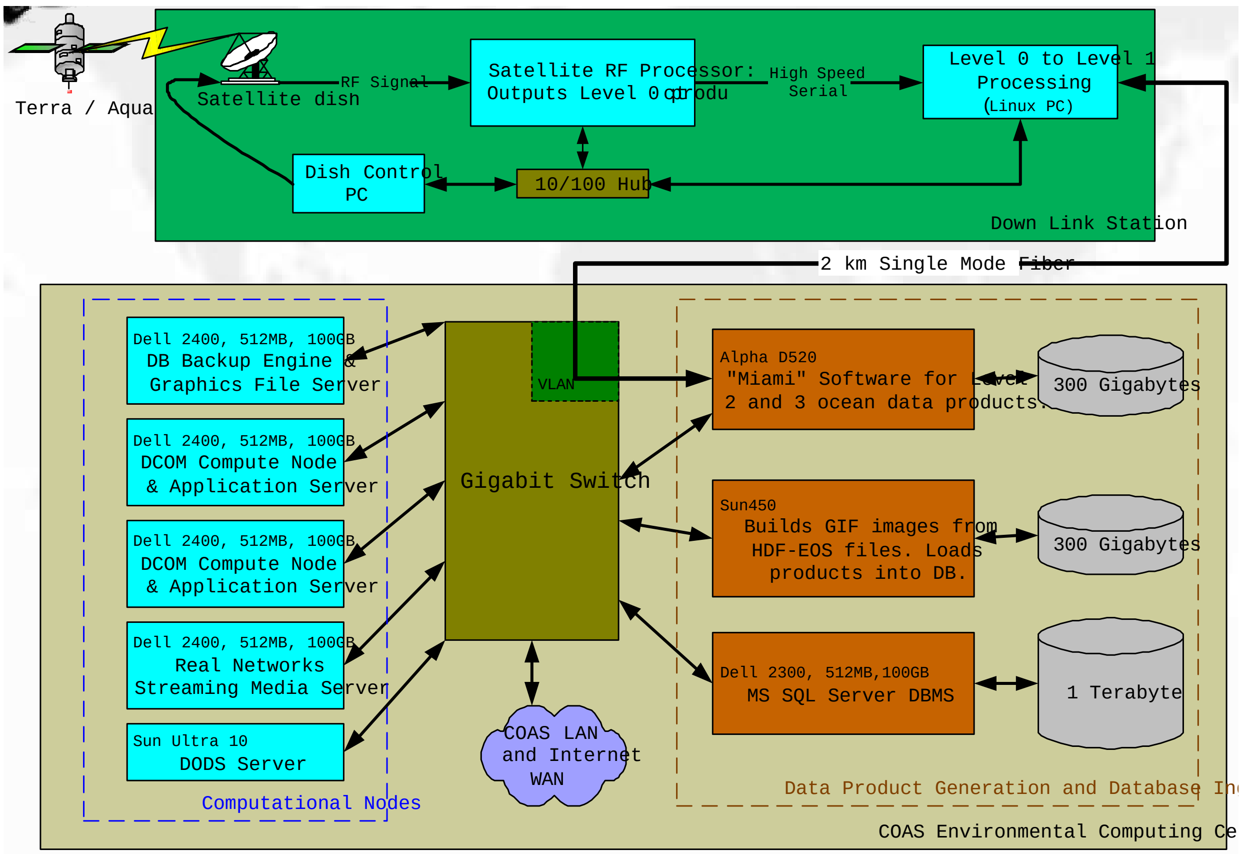
Figure 11 shows FLH vs. chlorophyll for this image area, where the colors represent the number of FLH/chlorophyll pairs. Chlorophyll was calculated using the usual absorption-based ocean color models, such as those used for CZCS and SeaWiFS. The effective noise level of MODIS can be seen in this image (about 0.25 mg/m3) which is consistent with that estimated by Letelier and Abbott (1996). Of greater interest are the two nearly linear clusters that extend from the noise. Each has a distinctly different slope, similar to the patterns observed with the TSRB II in Figure 6. We expect that the lower FLH/chlorophyll slope is indicative of healthier phytoplankton, much as was observed in the Southern Ocean (Abbott et al., in press) and in the Gulf of California (Fig. 6, left panel). The cluster with the lower slope corresponds to the nearshore low CFE region (Fig. 10) whereas the cluster with the steeper slope corresponds to the offshore high CFE region. The large difference in slopes (nearly a factor of ten) implies that simple fluorescence-based models of chlorophyll will be challenging.

Much remains to be done before satellite-sensed passive fluorescence can be used to estimate the photosynthetic state of the phytoplankton. It appears unlikely that a single image of FLH will provide sufficient information. Rather morning and afternoon passes or time series of FLH will probably be required. However, the field, laboratory, and satellite measurements presented here suggest that there are signals in the variability of the fluorescence/chlorophyll relationship that may be exploited to improve models of primary

productivity.

Direct Broadcast

Our EOS Direct Broadcast facility is nearly complete. We presented our plans at the EOS DB Users Meeting in Dundee, Scotland in late June. Oregon State University has provided substantial funds to modify an existing pad and renovate the control facility. For example, a concrete block 2 m high had to be poured so that the dish could see the western horizon over the top of an existing building (Fig. 12). We are just now completing the fiber optic cable connections, linking the DB facility with our MODIS data processing and archiving facility via gigabit Ethernet. Figure 13 shows the schematic of the data flows. We expect the facility to be fully operational in late September.



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. A report given at the ECS prototyping workshop may be found at http://proto.gsfc.nasa.gov/esdis/tech_act/workshop/ETTW4/AgendaDocs/Gopalan.pdf.

On the front-end, we are in the process of providing a Dynamic HTML (DHTML) implementation of an interface that allows users to locate data within specific data sets. The interface will initialize itself by looking at information provided about data sets that we wish to expose. This information is provided as XML (eXtensible Markup Language), so that the client can search for specific XML tags/attributes and populate the DHTML UI with their contents.

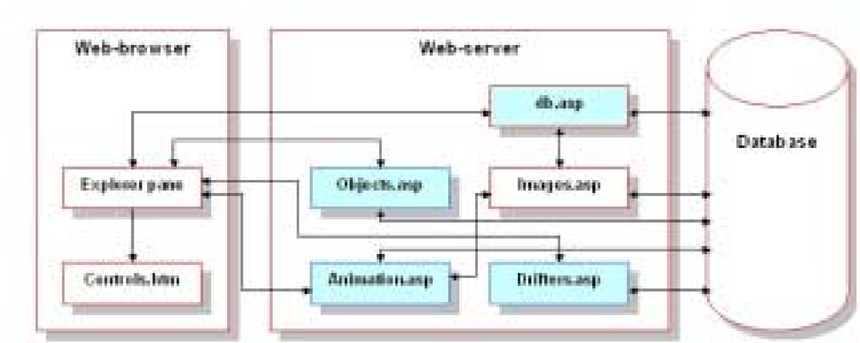
A Microsoft SQL Server relational database serves as the backend. Database access will be provided primarily with Active Server Pages (ASP - the means of generating HTML on the fly) and Active Data Objects (ADO). In situations where a more powerful language is required for tasks such as complex image manipulations, a custom COM component written in Visual C++ will be used for data access and processing.

We have transitioned from the ISAPI extension backend architecture (Fig. 14) for accessing data in the project where we will use custom COM components on the backend, an ISAPI extension will be used as the entry point into the system. The ideal solution is to access COM components directly from across the Internet using DCOM (which is currently not possible). We will evaluate the Simple Object Access Protocol (SOAP) for accessing software components directly across the Internet.

ActiveX Controls are a powerful means of implementing advanced visualization capabilities not generally available in scripting languages. They can be developed independently and reused in any application that is an ActiveX container (e.g. Internet Explorer).

XML can be conveniently generated on the server-side using Active Server Pages (ASP). The ASP model also has built-in database functionality that can be accessed from server-side scripts and the Active Data Object (ADO) model. ASP and ADO greatly simplify the task of building data access applications.

XML can also be used to integrate content from one or more web sites. This will become more feasible when companies and organizations agree on standard means by which they expose their content. The content may or may not come from relational databases. Data sub-setting is also possible through XSL patterns that can be applied to the XML sub-tree. This is similar to making SQL queries to retrieve data from a database. This feature is not available with HTML or DHTML unless explicitly implemented by the application.



XML schemas eliminate any guesswork on the client as to what the tags and the data actually represent by attaching type information to the tags. This opens up several new possibilities for smart clients to support meaningful functionality using this type information. XSL, when generated by the data provider, spares the client from interpreting the data and rendering it. As a result, XML and XSL together make the data completely self-describing.

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/ORSOO .

We have also developed a set of Java components to scan and ingest SeaWiFS and MODIS imagery into our data base. We are now incorporating the MODIS validation in situ data in our data base as part of an effort to consolidate all of the MODIS Oceans team in situ measurements. This system will be coupled with our EOS DB system as well.

<u>Anticipated Future Actions</u>

- Continue testing and evaluation of MODIS fluorescence algorithms with MODIS data
- Participate in MODIS validation cruise in spring 2001?
- Bio-optical cruises off Oregon coast in August 2000
- Retrieve and redeploy bio-optical mooring in Hawaii and continue analysis of bio-optical data
- Continue work on chemostat experiments on the relationship of fluorescence quantum yield to environmental factors. Extend research to more phytoplankton species.
- Continue to develop and expand browser-based information system for in situ bio-optical data.

Problems and Solutions

The most significant concern now is the quality and availability of Level 1B and Level 2 data from Terra. We have had difficulty in acquiring data during validation cruises because of spacecraft operations. Also, the data continue to be noisy, limiting their usefulness. We are also concerned about the effective network bandwidth between GSFC and OSU. Our rating has been consistently labeled as “bad” for over one year.