

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,
- Complete analysis of bio-optical from JGOFS cruises in the Southern Ocean
- Participate in MODIS validation cruise off California and Mexico
- Revise plan for MODIS Direct Broadcast facility
- Complete 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 1999. After retrieving the data, the sensor package was serviced and redeployed. We now have over 36 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 accepted for publication in *Journal of Geophysical Research*, and a revision has been submitted.

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/ORSOO>. The data continue to be provided to the SIMBIOS project.

Analysis of Data from the Southern Ocean

We will present our results from the U.S. JGOFS Southern Ocean in two invited talks at the AGU/ASLO Ocean Sciences meeting. Invited talks will also be presented at the International Southern Ocean JGOFS meeting in Brest, France next July and at the German JGOFS Ocean Biogeochemistry meeting next September.

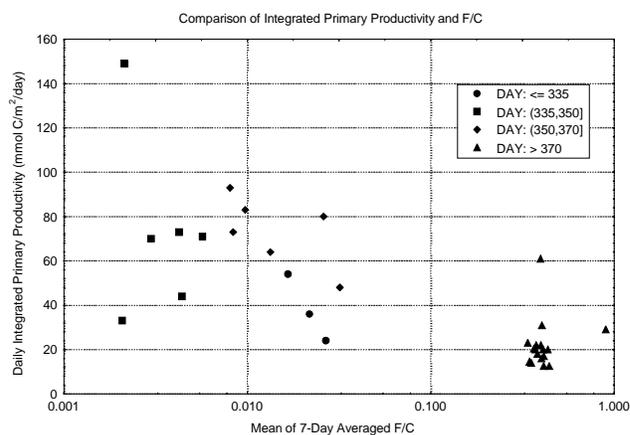
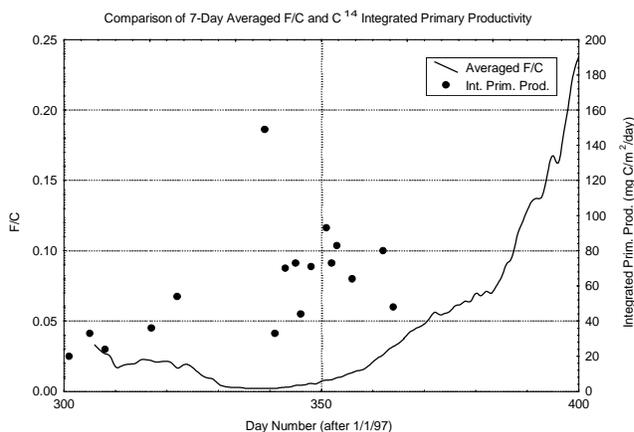
All of the mooring, drifter, and TSRB data are available on our Web site, <http://picasso.oce.orst.edu/ORSOO>

A manuscript has been accepted in *Deep-Sea Research*, pending revision. As we noted in previous reports, the bio-optical moorings captured the spring bloom in the Southern Ocean in terms of changes in the optical properties. To determine whether the temporal variations in the spectral irradiance data could be explained solely in terms of vertical mooring fluctuations, the measured values were compared with model results from HYDROLIGHT (C. Mobley, version 4.0), a radiative transfer model. For the model calculations, the spectral irradiance near solar noon at the sea surface was calculated assuming clear sky conditions. This irradiance was then transmitted across the air-sea interface into the water column, and

then attenuated to depth assuming a vertically homogeneous chlorophyll distribution. The effects of three different chlorophyll concentrations were examined: 0.2, 1.0 and 1.5 mg m⁻³. These values were chosen based on the range of chlorophyll concentrations measured by SeaWiFS during the period of the mooring deployments. The spectral downwelling irradiance was calculated at depths between the surface and 100 m, assuming an infinitely deep water column. Fluorescence by phytoplankton was included in these calculations, using a chlorophyll fluorescence quantum efficiency of 0.1. This relatively high value was required to prevent the calculated downwelling irradiance at 683 nm (the wavelength of maximum chlorophyll fluorescence) from being negative at depth. Spectral variations in the downwelling irradiance caused by seasonal variations and changes in cloud coverage were neglected. These effects are expected to be small relative to the effects of variations in chlorophyll concentration and sensor depth on the spectral shape of the measured downwelling irradiance.

The ratios of irradiance at 555 nm to 443 nm were calculated for both the modeled and measured irradiances. The measured ratios show a larger range in value (0.06 – 4.5) than the ratios modeled between 0 and 100 m depth (1.0 – 1.7), assuming a chlorophyll concentration of 1mg m⁻³. This indicates that the observed temporal variations in this irradiance ratio cannot be explained solely in terms of vertical mooring fluctuations. Modeled ratios assuming chlorophyll concentrations of 0.2 and 2 mg m⁻³ yield similar results. On the other hand, assuming a constant depth of 100 m, the temporal variation in measured irradiance ratios can be explained by changing the chlorophyll concentration between 0.2 and 1.5 mg m⁻³. This latter scenario is likely to be the dominant effect producing the observed peak in measured irradiance ratios near day 340.

A similar comparison was made between the measured and modeled irradiance ratios of 683 nm to 555 nm. In this case, however, neither depth fluctuations nor changes in chlorophyll concentration can



explain the temporal variation in the measured irradiance ratio. Although a relatively high value for the chlorophyll fluorescence quantum efficiency was used (0.1), it does not appear to be sufficient to reproduce the observations. The temporal variation in this ratio may instead be caused by temporal changes in the chlorophyll fluorescence quantum efficiency.

Sun-stimulated fluorescence has been used to estimate primary productivity (Kiefer et al., 1989; Chamberlin and Marra, 1992; Stegmann et al., 1992). These models rely on a constant quantum yield of fluorescence and that the photosynthetic system is operating close to light saturation. Thus changes in irradiance will lead to changes in photosynthetic potential. However, this is not always the case, as demonstrated in Letelier et al. (1996). The quantum yield of fluorescence is not always constant, especially as nutrient availability changes. In this case, sun-stimulated fluorescence/chlorophyll (F/C) is not only a function of PAR, but rather a function of the quantum yield of fluorescence as well. Changes in F/C, therefore, should be indicative of changes in nutrient stress.

We calculated chlorophyll accumulation rates at each mooring as change in chlorophyll concentration between successive days normalized by the concentration on the first day of the pair. We then calculated a 7-day moving average

of the accumulation rates. The average of the individual mooring accumulation rates in comparison with a 7-day moving average of F/C, averaged over all of the moorings. We have overlaid in Fig. 1 the integrated primary productivity measurements (using ^{14}C incubations) made during the AESOPS surveys and process cruises (data were obtained from the US JGOFS web site (<http://usjgofs/who.edu>)). There is a weak inverse relationship between accumulation rate and F/C, although there is a fair amount of scatter as accumulation rate is a function of both growth and loss processes whereas F/C is only an indicator of growth (Fig. 2). Similarly, there is an inverse relationship between integrated primary productivity and F/C with a similar level of scatter. In part, this is because we have included all of the primary productivity data collected during the APFZ cruises, so many of the stations are not located near the moored array.

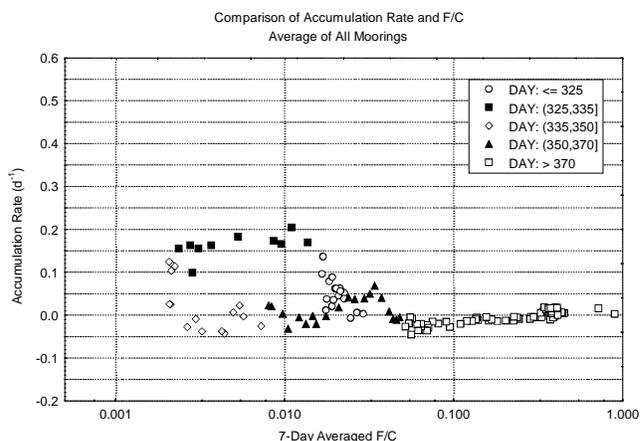


Figure 3 shows the 7-day averaged F/C (averaged over all of the moorings) versus the 7-day averaged accumulation rate (also averaged over all of the moorings). During the period of positive accumulation rates (roughly from the beginning of the mooring record until day 340), F/C decreases consistently, although the accumulation rate reaches a maximum of about 0.2/day around day 327. Accumulation rates then become slightly negative for a long time period (from about day 342 to day 360) while F/C increases. Accumulation rates are slightly positive for a short period between days 360 and 370. From this point, the accumulation rates were nearly zero, and F/C

continued to increase steadily.

These results suggest that the moorings captured the spring bloom at the Polar Front, despite the variations in mooring depth. The development of the bloom was similar at all locations in terms of timing, although there were variations in the intensity of the bloom and its duration. Following initial stratification of a deep mixed layer, the phytoplankton took approximately 1 to 2 days to photoadapt to the new light environment. This interpretation is based on the initial increase in F/C which implies that phytoplankton were able to absorb light but not use it efficiently in the photosynthetic process. This effect was most pronounced in the shallow moorings where the change in the light environment would be the strongest. As the light absorption/utilization processes came into balance, the total chlorophyll content increased rapidly. During the primary bloom period, F/C was low and continued to decrease, suggesting that phytoplankton were not limited by light or any nutrient involved in the photosynthetic process (Letelier et al., 1997). However, the peak in chlorophyll concentration occurred well before F/C indicated any stress. This suggests that some process not involved in photosynthesis was limiting the further accumulation of phytoplankton chlorophyll.

There are two processes that may be responsible for the cessation of chlorophyll accumulation around day 330. Availability of dissolved silicon could limit the growth of phytoplankton if diatoms dominate the community. Since silicate does not play a role in photosynthesis, there would not be a signal in the F/C record. Observations of Si uptake and dissolved silicon concentrations (Franck et al., submitted; Brzezinski et al., submitted) showed that dissolved silicon became nearly depleted at the Polar Front by early January and that phytoplankton growth rates responded strongly to Si enrichment. The horizontal gradient dissolved silicon moved southwards 5° between the first survey (November) and the second survey in January (Franck et al., submitted). Both studies suggest that the phytoplankton in the APFZ are limited by a complex interaction between iron and Si availability. Franck et al. (submitted) suggest that within the APFZ, uptake of silicic acid by phytoplankton is limited by iron availability in spring (November/December) and shifts to Si availability in summer (January). These studies, though, focused on Si uptake and production of biogenic silica, not on phytoplankton growth rates. Moreover, the accumulation rates began to decline around Day 335 (early December) and were negative by mid-December before there were suggestions of Si limitation. The cessation of phytoplankton accumulation

before there was evidence of nutrient stress (which should be observed as an increase in F/C) suggest that increasing loss rates were dominant, rather than decreases in growth rate.

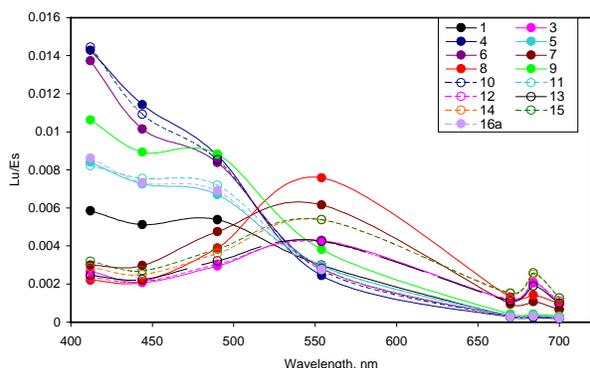
The other process that could limit and reduce accumulation rates (but without inducing stress in photosynthetic processes) is zooplankton grazing. Landry et al. (submitted) measured grazing rates downstream of the moorings and estimated grazing rates of nearly 0.2 d^{-1} . They showed that this loss was nearly equal to phytoplankton growth. It is interesting to note that the accumulation rate peaked at about 0.2 day^{-1} on day 327, and then slowly decreased for the next 7 days. Its rapid decline early to mid-December is consistent with increasing grazer pressure which was sufficient to crop the entire daily production of phytoplankton. By late December/early January, phytoplankton were showing signs of increasing stress. Although we suspect that growth rates were lower by the time of the second survey cruise in January 1998, no primary productivity measurements were made on that cruise. For the rest of the summer, F/C increased, implying increasing nutrient stress. Since accumulation rates were nearly zero, loss rates (presumably grazing) were in balance with growth rates.

There were consistent patterns in the physical data as well. The time history of sigma-t for the four moorings that had both MicroCAT and radiometers (moorings 2, 4, 8, and 12). The T/S plots showed that this increase was driven by a rapid increase in salinity. In all four moorings, the maximum chlorophyll values were associated with a sigma-t value of around 27.15, similar to that observed in the SeaSoar surveys (Barth et al., submitted). This suggests that although the proximate cause of the phytoplankton bloom may have been a combination of an increase in light (increased stratification), an absence of iron and dissolved silicon limitation, and low grazing, the ultimate cause may have been physical processes associated with the Polar Front.

Validation Cruise

The validation cruise was conducted in October 1999. We sent two people on the cruise to collect Fast Repetition Rate fluorometry (FRRf) data, sea surface radiometric upwelling spectra, and assist with optical data collection. We will also help with productivity and pigment analyses. Even though the continuing delay in the launch of Terra did not permit the use of this cruise for MODIS initialization, we were able to collect samples to study in situ the relation between Fluorescence Line Height (FLH), Chlorophyll Fluorescence Efficiency (CFE), pigment biomass and algal photosynthetic parameters.

Measurements by the Oregon State component involved Inherent Optical Properties measurements (IOP, Andrew Barnard and Sarah Searson), and phytoplankton passive fluorescence and physiology (Claudia Mengelt and Ricardo Letelier). The IOP/CTD/FRRf package was deployed every morning prior to the main CTD/rosette deployment. This package was also equipped with a Fast Repetition Rate fluorometer

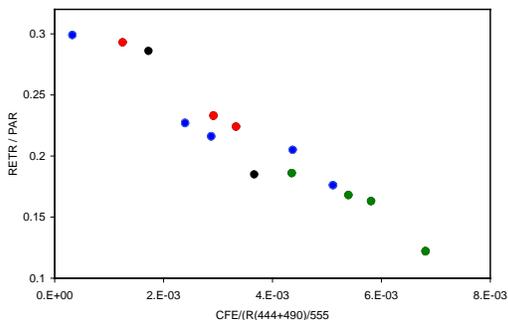


that allows the assessment of phytoplankton physiological status in situ. Ancillary deployments for ac-9 intercalibrations and phytoplankton physiology studies were performed when possible during the afternoon or at night.

Digital pictures of the sea surface and sky were taken during each IOP deployment performed during daylight hours. Microtop measurements are also taken during these deployments and during SeaWiFS overpasses, as long as the sky was not cloudy. Tethered Spectro-Radiometer Buoy (TSRB-II) deployments were carried out every day, with the exception of October 2. They started before the IOP/CTD/FRRf morning cast and lasted until 11:00 AM (local time) or for at least two

hours. Finally, water samples from every CTD casts were filtered for particulate absorption measurements and for microscopy. All these samples will be analyzed at our shore based laboratories in Corvallis.

During the present cruise we encountered very distinct water masses with surface chlorophyll a concentration values ranging from 0.128 to 12.5 mg m⁻³. This large range is reflected in the surface upwelling irradiance characteristics derived from the Tethered Spectral Radiometer Buoy (TSRB, Fig. 4).



An initial evaluation of the relation between CFE, derived from TSRB measurements, and photosynthetic rates using relative electron transport rates (RETR), derived from the Pulse Amplitude Modulated (PAM) fluorometry, suggests that there is a negative relation between the quantum yield of fluorescence and photosynthesis. However, this relation appears to be also dependent on the surface water reflectance spectrum. When the TSRB derived CFE are weighted using the derived ratio of reflectances (R(444+490)/555) then one single relation between CFE and RETR is achieved (Fig. 5). This may be the result of the difference between PAR and PUR. These preliminary results need to be tested change using the real chlorophyll

absorption spectra (a*, K Carder, D. Clark, and M. Abbott) and ¹⁴C Productivity vs Irradiance curves (D. Clark).

Direct Broadcast

We recently learned that our proposal to build an EOS Direct Broadcast facility at OSU, in collaboration with Steve Running at the University of Montana, has been funded by NASA HQ. For the Oregon State University site, the EOS standard ocean products will need to be validated against in situ observations collected from ships. Sampling will focus on specific bio-optical features in order to test the performance of the MODIS algorithms in a wide range of oceanographic conditions. Such features include ocean eddies, jets, and fronts, which can develop on time scales of a few days. The use of near real-time MODIS imagery can be used to guide the ship towards these features, thus reducing costs and improving the validation process (typical ship costs for a large research vessel average \$20,000-25,000 per day).

For the University of Montana site, near real-time MODIS data are required for two primary applications critical to the Pacific Northwest Region: wildfire activity and smoke production. The fire activity and smoke products must be delivered to resource managers within three hours of satellite overpass, necessitating regional access to the MODIS data stream. At present, the University of Montana NTSG is uniquely positioned to process and push these products to the end users. More importantly, they have already developed a regional fire and air quality client base and maintain an active training program (EOS Natural Resources Training Center).

Key aspects of the overall DB approach are:

- A tight functional integration with our existing MODIS Land and Ocean SCF hardware, software, and QA operations facility and staff.
- A complementary role to EOSDIS, via a one-month "rolling archive" of latest low level MODIS land and ocean products for selected channels over the Pacific Northwest region and the Northeast Pacific Ocean.
- Scalable program scope, initially limited to L1/L1B product stream, later extending to higher level L2/L3/L4 product stream as resources and mission direction permit.
- Adaptation of our existing segmented system architecture, tailored to the unique performance drivers associated with near real-time access (high-availability emphasis, rapid turn-around).
- Integration of selected land product streams with the key International EOS Training Center real-time product needs and objectives.

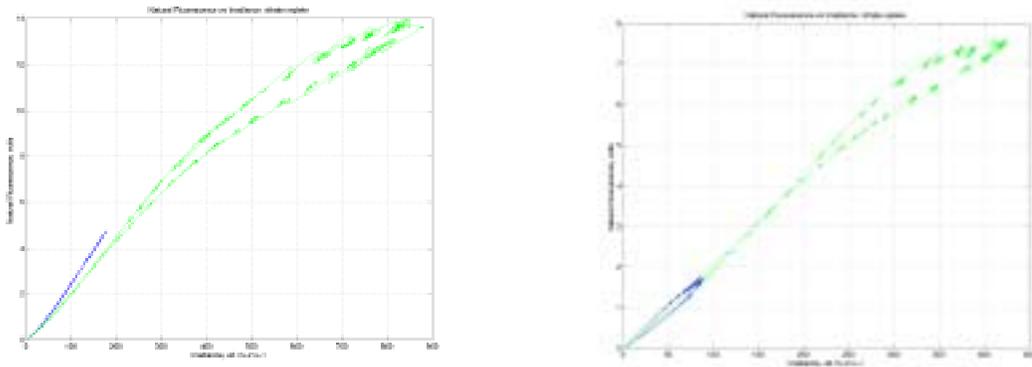
- An open distribution policy, whereby an effort will be made to make any DB acquired low-level data products available to the public, initially through a simple FTP facility, and (in a later phase as approved), via a better integrated Web/Database query driven retrieval system. Development of a more refined distribution plan for the wider DB community should occur in coordination with a number of relevant NASA outreach programs, including the International EOS Training Center at UM.

We hope to have the system installed and operational by mid-summer 2000.

Chemostat Experiments

We have completed the basic design and testing of our natural fluorescence chemostat system. Additionally, we have evaluated a number of experimental protocols in order to obtain the most sensitive measurements under various experimental conditions. We have recently completed a pair of chemostat experiments with the marine diatom *Thalassiosira weissfloggi* in which laboratory cultures with different concentrations of available nitrate were subjected to similar manipulations in irradiance intensity. We are analyzing the results from these experiments in order to characterize the influence of light and nutrient availability on the diurnal natural fluorescence signal.

Two cultures of *T. weissfloggi* were grown under limiting irradiance, one in chemostat mode with low levels of available nitrate and the other in batch mode with an excess of available nitrate. Once the diatom inoculation “took”, cell numbers in the nitrate deficient culture remained relatively constant while cell numbers in the nitrate replete culture increased exponentially. Each culture was initially exposed to identical irradiance models: a 12:12 sinusoidal photoperiod with a maximum daily intensity I_{\max} of $75 \mu\text{E m}^{-2} \text{s}^{-1}$. After a period of stabilization corresponding to several volume turnovers, I_{\max} was



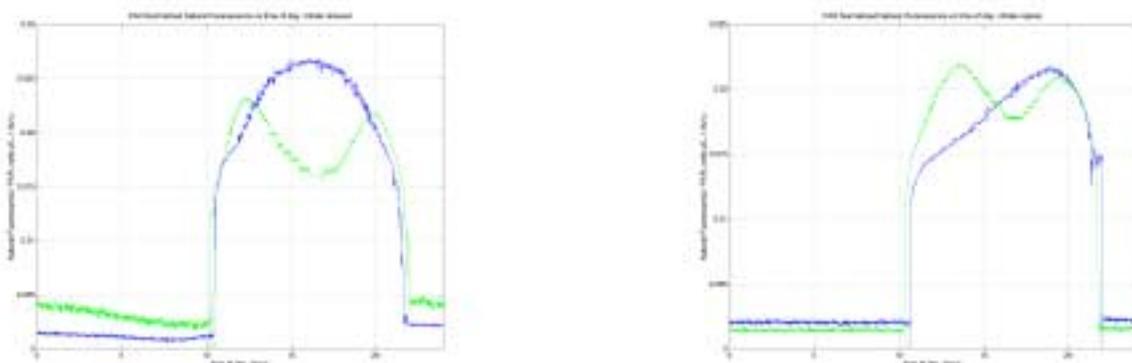
Figures 6a & b: F_{nat} (y axis) versus EPAR (x axis) for the nitrate reduced culture (left) and nitrate replete culture (right). Blue traces show the relationship between natural fluorescence and PAR irradiance before the shift up in irradiance. Green traces show the relationship after a fivefold increase in irradiance.

increased fivefold. The natural fluorescence response to this manipulation was monitored for approximately two weeks for each experiment at a sampling frequency of 1 second. Observed changes in cellular carbon to nitrogen ratio and abundance data are consonant with our experimental design that irradiance, not nitrate availability, ultimately limited culture growth before the manipulation was effected.

The relationship between natural fluorescence F_{nat} and incident PAR irradiance EPAR is fundamentally different between the nitrate replete and nitrate reduced cultures during the period preceding the shift up in irradiance (Figure 6a & b, blue traces). In the nitrate reduced culture, no diurnal variability is evident in the natural fluorescence signal, as fluorescence progresses and regresses along the same line (during the 12 hour simulated daytime, EPAR is changing sinusoidally with time). In contrast, a similar representation for the nitrate replete culture shows that the morning and evening paths are not collinear, reflecting greater fluorescence after solar noon than before. After the shift up in irradiance (green traces), the fluorescence-irradiance shows a more complex kinetic, but the two are fundamentally similar

in shape.

We have looked at different ways of interpreting such data in order to better determine what physiological or environmental factors contribute to such variability. Figures 7a and b show the same data as in Figure 6, except that we plot F_{nat} normalized to E_{PAR} as a function of time. During simulated daytime, such plots of PAR normalized fluorescence may be used to identify thresholds, decay rates, and other kinetic features of the natural fluorescence response which are not evident in simple plots of F_{nat} versus E_{PAR} . We are presently using this approach to investigate more deterministic explanations of the diurnal character of natural fluorescence



Figures 7a & b: F_{nat} normalized to E_{PAR} (y axis) versus time of day (x axis) for the nitrate reduced culture (left) and nitrate replete culture (right). Blue and green traces are as in Figure 6. The symmetry of pre shift conditions in the nitrate reduced culture is markedly different than that in the nitrate replete culture.

During this pair of experiments we also collected discrete samples for analysis of pigment content using high performance liquid chromatography. We integrate these results into our fluorescence data to identify variability in F_{nat} due to changes in photoprotective and photosynthetic pigment content. Similarly, during each culture experiment we also collected high resolution time series of variable fluorescence using a Fast Repetition Rate fluorometer. These data are being analyzed to identify variability in F_{nat} stemming from physiological changes in the structure and operation of the photosystems. Further, we programmed the chemostat system to measure the fluorescence action spectrum of the cultures every 30 minutes. We intend to use these data to better identify the wavelength dependent variability in natural fluorescence. The entire data set from these two experiments provides the first detailed look into the variability of natural fluorescence across a wide range of temporal scales. Our initial experiments with irradiance and nitrate availability provide a solid basis for future work with other taxa and environmental conditions.

MOCEAN Algorithm Documentation

We continue to revise 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 reviewed test data products developed by the University of Miami. These test products were based on SeaWiFS imagery. We provided a mechanism to derive pseudo-fluorescence data as SeaWiFS does not have a channel at 680 nm. Both the FLH and CFE algorithms are working satisfactorily, and we await the arrival of the first MODIS data after launch.

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://tigertail.oce.orst.edu/eos/reports/NASA1099.htm>.

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 imagery into our data base. This will be modified to handle MODIS data as well. 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.

Anticipated Future Actions

- Begin testing and evaluation of MODIS fluorescence algorithms with MODIS data
- Participate in MODIS validation cruise in spring 2000
- Bio-optical cruises off Oregon coast in June and August 2000
- Retrieve and redeploy bio-optical mooring in Hawaii and continue analysis of bio-optical data
- Complete analysis of 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 now is the availability of Level 1B and Level 2 data from Terra. We anticipate that the MODAPS and the GDAAC will be the primary data sources, although we expect to obtain some data from University of Miami. 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. We expect to participate in the upcoming MODIS validation cruise; however the slip in the Terra launch date now makes it likely that the cruise will conflict with our other cruises off the Oregon coast in May/June 2000.