

SEASONAL WIND FORCING AS IT AFFECTS CELLULAR OPTICS OF NATURAL POPULATIONS OF MICROORGANISMS IN THE ARABIAN SEA.

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LONG-TERM GOALS

We wish to predict changes in biological optics due to physical forcing in the upper layers of the oceans. There exists a growing perception that physical processes may directly influence the diversity of micro-organisms in the oceans. The observed effect is really the result of nutritional physiology: limiting nutrient conditions favor the growth of smaller species, while conditions of nutrient enrichment favor larger species. Observations in areas of low and high productivity tend to support this hypothesis, yet there is no quantitative model that will provide a prediction of the transition in cell size from an analysis of concentrations of nutrient scalars and their flux into the euphotic zone.

SCIENTIFIC OBJECTIVE

The main effort is to measure the change in phytoplankton cell size/optical packaging, inherent and apparent optical properties within a well defined nutrient/density field over the course of a major climatological cycle such as monsoonal wind forcing in the Arabian Sea.

APPROACH

The basis of the observational program was the measurement of non-conservative properties within a three dimensional density field for two regions on either side of the Findlater Jet using a towed undulating instrument package (SeaSoar) during four cruises throughout the monsoonal cycle. Not all the instrumentation needed for this study could be fitted to the SeaSoar, so the strategy combined the SeaSoar activity with surface sampling and additional station activities to obtain samples at depth along a 900km offshore section and at numerous coastal stations. This strategy worked well for the five groups who coordinated during the experiment: Woods Hole Oceanographic Institution, Naval Research Laboratory, Oregon State University, University of Southern California and Bigelow Laboratory for Ocean Sciences.

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WORK COMPLETED

We have completed the analysis of all our particulate absorption samples including the surface radiator, filament and mooring samples for all SeaSoar cruises and the entire northeast monsoon dataset (cruise # TTN042) collected with Curt Davis' spectrometer due to the failure of our spectrophotometer at sea. We have also completed our analysis of the nutrient/density relationships for each cruise which show considerable differences for each season. We have restricted our analysis to the upper water column ($\sigma-t < 25.5$) in order to avoid the region of denitrification found in each season where $\sigma-t$ was greater than 25.5 and less than 27. Considerable variability occurred in surface waters during the northeast monsoon, modelling this season has been difficult. These datasets, along with our previous results on mesoscale chlorophyll distributions in the surface radiator surveys and the shift in phytoplankton cell size from flow cytometry data, complete the framework of parameters needed to begin synthesis papers.

We participated in the July 1997 Workshop at UNH which resulted in several working groups to merge JGOFS and ONR datasets. Bottle cast data from the ONR cruises was to be placed in the JGOFS database as part of the core hydrographic data reporting. We agreed to report our fluorometric chlorophyll values from the bottle casts as part of that data transfer. The JGOFS database required that chlorophyll a be calculated separately which required us to recalculate and resort 4700 chlorophyll analyses prior to merging with the bottle data. Associated metadata were also submitted. It was agreed that pigment distributions were to be expressed as chlorophyll a, this required that early calibrations for the SeaSoar in situ fluorometer be recalculated based on comparisons to chlorophyll a rather than total chlorophyll, we have also replotted the mesoscale pigment distributions presented in Doug Phinney's two ASLO posters according to this standard prior to sub-mission for publication. JGOFS requires their investigators to report a conversion factor for fluorometric chlorophylls, we determined that while fractionated HPLC samples were analysed on three of the ONR cruises by Rory Toon (USM), sufficient data did not exist comparing his HPLC's and our fluorometric chlorophylls to determine this factor.

Bob Arnone (NRL Stennis) and Chuck Trees (SDSU) announced that they were pulling together a complete optical dataset for the Arabian Sea as input to the Ocean Optics Program and solicited contributions of data for spectral absorption, scattering and attenuation; spectral downwelling and upwelling irradiance as well as spectral downwelling and upwelling radiance. Our particulate absorption dataset was already part of this, we have also contributed our AC-9 and Atlantic Tethered Spectral Reflectance Buoy data from the last two cruises.

RESULTS

The distributions of chlorophyll a and density for the offshore section show seasonal variability with chlorophyll a concentrations ranging between 0.05 to 3mg/m³ and density ranging between 23.2 to 26.4 $\sigma-t$. The same is true for spatial chlorophyll a variability in terms of the form and position of features along the section. During the NE monsoon, maximum chlorophyll a values of 0.8mg/m³ were observed with no organized features, mixed layer depth was 50-75m increasing offshore. The February inter-monsoon was characterized by eddies (50-100km diameter) on either side of the mooring, chlorophyll a was greater than 1.5mg/m³ with the densest surface waters and deepest mixed layer (100m) found offshore at this time. The SW monsoon showed strong upwelling

along the coast with an eddy driven filament extending 300km offshore. Chlorophyll a was highest in the upwelling zone ($>3\text{mg}/\text{m}^3$), the most oligotrophic conditions were found offshore beyond the mooring. Finally, the October inter-monsoon was characterized by a sub-surface chlorophyll a maximum layer less than $1\text{mg}/\text{m}^3$ along the entire section and weak upwelling along the coast. An east-west section across a coastal filament in June showed complex structure with chlorophyll a concentrations greater than $3\text{mg}/\text{m}^3$.

Nitrate/density relationships for each season and the filament for sigma-t less than 26.6 (representing the upper 200m) were quite similar with the exception of the NE monsoon when the relationship is very noisy. TT48 and TT51 curves demonstrate the substantial increase in nutrient concentrations found in low density, near-surface waters during and after the SW monsoon.

The percent of particles which fluoresce (%FL) was linearly related to chlorophyll a during the NE monsoon ranging from <10 to 80% when chlorophyll a was less than $0.8\text{mg}/\text{m}^3$. As the seasons progressed and chlorophyll a increased, the range in %FL stayed constant, but became non-linear at high chlorophyll a concentrations with a range in %FL of 40 - 80% . Non-fluorescent particle concentrations from the euphotic zone are not generally related to chlorophyll a. When the same analysis was used for particle concentrations vs. particulate absorption at 440, 410 and 350nm, non-fluorescent particles were also poorly related at each wavelength.

Spectral curves for samples of similar chlorophyll a concentration ($1.3\text{mg}/\text{m}^3$) but different %FL values ranging from 28 - 74% were normalized at 675nm and compared. The curves were surprisingly similar given the large range in %FL, leading us to examine the spectral effect when chlorophyll a was varied for fixed values of %FL equal to 52 and 28% . In each case, when chlorophyll a was less than $1\text{mg}/\text{m}^3$, absorption below 500nm increased with larger effects below 440nm when both %FL and chlorophyll a were low.

IMPACT

The important physical and biological processes that occur seasonally within the offshore section concern the delivery and utilization of nutrients. Ekman dynamics were weak during the NE monsoon and February inter-monsoon resulting in low surface nutrients (Bauer, et al., 1991). The surface chlorophyll features were detrainment blooms operating on low nitrate levels in shallow mixed layers (40-60m) within the euphotic zone (McCreary, et al., 1993). During the SW monsoon, wind forced upwelling brought high concentrations of nutrients to the surface waters along the coast (Yentsch and Phinney, 1992) which were advected offshore by filaments and eddies, not through the action of a well developed inertial current such as a western boundary current.

The filament section showed a shallow, low density surface feature with high density, nutrient rich waters on either side. The nitrate/density relationship for this section is similar to the rest of the cruise, however, the mixed layer depth is shoaled to $< 10\text{m}$ in the filament while the rest of the offshore section is 30m or greater. These conditions are ideal for the development of phytoplankton blooms which are then advected offshore. In the course of the monsoon cycle, mixed layer depth and delivery of nutrients to surface waters remain the important factors which determine phytoplankton growth in the Arabian Sea.

The biological optics of the Arabian Sea fit the classical 'case 1' scenario: phytoplankton and their by-products are the major absorbing compounds. We have studied the contribution of detritus to particulate absorption using a particle counting technique which discriminates between fluorescent and non-fluorescent particles. The effect of detrital absorption is most important at wavelengths shorter than 500nm for chlorophyll a concentrations less than 1mg/m³. Pigments dominate particulate absorption at chlorophyll a concentrations greater than 1mg/m³, a three-fold change in the percent of non-fluorescent particles (26 to 72%) has little affect on the absorption of blue light.

TRANSITIONS

We are not aware of any transitions to industry, the fleet or persons in other countries. The bio-optical modelling of detrital absorption is being used by other groups involved in the Ocean Optics Program in order to correct spectral absorption data.

RELATED PROJECTS

We continue to collaborate with a variety of groups, Arnone (NRL Stennis), Marra (Lamont-Doherty), Trees (SDSU) and Patch(USF) on particulate absorption; Hoge (NASA Wallops) on LIDAR pigment calibrations; Brink (WHOI) and Wiggert (USC) on SeaSoar pigment calibrations; and Wood (U Oregon) on distribution of phytoplankton spectral types and sizes.

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