BIO-OPTICAL AND NUTRIENT RESPONSES TO PHYSICAL FORCING PROCESSES DURING MONSOONS IN THE NORTHWEST INDIAN OCEAN

Burton H. Jones
Department of Biological Sciences
University of Southern California
Los Angeles, CA 90089-0371
Phone: 213-740-5765
FAX: 213-740-8123
E-mail: bjones@usc.edu

Award # N00014-94-1-0362

LONG TERM GOALS

The overall goal of this research program is to understand the interaction between physical processes, nutrient fluxes, and biological and optical responses within the upper ocean layers of both coastal and open ocean regions.

OBJECTIVES

The objectives of this research are to characterize the distributions of physical, biological and optical variability within the Arabian Sea as a function of the annual monsoon cycle. In particular, we are examining the processes contributing to nutrient fluxes into the upper layer, the interaction of the euphotic zone and surface mixed layers, the spatial scales of variability within the upper layer, and the bio-optical responses to these processes. This research is supported by ONR Biological Oceanography.

APPROACH

Spatial variability of physical, bio-optical and bio-acoustic variables were sampled with a SeaSoar (Brink and Lee, WHOI) carrying sensors for temperature, conductivity, chlorophyll fluorescence, photosynthetically available radiation (PAR), beam transmission (C_{660}), DOM fluorescence (P. Coble, USF), dissolved oxygen (C. Langdon, LDEO), and acoustic back-scatter (Holliday, Tracor). The SeaSoar was used to map 2-D and 3-D distributions of these variables using long transects and radiator patterns, respectively. During SeaSoar mapping nutrients were measured continuously from the ship’s underway seawater system. Hydrographic sections were obtained along the southern JGOFS line, on a cross-shelf transect at about 19° 20’N, just north of Ras al Madraka, and a high resolution transect associated with a SeaSoar radiator pattern. Other sections were added opportunistically. Hydrographic variables included T, S, dissolved oxygen, nutrients, extracted chlorophyll (Yentsch and Phinney) and chlorophyll fluorescence, C_{660}, and PAR.

Report Documentation Page					*Form Approved* *OMB No. 0704-0188*
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302 Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number					
1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE				3. DATES COVERED **00-00-1997 to 00-00-1997**
4. TITLE AND SUBTITLE **Bio-optical and Nutrient Responses to Physical Forcing Processing During Monsoons in the Northwest Indian Ocean**					5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)					5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Southern California, Los Angeles,Department of Biological Sciences,Los Angeles,CA,90089**					8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)					10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Analysis of the data set includes three major components. The first component is to examine the processes and scales of variability that are apparent in the Seasoar and underway data sets. The second component is to examine the bio-optical variability within the SeaSoar data set, including the examination of basic relationships between beam attenuation, chlorophyll fluorescence, and the attenuation of PAR, the spatial interaction of the euphotic zone depth and mixed layer depth, and modeling of the spatial distribution of primary productivity based on beam attenuation, chlorophyll fluorescence, and PAR. The third component of analysis is to examine the relationships between water mass and nutrient variability, the implications of this variability to vertical nutrient fluxes, and the impact of the suboxic layer and denitrification on upper ocean processes.

WORK COMPLETED

During the past year, we have been working on three fronts. One is the analysis of the hydrographic variability along the JGOFS southern line. This work focuses on the variability of the zone of denitrification and its influence on nutrient fluxes into the upper layer. The second area of effort has been on the optical variability within the Seasoar data set, the depth of the euphotic zone, and the interaction with the mixed layer and stratification processes in the Arabian Sea. The third area has been modeling of the upper layer during the NE monsoon to understand the interaction of nutrient fluxes, convective mixing, and diurnal stratification and destratification. This work has resulted in a manuscript which is being submitted to Deep-Sea Research.

RESULTS

During the SW monsoon upwelling filaments contributed to seaward fluxes of nutrients and phytoplankton biomass. The filaments were observed near the mooring (~550 km offshore). High ammonium concentrations in the filament indicated significant nutrient regeneration activity and suggest grazing activity. Subduction was evident as the filament advected offshore. Physical analysis of the Seasoar data set by Lee and Brink (WHOI) suggests little evidence for wind stress curl driven upwelling during either July or September-October 1995. Distributions of water masses and nutrients support this conclusion. This indicates that the broad scale productivity occurring at the end of the SW monsoon season is the result of horizontal advection from the coast, as suggested by Young and Kindle (1994).

Multivariate analysis has been used on the hydrographic data set to further understand the annual variability along the southern JGOFS line in the Arabian Sea. Using data from 10 cruises (our four Seasoar cruises and six JGOFS cruises [data provided by Codispoti and Morrison]) and from the upper 500 m, we were able to evaluate the major regions of variability associated with the nutrient variables. Ammonium variability indicative of nutrient regeneration over the 10 cruise series had its dominant variability within the upper 100m along the JGOFS line. This component was highest during both the NE and SW monsoons apparently coupled with primary productivity and grazing in the upper layer. Nitrite, in contrast, was most dominant between 125 and 325 m, but with and offshore spatial maximum in variability beyond 800 km from the coast in the depth range of 125-225 m, perhaps indicating the influence of the well documented denitrifying region in the eastern half of the Arabian Sea (e.g. Naqvi, 1991).

We are in the process of analyzing the bio-optical data set from the Seasoar cruises. During the SW monsoon there were distinct populations that were apparent in the bio-optical relationships between beam attenuation at 660 nm (C_{660}), chlorophyll fluorescence and the apparent optical property Kpar. In the upwelling filament that extended seaward from the coast the slope of the Kpar / C_{660} was low compared with the slopes further offshore where mixing was deeper, indicative of both photoadaptation and perhaps species changes. The Kpar vs. C_{660} (or chlorophyll) relationship has been used to estimate the euphotic zone depths for the entire Seasoar data set, including the night-time data. In the filament nearshore the mixed layer depth was shallower than the euphotic zone depth and therefore the water column was conducive to high productivity resulting from the upwelled nutrients. Farther offshore, high wind stress caused deep mixing of up to 65m but the mixing did not penetrate the pycnocline. The mixed layer was generally shallower than the euphotic zone depth due to very little phytoplankton biomass in the mixed layer due to the lack of nutrient availability. During the late NE monsoon in February, mixed layer depths were often deeper than the euphotic zone depth and deeper than during the SW monsoon, contributing to the vertical nutrient supply, and the inability of the phytoplankton to utilize all of the available nutrients.

Modeling analysis by J. Wiggert of the upper layer during the NE monsoon suggests that primary productivity and accumulation of biomass may be limited by the physical dynamics of the system. While deep convective mixing transports nutrients into the surface layer during this period, the mixing at the same time prevents a large accumulation of biomass from occurring. While daytime stratification contributes to productivity in the upper layer, night-time convection deepens the mixed layer, diluting the phytoplankton and transporting a part of the biomass below the euphotic zone. A result of this process is that the phytoplankton population remains tightly coupled with grazing and nutrient regeneration processes, further impeding development of a larger phytoplankton population, and probably affecting the phytoplankton species composition.

IMPACT

The results from the Arabian Sea indicate that while the responses to the NE and SW monsoons are predictable at a gross level, the region is highly complex as evidenced by water mass variability, small spatial scales, and spatial an temporal variability of the forcing processes. Traditional shipboard hydrography will under sample the variability because of the very short spatial scales.

TRANSITIONS

During the last year, the bulk of the initial data processing was completed and the hydrographic data base was submitted to the JGOFS data base. Dr. Jerome Wiggert completed his postdoctoral position with myself and Professor Tommy Dickey (now at UC Santa Barbara) from which one paper has already resulted (Wiggert et al., 1997).

RELATED PROJECTS

This research effort is highly collaborative with investigators in both the ONR-funded Forced Upper Ocean Dynamics Program (FUOD) and NSF-funded JGOFS Program. Our major collaboration is with Drs. Brink and Lee of the WHOI Seasoar Group. We are complementing their analysis of the physical data set from the Seasoar with analysis of the bio-optical data set. We are also collaborating with the JGOFS hydrographic team (L. Codispoti and J. Morrison) to integrate the hydrographic observations from the entire Arabian Sea data set. This has already resulted in one major overview paper (Morrison, et al., 1997).

In addition, we are collaborating with Drs. Dickey (UCSB) and Marra (LDEO) to compare Seasoar bio-optics with moored bio-optical observations from the central mooring (e.g. Wiggert et al., 1997). We also collaborating with other FUOD investigators including Dr. Michelle Wood who is analyzing phytoplankton taxonomy, and Dr. Robert Arnone who is analyzing AVHRR imagery and nearsurface optical observations.

REFERENCES

Morrison, J, L. A. Codispoti, S. Gaurin, B. Jones, V. Manghnani and Z. Zheng, The Hydrographic Milieu of the U.S. JGOFS Arabian Sea Process Experiment, submitted to Deep-Sea Research, 1997

Naqvi, S.W.A., 1991, Geographical extent of denitrification in the Arabian Sea in relation to some physical processes. Oceanologica Acta, 14:281-290.

Wiggert, J.W., B. Jones, T. Dickey, J. Marra, K. Brink and B. Weller, 1997, The impact of NE monsoon forcing on mixing, primary productivity, and nutrient cycling: An interdisciplinary modeling study. In preparation for Deep-Sea Research.

Young, D. K., and J. C. Kindle, 1994, Physical Processes Affecting Availability Of Dissolved Silicate For Diatom Production In the Arabian Sea, J. Geophys. Res., 99, 22619-22632.