

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this 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, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</small>				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE		3. REPORT TYPE AND DATES COVERED
4. TITLE AND SUBTITLE			5. FUNDING NUMBERS	
Moored observations for the forced upper ocean dynamics experiment in the Arabian Sea			N00014-94-1-0450	
6. AUTHOR(S)			8. PERFORMING ORGANIZATION REPORT NUMBER	
John Marra			NA	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
Lamont-Doherty Earth Observatory of Columbia University Palisades, NY 10964			NA	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			11. SUPPLEMENTARY NOTES	
Office of Naval Research 800 N. Quincy St. Arlington, VA 22217-5660			The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.	
12a. DISTRIBUTION/AVAILABILITY STATEMENT			12b. DISTRIBUTION CODE	
Approved for public release; distribution unlimited.			UNCLASSIFIED	
13. ABSTRACT (Maximum 200 words)				
<p>The year-long mooring records in the Arabian Sea (15°30'N/61°30'E) show clearly the semi-annual biological response to the northeast and southwest monsoons. Each monsoon causes the mixed layer to deepen, but for the northeast monsoon, convective processes dominate, while during the southwest monsoon, the mixed layer deepens via wind-induced mixing. During both mixing periods, chlorophyll declines, and then increases as the water column stratifies. The annual cycle of chlorophyll variability at the mooring site (the climatological center of the Findlater Jet) generally follows the mixed layer depth. Strong diel variability in phytoplankton and particle variables were observed, and coherence analysis indicated that these were modulated more by water column processes (e.g., changes in the mixed layer depth) than by solar variability. We have demonstrated the utility of moored sensor systems in an unforgiving environment. The high-resolution data are extremely useful to those trying to understand the drivers for seasonal variability in productivity. The seasonal variability in productivity is crucial to interpret the export of carbon from the surface ocean to depth. The results will fuel consideration of the importance of diel processes in determining the activities of plankton.</p>				
14. SUBJECT TERMS			15. NUMBER OF PAGES	
moorings, monsoons, Arabian Sea, productivity, plankton			3	
17. SECURITY CLASSIFICATION OF REPORT			16. PRICE CODE	
UNCLASSIFIED				
18. SECURITY CLASSIFICATION		19. SECURITY CLASSIFICATION OF ABSTRACT		20. LIMITATION OF ABSTRACT
UNCLASSIFIED		UNCLASSIFIED		UL

**MOORED OBSERVATIONS FOR THE FORCED UPPER OCEAN
DYNAMICS EXPERIMENT IN THE ARABIAN SEA**

Award # N00014-94-1-0450

Final Report

submitted by

John Marra
Lamont-Doherty Earth Observatory of Columbia University
PO Box 1000
Palisades, NY 10964
Tel: 941-365-8891
Fax: 914-365-8150
e-mail, marra@ldeo.columbia.edu

19990119 018

The scientific objectives of this grant were to (1) determine the diurnal, within-season, and seasonal variability of phytoplankton for a locale subject to strong seasonal wind-stress; (2) understand how POC:Chl changes with the advent of the SW monsoon; (3) determine whether the seasonal increase in phytoplankton affects the surface heating of the water column; and (4) determine whether the chlorophyll-specific primary production is constant through the year in the Arabian Sea, where strong seasonal signals in nutrients are characteristic.

The work completed for this grant is as follows:

1. We completed two data reports, one for each deployment (Ho et al., 1996a, 1996b), and contributed to a preliminary results article for EOS (Rudnick et al., 1997).
2. We made presentations of data at the Arabian Sea Workshop in July, 1997.
3. We have several manuscripts (published or in press) in Deep-Sea Research-II Special Volume on the Arabian Sea Expedition (Marra et al., 1998; Kinkade et al., 1999a,b), and were co-authors on three other manuscripts.

The year-long mooring records show clearly the semi-annual biological response to the northeast and southwest monsoons. Interestingly, prior to each mixed-layer deepening associated with the monsoons, there is evidence of mesoscale eddies passing the mooring site, and which contain enhanced quantities of chlorophyll. Each monsoon causes the mixed layer to deepen, but for the northeast monsoon, convective processes dominate, while during the southwest monsoon, the mixed layer deepens via wind-induced mixing. During both mixing periods, chlorophyll declines, and then increases as the water column stratifies. The annual cycle of chlorophyll variability at the mooring site (the climatological center of the Findlater Jet, 15°30'N/61°30'E) generally follows the mixed layer depth. When the mixed layer is deep, the quantity of chlorophyll in the water column is low, and increases when the mixed layer shallows following the cessation of monsoon winds. Prolonged stratification, during the intermonsoons, also results in declines in photosynthesis.

The variability in productivity over the year generally follows the change in chlorophyll except where there may have been changes to community structure (Feb-Mar, '95), or when grazing might be important (May, July, '95). Strong diel variability in phytoplankton and particle variables were observed, and coherence analysis indicated that these were modulated more by water column processes (e.g., changes in the mixed layer depth) than by solar variability (Kinkade et al., 1999a).

We have demonstrated the utility of moored sensor systems in an unforgiving environment. The high-resolution data are extremely useful to those trying to understand the drivers for seasonal variability in productivity. The seasonal variability in productivity is crucial to interpret the export of carbon from the surface ocean to depth. The results will fuel consideration of the importance of diel processes in determining the activities of plankton. We now have a better idea of the relationships among phytoplankton production, nutrient supply, and changes in mixed layer depth. The importance of mesoscale processes in distributing heat and momentum was demonstrated over a large part of the study area, and is probably the reason why productivity can remain relatively high despite the extreme variability in wind-forcing.

During this project we have developed a low-cost, compact, easy-to-use moorable spectro-radiometer with 32 wavelengths. It should find a variety of uses. Four companies sell in situ fluorometers which had a basis in design developed for a predecessor mooring program, Biowatt-II (1986-1988). I think that the efforts by both LDEO and UCSB (see T. Dickey et al., 1998) have had something to do with the use of chlorophyll fluorescence measurements at sea.

REFERENCES

- Ho, C., C.S. Kinkade, C. Langdon, M. Maccio, J. Marra. 1996a. The Forced Upper Ocean Dynamics Experiment in the Arabian Sea. Results from the multi-variable moored sensors from deployment-2 of the WHOI mooring. LDEO Tech Report LDEO-96-7, pp. 19+figs., app.
- Ho, C., C.S. Kinkade, C. Langdon, M. Maccio and J. Marra. 1996b. The Forced Upper Ocean Dynamics Experiment in the Arabian Sea. Results from the multi-variable moored sensors from deployment-2 of the WHOI mooring. LDEO Tech Report LDEO-96-8, pp. 19+figs., app.
- Kinkade, C.S., J. Marra, T. Dickey, C. Langdon, D. Sigurdson, R. Weller. 1999a. Diel variability of bio-optical signals in the Arabian Sea. Deep-Sea Research-II (in press).
- Kinkade, C., J. Marra, T. Dickey and R. Weller. 1999b. An intercomparison of moored optical sensor data and an annual cycle of phytoplankton biomass in the Arabian Sea. Deep-Sea Res. II (in press).
- Marra, J., T.D. Dickey, C. Ho, C.S. Kinkade, D.E. Sigurdson, R. Weller, R. T. Barber. 1998. Variability in primary production as observed from moored observations in the central Arabian Sea in 1995. Deep-Sea Research-II 45, 2253-2267.
- Rudnick, D., R.A. Weller, C. Eriksen, T.D. Dickey, J. Marra and C. Langdon. 1997. One-year moored observations of the Arabian Sea Monsoons. EOS 78, pp. 117, 120-121.
- Dickey, T.D., J. Marra, D.E. Sigurdson, R.A. Weller, C.S. Kinkade, S.E. Zedler, J.D. Wiggert and C. Langdon. 1998. Seasonal variability of bio-optical and physical properties in the Arabian Sea: October 1994-October 1995. Deep-Sea Res. II 45, 2001-2025.