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Three-dimensional structure and evolution of the mixed layer in the Arabian Sea

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Long-Term Goals:

The long term goal of this effort was to understand better how the upper ocean responds to realistic, spatially complex wind stress patterns. Specifically, upper ocean effects related to both mid-ocean and coastal upwelling were of interest.

Objectives:

The main scientific objective was to understand the physical processes that control the structure and evolution of the mixed layer in the Arabian Sea. Of particular interest were the effects of these variations and processes upon the bio-optical properties of the mixed layer and upper ocean. One of the main hypotheses of the Arabian Sea ARI was that the large scale structure of the atmospheric fields associated with the Findlater jet determines the mixed layer structure and that the variations across the northern Arabian Sea are due to the cyclonic or anticyclonic nature of the wind field on the two flanks of the jet. We were interested in observing the upper ocean structure in various regimes, including both monsoon periods as well as the near-coastal environment off Oman to observe filament structures and comparing them to those observed during the ONR Coastal Transition Zone study.

Approach:

Our approach was to carry out upper ocean surveys in the Arabian Sea using SeaSoar, a towed undulating vehicle. The system was configured to measure temperature, pressure, conductivity, fluorescence, light transmission, dissolved oxygen, photosyntheically available radiation (PAR) and acoustic backscatter. The surveys took place during 1994 and 1995 along a repeated pattern

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13. ABSTRACT *(Maximum 200 words)*

Our goal was to understand how the physical (temperature, salinity, density, currents) and optical (fluorescence, light transmission) properties of the upper 200 m of the Arabian Sea vary in response to the strong seasonal, monsoonal wind forcing. Four cruises, covering four phases of the Arabian Sea monsoons, took place during 1994-1995. During these cruises, we deployed SeaSoar (a towed, undulating underwater vehicle) to measure the properties of interest rapidly and with high spatial resolution. Our results show that the traditional picture of basin-scale upwelling and downwelling driven by wind patterns is too simple, and that upper ocean changes seem to be more strongly driven by effects associated with eddies, vertical mixing and horizonal transport.

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Upper ocean, Arabian Sea, upwelling, filaments

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involving mapping surveys ("radiators") on either side of the climatological Findlater jet, as well as a detailed survey in the vicinity of the moored array (Weller, Rudnick and Eriksen components). Some repeat sampling took place to investigate shorter-scale time dependence, and a filament radiator pattern was executed during the June 1995 cruise. Spatial resolution of the surveys was about 1-2 km horizontally along a cruise track, and about 25 km in the across-track direction. These data were analyzed in cooperation with Jones (USC) to investigate how the spatial physical and biological patterns evolve and relate to wind forcing.

Work Completed:

We carried out four cruises in the Arabian Sea:

December 1994 (northeast monsoon), February 1995 (transitional), June 1995 (southwest monsoon), and September 1995 (transitional). We have thus documented the entire upper ocean seasonal evolution for a one-year period. The data from these cruises were completely edited, calibrated and archived. We carried out the analysis phase of the project, including cooperation with scientists from other components. Two manuscripts are in press and one published. One more is anticipated. Numerous presentations have been made at national or international meetings.

Results:

We have shown that a cool filamentary structure observed during the summer (coastal upwelling season) has many properties (latitude-scaled size, transport, and nutrient distributions) in common with features off the west coast of the US. The intense jet associated with the filament is largely in thermal wind balance. Away from the filament, during the Southwest Monsoon, lateral advection and vertical mixing often obscure the weaker effects of vertical motion driven by surface Ekman pumping. Estimates using ECMWF wind fields suggest that vertical displacements away from the coast are of the order of 20m over a seasonal cycle. In contrast to initial expectations of alternating upwelling and downwelling offshore of the Findlater jet, wind data indicate downward Ekman pumping throughout the year in the region offshore of the jet, with enhanced downwelling during the Southwest Monsoon. The net result is that coastal upwelling, eddy processes and mixed layer deepening seem to play much more of a role in determining the upper ocean structure than does open-ocean upwelling. Clear associations between physical and optical structures in the upper ocean have been documented.

Impact/Implications:

Our results help to explain the evolution of upper ocean physical and biological patterns in the Arabian Sea. By coordination with modeling and other observational groups, results from this area will deepen our understanding of upper ocean dynamics in other regions as well. The spatial resolution of our measurements has helped to refine ideas of what is resolved with the more traditional sampling used by JGOFS chemists and biologists.

Transitions:

Related Projects:

This effort is a component funded through the ONR Arabian Sea ARI. As such, we have had close cooperations with the moored array group (Weller, Rudnick and Eriksen), remote sensing personnel (Arnone, Coble, Davis), and with biological investigators (Jones, Wood, Yentsch/Phinney).

Further, we have cooperated with the NRL numerical modeling team (Kindle) at sea and during the analysis stage.

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