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By

NEEMA C. P.

DEPARTMENT OF ATMOSPHERIC SCIENCES
COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY
COCHIN 682 016

SALIENT FEATURES OF THE NORTH INDIAN OCEAN ASSOCIATED WITH THE INDIAN SUMMER MONSOON

The north Indian Ocean is a region of complexities due to the seasonal reversal of winds and currents associated with the southwest and northeast monsoon, Indian Ocean warm pool, eddies, fronts, planetary waves, massive fresh water discharge at the head Bay, storms and depressions. These features make the north Indian Ocean an interesting region for experimentalists and modelers. Despite of this, studies are fragmentary due to lack of sufficient field measurements. It is very difficult to study these features from the field measurements alone. To capture low frequency signals like propagating waves, evolution of warm pool, eddies, etc., synoptic snap shots of ground truth measurements for long duration over a basin scale are required. With the availability of various satellites and advanced remote sensing techniques, understanding of the synoptic scale variability of the ocean was considerably improved. In spite of this, most of the features in the ocean still remain unexplored. In this thesis, an attempt is made to explain salient features in the north Indian Ocean and their variability on different time scales.

The thesis contains seven chapters. In the first chapter, a detailed literature survey pertaining to the scope of the thesis is presented. The occurrence of Arabian Sea warm pool prior to the onset of monsoon attracted many researchers. Some studies showed that there exists a relationship between the sea surface temperature of the warm pool and Indian summer monsoon, which was mostly due to the seasonal reversal of wind pattern. Several atmospheric systems form during summer monsoon and significantly influences the upper ocean dynamics. Moreover, transition of wind regime from southwest to northeast and vice versa resulted in the formation of eastward propagating Kelvin wave and many other propagating waves. Theoretical studies demonstrated that eddies and planetary waves play a vital role in the dynamics

of the north Indian Ocean. It was established that these features could be mapped using satellites. A detailed account of all these processes in the Indian Ocean is discussed in this chapter. The influence of local forcing on the upper ocean dynamics can be investigated using one-dimensional mixed layer models. Various techniques utilized to simulate the mixed layer temperature and depth of the Indian Ocean is also described in the introduction.

One of the active areas of recent research is the Indian Ocean warm pool and associated monsoon activity. In the second chapter, the main focus is given on the evolution and dissipation of the Arabian Sea mini warm pool in the eastern Arabian Sea, which is a part of the Indian Ocean warm pool. Moreover, the variation in the characteristics of this mini warm pool associated with the wet, normal and dry monsoon years are discussed. The data sets utilized are the NCEP/NCAR Reanalysis (herein after as NNR data), sea truth measurements of sea surface temperature and salinity for more than 40 years and the TMI SST data for 2001, 2002 and 2003. A mini warm pool, defined as the region with temperature in excess of 30°C in this study, formed in the southeastern Arabian Sea during May. This mini warm pool attained the maximum intensity about two weeks prior to the onset date. Its extent and core temperature showed marked variability with different types of monsoon, viz. wet, normal and dry years. In all the cases, it was found that the triggering of the dissipation of the warm pool started one to two weeks prior to the onset of southwest monsoon over Kerala. This can be utilized as an index for the monsoon prediction. Further, the extent and the core temperature showed marked variability with wet, normal and dry years. Prior information of this aspect, which can be obtained from satellite imageries, will help in the prediction of the type of the monsoon.

Many systems form over the Bay of Bengal associated with the summer monsoon. Studies are quite meager describing the variations in the marine boundary layer characteristics over the ocean, especially over the Indian region during the monsoon period. In the third chapter, the marine boundary layer characteristics of the northern Bay of Bengal during the summer monsoon of 1999 is discussed utilizing the radiosonde data collected during this period during the BOBMEX cruise period. The data collected included pressure, dry bulb temperature, relative humidity, wind speed and direction up to tropopause covering both the active (when atmospheric disturbances were formed) and weak phases of the summer monsoon. This data is used to compute the radio refractive index, stability parameters, low-level condensation level, marine boundary layer height and inversion height. Influence of the atmospheric disturbances viz. deep depression, low-pressure system and rainfall, formed during this period on the marine boundary layer parameters are discussed.

BOBMEX-99 experimental program was planned to enhance the understanding of the upper ocean dynamics of the northern and southern Bay of Bengal and to study the response of these two regions to the atmospheric forcing during the summer monsoon. In the fourth chapter, the responses of the summer monsoon at the northern and southern Bay of Bengal are discussed in detail, utilizing the marine meteorological and oceanographic data. Moreover, one of the conditions based on sea surface temperature for the formation of a deep depression, low-pressure and heavy rainfall associated with a small-scale convective system is discussed. The dominance of remote forcing over local forcing was studied utilizing a one-dimensional mixed layer model. The simulation revealed that the one dimensional processes could not simulate the observed variability in MLD and MLT at the northern and southern Bay of Bengal, suggesting the dominance of processes other

than one dimensional, like internal waves, propagating waves, eddies, etc. in controlling the upper ocean dynamics of Bay of Bengal during the summer monsoon season.

Indian Ocean is notable for its seasonal reversal of monsoon winds. Winds are northeasterly over the north Indian Ocean during northeast monsoon and change to southwesterly during the southwest monsoon. During the transition period between the monsoons i.e. during March/April and October, winds are comparatively weak and westerly over the equatorial region. In the fifth chapter, the surface winds are analysed for a period of 5 years from 1993 to 1997, utilizing NCEP/NCAR Reanalysis wind at 10m level over the Indian Ocean region from 25°S to 25°N and 40°E to 120°E. Large inter-annual variability in the surface wind field and wind stress curl is noticed over the region.

The availability of satellites provides information of the ocean over a larger area at regular intervals of time. This satellite information is utilized to investigate some of the oceanographic features, viz. long period propagating waves and eddies, in the Indian Ocean. In the sixth chapter, the focus is given on the long period propagating waves from the sea surface anomaly data retrieved from TOPEX/Poseidon altimeter. The processed data for 1993-1997 is obtained from the WOCE Data products Committee, Jet Propulsion Laboratory, USA, 1998. Hovmoller diagrams are prepared along the equator, 15°N, 15°S and 20°S latitudes. The analysis revealed the inter- and intra-annual variability of the sea surface height variation along these latitude belts. Wavelet decomposition method is utilized to obtain the dominant harmonics from the time series of sea surface height data derived for selected locations. Confidence limits of these results are tested using statistical significance tests. Formation of Kelvin waves along the equator showed large inter-

and intra-annual variability associated with the transition winds. The other major propagating waves noticed is the westward propagating Rossby waves, which also exhibited large variability. Characteristics of these waves, like its time of formation, dimension, speed etc are derived from the Hovmoller diagram.

Another oceanographic feature studied utilizing the sea surface height data is the eddies and is discussed in the seventh chapter. In this chapter, inter- and intra-annual variability of Laccadive high and low, Somali eddies, Arabian anti-cyclonic eddy, cyclonic and anti-cyclonic eddies in the Bay of Bengal and Sri Lanka dome are explained. The formation of Laccadive high and low off the southeastern Arabian Sea during winter and summer respectively is related to the radiation of Rossby waves from the coastally trapped Kelvin waves. Somali eddies are formed near the Somali coast during the southwest monsoon season whereas the Arabian anti-cyclonic eddy is formed off Arabia during pre-monsoon season. In the Bay of Bengal eddies are prominently seen throughout the year. The prominent anti-cyclonic eddies are found east of Sri Lanka and in the northern Bay during January-June. A cyclonic eddy, known as Sri Lanka dome, as formed east of Sri Lanka during the southwest monsoon period. All these eddies showed large inter- and intra-annual variability in their location, time of formation, dimension and dissipation.

In the last chapter, the major finding of this thesis is summarized. Limitations of the work and the scope for improvements are also discussed.