Summary

The oceans which cover about 70% of the earth’s surface play a major role in driving its climate system (Mellor, 1996). The oceans act as thermal flywheels. They are huge reservoirs of heat making them key regulators of the earth’s climate system. The Indian Ocean is only the third largest ocean of the world. Yet it is considered to be highly complex and the least understood of all the oceans. The Indian Ocean is an ideal “laboratory” for studying a variety of phenomena related to ocean dynamics such as coastal, equatorial and sub-tropical ocean circulations as also the time dependent response of the ocean to changing wind forcing. Moreover, the Tropical Indian Ocean (TIO) is of paramount importance to the oceanographers and meteorologists as it experiences seasonally reversing monsoon winds and is land-locked on its northern side unlike Atlantic and Pacific oceans.

In oceans, the temperature profile at any given point can be divided into three different zones; the mixed layer zone, within which most of the ocean parameters remain constant, the thermocline zone, wherein the temperature changes rapidly with respect to depth and the deep ocean, where the temperature is low and remains almost constant along with depth. The mixed layer, because of its proximity to the sea surface is practically in direct contact with the atmosphere. For this reason, the mixed layer is considered to be an active participant in various air-sea interaction processes, which in turn drive the climate. For the TIO, the middle layer has varying temperature scales from 17-24°C. The temperature of 20°C falling in this zone is a good indicator of thermocline. So, conventionally we define thermocline depth to be the depth of the
20°C isotherm, hereafter referred to as D20. On interannual time scale, the mixed layer depth is strongly influenced by thermocline variability.

Since analyzing thermocline variability is the key objective of this study, we must have sufficient tools to monitor the processes involved therein. Variability could be both spatial as well as temporal. The regional variations are included in spatial variability and seasonal (intraseasonal too) changes lead to temporal variability. We have used buoy observations, satellite data as well as Ocean General circulation Models (OGCMs) to study the thermocline variability.

**Objectives of the Thesis**

- To validate reanalyzed and satellite derived wind products using the available *in situ* observations and also to inter compare the two wind products among themselves.
- To analyze the variability of thermocline depth (D20) in the TIO through model simulations.
- To establish a relationship between D20 and sea level anomaly (SLA) through an analysis of the principal modes of their variability.
- To analyze the impact of altimeter SLA assimilation on D20 simulation.
- To study the interannual and intraseasonal variability of D20 in the TIO.

A step-by-step approach to achieve these objectives is presented in detail in the thesis, which is divided in six major chapters. Chapter wise summary of the work is as follows:
Chapter-1 describes the literature survey on the thermocline variability including the physical processes responsible for D20 variability. Along with this the importance of D20 and various approaches to study thermocline variability have also been outlined in this chapter.

Chapter-2 gives the description of the OGCM used in the study. The model is based on Modular Ocean Model -version 3 (MOM-3) acquired from Geophysical Fluid Dynamics Laboratory (GFDL), National Ocean Atmosphere Administration (NOAA). Details of the underlying principles and assumptions on which model physics is based and the fundamental equations used in the model are given in this chapter. The chapter discusses the model grid structure, domain and various boundary conditions used during the study. All the atmospheric quantities used to force the model viz., daily mean air temperature at 2m height \((T_a)\), specific humidity at 2m \((q_a)\), zonal \((U_{10})\) and meridional \((V_{10})\) component of wind at 10m height, net shortwave radiation \((Q_s)\) and net longwave radiation \((Q_l)\) at sea surface were obtained from the National Center for Environmental Prediction (NCEP) reanalysis (Kalnay, 1996).

Twin experiments are performed for the period 2004-2008 with the same input fluxes and different wind products, one uses reanalyzed wind and the other utilizes QuikSCAT scaterometer-derived wind. With the availability of Oceansat-2 scatterometer (OSCAT) derived winds, another set of experiment (similar to the first set) has been performed for 2011, where QuikSCAT winds are replaced by OSCAT winds. The respective wind products are validated at the available RAMA buoy locations.
Chapter-3 describes the mean features of thermocline, includes a comparative study of thermocline simulated through each of the experiments performed and proposes a new approach of computing thermocline depth (D20) in the Arabian Sea using satellite-derived Sea Level Anomaly (SLA). The method involves the comparison of dominant modes of variability of each of the parameters (D20 and SLA) and the modes are isolated by Empirical Orthogonal Function Analysis (EOF), which is an efficient way to correlate two sets of spatiotemporally distributed data. This technique is mathematically described in one of the sections. This method of estimating D20 from SLA advocated here could be used as an efficient and attractive alternative for estimating basin-wide fields of D20 in the Arabian Sea using only satellite data. This signifies an enormous computational advantage, since for computing D20, one needs only the satellite altimeter-observed SLA and the pre-computed EOFs of SLA and D20. This is in contrast to the huge computing resources required to run an OGCM. A similar attempt was made in the Bay of Bengal, where such a relationship could not be established.

Chapter-4 introduces a technique of combining model data with observed data to provide a state analysis of the system which is better than that could be obtained using just the observed data or model data alone. This technique is termed as assimilation and this chapter focuses on the impact of altimeter data assimilation on the simulations of the model. Apart from discussing details of the specific data assimilation scheme used here, a brief overview of previous studies dealing with data assimilation in ocean circulation models is also included. Altimeter data have been assimilated in our model using the water property conserving scheme (Cooper and Haines, 1996).
Two runs of the model have been conducted for the year 2004 in the TIO. In one of the runs, altimeter data have been assimilated sequentially (ASSIM-R), while in another run, assimilation has been suppressed (CNTL-R). An assessment of the strength of the scheme has been carried out by comparing the D20 simulated through the experiments (ASSIMD20 and CNTLD20 respectively) with those at RAMA buoy (90°E, 1.5°S) and with ARGO data.

It has been found that the assimilation exhibits a significant positive impact on the model simulated SST and D20 and also improves the forecast capability of the model. The assessment/inter comparison is done using D20 derived from GODAS temperature profiles. It has been found that the error in case of ASSIMD20 is less than 18m practically everywhere and in most of the regions, it is of the order of 12m. (Mankad et al., 2012). Also the correlation improves from 0.51 (in case of CNTLD20) to 0.63 (in case of ASSIMD20).

Chapter -5 discusses the variability of D20 in the Indian Ocean and the causes responsible for this variability. Two periodicities (30-60 day and 90-day) are found in the equatorial Indian Ocean circulation. Although detailed diagnostics of these periodicities have been carried out using various datasets and numerical models, analysis of intraseasonal thermocline variability has so far not been carried out in the equatorial Indian Ocean. In this study, which is albeit of a preliminary nature, we have carried out spectral analysis of this parameter at a RAMA buoy location. In support of this intraseasonal variability, other parameters like sea level anomaly, observed and simulated near-surface current and scatterometer observed zonal winds have also been subjected to spectral analysis. Band pass filtering of D20 has also been
effected to isolate these periodicities. The study suggests that there is indeed such an intraseasonal oscillation in D20. Both the periodicities appear to be linked to the direct wind-forced response of the equatorial Indian Ocean.

Chapter-6 summarizes the entire study and the major findings of the work done. The major conclusions comprise of new approach of computing D20s, using satellite-derived SLAs in the Arabian Sea and application of a relatively simple algorithm for assimilating mapped altimeter data in a coarse resolution OGCM in which assimilation has been restricted to the Indian Ocean. This scheme works well in the Indian Ocean and lays a positive impact on the simulation of D20.