Abstract

The upper ocean is the most variable and dynamically active part of the marine environment that couples the underlying ocean to the atmosphere above through the transfer of mass, momentum and energy. The oceanic surface layer assumes many shapes and forms. More common among others are, inversion layers, mixed layers, sonic layers, and barrier layers. The thickness of mixed layer is an important parameter in determining the quantity of heat that is available for exchange with atmosphere which is capable of triggering several ocean-atmosphere coupled processes. Mixed layer also plays an important role in determining the chlorophyll biomass and biological productivity of the upper ocean. Also ocean being almost opaque to electromagnetic radiation, sound is the only means to probe the ocean interior. Further, acoustic system plays a very important role in many civilian and military strategic applications. The depth of sonic layer plays an important role in refraction of sound rays traveling in the ocean, which in turn affects the sonar detection ranges. The present work is an attempt to study basin-scale variability of the mixed layer and sonic layer in the Arabian Sea, their inter relationship and factors responsible for it. In literature though sonic layer is considered almost equal to mixed layer, in this thesis a study is made, to understand how tightly these two are coupled during different seasons.

After the introduction in Chapter 1 of the thesis, various data set and methodologies used for the work in this thesis is presented in Chapter 2. Data for the proposed work mainly comprises of in situ temperature and salinity profile data from the Argo floats acquired during the period 2002 – 2008. From the above source 15585 profiles of temperature and salinity were extracted. All the profiles were quality controlled by passing them through 18 quality control checks as per the guidelines implemented by the International Argo Data Management Team. Further each profile was visually checked for obvious errors and spurious values were removed. The quality control procedure reduced the profiles to 14572. The atmospheric data such as monthly mean climatology of the incoming short wave radiation, wind speed, evaporation minus precipitation and net heat flux obtained from Comprehensive Ocean Atmospheric Data Sets (COADS) for the period 1950 – 1995 were used to study the factors responsible for the variability of mixed and sonic layers. Various objective analysis methods like
Krigging, Kessler & McCreary used for gridding irregular in situ observations on regular grid is also described in detail. The equation used for estimating sound velocity profile, various criterions for estimating mixed layer depth (MLD) and the one chosen for the work in the thesis, sonic layer depth (SLD) estimation method are all given in detail in this chapter.

Changes in atmospheric forcing cause variations in mixed and sonic layers. In order to understand physical forcing that is responsible for the basin-wide variability of mixed layer and sonic layer depth, all possible atmospheric forcing were examined in Chapter 3. Towards this the atmospheric forcing such as incoming short wave radiation, net heat flux, wind speed, wind-stress curl and evaporation minus precipitation were analyzed and presented in this chapter.

The seasonal variability of upper ocean parameters i.e MLD and SLD, their inter-relationship and factor responsible for their variability are presented in detail in Chapter 4. It is observed that strong stratification induced by peak solar heating and subsequent highest net heat gain by the ocean caused shoaling of MLD and SLD during March – May. During summer monsoon period (June – September) a remarkably strong and steady jet called Findlater jet is developed over Arabian Sea. This strong jet imposes a wind stress curl that lead to Ekman upwelling to the north and west of the jet, off the coast of Arabian Peninsula and Ekman downwelling to the south and east of it, in the central Arabian Sea. It is observed that Ekman downwelling caused by the negative wind-stress curl led to deepening of MLD and SLD in the central Arabian Sea, where as Ekman upwelling caused shoaling of MLD and SLD all along the coast of Oman and along the west coast of India.

During inter monsoon period (October – November) shoaling of MLD and SLD is predominantly observed owing to strong stratification induced by secondary peak observed in solar heating, weak winds and high net heat gain by the ocean, which are incapable of mixing the surface layers. During winter monsoon period (December – February) moderate, cool and dry winds are observed over Arabian Sea by which the longwave heat loss at the sea surface is high and evaporation minus precipitation is found to be at it peak. All these factors cause buoyancy flux to be destabilizing. These destabilizing buoyancy fluxes caused deepening of mixed layer and sonic layer.
Abstract

An interesting feature of SLD is observed in the south eastern Arabian Sea (SEAS) during winter monsoon period (Dec – Feb). Deep SLD were observed along the south west coast when MLD is found to be shallow. The possible reasons for the observed phenomenon are further explored. It is observed that temperature inversions (TI) form in SEAS during December and prevail up to early March. Also during this period the East Indian Coastal Current and Winter Monsoon Current acts together to bring low salinity water from Bay of Bengal in to SEAS which is observed to be cooler than ambient waters in SEAS. The advection of cooler low saline water over warmer saltier water leads to the formation of TI. As sound velocity is more sensitive to temperature than salinity, SLD is found to deepen tracing up to the depth of inversion. Where as the high stratification caused by the presence of low salinity waters hampers mixing and hence shoaling of MLD.

Observing the dependence of sound velocity on temperature, a new method is proposed for utilizing all the available temperature profiles for estimating SLD in Chapter 5. In general salinity data over the oceanic region is sparse compared to temperature alone profiles. Climatological temperature/salinity relations have been obtained to infer salinity from temperature data by many researchers. A new method of estimating SLD is proposed for maxing use of voluminous temperature profiles besides other XBT data. This method proposes estimation of SLD using temperature from XBT and salinity from World Ocean Atlas 2001 (WOA01) climatology. This method is demonstrated by using Argo temperature and salinity profiles. SLD is first estimated from Argo T/S profiles (SLD_A). The Argo salinity profiles are then replaced by climatological salinities and SLD is re-estimated (SLD_C). The monthly RMS difference between the two estimations is observed to vary between 3 – 12 m. On an average SLD_A and SLD_C matched in more than 90% of cases. To further check the robustness of proposed method skill score is estimated. Perfect skill score of value 1 is observed between SLD_A and SLD_C ovr most of the study region, indicating the use of climatological salinity in place of observed salinity.

As most of the studies on MLD and SLD in Arabian Sea relied on climatologies or historical hydrographic data or limited in situ observations obtained prior to the start of Argo program, a major goal of this thesis work is to:
1. Check usability of Argo data for estimating MLD and SLD which is dense both spatially and temporally.

2. Study in detail MLD & SLD variability in Arabian Sea, their inter-relationship and factors responsible for them.

3. Identify the conditions under which MLD and SLD differ in time and space in Arabian Sea. Exploit the statistical relationship between MLD and SLD in order to provide a means of predicting SLD from MLD estimates and vice versa.

4. Propose a method to utilize voluminous number of temperature alone profiles, for estimating SLD. This is particularly useful when temperature only profiles (like XBT which is easy to operate) are available while at sea.