SEASONAL VARIABILITY OF UPPER OCEAN HEAT CONTENT IN THE NORTH INDIAN OCEAN

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ABSTRACT

The thermal energy needed for hurricanes and monsoons come from the upper layers of the oceans, but not from the thin layer represented by sea surface temperature alone. Different ocean layers have different modes of variability of the Ocean Heat Content (OHC) due to the ocean-atmosphere interaction that varies with the ocean depth. However, which layer of the ocean has which type of variability is not precisely known due to the non-availability of the in situ measurements at required spatial and temporal scales. Here, we use the OHC estimated using the remote sensing observations of sea surface height anomalies and sea surface temperature estimated at a spatial scale of 0.25 degrees on daily basis and report the OHC variability of the north Indian Ocean during 1998–2014. Daily, monthly, seasonal and annual variations are estimated for the Arabian Sea (AS) and the Bay of Bengal (BoB) separately. Seven layers (surface to 50m, 100m, 150m, 200m, 300m, 500m and 700m) are considered for this analysis. OHC has both temporal and seasonal variations. The OHC values are high in BoB compared to AS for all months at all depths.

1. INTRODUCTION

The ocean has the largest heat capacity of any single component of the climate system, and over the past 40 years, it has been the dominant source of changes in global heat content (Levitus et al., 2001). The ocean thermal energy is one of the key factors fueling the genesis and propagation of cyclones. Utilization of this thermal energy to improve the atmospheric models for cyclone and monsoon predictions has been realized in recent years (Nagamani et al., 2012). Ocean Heat Content (OHC) and Ocean Mean Temperature (OMT) are important ocean climatic parameters required for atmospheric and oceanic studies like cyclone and monsoon predictions and ocean heat transport estimations. Hence, a precise estimate of OHC is essential for understanding the role of oceans in assessing the past and future climate change. Heat content of a slice of the ocean can be estimated as a product of integrated temperature, density of sea water and specific heat capacity from the surface down to a required depth. It is obtained by summing the heat content of the ocean column from the sea surface to a particular depth (Suresh Kumar et al., 2014).

The best approach for computing OHC is to use the in situ measurements, but due to the limited availability of in situ temperature profiles in space and time, remotely sensed sea surface temperature (SST) and sea surface height anomalies (SSHA) are employed in the computation of OHC in the Indian Ocean. OHC derived from in situ temperature profiles from ARGO floats along with collocated SST, SSHA and OHC climatology are generally used to estimate OHC values at various depths using an artificial neural network model (Ali et al., 2012). SST is the skin temperature of a very thin layer of about a few micrometres of the ocean, and has direct interaction with atmosphere. It is only the oceanographic parameter used to represent the ocean heat energy. However, tropical cyclones and monsoons have long been known to interact with the deeper layers of the ocean than sea surface represented by the SST alone. The SSHA provides an integrated picture of ocean from bottom to surface. Typically, positive (negative) SSHAs correspond to more (less) upper OHC/OMT. Such information has been used to study tropical cyclones (Sharma et al., 2013). Since the SSHA is strongly correlated with the thermal structure of the upper ocean, the OHC can be estimated from this parameter over finer spatial and temporal scales on an operational basis. Ali et al., 2012 suggested a better method of estimating tropical cyclone heat potential from SSHA and SST using a neural network approach. Jagadeesh et al., 2015 also used a similar approach. The only difference is that heat content, mean temperature values are made available up to various depths 50m, 100m, 150m, 200m, 300m, 500, 700m and surface to 26°C isotherm instead of providing heat content values only up to 700m (Chacko et al., 2015). The parameters are estimated at various depths because as of now there is no database information on which layer of the ocean interacts with different atmosphere process. Daily, monthly, seasonal and annual variations are estimated for the Arabian Sea (AS) and the Bay of Bengal (BoB) separately.

2. DATA AND METHODOLOGY

Daily OHC of the North Indian Ocean (NIO) spanning $0\text{-}30^0$ N and $40\text{-}120^0$ E at 0.25° x 0.25° spatial resolution during 1998 to present available in NRSC Bhuvan website (nrsc.gov.in/bhuvan). The procedure adopted to estimate these products and their accuracies is given in Jagadeesh et al., (2015). The ocean layers used in this analysis are from surface to 50m, 100m, 150m, 200m, 300m, 500m and 700m depth for the years 1998 to 2014. Daily averages were obtained for Arabian Sea (AS) ($0\text{-}30^0$ N; $40\text{-}77^0$ E) and Bay of Bengal (BoB) ($0\text{-}30^0$ N; $77\text{-}98^0$ E) separately from 1998 to 2014. Similarly monthly, seasonal and annual average values also computed. Besides, standard deviation of OHC of all the layers at 0.25° spatial resolution has been computed using daily data.

3. RESULTS AND DISCUSSIONS

The 17-year average OHC, their standard deviations (SDs) and the coefficient of variations (CV), which is defined as SD divided by the respective averages of these 7 layers for the entire NIO as a whole are given in Table-1. OHC increases as the depth increases as this is the value integrated from surface to a depth. The values vary from 570.3 kJ/cm^2 to 4057 kJ/cm^2. Similarly, the SD also increases from 13.7 kJ/cm^2 at surface to 47.0 kJ/cm^2 at 700m as the OHC increases with depth. This is obvious because the upper layers of the ocean have maximum interaction with the surface radiation and fluxes, which have diurnal and seasonal variations.

Table 1. Average, standard deviation (SD) and coefficient of variation (CV) of Ocean Heat Content (OHC) of surface to 50m, 100m,150m, 200m, 300m, 500m and 700m depths.

Depth (m)	Average OHC (kJ/cm^2)	SD	CV (%)
50	570.3	13.7	2.4
100	1077.5	22.6	2.1
150	1478.5	29.7	2.0
200	1801.5	33.3	1.9
300	2346.9	37.5	1.6
500	3264.6	42.4	1.3
700	4057.7	47.0	1.2

For entire NIO basin spanning $0\text{-}30^0$N, $40\text{-}98^0$E, the monthly average values are computed for all the layers and these values are normalized to annual mean as shown in Fig1. It is clearly showing that as depth increases the variations are decreasing i.e. 50m has highest variations as compared to 700m layer.

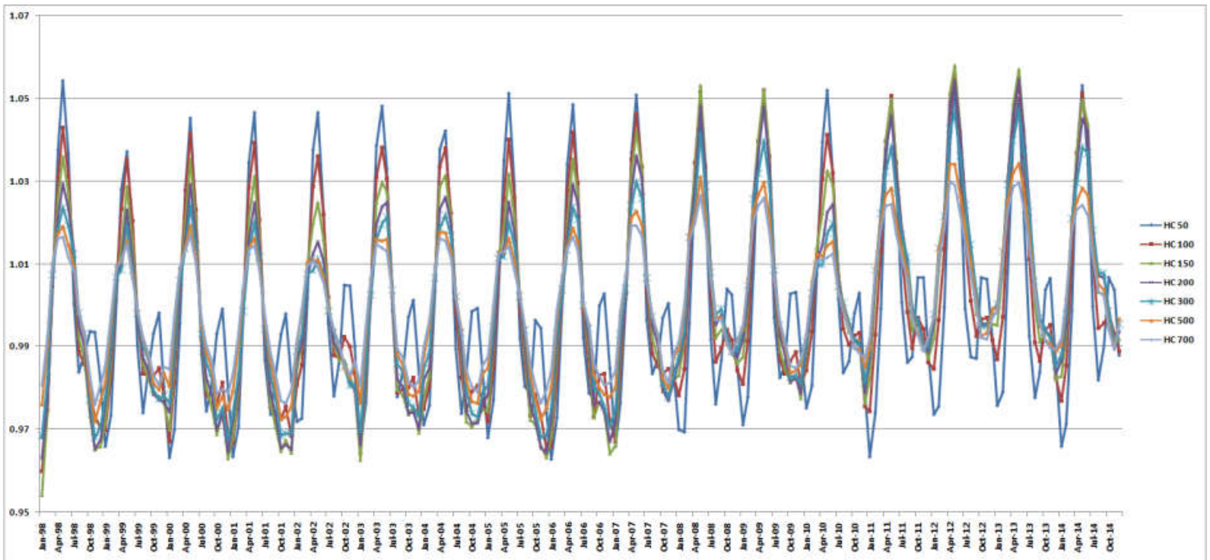

Figure 1. Time series of OHC (all layers) normalized to annul mean for NIO (0-25N; 40 – 98E)

Since the 50m layer has the highest variation, we selected this layer for further analysis. Monthly averages of OHC_{50} computed separately for AS, BoB are shown in Fig 2. The range of OHC in AS is from 526.9 to 597.14 kJ/cm^2, where as it is 544.15 to 605.31kJ/cm^2 for BoB with average min (max) of 531.3(594.1) kJ/cm^2 for AS and 553.7(602.2) kJ/cm^2 for BoB. From this analysis, it is clear that OHC of BoB more than that of AS with average OHC of 579 and 530 kJ/cm^2 respectively. On the contrary variation in AS is more than BoB with a 70kJ/cm^2 for AS, 61 kJ/cm^2 for BoB. This could be because the winds are stronger in AS (particularly during monsoon) than of BoB.

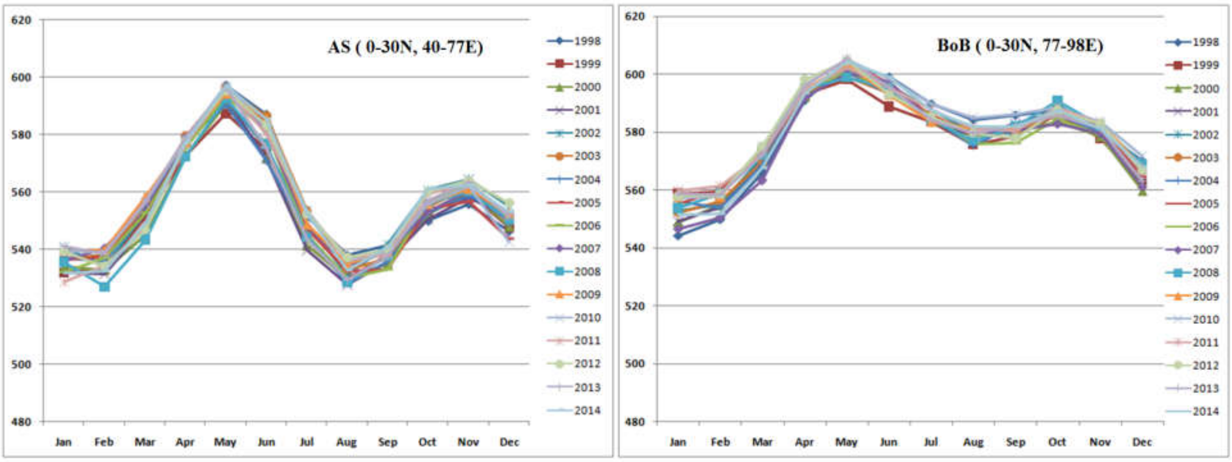

Figure 2. Monthly averages of OHC_{50m} for AS and BoB from 1998 to 2014.

The annual variation of OHC for AS and BoB (Fig 2) show bi-model oscillation in all the years with first peak in May and second peak in November for AS and October in BoB. The amplitude in AS is quite significant compared to that of BoB, The peak values and the minimum values during Jan-Dec are almost same but drop in heat content is more in AS compared to BoB in August. From July to August, drop in AS is quite high may be because of monsoonal winds and loss of heat such a drop is not seen in BoB, This drop is responsible in bringing the average heat content of AS less that of BoB. Since winds in AS are much stronger (particularly in monsoon season) the heat content of AS dropped prominently from June to August because of low winds in that region compared to BoB. Irrespective of performance of monsoon, the variations in OHC are not significantly changing. To confirm this we analyzed OHC of two contrasting years (2007 with annual average summer monsoon rainfall of 943mm and 2009 with 698.20mm) (www.imd.gov.in) but could not find any difference in OHC either in AS or BoB. This analysis reveals that irrespective of strong or weak winds during monsoon seasons, OHC of two regions are not affected.

The monthly OHC standard deviation values which are normalized to annual mean for 50m and 700m dephs are compared seperatly for entire north Indian ocean basin, arabian sea and bay of bengal shown in Fig3. It shows that the variations in BoB are more compared to AS and 50m layer is more variable than 700m may due to ocean-atmosphere interactions.

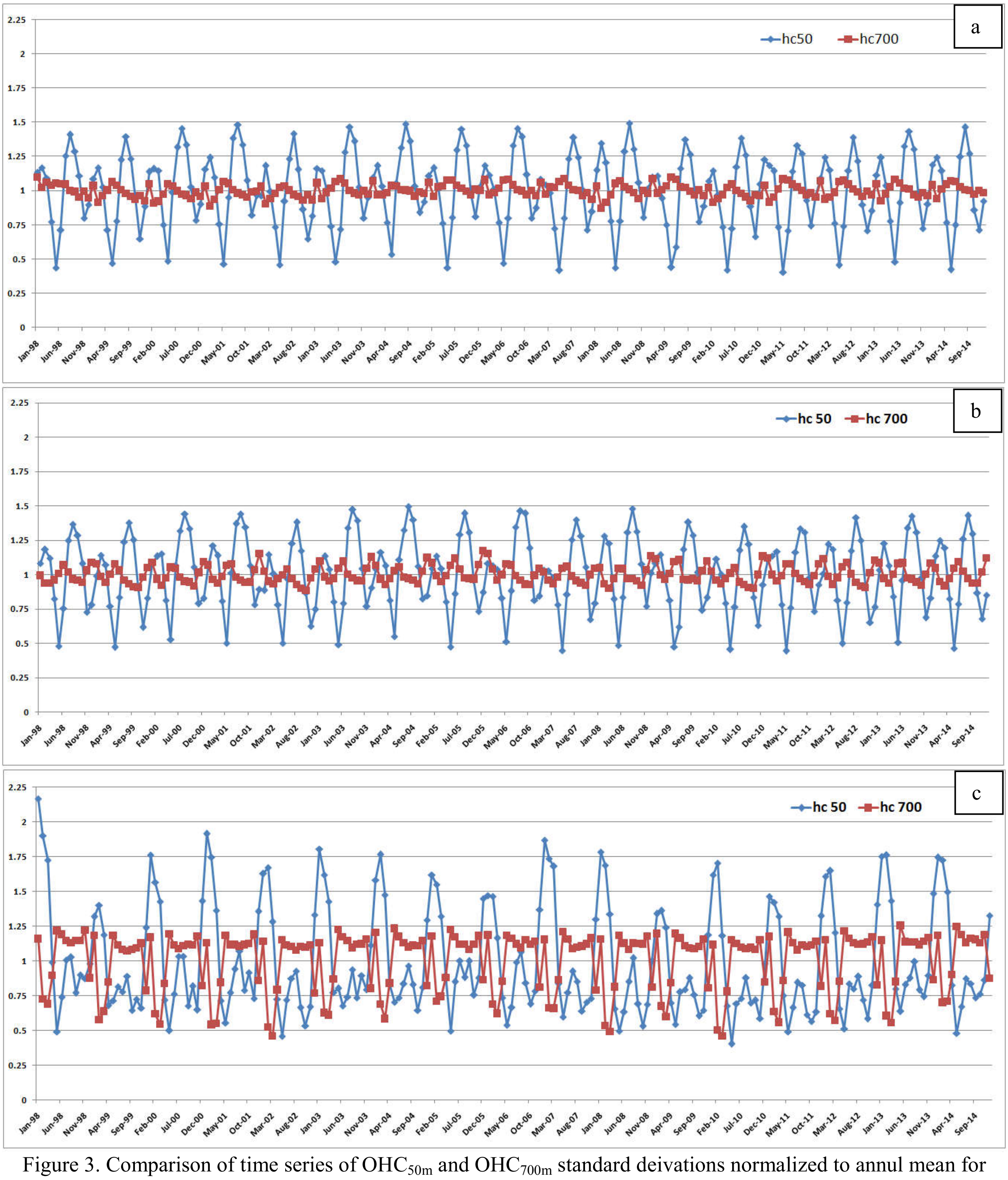

Figure 3. Comparison of time series of OHC_{50m} and OHC_{700m} standard deivations normalized to annul mean for a) NIO b) AS c)BoB

The spatial distribution of OHC over NIO for four seasons (winter, summer, monsoon and post monsoon) (Fig. 4) has more OHC in summer season compared to winter season as expected. In all the seasons OHC increases from west to east, the influence of Somalijet in increasing the evaporation and consequently descreasing the OHC is clear in the western AS. Compared to other seasons, heat content of BoB is less in the post monsoon period primaly due ot the cyclonic effect. High heat content in AS mini warm pool is also seen during winter, monsoon seasons. Nagamani et al., 2016 reported that heat content of this region is increasing and they hypothesized that this increase is reducing overall monsoon performance.

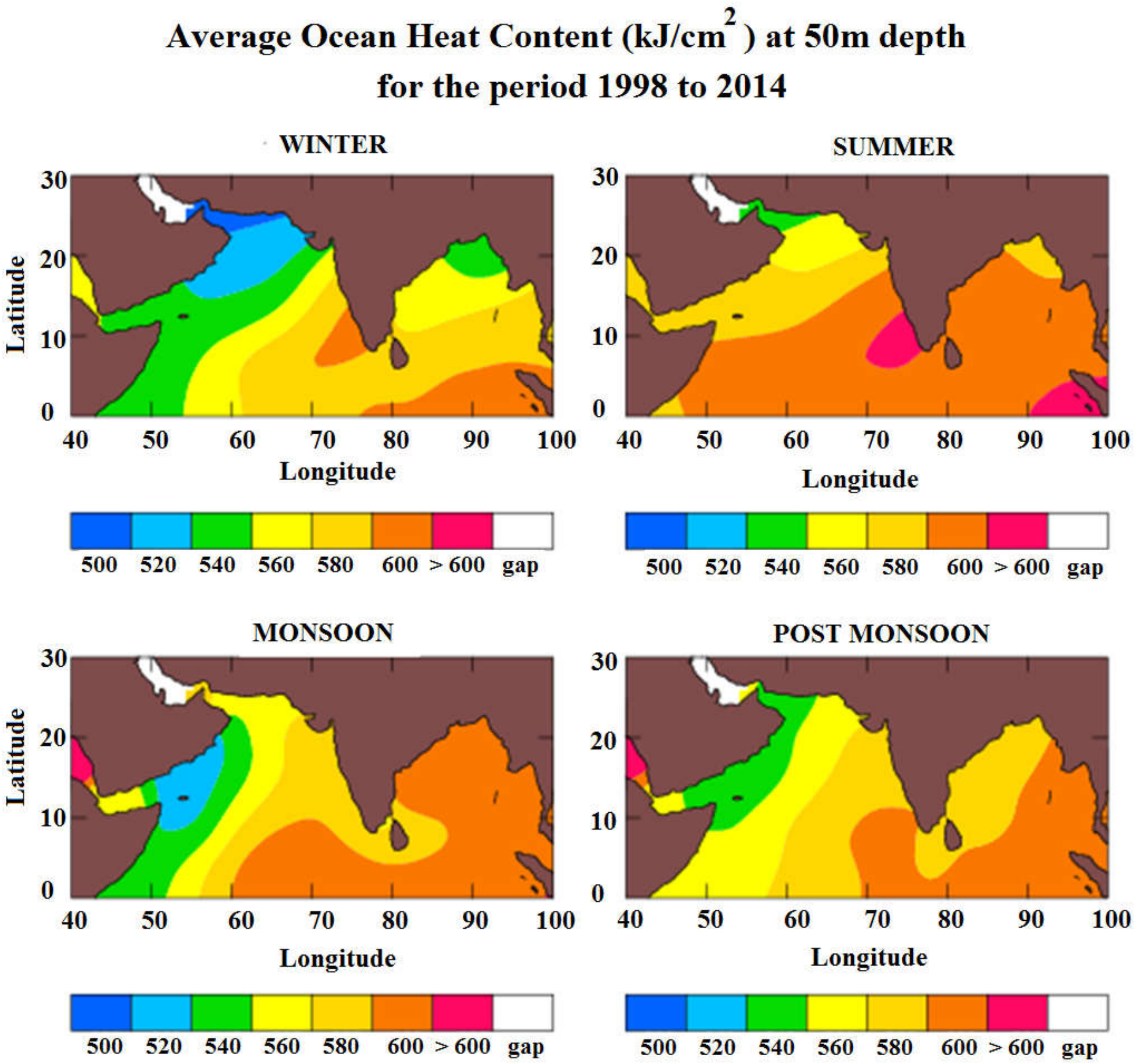

Figure 4. Seasonal variation of OHC_{50m} for different seasons from 1998 to 2014.

4. CONCLUSIONS

As which layer of the ocean has which type of variability is not precisely known, the OHC values are estimated using the remote sensing observations of sea surface height anomalies and sea surface temperature at different depths, surface to 50m, 100m, 150m 200m, 300m, 500m and 700m. For all these depths the average, standard deviation and coefficient of variations are computed. The fluctuations are more in AS compared to BoB but peak values are almost matching for both AS and BoB. The spatial distribution of OHC over NIO for four seasons (winter, summer, monsoon and post monsoon) are also computed and found that OHC is more in summer season compare to winter season.

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