



Association of meridional temperature and OLR over India using satellite observations

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Abstract

To investigate association between meridional temperature and Outgoing longwave Radiation (OLR) over Indian region starting from Arabian Sea (AS) to Bay of Bengal (BOB) analysis is performed using Atmospheric Infra Red Sounder (AIRS) satellite temperature and outgoing long-wave radiation (OLR) data of 6 years (2005-2010). Temperature variations and OLR have been studied and their association have been shown for summer March-April-May (MAM), summer monsoon June-July-August-September (JJAS) and winter November-December-January-February (NDJF) months. It was observed that during MAM and NDJF the temperature increases latitudinally by $\sim 2\text{-}3\text{K}$ and $\sim 4\text{-}5\text{K}$ from 3.5°N to 20.5°N respectively. However the temperature decreases by $\sim 2.0\text{-}2.5\text{K}$ during JJAS. Analysis suggests the latitudinal change in temperature occurs due to low OLR (proxy of convection) and its northward progression during summer monsoon. Correlation coefficient (R_{xy}) between OLR and temperature is computed latitudinally (3.5°N to 20.5°N) at different longitudes which is found quite high (~ 0.92) for summers and winters. However during JJAS, R_{xy} is negative (~ -0.73) over 60°E and 70°E longitudes but it turns positive (~ 0.92) over 80°E and 90°E longitudes (which is convectively active region) suggesting a close association between temperature and OLR.

Keywords: meridional temperature, AIRS satellite data, Indian summer monsoon, OLR

Introduction

In the last few decades, there has been an increase in interest and efforts to investigate the variability of temperature field at different time scale and over different regions. Most of the analyses focussed on estimating trends in temperature for both hemispheres (Borzenkova *et al.* 1976; Barnett 1978) [6, 3] as well as for the entire Earth (Mitchell 1963; Angell and Korshover 1975, 1977) [15]. Angell and Korshover (1975, 1977) [15] have studied the temperature variations from surface to 100 hPa globally. They investigated the global variation in temperature during the period 1958 – 1975 using several radiosonde stations. However, the hemispheric and global studies mask much detail concerning the spatial patterns of the climatic change. Therefore, regional scale studies of temperature variations proved to be quite relevant (Hingane *et al.* 1985) [8].

Past studies over Indian region are confined to the annual and seasonal variation of temperature for some individual stations (Pramanik and Jagannathan, 1954) [16]. They used large dataset (30 stations for 55-75 years) and concluded that there is no general tendency of a systematic increase or decrease in the temperatures. However, oscillatory tendency has been observed at plenty of satellite stations. Jagannathan and Parthasarathy (1972) [9] analysed the time series of mean annual temperature and characteristic parameters using about 90 years of data, representing seasonal variation of temperature over another set of 8 Indian stations. They, however, reported increasing trend in the mean annual temperature at Calcutta, Bombay, Bangalore and Allahabad, and decreasing trend at Fort Cochin. However, there was no report about the meridional change in temperature and its association with OLR in their studies.

Hingane *et al.* (1985) [8] presented the salient features of long-term variation of surface air temperature for India as a whole, as well as for different regions in the country. They

collected mean monthly temperature data from 73 Indian stations and calculated all India means of the anomalies for each season, while calculating the averages the differences in data periods for individual stations have been considered. To identify the regional patterns of temperature variation within the country, three types of classification i.e. regional, latitudinal and longitudinal have been made and the means are computed. They have also shown that the mean annual temperature has risen by about 0.4°C in India during the past century.

Until recently, due to lack of satellite observations, there was no information about the temperature changes either over long term basis or spatial and temporal changes at high resolutions over oceans covering Indian region. Though there have been some ship observations campaigns that pertain to investigate the temperature changes during summer monsoon at some particular locations in Arabian sea as well as Bay of Bengal (Bhat *et al.* 2001, 2002; Jain *et al.* 2010, 2011) [4, 5, 10, 11]. In these ship observations, the temperature near the tropopause height during the active phase of convection has been observed to be cooler by $\sim 2\text{K}$ than that observed during the weak phase of convection.

All the above mentioned studies are focused on either annual variation in temperature or association of temperature with other parameters over Indian region, there has been dearth of information on monthly, seasonal and meridional variation of temperature on a fine spatial and temporal scale. With the advent of technology and sensitive instruments like Atmospheric Infrared Sounder (AIRS) on board the NASA's Earth Observing System (EOS) satellite, we are now able to observe the change in temperature globally on a fine scale covering AS, Indian land region and BOB region which could not be done extensively in the past.

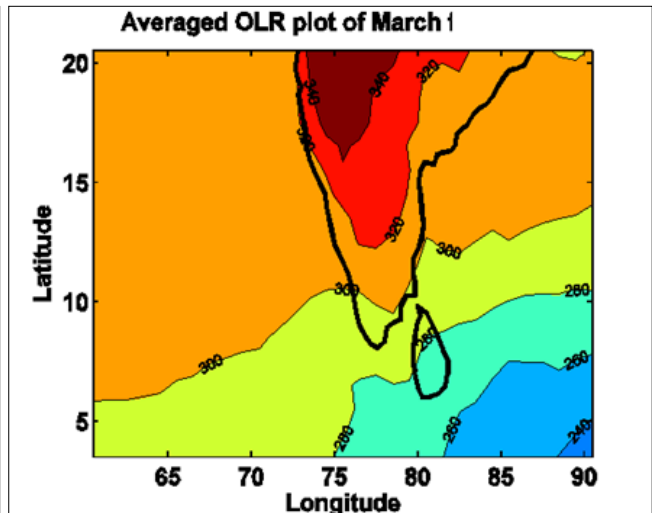
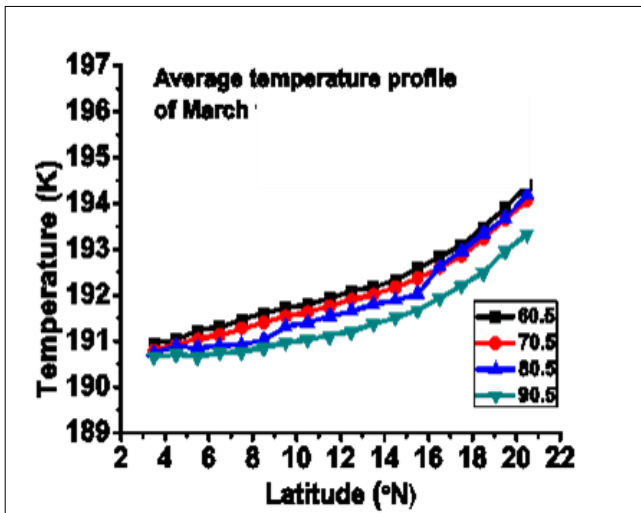
The main objective of this study is to show the existence of meridional temperature gradient over Indian region (3.5°-20.5°N, 60°-90°E) covering Arabian Sea and BOB and its association with OLR using AIRS data. To examine the seasonal latitudinal variations in temperature and its association with OLR, we have analysed 6 years (2005-2010) of monthly averaged temperature data and OLR data during March-April-May (MAM), June-July-August-September (JJAS) and November-December-January-February (NDJF), which are the representation of summer, summer monsoon and winter seasons, respectively. This paper is organised in the following manner: Data is described in section 2. Results are analysed in section 3, and summary and concluding remarks are given in Section 4.

Data

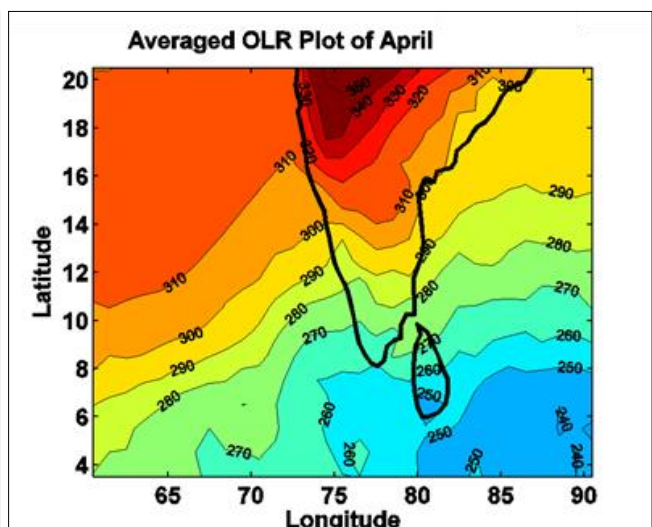
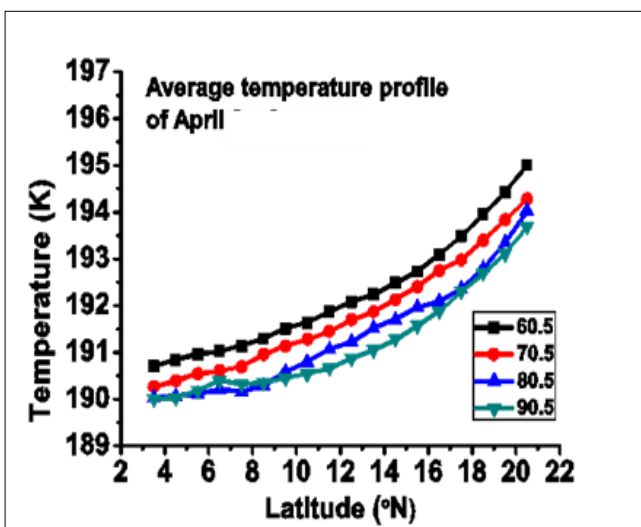
We have used AIRS (AIRX3STM) version 5 level 3 research quality product (<http://airs.jpl.nasa.gov/>) for our analysis. Each product is separately derived from Microwave (MW)-only retrievals and combined

Infrared/Microwave (IR/MW) retrievals (using cloud clear algorithm method as described by Susskind *et al.* (2003)^[17]. AIRS is the first of a series of satellite sensors that exploit high spectral resolution (Chahine *et al.* 2006)^[7] and broad spectral coverage of the mid infrared to improve the retrieval accuracy of passive infrared sounding. AIRS has multiple advantages, it is helpful to distinguish two modes of use: as a pure radiometer, producing radiance measurements at multiple frequencies for assimilation into forecast models; and as a means for directly retrieving geophysical products, such as profiles of temperature, moisture, and ozone, independent of assimilation models. With the use of such high resolution satellite data one can examine the gradual and systematic northward change in temperature at a fine scale.

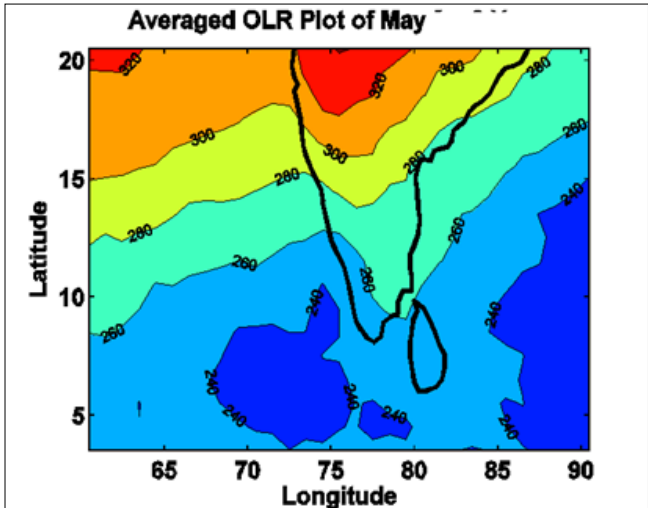
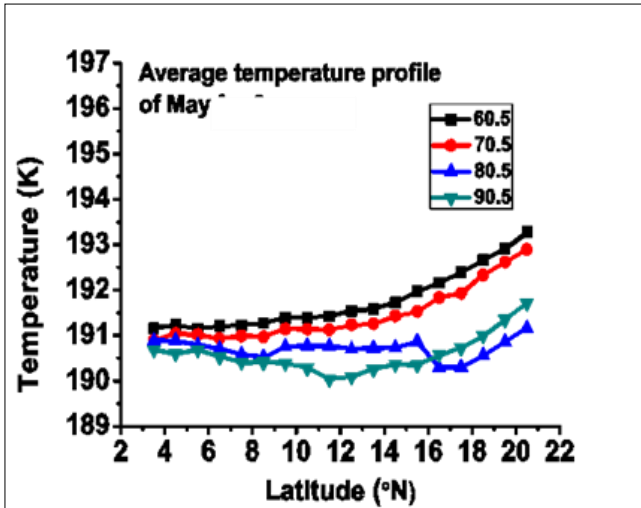
For the present analysis, monthly averaged temperature and OLR data over Indian region (3.5° – 20.5°N, 60° – 90° E) during MAM, JJAS, and NDJF for 6 years (2005-2010) with a high spatial resolution 1° × 1° have been used.



a

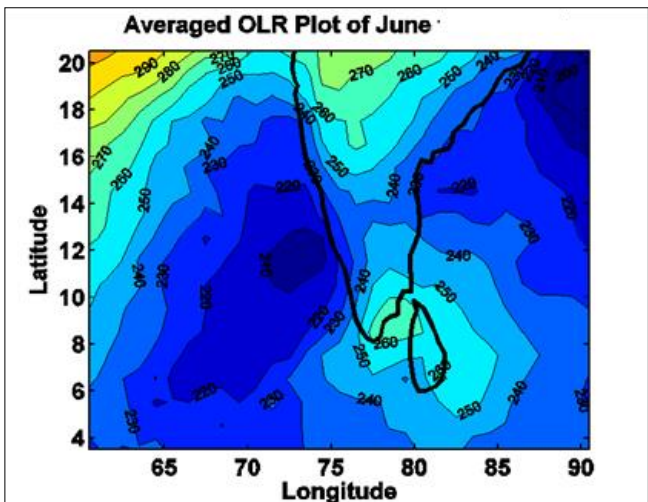
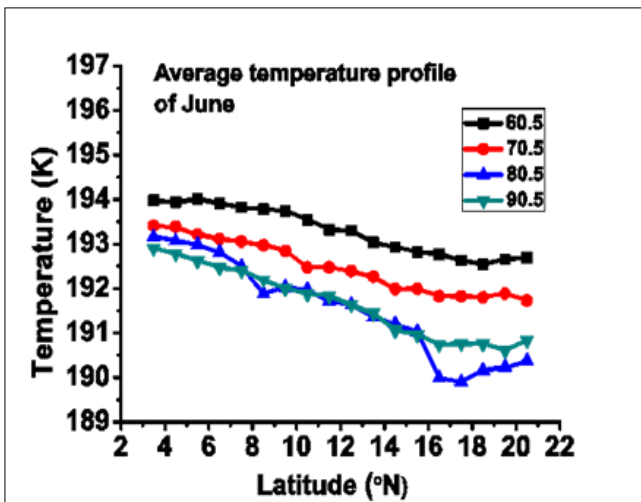


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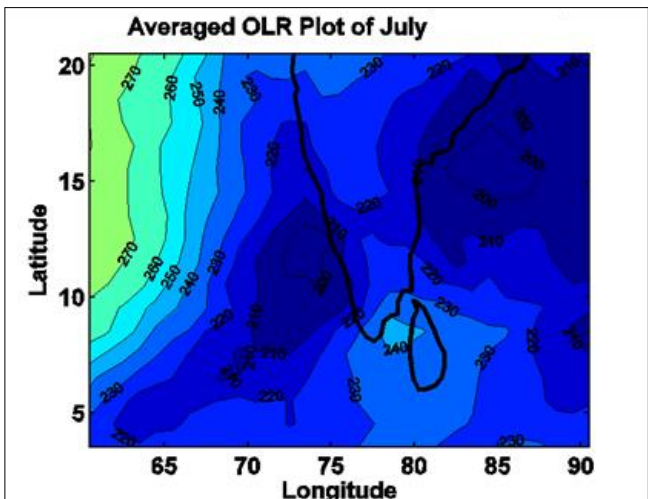
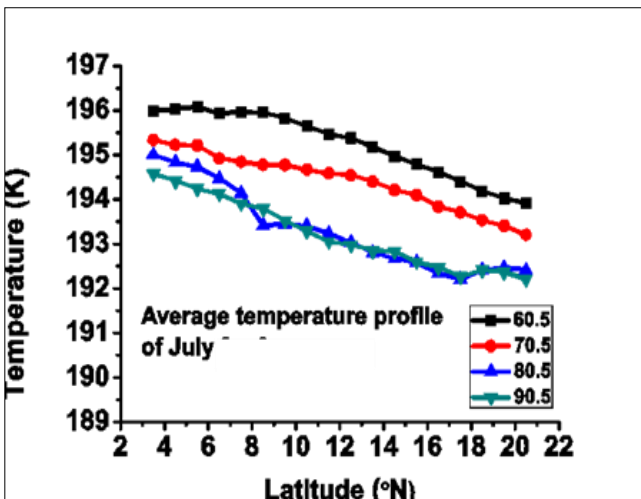


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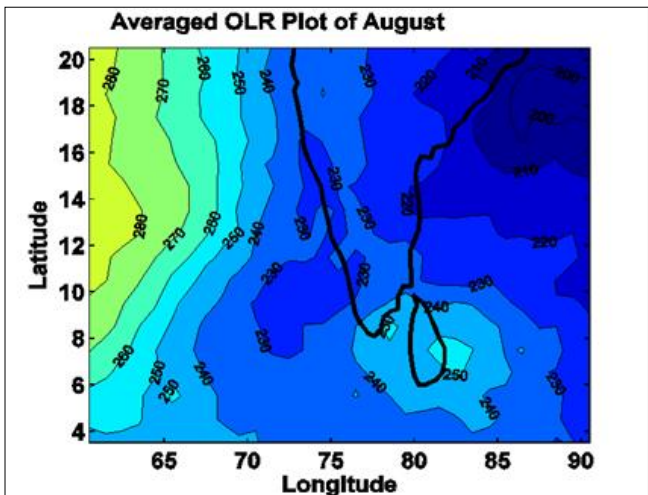
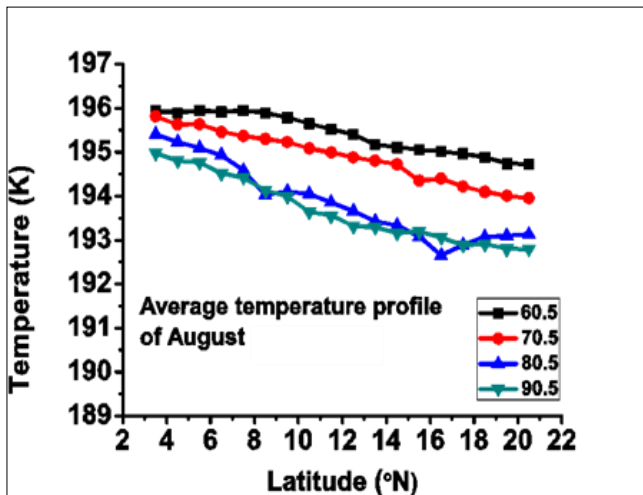
Fig 1 (a, b, c)



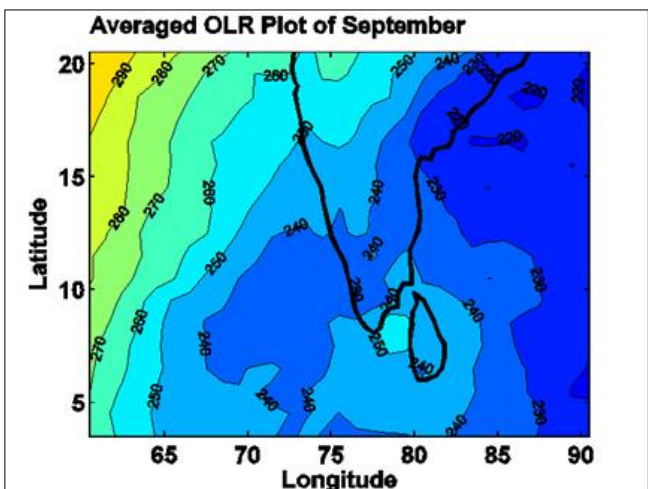
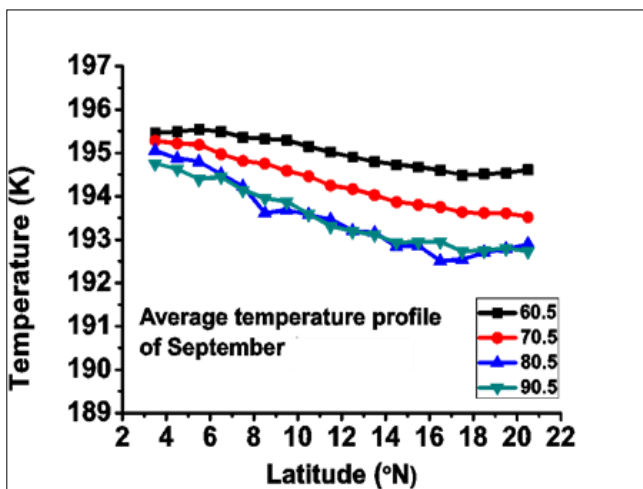
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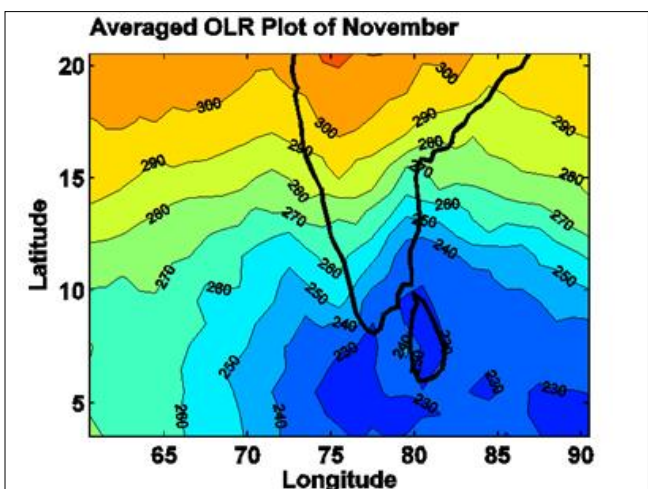
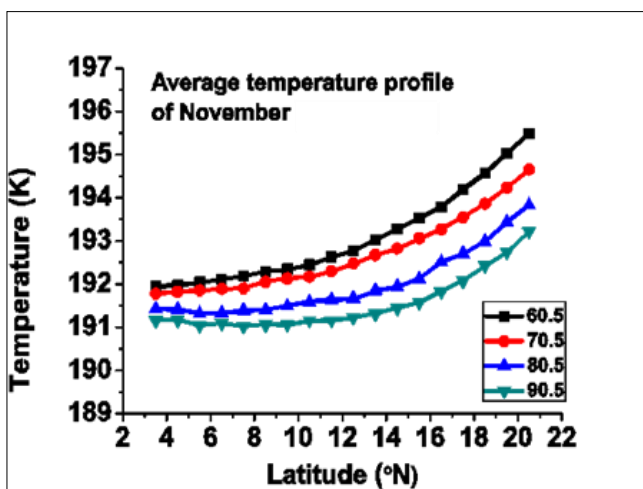


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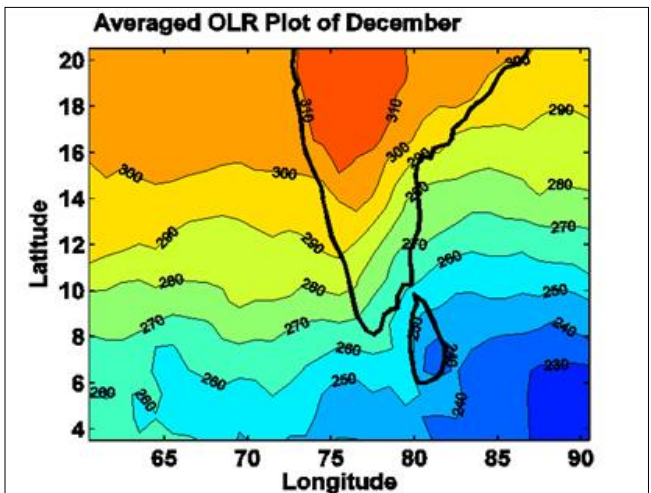
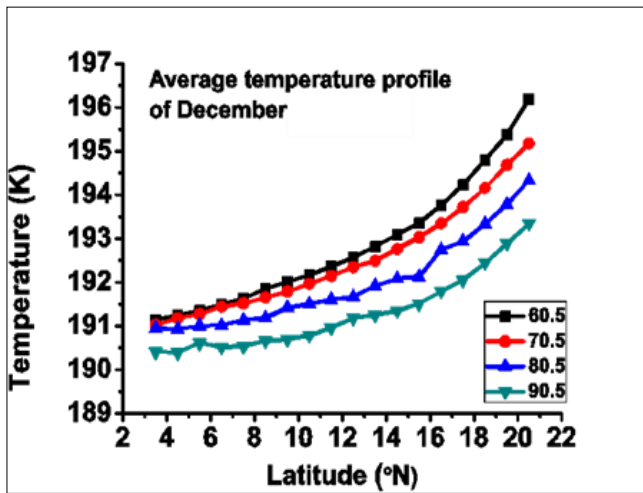


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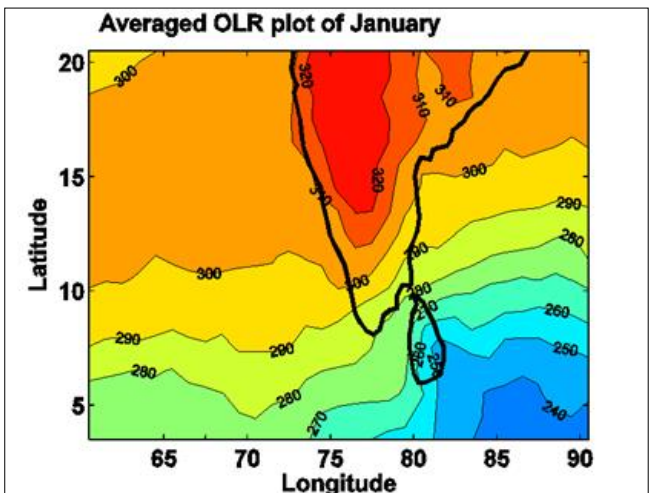
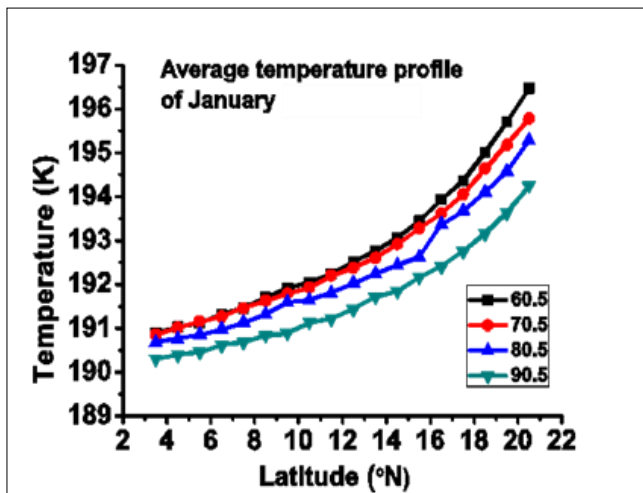
Fig 2 (a, b, c, d)



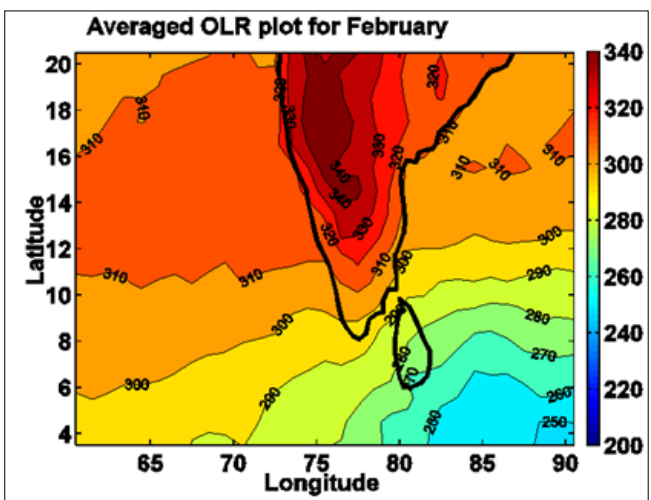
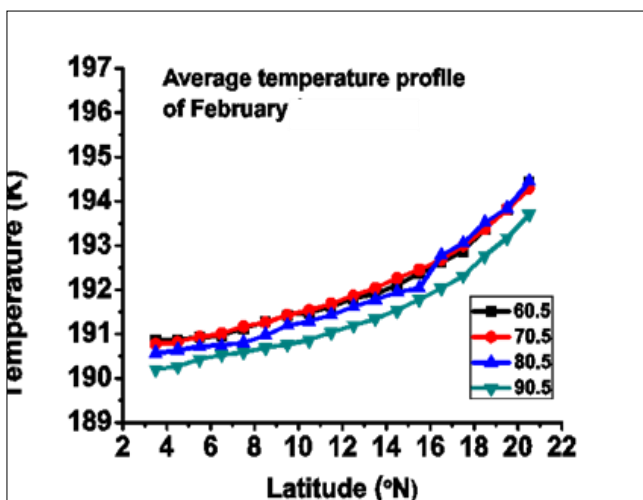
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Fig 3 (a, b, c, d)

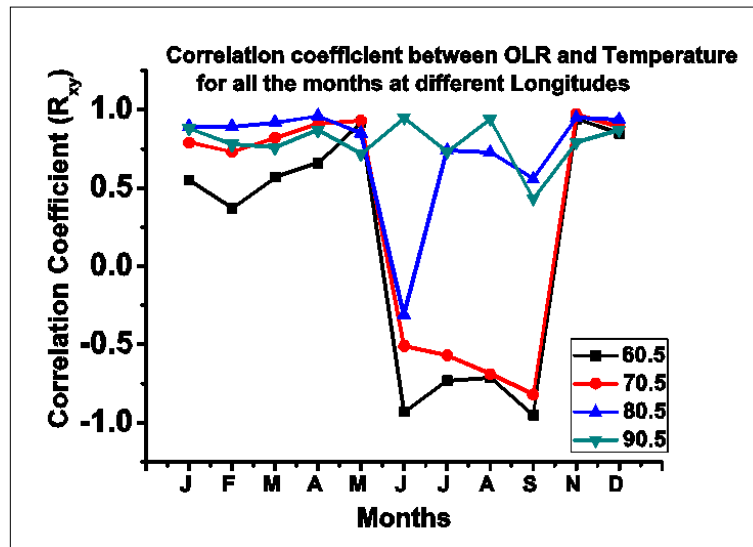


Fig 4

Results and Discussion

In this section we present the results pertaining to latitude-longitude sector 3.5° - 20.5° N; 60° - 90° E over the years 2005-2010 for summer (MAM), summer monsoon (JJAS), and winter (NDJF) months to analyse the similarities and differences in temperature variations. Average features of latitudinal variation of temperature (i.e. meridional temperature gradient) during MAM, JJAS and NDJF are computed and to examine the association between temperature variation and convection, we have also analysed 6 years of OLR data from AIRS. OLR data are taken as a proxy of convection.

1. Latitudinal Variation of average temperature and OLR during 2005-2010

Figures 1(a,b,c), 2(a,b,c,d) and 3(a,b,c,d) show the latitudinal variation of temperature and OLR at different longitudes for the summer, summer monsoon, and winter months respectively. Monthly averaged temperature data (spanned over 6 years) is plotted to show the average features of temperature variations during 2005-2010. Figure 1(a,b,c) left panels (for MAM) show the consistent rise in temperature (~ 2 - 3 K) on moving from 3.5° N to 20.5° N indicating the existence of latitudinal or meridional temperature gradient decreasing from ~ 0.18 K/deg. at 60° E to ~ 0.14 K/deg. at 90° E longitudinally. There has been some mention of temperature variation latitudinally (Kishore *et al.* 2006; Johny *et al.* 2009)^[13, 12] using satellite data, but their studies did not include any detailed quantitative analysis for this region. The change in temperature may occur due to the presence and northward movement of convective clouds. To explore the effect of convection on temperature, OLR data (taken as a proxy of convection) is analysed as shown in the right panels of figure 1. One can notice low OLR (~ 220 - 240 W/m²) area (indicated by blue patch) in figure 1, for summer months. This low OLR area further deepens, and become prominent in the range of 4° - 8° N covering AS and BOB regions, as we move from March to May. This feature of low OLR at the southern tip of Indian peninsula denotes the onset of Indian monsoon, which progressively moves northwards as shown in figure 2. In this region (4° - 8° N), the decrease in temperature, is associated with low OLR (enhancement in convection activity) as seen in right panels of figure 1.

To further examine the effect of convection and to describe the detailed feature of monsoonal effect on temperature we have analysed temperature and OLR data for June-July-August-September (JJAS) as well. The general features and association of temperature and OLR are shown in figure 2. It is observed during JJAS, temperature decreases latitudinally (from 3.5° N to 20.5° N) which is in contrast to the rising trend observed during MAM. The temperature decreases latitudinally for all the four consecutive months (JJAS). This result is almost similar to the analysis done by Li *et al.* (1996)^[14], that there is a reversal of meridional upper tropospheric temperature gradient during the active monsoon period, which is responsible for the change in nature of temperature variation. The temperature decreases by ~ 2.0 - 2.5 K as we move from 3.5° N to 20° N. The decrease in temperature is most probably caused by the northward movement of monsoon system. One can see the low OLR (~ 220 - 240 W/m²) which was around AS (4° - 8° N, 70° - 75° E) to BOB (4° - 8° N, 90° E) during May shown in figure 1(c), had shifted to 10.5° N- 13.5° N during June as seen in figure 2(a). It further extends over the region of 15° N- 20° N latitudes during July, August and September figure 2(b,c,d). This northward movement of low OLR (proxy of convection) causes the decrease in temperature as seen in figure 2. Keeping in view the above mentioned results, it appears that there is a close association between occurrence of low temperature and low OLR in the same regions. The latitudinal temperature gradient for JJAS increases from ~ 0.10 K/deg. to ~ 0.14 K/deg. as we move from 60° E to 90° E. This can be attributed to the decrease in temperature, for the latitudes 15° - 20° N over 80° - 90° E longitudes, caused due to the low OLR in the same region. Thus northward movement of Indian summer monsoon system is responsible in maintaining the northward temperature gradient.

In a recent study, as mentioned above Jain *et al.* (2010, 2011)^[10, 11] have shown that OLR and temperature in the tropopause region are highly correlated. They have used both ARMEX and BOBMEX campaign data along with satellite (CHAMP, COSMIC, KALPANA) observations to show the strong association of OLR and low tropopause temperature in a given region. However their study was focussed at a particular location and there was no information about the latitudinal variation at that region. We

further extended the investigation to the winter season as well, to analyse the overall seasonal behaviour of low OLR and temperature. Winter season temperature and OLR data are shown in figure 3. We observe that there also exists a temperature variation (increase in temperature) similar to summer as we move latitudinally (from 3.5°N to 20.5°N) however the maximum change noted in temperature is of the order of ~ 4-5K (left panels). The latitudinal temperature gradient is found to decrease from ~0.25K/deg. at 60°E to ~0.18K/deg at 90°E. It is important to note the temperature gradient for winter months is larger by a factor of ~1.5 as compared to summer months suggesting that variation in temperature for the winters is more as compared to summers. Also it is to be noted that the latitudinal variation in temperature (~12.5°N-20.5°N), among different longitudes, is more for the months of November and December as compared to January and February. To further examine, we also plotted 6 years of averaged OLR data for the winter months, shown in the right panels of figure 3. Figure 3(a) shows that low OLR (~220-240W/m²) is located in the region 4.5°N- 8.5°N and 80°E- 90°E and it shifts towards equator and enters into southern hemisphere with the passage of time (from December to February). The occurrence of low OLR at lower latitudes (4.5°N- 8.5°N) during November & December is responsible for larger variation in temperature (for 12.5°N-20.5°N, among different longitudes), as compared to January and February which are observed to be dry.

It is also seen that the latitudinal difference in temperature variation for the winter months is higher than summer and summer monsoon months. Analysis suggests that variation in temperature is because of the presence of convection (i.e low OLR) in particular months that defines the thermal structure in a particular latitudinal range.

Correlation coefficient (R_{xy}) is also computed between OLR and temperature (figure 4) at each longitude (60°,70°,80° and 90°E) in the range of 3.5°N-20.5°N latitude. It is computed in each month to examine the association of OLR and temperature during different seasons. R_{xy} is found to vary between 0.70 and 0.92 during winters (NDJF) and summers (MAM). However, for monsoon period R_{xy} is negative (between -0.70 and -0.93) over 60°-70°E longitudes and it becomes positive (from 0.70 to 0.92) over 80°-90°E longitudes indicating convective activity to be the key factor in controlling the temperature variations.

Summary and Concluding Remarks

The study, mainly centered over Indian region (3.5-20.5°N, 60-90°E) is performed to investigate the changes in temperature during summer, summer-monsoon and winter months. Present study shows observations on both land and sea simultaneously at a fine spatial and temporal resolution. We have taken monthly averaged temperature data and OLR data and analysed its meridional variation at different longitudes (60°E-90°E at an interval of 10° longitudes). Following are the important conclusions:

a. For the summer months, temperature increases latitudinally by ~2-3K. This latitudinal increase in temperature can be accounted for the onset of monsoon at low latitudes (3.5°N) as compared to 20.5°N latitudes (shown in right panels in figure 1). Latitudinal temperature gradient is found to decrease from ~0.18K/deg. to 0.14K/deg. over the longitudes 60° to 90°E, respectively. For the summer monsoon (JJAS) the

temperature decreases latitudinally (~2.0-2.5K) which is in contrast to the rising trend observed during MAM. This decrease in temperature is due to northward movement of low OLR as shown in the right panels of figure 2, suggesting deep convection is a cause of such change. The latitudinal temperature gradient (for JJAS) increases from ~0.10K/deg. (at 60°E) to ~0.14K/deg (at 90°E) longitudinally.

- b. For the winter months, the temperature increases by ~ 4-5 K from 3.5° to 20.5°N. The latitudinal variation in temperature (~12.5°N-20.5°N), among different longitudes, is more for the months of November and December as compared to January and February. Latitudinal temperature gradient for winter months (~0.25-0.18K/deg) is larger by a factor of 1.5 than the summer months (~0.18-0.14K/deg).
- c. For all the months, it is noted, the temperature decreases while moving from 60° to 90°E. At 90°E i.e. over Bay of Bengal, the temperature is lowest in comparison to 60°, 70° and 80°E. Such a decrease in temperature is mostly due to appearance of deep convection in this region, which is confirmed by the low OLR (right panels of figure 2).
- d. Correlation coefficient (R_{xy}) between OLR and temperature is positive, varying between 0.70 and 0.92, for the summer and winter months at all the longitudes. However, for monsoon period R_{xy} is negative ranging from -0.70 to -0.93 over 60°-70°E longitudes and it becomes positive (from 0.70 to 0.92) over 80°-90°E longitudes indicating convective activity to be the key factor in controlling the temperature variations centered over BOB.

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