Characteristics of heat budget components in the Indian Ocean during active and break phases of monsoon

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Abstract

Indian summer monsoon is associated with formation of monsoon organized convection or monsoon surge in the equatorial Indian Ocean. It moves to the north producing monsoon rainfall over the region it passes. When the surge is in the Indian main land, the situation is treated as active monsoon and away from the main land is considered as break monsoon situation. A better understanding of the Indian summer monsoon, especially factors responsible for active-break situations is need of the hour. Air sea interaction processes play vital role in the formation of a new monsoon surge, its passage to the northern region leading to a break monsoon situation in the main land and revival of monsoon when another surge forms. In this analysis, the oceanic heat budget components are studied in detail for monsoon 2013 in the Arabian Sea, Bay of Bengal and equatorial Indian Ocean during evolution and propagation of monsoon surges. The Indian summer monsoon during 2013 was vigorous with above normal monsoon rainfall in most of the subdivisions of India. Daily values of heat budget components are computed utilizing mainly remotely sensed satellite data. QuikSCAT wind, NCEP/NCAR Temperature, TMI SST and INSAT Kalpana OLR were utilized for the study. 2.5 X 2.5 resolution NCEP/NCAR Temperature data was made uniform spatial resolution after re-gridding into 0.25 X 0.25. The computation of heat budget components was done from the basic meteorological and oceanographic variables. The bulk equations used for deriving latent and sensible heat fluxes and short wave radiation flux is derived from OLR. Variation of the heat budget components in the three oceanic basins near the surge shows high latent heat flux, low net flux, low long wave flux, low short wave flux and high sensible heat flux. The movement of monsoon surge from equatorial region to the foot hill of Himalaya was studied using a Hovmoller diagram for OLR for the monsoon season. The values of the heat budget components also show variation in the similar manner in association with the propagation of monsoon surge. The analysis provide an insight into the mechanisms that involve in the evolution and propagation of monsoon surge during the surplus monsoon year and hence the intra seasonal variability of the heat budget components during the different epochs of Indian summer monsoon. It helps for a better understanding of the influence of the different parameters on the variability of oceanic heat budget.

Introduction

The air sea interaction processes that are the main contributing mechanisms towards the supply of moisture in the development of a weather system. The variability of oceanic heat budget components is studied in detail for monsoon 2013 in the Arabian Sea, Bay of Bengal and equatorial Indian Ocean during evolution and propagation of monsoon surges. The Indian summer monsoon during the year 2013 was vigorous with above normal monsoon rainfall in most of the subdivisions of India.

A better understanding of monsoon system, especially active-break cycle can be made by studying the oceanic heat budget components associated with the evolution and propagation of monsoon organized convection. A few studies reported the role of moisture and heat budget during different phases of the Indian summer monsoon (Mohanty et al., 1983; Krishnamurti et al., 1988; Sengupta and Ravichandran, 2001; Hareesh Kumar and Mathew, 1997; Shenoi et al, 2002). The objective is to study the heat budget components in three adjoining oceanic regions of India during the evolution of monsoon organised convection and its northward propagation during the monsoon 2013, which was surplus monsoon year. The study was carried out deriving heat budget components in the three oceanic regions, Arabian Sea : 5^o N-15^o N and 62^o E to 72^o E, Bay of Bengal : 5^o N-15^o N and 82^o E to 92^o E and equatorial Indian Ocean : 5^o S to 5^o N and 65^o E-90^o E. Figure-1 gives the study area chosen in the Indian region

Data and Methodology

The heat budget components were derived from QuikSCAT wind, NCEP/NCAR air temperature, TMI SST, IITM Kalpana OLR. The 2.5 X 2.5 degree resolution air temperature was re-gridded into 0.25 x 0.25 degree for making the data into uniform resolution. The heat budget equation (Pickard and Emory, 1990) for a water body is :$+Q_s+Q_b+Q_h+Q_e+Q_v=Q_{T,}$ where Q_T is the total rate of gain or loss of heat of the water body. In practice Q_s value is always positive, Q_b value is negative, Q_h and Q_e values are generally negative but may be positive in limited areas at times. Q_v may be positive or negative. Hence after applying sign convention the equation is modified with Q_l instead of Q_b (long wave radiation), Q_{sen} instead of Q_h (sensible heat flux) and Q_{net} instead of Q_T (net heat flux) to have widely used form.

Thus the net heat budget equation : $Q_{net}=Q_s-Q_e-Q_{sen}-Q_l$, where Q_{net} is the net heat flux, Q_s is the incoming short wave radiation flux, Q_l is the effective outgoing long wave radiation flux, Q_{sen} is the sensible heat flux, and Q_e is the latent heat flux. In the above budget equation, Q_s contributes significantly to the oceanic heat gain whereas the other terms contribute towards the heat loss from tropical oceanic surfaces. The algorithm to predict short wave radiation flux (net surface insolation) from OLR is based on linear regression of OLR onto Surface Radiation Budget: (Shinoda et al., 1998)

$Q_s = 0.93Q_o - 1.3$, Where Q_s is the net surface insolation (in Watts per square meter), and Q_o is the OLR (in Watts per square meter).

The net long wave radiation, Q_l, is the net amount of energy lost or gained by the sea as long wave radiation. This is the difference between the energy radiated outward from the sea surface in proportion to the fourth power of its absolute temperature and the long wave radiation received by the sea from the atmosphere, which also radiates at a rate proportional to the fourth power of its absolute temperature (Waliser and Graham, 1993)

$Q_l=(0.94*(5.67x\ 10^{-8})SST^4- (-2800.0+(SST\ x\ 10.64)$

The bulk expressions for the latent and sensible heat fluxes,

Q_e and Q_{sen} are : $Q_e =\rho C_e L_e U(q_s-q_a)$ and $Q_{sen} = \rho C_p C_{sen} U(T_s-\theta)$

where ρ is the density of air, L_e is the latent heat of evaporation, C_p is the specific heat capacity of air at constant pressure, U is the average value of the wind speed at the ocean surface, C_e and C_{sen} are the stability and height dependent turbulent exchange coefficients for latent and sensible heat respectively, T_s is the sea surface temperature, θ is the near-surface air potential temperature and q_s and q_a are the sea surface and near surface atmospheric specific humidity values, respectively. Note that q_s is computed from the saturation humidity, q_{sat} at T_s , $q_s = 0.98q_{sat}[T_s]$.

$Q_{sen}=1.3*1030*0.001*(SST-((T-273.15) +0.0065*10))$

On the basis of OLR pattern the dates in which organized convection occur over the Arabian Sea are chosen as 7, 8, 9 and 10 July 2013.

Results and Discussions

Figure-2 depicts the All India summer monsoon rainfall for the year 2013 and Hovmoller diagram for OLR. The upper panel represents all India daily mean summer monsoon rainfall (mm) and lower panel indicates Hovmoller diagram for OLR (Wm^{-2}) for the same period : 1 Jun to 30 Sep., 2013 (Longitude belt 70^oE-95^oE).

Figure-3 gives the organized convection as indicated by the low OLR during the dates 7 to 10 July 2013. The figure indicates presence of monsoon organised convection in the Arabian Sea and adjoining areas. The intensity of the surge over the Arabian Sea increases during the course of time as revealed by 0.25 X 0.25 degree resolution OLR data. Patches of strong surge with OLR values less than 120 Wm^{-2} are observed on 9th July, 2013.

The figure-4 gives the Time- Latitude Hovmoller diagram of OLR averaged over the Arabian Sea for the monsoon season of 2013. The northward propagation of the surges during different epochs over the Arabian Sea are identified in the diagram. From the figure-5 Long wave radiation flux is minimum over the centre of monsoon organised convection with a value 30 Wm^{-2}. The long wave radiation flux is small as it is derived from the SST

The distribution of latent heat flux is shown in the figure-6. Since latent heat flux is derived from wind and temperature it follows the pattern of wind maximum. Generally the wind maximum will be over the north of the organized convection so that latent heat flux is maximum to the north of convection.

The sensible heat flux is maximum (figure-7) over the centre of monsoon organised convection with a value 35 Wm^{-2}. The net radiation flux is a minimum (figure-8) over the centre of monsoon organised convection with values -120 Wm^{-2}. The contributing factors to the net radiation flux is the decreasing short wave flux and long wave flux. The corresponding Hovmoller diagrams for OLR, Latent heat flux, Long wave flux, Net flux, Short wave flux and sensible heat flux is given in the figures 9-11. The pattern of the diagrams follows with that of the organized convection with latent heat flux maximum, net flux becomes minimum, long wave flux decreases, short wave flux decreases and sensible heat flux increases

Summary of results

The Hovmoller diagram of the heat budget components over the selected area in the Arabian Sea depicts the corresponding variation and propagation for the components during the period between 15^{th} June to 15^{th} July. In the centre of monsoon organized convection, the pattern of latent heat flux in the Hovmoller diagram is with maximum values. The short wave flux decreases over the convective region and the sensible heat flux increases.

Corresponding to the intensity of monsoon organised convection, latent heat flux becomes maximum, net flux becomes minimum, long wave flux decreases, short wave flux decreases and sensible heat flux increases. The computation is made for the other two areas in the Bay of Bengal and Indian Ocean and the results are compared. In the Bay of Bengal it is found that the intensity for the heat budget components is more than that over the Arabian Sea for the same values of OLR. The Hovmoller diagram of net flux closely follows that of OLR and net flux is a minimum over the cloud bands in the oceanic region. The heat budget components were evaluated for the three oceanic basins which are Arabian Sea, Bay of Bengal and the Equatorial Indian Ocean. The computation of heat budget components from the basic meteorological and oceanographic variables provides an insight into the mechanisms that involve in the evolution and propagation of monsoon organized convection and hence the intra seasonal variability of the heat budget components. It helps for a better understanding of the influence of the different parameters on the variability of oceanic heat budget.

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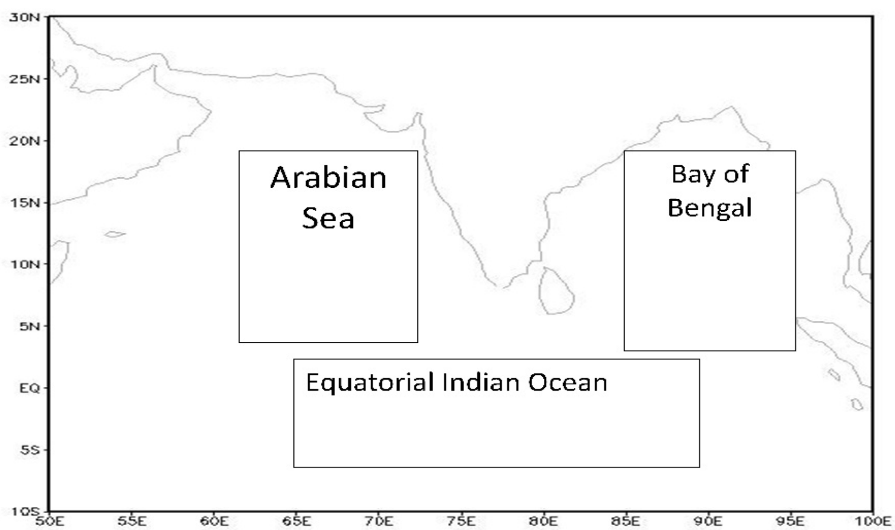

Fig-1:Study area in the Indian Ocean

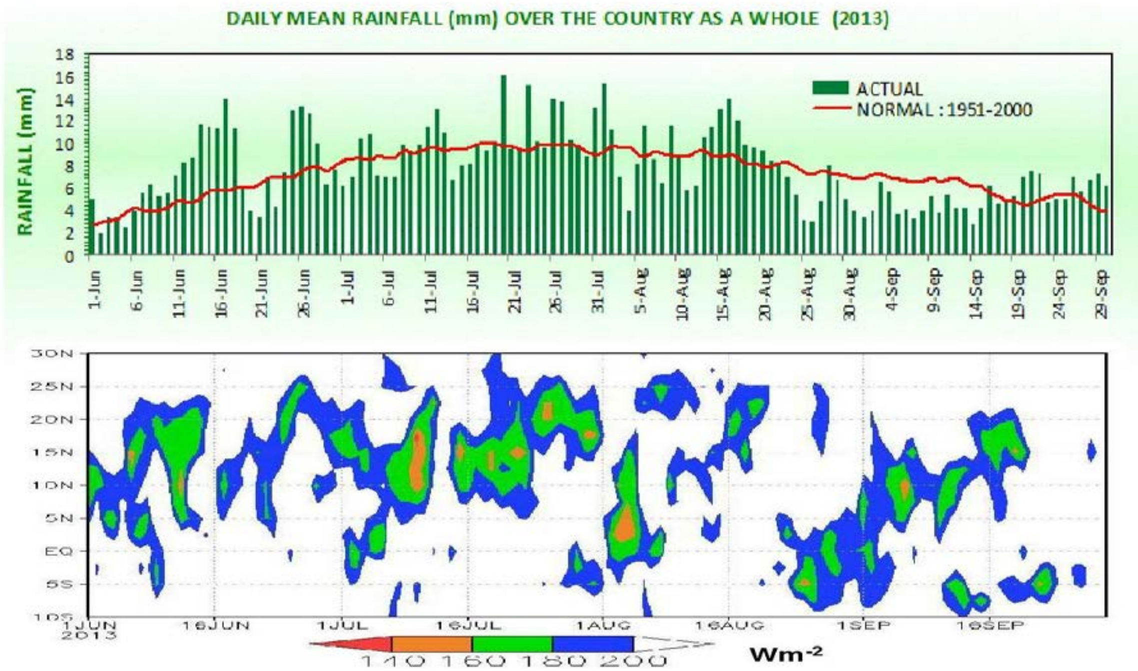

Fig-2: All India daily mean summer monsoon rainfall (mm) (upper panel) and Hovmoller diagram for OLR (Wm^{-2}) for the same period (lower panel) : 1 Jun to 30 Sep., 2013 (Longitude belt 70^oE-95^oE).

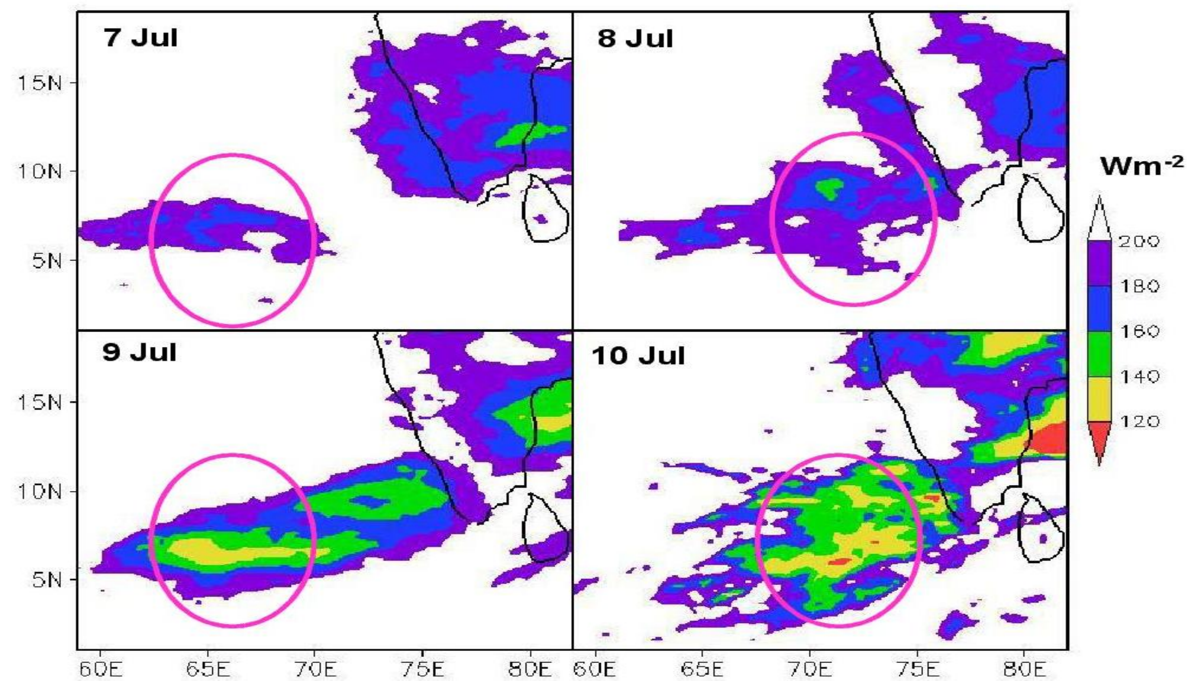

Fig-3: Outgoing Long wave Radiation (OLR) over Indian region during 7, 8, 9, 10 July 2013. The circle indicates the evolution of the surge during the 4 days.

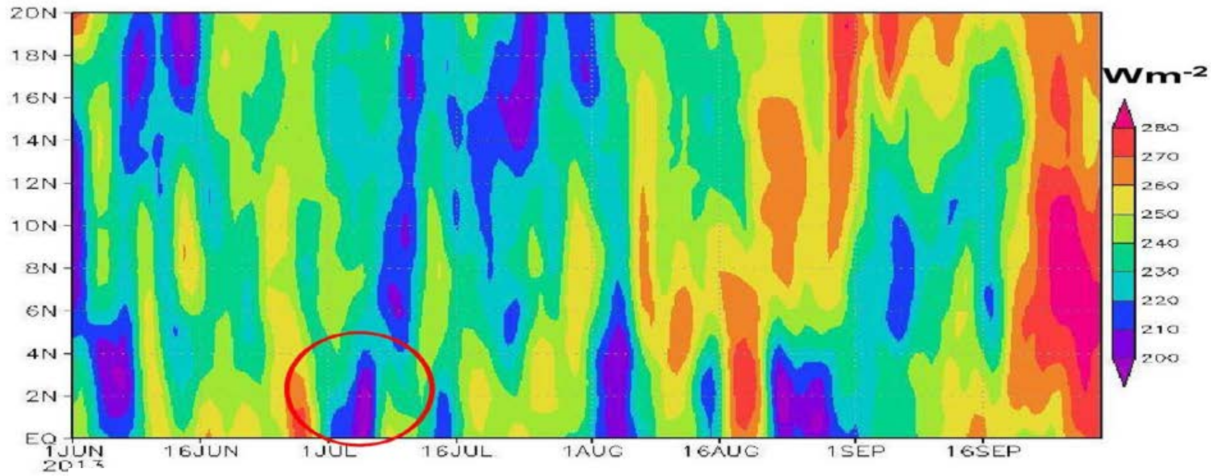

Fig-4: Hovmoller diagram for OLR Over Indian region averaged over 50° E to 90° E. The circle indicates the selected dates under study over the Arabian Sea.

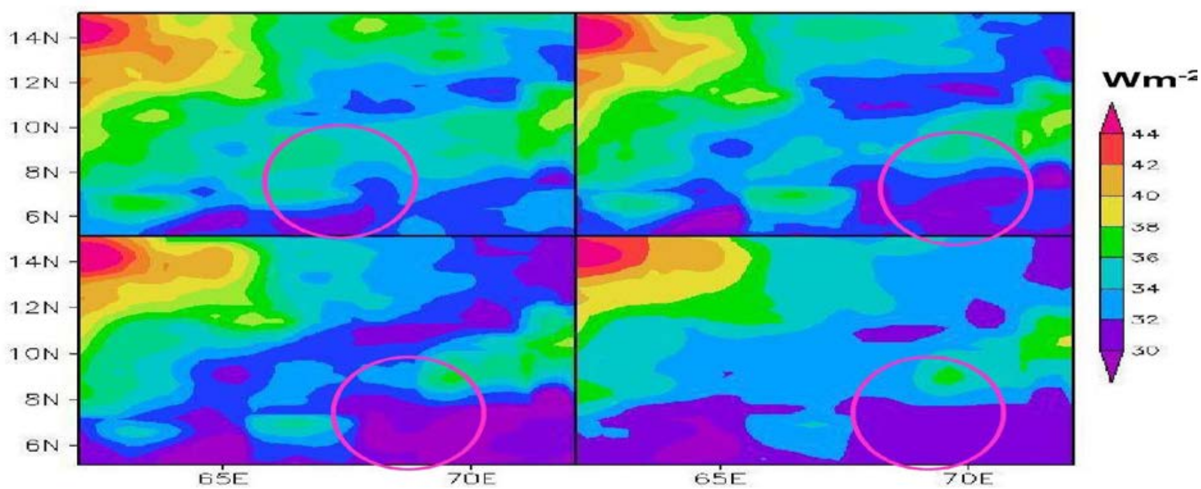

Fig-5: Long wave radiation flux (Q_l) Over the Arabian Sea during 7,8, 9, 10 July 2013

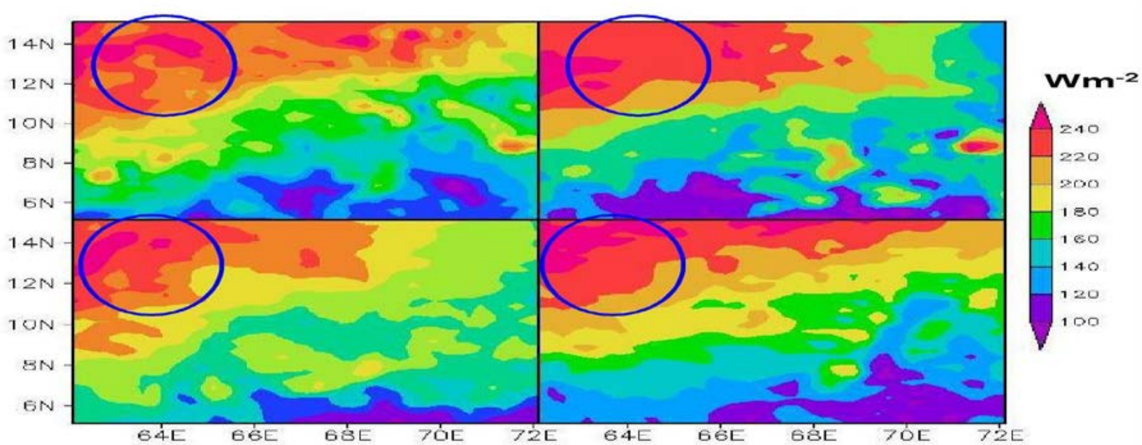

Fig-6: Latent Heat flux (Q_e) Over the Arabian Sea during 7,8, 9, 10 July 2013. The circle represents the location of maximum of latent heat flux to the north of organized convection

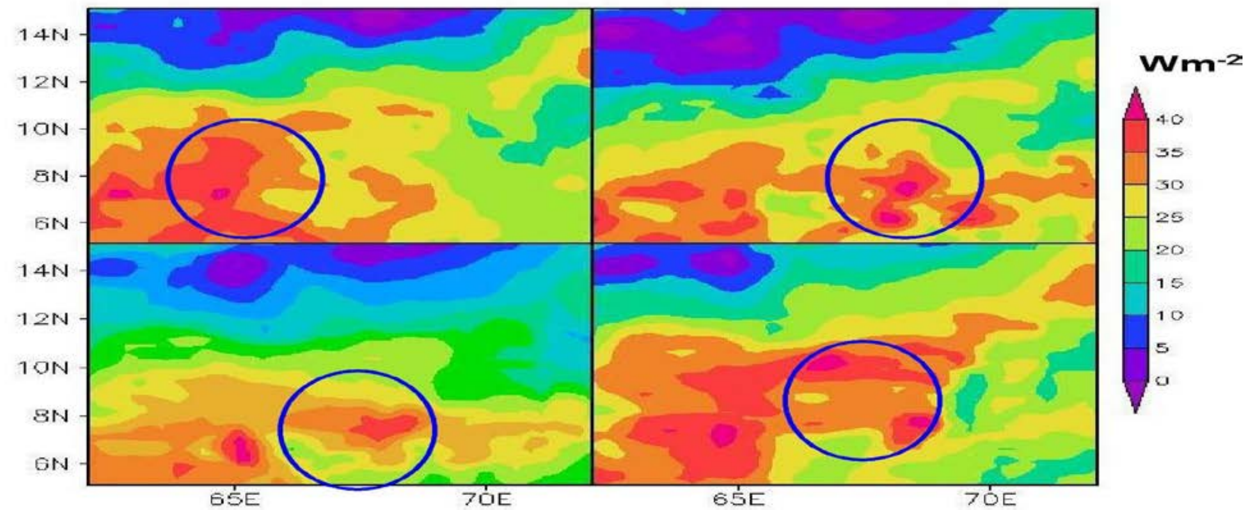

Fig-7: Sensible heat flux (Q_{sen}) in the the Arabian Sea during 7,8, 9, 10 July 2013. The blue circle gives the location of maximum sensible heat flux.

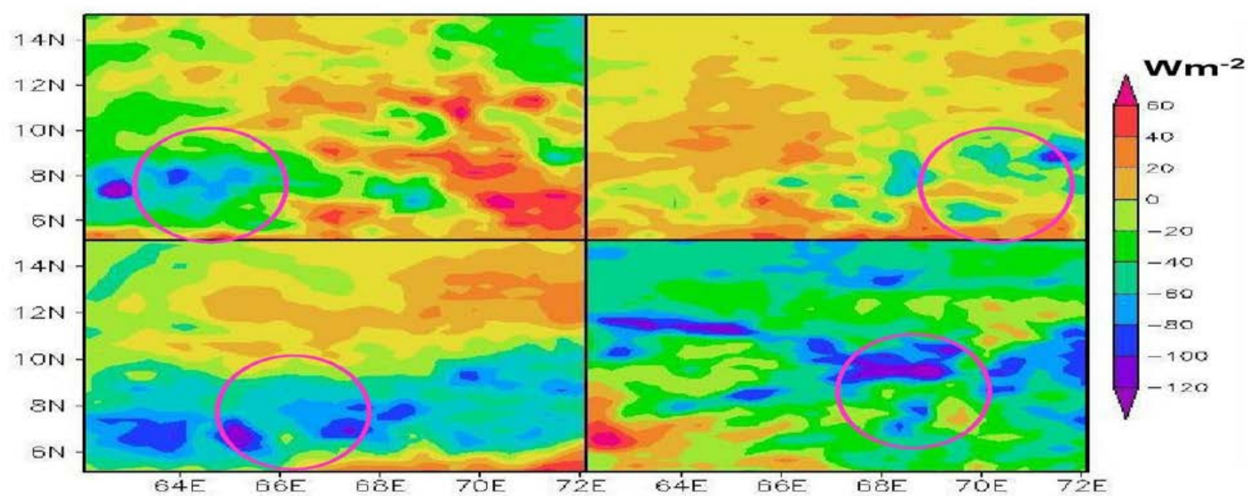

Fig-8: Net flux (Q_{net}) Over the Arabian Sea during 7,8, 9, 10 July 2013. The circle gives the location of organised convection.

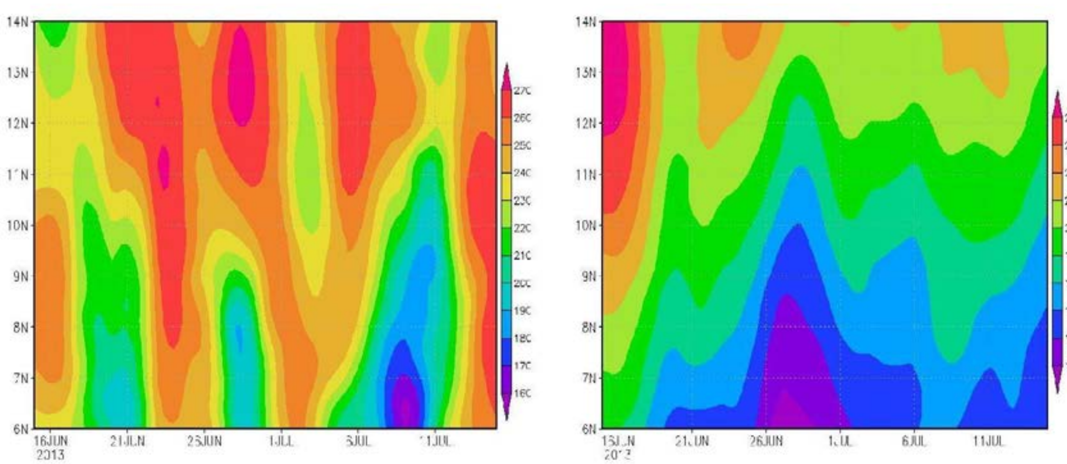

Fig-9: Hovmoller diagram OLR and Latent heat flux ave(62^oE-72^oE)

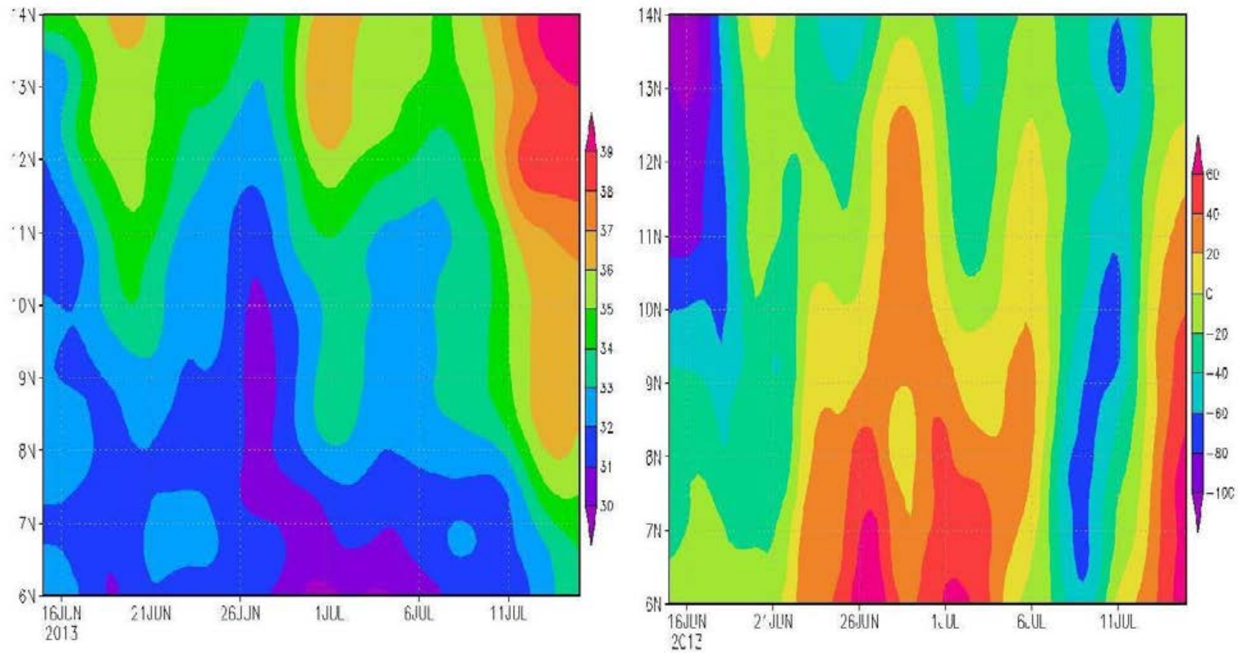

Fig-10: Hovmoller diagram Long wave flux and Net flux ave(62^{o}E-72^{o}E)

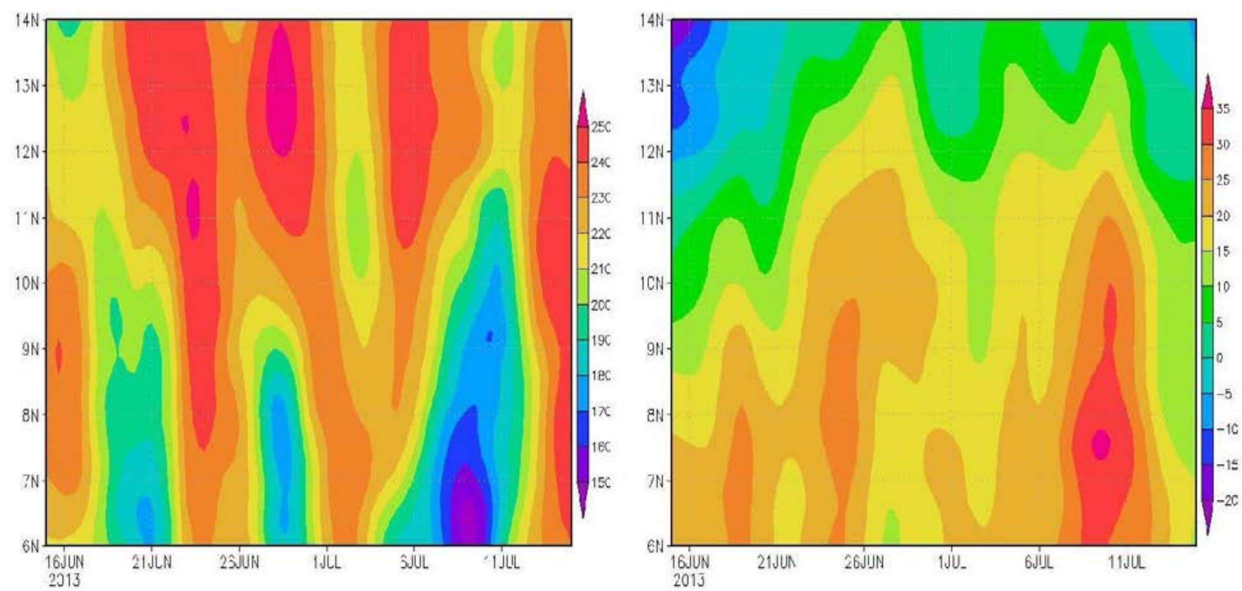

Fig-11: Hovmoller diagram for Short wave flux and sensible heat flux ave(62^{o}E-72^{o}E)