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Case Study of Indian Summer Monsoon on the Basis of Upper Atmospheric Jet Stream

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Abstract: Indian economy largely depends on South west monsoon known as Indian Summer Monsoon(ISM). It is one of the key factors to good agricultural production and adequate resource of rural life. The tropical easterly jet stream (TEJ) whose existence was established by Koteswaram(1958) is an important component of Indian summer monsoon. The TEJ overlies southern eastern Asia in the upper troposphere (9 km-14km) with the core near 15°N latitude. In this piece of work, the change of wind direction at the upper troposphere has been investigated. Heat Flux has been found out using upper air Radio Sonde Radio Wind (RSRW) data by calculating wind direction & temperature at 9 km. to 14 km. level. A relationship between onset of ISM and TEJ stream has been established. Heat flux is calculated in the regions of latitude ranging from 1°N to 22.65°N for three Years (2014, 2015, 2016) for the months from February to October. The result depicts that TEJ is a precursor for long range weather forecast of ISM.
Keywords: Indian Summer Monsoon, Tropical Easterly Jet stream, heat flux and Radio sonde Radio Wind data.

I. INTRODUCTION

Indian economy is vitally linked with the monsoon because of its water resources. A large part of the country gets more than 75% of the annual rainfall during the four months, June to September. The production of food grains depends fairly on the monsoon rainfall over the country. Agriculture adds up to 15% of India's GDP. Further the hydroelectric power has been traced over the past 20 years. In a word Indian Summer monsoon(ISM) plays multiple key role of Indian economics. The study of ISM has started just after independence. The tropical easterly jet stream (TEJ), whose existence was established by Koteswaram(1958) is an important component of Indian summer monsoon. It is one of the most conspicuous features in the summer monsoon circulation of the northern Hemisphere. In the upper troposphere this jet extends from Indochina to the west coast of Africa and has its maximum speed of about 25m/s near latitudes 5^0N-10^0N over the Arabian Sea(Krishnamurti,1971b). Koteswaram (1958) showed that the TEJ is maintained by the thermal contrast between subtropics and equatorial Indian ocean in the upper troposphere. He also pointed out that the time fluctuation of the tropical easterly jet is related to low level Indian monsoon. The TEJ is energetically maintained by the release of available potential energy in the Hadley and Walker Circulations (Chen 1980). VENKITESHWARAN(1950)show a wide belt of easterlies in the high troposphere and stratosphere over India during summer. During weak monsoon period strong winds from the east have been noted over southern India in summer when pilot balloons could be followed to great heights. KRISHNA RAO (1952)guessed the existence of an easterly jet stream from the observation of the winds. FROST (1952) noted an average maximum of 70 knots between 150 and 100 mbs in summer. Strong easterly Jet Stream are frequent over south Indian, but rare over the Pacific and Atlantic Ocean areas. So, it was considered appropriate to study the high tropospheric flow of jet stream and use the upper wind circulation in these regions as a precursor to Indian summer monsoon circulation feature of the lower Troposphere. In the present study, the variation is studied of upper air Jet stream in the tropics(1^0N-110.83^{0}E to 22.57^{0}N -88.36^{0}E) and how they can be used to predict monsoon over the Indian Subcontinent.

A. Monsoon

Traditionally a monsoon is a seasonal change in the direction of the prevailing wind. Thisbrings about a marked change in local weather and are often associated with rainy seasons in the tropics and the subtropics. Monsoon largely affects the lives in these areas. A weak monsoon rainy season may cause drought, crop failures, and hardship for people and wildlife. Many parts of the world experience monsoons to some extent. The most famous are the Asian monsoons, that include the distinctly different monsoons that affect India, north China, and Japan, and south China and Southeast Asia. In some portions of Central Africa, monsoon rain is critical to supporting life in the area south of the Sahara Desert. Lesser monsoon circulations can also be noticed in the parts of the southwestern United States. These summer rainy periods bring much needed rain to the dry plateaus of Arizona and New Mexico.

B. Indian Monsoon

Indian monsoon, the most prominent of the world's monsoon systems, affects India and its surrounding water bodies. It blows from the northeast during cooler months (North East Monsoon)and reverses direction to blow from the southwest (South West Monsoon) during the warmest months of the year. This process brings large amounts of rainfall to the region during June and July.

C. Monsoon Cycle

During April, India becomes particularly prone to rapid heating and a heat sink appears over the southern Indian Ocean. Monsoon winds at the surface blow from heat sink to heat source. This resultsa well-establishment of the southwest monsoon by May over Sri Lanka. Also in May, the dry surface of Tibet absorbs and radiates heat that is readily transmitted to the air immediately above. At about 6,000 metres an anticyclonic cell arises, causing a strong easterly flow in the upper troposphere above northern India. The subtropical jet stream suddenly changes its direction to the north of the anticyclonic ridge and the highlands. It then coincides with a reversal of the vertical temperature and pressure gradients between 600 and 300 millibars. The accelerated spread of heating, combined with the general direction of heat being transported by winds, results in a greater initial monsoonal activity over the Arabian Sea than over the Bay of Bengal. The easterly jet becomes firmly established during June at 150 to 100 millibars. The highest speed of the jet is observed at about 15° N. The position of the easterly jet controls the location of monsoonal rains. The strong, humid southwesterly, surface flow brings humidity of more than 80 percent and heavy squally showers that are the "burst" of the monsoon. Towering cumulonimbus clouds produce violent thunderstorms and release latent heat in the surrounding air. As a result, the upper tropospheric warm belt migrates northwestward from the ocean to the land. The main body of air above 9,000 metres maintains a strong easterly flow. In June and July, the monsoon is strong and well-established to a height of 6,000 metres , with occasional thickening to 9,000 metres. Topography introduces some extraordinary differences in the wind flow, amount of rainfall, formation of low pressure systems in all over India. Mainly in July and August the waves of low pressure appear in the body of monsoonal air. Fully developed depressions travel from east to west more or less concurrently with high-level easterly waves and bursts of speed from the easterly jet, causing a local strengthening of the low-level monsoonal flow.

D. Tropical Easterly Jet Stream

Jet stream, a region of long, narrow, high-speed winds typically flows northeastward, eastward, and southeastward in the middle and upper troposphere or lower stratosphere. The Tropical Easterly Jet is the meteorological term referring to an upper level easterly wind that starts in late June and continues until early September. This strong flow of air that develops in the upper atmosphere during the Asian monsoon is centered on 15°N, 50- 80°E and extends from South-East Asia to Africa. The strongest development of the jet is at about 15 km above the Earth's surface with wind speeds of up to 40 m/s over the Indian Ocean. The Sub Tropical Jet (STJ) shifts to the north of the Himalayas (Early June) and the Tropical Easterly Jet (TEJ) comes into existence.It flows from east to west over peninsular India at 6 – 9 km and over the Northern African region.Due to the formation of TEJ upper air circulation patterns reverse and high pressure switches to low pressure. This results in the quick onset of monsoon.The sufficiently hot air coming from Tibet helps in strengthening the easterly jet and results in heavy rainfall in India. But if the snow over the Tibet Plateau does not melt, the easterly jet does not exist. That year then turns into a weak monsoon year due to less rainfall in India.

II. DATA SOURCES

Radiosonde Data of Wind direction, windspeed & temperature at different pressure level have been taken from the Data Access Portal of NOAA(National Oceanic and Atmospheric Administration),as well as upper air Soundings from the University of Wyoming, the URL link of which is provided below.

A. ftp://ftp.ncdc.noaa.gov/pub/data/igra/data/data-por/
B. http://weather.uwyo.edu/upperair/sounding.html

III. METHODOLOGY

A. From Calorimetry, $Q = mc\Delta T$.

Q is the enthalpy of heat energy of the atmospheric jet streem, m is the mass of air. c is the specific heat of air for unit mass of air. The total heat of air mass around Jet stream level is proportional to temperature and wind velocity as well. Hence, $Q \propto T$ [Heat contained by unit mass of air is proportional to Temperature of the air mass][wind velocity]. Also, we know that the direction of Westerly Wind is 270º. Therefore proportionate heat flux along westerly direction = [{COS(270°-wind direction)}*T][wind speed]. Heat flux has been calculated for the usual upper atmospheric jet stream pressure levels (300hpa,250hpa,200hpa,150hpa) of the following stations with respect to their position from the equator(latitude-wise).

1) KUCHING Latitude: 1.4833 ºN.
2) COLOMBO Latitude: 6.9º N.
3) TRIVANDRUM Latitude: 8.4833 ºN
4) CHENNAI Latitude: 13 ºN
5) HYDERABAD Latitude: 17.45º N
6) BHUBANESWAR Latitude: 20.25 ºN
7) Station: CALCUTTA Latitude: 22.65ºN

A negative value of proportionate heat flux indicates that easterly Jet stream. Also the height at which the Radiosonde data (i.e. Wind Direction & Temperature) have been collected are between 08 Km to 14 Km representing atmospheric Jet stream (near the tropopause). The graphical representation of works calculated from RSRW data are as follows:

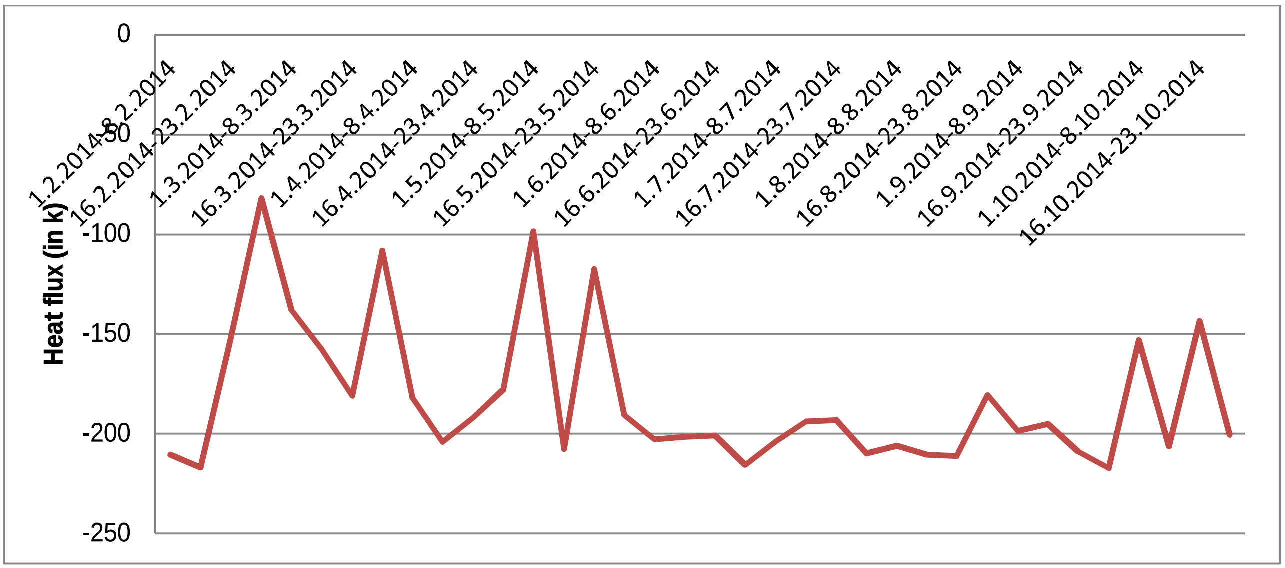

Fig 1: Time series plot of proportionate heat flux of 2014 at KUCHING (Lat.- 1.4833ºN, Long.-110.3ºE)

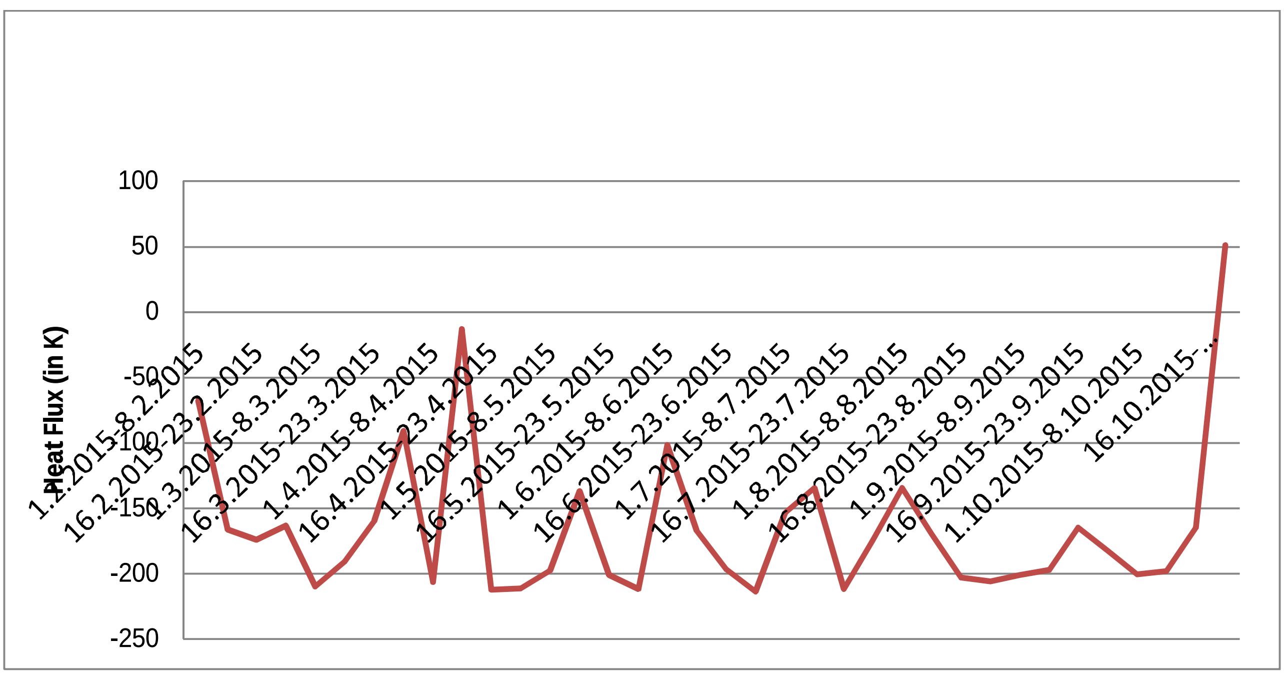

Fig 2: Time series plot of heat flux of 2015 at KUCHING (Lat.- 1.4833ºN, Long.-110.3ºE)

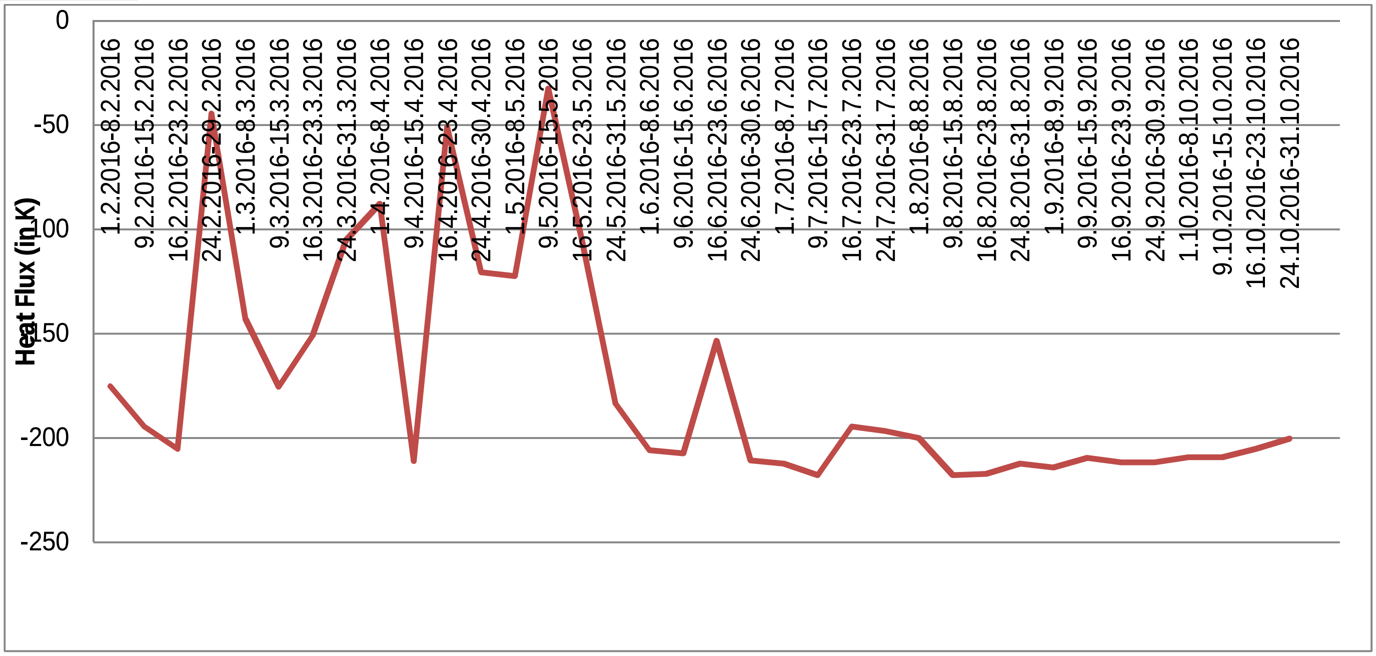

Fig 3: Time series plot of proportionate heat flux of 2016 at KUCHING (Lat.- 1.4833ºN, Long.-110.3ºE)

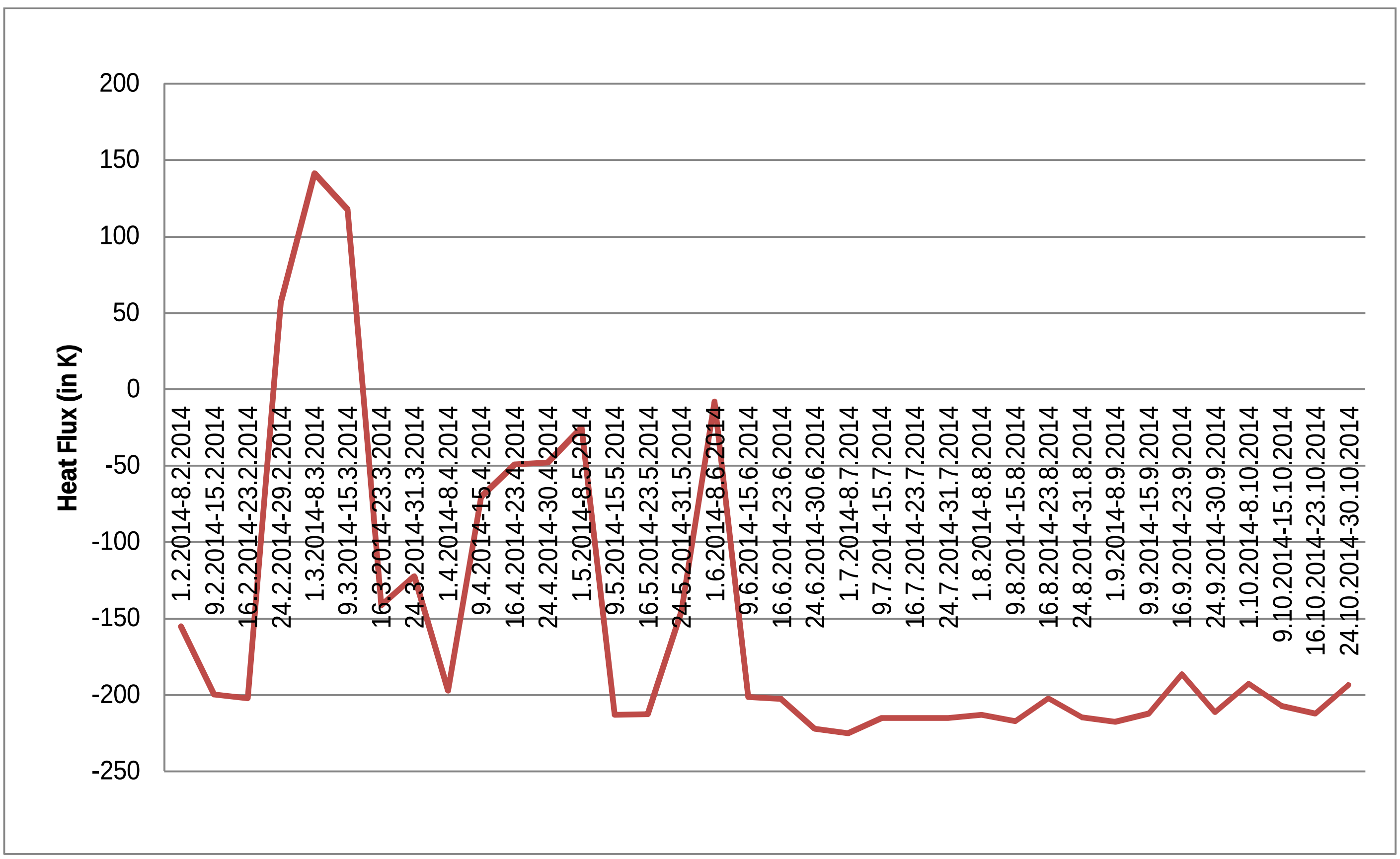

Fig 4: Time series plot of heat flux of 2014 of Station COLOMBO (Lat.- 6.9 ºN, Long.-79.8667 ºE)

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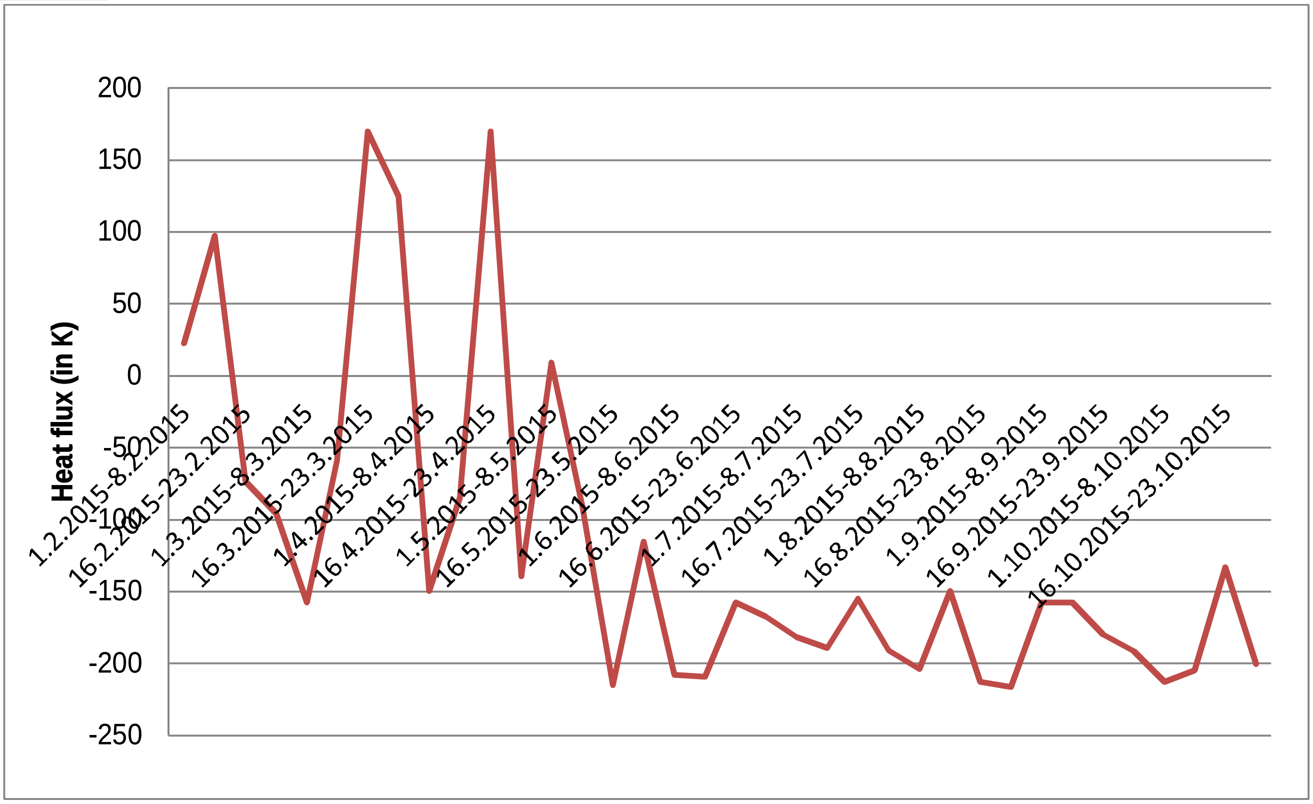

Fig 5: Time series plot of heat flux of 2015 of Station COLOMBO (Lat.- 6.9 ºN, Long.-79.8667 ºE)

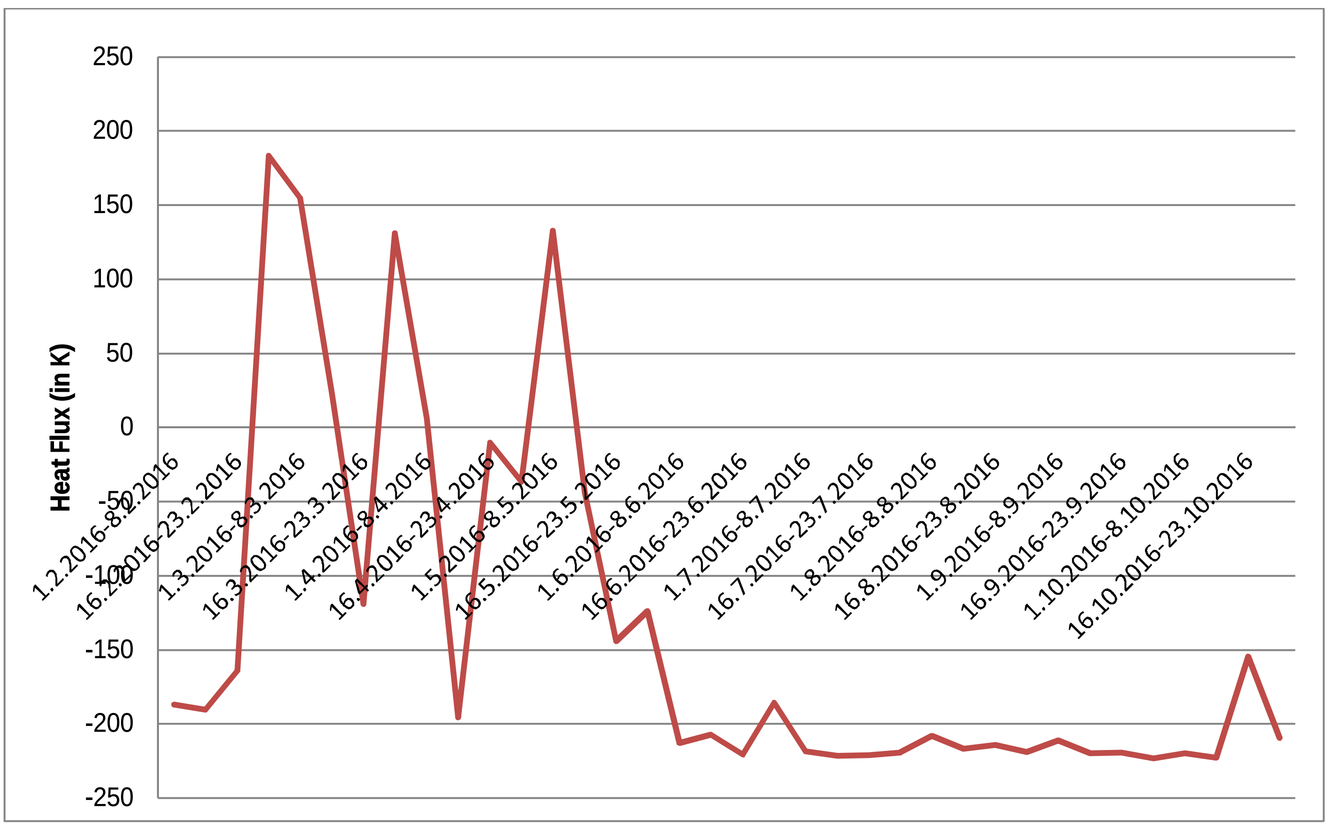

Fig 6: Time series plot of heat flux of 2016 of Station COLOMBO (Lat.- 6.9 °N, Long.-79.8667°E)

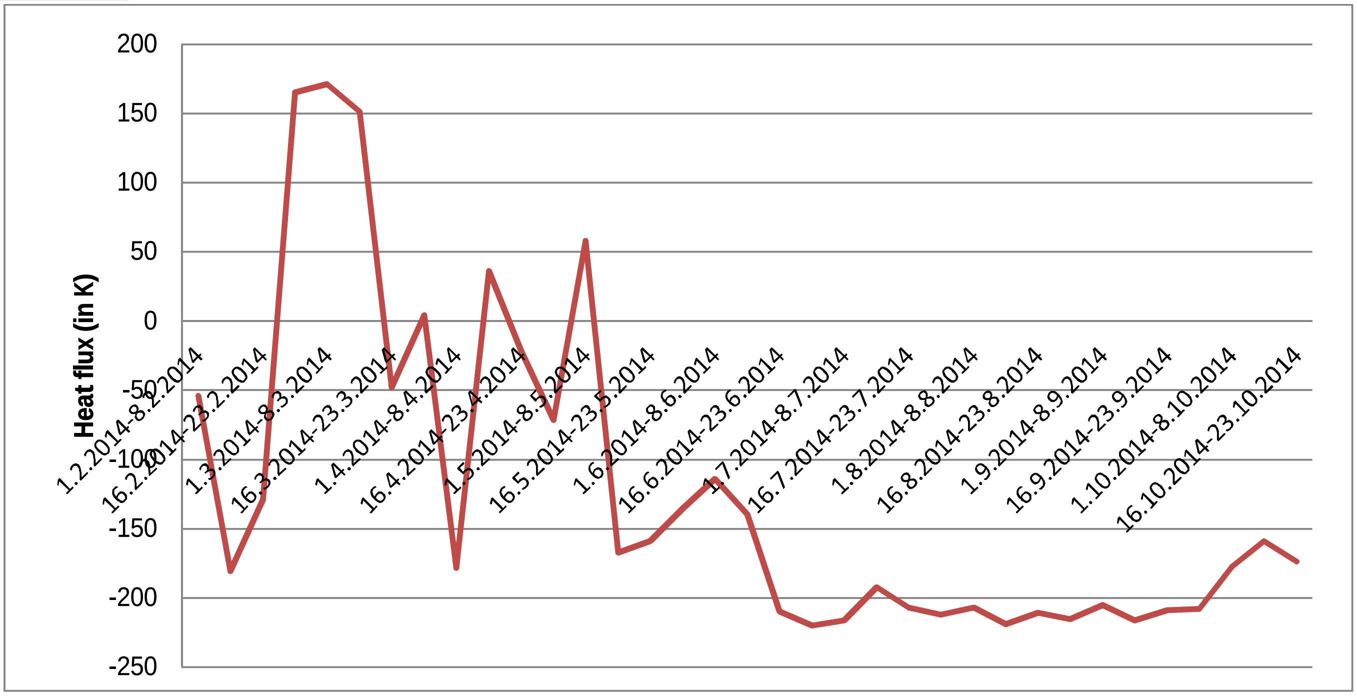

Fig 7: Time series plot of heat flux of 2014 of Station TRIVANDRUM (Lat.- 8.4833 °N,Long.-76.95 °E)

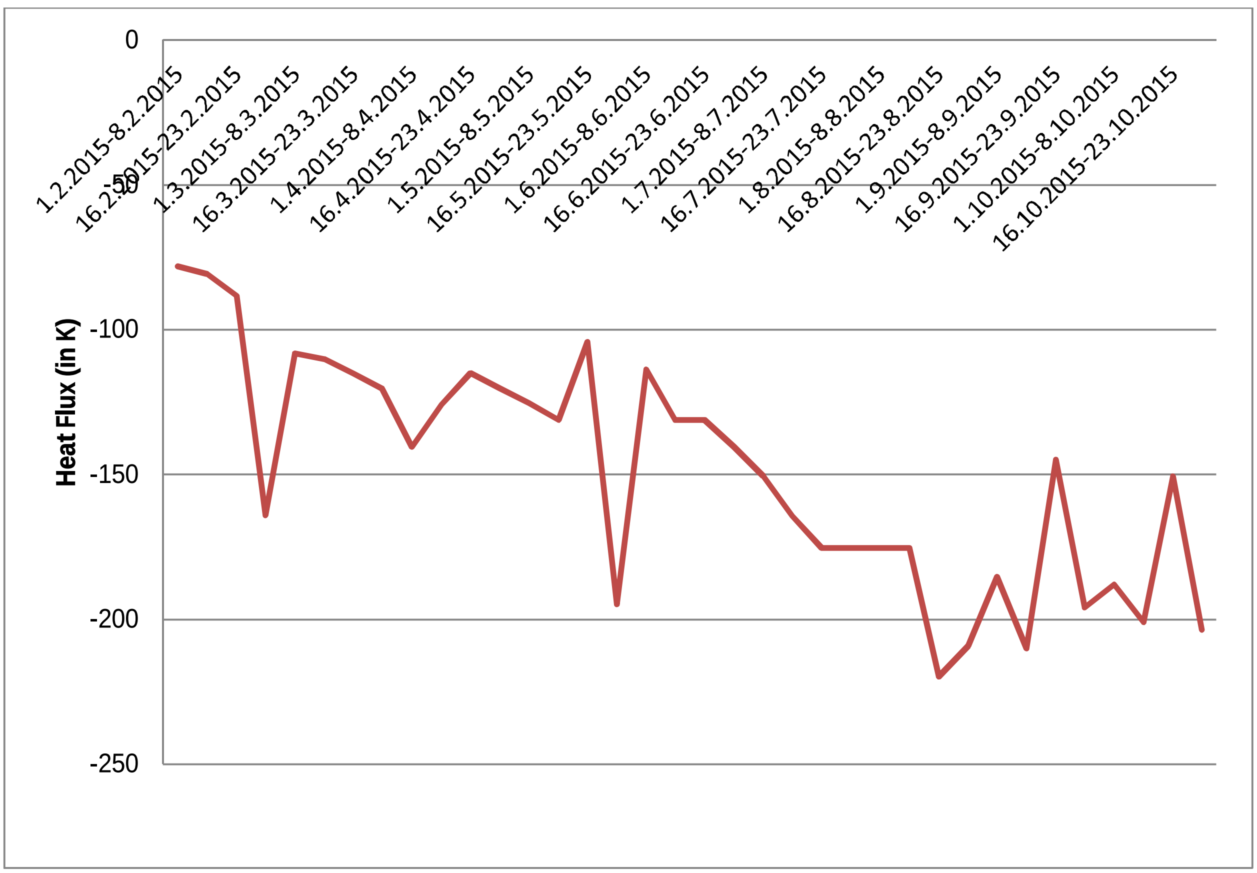

Fig 8: Time series plot of heat flux of 2015 of Station TRIVANDRUM (Lat.- 8.4833 °N,Long.-76.95 °E)

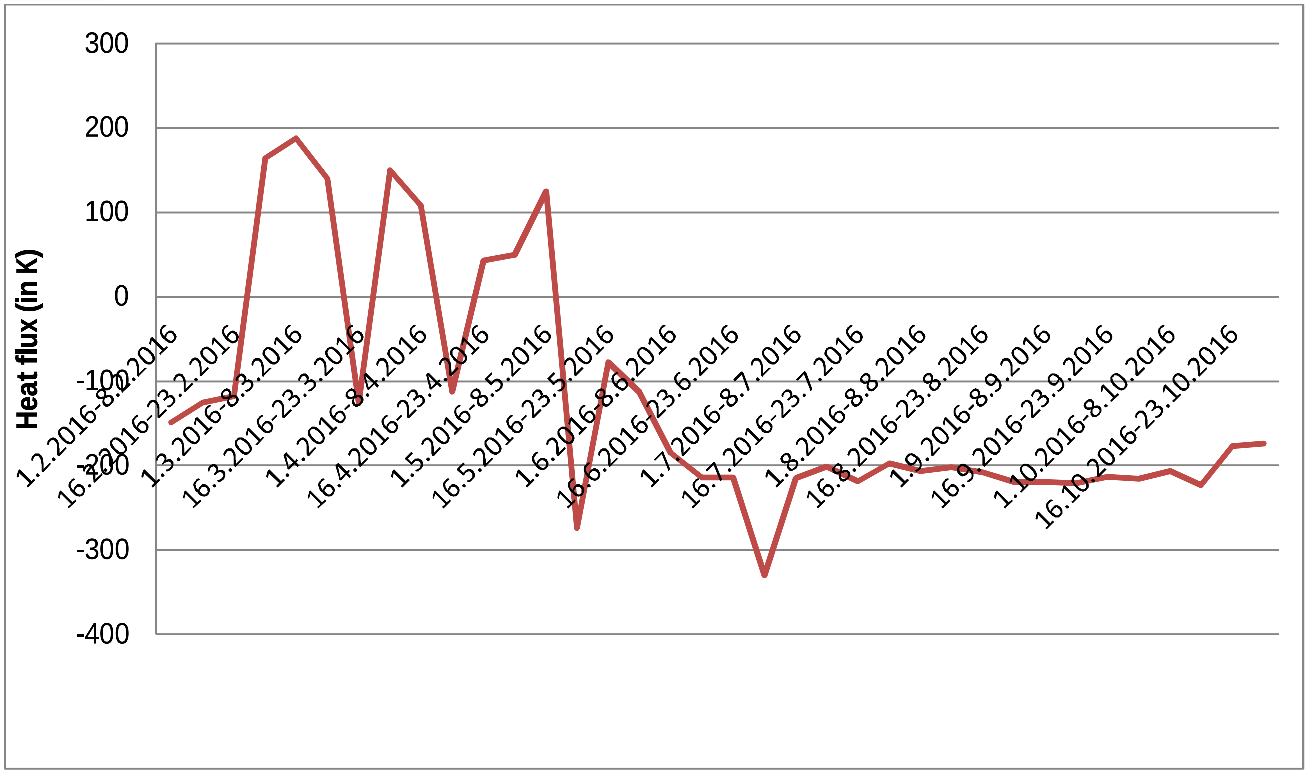

Fig 9: Time series plot of heat flux of 2016 of Station TRIVANDRUM (Lat.- 8.4833 °N,Long.-76.95 °E)

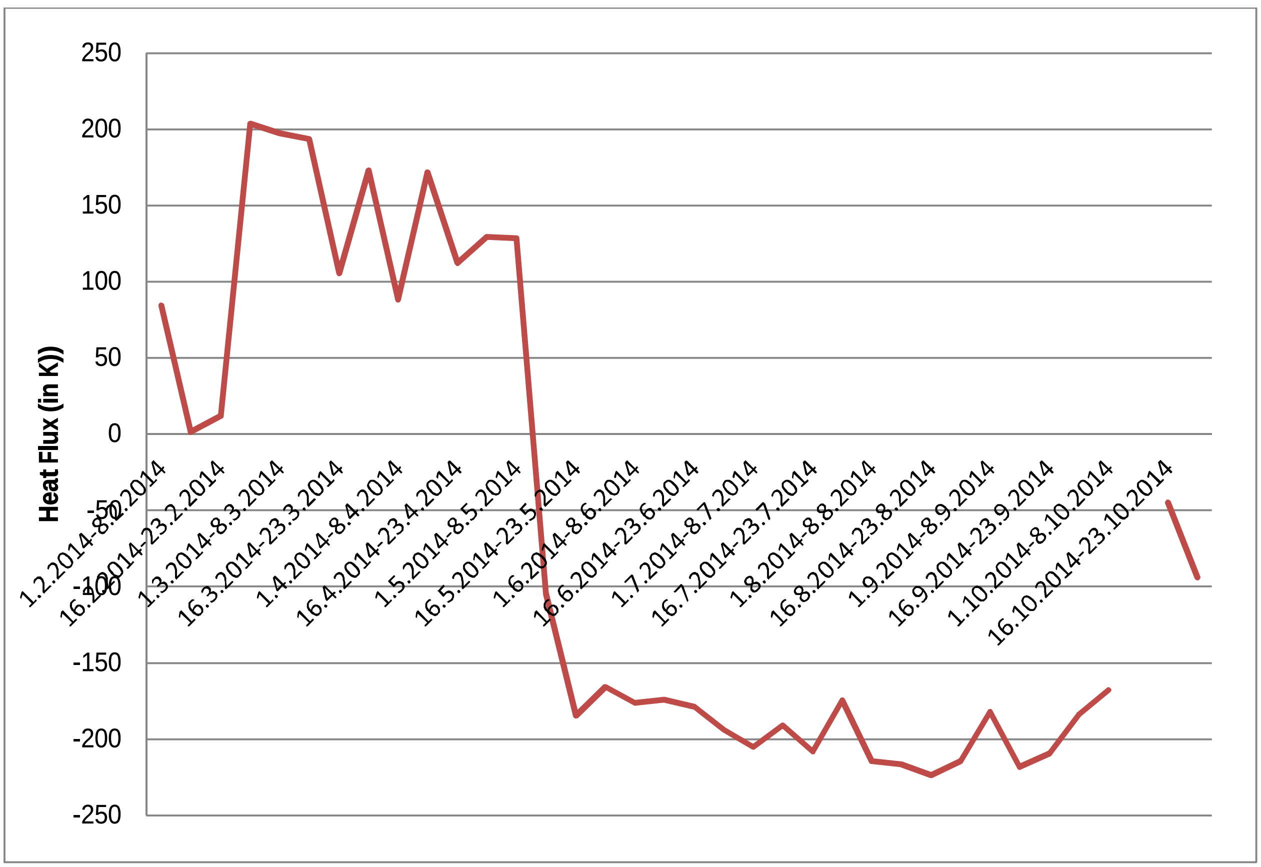

Fig 10: Time series plot of heat flux of 2014 of Station CHENNAI (Lat.- 13 °N, Long.- 80.1833 °E)

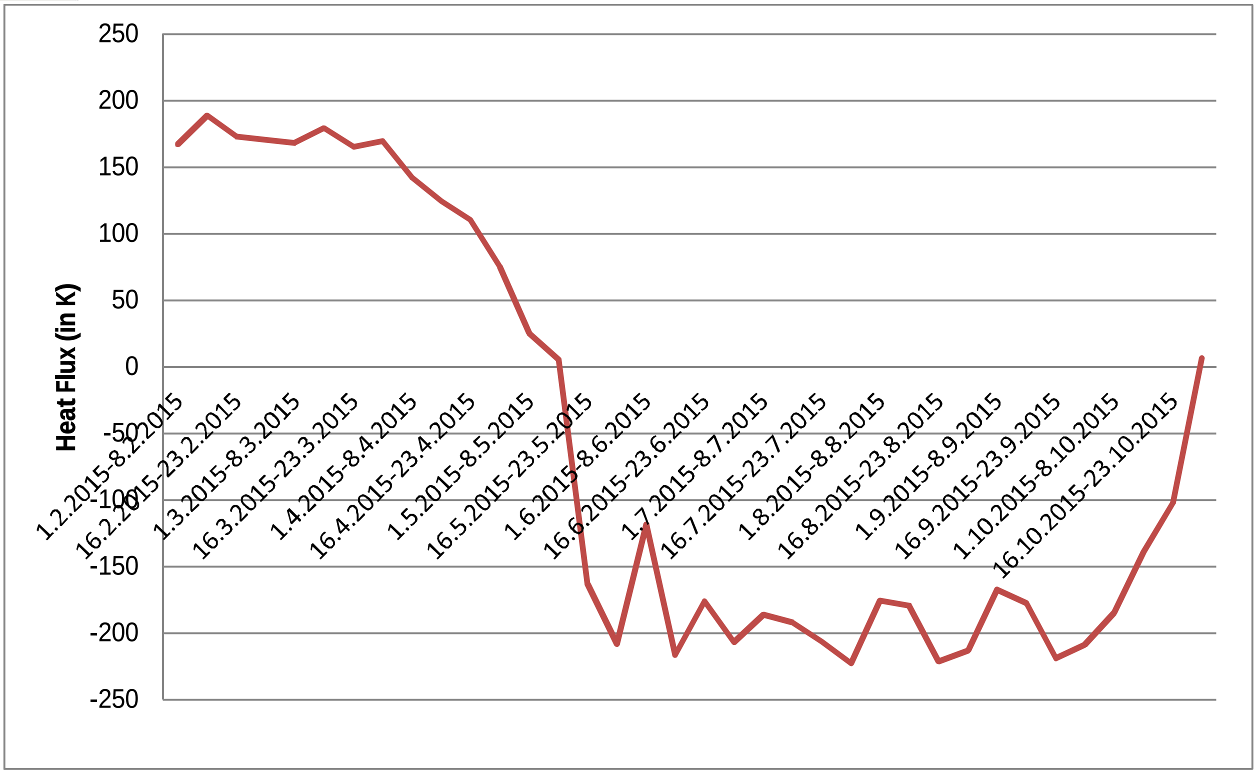

Fig 11: Time series plot of heat flux of 2015 of Station CHENNAI (Lat.- 13 °N,Long.- 80.1833 °E)

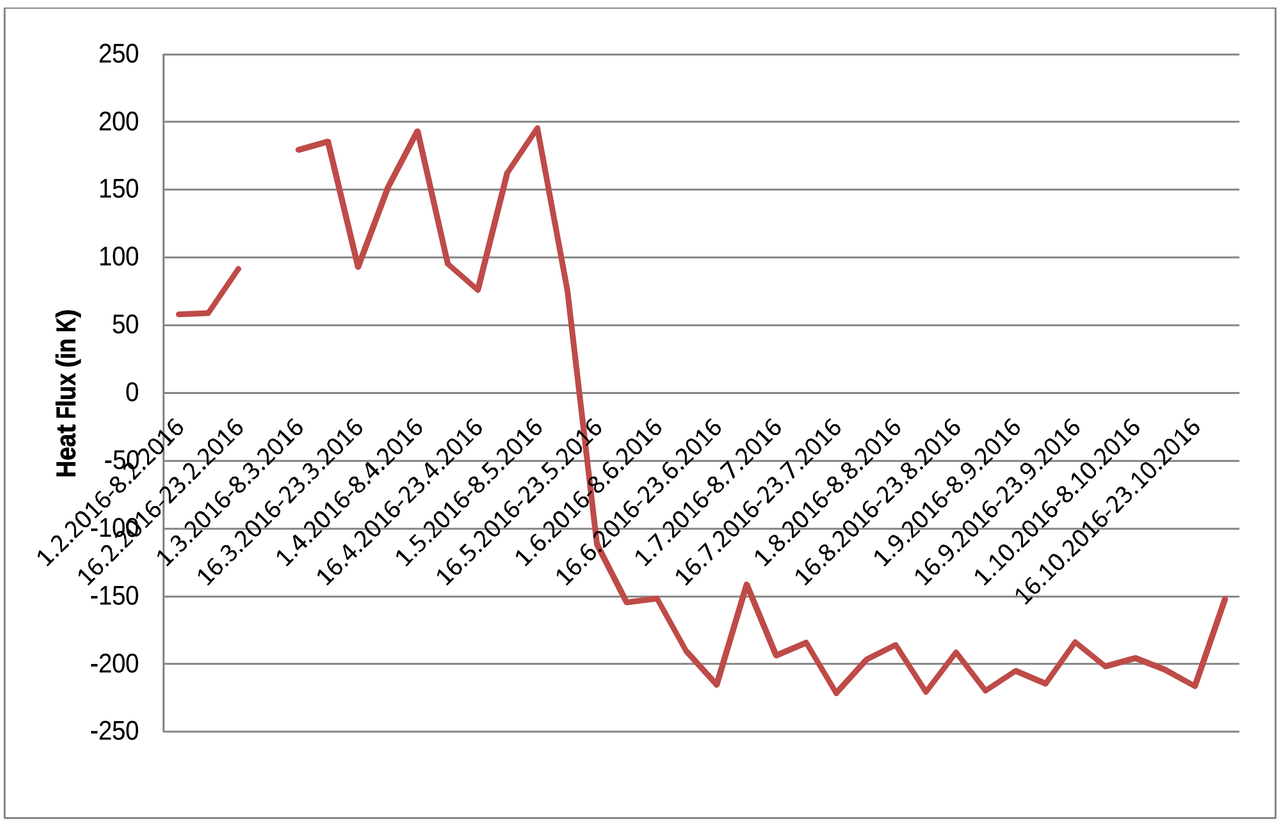

Fig 12: Time series plot of heat flux of 2016 of Station CHENNAI (Lat.- 13 °N,Long.- 80.1833 °E)

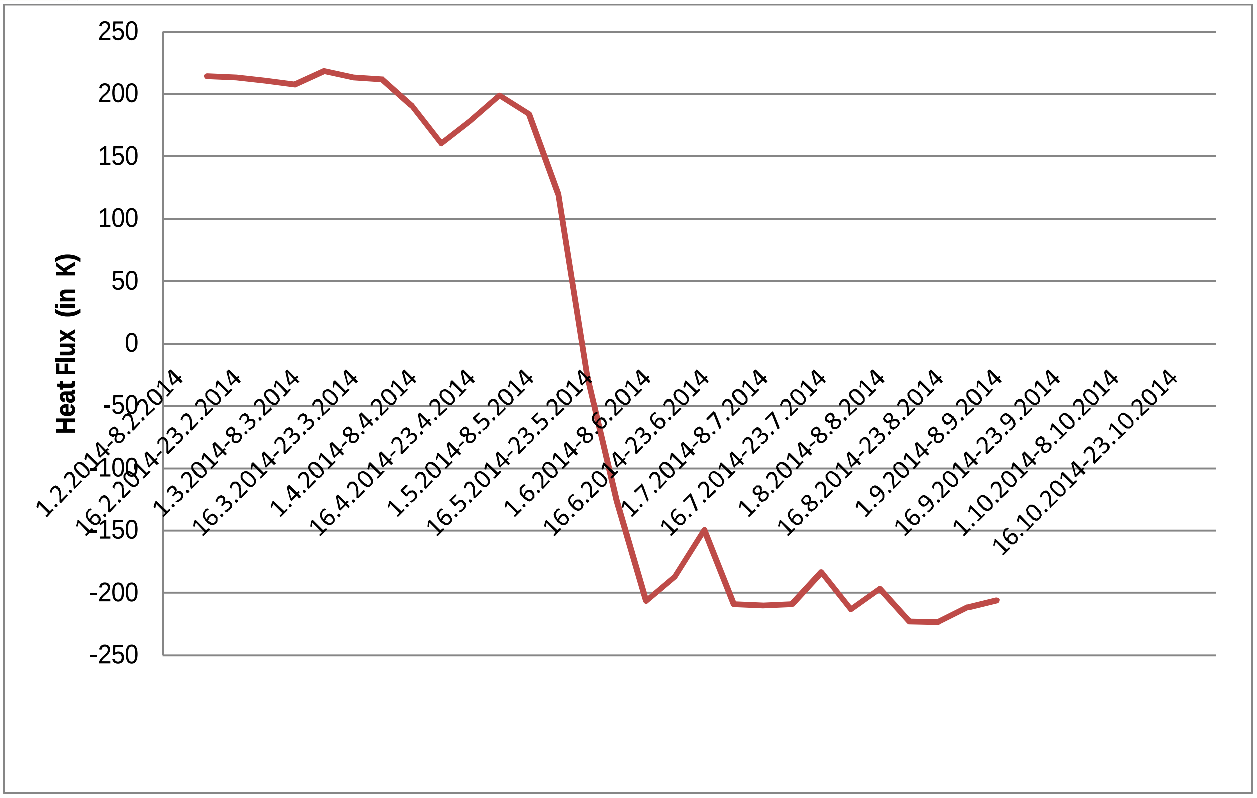

Fig 13: Time series plot of heat flux of 2014 of Station HYDERABAD (Lat.- 17.45° N,Long.-78.4667°E)

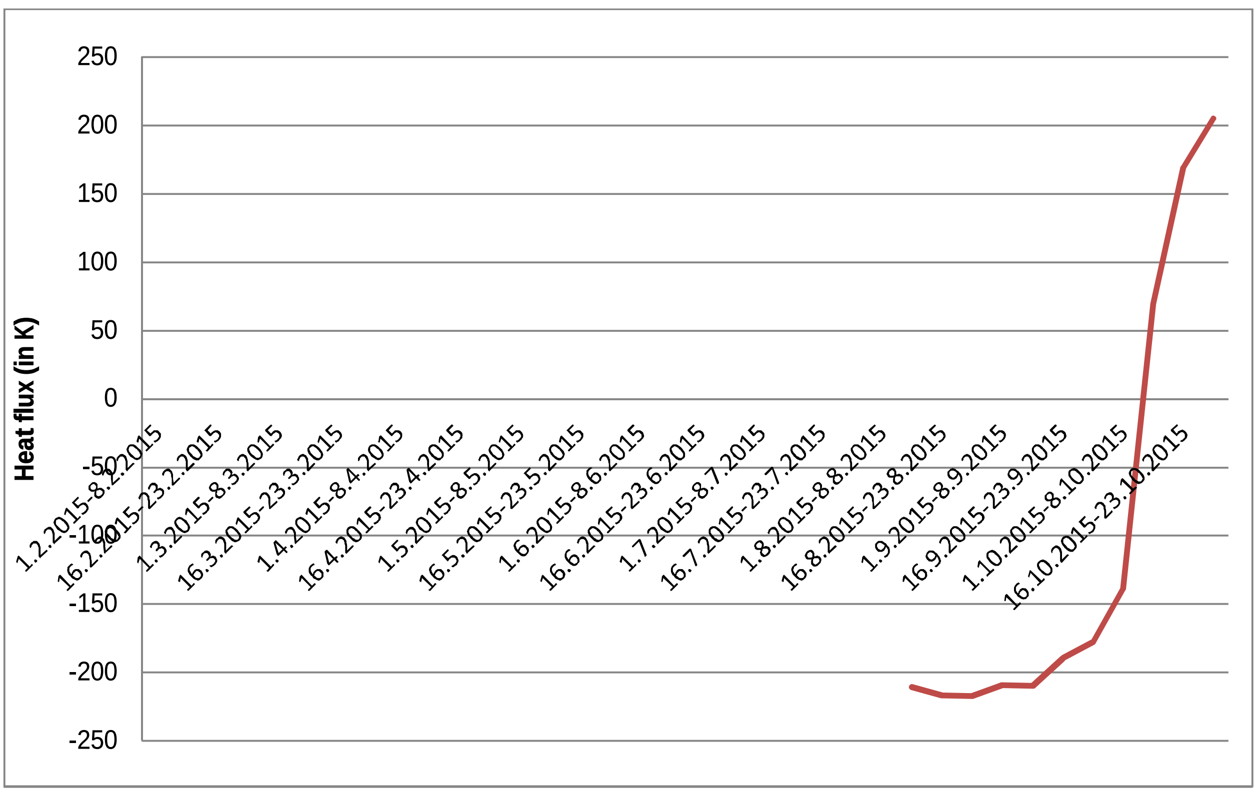

Fig 14: Time series plot of heat flux of 2015 of Station HYDERABAD (Lat.- 17.45 °N ,Long.-78.4667 °E)

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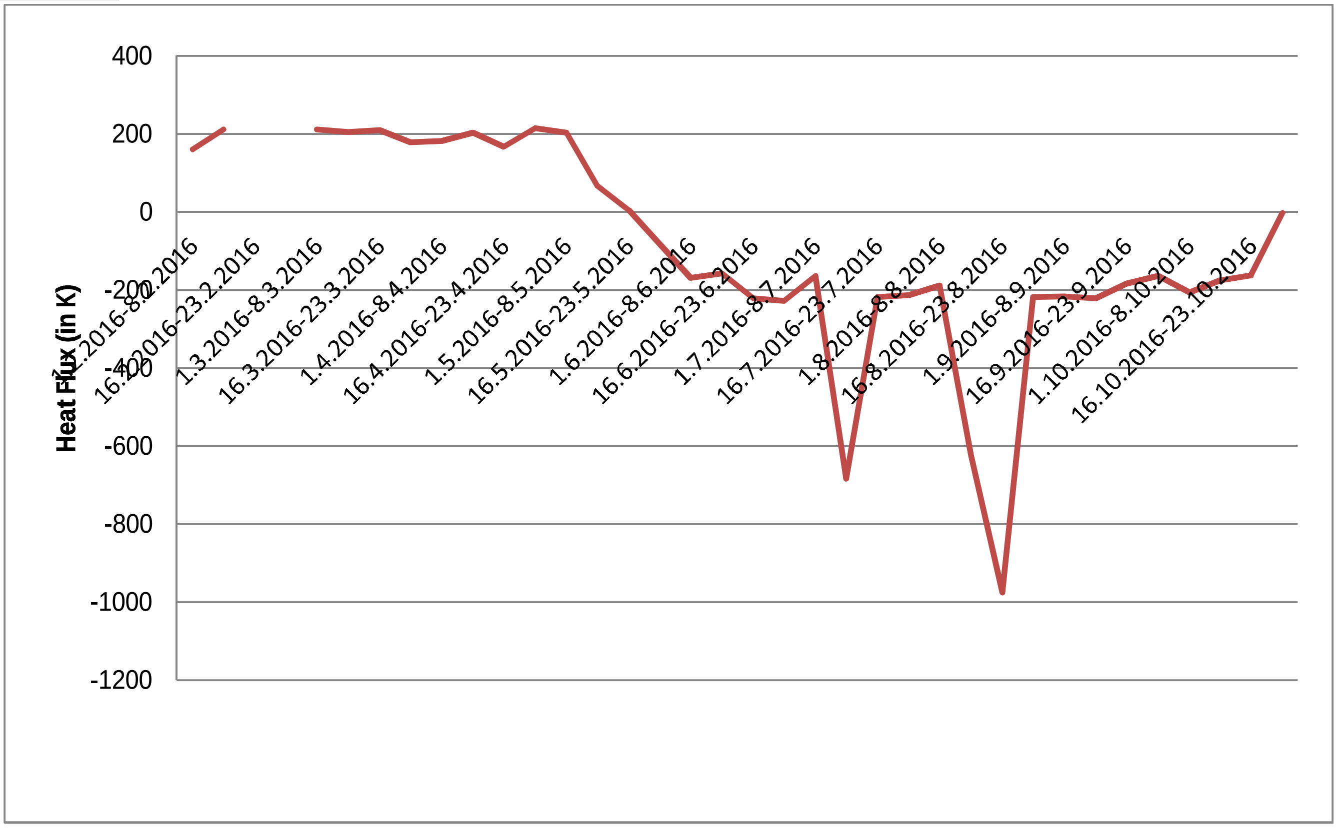

Fig 15: Time series plot of heat flux of 2016 of Station HYDERABAD (Lat.- 17.45 °N,Long.-78.4667 °E)

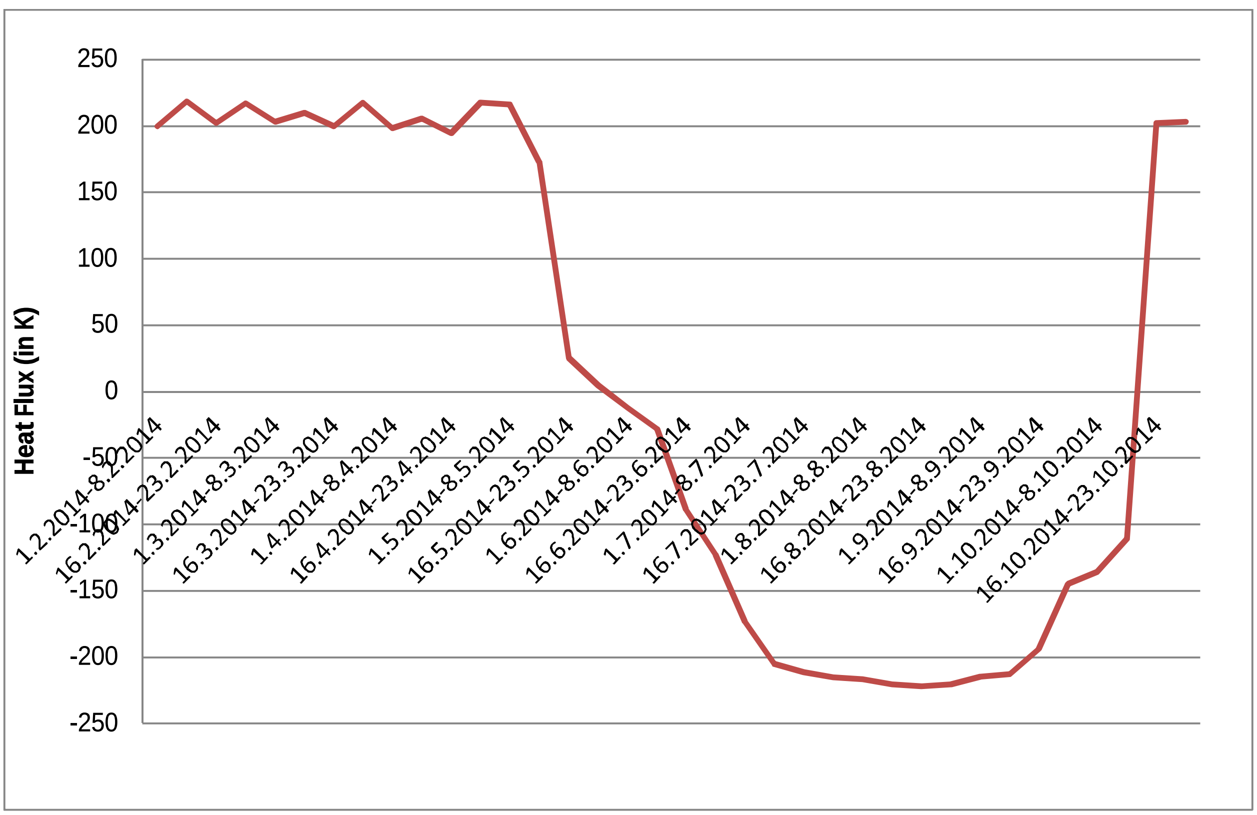

Fig 16: Time series plot of heat flux of 2014 for Station BHUBANESWAR (Lat.- 20.25 °N,Long.-85.8333 °E)

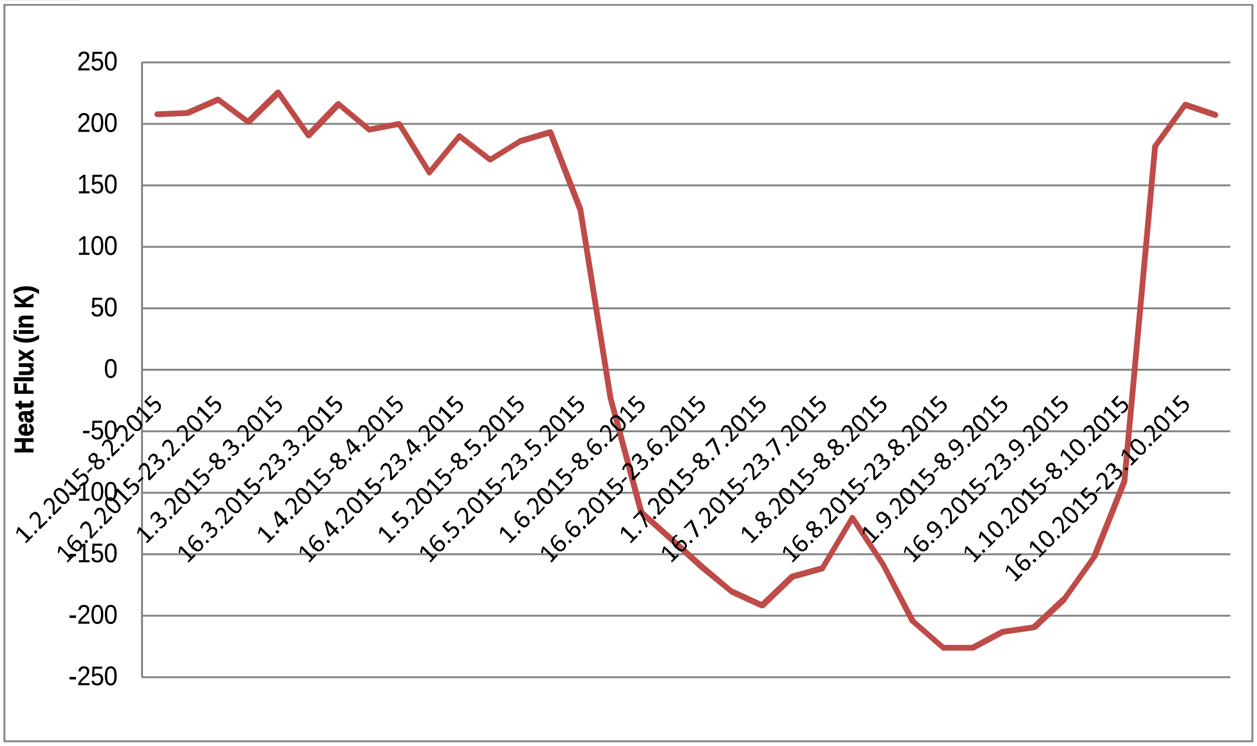

Fig 17: Time series plot of heat flux of 2015 for Station BHUBANESWAR (Lat.- 20.25 °N,Long.-85.8333 °E)

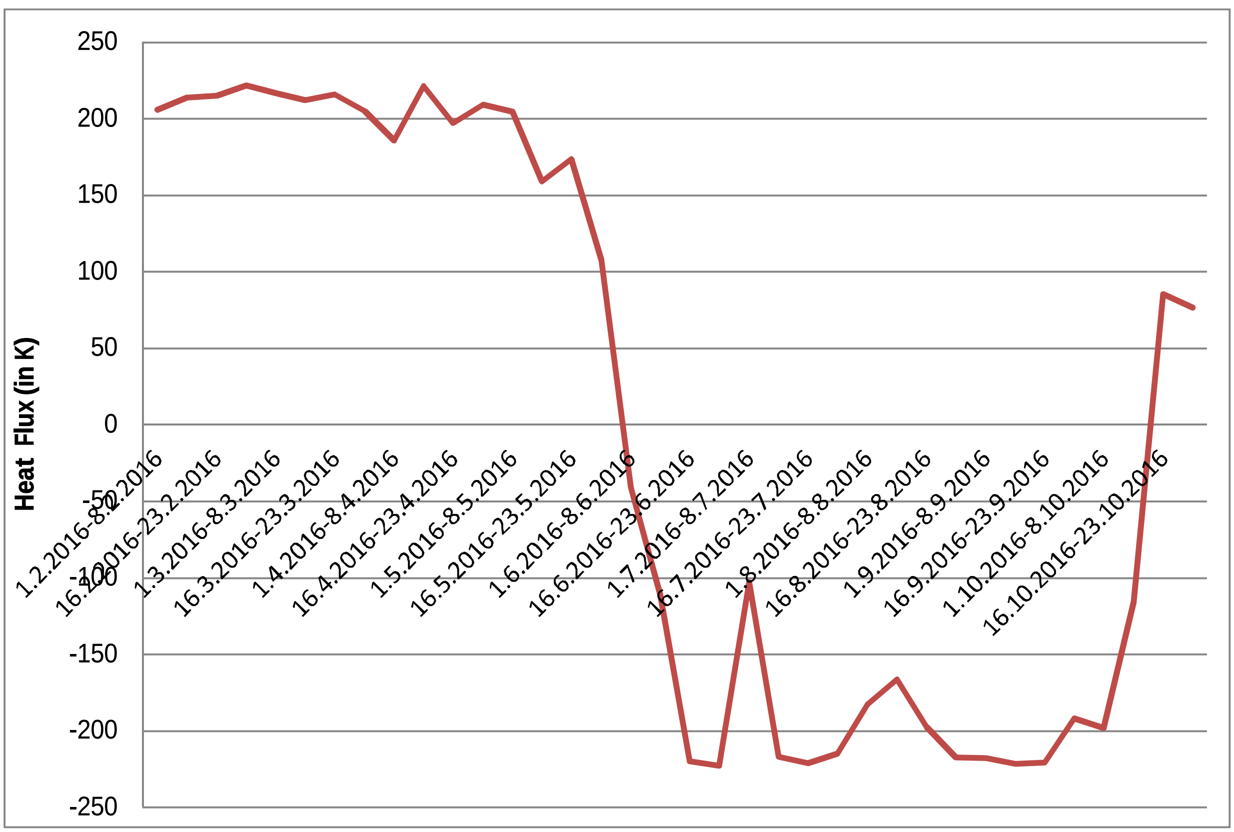

Fig 18: Time series plot of heat flux of 2016 for Station BHUBANESWAR (Lat.- 20.25 °N,Long.-85.8333 °E)

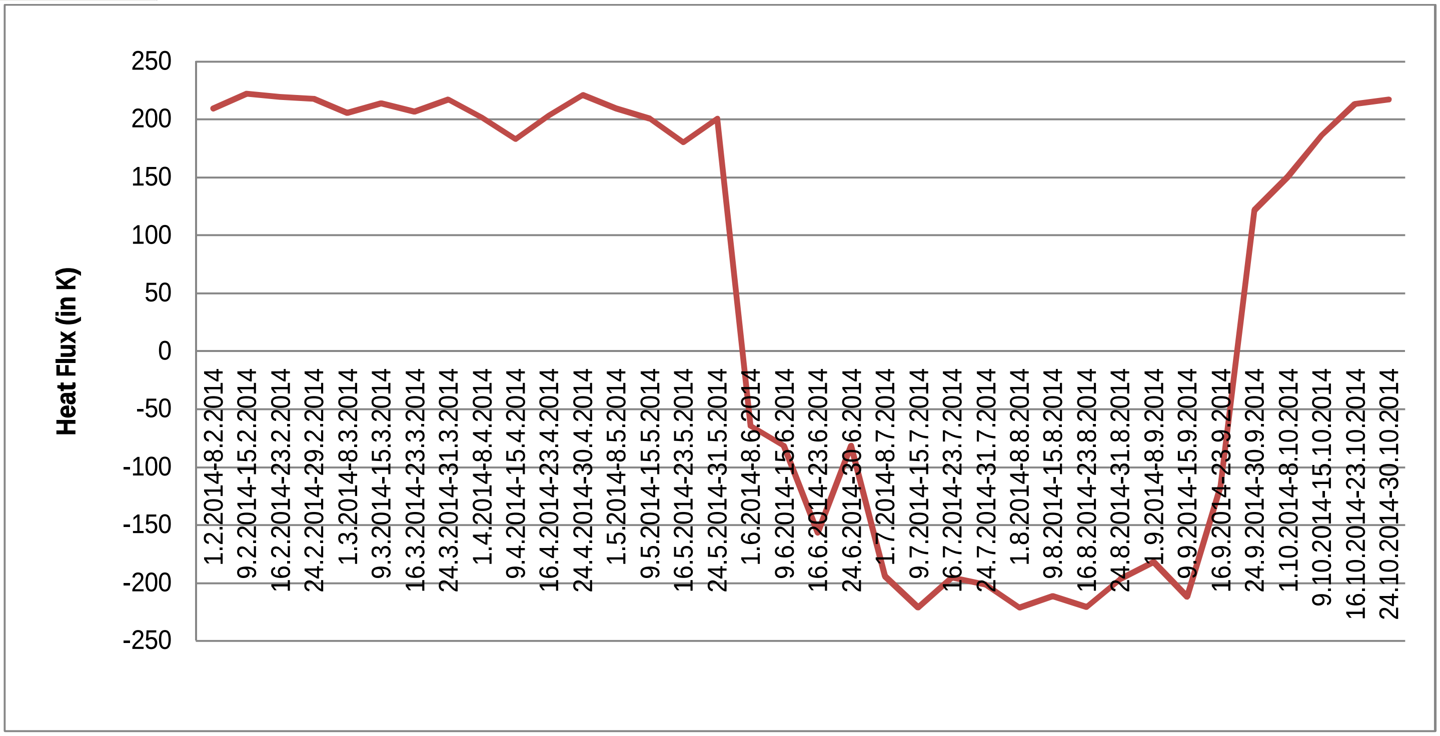

Fig 19: Time series plot of heat flux of 2014 for Station:CALCUTTA (Lat.- 22.65 °N,Long.-88.45 °E)

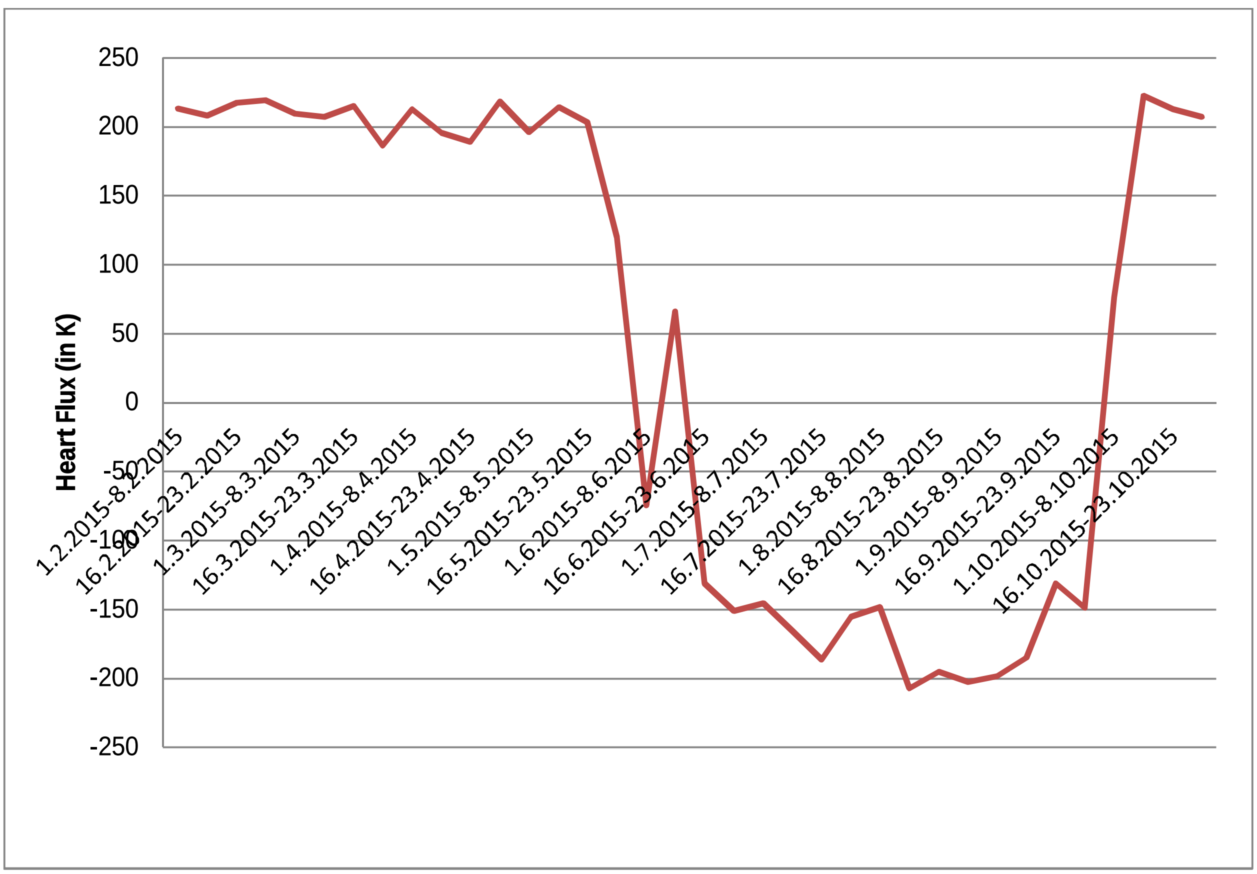

Fig 20: Time series plot of heat flux of 2015 for Station CALCUTTA (Lat.- 22.65 °N,Long.-88.45°E).

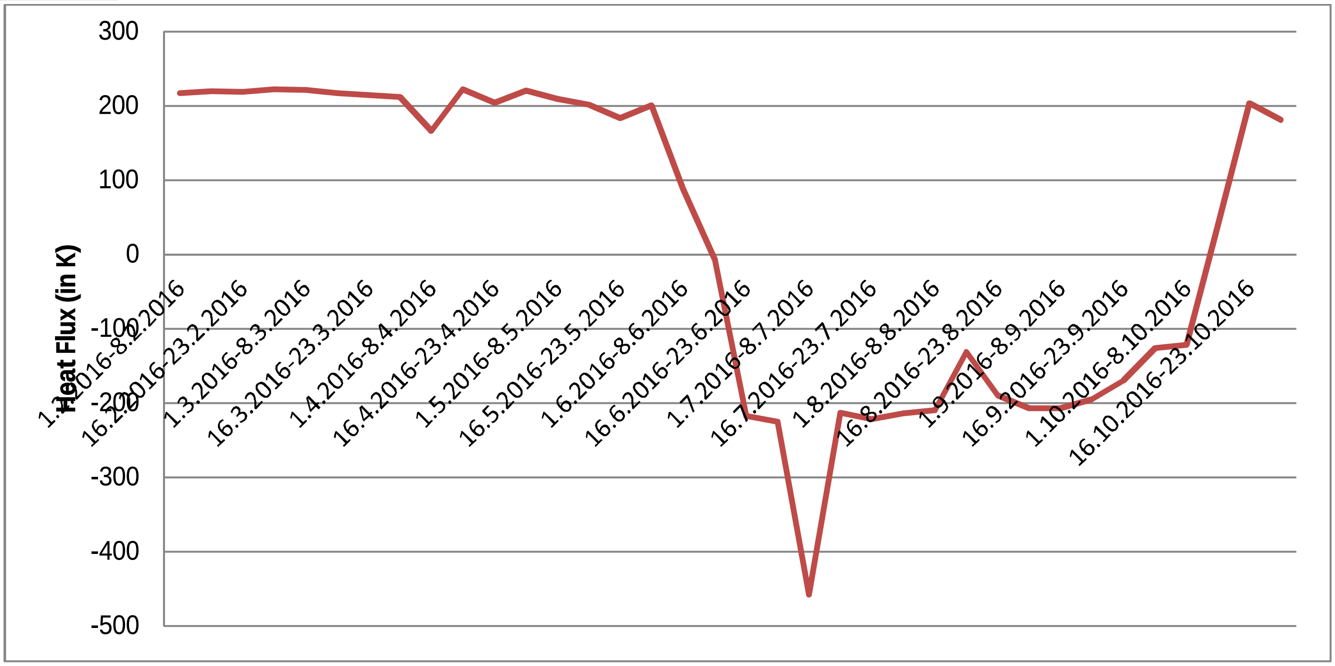

Fig 21: Time series plot of heat flux of 2016 for Station CALCUTTA (Lat.- 22.65 °N,Long.-88.45 °E).

IV. DISCUSSION ON PROPORTIONATE HEAT FLUX ANALYSIS FROM THE GRAPHS :

A. *2014*

1) *Kuching:* The time series plot of Heat flux from February to October 2014 at Kuching (1.4833°N, 110.3°E) is shown in fig 1. Throughout the observation, the heat flux is negative over this station. It is higher in the previous months than the later, but no change of sign of Heat Flux (from positive to negative) can be observed.
2) *Colombo:* Fig 4 shows the weekly variation of heat flux of 9months (February-October) of 2014 at Colombo (6.9°N, 79.8667°E). The heat flux remains positive frommid of February–mid of March. The flux value is maximum in the month of March (01.03.2014-08.03.2014). The heat flux has both positive and negative values, and the transition from positive to negative value is observed after the 2nd week of March.
3) *Trivandrum:* Fig 7 shows the time series plot of heat flux of 2014 of station Trivandrum (8.4833°N, 76.95°E) for the months of February to October. At first, a rapid fluctuation in the heat flux is observed till the month of May, then it becomes comparatively stable. Though the maximum heat flux is recorded in March (1.3.2014-8.3.2014), the transition of heat flux from the positive to negative value is found in between 1st and 2nd week of May. After this transition heat flux remains negative till October and ranges along -200K flux line.
4) *Chennai:* In the time series plot of heat flux of station Chennai (13°N, 80.1833°E) for the year 2014, shown in fig 10, the heat flux value remains positive till April. Heat flux reaches its maximum value, slightly greater than 200K in the month of February (24.2.2014-29.2.2014). The transition of the heat flux from positive to negative takes place in between the 1st and 2nd week of May. In this station also heat flux remains negative after the sign change and stays along the -200K flux line.
5) *Hyderabad:* The time series plot of heat flux of 2014 of station Hyderabad (17.45°N, 78.4667°E) is shown in the fig 13. The heat flux remains more than 200K till the month of March (16.3.2014-23.3.2014). After that it decreases and changes its sign from positive to negative in May (16.5.2014-23.5.2014). The heat flux is negative for the next other months till October.
6) *Bhubaneswar:* From the time series plot of station Bhubaneswar (20.25°N, 85.8333°E) shown in fig 16 for the year 2014, the heat flux value remains high enough from February to April and again at the end of October. In 2014 complete data are not available so the transition cannot be clearly observed. Hence the analysis cannot be done completely.
7) *Calcutta:* With the increase in latitude in northward, clear peak in heat flux can not be found. Rather it remains continuously high in the first half of the time series plot. In fig 19, the same is observed for the station Calcutta (22.65°N, 88.45°E). In 2014, the flux value remains along 200K flux line from February to May. The clear transition of heat flux from positive to negative sign takes place in the month of June (1.6.2014-8.6.2014). One more thing can be observed here that the heat flux stays negative for a comparatively short time span than the previous stations as it becomes positive again at the end of September.

B. 2015

1) *Kuching:* The time series plot of heat flux of 2015 (February- October) for the station Kuching (1.4833°N, 110.3°E) is shown in fig 2. Though the heat flux rapidly fluctuates below the zero line, it never changes its sign till September. It becomes positive at the end of October, but the required transition from positive to negative cannot be observed throughout the observation.
2) *Colombo:* In the time series plot of heat flux at station Colombo (6.9°N, 79.8667°E) plotted for the months February to October 2015 (fig 5), the heat flux fluctuates rapidly and changes its sign several times till mid May. The transition from positive to negative is found in between the 1st and 2nd week of May. After that, heat flux remains negative till October.
3) *Trivandrum:* The time series plot of heat flux of 2015 of station Trivandrum (8.4833°N, 76.95°E) is shown in fig 8. Due to incomplete data, transition can not be clearly observed and hence analysis cannot be done completely.
4) *Chennai:* The weekly variation of heat flux from February to October 2015 is shown in fig 11 for the station Chennai (13°N, 80.183°E). In the previous months, some data are missing, so this portion cannot be analysed. The transition from positive to negative takes place in the month of May (9.5.2015-15.5.2015). The heat flux remains negative till the mid of October.
5) *Hyderabad:* As there is insufficient data available for plotting the time series of heat flux for station Hyderabad (17.45°N, 78.4667°E), the analysis cannot be done in the fig 14.
6) *Bhubaneswar:* The time series plot of heat flux of 2015 for station Bhubaneswar (20.25°N, 85.8333°E) for the months February- October is shown in fig 17. The transition of the heat flux from positive to negative occurs in the month of May (24.5.2015-31.5.2015). It remains negative till the 1st week of October and then becomes positive again.
7) *Calcutta:* The time series plot of heat flux of 2015 for station Calcutta (22.65°N, 88.45°E) shows that the flux value is high enough till the middle of May. The heat flux makes its transition from positive to negative in between the 2nd and 3rd week of June. Hence it is clear that with the increase in latitude in northern hemisphere, the transition time of the heat flux shifts from May to June. The heat flux remains negative till the end of September.

C. 2016

1) *Kuching:* From the time series plot of Kuching (1.4833°N, 110.3°E), it is observed that the heat flux is negative throughout the year 2016. So, there is no transition of heat flux from positive to negative is available in the fig 3. The heat flux has a maximum value in the month of May (9.5.2016-15.5.2016).
2) *Colombo:* Fig 6 shows the time series plot of heat flux for the year 2016 for the months of February to October at Colombo (6.9°N, 79.8667°E). The heat flux has a maximum value in the month of February (24.2.2016-29.2.2016). Heat flux transition from positive to negative happens in May (9.5.2016-15.5.2016). In the first few months of the observation the flux fluctuates along the zero line, but after the transition it becomes comparatively stable.
3) *Trivandrum:* The heat flux has both positive and negative values at Trivandrum (8.4833°N, 76.95°E) in the year 2016 for February to October, shown in fig 9. Heat flux reaches its maximum in the month of March (1.3.2016-8.3.2016). It makes its transition from positive to negative in between 1st and 2nd week of May.
4) *Chennai:* In the year 2016, heat flux has positive values from February till Mid of May and negative values from Mid of May till October, shown in fig 12. The transition from positive value to negative value of heat flux can be seen in between the 2nd and 3rd week of May at the station (13°N, 80.183°E). The maximum heat flux recorded in the 1st week of May.
5) *Hyderabad:* The time series plot of heat flux for the year 2016 (fig 15) for the months of February to October at Hyderabad (17.45°N, 78.4667°E), shows that the heat flux has positive values from February till May and negative values from June till October. The transition from positive to negative value of heat flux can be seen in the 1st week of June.
6) *Bhubaneswar:* At this station(20.25°N, 85.8333°E), heat flux has positive values from February till May and negative values from June till October in the year 2016. Fig 18 shows that the transition of heat flux from positive to negative value occurs in the 1st week of June.
7) *Calcutta:* From the time series plot (fig 21) of Calcutta (22.65°N, 88.45°E), it is observed that the heat flux is positive from February till the mid of June and negative from the mid of June to the mid of October.In 2016, the transition from positive value to negative value of heat flux can be seen in the 2nd week of June.

V. CONCLUSION

From the above discussion it may now be concluded that:

A. The on set of Indian south west monsoon depends on the reversal of Tropical Easterly Jet(TEJ).
B. The reversal of proportionate heat flux of TEJ and date of onset of south west monsoon has been related with latitude of the place.
C. The reversal of proportionate heat flux of TEJ occur much before the onset of south west monsoon of that place.
D. The date of reversal of proportionate of TEJ heat flux may be taken as the precursor or predictor of onset of south west monsoon at that place.
E. However, this use of change of sign of Heat Flux as a predictive tool for forecast of Monsoon is valid only for a limited area as we can see from our graphs. The change of sign of Heat Flux occurs only within the latitude range between 13°N to 22.65°N.This is because Tropical Easterly Jet Stream are high speed winds that limited to narrow bands at height between 9km to 14km.

VI. ACKNOWLEDGEMENTS

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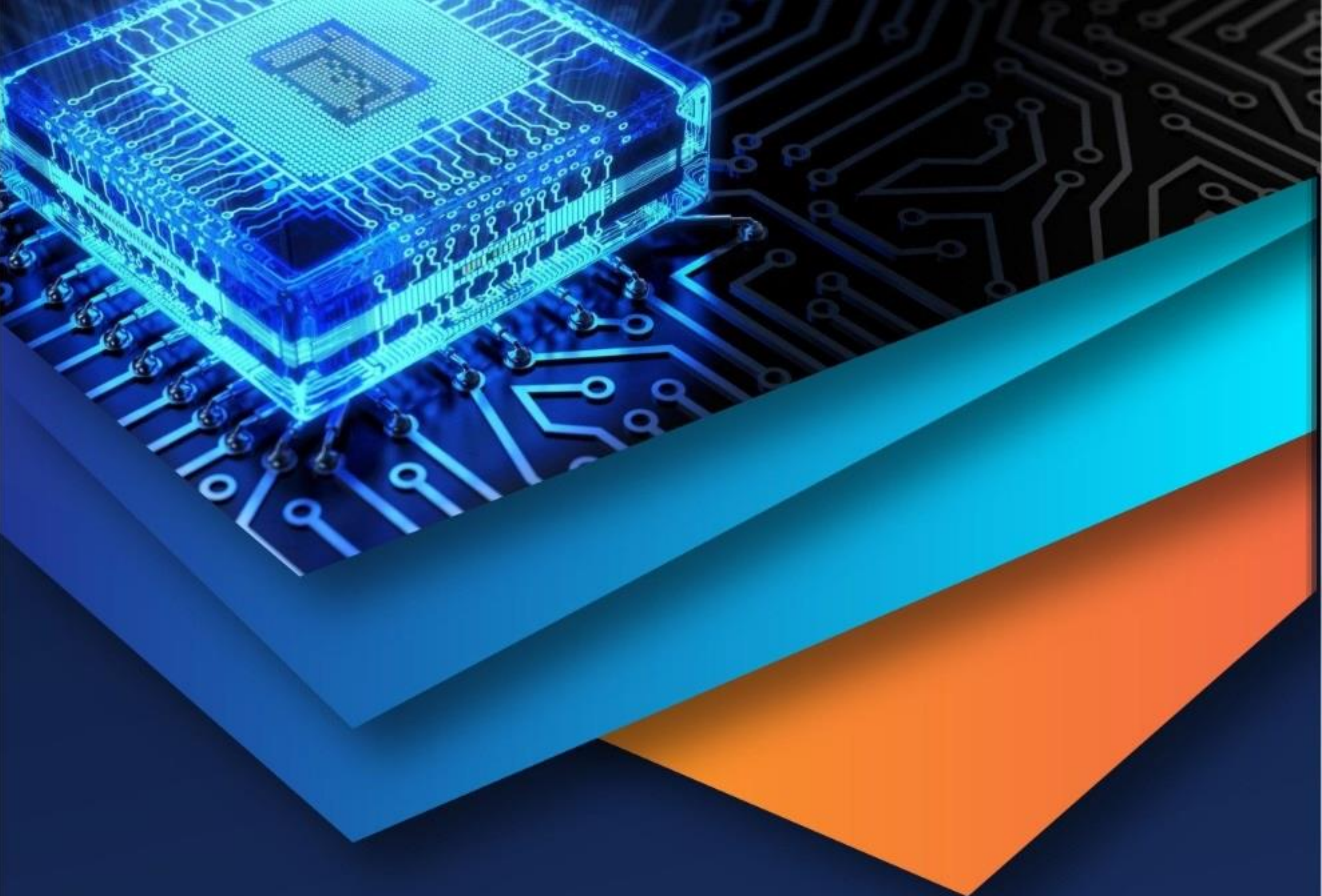

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