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A Comparative Case Study on Low Level Jet Stream on Indian Summer Monsoon at Different Regions

Ramkrishna Datta[1,2], Emili Singha Roy[1]
[1]Department of Atmospheric Science, University of Calcutta, 51/2, Hazra Road, Kolkata -700019.
[2]Ex-Meteorologist, India Meteorological Department.

Abstract: The Indian summer monsoon(ISM) also called South-West Monsoon, is characterized by strong cross-equatorial low level jet stream (LLJ) with its core around 850 hPa. The monsoon is found to have large intra- seasonal variability within June to September. During the onset monsoon, the LLJ is empowered by Madagascar (Island in the southern hemisphere) high along with Somali current and flows at different time at different places over Indian Subcontinent. Our probe areas are Our probe areas are Thiruvananthapuram (43371, 08-29N, 076-57E), Chennai (43279, 13-00N, 080-11E), Mumbai (43003, 19-07N, 072-51E), Kolkata (42809, 22-39N, 088-27E), Delhi (42182, 28-35N, 077-12E) and Dibrugarh (42314, 27-29N, 095-01E). Vertical profile of Radio Sonde and Radio wind (RSRW) data are collected from University of Wyoming website. We have considered 925 hPa, 850 hPa,700 hPa and 500 hPa within scale height levels for temperature, humidity and wind(direction and speed) from February to august of the years 2017, 2018 and 2019. The components of the Moisture influx calculated along the direction of the south west (225 degree) for each date. And the integration of consecutive seven days output have been taken as week1 then week2 etc. respectively. It is found that the moisture flux reversal happened at different places at different dates. Not only that, the dates of occurrence of moisture influx reversal are forestalled more than a fortnight before the onset date of monsoon of the respective places. These shows that our result is a precursor of long range forecast of ISM.
Keywords: Low Level Jet, Madagascar High, Somali current, RSRW, Moisture Influx, Scale Height.

I. INTRODUCTION

India is an Agriculture based country. Even in this decade of digital technology, development of India is expressed on the production of Agriculture. Countries every Yearly budget or in every Five-Year plane, special attentions are drawn for cultivation. It is well known to all that agriculture or cultivation depends on rainfall. The anomalies of rainfall sometimes brings situation of epidemic India.

This rainfall is totally depends on the synoptic scale weather phenomena Indian Summer monsoon(ISM). For this reason government of India is given highest attention on the activity of monsoon through India Meteorological Department (IMD), Indian Institute of Tropical Meteorology(IITM), National Centre for Medium Range Weather Forecast(NCMRWF), Indian Agricultural Research Institute(IARI), Moulanabish National Crop Forecasting Centre (MNCFC) etc. under the umbrella of the Ministry of Earth Science, Government of India.

Indian Summer Monsoon Depends on Many atmospheric phenomena. The Low-Level Jet (LLJ) and Tropical Easterly Jet (TEJ) are the two synoptic-scale weather phenomena associated with the Indian summer monsoon give us prominent indication in predicting the regularity , activity ,strength , duration, blockening of the monsoon system. According to Joseph and Raman, 1966; Findlater, 1966, 1967; Mokashi, 1974; Desai et al., 1976; core of these two jets are located at 850 hPa and 150 hPa respectively over southern India. The winds go along with the LLJ with speed less than 30ms-1, but sometimes the wind speeds exceed this value and the Jet is described as the synoptic scale phenomena. According to Stull, 1990; Low Level Atmospheric Jet is a nocturnal phenomenon. It is also a feature of the stable boundary layer and over the Indian Peninsula, it is an Afro-Asian cross-equatorial phenomenon. Joseph and Raman (1966) and Desai et al. (1976), examined and then confirmed that over the Peninsular India westerly LLJ stream flows with strong vertical and horizontal wind shears. According to Findlater, 1969; there is a strong link of LLJ over tropical India with the Indian Monsoon Rainfall. Later in his studies it is also found that a strong cross-equatorial wind flows to Indian Ocean and southern India from South Africa via Somalia. Using Radiosonde/Rawinsonde (RS/RW) data many scientists have shown that Low Level Jets (LLJ's) occur frequently in many parts of the world. In India these jets are mainly observed in the atmosphere of the lower troposphere of the southern peninsula and western India region. However most of the RS/RW observations in various regions of India are taken at 0000 and 1200 hrs GMT, there is no sufficient work that reports the day and night occurrence of the LLJ.

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LLJ’s have a great contribution to regional as well as global climate. The research work of Joseph and Raman revealed that low level westerly jets that flow over the peninsular India during the south-west monsoon in the period June to September, flow with varying frequency and intensity all the way up to latitudes of 20^{o}N. The highest frequency is observed in the month of July and also the maximum wind speeds are reported typically at heights lower than 2.4 km. The strength of the lowlevel monsoon winds is directly related to the rainfall over that region. According to Findlater, LLJ’s which is observed in the peninsula and western Indian region in July are a part of the Somali Jet branch. There is a peculiar feature of Somali Current that it reverses in direction with the onset of the summer monsoon.

II. DATA & METHODOLOGY

In this work, atmospheric sounding data from the website of the University of Wyoming have been studied for three years 2017,2018 and 2019. We have observed the southwest monsoon current in the form of a cross-equatorial low level jet stream (LLJ) from 925 hPa pressure level at a height of 0.78 km to 500 hPa at a height of 5.5 km approximately within Scale height of the local atmosphere from the ground. The core lies at an altitude of about 1.5 km where the pressure is 850 hPa and the core wind speed is 80- 100 km/h. We have done the analysis based on 3 years data from 2017 to 2019. We have included six stations starting from the south at 8.5241^{o}N, 76.9366^{o}E to north 28.7041^{o}N, 77.1025^{o}E and west at 19.0760^{o}N, 72.8777^{o}E to east 27.4728^{o}N, 94.9120^{o}E. The moisture flux values have been calculated for the pre-monsoon and monsoon months. In the present study we have observed the weekly variation of moisture flux at each station in every year and tried to understand the variation of moisture flux from pre-monsoon to the monsoon months over India.

Only four weather parameters of the pre-monsoon and almost full SW monsoon season at four different pressure levels of troposphere are observed. The purpose here is to study the characteristics of LLJ on Indian South West summer monsoon at different parts of India by studying the upper air data of some particular stations. The onset of monsoon at different regions of India can also be understood from this study. An active monsoon indicates the period when strong LLJ passes through the 10^O – 20^{O}N latitude belt with active convection i.e rainfall in that region.Data of 7month areobserved starting from February to August for the years 2017, 2018 and 2019.

The four parameters of 00Z at four different pressure levels have been considered that include temperature, relative humidity, wind speed and wind direction. Orography and surface heat fluxes have a huge impact on the Indian Summer Monsoon. Change in topography and reduced surface heat fluxes, strength of the monsoon in terms of vertical wind shear index have a high correlation with the amplitude of maximum equivalent potential temperature of boundary layer. As the heat flux is proportional to temperature, relative humidity, wind speed and wind direction, those data are collected from the layers ranging from 925 hPa to 500 hPa. Again to visualize the monsoon wind reversal, the component along 270^{O}has been used for calculating moisture flux at each pressure level where the variation of wind direction is considered by taking the difference between the exact direction of wind flow at that level in that particular day and 225^O angle.

Using a simple computer program the moisture flux is calculated and then taken the average of the particular four levels. Graph of every month has been plotted for observing the variation of the average of moisture flux of every week. The data of very few days are not available in the site, so in that case only 4-5 days data are considered for the week’s average. Six stations have been studied in this way including Thiruvananthapuram, Chennai (then Madras), Mumbai (then Bombay), New Delhi, Kolkata (then Calcutta) and Dibrugarh.

The link of the site is given below:
http://weather.uwyo.edu/upperair/sounding.html

We have estimated Moisture Flux as the product of temperature, humidity, and wind. We are also interested to find the component of the moisture flux along south westerly direction. For this reason we have calculated Moisture Flux= Temperature of that pressure level in ^{O}C X Relative Humidity at that level X Wind Speed of that pressure level in Knots X Cosine of difference between 225^O angle and the wind direction of that pressure level in radian. A graph has been plotted for observing the variation of average moisture flux with the number of weeks by taking the weekly average of moisture flux. The graph shown here is of Chennai of 2019. Here the sign change of the flux has occurred due to the starting of monsoon. In this way repeating every step we have tried to observe the variation of moisture flux is observed at the stations of various regions of India for studying the characteristics of LLJ.

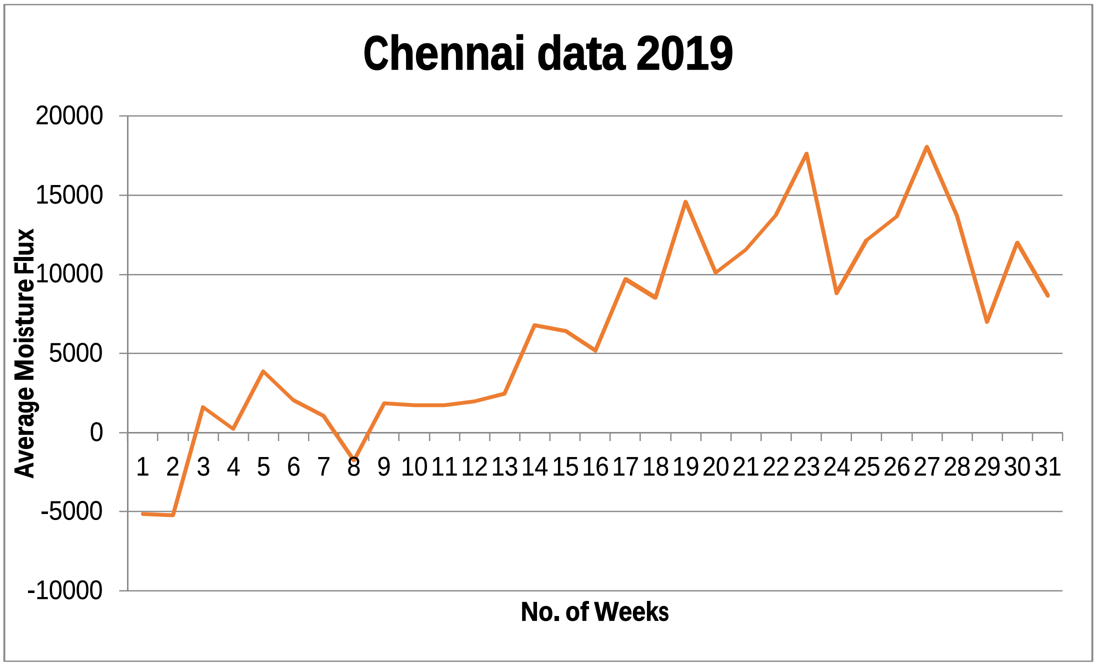

Fig-1

A. Analysis

In the present study I have tried to observe the relationship between the convective heating of the atmosphere over the six stations from the different parts of India and the LLJ. As a measure of the strength of the LLJ an index named Moisture Flux is used which is the summation of the flux from 925 hPa to 500 hPa pressure levels.

B. Thiruvananthapuram: 2019

Weekly variation of average moisture flux of the station Thiruvananthapuram (8.5241^{O} N, 76.9366^{O} E) has been shown in fig 2(a) with the help of the graphs plotted considering the weeks from February to August of the year 2019. As Thiruvananthapuram is situated at the extreme southern part of India, the onset of the southwest monsoon in India first occurs in Kerala. From the graph we can observe that the moisture flux has changed its sign after the 17th week (24th May to 30th May). Therefore the seasonal wind changes its direction from the 18th week (31st May to 6th June). The moisture flux value up to the 17thweek is negative because of the wind flows from the north-east direction while the positive moisture flux indicates the wind flowing from south-westerly direction. The change in the sign of moisture flux suggests reversal of monsoon. In 2019 the onset of the monsoon over Kerala was reported on the 8th June, 7days later than the normal. And we have got wind reversal at LLJ on 24Th May 2019. Which indicates more than 14 days earlier of onset of monsoon there.

C. Thiruvananthapuram: 2018

Fig- 2(b) shows that in the year 2018 the moisture flux changed its sign after the 16th week (17th May to 23rd May) and remained positive. After the 29th week (16th August to 22nd August) the flux value again becomes negative. In two positions the values are taken as zero as the data is not available on those days. Therefore, from fig 2(b) it is clear that after 16th week, the seasonal wind changes its direction of flow and monsoon reversal occurs after that week.The official date of southwest monsoon hitting Kerala in 2018 was June 1, three days before its scheduled arrival. The graph shows that the south-westerly wind started flowing over Thiruvananthapuram from the 17th week.

D. Thiruvananthapuram: 2017

In 2017, rapid fluctuation of the average moisture flux value is observed from fig 2(c). Raw data for the calculation of moisture flux is unavailable in those weeks where the flux value touches the zero level. The value finally changes its sign after the 18th week (31st May – 6th June). The average moisture flux value is almost negative in the first weeks and after the 18th the value finally changes its sign and rapid increase is observed. From the records, it is studied that the southwest monsoon has set in over Kerala in 30th May 2017.

E. Chennai:2019

The average moisture flux value how varies in every week from February to August of 2019 of the station Chennai (formerly known as Madras) situated in 13.0827 ^{O}N, 80.2707 ^{O}E is described in fig 3(a). Here the average moisture flux changes its sign from negative to positive two times. Between the 8th (22 March- 28 March) and 9th week (29 March- 4 April) it changes sign and then increases. The negative value indicates that in those weeks the wind flows from north-west and in the other weeks having positive flux value indicates the wind flow from south-west direction. As the flux value becomes positive after the 8th week and then it grows higher, monsoon reversal occurs that time. Normally monsoon onset occurs over Chennai in the mid of June. A decreasing trend in the last weeks of the graph is observed which may be due to the weakening of the monsoon low level jet.

F. Chennai: 2018

In 2018, the average moisture flux was negative up to the 8th week, shown in fig 3(b).Then it increases and becomes positive for the first time. After one week it again decreases and becomes negative. Just before the 11th week it starts to increase and again crosses the horizontal axis. From the 11th week (12April- 18April) a rapid increase in the flux value is observed. This indicates the reversal of monsoon wind flow. Average moisture flux value is taken as zero in some weeks when the data for calculating moisture flux is absent.

G. Chennai: 2017

In the fig- 3(c), average moisture flux is negative in the first three weeks over Chennai. After the third week it starts to increase and becomes positive. As the flux value becomes positive, a change in the seasonal wind flow is observed. After the third week (14th February- 21st February) the moisture flux is no longer negative, so the monsoon reversal occurs after that week over Chennai.

H. Kolkata: 2019

Weekly variation of average moisture flux of the station Kolkata (22.5726^{O} N, 88.3639^{O} E) has been shown below with the help of fig- 4(a). In the year 2019, advancement of SW monsoon has remained snail like slow and performance was weak. After the formation of a low pressure area in the Bay of Bengal monsoon starts to advance over Kolkata. Kolkata lies in the north of the system and more rains are observed over the southern areas of the system. From the graph 4(a) it is observed that the value of the moisture flux has become positive after the third week of February. Therefore a change in the wind flow is found. In the first three weeks it is negative due to the wind flow from the north-east direction. The positive value of the moisture flux normally signifies that the wind flow is from the south-west direction. This is the indication of monsoon reversal. Monsoon is announced in Kolkata in the mid of June and it is accompanied with a couple of moderate spells in some part of the city. It is observed in the graph by sharp decrease of the flux value in some weeks of June, July and August.

I. Kolkata: 2018

In fig 4(b), average moisture flux is negative up to the second week. The sign change has occurred from the third week of February. As the value of average moisture flux is positive from the third week, so the direction of wind flow changes from that week and monsoon reversal occurs over Kolkata. If the average moisture flux is negative in a particular week, the wind flow occurs from the northeast direction, otherwise from southwest direction. In this graph the values have almost increased continuously up to the end of May but after that a rapid fluctuation is observed. This may be due to some moderate spells in the city. Sharp fall of the flux value has occurred three times due to the discontinuous data and in those weeks the value of average moisture flux has been considered as zero.

J. Kolkata: 2017

In the case of 2017 data, fig 4(c) shows that the wind reversal occurs in the second week of February, as the average moisture flux becomes positive from negative. So direction of seasonal wind flow changes and monsoon reversal occurs there. The moisture flux value shows an increasing trend in wind speeds on seasonal and monthly scales, but in August a decreasing trend is observed. This may be due to the increase of number of monsoon depressions forming over the Bay of Bengal.

K. Dibrugarh: 2019

The variation of average moisture flux in every week of seven months (February- August) of 2018 of station Dibrugarh (27.4728 ^{O}N, 94.9120 ^{O}E), a city of Assam in northeast India is shown in the fig 5(a). From the above graph we can understand that average moisture flux is negative up to 7th week (14th March – 21st March). After that seasonal wind starts to change its direction. From the 17th week (24th May – 30th May) complete change in the direction of wind flow can be found.

This is the indication of monsoon reversal as the moisture flux value changes from negative to positive. Negative value of moisture flux means the wind flow from the northeast direction and positive value indicates the wind is flowing from the southwest direction over that station. According to the reports southwest monsoon hit Dibrugarh in the 2nd week of June (here 19th week).

L. Dibrugarh: 2018

Except the sixth week, temperature, relative humidity etc data are absent up to the 10th week (5April-11April) in fig 5(b). So, the average moisture flux value has been considered as zero. The moisture flux becomes positive permanently after the 19th week (7th June – 13th June). Direction of wind flow changes at that time. This is the indication of monsoon reversal. In the last few weeks, a decreasing trend is observed in the average moisture flux data of 2018 over Dibrugarh.

M. Dibrugarh: 2017

In the fig 5(c) fluctuation of the average moisture flux beside the zero line is noticedover Dibrugarh. Wind direction completely changes after the 19th week (7June – 13June), which is the indication of monsoon reversal. In 2017 southwest monsoon hit the northeast India from the 1st week of June.

N. New Delhi: 2019

In the graph 6(a), the variation of average moisture flux in every week is shown starting from February to August in 2017 over station New Delhi (28.6139^{O} N, 77.2090^{O} E). From thegraph it can be seen that the average moisture flux is positive only in May and June. Otherwise it is negative throughout the observation. Negative value of moisture flux means wind blows from the northeast direction and positive flux value indicates the wind flow from southwest direction. Here change in sign can be found from the 14th week (3-9 May). Therefore, wind flow changes its direction that time and this indicates the reversal of monsoon over Indian region. Monsoon trough almost ends near the latitude of Delhi, so monsoon is not steady over New Delhi in 2019 and a high fluctuation is observed.

O. New Delhi: 2018

In 2018 (fig-6(b)), rapid fluctuation in the data of average moisture flux is observed beside the zero line. After the 17th week (24May-30May) an increasing trend of the flux value is observed. This may indicate reversal of southwest monsoon from the northwest as the wind direction becomes completely opposite from then. According to the reports, the normal onset date for monsoon in Delhi is June 29.

P. New Delhi: 2017

In 2017 also a rapid fluctuation of average moisture flux is observed beside the zero line over New Delhi. From fig-6(c), February 1st week to 9th week (29March-4April) the flux value is negative. After that week, fluctuation starts. If the moisture flux is negative, it can be said that the wind is flowing from northwest direction and if the moisture flux is positive, the wind is flowing from southwest direction. In 2017, monsoon onset occurred here in the last week of June.

Q. Mumbai: 2019

Weekly variation of average moisture flux of the station Bombay, now Mumbai (19.0760^{O} N, 72.8777^{O} E) has been shown in fig-7(a) considering the weeks from February to August of the year 2019. Bombay is a narrow peninsula lies beside the Arabian Sea. From the graph a rapid fluctuation of the average moisture flux value is observed up to May over Bombay. The flux value changes sign several times. After the 17th week (24May – 30May) sign change stops and an increasing trend is observed. Changing sign of moisture flux means change in the direction of wind flow. If the average moisture flux is negative, the wind is flowing from northeast direction on that week and if the flux is positive, the wind is flowing from the south west direction over that place. A decreasing trend of moisture flux is observed from the 28th week (9August- 15August) which may be due to the weakening of monsoon low level jet over Bombay in the month of August.

R. Mumbai: 2018

In the fig- 7(b) average moisture flux is negative up to the 13th week (26April- 2May). After that the moisture flux increases and the values of every week remain positive till 27th week (2August-8August). Sharp fall in 28th week and the zero value of flux up to 31st week are due to the absence of data required for calculating the average moisture flux. Change in wind flow is observed from the 13th week because the sign change occurred that week. As per the report monsoon rain started in Bombay from the 2nd week of June.

S. Mumbai: 2017

The average moisture flux data is not available in the first two weeks of February in the graph 7(c). After that the flux value fluctuates for a number of weeks. From the 16th week (17May – 23May) average moisture flux stops its rapid fluctuation and changing of sign. In June and July month huge amount of moisture flux is observed in the lower atmosphere of Bombay. In the 22nd week (28June – 4July) maximum amount of moisture flux is observed. After the 25th week (19July -25July) a decreasing trend of average moisture flux is noticed which may be due to the weakening of monsoon low level jet in the month of August. The negative value of the flux means the seasonal wind is flowing from the northeast direction in those weeks and the positive value indicates the wind flow from southwest direction. The permanent change in wind flow in between the 15th and 16th week which is said to be the monsoon reversal has occurred.

III. CONCLUSION

In view of above analysis It may now be concluded

A. It is possible to predict the onset of south west monsoon at a place of Indian sub-continent from the moisture incursion at that place.
B. Different places have different time onset of South West Monsoon.
C. The progress of onset of SW monsoon and block of monsoon are also possible to track through these analysis.

Moisture flux incursion takes places much before the set up of monsoon over India. Therefore it is the precursor of summer monsoon and may be considered as the long range forecast to depict the progress of Indian summer monsoon. Although irrigation techniques have been improved a lot but India is highly dependent on monsoon rainfall distribution for economical growth even now. Distribution of summer monsoon rainfall in various parts of India is the main factor of sound agriculture product. The method may be taken as Long Range Forecast of southwest monsoon.

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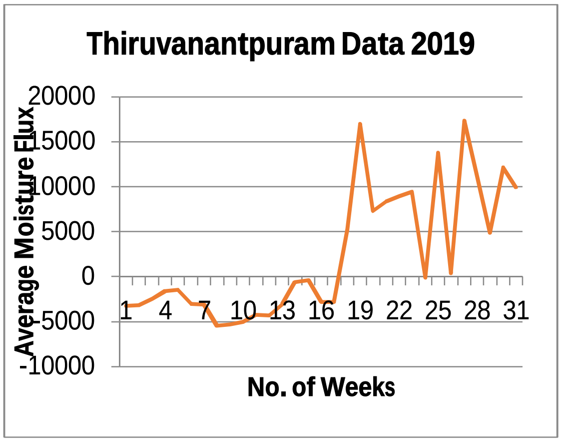
Graphs



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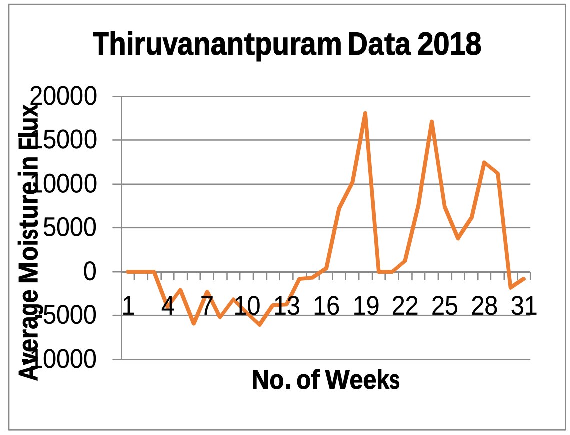

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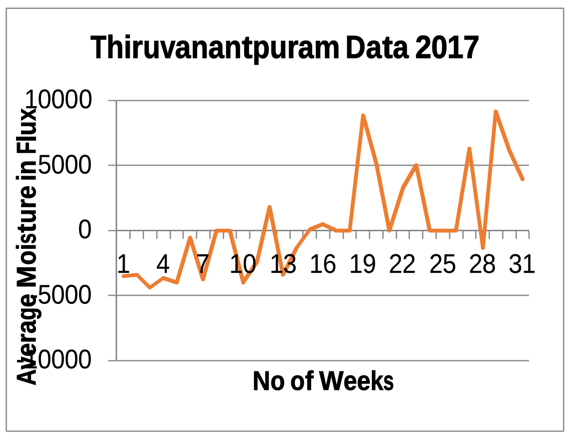

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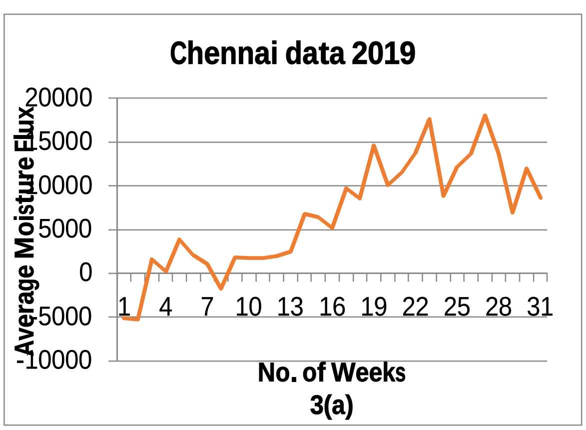

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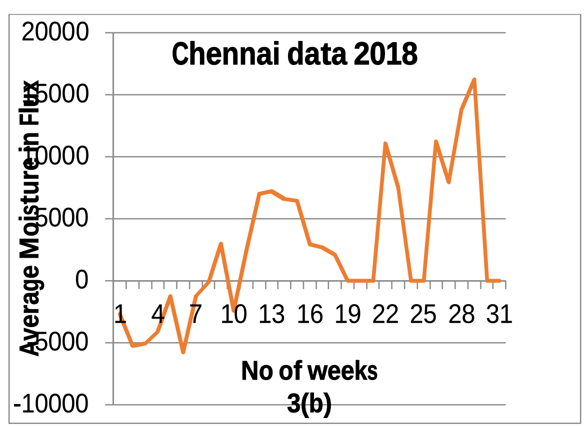

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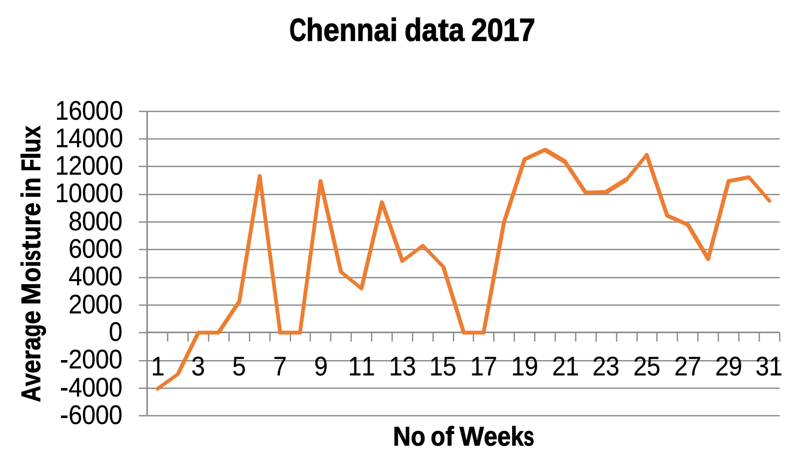
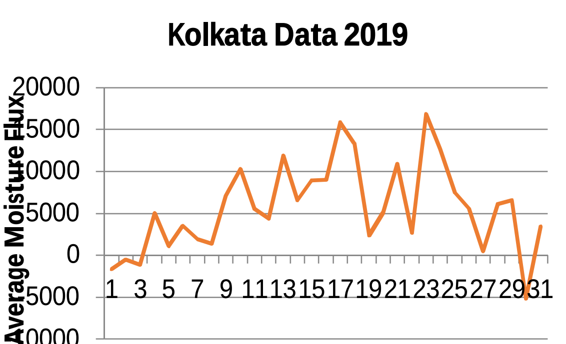
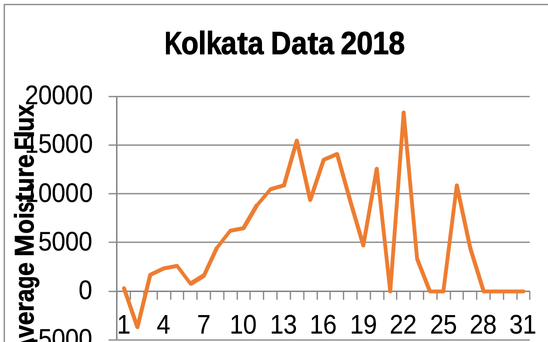

Chennai data 2017
Average Moisture in Flux
16000
14000
12000
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
No of Weeks

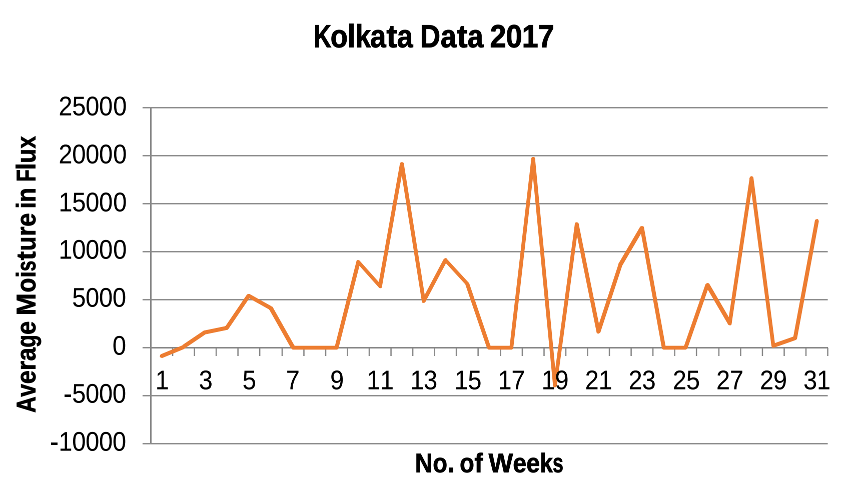
3(c)


Kolkata Data 2019
Average Moisture Flux
20000
15000
10000
5000
0
-5000
-10000
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
No. of Weeks

4(a)


Kolkata Data 2018
Average Moisture Flux
20000
15000
10000
5000
0
-5000
1 4 7 10 13 16 19 22 25 28 31
No. of Weeks

4(b)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Average Moisture in Flux
25000
20000
15000
10000
5000
0
-5000
-10000
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
No. of Weeks

4(c)

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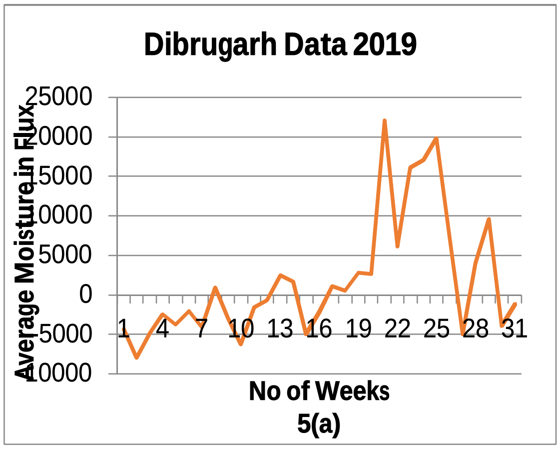

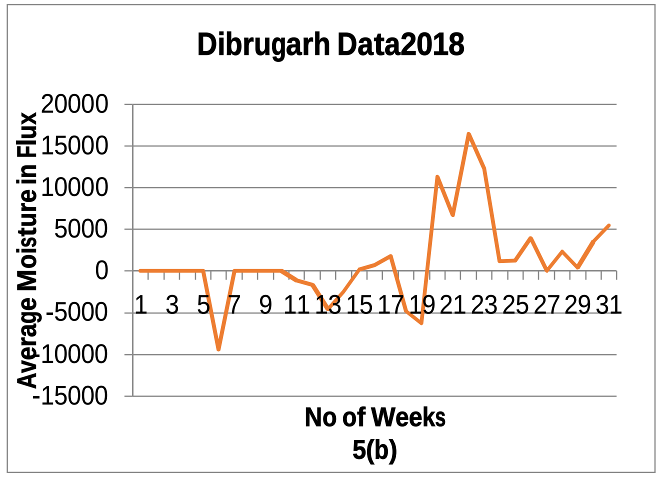

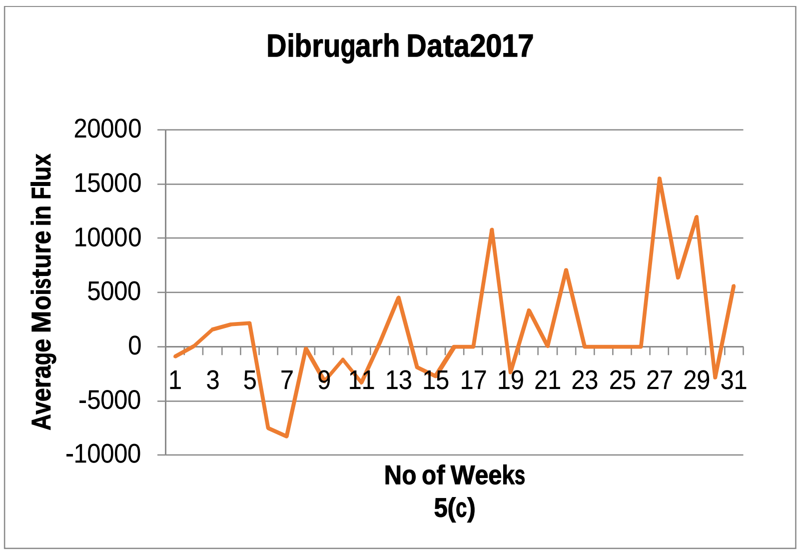

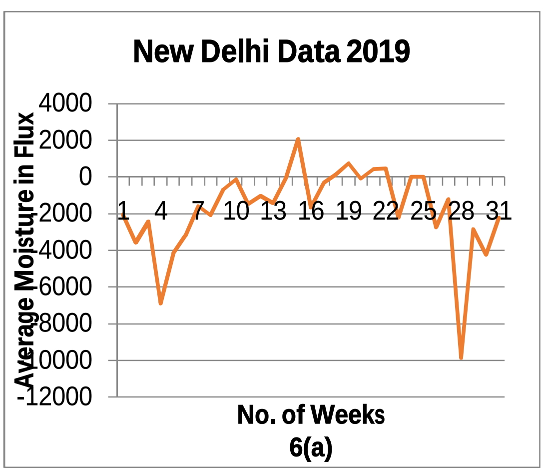

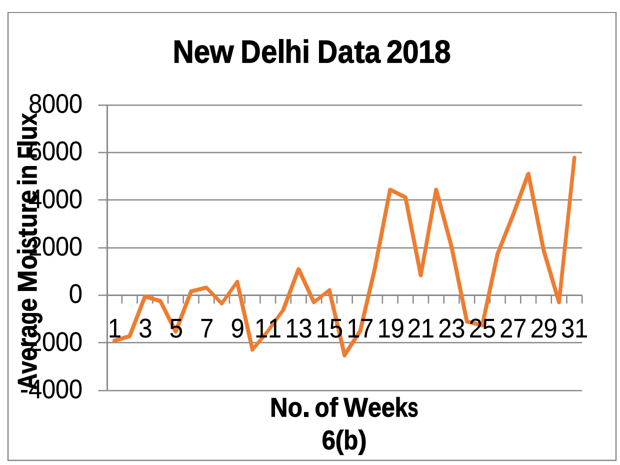

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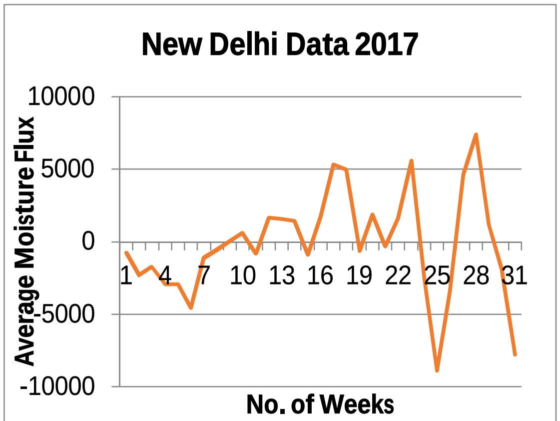

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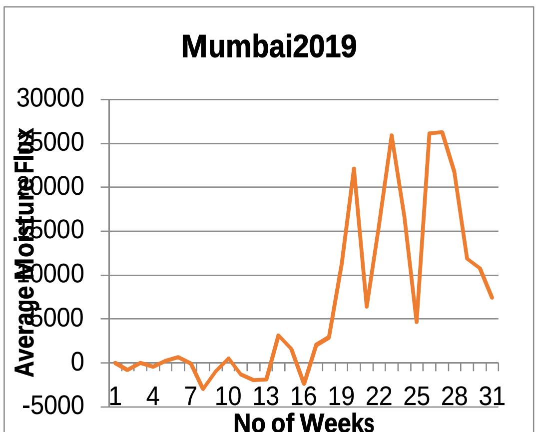

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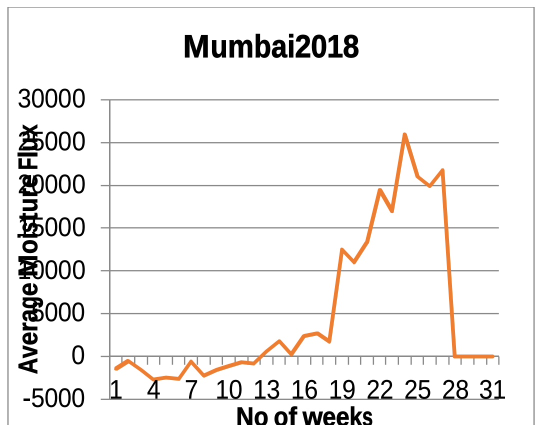

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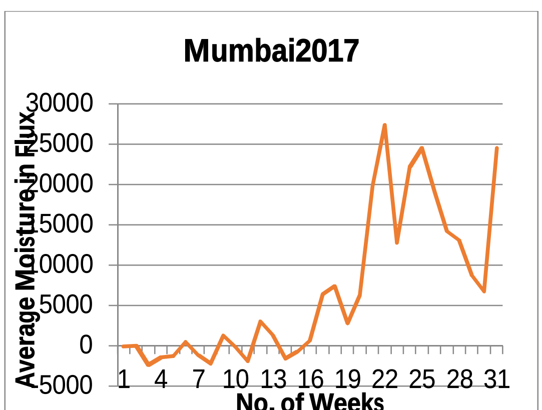

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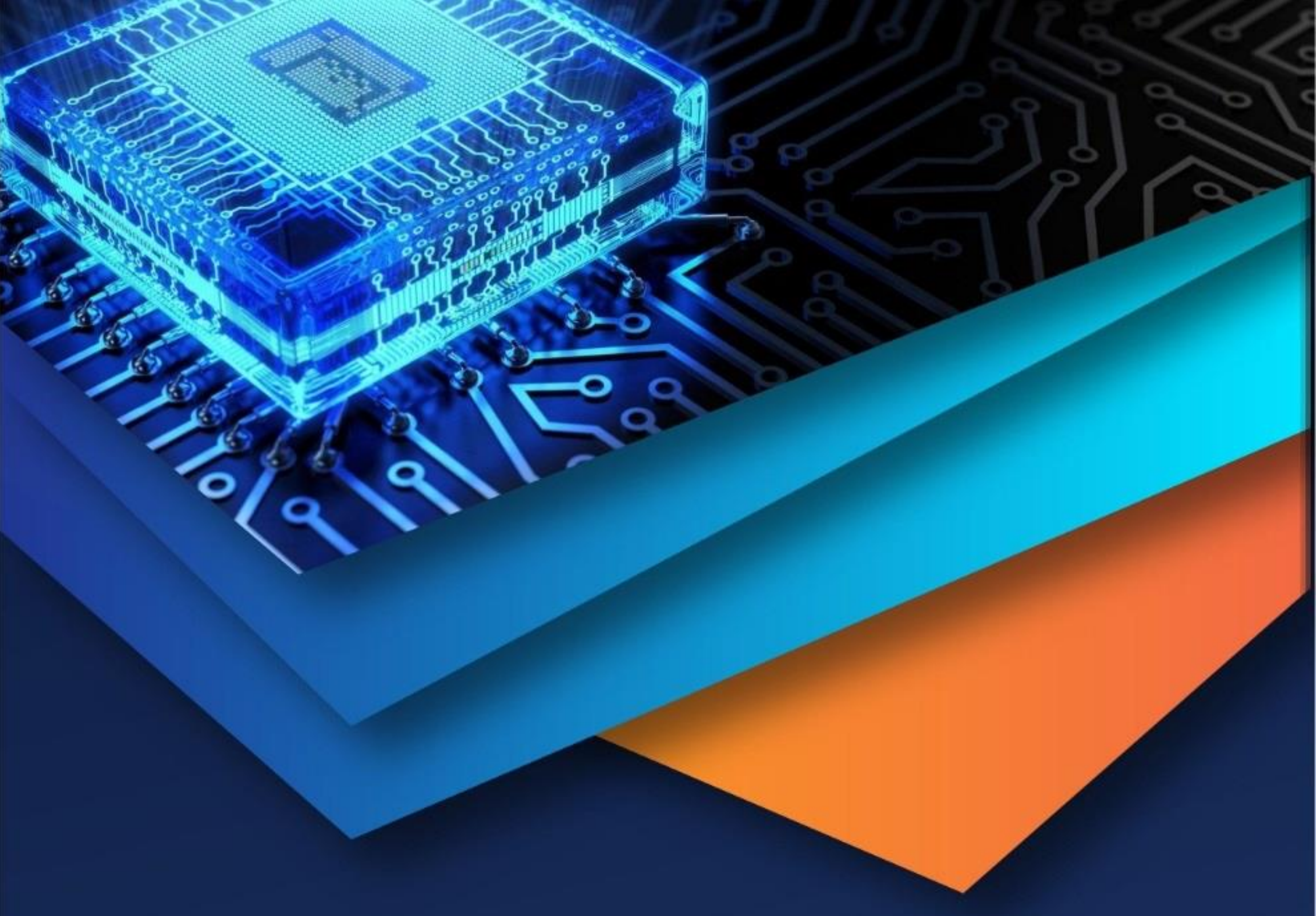

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