

Some Climatological Aspects of Convective Systems at Five Major Cities of West Bengal, India

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ABSTRACT

Disasters related to convective systems are considered to be global phenomena, as they may occur anywhere in the world, at any instant. Thunderstorms, hailstorms, lightning, dust storms are some of the disasters associated with these convective systems. Some of these systems may possess great potentiality to produce serious damages to human life and property. Indian region is vulnerable to severe convective systems during the hot period of pre-monsoon season. In this paper, the climatological aspects of the convective systems over five major cities of West Bengal region namely Kolkata, Darjeeling, Asansol, Silliguri and Durgapur has been attempted using LIS TRMM satellite data (1995-2014), ERA-Interim ECMWF satellite data (1979-2010) and GPCC precipitation dataset (1901-2010). Thermodynamic atmospheric stability indices such as K Index (KI), Total Totals Index (TTI), Humidity Index (HI) and Total Precipitable Water (TPW) associated with severe convection system over study region were studied to provide guidance to severe convective activity. Convective available potential energy (CAPE) and Rainfall also helped us to study the convective systems seasonally and decadal. All the major cities in West Bengal on an average are receiving high lightning flashes which is a major disaster leading to human loss and high property and crop damage. The threshold values of the indices we have taken for the study are satisfied with values mentioned in the literature. Results of this study may help disaster management to take risk reduction steps.

Keywords: Rainfall, Convective available potential energy (CAPE), K Index (KI), Total Totals Index (TTI), Humidity Index (HI) & Total Precipitable Water (TPW).

INTRODUCTION

Convective systems are mesoscale phenomena which occur around the world. These are accompanied by large hail, damaging winds and torrential rainfall, causing substantial damages. Convection is the major source for the formation of clouds such as cumulonimbus. This feeds the development of weather systems such as thunderstorms,

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tornadoes etc. Deep convection involve instability, moisture and updraft (Miller, 1976). Severe convective weather events such as thunderstorms, hailstorms, squalls, duststorms and lightning results in human loss and property (Johns and Doswell, 1992). Thunderstorms usually occur due to intense heating of atmosphere at surface level and it happens during pre-monsoon season. Hailstorms are convective clouds which includes precipitation in the form of rain and icecubes. Squalls are similar to thunderstorms but their wind speeds are increased suddenly for short span causing damage. The Indian subcontinent is one of the most disaster prone area in the world. Disasters like thunderstorm, lightning and squalls are creating more devastation affecting lots of human life and property loss in recent years over different parts of the country (Source: Annual Report, NCRB). During the pre-monsoon season, Gangetic West Bengal and surrounding areas are affected with severe thunderstorm called Norwesters (Sinha *et al.*, 2006). In Bangladesh and adjacent parts of India, these norwesters brings high wind and very heavy rain, usually in pre-monsoon. During this time, Bangladesh, eastern and northeastern states of India are affected by violent thunderstorms. They cause considerable damage to life and property (Das, 2015; Tyagi, 2007). The cool dry northwesterly wind flow and warm moist southerly wind flow from Bay of Bengal exits over west Bengal region favouring the formation of convective systems, strong surface wind speed, heavy rains, huge cloud mass and hails are some of the signs for severe convective system (Basak *et al.*, 2012). According to National Crime Records Bureau (NCRB), lightning is associated with minimum 2,000 deaths since 2005. Approximately, 1700 people are being subjected to death or injuries due to disasters caused by convective systems. Only lightning disaster has accounted for 39% of deaths in India during 1967–2012 (Source: Annual Report, NDMA, 2018). The lack of a reliable warning system is often cited as one reason for the high number of deaths. Another is that a large number of people work outdoors in India compared to other parts of the world, which makes them more vulnerable (Earth Networks Organisation).

According to Indian Meteorological Department (IMD), the Indian climate has been divided into four seasons (a) Winter Season (December + January + February: DJF); (b) Pre-monsoon Season (March + April + May: MAM); (c) Monsoon Season (June + July + August + September: JJAS); (d) Post-monsoon Season (October + November: ON). In this paper, we made an attempt to understand some of climatological aspects of convective systems over five major cities of West Bengal region namely Kolkata, Darjeeling, Asansol, Silliguri and Durgapur. The role of stability indices and CAPE were discussed seasonally and decadal for triggering the convective activity over the five stations of West Bengal region. For that we used GPCP Precipitation dataset to study the rainfall, flashrates density from LIS TRMM satellite and stability parameters from the ERA-Interim ECMWF satellite data.

DATA AND METHODOLOGY

The present study was carried out over the West-Bengal region extending from 21-28° N latitudes and 85-90° E longitudes. The following data sets were used for analysis:

- (a) We have collected flash rate data at 0.5 degree resolution from Lightning Imaging Sensor (LIS) onboard TRMM satellite from the website of Global Hydrology Resource Center (GHRC, <https://ghrc.nsstc.nasa.gov/home>) (Christian *et al.*, 1999).
- (b) The data needed to analyse the stability and thermodynamic parameters over the study region was collected from the ERA-Interim ECMWF satellite at 0.125 degree resolution (http://apps.ecmwf.int/datasets/data/interim_full_daily/).
- (c) Global Precipitation Climatology Centre (GPCP) monthly gridded precipitation dataset for the study region at 0.5 degree resolution has been collected from <https://www.esrl.noaa.gov/psd/> (Schneider *et al.*, 2011).

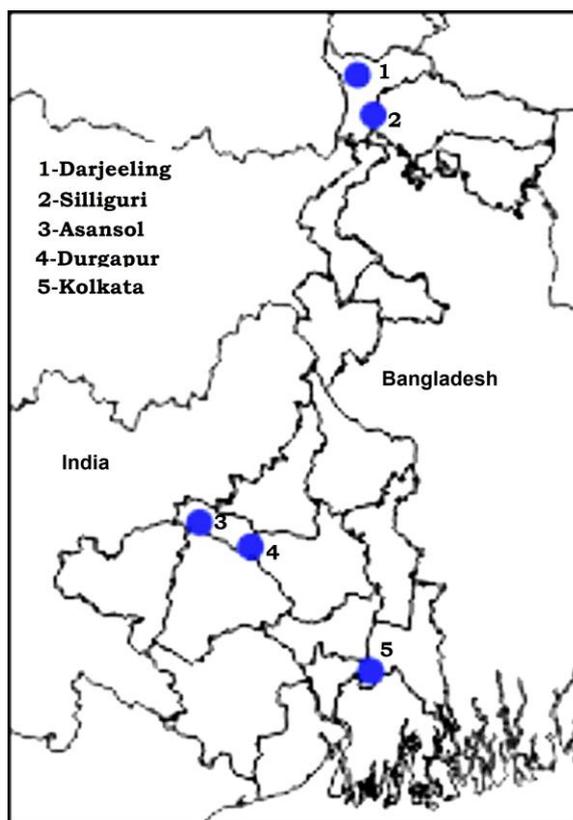


Fig. 1: Study region of West-Bengal

METHODOLOGY

The computational aspects of the different indices that have considered for identification of convection from the INSAT-3D and MODIS data are briefly presented here.

(i) K Index (KI):

The K Index is determined by using the air and dew point temperatures at different levels of the atmosphere using the formula (George, 1960):

$$KI = (T_{850} - T_{500}) + T_{d850} - (T_{700} - T_{d700})$$

where T is the air temperature; T_d is the dew point temperature. The values of KI represent the stages of convection, higher the value higher is the probability of thunderstorm occurrence, as given below. KI values higher than 293 K denote the possibility of thunderstorm occurrence.

K index (KI)	Thunderstorm Probability
<288	0%
288-293	<20% unlikely
294-298	20-40% isolated thunderstorm
299-303	40-60% widely scattered thunderstorms
304-308	60-80% widespread thunderstorms
309-313	80-90% numerous thunderstorms
>313	>90% chance for thunderstorms

(ii) Total Totals Index (TTI):

The total totals index is derived from the temperature lapse rate between 850 and 500 hPa levels and the moisture content at 850hPa. TTI value higher than 44 indicates thunderstorm occurrence. This index is actually a combination of the vertical totals and cross totals, which are defined as follows (Miller, 1967):

Cross totals, CT = Td850 – T500
 Vertical totals, VT = T850 – T500
 Total totals, TT = CT + VT = T850 + Td850 – 2T500

The risk of severe weather activity is defined as follows:

TT index (K)	Thunderstorm Probability
44 – 45	Isolated moderate thunderstorm
46 – 47	Scattered moderate/few heavy thunderstorms
48 – 49	Scattered moderate/isolated severe thunderstorms
50 – 51	Scattered heavy/few severe thunderstorms and isolated tornadoes
52 – 55	Scattered to numerous heavy/few to scattered severe thunderstorms/few tornadoes
>55	Numerous heavy/scattered severe thunderstorms and scattered tornadoes

(iii) Lifted Index (LI):

This is an index that is dependent on the stability of the lower half of the troposphere. LI values lower than -2 are indicative of thunderstorm occurrence (Galway, 1956).

Lifted index (LI) = T₅₀₀ – T_{parcel}

Lifted index (K)	Air mass Thunderstorm Probability
> 2	No significant activity
0 < LI < 2	Thunderstorms possible with other source of lift
-2 < LI < 0	Thunderstorms possible
-4 < LI < -2	Thunderstorms more probable, some severe
LI < -4	Severe thunderstorms possible

(iv) Humidity Index (HI):

Humidity Index HI assesses the degree of saturation at the mandatory levels 850, 700, and 500 hPa (Jacovides et al., 1990). It explains the importance of deep layer of high relative humidity in the generation of thunderstorms.

HI = (T-Td)850+(T-Td)700+(T-Td)500

where T is temperature and Td is dewpoint temperature

(v) Convective available potential energy (CAPE):

CAPE is defined as (Kunz, 2007)

$$CAPE = \int_{Z_f}^{Z_u} g \left[\frac{T_{v,parcel} - T_{v,env}}{T_{v,env}} \right]$$

Where $T_{v,parcel}$ and $T_{v,env}$ stands for the virtual temperature of the parcel and environment respectively. Z_f and Z_n are the levels of free convection and neutral buoyancy.

The value of CAPE can be interpreted for occurrence of thunderstorms as

<300	little or no convective potential
300 to 1000	weak convective potential
1000 to 2500	moderate convective potential
>2500	strong convective potential

RESULTS AND DISCUSSION

For this study, we took five stations from West Bengal region of India namely Kolkata, Darjeeling, Asansol, Silliguri and Durgapur. We tried to analyse the climatology over those stations. The GPCP monthly gridded precipitation dataset at 0.5 degree resolution for the study region of West Bengal was analysed from 1901 to 2015. The flash rate data from LIS onboard TRMM satellite at 0.5 degree resolution for the study region of West Bengal was analysed from 1995 to 2014. The stability and thermodynamic parameters were analysed over the study region was collected from the ERA-Interim ECMWF satellite.

In Fig 2(a), at all the stations we have observed that the average no. of flashes is higher during pre-monsoon season than other seasons. After pre-monsoon season, monsoon season shows the good occurrence of flashes followed by winter and post monsoon seasons. The average MAM Flashes for Kolkata, Darjeeling, Asansol, Silliguri and Durgapur are 105, 39, 86, 89 & 111 respectively. If we observe the Fig 2(b), the average CAPE values are higher in pre-monsoon season. The average CAPE value for pre-monsoon season of Kolkata city for recent 3 decades is 1900 J/kg which is much higher than the other cities. The MAM mean CAPE values for Kolkata, Darjeeling, Asansol, Silliguri and Durgapur are 362.4J/Kg, 898.2J/Kg, 363.2J/Kg & 1030.5 J/Kg respectively. The mean KI values in Fig 2(c), for Kolkata, Darjeeling, Asansol, Silliguri and Durgapur are 312.87K, 311.47K, 312.72K, 311.67K & 312.71K respectively. The average pre-monsoon TTI values in Fig 2(d), for Kolkata, Darjeeling, Asansol, Silliguri and Durgapur are 34K, 44K, 35K, 41K & 35K respectively. CAPE, KI & TTI parameters helps us to understand the instability in atmosphere which is key for the formation of intense convective systems. From the mean analysis of these parameters, we can observe high values favouring for the convective systems in pre-monsoon season. This indicates that the occurrence of convective activities such as thunderstorms, lightning, hailstorms etc. are higher in pre-monsoon season than the other seasons. This analysis also helps us to understand that these cities are prone to convective systems on mesoscale.

In Fig 3(a), we have observed that the highest mean rainfall is recorded during monsoon season followed by pre-monsoon, post monsoon and winter seasons. During monsoon and pre-monsoon season, highest amount of rainfall is observed over Silliguri followed by Darjeeling, Kolkata, Durgapur and Asansol whereas Kolkata receives highest rainfall during post-monsoon and Darjeeling receives highest during winter. The drop of HI values during monsoon season favours more precipitation as clearly seen in Fig 3(b). High TPW values shown in Fig 3(c) indicate that high availability of water vapour favouring high amounts of rainfall to occur. In Fig 3(d) we can observe a sudden increase in mean zonal wind value from winter season to pre-monsoon season at Kolkata. This indicates a strong zonal wind over Kolkata triggering the convective systems. These are norwesters. We can also observe that the mean zonal wind values decrease from winter season to pre-monsoon and change to negative values in monsoon season and they again increase in post monsoon season.

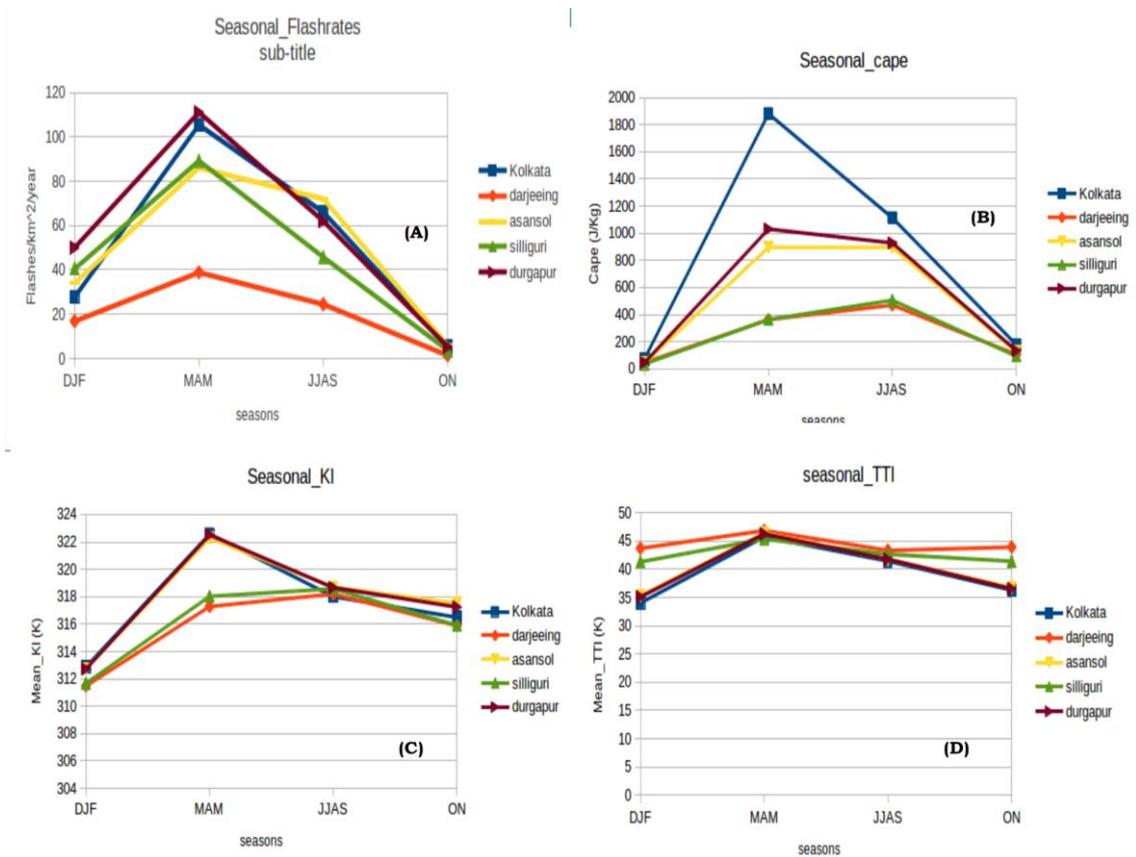


Fig. 2: Seasonal Plots of (a). Lightning Flashes (b). CAPE (c). KI (d). TTI over the West-Bengal Stations.

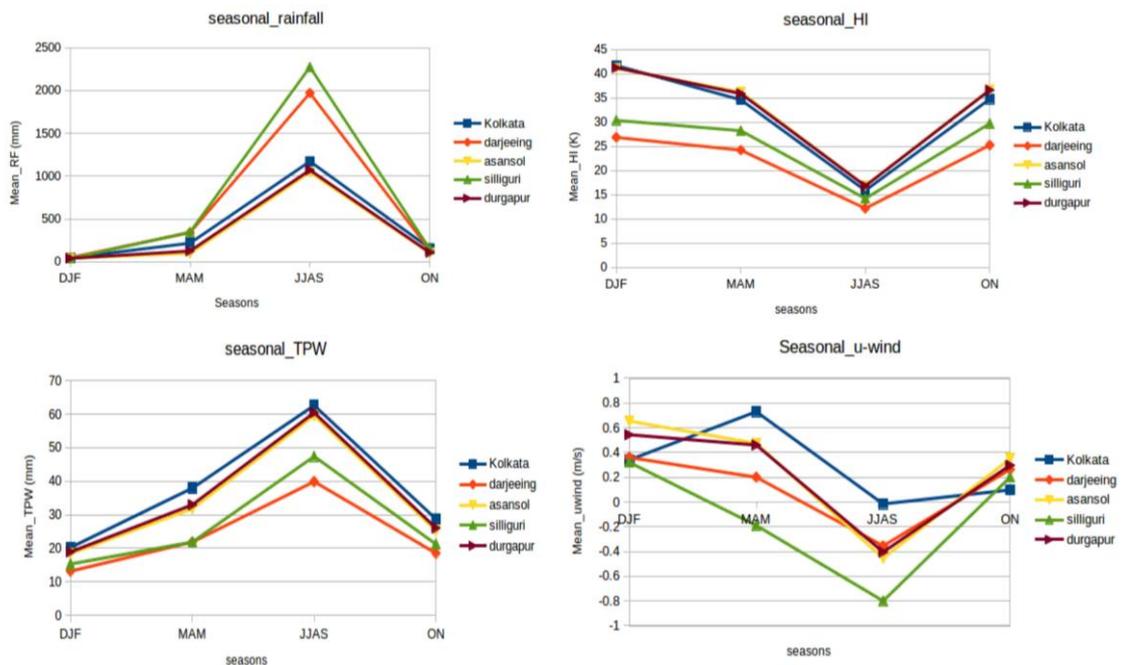


Fig. 3: Seasonal Plots of (a). Rainfall (b). HI (c). TPW (d). U-Wind over the West-Bengal Stations.

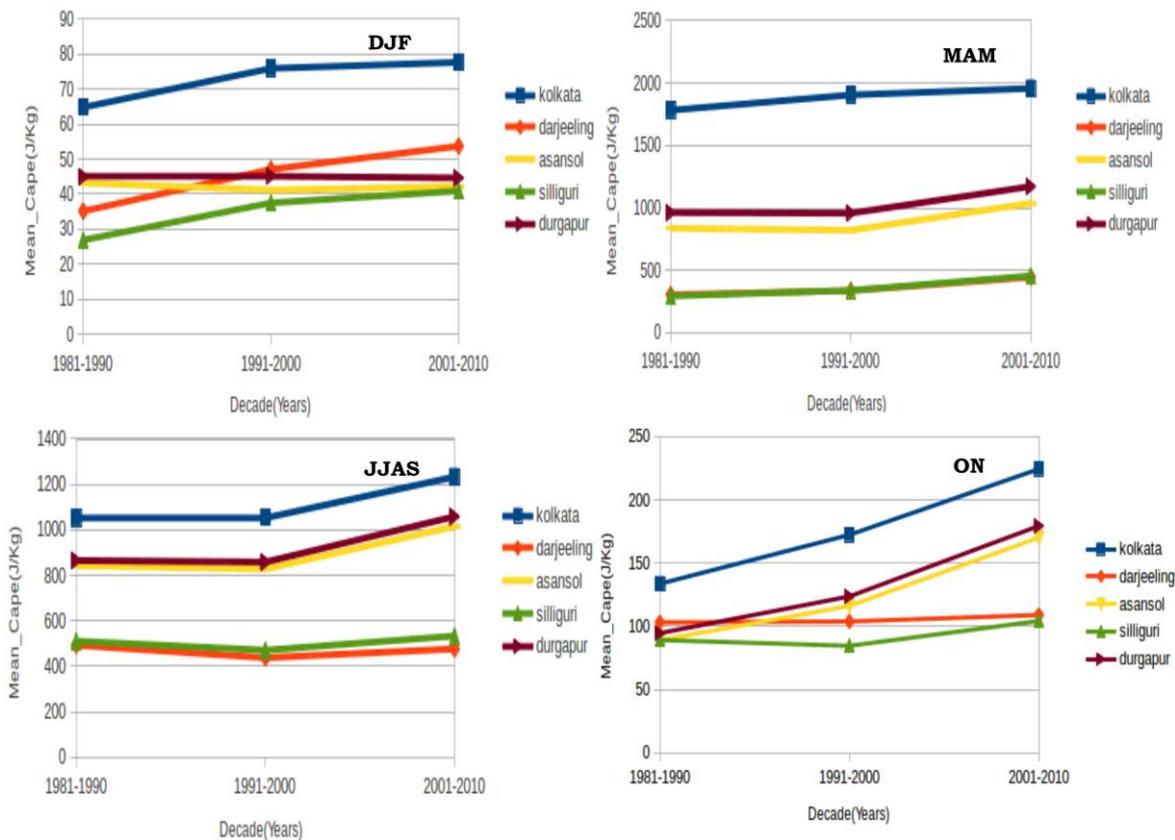


Fig. 4: Seasonal Plot of decadal variation in CAPE parameter over the West-Bengal Stations.

If we observe the Fig 4, the average CAPE values are increasing in the recent decade (2001-2010) when compared to the previous two decades [1981-1990, 1991-2000] over all seasons. Since ECMWF data is available from 1979 so we can observe only three decades. In winter season, average CAPE values for Kolkata, Darjeeling and Silliguri stations have been increasing decadally, whereas Durgapur and Asansol stations haven't shown any significant increase in CAPE values *i.e.* neutral. Usually in pre-monsoon CAPE values are higher as it's a convective season. The CAPE values are increasing in recent decades. The significant increase in CAPE values in recent decade explains the increase of convective systems. The CAPE values are highest in recent decades over all stations in monsoon and post-monsoon seasons. In all stations, Kolkata is recording high mean CAPE values in past three decades over all seasons. Therefore, Kolkata has strong convective potential which favours strong convective systems. Durgapur and Asansol have moderate convective potential whereas Silliguri and Darjeeling have weak and little convective potential.

If we observe the Fig 5, the average HI values are increasing in the recent decade (2001-2010) in winter season, whereas the HI values decreased in past two decades (1981-1990, 1991-2000) in pre-monsoon, monsoon and post-monsoon seasons. The decrease in HI values indicate the increase of convective systems. In all seasons, Darjeeling records less threshold values which is key for likelihood of precipitation. If we observe monsoon season, the HI values are very low <18K which indicates high occurrence of rain. Silliguri, Asansol, Kolkata and Durgapur are also showing good threshold for HI values. In winter, pre-

monsoon and post-monsoon season the threshold values of HI lies between 25 to 45K. Darjeeling, Silliguri and Asansol are favouring good amounts of precipitation.

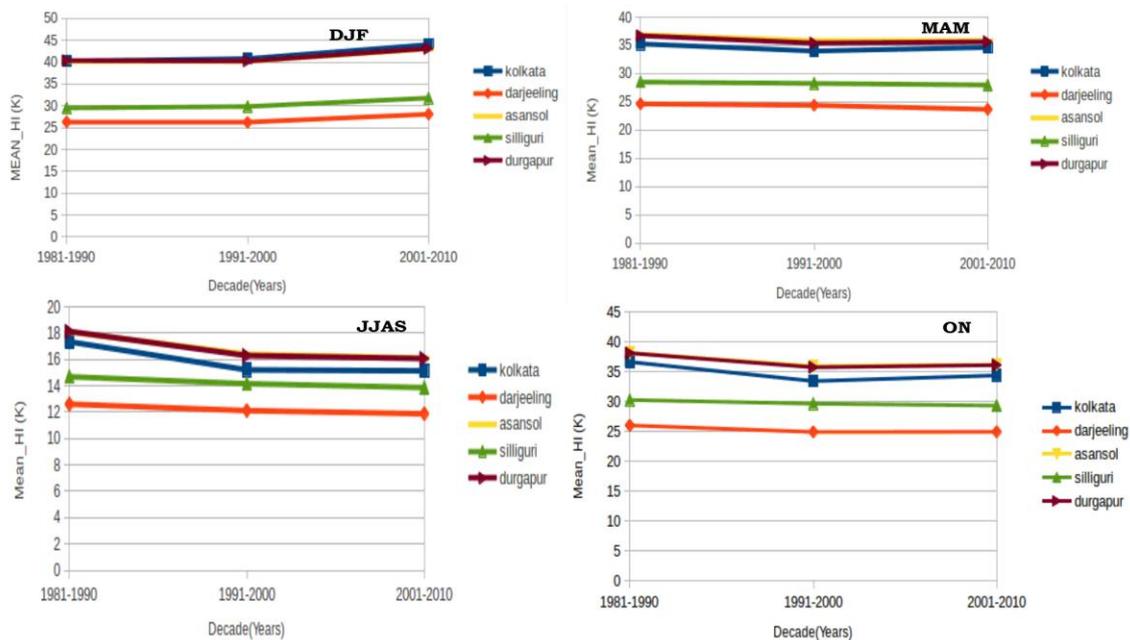


Fig. 5: Seasonal Plot of decadal variation in HI parameter over the West-Bengal Stations.

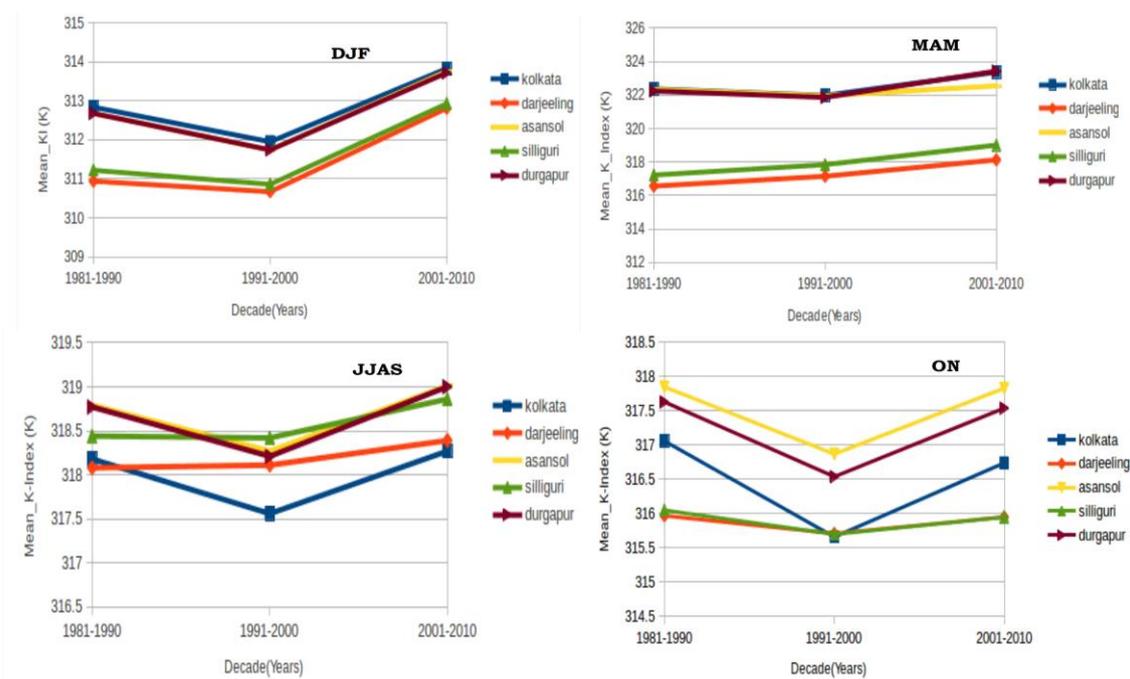


Fig. 6: Seasonal Plot of decadal variation in KI parameter over the West-Bengal Stations.

If we look at Fig 6, the average KI values are decreased from 1981-1990 decade to 1991- 2000 and increased significantly from 1991-2000decade to 2001-2010 decade in all seasons. K-Index is a good measure of thunderstorm potential. Kolkata has the highest mean KI value in winter and pre-monsoon season. Durgapur and Asansol are showing high mean KI values for monsoon and post monsoon seasons respectively. In Winter, the KI

threshold is 311-314 K which is quite low when compared to pre-monsoon KI threshold which is 316-324K. The Monsoon and post monsoon KI threshold ranges from 316- 319 K. As pre-monsoon is hotter than all seasons there is much potential for convective systems than other seasons.

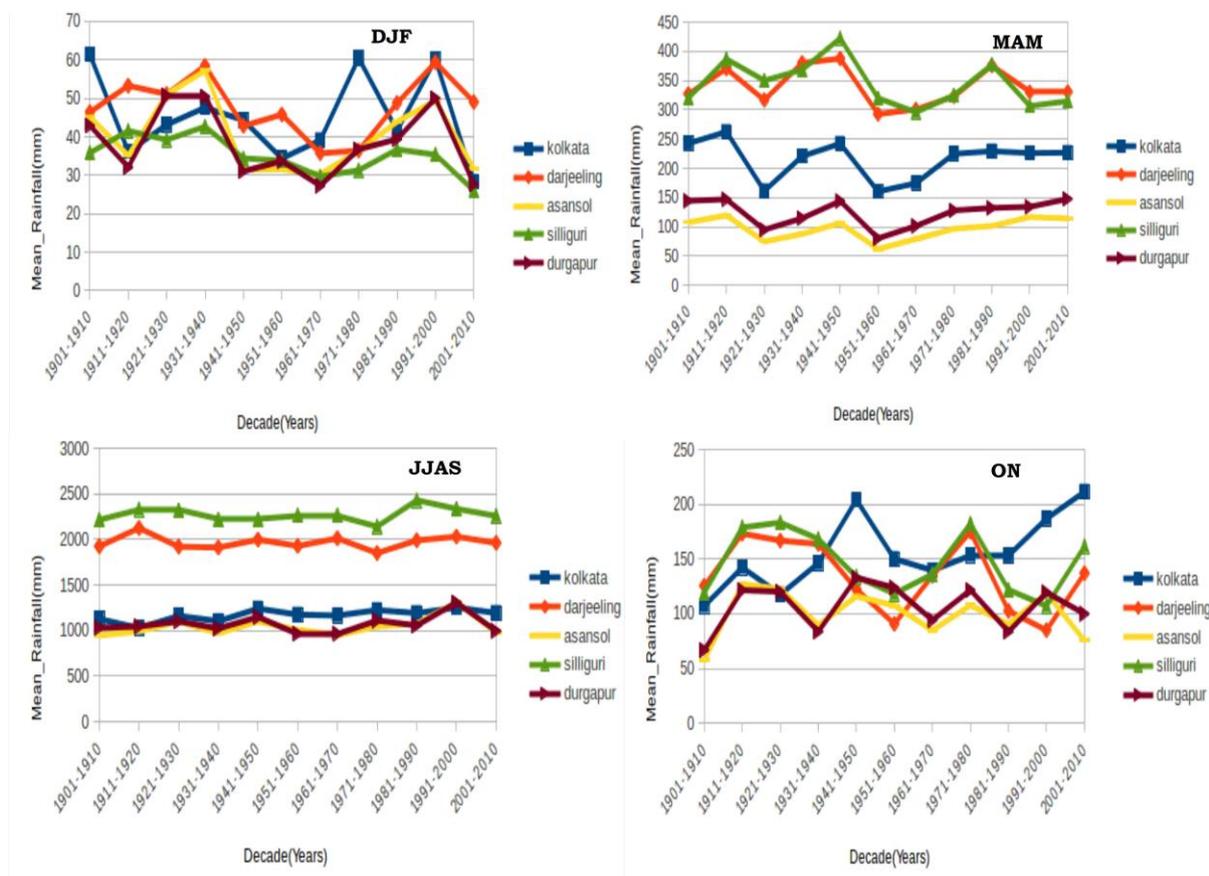


Fig. 7: Seasonal Plot of decadal variation in Rainfall parameter over the West-Bengal Stations.

As Silliguri and Darjeeling are Northeast stations of West Bengal they receive rainfall than other stations during all seasons which is seen clearly in Fig 7. In recent decades Kolkata is receiving higher rainfall than other stations during winter and post monsoon seasons. The monsoon trough from Bay of Bengal which brings moist air usually triggers high rainfall in West Bengal especially in Darjeeling, Silliguri and Kolkata. In recent decades, the rainfall has increased over all stations which indicates that we should take some measures to withstand heavy rains.

In all seasons observed in Fig 8 Kolkata has high TPW values which indicates the high water vapour availability for the convective system to take place. Since Kolkata is nearer to Bay of Bengal more amount of moisture is available. In winter and post-monsoon seasons, the mean TPW values are ranging from 12-20mm and 18-30mm respectively. In monsoon and pre-monsoon seasons, the mean TPW values are ranging from 40-65 mm & 20-40mm respectively. Almost in all seasons, the highest amount of TPW values are seen in the order of stations Kolkata, Durgapur, Asansol, Silliguri and Darjeeling respectively.

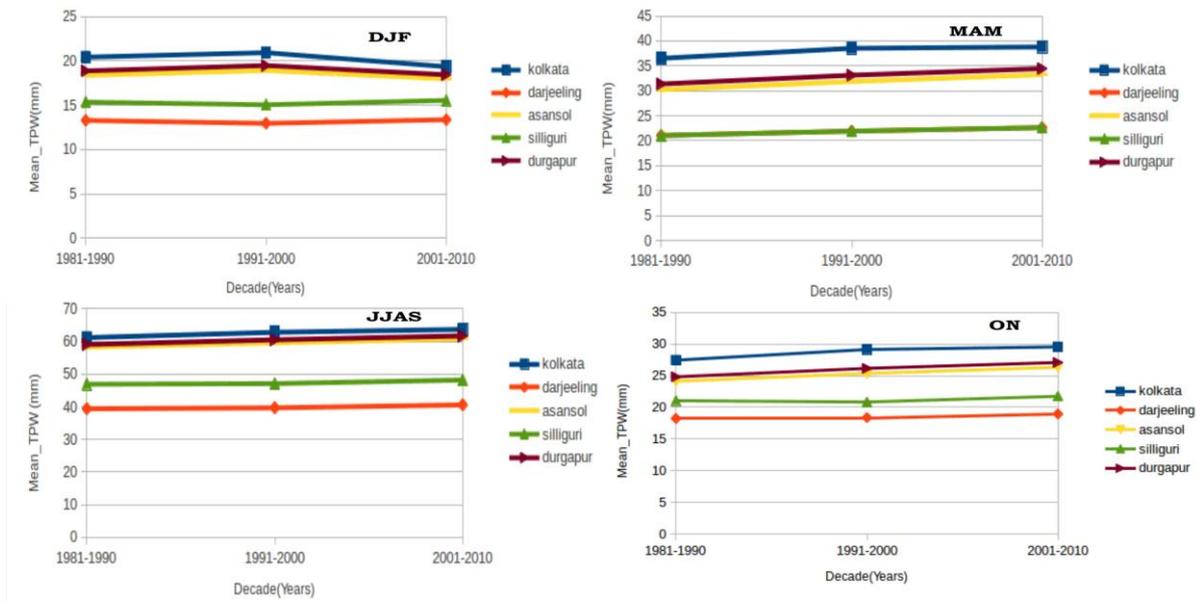


Fig. 8: Seasonal Plot of decadal variation in TPW parameter over the West-Bengal Stations.

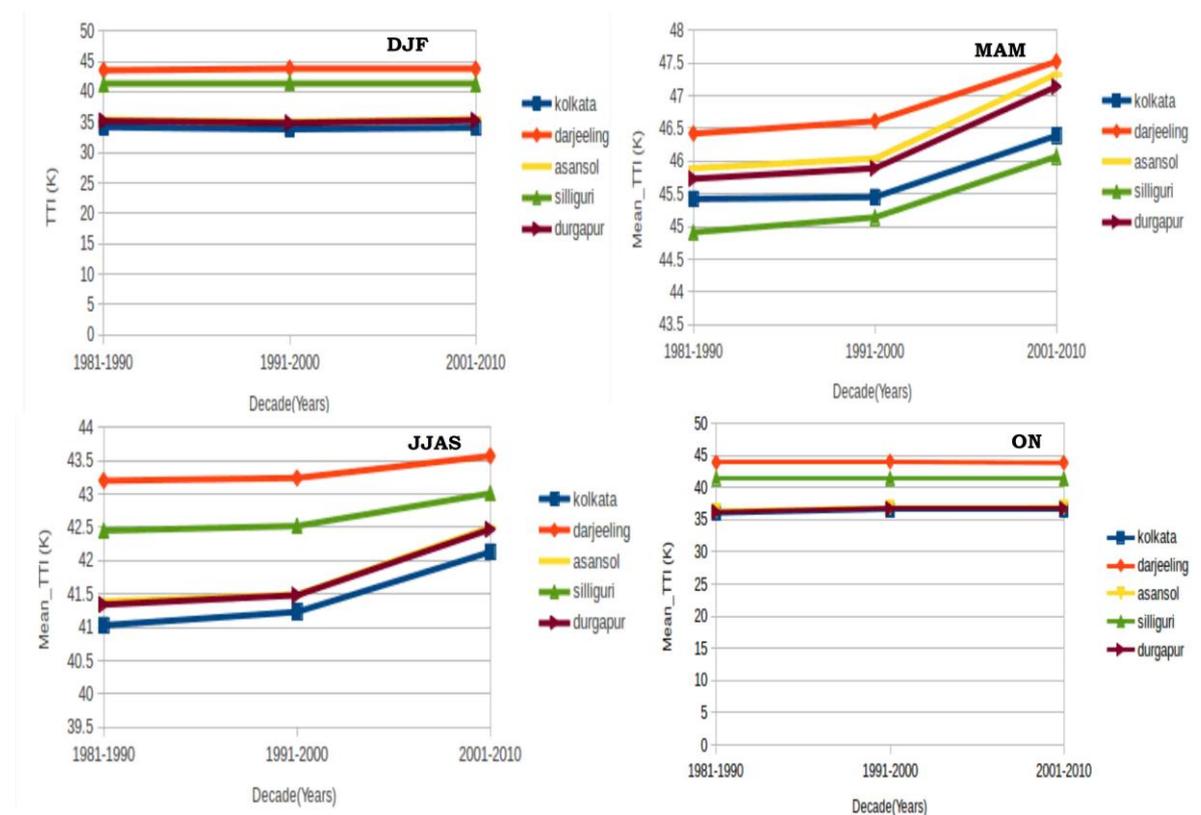


Fig. 9: Seasonal Plot of decadal variation in TTI parameter over the West-Bengal Stations.

If we observe the Fig 9, Darjeeling records high mean TTI values in all seasons which indicates that it is likely for the high occurrence of convective activity to take place. In winter and post-monsoon seasons the mean TTI values ranges from 34-45K whereas in monsoon and pre-monsoon season the values are 41-44K & 45- 48KL respectively. From this we can understand that during pre-monsoon season the higher the TTI values there is more chance for the occurrence of severe convective systems. There is no increase over

TTI values in winter and post-monsoon seasons. The mean TTI values have increased in recent decade (2001-2010) for pre-monsoon and monsoon seasons.

SUMMARY AND CONCLUSIONS

From the analysis of ECMWF satellite data, all the stability indices have shown excellent results for the occurrence of convective systems over all seasons.

1. For Winter Season: the occurrence of convective events in terms of threshold values. flashrate: 28-50; KI: 311 - 314 K; TTI: 34- 44 K; CAPE: 41- 78 J/kg and HI: 30 - 44 K and TPW: 40-45 mm significantly indicate isolated moderate convection associated with little chance for thunderstorm activity.
2. For Pre-monsoon Season: the occurrence of convective events in terms of threshold values. flashrate: 86-112; KI: 318 - 324 K; TTI: 45- 48 K; CAPE: 1000- 2000 J/kg and HI: 23 - 36 K and TPW: 40-45 mm significantly indicate isolated strong convection associated with high chance for thunderstorm activity.
3. For Monsoon Season: the occurrence of convective events in terms of threshold values. flashrate: 45-73; KI: 317 - 319 K; TTI: 41- 44 K; CAPE: 900- 1300 J/kg and HI: 11 - 18 K and TPW: 40-45 mm significantly indicate isolated moderate convection associated with heavy rainfall.
4. For post-monsoon Season: the occurrence of convective events in terms of threshold values. flashrate: 2-6; KI: 316 - 318 K; TTI: 36- 42 K; CAPE: 90- 225 J/kg and HI: 24 - 39 K and TPW: 40-45 mm significantly indicate isolated little convection associated with very less chance for convective activity.
5. During pre-monsoon season, the LIS TRMM data showed that on an average Kolkata and Durgapur have been receiving approximately 100 - 112 flashes, Asansol and Silliguri receiving 85- 90 flashes whereas Darjeeling receives 39 flashes. This is supported by KI, CAPE, TTI parameters showing the high threshold values for severe convection systems.
6. On an average Kolkata receives high lightning flashes. The mean values of CAPE, KI, TTI, HI indicates the severity of convective systems especially in pre-monsoon season.
7. During pre-monsoon season, Kolkata and Durgapur city have shown 106 & 111 mean flashes have been observed for pre-monsoon season. This is supported by KI, CAPE, TTI parameters showing the high threshold values for severe convection systems. The convective systems formed in this season are majorly supported by KI, CAPE, TTI parameters showing the high threshold values for severe convection systems.
8. The Pre-monsoon convective systems are majorly supported by KI, CAPE, TTI parameters showing the high threshold values for severe convection systems.
9. The Monsoon convective systems are mainly supported by TPW, HI & mean zonal wind values.
10. The severity of convective systems has increased in recent decade when compared to past decade.
11. During Monsoon season, Asansol, Durgapur and Kolkata receives high rainfall.

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