International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-4, November 2019

Impact of Atmospheric Stability Indices on Convective Systems Over India and Srilanka

N. Umakanth, G.Ch. Satyanarayana, B. Simon, M.C. Rao, N. Ranga Babu and T. Satyanarayana

Abstract: Thunderstorms are real-time global phenomena, as their occurrence can take place at anytime at any place. Though their duration is less when compared to large scale processes, their damage is devastating to human life. Thunderstorms are linked with damage factors such as lightning, damaging wind, hails and rain. Real-time satellite data provide atmospheric data which is useful for prediction of thunderstorms. In this paper, an attempt is made to analyze the statistical based stability indices from INSAT-3D, MODIS and ECMWF satellites for the now casting of thunderstorms. The occurrences of severe thunderstorms over India and Srilanka during the month of October 2013, 2014 and 2015 have been analyzed. In these three years, five severe thunderstorm cases were identified using Insat-3D cloud images and thunderstorm reports. Atmospheric stability indices such as K Index (KI), Lifted Index (LI), Total Totals Index (TTI), Total Precipitable water (TPW), Humidity Index (HI) related with severe convection system over India and Srilanka during October month were identified to provide guidance for the study of convection and thunderstorm activity. These indices give us a clear indication of development of convective system before 3 to 4 hours. Results of this study indicate the importance of satellite data for studying the development and decay of convective systems.

***Keywords*: Convective available potential energy (CAPE), Convective Inhibition (CIN), K Index (KI), Lifted Index (LI), Mesoscale convective system and Total Totals Index (TTI).**

I. INTRODUCTION

Thunderstorms are cloud related circumstance which is linked with thunder and electric lighting. These are usually occurred in cumulonimbus clouds. Thunderstorm formation takes place by moist air rising upwards and liquid water downwards. This leads to the updraft of the thunderstorm. Factors leading to thunderstorm formation are (i). atmospheric instability: This is usually referred to as unstable situation of weather with some lifting motion. (ii). Wind shear: this is termed as the variations in the wind speeds causing a turning force. (iii). Relative humidity: This is related to amount of moisture present in the atmosphere. These play crucial role in thunderstorm occurrence [1-11]. According to a report from National Oceanic and Atmospheric Administration (NOAA), 16-million thunderstorms are observed every year across the globe [12]. Due to less authentic weather warning systems was the main reason for more thunderstorm deaths. Another main reason is lack of thunderstorm awareness for the outdoor working people in India. India is one among the highly populated nations in the world; more thunderstorm victims are seen when compared to other parts of the world (Earth Networks organization). Due to some difficulties in forecasting of thunderstorm events using conventional methods, satellite data utilization have paved the way for more reliable thunderstorm prediction [2]. The advent of Kalpana and INSAT-3D satellites has provided an opportunity to use satellite derived indices for the prediction of thunderstorms. Research by [7], [2] on lightening showed the usage of TRMM-LIS data for studying the lightning and thunderstorms. Jayakrishnan and Babu (2014) [6] used the MODIS satellite derived stability indices such as K Index (KI) , Lifted Index (LI), Total Totals Index (TTI) to identify their thresholds for convective formation over south peninsular India. In addition to MODIS satellite I have tried to use INSAT-3D satellite. Three satellite datasets have been utilized for this study. INSAT-3D satellite is an Indian Space Research Organization (ISRO) weather satellite with 6-channel imager and a 19-channel sounder which is incorporated with high imaging system and sounder. This is also used for the search and rescue operations. Moderate Resolution Imaging Spectroradiometer (MODIS) satellite is an National Aeronautics and Space Administration (NASA) weather satellite with 36 spectral bands viewing every point on our globe. It is a polar orbiting satellite. It has two sub-satellites, TERRA and AQUA. Each gives two passes a day. Data from all the passes of TERRA and AQUA satellites were downloaded and analyzed for the study. European Centre for Medium range weather forecasting (ECMWF) data is also used for this study. This satellite gives good numerical weather predictions globally. 12.5 km data was collected from this satellite which helps for better study of thunderstorm.

Manuscript published on November 30, 2019.
* Correspondence Author
N. Umakanth*, Department of Atmospheric Science, Koneru Lakshmaiah Education Foundation, Vaddeswaram–522502, India.
G. Ch. Satyanarayana, Department of Atmospheric Science, Koneru Lakshmaiah Education Foundation, Vaddeswaram–522502, India.
B. Simon, Space Applications Centre (SAC), Ahmedabad–380023, India.
M.C. Rao, Department of Physics, Andhra Loyola College, Vijayawada-520008, India.
N. Ranga Babu, Department of English, Andhra Loyola College, Vijayawada-520008, India.
T. Satyanarayana, Department of EIE, Lakireddy Bali Reddy College of Engineering, Mylavaram–521230, India

In this paper, the influence of atmospheric indices on convective systems over India and Srilanka has been attempted using various satellites such as INSAT-3D, MODIS and ECMWF. These satellite datasets were useful to study the evolution of mesoscale convective system and to identify cases of mesoscale systems over Indian region.

Brightness temperature plots from INSAT-3D help us to study the development of convective system. Atmospheric stability indices such as LI, KI, TTI, TPW, HI derived from MODIS satellite help us to provide guidance to convection system. Different parameters derived from ECMWF satellite such as temperature, specific humidity, relative humidity, vertical velocity helps us to study the convective system. By using temperature and dew point temperature profiles Tephigram was plotted.

II. DATA & METHODOLOGY

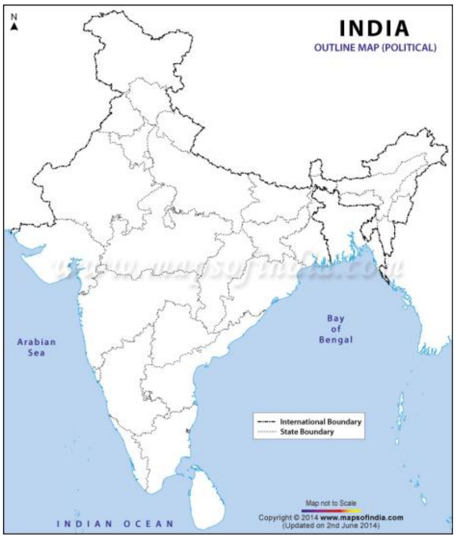


Figure 1: Study region of India and its neighborhood.

The present study was accomplished over the area covering India and Srilanka extending from 5 to 40˚N latitudes and 60 to 100˚E longitudes (**Figure 1**). The subsequent data sets were analyzed for this particular study are (a). The data from INSAT-3D satellite was collected at http://www.mosdac.gov.in/. (b). The data extracted from MODIS satellite was collected at **https://ladsweb.modaps.eosdis.nasa.gov/.** The data extracted from MODIS (MOD07_L2) were temperature profiles, moisture profiles from which indices were calculated. (c) Different parameters such as temperature, specific humidity, relative humidity, vertical velocity were derived from ECWMF satellite data. It was collected at **http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/.**

Methodology:

The different indices that have considered for studying convective systems are discussed below.

(1) K Index (KI): The K Index is calculated by the formula shown below [4]:

KI = (T850 – T500) + Td850 – (T700 – Td700)

Where T is the air temperature; Td is the dew point temperature.

When KI values are greater than 313K there is high chance for severe convective systems such as thunderstorms.

(2) Total Totals Index (TTI):

The total totals index is obtained by the union of the vertical totals and cross totals, discussed below [6]

Cross totals, CT = Td850 – T500

Vertical totals, VT = T850 – T500

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

When TTI values are greater than 55K there is high chance for scattered thunderstorms.

The risk of severe weather activity is defined as follows:

(3) Lifted Index (LI):

This Index is used to study the stability of the lower half of the troposphere and its formula is shown below [3]**.**

Lifted index (LI) = $T_{500} - T_{parcel}$

When LI values are lower than -4 K then there will be higher chance for severe convective thunderstorms.

(4) Convective available potential energy (CAPE):

CAPE is calculated by the formula shown below [9], [6]

$$CAPE = \int_{Z_f}^{Z_n} g[\frac{T_{v,parcel} - T_{v,env}}{T_{v,env}}]\, dz$$

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.

When CAPE values lying between 2000 J/kg to 2500 J/kg then there is high chance for severe thunderstorm.

(5) Convective Inhibition:

CIN is defined as

$$CIN = \int_{Z_{bottom}}^{Z_{top}} g[\frac{T_{v,parcel} - T_{v,env}}{T_{v,env}}]\, dz$$

Where Z_{top} and Z_{bottom} denote the level of free convection and ground surface.

0 to 25	J/kg	weak inhibition
-25 to -50	J/kg	moderate
-50 to -100	J/kg	large inhibition

The two parameters that represent convection formation in the atmosphere, namely the Lifting Condensation level (LCL) and the Level of Free Convection are generally computed using Tephigram.

(vi) Lifting Condensation Level (LCL): It is the pressure level at which a parcel, when lifted adiabatically, becomes saturated (i.e. temperature of the parcel reaches its dew point temperature). The cloud base generally occurs at the LCL. Below the LCL, the lifted parcel cools at the Dry Adiabatic Lapse Rate (9.8 C/km) and above this point the parcel cools at the Saturated Adiabatic Lapse Rate (~5 C/km).

(vii) Level of Free Convection (LFC): It is the pressure level at which a parcel of air, lifted dry adiabatically till saturation and then moist adiabatically, would first attain buoyancy (warmer than its surroundings).

The height difference between LCL and the LFC indicate the convection structure, smaller the difference deeper the convection.

(viii) Humidity Index (HI):

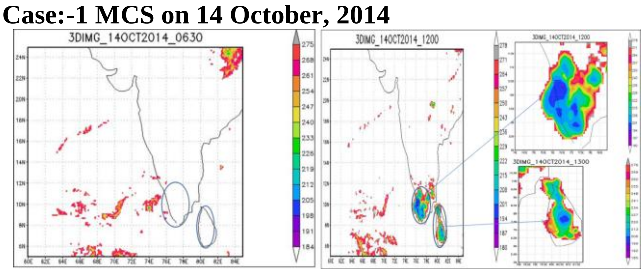
Humidity Index HI is calculated by the formula shown below [5]. If HI values are lower than 30 K, it’s indication for high moisture availability [10].

$HI = (T\text{-}Td)_{850} + (T\text{-}Td)_{700} + (T\text{-}Td)_{500}$

III. RESULTS AND DISCUSSION

For this study, five severe thunderstorm cases (Table1) were identified and analyzed over the India and its neighborhood, for the time period of 2013, 2014 and 2015. Two cases were kept for visualization.

Case:-1 MCS on 14 October, 2014



(a) (b)

Figure 2: Spatial distributions of BT (K) (a) before convection, (b) at peak of convection derived from INSAT-3D Imager satellite for October 14, 2014.

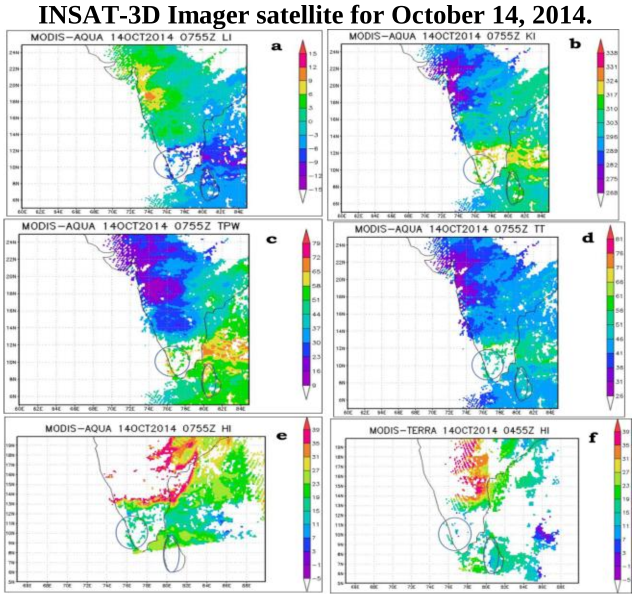


Figure 3: Spatial distributions of (a) LI (b) KI (c) TPW (mm) (d) TTI (e) HI; all derived from MODIS-AQUA satellite on October 14, 2014 & (f) HI Derived from MODIS-TERRA satellite on October 14, 2014.

In this present case study a clear MCS is present over the region of event.INSAT-3D derived BT maps indicate that the system started developing around 0800 GMT. Figure 2(a) indicates the brightness temperature (BT) map before the development of the MCS and reached peak by 1200 GMT (Figure 2(b)) and dissipated after 2300 GMT.MODIS Stability Indices for 0455Z TERRA pass i.e. nearly 7 hours before the peak of MCS and for 0755Z AQUA pass i.e. nearly 4 hours before the peak of MCS are discussed above (Figure 3(a-f)). The above values over Kerala and Srilanka indicate severe mesoscale systems and a very high chance for severe rainfall and thunderstorm activity. The MODIS Stability Indices indicated severe thunderstorm activity will take place at the region of MCS before 4 hours.

The HUMIDITY INDEX calculated for 0755Z AQUA passes over Srilanka and Guntur indicates severe thunderstorm to take place at the region of the event. HI values ≤ 30 indicates very good threshold for thunderstorms to occur.

Temperature and Humidity profiles derived from MODIS, ECMWF & IASI are able to elucidate the MCS development.

Over Srilanka, the T & Td profiles and Tephigrams (Figure 4(a-c)) indicate the cold dry air is overlying on the warm moist air which is leading to convective instability causing to severe MCS to occur.

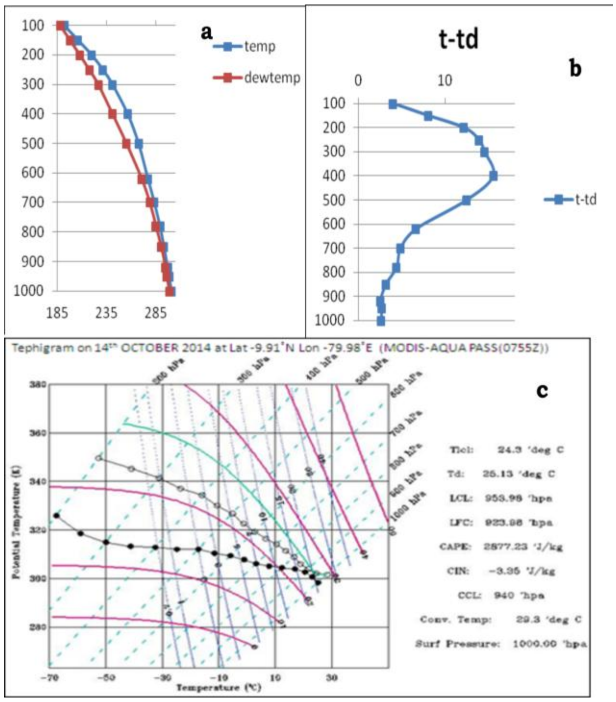


Figure 4:(a) Vertical profiles of T and Td interpolated at 100 hPa interval (b) Dew point depression; (c) Tephigram with T and Td; all derived from MODIS-AQUA satellite for October14, 2014.

The height of LFC is 1.5 km where thunderstorms become more likely in super cells. Cape value is 2877.23J/Kg which indicates strong convective potential and CINE value is -3.35J/Kg indicating weak inhibition.

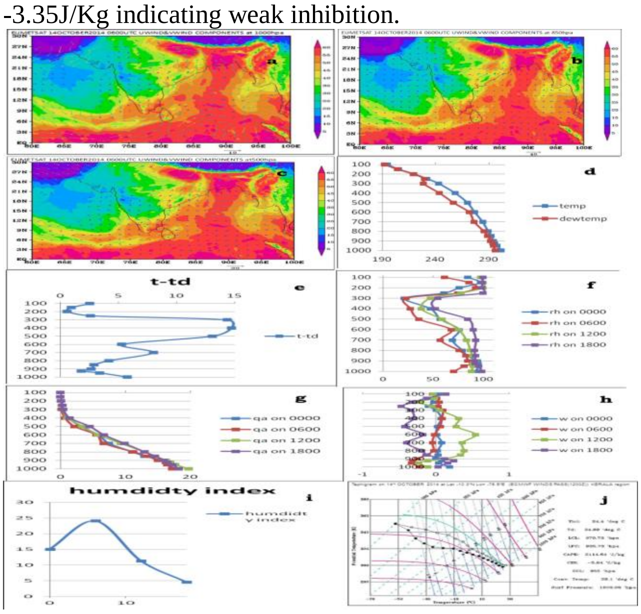


Figure 5: (a)-(c) EUMETSAT wind plots interpolated with total precipitable water at 1000 hPa, 850 hpa & 500 hPa respectively. (d) Vertical profiles of T and Td interpolated at 100 hPa interval (e) Dew point depression (f) relative humidity(g) specific humidity (h) Vertical velocity (i) Humidity Index (j) Tephigram with T and Td; all derived from ECMWF satellite for October14, 2014.

There was some induced weak cyclonic circulation at Kerala as seen at 1000 hPa on 0600UTC (Figure 5(a)). High moisture winds with high TPW values of the order 40-60 mm were present over Srilanka and Kerala. The north westerly's from Pakistan and the high moisture winds from Bay of Bengal have interacted and caused severe rainfall over the MCS region as seen at 500 hPa & 850 hPa on 0600UTC (Figure 5(b-c)). The subtropical Jet stream in winter and premonsoon seasons fluctuates by 5-10˚ latitude with significant impact on the weather in northern parts of south Asia particularly, in pre-monsoon and post-monsoon seasons (Koteswaram and Parthasarthy, 1954).

Specific Humidity, Relative Humdity, Vertical Velocity Profiles and Humidity Index were drawn at 0000, 0600, 1200 and 1800 GMT as shown in Figure 5(d-j). Over Kerala, the T & Td profiles and Tephigrams indicate the cold dry air is overlying on the warm moist air which is leading to convective instability causing to severe MCS to occur. The Specific humidity decreases sharply at the surface but increases at 850 hPa showing a sharp gradient 6 hours before the peak. The Vertical velocity profile indicates convective motion of cloud with rain and updraft which signifies, severe MCS at 6 hours before. Humidity Index drastically reduced as it approaches towards peak.

Case:- 2 MCS on 07 October, 2015

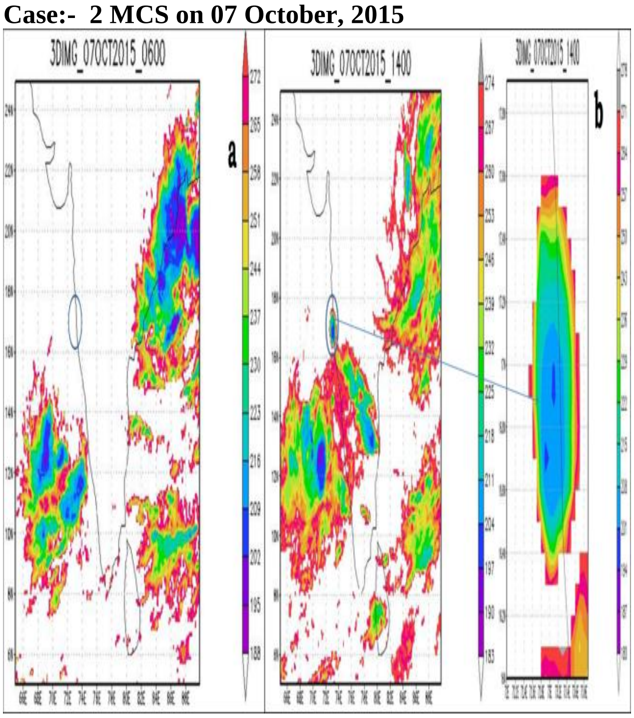


Figure 6: Spatial distributions of BT (K) (a) before convection, (b) at peak of convection derived from INSAT-3D Imager satellite on October 07, 2015.

On October 07, 2015 the brightness temperature (BT) map before the development of the MCS (Figure 6 (a)) as shown. At 1200UTC the BT values have just started reducing from 264 to 215 K which indicates the initial stage for the development of the mesoscale convective system. Later, the MCS intensifying into strong and moving convective systems over Ratnagiri at 1400 UTC as shown in Figure 6(b). At 1400 UTC, the MCS was at peak stage over Ratnagiri and the BT values were in the range from 194 to 215 K. Later, it started to dissipate slowly from 1500 UTC over Ratnagiri. The MCS dissipated completely by 2000 UTC over MCS region. At the peak of the development the MCS reached a height of 12 km approximately.

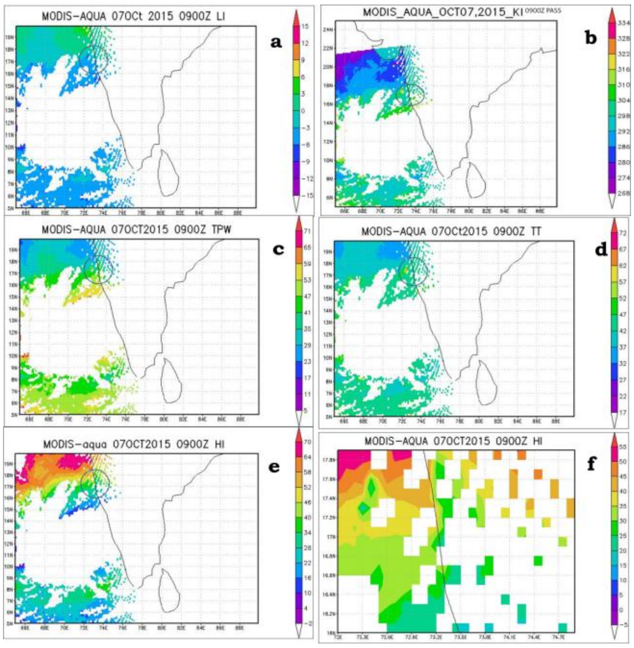


Figure 7: Spatial distributions of (a) LI (b) KI (c) TPW (mm) (d) TTI (e) HI; all derived from MODIS-AQUA satellite for October 07, 2015 & (f) HI Derived from MODIS-TERRA satellite for October 07, 2015.

MODIS Stability Indices for TERRA pass (0555UTC i.e. nearly 8 hours before the peak of MCS) and AQUA pass (0900UTC i.e. nearly 5 hours before the peak of MCS) over Ratnagiri were discussed below (Figure 7(a-f)). The LI, KI, TPW, TTI and HI values showed very good environment for severe thunderstorm. These Stability Indices values showed conducive environment for occurrence of moderate to severe thunderstorm at 0555Z Terra pass. The Stability Indices values in 0900Z Aqua pass clearly indicated severe thunderstorm activity over the Ratnagiri region of MCS event.

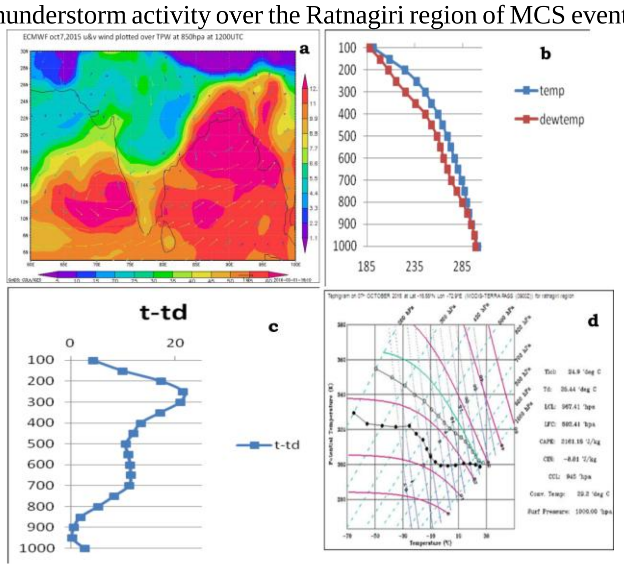


Figure 8(a) EUMETSAT winds plotted over total precipitable water at 850 hPa (b) Vertical profiles of T and Td (c) Dew point depression; (d) Tephigram derived from MODIS-AQUA satellite for October07, 2015.

A clear cyclonic circulation is interacted with the north-south cold dry air is observed at Ratnagiri region from 1000 hPa & 850 hPa plots on 1200UTC (Figure 8(a)). The wind speed was the order of 5.4-7.2 m/s and high TPW values of the 45-60 mm are observed at 1000 hPa plot.

A strong westerly to north-westerly winds of the order of 15-22 m/s were blowing over Ratnagiri is observed from 500 hPa plot on 1200UTC. MODIS derived Temperature and Humidity profiles are able to elucidate the MCS development over Ratnagiri. The T & Td profiles and Tephigram (Figure 8(a-d)) indicate the cold dry air is overlying on the warm moist air which is leading to convective instability causing to severe MCS to occur. The height of LFC is 1.5 km where thunderstorm becomes more likely in super cells. Cape value is 2161.18 J/kg which indicate strong convective potential and CINE value is -8.81 J/kg indicating weak inhibition.

IV. SUMMARY AND CONCLUSIONS:

Table1: ECMWF ERA & MODIS Satellite Stability Indices at Peak time of MCS.

ECMWF ERA					
Date	HI (K)	KI (K)	TPW (mm)	TTI (K)	CAPE (J/kg)
October 7 , 2015	15	325	60	45	2500
October 5, 2015	20	324	55	46	2000
October 14, 2014	15	320	55	45	2500
October 15, 2014	10	320	60	48	4000
October 02, 2013	20	326	60	46	2000
MODIS TERRA/ AQUA					
October 7 , 2015	16	322	59	57	2161.18
October 5, 2015	19	303	52	51	1949.14
October 14, 2014	19	317	65	56	2114.64
October 15, 2014	19	305	68	60	3798.73
October 02, 2013	15	320	70	51	2100

In this paper, an attempt is made to analyze the statistical based stability indices from INSAT-3D, MODIS and ECMWF satellites for the now casting of thunderstorms. The occurrences of severe thunderstorms over India and its neighborhood during the October month of 2013, 2014 and 2015 have been analyzed.

Initially, Real-time satellite images, Doppler weather radar images over India and Srilanka for the month of October 2013, 2014 and 2015 have been examined. We collected data for INSAT-3D, MODIS and ECMWF satellites. From this data, we calculated brightness temperature (BT) which helps us to monitor the convective cloud system every 30 minutes. The convective precipitation is calculated from Hydro-Estimator rainfall product. A clear drop in the brightness temperature values of convective systems was observed before 3 to 4 hours. As BT values are decreasing the rainfall start increasing. At the peak stage of convective system, the BT values decreased till 190 K (i.e. - 83˚C) at which there was high amounts of rainfall were seen. By using MODIS and ECMWF satellites we are able to compute the atmospheric indices (LI, KI, TPW, TTI, WI, HI) before 3 to 4 hours. These indices give us a clear indication of development of convective systems mentioned in Table1. All the convective cases show the extreme usefulness of INSAT 3D BT data, as an examination of the data at 30 minute interval helped identification of the onset, development and decay of thunderstorm convection. A threshold BT of 185 to 192 K for peak convection is clearly identified. The spatial distribution of BT, using 10 km resolution data, helped to delineate the precise area of convection. The Lifted Index, K- Index, Total Totals Index (TTI), Humidity Index (HI), Wind Index (WI) and Total Precipitable Water (TPW) derived using MODIS and ECMWF satellite data have brought out the thresholds related to severe convection as mentioned in Table 1. The LI values were less than -5, KI values > 320 K, TTI values > 50 K, HI values > 30, WI values > 40 m/s and TPW > 45 mm are indicative of thunderstorm activity for the chosen cases.

ACKNOWLEDGMENTS:

The authors thank the SAC, ISRO, India for supplying INSAT-3D satellite data, MODIS satellite data from NASA, USA and ECMWF organization for supplying ERA daily data. This research work is funded by CSIR-SRF, Govt. of India under sanction no. **09/1068(0001)/2018-EMR-I**.

REFERENCES:

1. M. Allaby,(2003) “Floods, Dangerous Weather Series”, New York: Facts on File Science Library, 50.
2. S. Chaudari, A. Midden, (2012) “Nowcasting lightning flash rate and peak wind gusts associated with severe thunderstorms using remotely sensed TRMM-LIS data,” International Journal of Remote Sensing, 1.
3. G. J. Galway, (1956) “The Lifted Index as a Predictor of Latent Instability,” Bulletin of the American Meteorological Society, Vol.37, pp. 528-529.
4. G. J. George, (1960) “Weather Forecasting for Aeronautics,” Academic Press, p. 673.
5. P. C. Jacovides, T. Yonetani, (1990) “An Evaluation of Stability Indices for Thunderstorm Prediction in Greater Cyprus,” Wether Forcasting, Vol.5, No. 4, pp. 559-569. http://dx.doi.org/10.1175/1520-0434(1990)005<0559: AEOSIF>2.0.CO; 2, 1990.
6. R. P. Jayakrishnan, C. A. Babu, (2014) “Assessment of Convective Activity Using Stability Indices as Inferred from Radiosonde and MODIS Data”, Atmospheric and Climate Sciences, 4, 122-130.
7. S. S. Kandalgaonkar, M. I. R. Tinmaker, J. R. Kulkarni, and Asha Nath., (2003) “Diurnal variation of lightning activity over the Indian region”, Geophysical Research Letters, Vol. 30, No. 20, 2022, doi:10.1029/2003GL018005.
8. P. Koteswaram and S. Parthasarathy, (1954) “The mean jet stream over India in the pre-monsoon and post-monsoon seasons and vertical motions associated with subtropical jet streams”, Indian J. Meteor. Geophys., 5, 138–156.
9. M. Kunz, (2007) “The skill of convective parameters and indices to predict isolated and severe thunderstorms”, Nat. Hazards Earth Syst. Sci., 7, 327–342.
10. J. Z. Litynska, Parfiniewicz and H. Pinkowski, (1976) “The prediction of air mass thunderstorms and hails”, W.M.O., 450, 128-130.
11. D, R, MacGorman, and W. D. Rust, (1998) “The Electrical Nature of Storms”, New York: Oxford University Press.
12. Yashvant Das, (2015) “Some Aspects of Thunderstorm over India during Pre-Monsoon Season: A Preliminary Report-I,” Journal of Geosciences and Geomatics, Vol. 3, No.3, 68-78 doi: 10.12691/jgg-3-3-3.