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ANN and ARMA based thunderstorm prediction over Andhra Pradesh using INSAT 3D Satellite

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Abstract: ***Extreme events such as severe thunderstorms, heat waves, cyclones, heavy rainfall events are increasing day by day in recent years over India. Out of all extreme events, thunderstorms are causing more damage and deaths when compared to others. Thunderstorms are tougher to be predicted in advance due to their faster development. In this paper, we tried to analyse two severe thunderstorm cases in premonsoon season for the time period 2017 and 2018 by using INSAT-3D satellite data. This satellite data helps us to monitor the convective cloud system every 30 minutes. Using this satellite data we are able to calculate the atmospheric indices like LI, KI, TTI and HI for every 30 minutes. After being analyzed by INSAT-3D satellite data, we tried to predict the peak stage of thunderstorms using ANN and ARMA techniques. The atmospheric based stability indices have been used as inputs for ANN & ARMA models inorder to achieve prediction. ANN prediction was better than ARMA prediction when compared to INSAT-3D satellite data.***

Keywords: ***Thunderstorm, atmospheric indices, brightness temperature, rainfall .***

I. INTRODUCTION

Thunderstorm is a weather phenomena characterized by the lightning and thunder. Its spatial scale varies withnin few meters to few kilometers. Its temporal scale varies within few minutes to few hours [1]. It is a local scale phenomena associated with intense rain, gusty winds in shorter time period. These systems force serious effects on agriculture, buildings and human loss [2]. It is a worldwide weather hazard and occurs at anytime. Usually thunderstorms are linked with cumulonimbus clouds which are very large and tall in appearance. They have a vertical development rather than horizontal [3]. Synoptically, the warm moist air from the lower levels of atmosphere interact with the cold dry air in the upper levels of the atmosphere. They include events like tornadoe, hail storms, squall winds etc. India is one of the huge geographical oriented countries where thuderstorms are commonly seen in pre-monsoon season. Usually this type of thunderstorms are observed in pre-monsoon season over India. Areas like Bihar, west bengal, northeast states, Andhra Pradesh, Orissa are frequently subjected to this thunderstorms [4-5]. Now a days, satellites are playing crucial role in weather prediction. India's weather satellite INSAT-3D has 6-channel imager and a 19-channel sounder. It is used in search and message relay operations. We have utilised INSAT-3D IMAGER and SOUNDER products for our study.

Artificial Neural Network (ANN) is a mathematical model which works similar to human nerve system. Its approach is similar to human neuron where it takes more inputs to give one output. It has very wide applications in present world like airlines control, data validation, risk management etc. Learning algorithms like Feed Forward propagation, Feed Backward propagation are used for predicting the variables. Some of the stability indices which are applied in this study are K Index (KI), Lifted Index (LI), Total Totals Index (TTI), Total Precipitable water(TPW), Humidity Index(HI) and Wind Index(WI).Therefore, these indices are given as the inputs for artificial neural network as shown in Figure 1. In Figure 1(a) we tried to predict LI using the other stability parameters. In Figure 1(b) we tried to predict KI using the other stability parameters. In Figure 1(c) we tried to predict TTI using the other stability parameters.

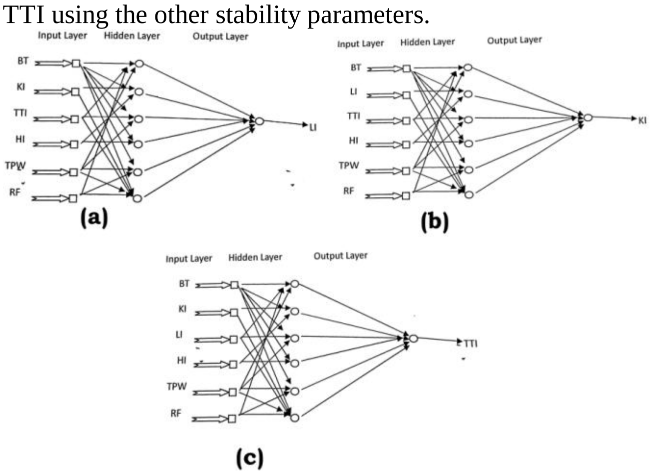

Figure 1: ANN models for the prediction of (a). LI (b). KI (c). TTI using atmospheric stability parameters.

Time series based analysis of Auto-Regressive Moving Average (ARMA) model was used for predicting output. It has two terms. One is auto regressive term(AR) and the other is moving average term(MA).This model helps in many applications like forecasting, engineering and technology. **Box-Jenkins** [6] has recommended the traditional time series prediction using ARMA model.

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Kong et.al 2017 [7] also suggested that ARMA based prediction is better for long term forecasting. The ARMA model we used for this study is mentioned below.

$$X_t = \Phi_1 X_{t-1} + \Phi_1 X_{t-1} + ... + \Phi_k X_{t-k} + w_t = \sum_{i=1}^{p} \Phi_i X_{t-i} + w_t \quad - (1)$$

Where X_t is stationary linear combination of previous values such as $X_{t-1}, X_{t-2}, ... X_{t-p}$; w_t is error

In this paper, the analysis of thunderstorms over Andhra Pradesh (India) was attempted for every 30minutes time interval using INSAT-3D satellite data for the time period 2017 and 2018. In two years, two severe thunderstorm cases were identified using INSAT-3D satellite cloud images , Doppler Radar Images and Thunderstorm Reports. After being analyzed by INSAT-3D satellite data, we tried to predict the peak stage of thunderstorms using ANN and ARMA techniques. The atmospheric based stability indices have been used as inputs for ANN & ARMA models inorder to achieve prediction.

II. DATA & METHODOLOGY

Data: INSAT -3D

In this paper, the area covering Andhra Pradesh which extends from 12-20 N and 75-85 E has been selected. The data from INSAT-3D satellite are collected at http://www.mosdac.gov.in/.

Methodology

2.2 Methodology

The formulas of different indices that are used for this work are discussed below.

(i) K-Index (KI): The K-Index is calculated by subtracting temperature and dew point temperature at 850, 700 and 500 hpa pressures levels as shown in below formula [8]:

KI = (Temperature$_{850}$ – Temperature$_{500}$) + Dew Point Temperature$_{850}$ – (Temperature$_{700}$ – Dew Point Temperature $_{700}$) – (2)

where Temperature is the air temperature; Dew PointTemperature is the dew point temperature.

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

(ii) Total Totals Index (TTI):

This index is a integration of two totals. The total totals index is estimated by adding cross totals product and vertical totals product as shown in below formula. When TTI values are greater than 44K there is high chance for thunderstorm possibility.

Cross totals= **Dew Point Temperature** 850 –**Temperature** 500

Vertical totals = **Temperature** 850 – **Temperature** 500

Total totals, TT = Cross totals + Vertical totals = **Temperature** 850 + **Dew Point Temperature** 850 – 2**Temperature** 500 – (3)

The risk of severe weather activity is defined as follows:

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

(iii) Lifted Index (LI):

This Index valuation is done to check the lower troposheric stability levels. LI values lesser than -2 are indication of thunderstorm occurrence [9].

Lifted index (LI) = $T_{500} - T_{parcel}$ -(4)

Occurrence of Thunderstorm	Lifted index (K)
No Thunderstorm activity	> 2
Probability of Thunderstorms	0 < LI < 2
possible for small Thunderstorms	-2< LI <0
Possible for moderate Thunderstorm	-4< LI <-2
Possible for Severe thunderstorms	LI <-4

(iv) Wind Index (WI): The Wind Index (WINDEX) is calculated to know the value of win gusts that triggers the severe thunderstorm occurence [10].

WI = 5[HM*RQ(G^2 - 30 + QL - 2QM)]^0.5 – (5)

where HM is the height of the melting level in km above the ground; G is the temperature lapse rate in degrees C km-1 from the surface to the melting level; QL is the mixing ratio in the lowest 1 km above the surface; QM is the mixing ratio at the melting level; and RQ = QL/12 but not > 1

(v) Humidity Index (HI):

HI is simply calculated by the subtraction of temperature and dew point temperature at 850, 700, and 500 hPa pressure levels [11]. If HI values are less than or equal to 30K, it's an indication of thunderstorm possibility [12].

III. RESULTS AND DISCUSSIONS

In this paper, the analysis of thunderstorms over Andhra Pradesh (India) was attempted for every 30minutes time interval using INSAT-3D satellite data for the time period 2017 and 2018. In two years, two severe thunderstorm cases were identified using INSAT-3D satellite cloud images , Doppler Radar Images and Thunderstorm Reports. INSAT-3D satellite data has been collected and analysed for the two cases. First we have calculated Brightness temperature from INSAT-3D IMAGER product for the clouds and the rainfall occurred using hydro-estimator rainfall data. Later using INSAT-3D Sounder data we have calculated different indices for studying the occurrence of thunderstorm. After being analyzed by INSAT-3D satellite data, we tried to predict the peak stage of thunderstorms using ANN and ARMA techniques.

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The atmospheric based stability indices have been used as inputs for ANN & ARMA models inorder to achieve prediction.

Case-1 :- May 21, 2017

An intense thunderstorm occurred over East Godavari District causing human loss and heavy damage to crops. For identification of thunderstorm, we monitored the real-time INSAT-3D satellite cloud images. Later, we verified doppler weather radar image for further confirmation. For analysing this case study we calculated brightness temperature and rainfall from Imager product for every 30minutes. The brightness temperature and rainfall parameters are linked with each other. After that, we calculated LI, KI, HI, TTI, WI and TPW for every half and hour. At 8 UTC, the thunderstorm was intial stage. At 12 UTC, thunderstorm was at peak stage and it was dissipated slowly by 16 UTC. All the indices have shown sudden fluctuations before 2-3 hours prior to the peak stage of thunderstorm. We have choosen LI, KI and TTI parameters for attempting the prediction of peak stage of thunderstorm using ARMA and ANN models. For both the models which are used for the prediction of thunderstorm on 21 MAY 2017, we have used previous day 24 hours data. This previous data is given for training the ANN model. We tried to predict the ANN model values from 10 UTC to 14 UTC. ARMA was also used to calculate the predicted values from 10 to 14 UTC. From Figure 2 (a) we can clearly observe that at the peak stage the INSAT-3D calculated LI values has decreased to the high thresholds such as -8 which indicates severe thunderstorm occurence. After comparing the ANN predicted with INSAT-3D, we realised that ANN technique was better than the ARMA. The correlation coefficient for INSAT-3D and ANN was 0.84 where as for INSAT-3D and ARMA it is 0.70. From Figure 2 (b) we can clearly observe that at the peak stage the INSAT-3D calculated KI values has increased to the high thresholds where values were greater than 313K indicating 90% chace for the occurence. After comparing the ANN predicted with INSAT-3D, we realised that ANN technique was better than the ARMA. The correlation coefficient for INSAT-3D and ANN was 0.88 where as for INSAT-3D and ARMA it is 0.72. From Figure 2 (c) we can clearly observe that at the peak stage the INSAT-3D calculated TTI values has increased to the high thresholds greater than 55K which indicates a scattered thunderstorm occurence. After comparing the ANN predicted with INSAT-3D, we realised that ANN technique was better than the ARMA. The correlation coefficient for INSAT-3D and ANN was 0.89 where as for INSAT-3D and ARMA it is 0.50.

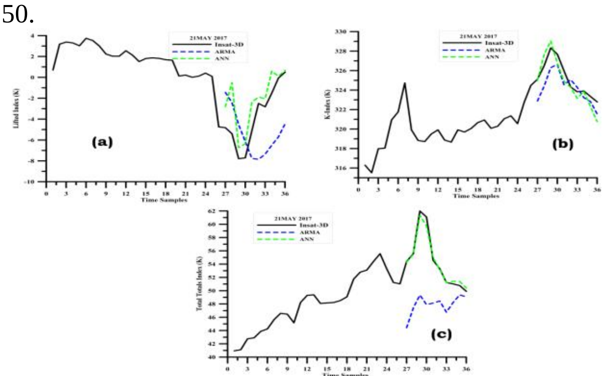

Figure 2: (a) – (c) Time Series plot of (a). Lifted- Index (b). K- Index and (c). Total Totals Index plotted from INSAT 3D satellite data, ARMA and ANN for May 21 2017.

Case-2 :- April 24, 2018

On April 24, 2018 a severe thunderstorm occurred over Visakhapatnam District causing more than 10 human deaths and huge crop damage. After initial identification from real-time INSAT-3D satellite cloud images we calculated brightness temperature and rainfall from Imager product for every 30minutes. The brightness temperature and rainfall parameters are linked with each other. After that, we calculated LI, KI, HI, TTI, WI and TPW for every half and hour. At 4 UTC, the thunderstorm was intial stage. At 7 UTC, thunderstorm was at peak stage and it was dissipated slowly by 13 UTC. All the indices have shown sudden fluctuations before 2-3 hours prior to the peak stage of thunderstorm. We have choosen LI, KI and TTI parameters for attempting the prediction of peak stage of thunderstorm using ARMA and ANN models. For both the models which are used for the prediction of thunderstorm on 24 APRIL 2018, we have used previous day 24 hours data. This previous data is given for training the ANN model. We tried to predict the ANN model values from 05 UTC to 11 UTC. ARMA was also used to calculate the predictied values from 05 to 11 UTC. From Figure 3 (a) we can clearly observe that at the peak stage the INSAT-3D calculated LI values has decreased to the high thresholds such as -9 which indicates severe thunderstorm occurence. After comparing the ANN predicted with INSAT-3D, we realised that ANN technique was better than the ARMA. The correlation coefficient for INSAT-3D and ANN was 0.88 where as for INSAT-3D and ARMA it is 0.80. From Figure 3 (b) we can clearly observe that at the peak stage the INSAT-3D calculated KI values has increased to the high thresholds where values were greater than 313K indicating 90% chace for the occurence. After comparing the ANN predicted with INSAT-3D, we realised that ANN technique was better than the ARMA. The correlation coefficient for INSAT-3D and ANN was 0.90 where as for INSAT-3D and ARMA it is 0.84. From Figure 3 (c) we can clearly observe that at the peak stage the INSAT-3D calculated TTI values has increased to the high thresholds greater than 55K which indicates a scattered thunderstorm occurence. After comparing the ANN predicted with INSAT-3D, we realised that ANN technique was better than the ARMA. The correlation coefficient for INSAT-3D and ANN was 0.80 where as for INSAT-3D and ARMA it is 0.55.

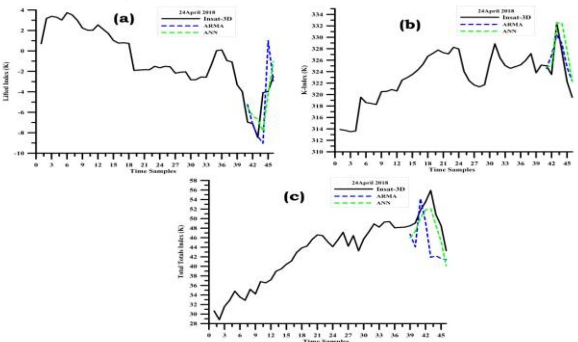

Figure 3: (a) – (c) Time Series plot of (a). Lifted- Index (b). K- Index and (c). Total Totals Index plotted from INSAT 3D satellite data, ARMA and ANN for April 24 2018.

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IV. SUMMARY AND CONCLUSIONS:

In this paper, the analysis of thunderstorms over Andhra Pradesh (India) was attempted for every 30minutes time interval using INSAT-3D satellite data for the time period 2017 and 2018. In two years, two severe thunderstorm cases were identified using INSAT-3D satellite cloud images , Doppler Radar Images and Thunderstorm Reports. After being analyzed by INSAT-3D satellite data, we tried to predict the peak stage of thunderstorms using ANN and ARMA techniques. The atmospheric based stability indices have been used as inputs for ANN & ARMA models inorder to achieve prediction. LI values < -6; KI values >320 K; TTI values >55 K; TPW values > 50 mm significantly indicate severe thunderstorm activity.

This study reveals the importance of INSAT-3D satellite data in thunderstorm prediction

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