Atmospheric Research 169 (2016) 24–31

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Prediction of convective events using multi-frequency radiometric observations at Kolkata

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ARTICLE INFO

Article history:
Received 21 April 2015
Received in revised form 22 September 2015
Accepted 25 September 2015
Available online 3 October 2015

Keywords:
Radiometer
Radiosonde
Nowcasting
Brightness temperature
Instability index
Convective rain

ABSTRACT

In the present study, the effectiveness of nowcasting convective activities using a microwave radiometer has been examined for Kolkata (22.65° N, 88.45° E), a tropical location. It has been found that the standard deviation of brightness temperature (BT) at 22 GHz and instability indices like Lifting Index (LI), K Index (KI) and Humidity Index (HI) has shown definite changes before convective events. It is also seen that combination of standard deviation of BT at 22 GHz and LI can be most effective in predicting convection. A nowcasting algorithm is prepared using 18 isolated convective events of 2011 and in all cases, a marked variation of these parameters has been seen an hour before the event. Accordingly, a prediction model is developed and tested on convective events of 2012 and 2013. It is seen that the model gives reasonable success in predicting convective rain about 7075 min in advance with a prediction efficiency of 80%.

1. Introduction

In the east and the north-eastern parts of the Indian subcontinent, intense convective activities are a very common feature. These types of activities occur during the pre monsoon period of March–May and are associated with severe lightning, heavy precipitation, hail and wind gusts. These activities also induce several adverse effects on various fields of life, such as agriculture and aviation. For this reason, prediction of such events has a very important implication on society.

In the past, short term prediction of convective activities is usually done using reflectivity echoes of impending storms using space borne and weather radars (Browning, 1982; Cluckie and Collier, 1991; Mecklenburg et al., 2000; Wang et al., 2009). However, there has not been much success in this regards because the less time span and localized nature of these activities make it difficult to predict them much in advance. Hermida et al. (2013) has studied the spatial variation and related climatological implications of hail storms which are accompanied with convective precipitation using a widely distributed network of 443 hailpads (ANELFA) covering various regions of France.

Knowledge based systems including radar, satellite, boundary layer profiler; lightning detector and upper air soundings are also being used for nowcasting intense convective activities. According to Kobler and Tafferner (2009) three parameters are important to understand the development of convection, namely, moisture, convective instability and lifting mechanism. Atmospheric temperature and humidity profiles and instability indices derived from atmospheric soundings like radiosondes can be very useful in nowcasting rain and thunderstorms (McCann, 1994; Geerts, 2001; Manzato, 2003; Midya et al., 2011; Midya and Saha, 2011; Saha et al., 2012; Chakraborty et al., 2015). However, radiosonde measurements suffer from poor temporal resolution. A microwave radiometer can generate humidity and temperature profiles of the atmosphere up to 10 km with high temporal resolution of 5 min and hence solves the problem faced by radiosondes. According to Chan and Lee (2011), alerting of wind shear can be done either by monitoring the stability of the boundary layer or by the standard deviations in the brightness temperature (BT) obtained from the microwave radiometer during both clear and cloudy skies at near elevation. The atmospheric water vapor and brightness temperatures around the water vapor absorption line measured by radiometer are used for such purposes (Won et al., 2009). The use of BT of oxygen absorption line along with water vapor can also predict rain with high accuracies (Chakraborty et al., 2014). In case of radiometric weather forecasting, two types of parameters are widely used — (1) utilization of level 0 products such as brightness temperatures and (2) parameters derived from BT measurements like Integrated Water Vapor (IWV), Liquid Water Content (LWC), Cloud Base Height (CBH) and instability indices (Koffi et al. 2007; Won

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http://dx.doi.org/10.1016/j.atmosres.2015.09.024
0169-8095/

et al., 2009). These types of measurements are reported from different temperate regions; however, limited performance assessment of such techniques is available for tropical regions (Wilson et al., 1998). Won et al. (2009) obtained that an increase of Brightness Temperature (BT) is observed in water vapor channels (22–30 GHz) at about two hours (2 h) before rain. Güldner and Spänkuch (1999) have also obtained similar observations for an increase in the LWC and Precipitable Water Vapor (PWV) at about two hours (2 h) before rain. According to Chan (2009), the average values of K-index obtained from temperature and humidity profiles have a reasonable correlation with the tropospheric instability indicated by the number of lightning flashes within regions located about 10–40 km from the radiometer. Clifford et al. (2009) and Won et al. (2009) have studied the atmospheric conditions at boundary layer using radar, lidar, wind profiler and Radiometer. Many attempts have been made to predict convective activities using instability indices from atmospheric profilers (Faubush et al., 1951; Madhulatha et al., 2013; Showalter, 1953; Galway, 1956; Darkow, 1968; Chowdhury and Karmakar, 1986; Saha et al., 2014, 2015).

In the last few years, many attempts have been made to predict precipitation related activities. Dotzek and Forster (2011) had employed Cb-TRAM prediction algorithm with ESWD dataset for six severe weather days in Europe from 2007 to 2008 to detect storms in advance. The maximum prediction efficiency obtained for 30–60 min forecast was around 58%. Kohn et al. (2011) employed WDSS-II algorithm to nowcast thunderstorms using one year lightning data over the Mediterranean region. The technique was successful in predicting thousands of thunderstorms about 30 min in advance with a minimal False Alarm Rate (FAR) of 0.03 but with a very low Probability of Detection (POD) of 0.46. Dvorak et al. (2012) had devised a technique to detect precipitation and cloudiness using brightness temperature observations at 10 GHz from a microwave radiometer with a prediction efficiency of 80% and false alarm rate of around 15%. Later, Merino et al. (2014) developed a technique to identify hailstorms using MSG data obtained from the MEV valley in Spain from 2006 to 2010. The obtained technique called HDT employs two detection algorithms, namely convective mask and hail mask algorithms to detect hailstorms. This technique has provided an accuracy of 76.9% with a false alarm rate of 16.7%. As an extension of the previous work, Gascón et al. (2015) has designed another technique using forward stepwise regression algorithms on five major instability parameters. This system has a high POD of 0.94 but the FAR obtained was 0.22 which is quite high. However, it may be noted that most of the above said techniques have provided prediction efficiency less than 80% or a false alarm rate greater than 20%.

Recently, Chakraborty et al. (2014) had made an attempt to predict convective heavy rain using the fluctuations in BT of 22 and 58 GHz. A high prediction efficiency of 90% was obtained; however, the obtained lead time was low. This work is an improvement to the previous attempt where instability indices have been used along with the previously used BT at 22 GHz to predict convective rain in terms of increasing convective strength marked by high values of Convective Available Potential Energy (CAPE). The present technique also provides a better understanding of the changing atmospheric conditions before convective events. The reason for this is that convective activities are generally associated with unstable lapse rates and high moisture contents at three important pressure levels of the lower atmosphere, namely, 850 mbar, 700 mbar and 500 mbar pressures. BT at 58 GHz could manifest a decrease in ambient temperatures, but only in lower heights (generally < 2 km). In light of the above, it is expected that this technique might detect convective growth in a better way compared to the previous model.

2. Instrument description and data

A multi frequency profiler radiometer (RPG-HATPRO) situated on the roof top of the Institute of Radio Physics and Electronics, University of Calcutta (about 10 m above the ground level), has been used for the study. It consists of two receiving units, a data acquisition system, rain sensor, GPS clock, and ground meteorological sensor (Rose and Czekala, 2009). This instrument measures brightness temperatures with a high temporal resolution of 3 s in a range of 0–800 K and provides an accuracy of 0.5 K at 14 frequency channels in two separate bands. The first frequency band (22–31.4 GHz) is sensitive to water vapor and hence is utilized for humidity profiling. The second frequency band (51.26–58 GHz), is sensitive to oxygen absorption and hence is utilized to obtain the temperature profiles. These brightness temperature datasets are then smoothed for a time window of 3 min (60 samples) to remove any unwanted fluctuations. Quadratic regression techniques are utilized to transform brightness temperature values into several atmospheric parameters like profiles of temperature and humidity, IWV and a series of instability indices, namely Lifted Index (LI), K-Index (KI), Totals Total Index (TTI) and Showalter Index (SI).

For the present study, brightness temperature and instability index observations from Radiometer for 18 convective events during 12 convective days and 58 non-convective days of March–May 2011 have been used. For validation of the prediction technique, radiometric data of 40 convective events during 28 days of March–May 2012 and 2013 has been utilized. A set of four parameters has been used to develop an algorithm to nowcast convective activities. They are LI, KI, BT standard deviation and HI.

The brightness temperature at 22 GHz indicates the amount of vapor in the atmosphere. Strong convective activities usually require bulk concentration of atmospheric water vapor. So these changes in the atmospheric vapor density prior to the event can be clearly indicated by large values of BT at 22 GHz. However, BT values show strong seasonal and diurnal variation; hence a change in this parameter related to convection can be indicated by an increase in its standard deviation value. For this reason, a 30 minute standard deviation of BT at 22 GHz has been included in the analysis instead of its absolute value.

The Lifting Index (LI) denotes the stability of air parcels. When an air parcel is lifted adiabatically to a height of 500 bar pressure then the parcel temperature and the environmental temperatures at that height are compared. Negative or near negative value of LI reflects condensation of saturated vapor parcel to liquid indicating instability and severe weather conditions.

The K-Index measures the thunderstorm potential in terms of the vertical temperature lapse rate between 850 and 500 mbar pressure levels, the moisture content at 850 mbar pressure and the depth of the moist layer at 700 mbar pressure level (George, 1960). KI values close to 30 K indicate severe weather conditions (Haklander and van Delden, 2003).

The Humidity index shows the difference of the dew point and environment temperature at various pressure levels of the atmosphere. These temperature differences at each level denote the degree of saturation of vapor and the extent of condensation at those layers. Lower values (HI < 30 K) indicate instability at all three pressure levels of the lower atmosphere (850, 700 and 500 mbar pressure levels) thereby indicating severe weather conditions (Litynska et al., 1976).

In this study, various instability indices have been used to predict convective activities. However, the strength of these activities can best be quantified by their convective available potential energy (CAPE). According to Emmanuel (1994), CAPE indicates the buoyant energy available to accelerate an air parcel vertically. It can be calculated using the summation of positive buoyant energy from the level of free convection (height where the parcel temperature > environment temperature) to the Equilibrium Level (height where parcel temperature = environment temperature). Higher CAPE provides more energy for convective growth; hence CAPE should be high in convective conditions and less in normal conditions. Rasmussen and Wilhelmson (1983) have mentioned that values of CAPE > 1500 J kg^{-1} are suitable for super cell formation. Hence the occurrence of CAPE values greater than 1500 J kg^{-1} is considered to be an indicator of the impending convective rain.