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Nowcasting of rain events using multi-frequency radiometric observations

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SUMMARY

Nowcasting of heavy rain events using microwave radiometer has been carried out at Kolkata (22.65°N, 88.45°E), a tropical location. Microwave radiometer can produce the temperature and humidity profiles of the atmosphere with fairly good accuracy. Definite changes are observed in temperature and humidity profiles before and at the onset of heavy rain events. Concurrent changes in the brightness temperatures (BT) at 22 GHz and 58 GHz are found to be suitable to nowcast rain. The time derivatives of brightness temperatures at 22 GHz and 58 GHz are used as inputs to the proposed nowcasting model. In addition, the standard deviation of the product of these time derivatives is also considered. The model has been developed using the data of 2011 and validated for rain events of 2012–2013 showing a prediction efficiency of about 90% with alarm generated about 25 min in advance.

1. Introduction

In the Indian subcontinent, sudden and heavy precipitations occur during pre monsoon period of March–May and monsoon period of June–September. These forms of precipitations are found to affect agriculture, aviation and in severe cases can cause loss of life and property. Nowcasting of heavy precipitations has many applications in mitigating some of the adverse situations resulting from such events.

Conventionally, satellite and radar data are used to nowcast thunderstorms (Browning, 1982; Cluckie and Collier, 1991; Dutta et al., 2010; Mecklenburg et al., 2000; Sokol, 2006; Wang et al., 2009; Wilson et al., 1998; Zahraei et al., 2013). The reported prediction efficiencies are usually around 80% with false alarm rates above 25% for both radar and numerical weather prediction (NWP) based nowcasting (Johnson and Olsen, 1998; Wilson et al., 1998; Lin et al., 2005). The temperature and humidity profiles of the atmosphere along with the instability indices obtained from atmospheric sounding measurements such as radiosondes can also be a useful tool for rain and thunderstorm predictions (Geerts, 2001; Manzato, 2003; McCann, 1994). Except radar, these instruments suffer from poor temporal resolution. However radars are costly and need much involved maintenance for continuous operation.

Heavy rain events also create attenuation of microwave signals. So microwave propagation through the atmosphere can provide a useful signature of heavy rain events. In this connection atmospheric brightness temperatures measured by a microwave radiometer can be useful for nowcasting of rain (Koffi et al., 2007; Won et al., 2009). Güldner and Spänkuch (1999) showed that the liquid water content (LWC) and perceptible water vapor (PWV) increases before rain. So an increase of brightness temperature (BT) in water vapor channels (22–31 GHz) can be observed about 2 h before rain (Won et al., 2009). Many convective indices from radiometer have been utilized for nowcasting heavy precipitation events (Darkow, 1968; Faubush et al., 1951; Galway, 1956; Madhulatha et al., 2013; Showalter, 1953). There are some efforts to predict rain using a microwave radiometer. Dvorak et al. (2012) used BT at 10 GHz to predict rain with a hit ratio of 74% and a false alarm rate of 7%. Won et al. (2009) also used BT at 22, 30 and 51 GHz for rain prediction with a probability of detection 0.9 for rain accumulated below 20 mm.

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However, models using radiometric observations are not highly accurate for nowcasting rain (Chan and Lee, 2011; Wilson et al., 1998; Won et al., 2009). The primary reason could be that an increase of atmospheric water vapor has been taken to be the only precursor of intense convective activities. However, water vapor can also increase significantly in the absence of rain (Sherwood et al., 2010; Won et al., 2009). So monitoring of other parameters of the atmosphere is also needed.

The radio environment over Kolkata (22.65°N, 88.45°E) has been studied using a multi-frequency profiler radiometer. Since convective rain is usually associated with drastic change in water vapor as well as temperature, brightness temperatures of water vapor and oxygen absorption bands can be considered to be indicators of the impending rain events.

2. Experimental setup and data

A Dicke radiometer system (RPG-HATRO) is used for the present study. It consists of two receiving sections along with a noise diode, a data acquisition system, rain sensor, GPS clock, and a ground pressure and temperature sensor (Rose and Czekala, 2009). It measures the brightness temperatures in the range of 0–800 K with an accuracy of 0.5 K at 14 frequencies in two frequency bands (7 frequencies in each band). As the first frequency band (22–31.4 GHz) is sensitive to water vapor absorption, it is used for humidity profiling. The frequency band (51.26–58 GHz), being sensitive to oxygen absorption, is utilized to obtain the temperature profile of the troposphere. A quadratic regression retrieval algorithms are employed to convert the brightness temperatures into atmospheric parameters like temperature profile, humidity profile, integrated water vapor (IWV) and liquid water content (LWC).

The radiometric system employs three types of calibration. In absolute calibration, a linear calibration curve between receiver voltage and antenna temperature is obtained by exposing the receiver to two different sources, an ambient target and liquid nitrogen target of 77 K. Since absolute calibration cannot be imparted frequently, the noise injection calibration is implemented, every 25–30 min, by using a noise diode which acts as a standard noise source. The radiometer is further calibrated once in every cycle to filter out cosmic and path length noises in the 22–31 GHz band by measuring the brightness temperatures at various elevation angles. This technique is known as the sky-tipping calibration.The relation between the profiles of atmospheric parameters and brightness temperatures (BT) are obtained using radiative transfer theory. About 15,000 radiosonde profiles of Kolkata have been utilized to obtain the retrieval algorithm. Quadratic regression inversion technique has been used to convert the brightness temperature to temperature and humidity profiles.

An impact type disdrometer (RD-80, Waldgovel type) is also used for ground based rain rate measurements for the present study.

Brightness temperature data from radiometer and rain rate data from disdrometer are collected for the year of 2011. From the dataset, 44 days where rain event occurred during pre-monsoon (March–May) and monsoon (June–September) period of 2011 have been utilized to develop the model for rain prediction. The rain events of at least 5 min duration and having the maximum rain rate exceeding 10 mm/h are considered for the study. To validate the efficacy of the model, it is tested on a new dataset comprising 130 rainy days of premonsoon and monsoon period of 2012 (March 2012–September 2012) and premonsoon period of 2013 (March 2013–June 2013).

To have a quality check of the data, the retrieved temperature and relative humidity profiles obtained with radiometer are compared with radiosonde measurements during the years 2011–2012 obtained by India Meteorological Department, Kolkata (<10 km aerial distance). A correlation coefficient value of 0.94 for temperature profiles and 0.83 for relative humidity profiles are obtained between the two data. Fig. 1 shows that in case of the temperature profile, radiosonde and radiometer data have a good matching. However above 2 km there is a small bias between the two instruments. In case of humidity profiles, some biases have been observed at various heights. The relative humidity profiles from a radiometer show a wet bias up to about 5 km and a dry bias above it and similar results were also observed by other researchers (Chan, 2009; Xu et al., 2014). This wet bias might due to the occasional occurrence of an elevated, moist layer not measured by the radiosondes (Chan, 2009). Another possible reason might be the variable weather conditions generated due to water vapor

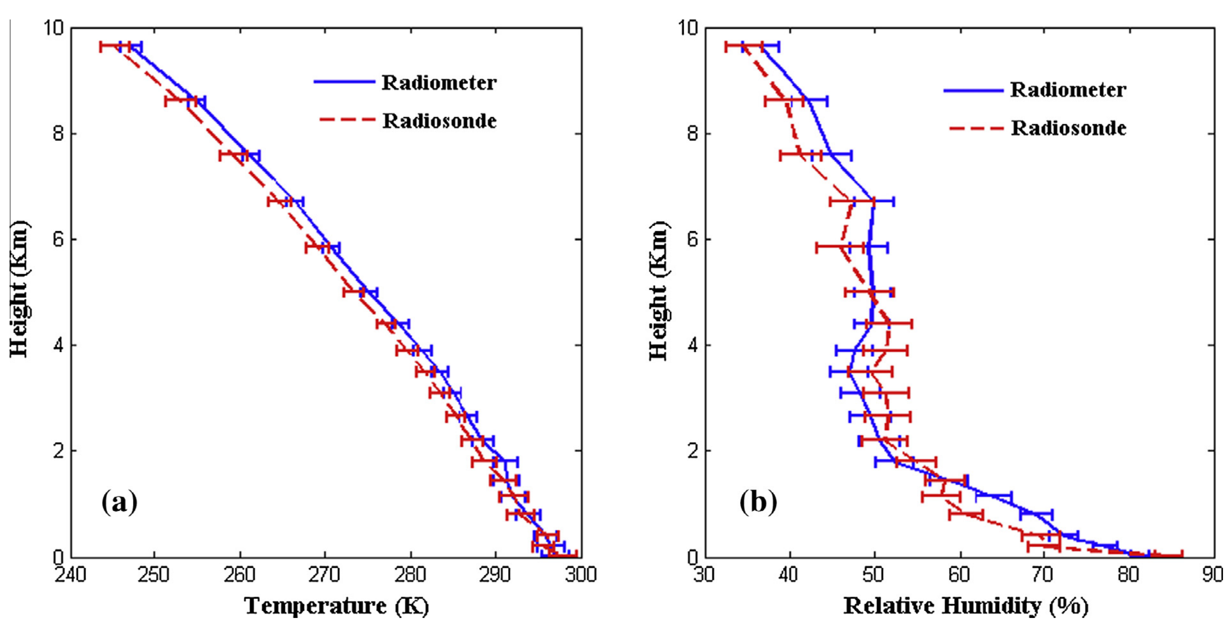

Fig. 1. Average profiles of parameters obtained from the radiosonde and radiometer (a) temperature and (b) relative humidity.