Rain Prediction Using Radiometric Observations at a Tropical Location

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Abstract

Nowcasting of intense rain is important in various fields of life. In this paper, radiometric brightness temperature measurements at Ka and V bands are utilized to predict rain event associated with impending convective processes. The instability parameters are estimated from radiometric data to point the development of atmospheric instability and an estimation of liquid water content is made from brightness temperature at 31.4 GHz, prior to rain events. The nowcasting technique is, therefore, able to predict both rain occurrence and rain accumulation. The model, when validated, gives a reasonable prediction efficiency of around 80%.

1. Introduction

Prediction of intense rain is of utmost necessity as it is a potential cause for loss of lives, property and disruption of infrastructure. The efficacy of the prediction system depends on how it accounts for the underlying processes responsible for the growth of convective processes. In the past, many researchers have used spatial and temporal interpolation to nowcast intense convective activities using satellite and radar data [1]. Atmospheric brightness temperature measured by a microwave radiometer can accurately produce the temperature and humidity profile of the atmosphere which can be used for nowcasting. Recently, there has been some attempts to nowcast rain occurrences using brightness temperatures at 22 GHz and instability indices [2-4]. However, in the previous cases, it was only possible to predict rain and not its amount. The present study aims to predict rainfall amount for impending convective processes in which a significant increment in liquid water occurs before rain which can be taken as a probable estimator of rain accumulation.

2. Experimental Setup and Data

To find out an effective precursor of heavy precipitation, we study the radio environment over Kolkata (22.65oN, 88.45oE) using a multi frequency profiler radiometer (RPG-HATPRO). It measures brightness temperatures at two frequency bands, (22.24-31.4 GHz, 51.3-59 GHz) with 7 frequency channels in each band. [5-6]. The Ka band is used for humidity sensing while the V band is used for temperature sensing. A disdrometer has been used for rain accumulation measurements.

Thirty rain events during 2011-2012 are considered in our study. Brightness temperatures (BT) at 31.4 GHz are used for analysis of these events. Rain accumulation data are taken from disdrometer measurements.

3. Methodology and Results

In heavy rain events, it is expected that about 30 minutes before the event, liquid water starts increasing due to formation of liquid water in cloud during convective maturity. As a result, it can be seen that brightness temperatures in bands sensitive to liquid water absorption should show an increase before rain.

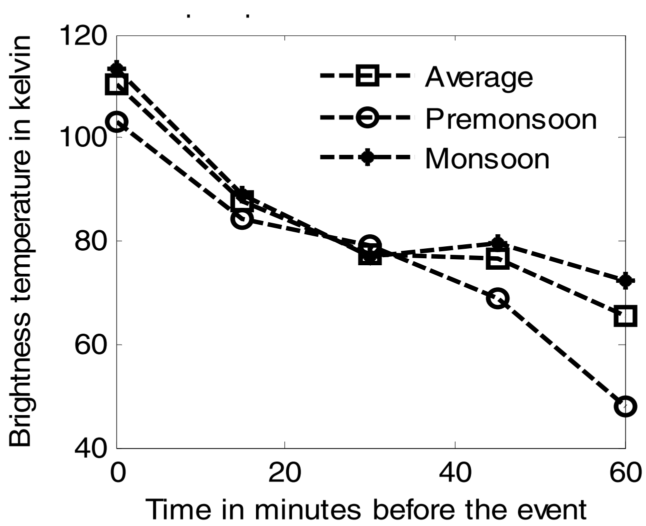

Figure 1. Average variation of BT at 31.4 GHz.

To investigate which particular frequency responds most significantly to cloud liquid water accumulation prior to rain, average brightness temperature variations are recorded at 22.24, 23.8, 26.4 and 31GHz. The analysis showed that brightness temperatures at 31.4GHz provides the largest increment before rain with a change of about 60 K within 1 hour of the event occurrence. As this frequency also provides the highest possible absorption due to liquid water, this frequency is used for further analysis. A case study for BT variation on 15 July, 2015 is shown in Fig 2 in which a heavy rain accumulation was recorded (53 mm).

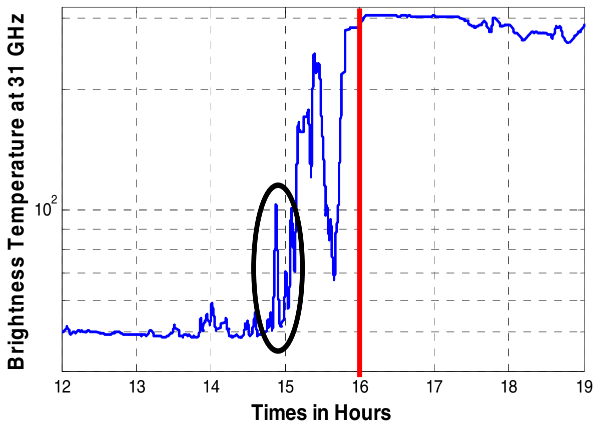

Figure 2. Variation of BT at 31.4GHz on 15 July,2015. Red line shows start of rain.

Fig. 2 clearly indicates that the brightness temperature at 31.4GHz shows a sharp increase before about 1 Hour before rain. It is necessary to check whether this variation in BT occurs before every such heavy rain event. Hence the variations are checked separately for raining and non raining episodes. However, this time it has to be mentioned that brightness temperatures show a large temporal, diurnal and seasonal variation. A net variation of BT in a particular time span has been calculated as follows. The BT data are recorded for every 30 min. The net variation is calculated in a normalized form as shown.

$$Net\ variation = \frac{(\text{Maximum BT} - \text{Initial BT})}{\text{Initial BT}}$$

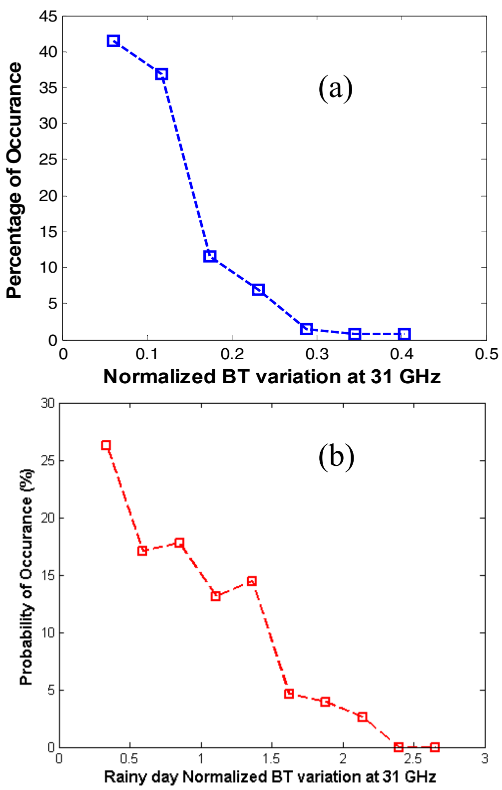

Figure. 3. Frequency distribution of BT variation during raining and non raining conditions.

The frequency distribution of BT variation in the previous figure shows that in absence of rain it is always below 0.4 while in case of rain it is above 0.5. The next concern of the study signifies that whether the BT variation at 31.4GHz can represent the amount of impending precipitation in advance. A variation of this parameter is plotted against rain accumulated for all the rain events. The variation shows that there is a fairly linear agreement between these two parameters.

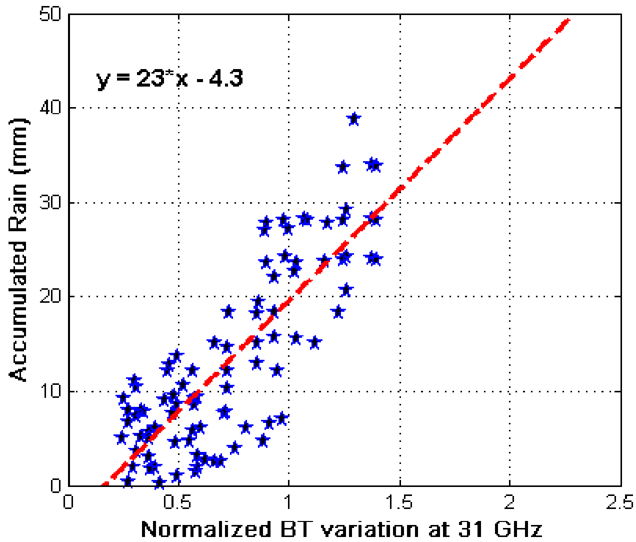

Figure 4. BT variation vs rain accumulation.

From Fig. 4, it follows that the BT variation at 31.4GHz can to a reasonable extent indicate the rain accumulation. However, the next concern is related to the physical basis behind such changes in BT before rain. We know that before rain, instability sets up in the atmosphere resulting in intense hot updrafts carrying water vapour. This vapour can get converted to cloud liquid water due to saturation. Due to dearth of adequate instability, it cannot fall down as rain. Now, it has been found that this conversion of vapour into liquid results in latent heat release which further heats up the atmosphere leading to more instability. A larger cloud releases more latent heat to trigger a larger convective cell. Thus, the resultant rain accumulation is generally influenced by latent heat release about 1 hour before the event which again might be related to liquid growth or BT variation at 31.4 GHz. To check this proposition, the latent heat has been calculated from temperature profiles obtained from radiometer measurements at about 1 hour before every rain event. The variation is depicted in Fig 5 from which it can be seen that the BT variation has a good agreement with the latent heat released before rain. It should also be mentioned that BT variation is calculated from the 22-31.4GHz band while the latent heat is calculated from 51-58 GHz. Hence their mutual independence further validates the physical basis behind the estimation of rain accumulation using BT at 31.4 GHz.

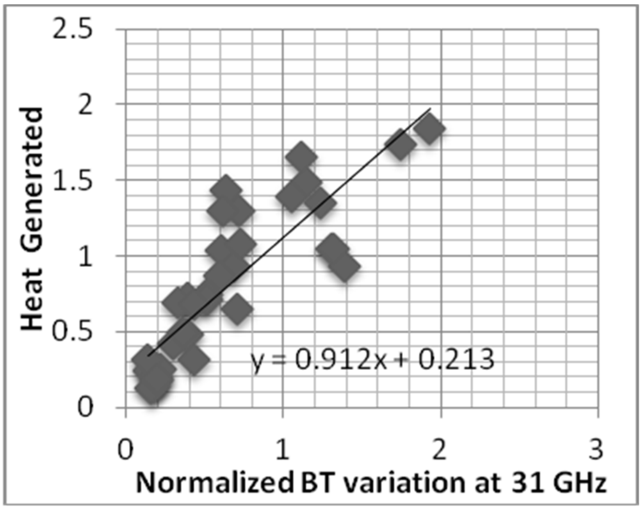

Figure 5. BT variation against rain accumulation.

4. Model validation

To test the efficacy of this technique, it has been validated for a number of rain events of 2013-2014. The model has performed equally well in those cases. In a preliminary stage, it was seen that on a test event of 15/07/15, when the model was applied, it yielded an estimated accumulation of 50 mm which is very close to that calculated from radiometric measurements. However, it was noticed that, the system had one loophole. We know that the accumulation of vapour alone does not guarantee the chance of rain as atmospheric instability also plays a major role in such cases. In the previous study, it has been shown that a model can be developed to check the standard deviation of BT at 22 GHz and LI instability after every 30 min. If both conditions regarding the moisture content and instability are satisfied, then an alarm for rain occurrence is generated. Subsequently, one needs to know the amount of precipitation once the rain alarm has been generated. In light of the above, this technique has been upgraded from the previously created model. The newly generated system would check LI and BT std at 22 GHz in every 30 min and generate an alarm once the threshold for this parameters are crossed. Once, rain alarm is generated, the BT variation is then checked at 31.4 GHz to find out how much rain will occur after 1 hour. This system would as a result enable an accurate nowcast of rain both qualitatively and quantitatively with a good lead time. The obtained prediction efficiency is about 80% while the false alarm rate is 16%. The demonstration of the final prediction technique is shown for a typical heavy rain event in Fig 6.

Fig. 6. clearly indicates that about an hour before rain, BT standard deviation at 22 GHz increases and LI deceases indicating that rain would occur. At the same time, BT variation of 1.26 was recorded which indicates that a rain would occur with a net accumulation of about 24 mm. The event recorded rain of 22.6 mm which is quite close to the estimated range. Hence this technique can effectively predict and quantify the impending rain about an hour before the event.

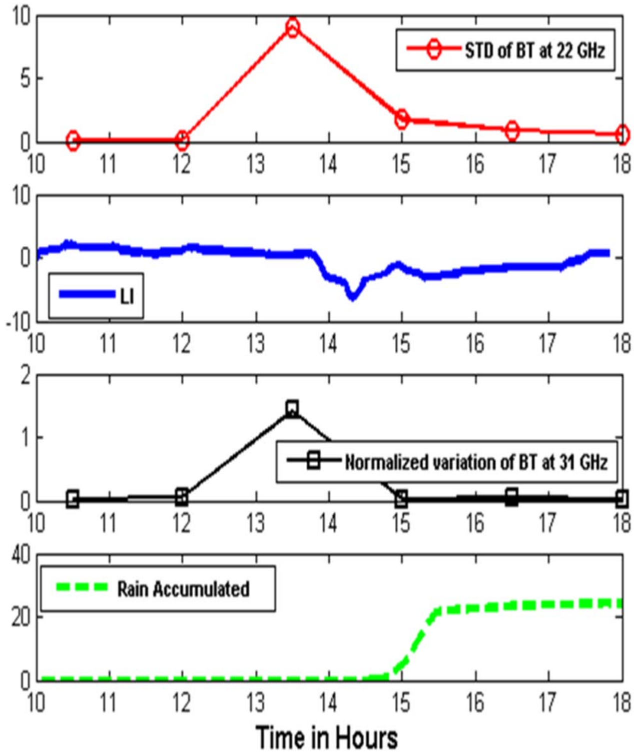

Figure 6. Variation of parameters on 26 August 2013

5. Conclusion

The present nowcasting technique effectively predicts rain occurrence and rainfall amount of impending convective precipitation events. The prediction technique is, in principle, based on identifying the development of the atmospheric instability and estimation of liquid water content prior to rain. Over the study period, the technique has provided a reasonable prediction efficiency of 80%.

6. Acknowledgements

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