Prediction of cloudburst using passive microwave remote sensing

Bikramjit Goswami[1], Manoranjan Kalita[2]

[1] Assam Don Bosco University
Guwahati, India
bikramjit.goswami@dbuniversity.ac.in

[2] Assam Don Bosco University
Guwahati, India
director.sot@dbuniversity.ac.in

Abstract- ***Cloudburst refers to the extreme form of precipitation, with a high amount of rainfall within a short span of time. It often leads to flash flood, landslide and damage of infrastructure due to heavy rainfall. The loss of lives is also not very uncommon. Hence a prediction mechanism of extreme precipitation is the need of the hour. The present paper presents a mechanism of prediction of cloudburst by detecting the formation of cumulonimbus type cloud, using the brightness temperature (TB) difference between 19 and 91 GHz TB values in horizontal polarization and descending passes of the SSMI satellite of NASA. This simple mechanism based on the Tb difference threshold value has been tested for several places in India, during 2013-2016. It is found that the prediction of cloudburst is possible with a lead time of 1-4 days using this algorithm.***

Keywords - Cloudburst, passive microwave remote sensing, brightness temperature, SSMI**.**

1. Introduction

Cloudburst is an event of extreme precipitation which often causes flash flood in the low lying areas nearby. The cloudburst is created by vertical accumulation of cloud over a relatively smaller area and may lead to heavy rainfall due to bursting of that vertically accumulated cloud water. The flash flood caused due to cloudburst is often very devastating in nature, because of heavy run-off of the extreme precipitation [1]. The loss of lives due to sudden occurrence of cloudburst is a common phenomenon, due to very little time obtained to react and rescue operations to be planned for. Hence, a prediction mechanism of the event of cloudburst by detecting the vertical accumulation of cloud may be useful for early warning purpose.

In the Indian subcontinent, a cloudburst usually occurs when a monsoon cloud drifts northwards from the Bay of Bengal or Arabian Sea across the plains, then onto to the Himalaya and bursts, bringing very high rainfall [2]. This is also the primary reason of frequent occurrence of cloudburst in the state of Uttarakhand, neighbouring the Himalayan ranges in India.

Most weather forecasters and satellite analysts are familiar with satellite measurements taken at visible (VIS) and infrared (IR) portions of the spectrum, and taken primarily from geosynchronous satellites. However, during the monsoon season in India cloud cover hampers the visibility by the conventional satellites. Therefore the microwave remote sensors are useful during that period of the year, due to the unique capability of microwaves to penetrate through cloud.

In approximate form, the passive microwave brightness temperature, *TB*, at a particular frequency, *f*, and polarization, *p*, can be represented by the following equation [3]:

$$TB_{f,p} = T_u + \tau_f\,[e_{f,p}\,T_s + (1 - e_{f,p})\,T_d] \qquad (1)$$

where, T_u is the upwelling atmospheric emission, τ_f is the atmospheric transmittance (which is the fraction of energy which emerges at the top of the atmosphere from the surface), T_s is the surface temperature, $e_{f,p}$ is the emissivity and T_d is the downwelling atmospheric emission.

Cloud and Rainfall affects earth emitted microwave radiation in two ways: absorption by rain drops, and scattering by ice particles. The scattering property is most prevalent at high frequencies and is caused by particles that are comparable in size to the wavelength of energy being measured. At 91 GHz, this translates to a particle size of about 4 mm or greater. In the rain layer, there is a mixture of snow, ice and rain particles and this is the main cause of the scattering. This affect is detected by a decrease in *TB* at higher frequencies, in the cloud covered regions.

*TB*s measured at 19 GHz and 91 GHz show variations due to both surface temperature (T_s) and atmospheric emission (T_u). However, the variation of *TB* due to the presence of cloud is more pronounced at 91 GHz, due to blocking of T_s and emission of T_u. This will be more so when the water particle size on the cloud is larger, like in case of cumulonimbus type clouds, which is formed vertically in a tall but horizontally narrow formation. However, lower frequencies like 19 GHz will be affected less by the cloud, due to their longer wavelength. Hence, the *TB* difference between lower and higher frequencies would be higher for a heavily cloud covered sky. If the cloud would be vertically formed with larger water droplets, then the *TB* difference will be even higher. This phenomenon is used as the characteristic criterion in the present work, for detection of cloud having the potential of causing very heavy rainfall, including cloudburst.

I. **TABLE I.** AREAS CONSIDERED FOR DETECTION OF CLOUD CAPABLE OF PRODUCING CLOUDBURST

Area of study	**Latitude (°N)**	**Longitude (°E)**	**Recorded date of cloudburst**
South Garo Hills	25.2	90.6	September 21, 2014
Kashmir Valley	34.0	74.7	September 6, 2014
Tehri	30.4	78.5	July 31, 2014
Pithoragarh, Uttarakhand	30.1	80.4	July 1, 2016

The earlier use of passive microwave remote sensing in the tropical regions include those for soil moisture and flood detection purposes [6,7,8]. However, for detection of cloudburst producing cloud and hence forecasting of the occurrence of cloudburst have not been recorded in any available literature.

2. Area of Study and Data Used

The areas considered for analysing the formation of cloud having the potential to cause cloudburst, are listed in Table 1, with the recorded dates of cloudburst event in those places. The areas selected are from the states of Meghalaya, Jammu & Kashmir and Uttarakhand. Geographically the places are at very different locations in India; the latitudes and longitudes of the places are mentioned in Table 1. Hence, the surface characteristics of all these places are also of different types. Overall, the study includes the major cloudburst events reported across India from 2013 to 2016.

The data used for the study are obtained from the passive microwave remote sensing satellite of National Aeronautics and Space Administration (NASA), called Special Sensor Microwave Imager (SSMI). The satellite records brightness temperature (*TB*) data at 19, 22, 37 and 91 GHz at both vertical and horizontal polarisations [5]. The satellite records the *TB* data twice a day over the earth during morning (ascending pass) and evening (descending pass). In the present study it is found that the near real time *TB* data at 19 and 91 GHz in Horizontal polarization during descending pass are useful for detecting cloudburst or heavy rainfall leading cloud. The sample images obtained from SSMI are shown in Figure 1.

3. Methodology

The methodology adopted for detecting heavy rainfall producing cloud is shown in Figure 2. The TB values are obtained from the images of 19 GHz and 91 GHz for the places under study. Then the difference in TB values for the same places are computed on different dates. The highly positive value of the TB difference would imply the presence of cloud, capable of producing cloudburst or very heavy rainfall. Low positive and negative values of the TB difference would confirm the absence of such cloud in the atmosphere. This methodology is adopted to do the overall analysis for detecting the presence of such cloud and thus for forecasting of the occurrence of cloudburst and very heavy rainfall 2 to 5 days in advance.

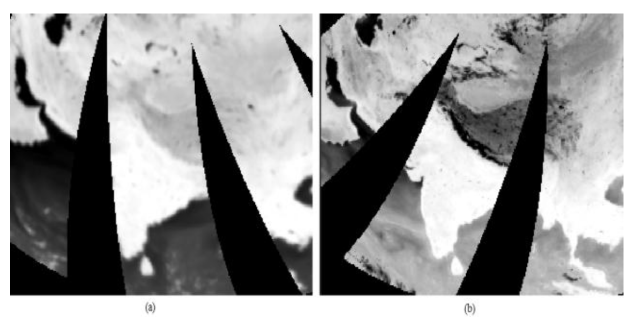

Figure. 1. Sample images containing *TB* values at (a) 19 GHz and (b) 91 GHz

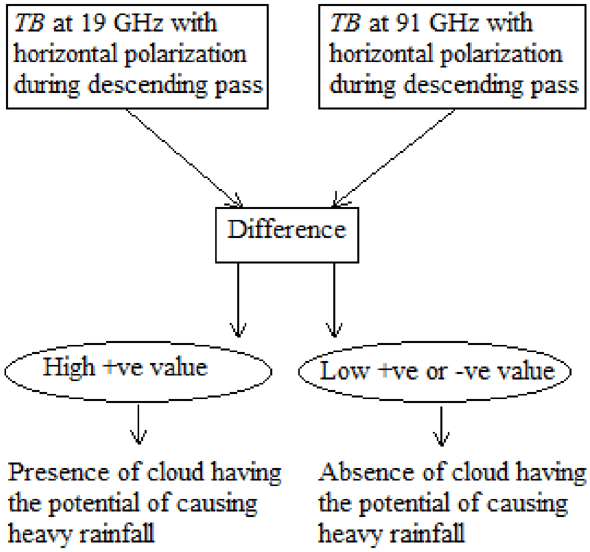

Figure. 2. Methodology for detection of heavy rainfall producing cloud

4. Results and Discussions

The results obtained by following the methodology, for the places under study, are shown in the form of the graphs in Fig. 3 to 7. From the figures it is seen that at least one day before the event of cloudburst, a high positive TB difference value is obtained in each case.

There are instances of non-availability of data on certain dates, including few days before and after the dates when the analysis shows high positive value. For example, for Tehri in Uttarakhand, the high positive value of TB difference is obtained on 26th July. After that, the passive microwave remote sensed data from SSMI for next three days for Tehri are not available, as the satellite did not have a pass over that area for those days. However, the cloudburst is reported at Tehri on 31st of July, 2014. In this case the high positive value is indicated 5 days in advance to the actual occurrence of cloudburst.

For South Garo Hills and Kashmir Valley the indications are obtained 2 and 5 days in advance respectively. The proposed methodology thus can be used for detection of formation of cloud which may lead to cloudburst (100 mm or more rainfall per hour), much in advance, to avert the possible damages caused due to unpreparedness.

The established methodology is then applied to test for the cloudburst predictability for a recent occurrence of cloudburst in Uttarakhand. The plot of TB difference versus dates in Figure 6 shows the high

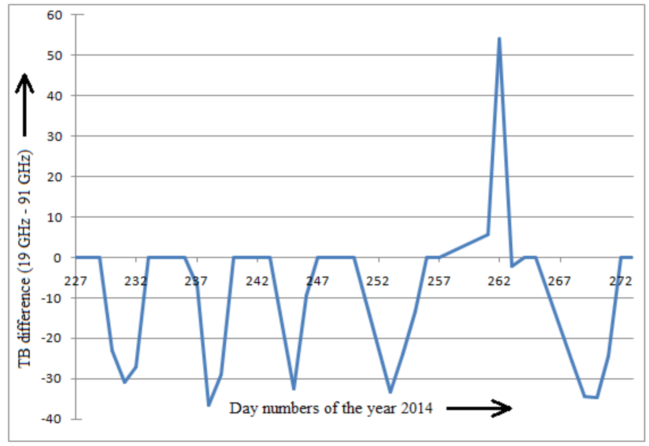

Figure. 3. High positive value obtained on the 262nd day (19th September) of 2014 for South Garo Hills

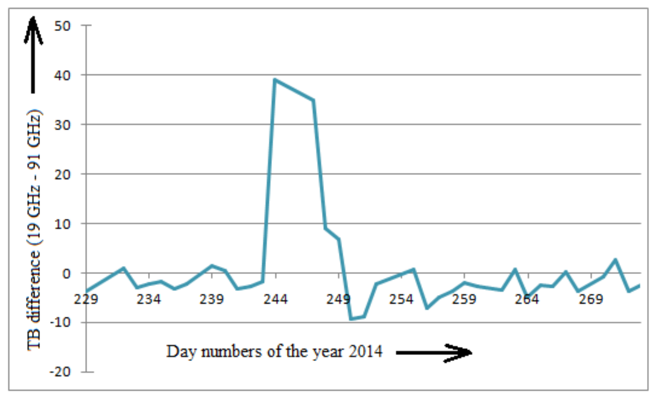

Figure. 4. High positive value obtained from the 244th to 247th day (1st to 4th September) of 2014 for Kashmir Valley

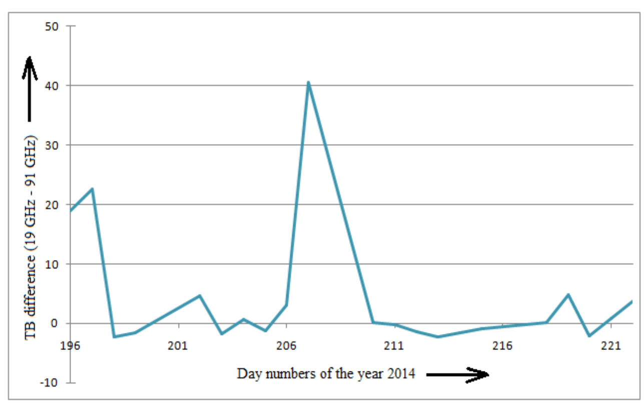

Figure. 5. High positive value obtained on the 207th day (26th July) of 2014 for Tehri

value of brightness temperature difference (+16.2) found to be on 29th of June 2016 evening (Descending pass of the satellite). As per the developed methodology the high TB difference signifies the presence of cloud having the potential of cloudburst. On 1st July early morning the cloudburst took place in the Singhali area near Pithoragarh in the state of Uttarakhand. The graph clearly shows the possibility of the methodology that could have been utilized for predicting the cloudburst which led to the flash flood, landslides etc. causing loss of 38 lives, as reported.

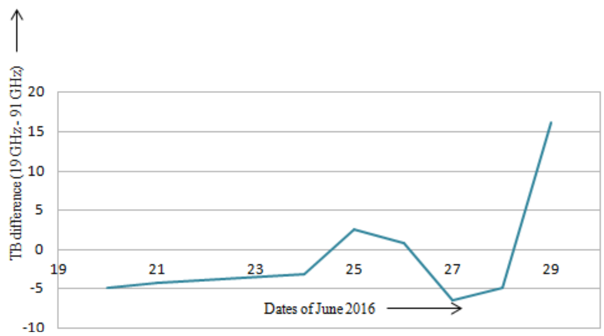

Figure. 6. High positive value obtained on 29th June 2016, for Pithoragarh in Uttarakhand

5. Conclusion

The methodology described in the paper for forecasting of cloudburst by detecting the formation of cumulonimbus type cloud formation is found to be valid for three cited lower Himalayan regions in India. The brightness temperature data with high temporal resolution, obtained from other sources such as NASA and JAXA satellites, in near real time basis, can also be used for the purpose. The methodology needs to be validated further by checking for another set of past and future events of cloudburst in different regions of the world using data from variety of other microwave remote sensing satellites. The use of ancillary data from high resolution active microwave sensors may further improve the forecasting accuracy of the method.

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