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A case study for cyclone ‘Aila’ for forecasting rainfall using satellite derived rain rate data

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सार – बंगाल की खाड़ी में बनने एवं जमीन से टकराने वाले चक्रवातीय तूफानों के परिणामस्वरूप भारी वर्षा की वजह से पश्चिम बंगाल के तट समेत भारत के पूर्वी तट के लोगों की जान माल को काफी खतरा रहता है। जमीन से टकराने वाले उष्णकटिबंधीय चक्रवाती तूफानों की वजह से होने वाली वर्षा की मात्रा का पूर्वानुमान करना बहुत कठिन है। उष्णकटिबंधीय चक्रवातीय तूफानों के दायरे में आने वाले वर्षा वाले क्षेत्रों में संभावित चक्रवातीय तूफान से होने वाले वर्षा संचयन का पूर्वानुमान करने के लिए उपग्रह से प्राप्त वर्षा दरों का उपयोग किया जा सकता है। इस शोध पत्र में ‘आइला’ के उष्णकटिबंधीय वर्षा मापन मिशन (टी. आर. एम. एम.), उपग्रह वर्षा दर आँकड़ों तथा तूफान के देखे गए मार्ग का उपयोग करते हुए उष्णकटिबंधीय चक्रवात ‘आइला’ के जमीन से टकराने से 24 घटें पहले तटीय स्टेशनों पर वर्षा का आकलन करने का प्रयास किया गया है। संयुक्त राज्य अमेरिका में विकसित सुपरिचित तकनीक के आधार पर उष्णकटिबंधीय चक्रवात ‘आइला’ के जमीन से टकराने के 24 घंटे पहले उष्णकटिबंधीय वर्षा विभव (टी. आर. ए. पी.) पूर्वानुमान विशेष रूप से तूफान की दिशा के सामने आने वाले तटीय क्षेत्रों के लिए अच्छी वर्षा का पूर्वानुमान उपलब्ध कराता है।

ABSTRACT. Major threat to the life and property of people on the east coast of India, including West Bengal Coast, is due to very heavy rainfall from landfalling tropical cyclones originated over Bay of Bengal. Forecasting magnitude of rainfall from landfalling tropical cyclones is very difficult. Satellite derived rain rates over the raining areas of tropical cyclones can be used to forecast potential tropical cyclone rainfall accumulations. In the present study, an attempt has been made to estimate 24 hours rainfall over coastal stations before landfall of tropical Cyclone ‘Aila’ using Tropical Rainfall Measuring Mission (TRMM) satellite rain rates data and observed storm track of Aila. Forecast Tropical Rainfall Potential (TRaP), 24 hours prior to landfall for the tropical cyclone ‘Aila’ based on well known technique developed in USA, provides a good rainfall forecast especially for the coastal areas lying at the head of direction of the storm.

Key words – Rainfall forecast, Tropical Cyclone, TRMM, TRaP.

1. Introduction

Very heavy rainfall which occurs due to landfall of tropical cyclones over east coast of India, including West Bengal Coast, is a major threat to life and property of people on the coastal areas. Though the extreme weather phenomenon generally associated with tropical cyclone that cause maximum disasters over coastal areas are storm surge and gale winds, torrential heavy rain from landfalling tropical cyclone causing freshwater floods is also equally important. Whenever heavy rainfall occurs with storm surges, it becomes more dangerous over affected coastal area. Also heavy rainfall creates difficulty in rehabilitations works. So, forecast for the rainfall potential of landfalling tropical cyclones is vital for guidance to the agencies that are engaged in taking safety measures or rehabilitations works.

Significant efforts have been made in the past for the estimation of storm surge and determination of maximum winds associated with tropical cyclone. Dube *et al.*, (1997) has given an overview of the major aspects of the storm surge problem in the Bay of Bengal and the Arabian Sea, the factors affecting the storm surge generation and prediction of storm surge based on well known techniques. The tropical cyclone intensity is directly related to surface pressure defect (ΔP) and maximum surface wind speed and many efforts have been made for intensity prediction of cyclone. Raj (2010) has presented details of review on the relationship between pressure defect and maximum winds of a tropical cyclone. Comparatively, prediction of quantative rainfall in association with tropical cyclone has not received much attention. Forecasting of amount of rainfall from landfaling tropical cyclone is a very challenging job. Numerical weather prediction model forecast provides good forecast of rainfall when weather system lies over land area, but when the storm is offshore, due to paucity of observations the initialization of models with sufficient details of the storm becomes difficult as a result of which accurate rainfall forecast is not possible. Satellite borne microwave radiometers can measure instantaneous rain rates through the entire cloud area of tropical cyclones (Kidder *et al.,* 2000). Most of the tropical cyclones gain intensity of a cyclone, or more, 24 -36 hours prior to their landfall (Singh and Bandyopadhyay, 2004). Thus 24 hours tropical cyclone rainfall potential has great importance for issuance of better warnings to the users.

Kidder *et al.,* (2000), described a technique for forecasting Tropical Rainfall Potential (TRaP) or the amount of rainfall likely to occur from a tropical cyclone expected to landfall within 24 hours period. A brief of the TRaP technique has been presented in the data and Methodology section below. The objective of the present study is to make a beginning in order to explore the possibility of using TRaP technique for forecasting of rainfall amount due to cyclonic disturbances over Bay Bengal. In view of this, a case study for estimation of 24 hours rainfall over coastal stations before landfall of tropical cyclone 'Aila' has been carried out using Tropical Rainfall Measuring Mission (TRMM) rain rates data.

2. Data & Methodology

Various applications of Advanced Microwave sounding (AMSU) data in tropical cyclone analysis have been well described by Kidder *et al.,* (2000), including the Tropical cyclone Rainfall Potential (TRaP). The calculation involved in the TRaP technique is described in the following steps:

Step-1. First to display/ look into the instantaneous rain rate retrieved from microwave measurements.

Step-2. A Line is drawn across the storm's rain area in the direction of storm motion. One attempts to draw the line through the most intense rain so that maximum potential of the storm can be analyzed.

Step- 3. The Diameter (D) of the storm and the average rain rate (R) along the line are calculated.

Step-4. Finally, the analyst applies the following rainfall potential formula

$$\text{TRaP} = RDV^{-1},$$

where V is the speed of the storm.

The TRaP technique is based on important assumptions that the satellite rain rates do not change either in magnitude or area and also the raining area move with the storm in the direction of forecast track with a constant speed. However, the convection pattern associated with tropical cyclone especially over Indian Ocean where most of the tropical cyclones do not gain severe intensity, like Atlantic or Pacific region, are changing over the time. Also, mostly the forecast-tracks are not matching with the observed track and 24 hours track forecast have errors of 50 to 100 km in most of the cases. In view of this, in the present study, the above technique has been adopted with some modification in the calculation methods. The average rain rate has been calculated along a path with a diameter of 0.5° in the forecast direction of the storm instead of average of available grid values along a line. Also TRMM derived multi satellite rain rate data has been used in this study.

The images and rain rate data used in this study were acquired using the GES-DISC Interactive Online Visualization and analysis Infrastructure (Giovanni) as part of the NASA's Goddard Earth Sciences (GES) Data and Information Services Center (DISC). (http://disc2.nascom.nasa.gov/Giovanni/tovas/TRMM_V6.3B42.2.shtml). The cyclone 'Aila' best track data has been taken from the report of Cyclone Warning Division, India Meteorological Department (IMD), New Delhi (2010). Actual rainfall data for 24 hours period over different coastal stations of West Bengal State, India has been taken from Regional Meteorological Centre, Kolkata.

3. Results and Discussions

Severe cyclonic storm 'Aila' is the first cyclone in the month of May making landfall over West Bengal Coast after a long gap of about 20 years. It crossed coast between 0800 & 0900 UTC of 25th May, 2009. Aila evolved from a tropical disturbance in the central Bay of Bengal. The disturbance organized into a tropical cyclone at 1200 UTC of 24th May and lay centered near Lat. 18.5° N / Long. 88.5° E and it continued to move in northerly direction and further intensified into a severe cyclonic storm at 0600 UTC of 25th May centered over northwest Bay of Bengal near Lat. 21.5° N / Long. 88.0° E on the West Bengal coast. It may be mentioned that the movement forecast given by India Meteorological for

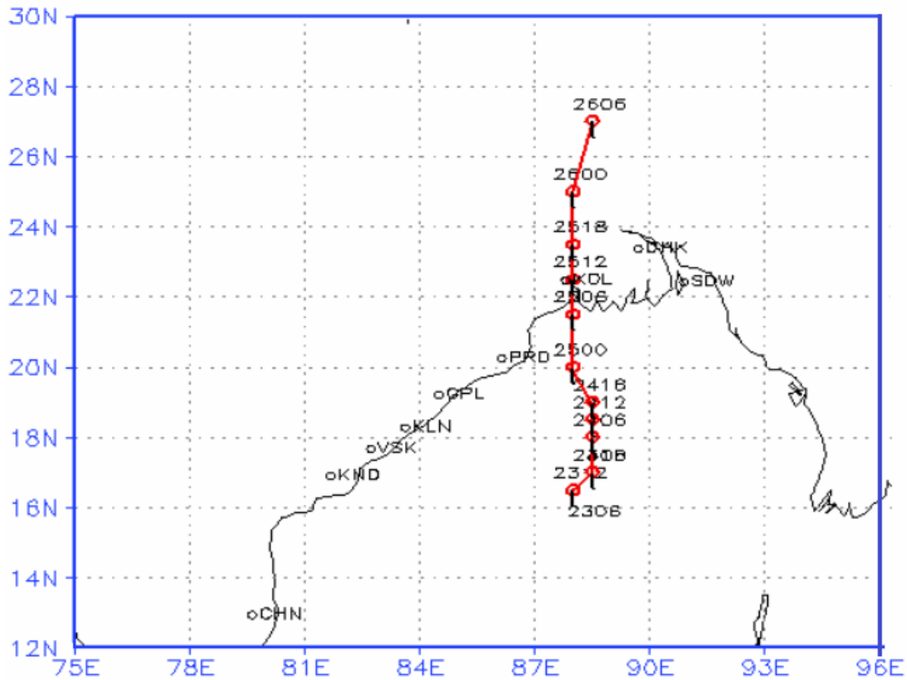


Fig. 1. Observed track of tropical cyclone 'Aila' crossed West Bengal coast on 25th May, 2009

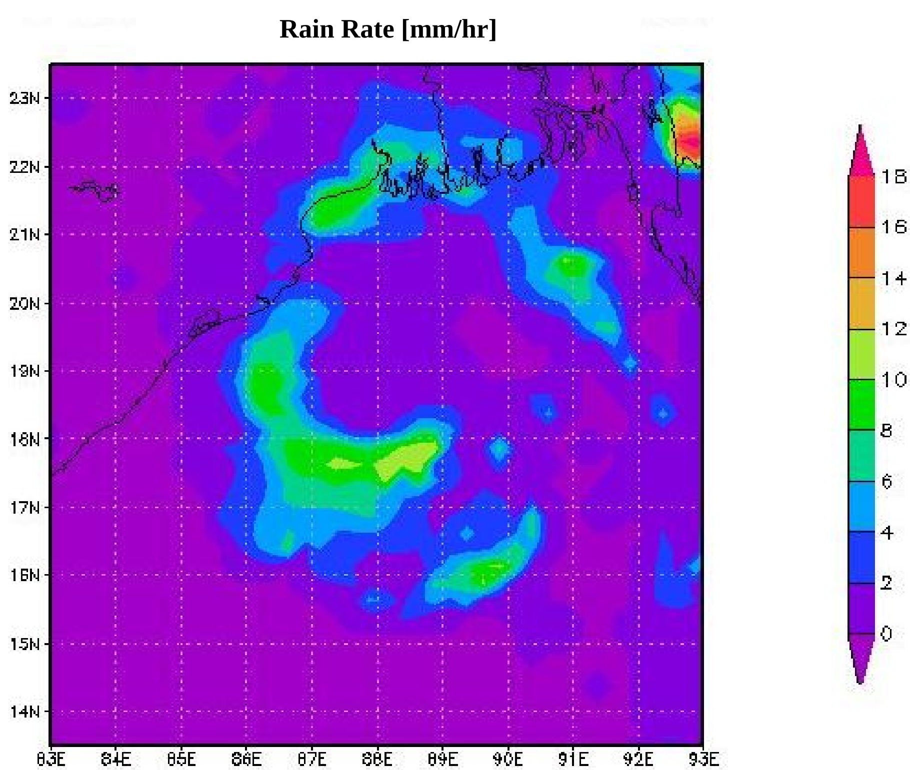


Fig.2. Rain rate distribution of cyclone Aila at 1200 UTC of 24th May, 2009

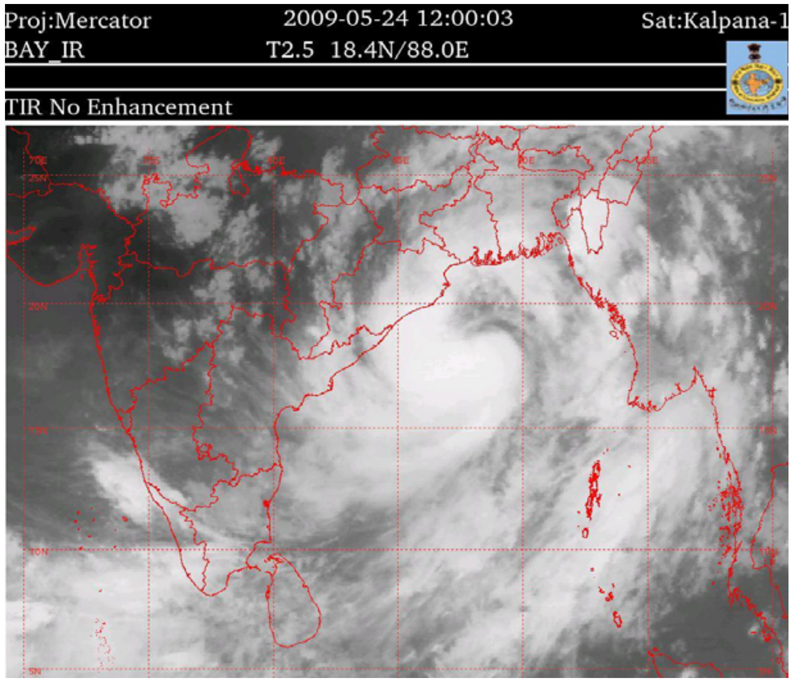


Fig. 3. INSAT IR image of tropical cyclone Aila at 1200 UTC of 24th May, 2009

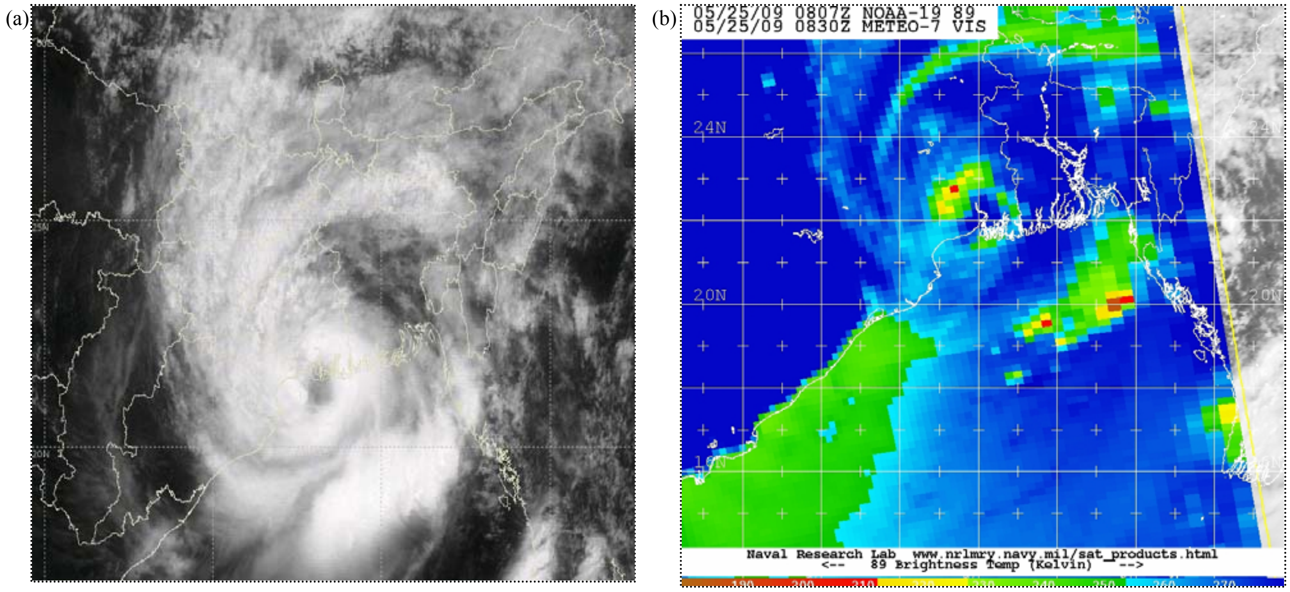
TABLE 1

Location, estimated and observed rainfall of different coastal stations of West Bengal

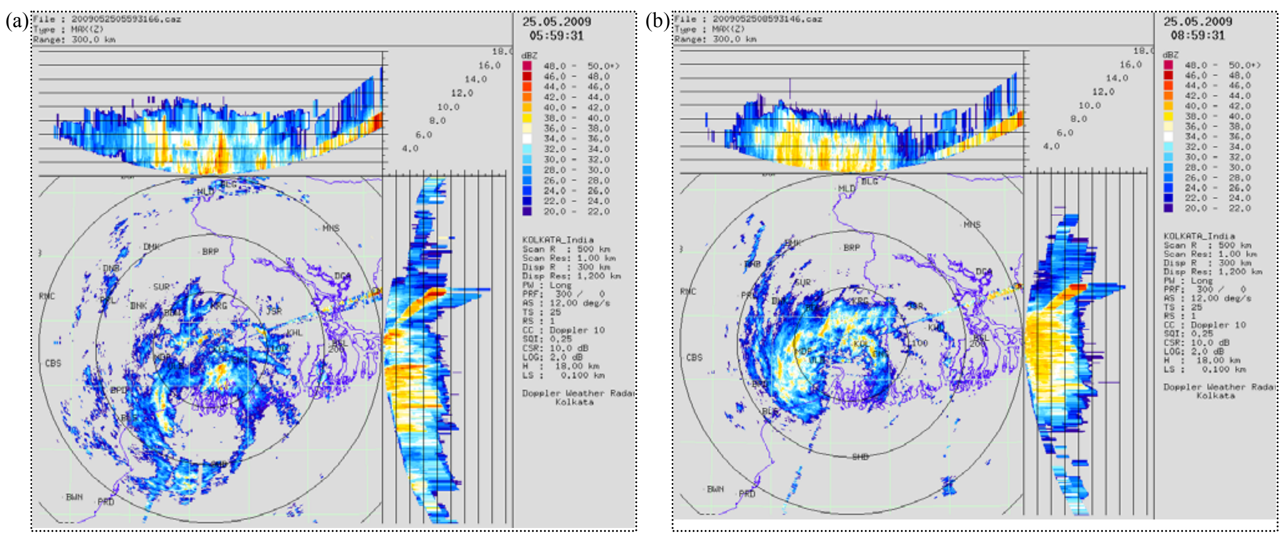
Station Name	Location		24 hrs Rainfall(mm)	
	Lat (°N)	Long(°E)	Estimated	Actual
Alipore	22.5	88.3	139	105
Dumdum	22.7	88.5	136	141
Digha	21.6	87.5	132	175
Haldia	22.1	88.1	109	61
Canning	22.3	88.7	119	72
Uluberia	22.5	88.0	141	99

cyclone 'Aila' before 24 hours of its landfall was almost same as the observed track. So, in the TRaP calculation the observed track of 'Aila' has been taken into account. The observed Track of 'Aila' is depicted in Fig.1. Also, it may be mentioned that even after landfall of the cyclone 'Aila', it maintained its cyclone strength upto 15 hours from the time of its landfall. It continued to move in a northerly direction after landfall and weakened into a cyclonic storm at 1500 UTC of 25th May, 2009 over Gangetic West Bengal, close to Kolkata.

As the tropical disturbance organized into a tropical cyclone at 1200 UTC of 24th May, 2009 about 21 hours before landfall, the rain rate data for 1200 UTC obtained from http://disc2.nascom.nasa.gov/Giovanni/tovas/TRMM_V6.3B42.2.shtml, has been taken for the TRaP measurement. This rain rate data has been depicted in Fig. 2. The INSAT IR image of 1200 UTC of 24th May, 2009 is also depicted in Fig.3 for sake of comparison between convection band in association with the disturbance and area of maximum rain rate. It has been observed that the maximum rain rate area estimated from TRMM system is in general agreement with maximum convection area as seen in the INSAT IR image. A path with diameter of 0.5° has been considered from different coastal points into the direction of the motion the storm and accordingly TRaP has been calculated using the formula as described in the methodology section. Five coastal stations namely Digha, Haldia, Canning, Uluberia, Kolkata (Two observatory-Alipore & Dum Dum) around the landfall point of the cyclone 'Aila' have been taken for comparison of estimated rainfall potential with the actual 24 hours rainfall amount. Location (latitude/ longitude) alongwith estimated and actual 24 hours rainfall amount at these five stations are depicted in Table.1. Amount of estimated rainfall for different stations located within about 100 km of landfall point ranges from 109 mm to 141 mm and the rainfall over Dum Dum (Kolkata) of amount 141 mm is matching fairly well with



Figs. 4(a&b). Kalpana-1 Satellite Visible image of 0630 UTC of 25th May 2009. (b) NOAA-19 (89 GHz) Satellite image of 0807 UTC over lying on Meteo Sat-7 image at 0830 UTC of 25th May 2009 (www.nrlmry.navy.mil/sat.products.html) indicating two intense convection zones, one in northwest and other on southeast side of storm centre position



Figs. 5(a&b). Kolkata Doppler Radar image at (a) 0600 UTC and (b) 0900 UTC of 25th May 2009

estimated rainfall amount 136 mm obtained from TRaP calculation. Gauge-observed rainfalls at all other places are lower than the estimated rainfall except at Digha which lies at a distance on the south west side of the extrapolated location of the storm after 24 hours from 1200 UTC of 24th May 2012. Kidder *et al.,* (2005) described the history, basic assumption and limitation of TRaP technique. As pointed out by Kidder *et al.,* (2005) there are three main sources of uncertainty in TRaP rainfall forecasts *viz*., (*i*) the satellite-estimated rain rates, (*ii*) the forecast storm track and (*iii*) the invariant spatial structure. In the present study, the TRaP has been calculated using the observed track of cyclone 'Aila', so it is necessary to see how the cloud structure associated with the storm has changed during 24 hours period from 1200 UTC of 24th May 2009, which is the time of base rain rate data taken for TRaP calculation. Mainly two intense convective zones developed, one lying to the northwest and other to the southeast in association with the tropical storm 'Aila' as it moved towards the land. Also comparatively in a large area there was weak convection in and around the centre of the storm and thus convective pattern changed significantly the structure at 1200 UTC of 24th May, 2009. These features were observed in the chronological Satellite images and Doppler radar observations. Some of them have been depicted in Figs. 4(a&b) and Figs. 5(a&b). Consequently there was a significant change in spatial pattern of rain rates relative to the storm centre in terms of magnitude as well as coverage area over the time as the cyclonic storm 'Aila' moved towards land. Digha, which is located on the western side of the storm path experienced maximum rainfall and Haldia, which is located closest to the storm centre (22.0° N / 88.0° E) at 0900 UTC of 25th May, 2009 just after the landfall, received minimum rainfall as compared to all other six surface observatories as listed in Table 1. Thus it may be stated that significant variability in rain rates associated with convection pattern could be one important reason for higher differences between TRaP 24 hours rainfall forecast and observed rainfalls. Apparently the convection pattern in association with tropical cyclones especially over Bay of Bengal, evolves continuously and consequently the rain rates also change over the time. In spite of this fact, the maximum rainfall potential before 24 hours period for the tropical cyclone 'Aila' obtained from the TRaP technique provides a good estimate especially for the area lying at the head of direction of the storm. Ferraro *et al.,* (2005) described a method for validation of TRaPs generated by Satellite analysts at the Satellite Services Division (SSD) of the National Environmental Satellite Data and Information Service (NESDIS), USA during the 2002 Atlantic hurricane season using National Centers for Environmental Prediction (NCEP) stage IV hourly rainfall estimates. They found that all TRaPs tended to underestimate the maximum rainfall. However, TRaP forecasts outperformed the Numerical Weather Prediction 'Eta' Model forecasts in virtually every statistical category. Outside influences *viz*., Terrain effect, intrusion of dry air or wind shear may also enhances or decreases the rainfall associated with the storm which is also neglected in calculation of TRaP forecast. Liu (2009) studied 38 Typhoons around Taiwan area to examine the effect of Taiwan Terrain and concluded that a correction factor due to the Terrain effect, applied on TRaP produces better results. Sub-Himalayan West Bengal region had experienced very heavy rainfall due to cyclone 'Aila' which may be due to orographic enhancement of rainfall. However, this is beyond the scope of present study as the region is located far away from the coast.

4. Conclusions

The following broad conclusion can be drawn from the present case study on application of rainfall estimation technique using satellite derived rain rate data for cyclone 'Aila'.

Estimation of maximum rainfall potential derived by TRaP technique using TRMM derived multi satellite rain rate data appears to be useful to provide good guidance to the forecaster for forecasting of 24 hours rainfall amount expected from a landfalling cyclone. Variability in convection pattern during TRaP forecast period of Cyclone 'Aila' resulted in some of the differences between observed rainfall amounts and TRaP forecast values. Many more cases are required to be studied for further developments of the technique.

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