Daily Merged Satellite Gauge Real-Time Rainfall Dataset for Indian Region

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ABSTRACT

Simulation and prediction of Indian monsoon rainfall at scales from days-to-season is a challenging task for numerical modelling community worldwide. Gridded estimates of daily rainfall data are required for both land and oceanic regions for model validation, process studies and in turn for model development. Due to recent developments in satellite meteorology, it has become possible to produce realistic near real-time gridded rainfall datasets at operational basis by merging satellite estimates with rain gauge values and other available in-situ observations. In this study, we show the representation of monsoon rainfall from a merged satellite-gauge dataset developed jointly by ESSO-IMD and ESSO-NCMRWF at 0.5° spatial grids for three recent monsoon seasons. These daily merged gridded rainfall datasets are available in real-time via IMD, Pune website since June 2012. The merged rainfall data are able to capture the monsoon large-scale rainfall distributions adequately. For severe weather systems also, this merged data set is found to be useful. The intra-seasonal variation shows realistic observed rainfall features in the merged dataset. Very soon improved multisatellite estimates from GPM constellation will be available, which is being planned to be used in the current merged product in place of TRMM. More and newer types of data from radar, AWS and ARG will be incorporated in future version of the daily merged rainfall analysis product.

Keywords : *Model validation, near real-time rain fall, severe weather systems.*

1. Introduction

Gridded rainfall data at various space-time scales are required in the research of weather/climate model verification/development, hydrology, agriculture, ecology, and environmental sciences. The continuity of gridded rainfall data is critical for climate studies. For India monsoon season, rainfall is the lifeline of the nation. The whole nation is dependent on monsoon rainfall for agriculture, and water related socio-economic activities. Therefore, understanding and realistic prediction of monsoon rainfall from days-to-seasonal time scale is of vital importance to India. At the same time, monsoon weather/climate system is one of the most complex phenomenons of the Earth's Climate System. Initialisation and simulation of monsoon rainfall in numerical dynamical modelling framework is a challenging scientific task for world modelling community. Government of India has initiated a mission mode research project named 'National Monsoon Mission' to meet the goal of improving the skill of monsoon rainfall forecasts from days-to-season scale using dynamical models of the earth system. Currently the models perform poorly for monsoon rainfall prediction. Indian regional monsoon intra-seasonal rainfall variability is seen as a source of predictability in extended range and finally contributing to skill development at seasonal scale.

Rainfall data in gridded form at daily scale covering both land and oceanic regions around India is of vital importance. Keeping this in view, IMD has developed gridded rainfall datasets at daily time scales (Rajeevan et al., 2006; Rajeevan and Bhate, 2009). Recently, a further higher resolution daily gridded data for land region has been released by IMD (Pai et al., 2014a). These rainfall datasets have been found to be very useful in monsoon process studies and other applications (Pai et al., 2014b). However, for study of complete monsoon systems, which spread across ocean and land regions it is necessary to prepare such gridded datasets for both land and ocean regions. With the advent of satellite technologies, high quality satellite rainfall estimates are available for oceanic and land regions (Kucera et al., 2013). With developments in coupled ocean-atmosphere models the skill in capturing monsoon intra-seasonal rainfall is improving, and there is a good possibility that the coupled models could be used in operational mode for extended range prediction of monsoon rainfall including wet and dry spells within a monsoon season. For this monsoon intra-seasonal rainfall studies we need reliable gridded rainfall data over both land and ocean at daily time scales. Merging of satellite information with rain gauge data is a viable option and many groups in the world have started producing this type of merged datasets. There are also some products named multi-satellite datasets which are calibrated with gauge and radar datasets for a realistic representation of satellite estimates (Xie et al., 2007; Huffman et al., 2007; Kubota et al., 2007). With the availability of a variety of gridded datasets, evaluation of each dataset for a particular geographic/climatic environment at a particular time/space scale is very important. For Indian monsoon region at daily scale the TRMM Multi-satellite Precipitation Analysis (TMPA)-V7 satellite estimate is more reliable in totality for model verification purposes (Prakash et al., 2014, 2015a, 2015b, 2015c). Merged satellite gauge daily data for Indian region has been found to be superior compared to other available daily datasets (Mitra et al., 2013b). At seasonal time scale, rainfall datasets produced by other groups are more reliable (Prakash et al, 2015d; Rana et al., 2015). These inter-comparison studies for any region and season are a continuous process and has to be undertaken regularly. Reliable rainfall observations for Indian monsoon are also another important point for climate model validation, model development and hence climate change studies (Collins et al., 2013; Mitra et al., 2013a). In this study, we show the representation of monsoon rainfall from a merged satellite-gauge dataset produced jointly by ESSO-IMD and ESSO-NCMRWF at 0.5° spatial grids for three recent monsoon seasons. These merged daily rainfall datasets are produced in real-time and is available to user community via IMD, Pune website in real-time since June 2012.

2. Merged Product Algorithm and Data

A successive correction based algorithm was used earlier to merge satellite rainfall with gauge data to obtain a daily gridded large-scale rainfall for Indian monsoon region (Mitra et al., 1997, 2003, 2009). Merged TRMM and gauge data have been produced by different centres and regions using successive correction algorithm. This successive correction algorithm is superior to just replacing box averaged values and has been found satisfactory to produce large-scale daily monsoon rainfall. In this distance-weighted approach, accuracy of estimation varies with the number of neighbourhood observed points used. Hence good number of gauges over land is crucial for the quality of the gridded data. In our present dataset, the satellite product used as a first guess is the TMPA-RT for daily estimates (Huffman et al., 2007). TMPA provides a calibration-based scheme for combining precipitation estimates from multiple satellites. TMPA has two sub-products, the real-time (RT) and the 3B42V6 (TMPA research version) products. The RT product was used here in real-time production at IMD Pune. The TRMM-based TMPA-RT rainfall data is good in capturing the pattern and phase of intra-seasonal variability of the Indian monsoon. The biases of the TRMM data can be corrected by merging gauge based information. This original TMPA-RT data are 3-hourly at 0.25° latitude/longitude grids, which have been accumulated over time and averaged over space to represent daily (24 hours accumulated) 0.5° latitude/longitude grids to be used for the preparation of new real-time merged dataset. The other ground-based rainfall data used here is the gauge information from IMD. This merged data product described here is named as NMSG product in all subsequent plots. In this current NMSG algorithm, the analysis resolution is 0.5° latitude/longitude. This resolution is appropriate to depict the large-scale description of rainfall patterns associated with the monsoon. The domain of analysis is between 50°E and 110°E longitude and 30°S and 40°N latitude, covering the Indian monsoon region. The successive correction method involves the successive modification of an initial guess field (satellite estimates) based on observed station data (rain gauge). Presuming that the gauges are perfect, the error (bias) correction for the satellite estimate at each grid point is derived. First, the satellite estimates are interpolated to station location to form a first guess. Their differences from the observed station values provide an error estimate at the station location. This set of irregularly spaced values is used to derive corrections at the desired grid points, using successive iterative corrections. The details of the weights and interpolations are described in Mitra et al. (2003). During the successive corrections, four scan radii (1.5°, 1.3°, 1.1°, and 0.8°) are used. Since the intention is to represent the observed large-scale monsoon rainfall at 0.5° latitude/longitude grid boxes, the scan radii were selected in this way to account for the continuity of large-scale rainfall in relation to the processes occurring in the neighbouring grids. The last scan represents the actual scale to be captured. The first guess used in this daily rainfall analysis is the TMPA-RT available at three-hourly time intervals at 0.25° latitude/longitude spatial resolution (Huffman et al., 2007) for the extended tropical belt in real-time. Hence, it is very suitable for the Indian monsoon region. From the three-hourly TMPA data, the daily-accumulated (24-hour accumulated) rainfall valid at 0300UTC is computed for the Indian region; which is compatible to the accumulated 24-hour (daily) rainfall values from the IMD gauges valid at the same 0300UTC. The original TMPA data at 0.25° resolution were bi-linearly interpolated to the analysis grid of 0.5° resolutions. At the time of testing and implementation of the algorithm, around 2000 station rainfall data were available. Figure 1 shows the distribution of rainfall observations on a typical day. For gauge data, in real time it goes to quality control at IMD and during monsoon 2014 season on an average around 2200 gauges were used daily in this real-time merged analysis product. Due to operational requirement, as a backup plan the INSAT IR-based rainfall estimates are used as a first guess when TRMM-RT data are not available due to technical reasons. On a continuous basis critical evaluation of different real-time satellites estimates of rainfall are being carried out to examine the most suitable first guess to be used in our merged algorithm (Prakash et al., 2015a, 2015b, 2015c). Until now TMPAV7-RT was the best real-time estimate for our region in the evaluation studies and hence this was used as a first guess in the merged product. As the life of TRMM satellite is almost over, from current year we have to start using other available satellite estimates in the merged product.

3. Discussion

On an operational basis real-time merged rainfall data are prepared by IMD, Pune from 01 June 2012 onwards, and these data are made available to user community via IMD website in real-time. This data has been found very useful by various users and researchers. Panels in Figure 2 show the total rainfall for the monsoon seasons (JJAS) of 2012 to 2014 from merged product, TMPA-RT satellite only and the IMD gauge only analysis. It is clearly seen that the inclusion of gauges modifies the satellite estimates in the final merged product. Over land regions, the merged product matches very well with IMD high resolution

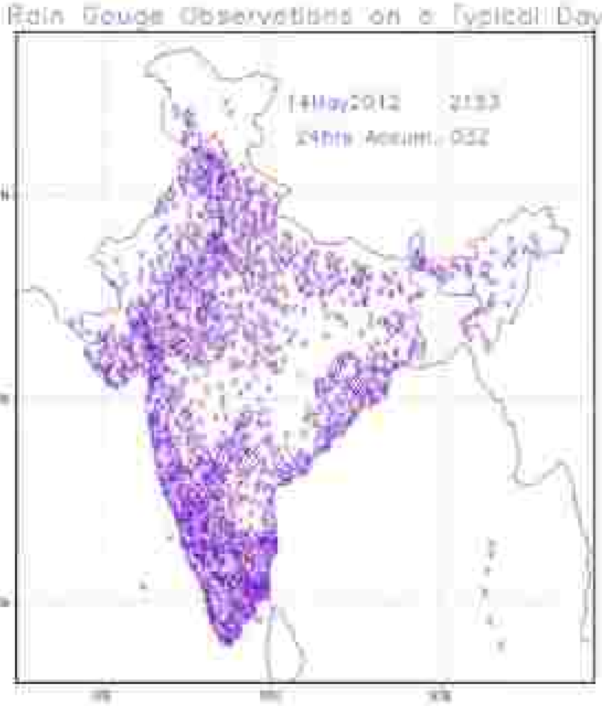

Fig.1 Surface in-situ rain observation distribution on a typical day.

gauge only product. The details of IMD gauge only product is described by Pai et al. (2014a). There are minor differences seen in the rainfall over land regions, which could be due to resolution of analysis being performed in merged product (at 0.5° degree grids) and the gauge only analysis (at 0.25° degrees grid). Another reason could be due to updated gauge data used in the IMD gauge only analysis in its final release. Figure 3 shows the time-latitude cross-section of both merged rainfall and the satellite only data for monsoon 2012-2014 seasons. The difference plot between merged and satellite only data shows the impact of inclusion of gauge information in the final merged product. The differences are quite noticeable. The merged data show realistic intensities of rainfall in its northward propagation in the monsoon intra-seasonal variations. Figure 4 shows the observed rainfall from merged data and the IMD gauge only analysis during three severe weather conditions. Two such events were the Uttarakhand and J&K deluge during June-2013 and September-2014, respectively. The other event was the very severe cyclonic storm HUDHUD during October 2014. There is good agreement between real-time merged product and the gauge only analysis. The merged product has extra information from satellite estimates in the neighbourhood of the severe weather systems.

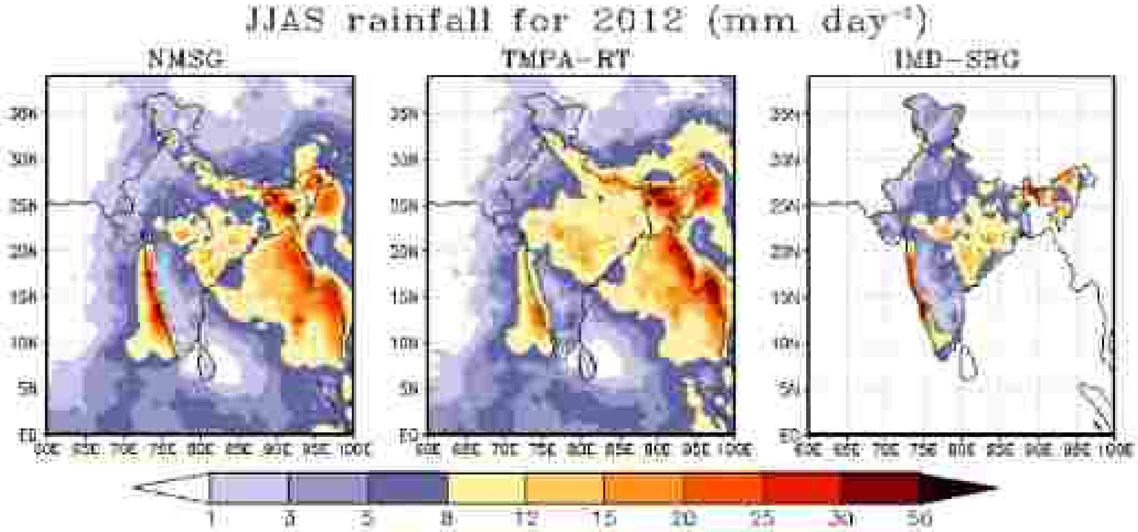

Fig.2(a) Monsoon seasonal rainfall for 2012 from merged product, TRMM and Gauge based analysis.

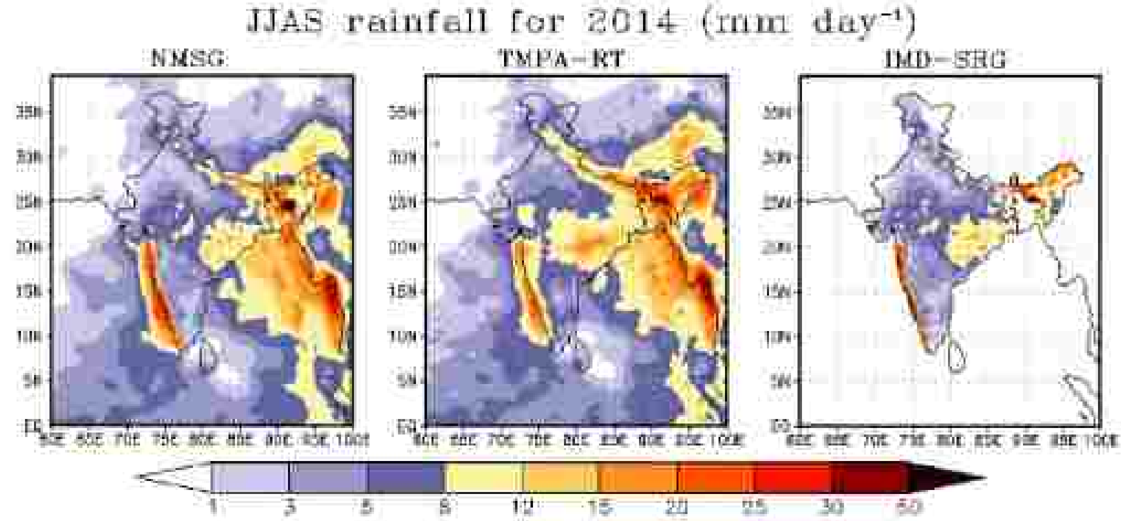

Fig.2(b) Same as figure 2(a), but for 2013 monsoon season.

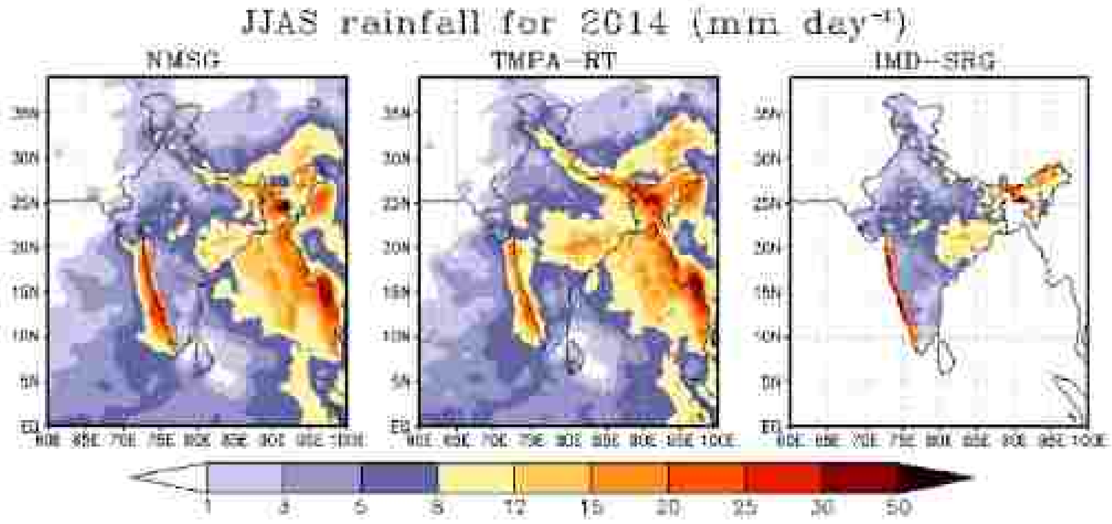

Fig.2(c) Same as figure 2(a), but for 2014 monsoon season.

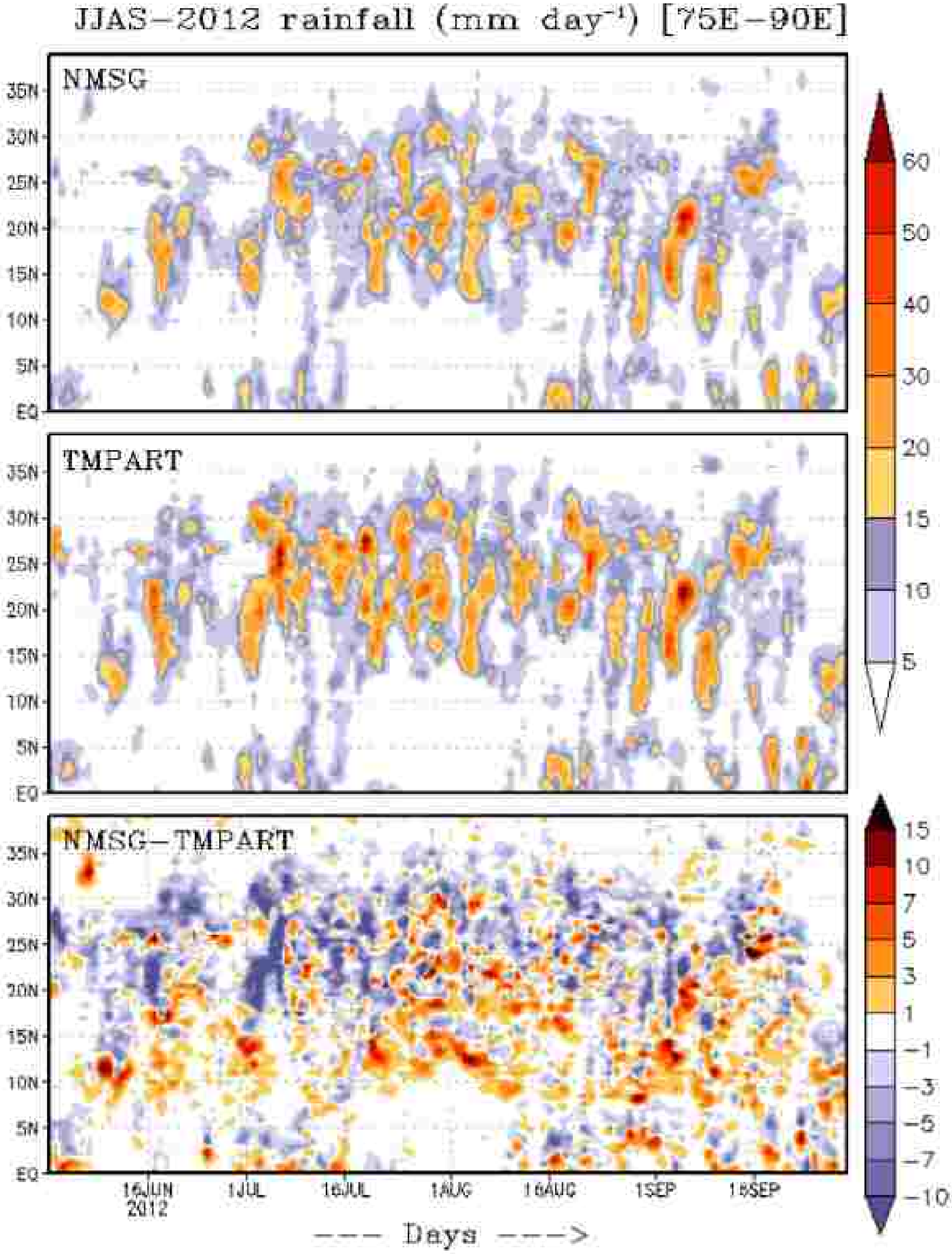

Fig.3(a) Time-latitude cross-section of rainfall showing monsoon intra-seasonal variations from merged product, TRMM and their difference during monsoon 2012 season.

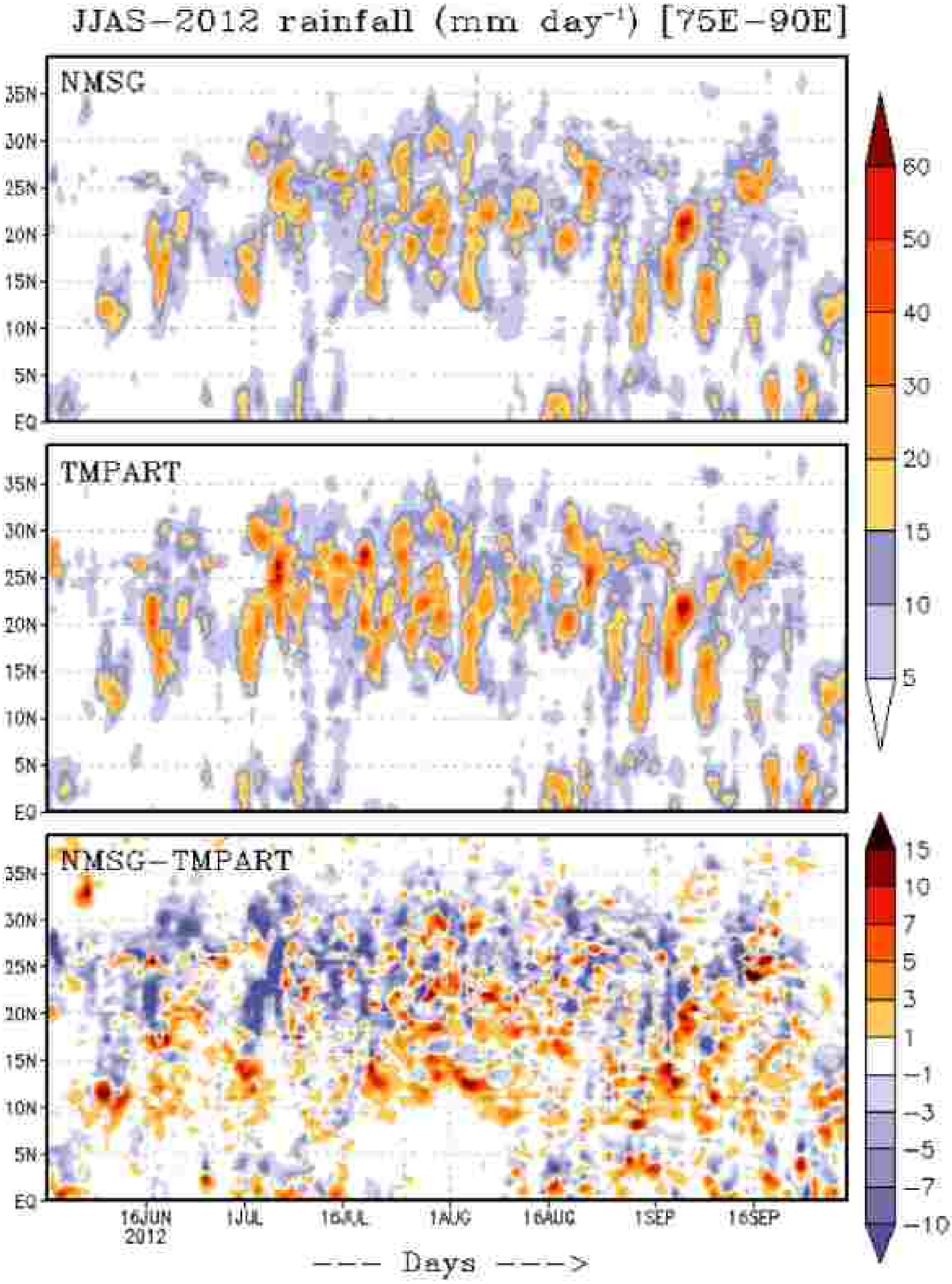

Fig.3(b) Same as figure 3(a), but for monsoon 2013 season.

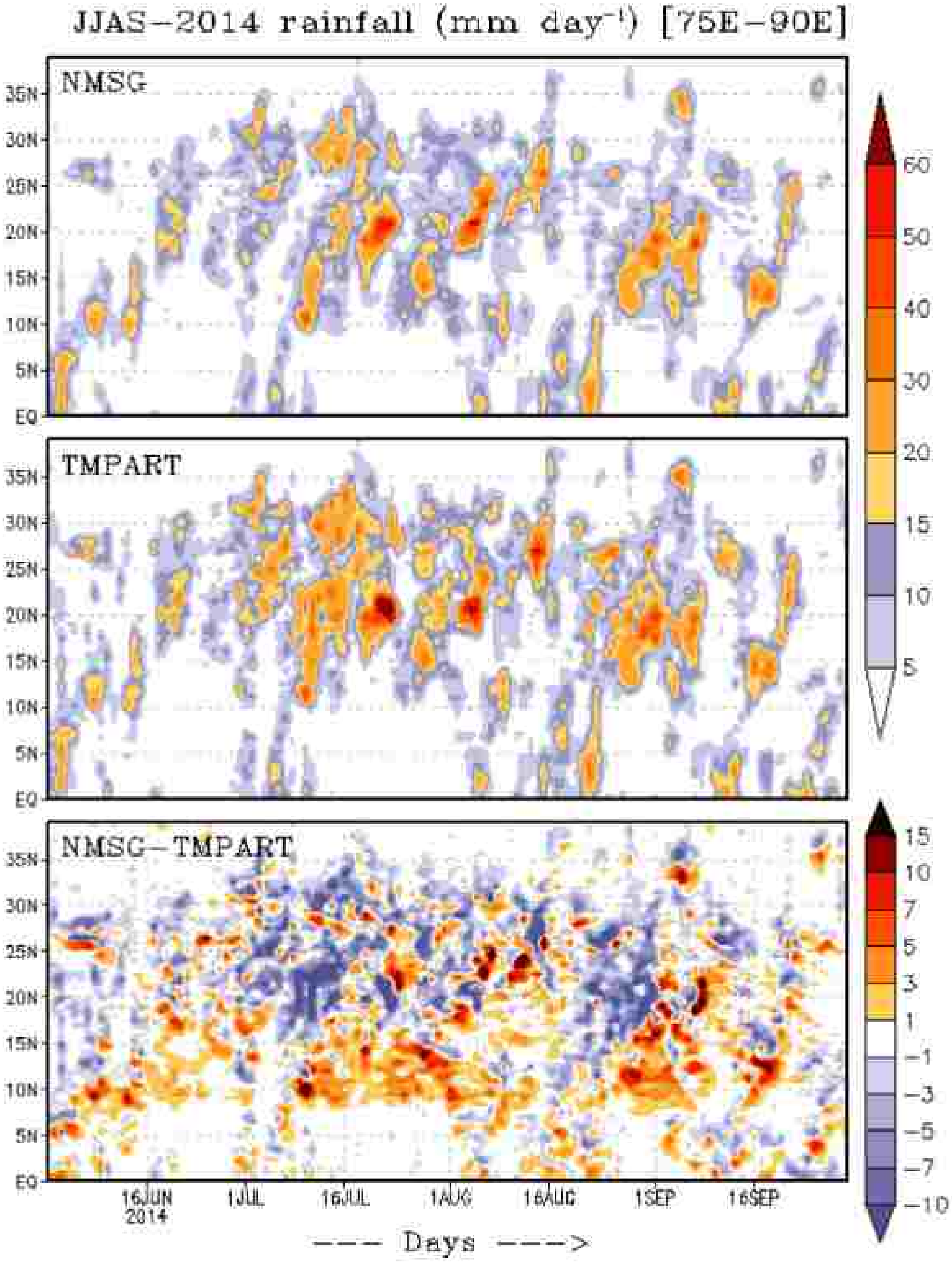

Fig.3(c) Same as figure 3(a), but for monsoon 2014 season.

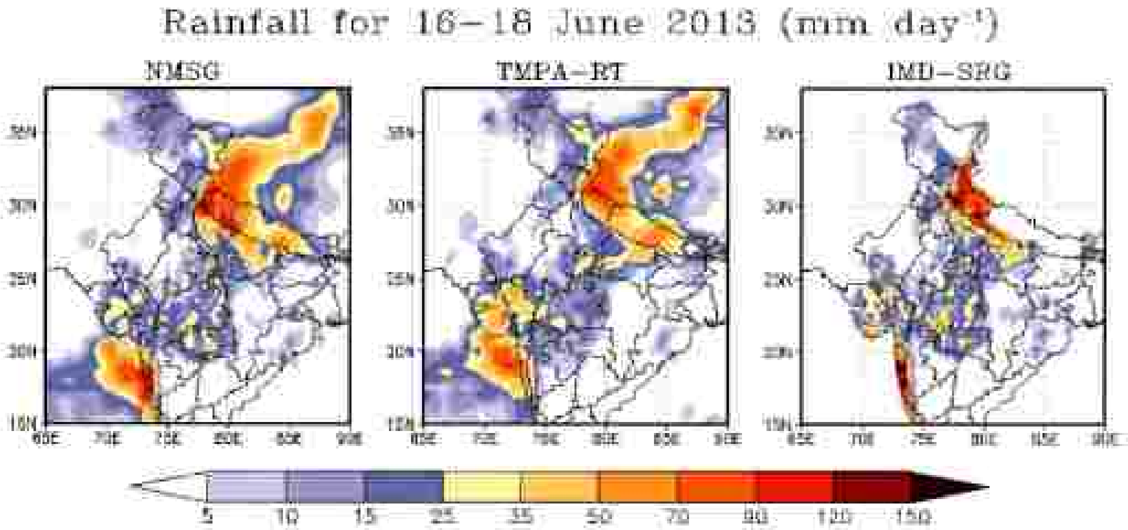

Fig.4(a) Total observed rainfall from merged product, TRMM and Gauge based analysis during a high impact weather system - Uttarakhand June 2013 case.

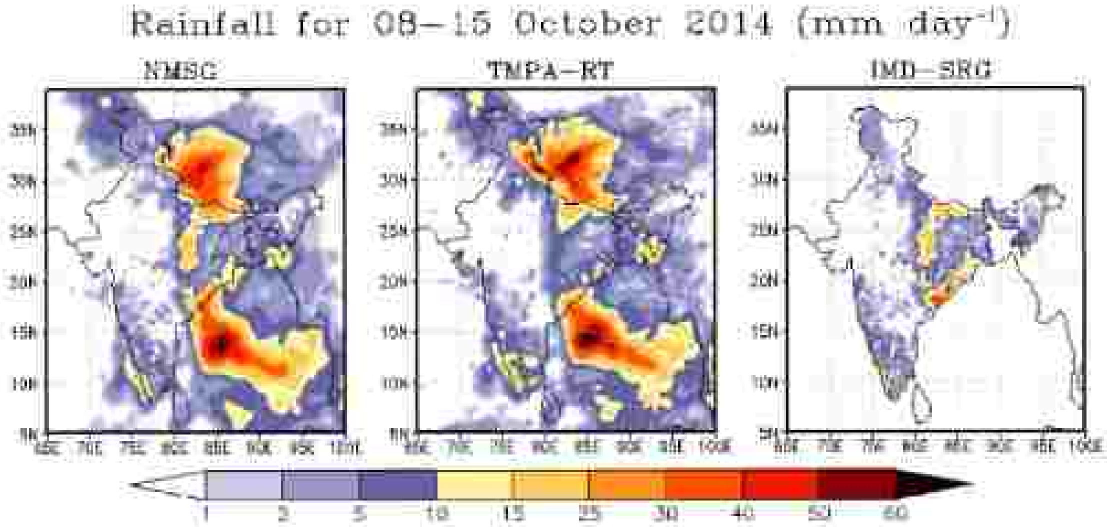

Fig.4(b) Same as figure 4(a), but for Jammu and Kashmir September 2014 case.

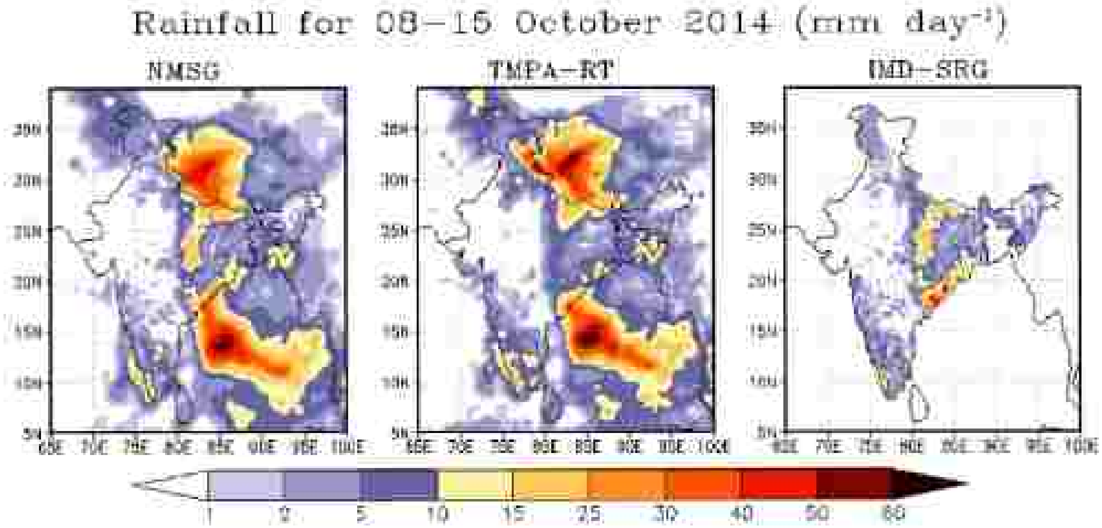

Fig.4(c) Same as figure 4(a), but for October 2014 'Hudhud' Cyclone case in Bay of Bengal.

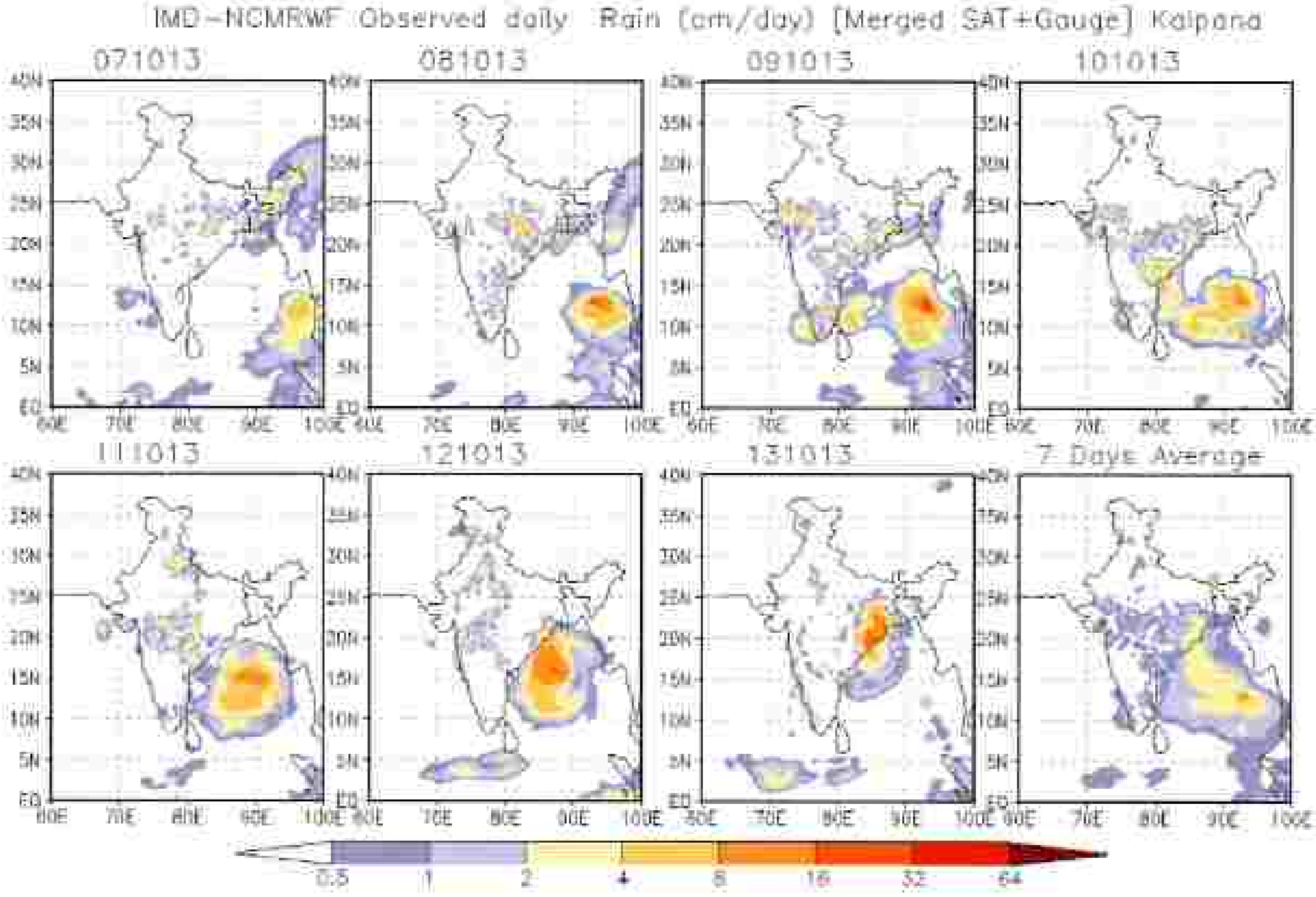

Fig.5 Real-time operational merged rainfall monitoring during very severe cyclonic storm PHAILIN in October 2013.

Due to technical reasons on rare occasions the TRMM data were not available in real-time via ftp. One of such occasion was during October 2013 when a very severe cyclonic storm PHAILIN in Bay of Bengal struck eastern part of India. At that time due to US shutdown TRMM data were not available in real-time and monitoring the cyclone-related rainfall on daily basis was very crucial. At that time the IR-based rainfall estimates from INSAT/ KALPANA was used as a first guess in place of TRMM-RT data and we found the products very useful (Figure 5). Later in archived data this merged data product were replaced with final product using TMPA-RT after the event in reanalysis.

4. Summary and Plans

The merged rainfall data of IMD are combining the best information from satellite over ocean and gauges over land regions. The daily merged dataset is able to capture the large-scale rainfall features of monsoon and is very useful for numerical monsoon model validation and in turn for monsoon model development related research and development. It is able to depict the rainfall associated with severe weather systems adequately. Currently the merged rainfall analysis in real-time is carried out at 0.5° latitude/longitude resolution. As the number of gauges will increase, the resolution of the merged analysis system will be upgraded to 0.25o latitude/longitude resolution. Large number of AWS and ARG data after suitable quality control has to be used optimally in this merged analysis system. Many ocean-based rainfall data from buoy, ships and other sources have also to be used. Oceanic rainfall is estimated from satellite observations, but the values are subject to significant uncertainties due to the scarcity of calibrating observations and the physical limitations involved. This is also true for difficult and unpopulated regions like mountains. Special efforts are required to calibrate the satellite estimates for these difficult and complex rainfall regimes. The life of current satellite TRMM is supposed to be over and it will be phased out any time shortly. There is a brand new project named 'Global Precipitation Mission' (GPM) which will soon be providing higher quality multi-satellite rainfall estimates in real-time (Hou et al., 2014). The current merged satellite-based algorithm will switch over to this GPM based product to be used as the first guess in place of TRMM. Our INSAT-3D based rainfall estimates have to be evaluated and could be used as a backup data for satellite estimates. Efforts at SAC/ISRO to improve rainfall estimates from current and upcoming satellites will also be useful in this work. There is a plan from GPM project to re-estimate the TRMM-era data (starting 1998) to be derived again using GPM algorithm. Hence, the daily merged products have to be reanalysed to produce updated high quality daily data from 1998 onwards for research and model development purposes. The use of radar to provide rainfall estimates is becoming more attractive. In India also the number of radars from various organisations is gradually increasing. However, while radars give very good spatial representations of rainfall, they tend to underestimate rainfall when compared to rain gauges for some selected areas. To improve the accuracy of radar estimates, they are usually adjusted by comparing the radar and rain gauge estimates. These calibration and validation of radar rainfall with gauges for varying rainfall intensities is an import work to be completed for Indian region, so that the radar data could be used in merged gridded products in real-time in future.

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