

AN INTER-COMPARISON OF SATELLITE BASED NOAA CPC RAINFALL ESTIMATES AND GAUGE OBSERVATIONS OVER SELECTED STATIONS IN INDIA

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ABSTRACT:

The spatial application of crop simulation models need grid based spatially distributed input of rainfall. The global products of satellite based rainfall estimation can provide spatial maps on regular time basis and can be used as an input to crop models. An attempt has been made to validate the satellite derived NOAA CPC rainfall estimation with ground based measurements for year 2003 and 2004 over 53 stations of India Meteorological Department (IMD) in India on daily, 5-day (pentad), weekly, 10-day (dekalal), monthly and seasonal scales. The mean bias between NOAA CPC estimated rainfall and IMD observed rainfall were 3.0, 3.9, 5.8, 10.6 and 50.5 mm over mean observed rainfall of 19.8, 31.2, 40.0, 128.8 and 1106.8 mm for pentad, weekly, dekalal, monthly and seasonal totals, respectively. The satellite estimates showed Willmott's index of agreement ranged from 0.91 to 0.97 and correlation coefficient from 0.84 to 0.94 for pentad to seasonal composites with the measured rainfall in plain areas. The percentage mean bias reduced from 15.2 to 4.5 per cent as period of comparison increased from pentad to season. The mean bias is below 5 mm for rainfall estimates upto 100 mm while it increases upto 25 –30 mm for rainfall estimates from 100-200 mm and above. For weekly estimates, the mean absolute error and root mean square error observed with 1:1 line were 15.0 mm and 30.2 mm, respectively. The estimates are very close to seasonal totals of observed rainfall for most of the stations except stations having altitudes greater than 500 m.

1. INTRODUCTION

Monitoring of crop growth and its yield is important in planning and management of agricultural resources. The process based crop simulation models are in wide use to predict the crop yield and crop growth due to their better stability over empirical models. In the last decade, point based simulation models were adapted for regional crop growth monitoring and predicting regional crop yield. Adaptation of the point-based model to spatial grids requires spatial inputs. Rainfall is a very dynamic weather variable and need high volume of closely distributed and timely reporting rain-gauge stations for accurate interpolation. The spatial run of crop simulation models need grid based spatially distributed input of rainfall, however, there is a lack of timely availability of rainfall datasets over India.

In the last two decades, there has been a great deal of research on methods for estimating rainfall using multi-satellite (geostationary and polar-orbiting) and multi-sensor observations in infrared and microwave regions. As a result there are now several algorithms running operationally and semi-operational from national centers and universities to produce rainfall estimates for time periods ranging from half-hourly to monthly. The NOAA/Climate Prediction Center's (NOAA CPC) Famine Early Warning System (FEWS) NET provides daily rainfall estimates (Herman et.al. 1997, Xie and Arkin, 1996 and Xie et al. 2002) at 0.1 x 0.1 degree grid. There are other global precipitation products available based on different algorithms like the NASA Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis Real Time - MPA-RT, 3B-42RT produced at 3 – hour basis with a spatial resolution of 0.25° grid (Huffman et al. 2002, 2003) and the CPC Morphing – CMORPH produced at every half-hour which the CPC/FEWS-NET group converts into daily at 8 km spatial

resolution (Joyce et al., 2004), GOES Multi-spectral Rainfall Algorithm – GMSRA (Ba and Gruber, 2001) etc.

The advantage of space-based precipitation estimates is their global coverage, providing information on rainfall frequency and intensity in regions that are inaccessible to conventional observing systems such as rain gauges. The disadvantage is that they are indirect estimates of rainfall, depending on the properties of the cloud top (in the case of infrared algorithms) and cloud liquid and ice content (in the case of passive microwave algorithms). It is therefore important to get an idea of their accuracy in a region of interest, although, the precipitation estimates were validated against rain gauge and radar observations, globally.

This paper describes the results of the study that was carried out with the objectives: 1). to validate the satellite derived NOAA CPC rainfall estimation with ground-based measurements and 2). to find out the best minimum composite period for which the estimates have good accuracies and can be used for the model.

2. MATERIALS AND METHODS

2.1 NOAA CPC Rainfall

The NOAA/CPC RFE is operationally available since May 2001 as global product for southern Asia area (70.0-110.0 degree E; 5.0-35.0 degree N) with temporal domain 00-00 hour eastern area local mean time. Its aerial extent covers mostly whole India and surrounding southeastern countries. The NOAA/CPC rainfall estimates are derived using satellite observations from passive microwave instruments, like Advanced Microwave Sounding Unit (AMSU), and the Special

Sensor Microwave/Imager (SSM/I), infrared cloud top temperature measurements from the Meteorological Satellites (Meteosat 5 & 7), and daily rainfall gauge data from up to 1000 Global Telecommunications System (GTS) stations. The 3-hour polar-orbiting microwave measurements and half-hour geo-stationary infrared satellite precipitation estimates are combined using linear interpolation and merged with gridded rainfall gauge measurements using predetermined weighing functions to create the RFE product (Xie, 2001).

The RFE algorithm provides 24-hour rainfall accumulations on a horizontal scale of 0.1 x 0.1 degree. Here, Daily rainfall accumulations are combined to compute data sets of pentad, weekly, dekad, monthly and seasonal totals. An example of the RFE product is shown in Figure 1, over Indian sub-continent. The data are located on the NOAA/CPC ftp server:

<ftp://ftpprd.ncep.noaa.gov/pub/cpc/fews/S.Asia/data/>

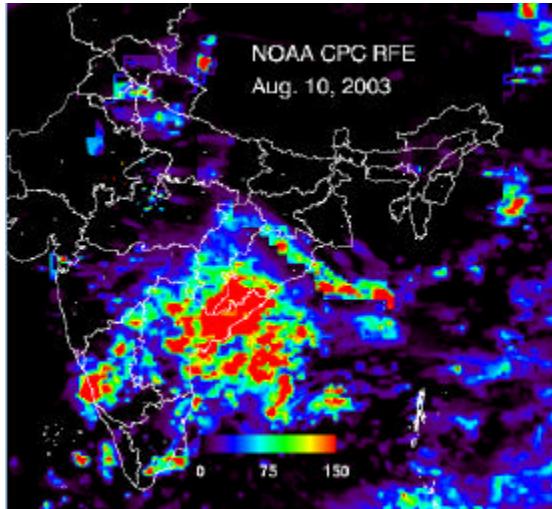


Figure 1. An example of rainfall estimation (mm) over South Asian sub continent August 10, 2003 using RFE v 2.0.

2.2 Gauge Observations

For the years 2003 and 2004, the gauge observations measured daily at 08:30 hour IST available from India Meteorological Department (IMD) for 53 stations well spread over India were acquired. The daily data were converted into pentad, weekly, dekad, monthly and seasonal totals for inter-comparison with satellite derived NOAA CPC rainfall.

2.3 Inter-comparison Procedure

All the daily satellite derived rainfall estimates were stacked together for 365 days of the year. The point regions of interest (ROI) of rain-gauge stations were created from the corresponding locations based on geographic co-ordinates and overlaid on the 0.1o grid map of rainfall estimates. The rainfall estimates from the corresponding grids belonging to the ground stations were extracted.

The “spatial” rainfall estimates of NOAA CPC at 0.1 degree grid were compared with the “point” observations of IMD rainfall. There is temporal gap between point observations with recording time daily at 08:30 hour IST and spatial estimates with mid-night to mid-night integration time. Therefore, to

minimize the effect of spatial and temporal discrepancies and to find out the best minimum period of composite having minimum errors, the pentad, weekly, dekad, monthly and seasonal (June to September, as per Indian south-west monsoon) totals of CPC RFE at 0.1-degree grid were compared with the corresponding totals of point measurements of IMD gauge observations. As the algorithm has not taken the effects of orography, the stations having altitude greater than 750 m were discarded for detailed analysis. The mean bias, mean absolute errors (MAE) and Willmott's index of agreement “D” (Willmott, 1982) were computed (Equation 1 & 2). The error analysis was made for periodic totals as well as different categories of rainfall amounts viz. 1-50 mm, 51-100 mm, 100-200 mm and more than 200 mm.

$$MAE = \frac{\sum(|E - O|)}{N} \quad (1)$$

$$D = 1 - \frac{\sum(E - O)^2}{\sum(|E - \bar{O}| + |O - \bar{O}|)^2} \quad (2)$$

Where
 O = gauge observed rainfall
 E = estimated NOAA CPC rainfall
 N = numbers of observations.
 \bar{O} = mean observed rainfall

3. RESULTS AND DISCUSSION

3.1 Comparison of Periodic Totals

The NOAA CPC rainfall estimates of different periodic totals viz. pentad, dekad, monthly and seasonal were compared with the corresponding totals of IMD gauge observations. The results of comparison for each period are summarized in Table 1.

Period	Mean Observed Rainfall (mm)	Mean Bias (mm)	MAE (mm)	RMSE (mm)	Corr. Coef. r	D
Pentad	19.8	3.0	10.8	23.9	0.84	0.91
Weekly	31.2	3.9	15.0	30.2	0.89	0.94
Dekadal	40.0	5.8	16.1	33.3	0.91	0.95
Monthly	128.8	10.6	43.9	74.9	0.92	0.96
Seasonal	1106.8	50.5	168.9	203.0	0.94	0.97
Dekadal (Hilly Stations)	71.4	-29.5	47.4	105.5	0.62	0.63

Table 1. Inter-comparison of periodic mean observed rainfall, errors of satellite estimates, correlation coefficient (r) and Willmott's index of agreement (D)

Table 1 reveals consistent positive bias in the satellite estimates at all the periodic totals except the stations having altitudes greater than 750 m (Here called “Hilly Stations”). The satellite estimates over hilly stations showed under estimation of 29.5 mm (41.3 per cent) with poor correlations of 0.62. It is obvious because the spatial composite of rainfall estimates at approximately 100 sq. km were compared with the point-based

gauge observations. The mean bias between NOAA CPC estimated rainfall and IMD observed rainfall were 3.0, 3.9, 5.8, 10.6 and 50.5 mm over mean observed rainfall of 19.8, 31.2, 40.0, 128.8 and 1106.8 mm for pentad, weekly, dekad, monthly and seasonal totals, respectively. Janowiak et al. (2003) validated NOAA CPC rainfall and found similar positive bias in United States. The “rediscovery” of this positive bias is consistent with the earlier studies of Scofield (1987), Rosenfeld and Mintz (1988) and more recently McCollum et al. (2001) who found that significant evaporation occurs in semi-arid regions between the cloud base and surface. In fact, Rosenfeld and Mintz estimate conservatively that 30 per cent of the rainfall evaporates in the first 1.6 km below the cloud base in semi-arid regions at rainfall intensities as high as 80 mm h⁻¹.

The percentage mean bias reduced from 15.2 to 4.5 as period of comparison increased from pentad to season. The correlation coefficient (*r*) and Willmott's index of agreement “D” ranged from 0.84 to 0.94 and 0.91 to 0.97 for pentad to seasonal comparisons. Although, accuracies improves as one can go on compositing from pentad to seasonal, it was also observed that *r* does not improve much from weekly to dekad and dekad to monthly totals which shows that all the spatial and temporal discrepancies gets minimized with the weekly composites (Table 1). The weekly composites of satellite based NOAA CPC estimates can be used as an input to crop simulation models.

An example of plot of satellite estimates against gauge observations for the weekly rainfall composites is shown in Figure 2. Satellite estimate showed a good correlation (*r* = 0.89) and Willmott's index of agreement (D = 0.94) with the

measured rainfall in plain areas. NOAA CPC estimated weekly rainfall showed overall mean bias of 3.9 mm over IMD observed mean dekad rainfall of 31.2 mm. The mean absolute error and root mean square error observed with 1:1 line were 15.0 and 30.2 mm, respectively.

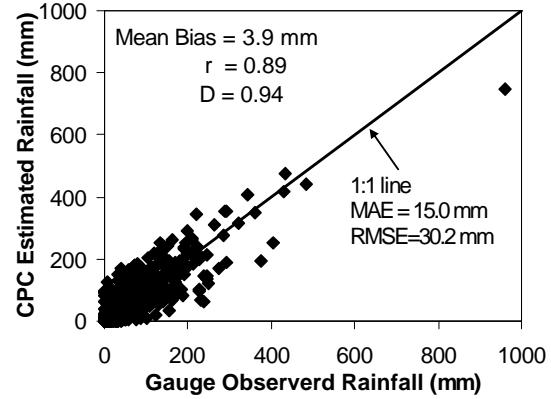


Figure 2. Comparison of weekly NOAA CPC rainfall estimates with weekly totals of IMD gauge observations

Figure 3a to 3d shows few examples of comparison of dekad rainfall at individual stations. The stations selected to show here represents different climatic situations like Mumbai on west-coast and Chennai on the east coast of Indian peninsular sub-continent while Bhopal and Patna are interior and far away from sea coast with 523 m and 51 m altitude from mean sea level (MSL), respectively.

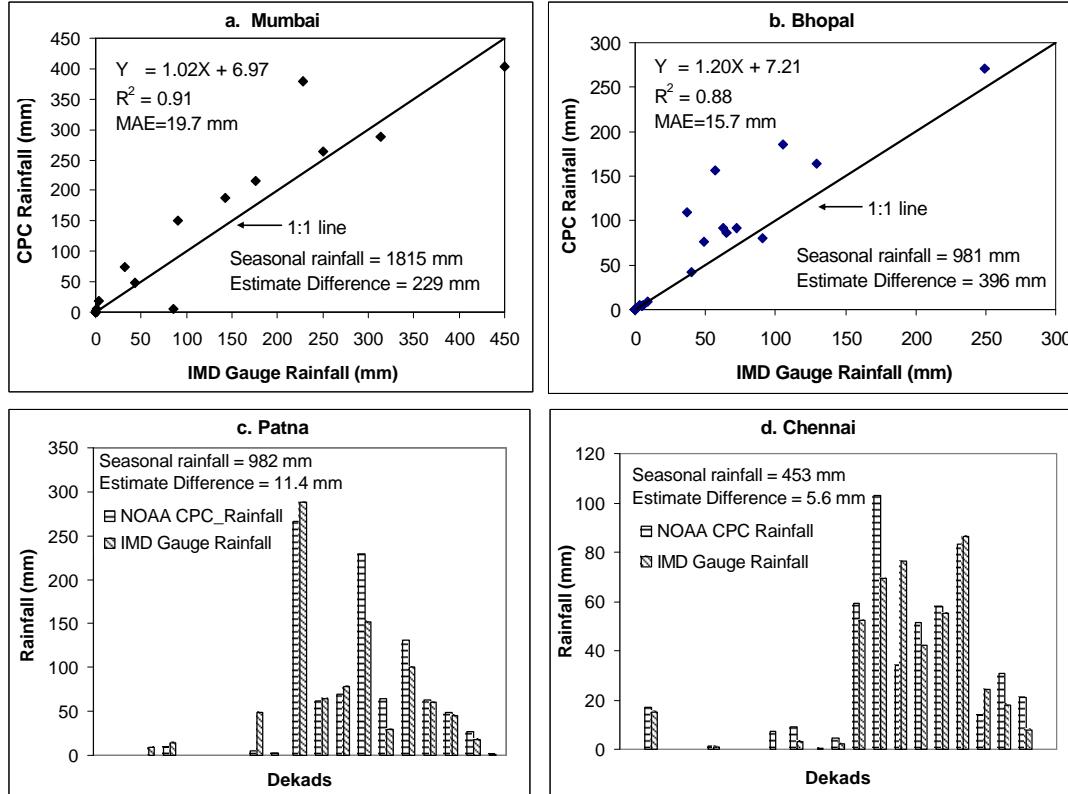


Figure 3. Comparison of NOAA CPC rainfall with gauge observations at few selected station

The comparison of satellite estimates with gauge observations, showed MAE of about 19.7 mm and 15.7 mm for Mumbai and Bhopal (figure 3a & 3b) which is more or less similar to the overall MAE showed for all stations (Table 1). Bhopal showed about 20 per cent over estimates of CPC dekadal rainfall and 40 per cent over seasonal rainfall as compared to gauge observations which may be due to the higher altitude i.e. 523 m from MSL, and CPC algorithm does not take into account the orographic effect (NOAA CPC, 2003). The high differences at hilly stations could be also due to scale difference spatially i.e. spatial product of RFE at 0.1 x 0.1 degree grid was compared with the point observation of rain-gauge data.

The estimates are very close to seasonal total observed rainfall for most of the stations. The error observed with seasonal total rainfall is very less i.e. within 10 per cent of the seasonal observed rainfall for most of the station. Figures 3a to 3d shows differences between satellite derived rainfall and observed rainfall for few selected stations at seasonal scale. The difference is within 10 per cent of the seasonal observed rainfall for Mumbai, Chennai and Patna stations which are having lower altitudes but it was about 40 per cent overestimated for Bhopal which is having high altitude.

From the above results, it is clear that the CPC RFE v. 2.0 algorithm is able to estimate rainfall within 10 per cent accuracy of seasonal rainfall for the plain areas. The algorithm needs altitude related corrections to predict the rainfall for the places having higher altitudes.

Though, there were more than 100 mm difference between estimated and observed rainfall for one or two dekads, the seasonal rainfall varied only 11.4 and 41 mm for Patna and Chennai stations, respectively (Figure 3c and 3d). The dekadal distribution of rainfall for individual stations shows that over/ under estimation in a dekad gets compensated by under/ over estimation in another dekad. The difference in dekadal rainfall could be due the difference in integration time of RFE i.e. at mid-night to mid-night and recording time of gauge observations i.e. at 8:30 am IST.

3.2 Error Comparisons for Rainfall Amount Categories

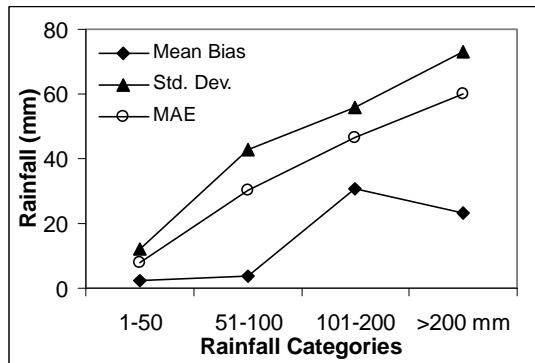


Figure 4. Error analysis at different rainfall categories

The comparison of errors in satellite based rainfall estimates in terms of mean bias, MAE and standard deviation (RMSE) as compared to gauge observations for different rainfall amount categories is shown in Figure 4. The mean bias observed were

2.4 mm and 3.6 mm (less than 5 mm) for rainfall categories 1-50 mm and 51-100 mm, respectively while it was 25 – 30 mm for than 100 mm rainfall categories. The MAE and standard deviations were less than 10 mm for 1-50 mm category while both increase with higher rainfall categories.

Laws et al. (2004) had also observed mean bias of 4 mm and RMSE of 21-25 mm for the category of 21-50 mm rainfall with similar algorithm while 11-12 mm overestimates for MPA_RT and CMORPH products. He also observed standard deviations more than 40 mm for rainfall categories of more than 50 mm.

4. CONCLUSIONS

The study carried out to validate the satellite derived NOAA CPC rainfall estimation with ground-based measurements showed the promising results for weekly to seasonal comparisons. The satellite estimates showed Willmott's index of agreement ranged from 0.91 to 0.97 and correlation coefficient from 0.84 to 0.94 for pentad to seasonal composites with the measured rainfall in plain areas. Weekly composites period seems to be the best minimum period having good accuracies of NOAA CPC rainfall estimates, showed overall mean bias of 3.9 mm over IMD observed mean weekly rainfall of 31.2 mm. The mean absolute error and root mean square error observed with 1:1 line were 15.0 mm and 30.2 mm, respectively. The study showed that satellite based spatial maps of weekly rainfall estimates can be used as an input to crop simulation model for the plain areas. The mean bias is below 5 mm for rainfall estimates upto 100 mm while it increases upto 25 – 30 mm for rainfall estimates from 100-200 mm and above. Although, there was significant difference in dekadal estimates, the estimates were very close to seasonal total observed rainfall for most of the stations. The estimates performed poor for the stations having altitudes greater than 500 m as it was spatial to point comparison.

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