

Performance evaluation of precipitation prediction skill of NCEP Global Forecasting System (GFS) over Indian region during summer monsoon 2008

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सार – इस शोध पत्र में भारतीय ग्रीष्मकालीन मानसून वर्षा ऋतु 2008 के दौरान एक दिन से पाँच दिन तक के एन. सी. ई. पी. जी. एफ. एस. की वर्तमान स्तर के कौशल को संक्षिप्त और संश्लेषित रूप में अभिलेखित किया गया है। इसमें वर्षा मापी प्रेक्षकों के लिए गए दैनिक वर्षा विश्लेषण और उपग्रह (कल्पना-1) का उपयोग करते हुए मात्रात्मक वर्षण आकलनों की परस्पर तुलना विस्तार से की गई है। एक दिन से पाँच दिनों तक के 24 घंटों की संचित वर्षा के पूर्वानुमानों के निदर्श के निष्पादन का मूल्यांकन सटिकता और कौशल के परिप्रेक्ष्य में किया गया है। पूर्वानुमान गुणवत्ता और विभव मान प्रभावित डाटा सेट, भूगोलिक क्षेत्रों और वर्षण पर बहुत अधिक निर्भर करती है। निदर्श द्वारा वर्षण पूर्वानुमान जब पूरे मौसम के लिए एकत्रित किए जाते हैं तो प्रेक्षित पैटर्न को पुनः व्युत्पन्न करते हैं। हालाँकि इस मौसम के दौरान देश के अधिकाँश भागों में प्रेषित वर्षा की अपेक्षा निदर्श द्वारा प्रागुक्त की गई वर्षा अपेक्षाकृत अधिक है। यह निदर्श समूचे भारत और भारत के चार व्यापक समरूपी क्षेत्रों में भी प्रतिदिन की और सभी माध्य वर्षा काफी कौशल दर्शाते हैं। निदर्श के आधार पर वर्षण पूर्वानुमान एक दिन के पूर्वानुमान को छोड़कर 25 मि. मी./दिन पर अधिक आकलन से कम आकलन के वर्षा पूर्वानुमान में परिवर्तित हो जाते हैं। 10 मि. मी./दिन की अपेक्षा वर्षा की घटना के लिए निदर्श कौशल प्रभावशाली होता है। इसका अर्थ यह हुआ कि चरम मानों के परिमाण और स्थान का पूर्वानुमान करने की अपेक्षा यह निदर्श वर्षा के होने का पूर्वानुमान अधिक अच्छा करता है। मानसून 2008 के लिए एन. सी. ई. पी. जी. एफ. एस. मॉडल वर्षा पूर्वानुमान के लिए विभिन्न स्किल स्कोर और वर्गीकृत सांख्यिकीय तैयार किए गए और उनका विवेचन किया गया।

ABSTRACT. The study provides a concise and synthesized documentation of the current level of skill of the NCEP GFS day-1 to day-5 precipitation forecasts during Indian summer monsoon of 2008, making detailed inter-comparison with daily rainfall analysis from the use of rain gauge observations and satellite (KALPANA-1) derived Quantitative Precipitation Estimates (QPE) obtained from IMD. Model performance is evaluated for day-1 to day-5 forecasts of 24-hr accumulated precipitation in terms of several accuracy and skill measures. Forecast quality and potential value are found to depend strongly on the verification dataset, geographic region and precipitation threshold. Precipitation forecasts of the model, when accumulated over the whole season, reproduce the observed pattern. However, the model predicted rainfall is comparatively higher than the observed rainfall over most parts of the country during the season. The model showed considerable skill in predicting the daily and seasonal mean rainfall over all India and also over four broad homogeneous regions of India. The model bias for rainfall prediction changes from overestimation to underestimation at the threshold of 25 mm/day except for day-1 forecast. Model skill falls dramatically for occurrence rainfall thresholds greater than 10 mm/day. This implies that the model is much better at predicting the occurrence of rainfall than they are at predicting the magnitude and location of the peak values. Various skill score and categorical statistics for the NCEP GFS model rainfall forecast for monsoon 2008 are prepared and discussed.

Key words – GFS, NWP, Global model, Rainfall analysis, QPE, Indian summer monsoon, Rainfall prediction skill.

1. Introduction

The summer monsoon season is meteorologically most important for India because more than 80% of the land area gets about 90% of its annual precipitation during this period. In India, where rainfall is seasonal and the agriculture is mostly rainfall dependent for planning its

day-to-day operations. The main crops, *i.e.*, rice, maize are cultivated during this season. Therefore, monsoon season (June - September) is the most suitable period for verification of the model-produced quantitative precipitation forecasts. Verification is an indispensable part of meteorological research and operational forecasting activities. If the methodology is properly

designed, verification results can effectively meet the needs of many diverse groups, including modellers, forecasters, and users of forecast information. It can be used to direct research, to determine where research funding is most needed, to check that forecasts are improving with time, to help operational modelling centers for model upgrades. One of the most critical issues in modeling the global atmosphere by Atmospheric General Circulation Models (AGCMs) is the simulation and initialization of precipitation processes.

The Global Forecasting System (GFS) is a primitive equation spectral global model with state of art dynamics and physics (Kanamitsu 1989; Kalnay *et al.*, 1990 and Kanamitsu *et al.* 1991). More details about the global forecast model (GFS) are available at <http://www.emc.ncep.noaa.gov/gmb/moorthi/gam.html> and the recent modifications to the GFS is model is also available at http://www.emc.ncep.noaa.gov/gmb/STATS/html/model_changes.html. This GFS model is run four times (0000, 0600, 1200, 1800 UTC) daily in real time operational mode at the National Center for Environmental Prediction (NCEP), USA and its outputs are available to the user community through ftp server. Many operational weather forecasting Agencies around the world started using the GFS model output for real time weather forecast. India Meteorological Department (IMD) is using the GFS model precipitation forecast in medium range for day to day operational district level weather forecast. So, it is very important to know the performance skill of the GFS precipitation forecasts over India during rainy seasons (south west monsoon period).

The main objective of this study is to investigate the precipitation forecast skill scores of the GFS model in the medium range (day-1 to day-5 forecast) during Indian summer monsoon season of 2008. Performance statistics for the precipitation forecast of many NWP models have been documented by various authors Mc Bride and Ebert, (2000) & Doswell *et al.*, (1990), etc.

2. Data and methodology

In this study verification were carried out for the GFS model run at 0000 UTC against daily rainfall analysis at the same resolution ($1^\circ \times 1^\circ$) based on rain gauge observations and satellite (KALPANA-1) derived quantitative precipitation estimates (QPE) (Roy Bhowmik and Das, 2007) obtained from India Meteorological Department (IMD), to diagnose the performance of the summer monsoon with respect to rainfall activity over monsoon regions of India. To compare with the model precipitation prediction, the observed precipitation amounts are averaged over the areas covered by the grid points of the model. The temporal and spatial distribution

TABLE 1

Rain contingency table applied at each grid point

Observed	Predicted	
	Rain	No Rain
Rain	H	M
No Rain	F	Z

Here, Z is the number of correct predictions of rain amount below the specified threshold, F is the number of false alarms, M is the number of misses, and H is the number of correct rain forecasts

of observed and model predicted day-1 to day-5 precipitation has been studied. Direct comparison can be made of accumulated values of seasonal rainfall, mean values of daily rain rate and seasonal mean error. Also, area averages have been computed to verify the model forecasts of precipitation over four broad homogeneous monsoon regions of India and the whole Indian land area. The four representative regions over Indian land, *i.e.*, North-West India (Lat. 24° N - 36° N; Long. 70° E - 83° E), North-East India (Lat. 22° N - 29° N; Long. 83° E - 96° E), Central India (Lat. 17.5° N - 24° N; Long. 70° E - 85.5° E) and South Peninsular India (Lat. 08° N - 17.5° N; Long. 73° E - 83° E) are chosen based on the consideration that daily variability of rain is more or less spatially uniform within each of these regions (Goswami *et al.*, 2006). Model performance is evaluated for day-1 to day-5 forecasts of 24-hr accumulated precipitation over Indian monsoon region by calculating simple point by point comparisons like mean error, root mean square error and coefficient of anomaly correlation and linear correlation between forecast and analysis. For computation of anomaly correlation coefficient, observed climatology on the basis of $1^\circ \times 1^\circ$ gridded daily rainfall dataset (Rajeevan *et al.*, 2005) based on rain gauge measurements from 1803 stations over Indian land for the period 1951-2003 from IMD is used.

In addition to these simple measures a number of categorical statistics are applied. The term categorical refers to the yes/no nature of the forecast verification at each grid point. Some threshold (*i.e.*, 0.1, 1, 2, 5, 10, 15, ...35, ...65 mm day⁻¹) is considered to define the transition between a rain *versus* no-rain event. Then at each grid point, each verification time is scored as falling under one of the four categories of correct no-rain forecasts (Z), false alarms (F), misses (M), or hits (H) as shown in the contingency Table 1.

A number of categorical statistics skill measures are used, computed from the elements of this rain/no-rain contingency table.

They include bias score (bias):

$$BS = \frac{F + H}{M + H} \quad (1)$$

The bias score is equal to the number of rain forecasts divided by the total number of observations of rain. Thus, the bias score is a measure of the relative frequency of rain forecasts compared with observations.

Threat score (critical success index):

$$TS = \frac{H}{H + M + F} \quad (2)$$

The Threat Score (TS) measures the fraction of observed and/or forecast events that were correctly predicted.

Equitable threat score (Gilbert skill score)

$$ETS = \frac{H - H_{\text{random}}}{H + M + F - H_{\text{random}}}$$

Where,

$$H_{\text{random}} = \frac{(H + M)(H + F)}{\text{Total}} \quad (3)$$

The Equitable Threat Score (ETS) measures the fraction of observed and/or forecast events that were correctly predicted, adjusted for hits associated with random chance. For example, it is easier to correctly forecast rain occurrence in a wet climate than in a dry climate.

In addition to above three score, probability of detection (POD) and false alarm ratio (FAR) could be generated easily by defining;

Probability of detection (POD)

$$POD = \frac{H}{H + M} \quad (4)$$

The Probability of Detection (POD) is equal to the number of hits divided by the total number of rain observations; thus it gives a simple measure of the proportion of rain events successfully forecast by the model.

False Alarm Ratio (FAR):

$$FAR = \frac{F}{H + F} \quad (5)$$

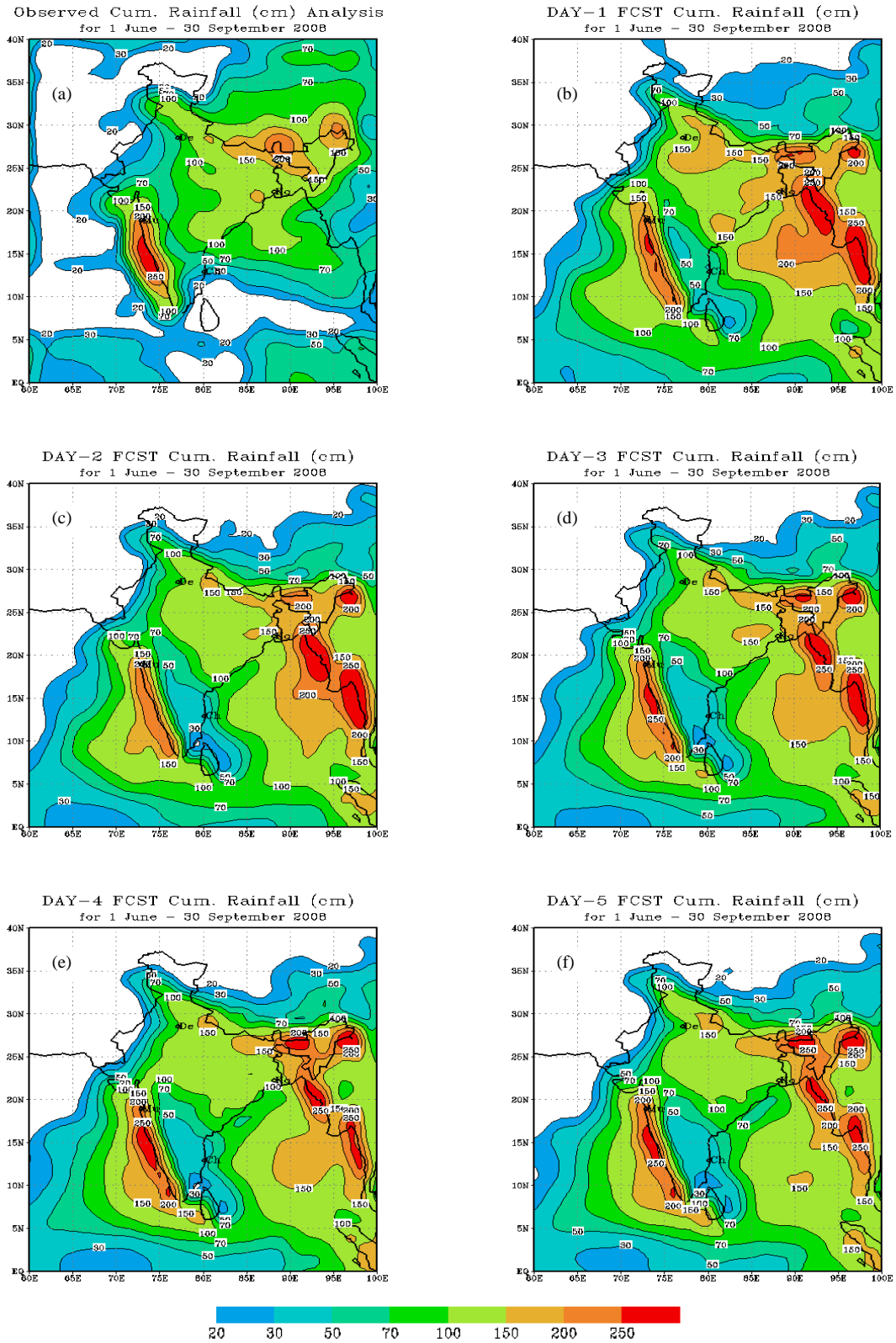
The false alarm ratio (FAR) is equal to the number of false alarms divided by the total number of times rain was forecast; thus it gives a simple proportional measure of the model's tendency to forecast rain where none was observed.

3. Result and discussions

3.1. Broad feature of Indian summer monsoon 2008

The seasonal (summer monsoon) rainfall pattern over India shows that large values of rainfall occur along the west coast and over the north-eastern parts of India where blocking effects of topography induce upward vertical velocity and enhance precipitation at the windward side and suppress precipitation in the lee side (Rao, 1976). The rain shadow due to the Western Ghats spreads over a large area of the Indian peninsular. The states in the northwest and southeast get the least amount of rainfall. The local scale features and passage of synoptic scale monsoon systems further modify this gross picture. There is an increase in daily rainfall at the beginning of the season that is coincident with the onset of the summer monsoon over the southern tip of India, and a gradual increase up to July when the whole of the country is under the influence of the summer monsoon circulation. The rainfall values decrease after August because the monsoon circulation starts withdrawing southward from the west and central parts of the country. The withdrawal process is complete over most of the country, except for the east coast of the extreme south, by the end of September. This general trend is, however, modulated by events of enhanced precipitation activity that are usually associated with one or more synoptic-scale weather systems, like low pressure areas of various intensity or extra tropical influence due to incursions of westerly troughs to the north of the country.

In the monsoon season of 2008, the cumulative seasonal rainfall for the country as a whole was near



Figs. 1(a-f). Spatial distribution of (a) observed and (b) – (f) model predicted cumulative rainfall (cm) based on NCEP GFS day-1 to day-5 forecasts for the period from 1 June to 30 September 2008

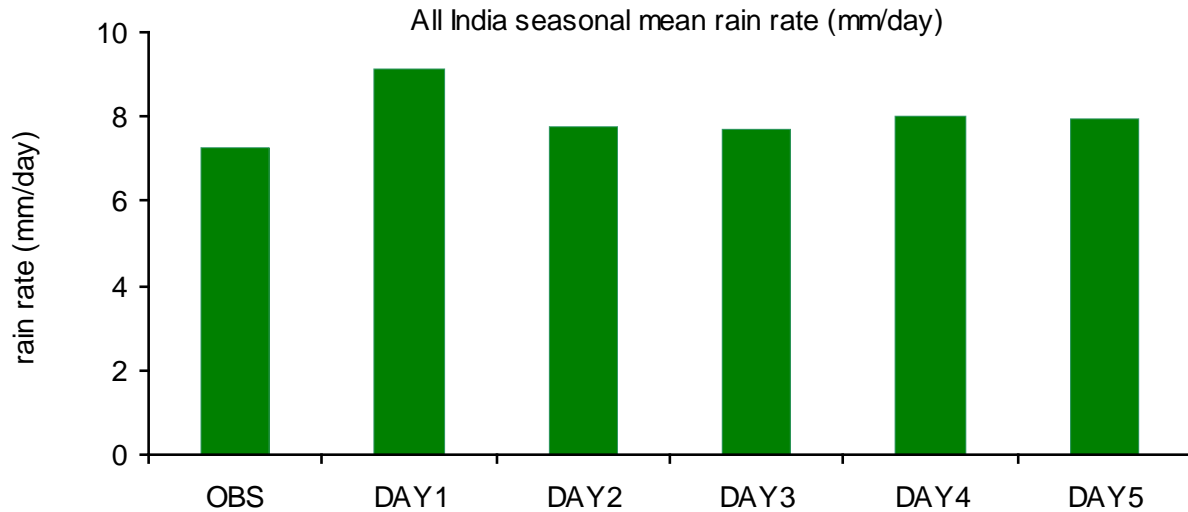


Fig. 2. Observed and model predicted All India seasonal (Jun-Sep) rain rate (mm/day) based on model day-1 to day-5 forecasts for the monsoon 2008

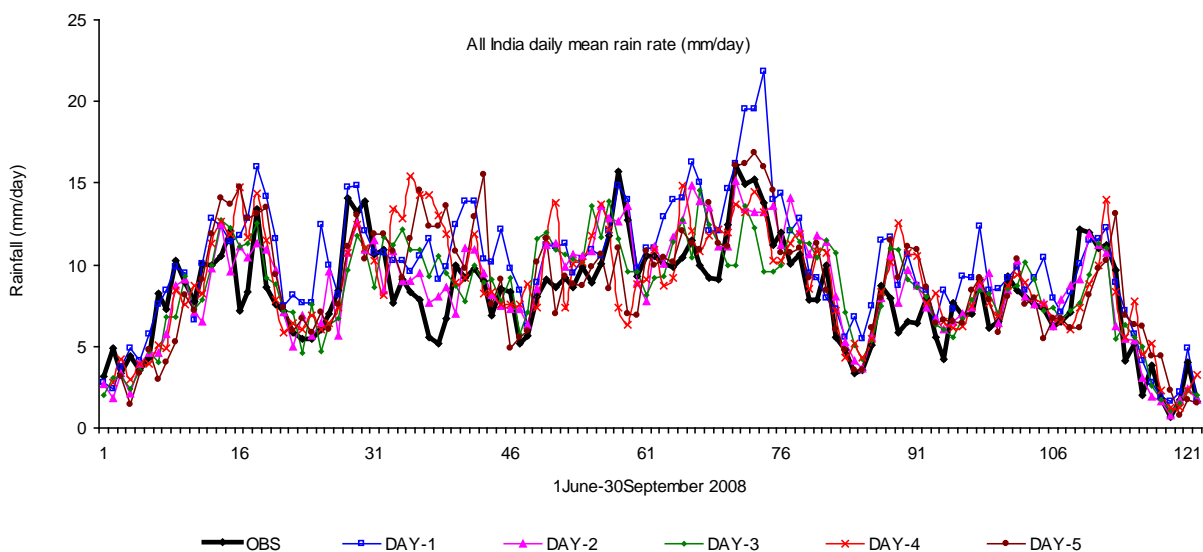


Fig. 3. Time series of daily country mean observed *versus* corresponding day-1 to day-5 rainfall (mm) forecasts by GFS model for the period from 1 June to 30 September 2008

normal and it was 98% of its long period average (IMD, 2008). The monsoon set in over Kerala on 31 May, one day prior to the normal date. Further, advance took place quite rapidly mainly due to a depression (5 - 6 June) over the east central Arabian Sea and a well marked low pressure area (9 - 11 June) over Saurashtra & Kutch and neighbourhood. By 16 June, southwest monsoon had covered most parts of the country except for some parts

of Rajasthan. The rapid advance of monsoon could be attributed to the interaction of the monsoon circulation with mid-latitude westerly system. Subsequently, there was a hiatus in the further advance due to the weakening of the monsoon current. The monsoon covered the entire country by 10 July, against normal date of 15 July. There was a delay in the commencement of withdrawal of southwest monsoon from extreme west Rajasthan. The

southwest monsoon withdrew this year from entire Jammu & Kashmir, Himachal Pradesh, Punjab, Haryana, Chandigarh & Delhi, west Rajasthan, most parts of Uttarakhand, west Uttar Pradesh and east Rajasthan, some parts of north Gujarat State and north Arabian Sea on 29th September. The normal date of withdrawal of southwest monsoon from west Rajasthan is 1 September. The delay was mainly due to the presence of systems in westerlies over northwest India interacting with the monsoon circulation.

3.2. Characteristics of observed and model predicted precipitation

We begin with a description of observed rainfall field for the Indian summer monsoon season (1 June - 30 September 2008). Fig. 1 (a) illustrates the spatial distribution of cumulative rainfall of the season based on the observations. The observed rainfall distribution during monsoon 2008 shows a north south oriented belt of heavy rainfall along the west coast with a peak of more than 250 cm. Another heavy rainfall belt is observed over the extreme north eastern parts of the country (over Arunachal Pradesh) with a peak of order 200 – 250 cm. Basu showed in his study (Basu 2001) that both of these heavy rainfall regions have accumulated precipitation in excess of 160 cm during the season based on ECMWF model forecasts averaged over 15 yrs (1979-93). The large seasonal total precipitation over these two regions is due to topographical forcing give rise to persistent upward motion (Rao 1976). Another region of large precipitation (IMD, 1981) in the eastern part of the country to the south of the seasonal average location of the eastern part of the monsoon trough is observed with a peak of 150 cm. In contrast to the other two regions, the large seasonal total precipitation over the eastern part of the country particularly over Coastal Orissa and adjoining Gangetic West Bengal (GWB) regions is not topographical forcing, but is due to dynamical forcing produced by the generation of cyclonic circulations near the eastern end of the monsoon trough dipping into the Bay of Bengal (Rao 1976). The sharp gradient of rainfall between the west coast heavy rainfall and the rain shadow region to the east, which is normally expected, is noticed in the observed field. The region of scanty precipitation over the desert to the west of the country and over south east peninsular India (southern part of Tamilnadu) are also noticed with the seasonal accumulated precipitation of less than 20 cm.

For a numerical model of the atmosphere to be successful in predicting summer monsoon precipitation over India, the first step is to reproduce the observed characteristic patterns in the seasonal accumulated values. The forecast fields (day-1 to day-5) of accumulated

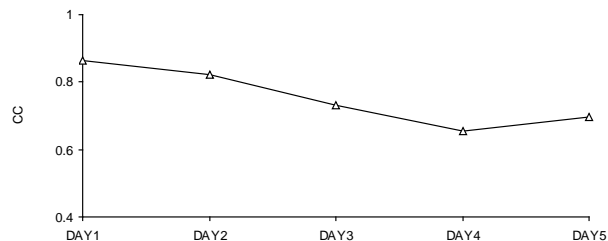
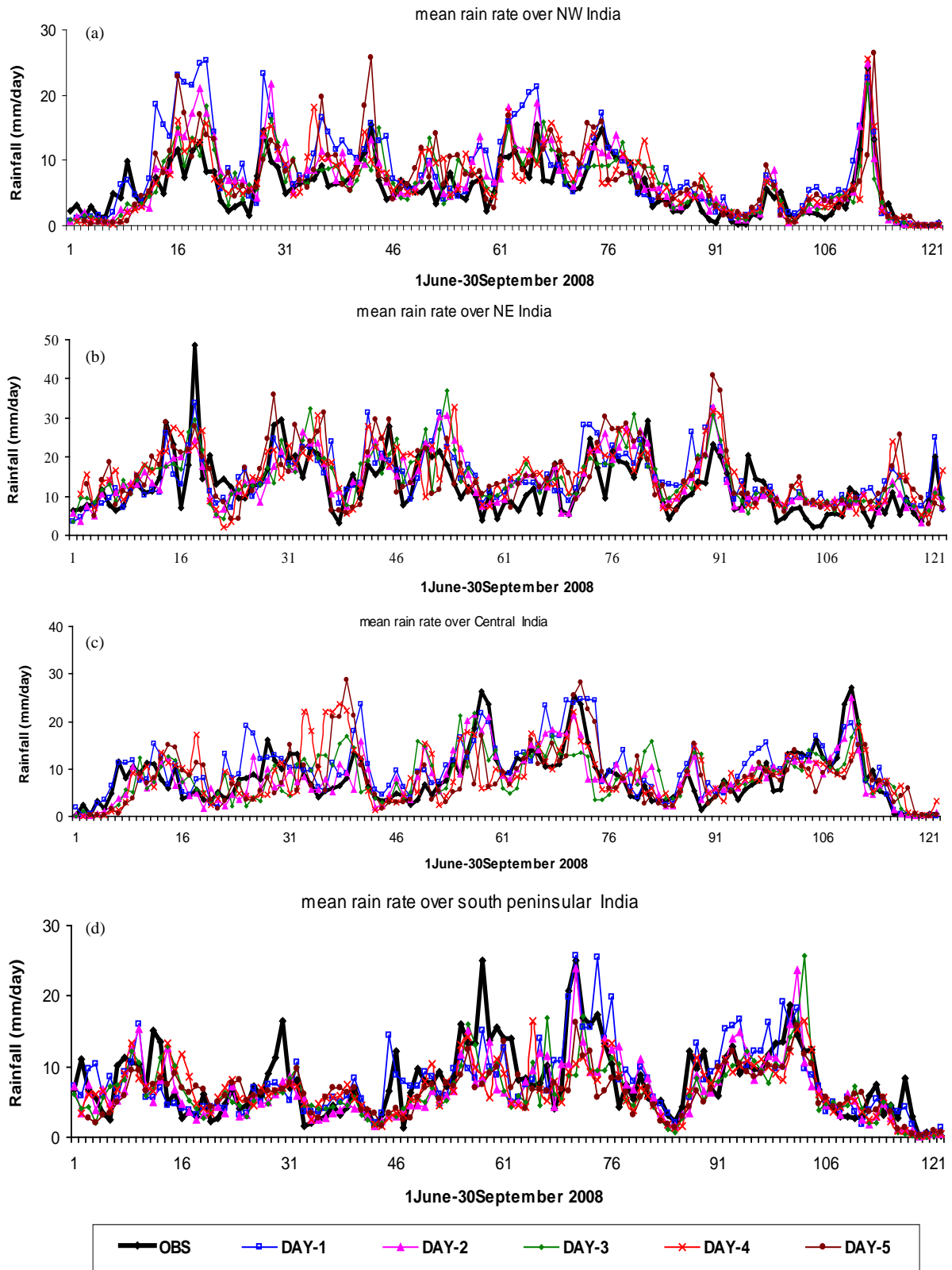


Fig. 4. The correlation coefficient (CC) between observed and model predicted daily mean rainfall over all-India for the period from 1 June to 30 September 2008

rainfall for the monsoon season 2008 based on the model is shown in Figs. 1 (b-f). The forecasts by this model, in general, could reproduce the heavy rainfall due to topographical forcing along the west coast and over North East India and along the foot hills of the Himalaya. The other large seasonal total precipitation due to dynamical forcing produced by the generation of cyclonic circulations over the eastern regions is also seen in the model prediction. The region of less precipitation over North-West India to the west of the country and over South-East Peninsular regions is also noticed in model forecasts. However, some spatial variations in magnitude are noticed. The spatial distribution pattern of model predicted rainfall is closer to the corresponding observed field.

The observed and model predicted All India seasonal (Jun-Sep) rain rate (mm/day) based on the model day-1 to day-5 forecasts for the monsoon 2008 is plotted in Fig. 2. It shows that the model forecasts of all India seasonal rainfall (mm/day) over Indian monsoon season are close to the observed rainfall of 7.3 mm/day, while the day-1 rainfall over estimate the seasonal mean rainfall by 1.8 mm/day and day-2 to day-5 rainfall by 0.5 to 0.8 mm/day during the season.

The time series of average precipitation (mm/day) as observed and model predicted for day-1 to day-5 over all India (Fig. 3) and four broad homogeneous regions of India [Figs. 5 (a-d)] shows that the day-1 to day-5 forecast are in phase with each other, indicating a consistency in the model forecast. The excess rainfall during the first three week of June for the country as a whole was mainly contributed by the excess rainfall over north and adjoining central India as shown in Figs. 5 (a&b), which could be attributed to the mid-latitude westerly systems interacting with the monsoon circulation. The excess rainfall over east-central & adjoining northeast India, Bihar, Jharkhand and West Bengal was mainly associated with the monsoon depression (16-18 June), which developed over north Bay of Bengal and moved north-westwards across Bangladesh, Gangetic West Bengal and Jharkhand.



Figs. 5(a-d). (a) Time series of daily domain mean observed *versus* corresponding day-1 to day-5 rainfall (mm) forecasts by GFS model for the period from 1 June to 30 September 2008 for North West India; (b) same as Fig. (a) but for North East India; (c) same as Fig. (a) but for Central India ;(d) same as Fig. (a) but for south peninsular India

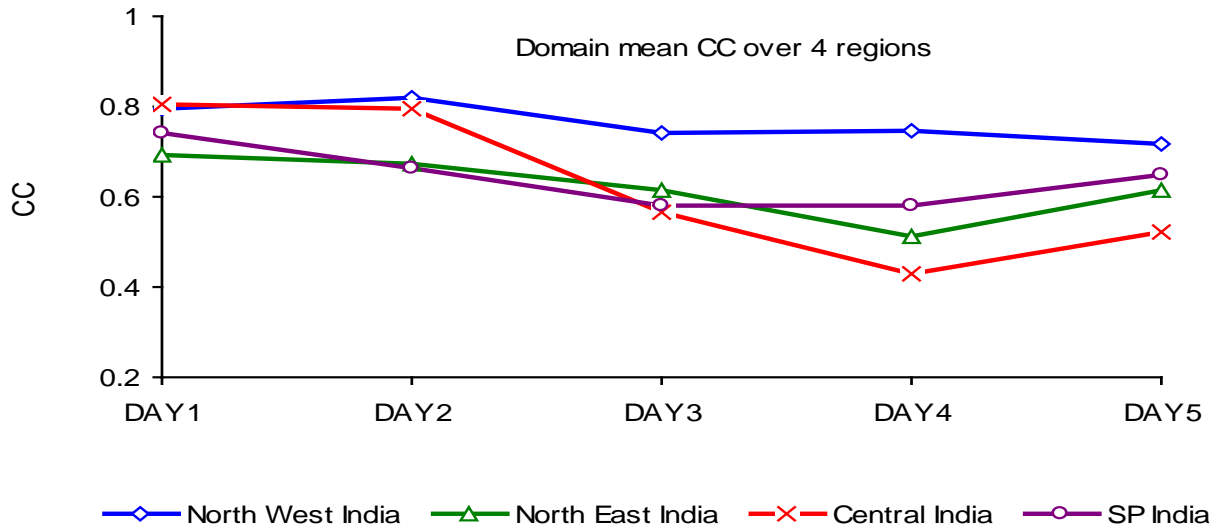


Fig. 6. The correlation coefficient (CC) between observed and model predicted daily mean rainfall over four homogeneous regions of India for the period from 1 June to 30 September 2008

The deficient rainfall for the country as a whole during the second and third week of July was mainly due to the deficient rainfall over central and south peninsular India [Figs. 5 (c&d)]. At the same time, the rainfall in July was higher along the foothills of the Himalayas, especially over east Uttar Pradesh, Bihar [Fig. 5(a)] and over north east India [Fig. 5(b)] particularly over Arunachal Pradesh. This type of rainfall distribution was mainly due to the break monsoon condition, which developed during 14-24 July. The deficient rainfall over south peninsular India [Fig. 5(c)] during June and July was compensated by the excess rainfall during August and September. The phase of all the model forecasts is in general agreement with the observed phase of the day-to-day variations for most of the 122 days in the monsoon seasons (June - September) during 2008, indicating the predictability of all India average rainfall.

The correlation coefficient between trends in the forecast and observation is a measure of the phase relationship between them. The correlation coefficient (CC) between daily domain mean observed and forecasted precipitation of day-1 to day-5 for all-India is shown in Fig. 4 and for four broad homogeneous regions of India is shown in Fig. 6. From Fig. 4, it is seen that the all India domain mean correlation coefficient (CC) for all day-1 to day-5 forecasts has values greater than 0.60, with a higher value 0.90 for day-1, followed by 0.85 for day-2 and 0.75 for day-3. The inter-comparison of domain mean correlation coefficient (CC) of day-1 - day-5 rainfall forecasts by the model over four homogeneous regions of India (Fig. 6) is more consistent with the daily rainfall

time series shown in Fig. 5. The higher correlation coefficient (CC) over North West India for all day-1 to day-5 shows that the difference in predicted and observed daily mean rainfall over this region is less as compared to other three regions. In general, the values of correlation coefficient (CC) for all day-1 to day-5 forecasts over all four regions are greater than 0.60, except the day-4 and day-5 forecast over central India. The skill of the model is dependent on both the time scale over which the forecasts are being examined and the spatial coverage of the rain itself, *i.e.*, it is easier to predict with reasonable accuracy the probability of it raining over a large area than a small one and when the rainfall is widespread rather than localized.

3.3. Verification of precipitation forecast

The precipitation forecast skills are highly depended on the resolutions of verified grids/boxes (spatial) and time period (temporal). There is higher skill if the verified grids/boxes are very large or the time period is very long. The average of the forecast errors over a long period of time is a measure of the systematic part of the forecast error, while root-mean-square error (rmse) is a measure of the random component of the forecast error. The correlation coefficient between trends in the forecast and observation is a measure of the phase relationship between them.

Spatial distribution of mean errors of rainfall for day-1 to day-5 forecasts by the model for monsoon 2008 (Fig. 7) shows that the magnitude of mean errors is

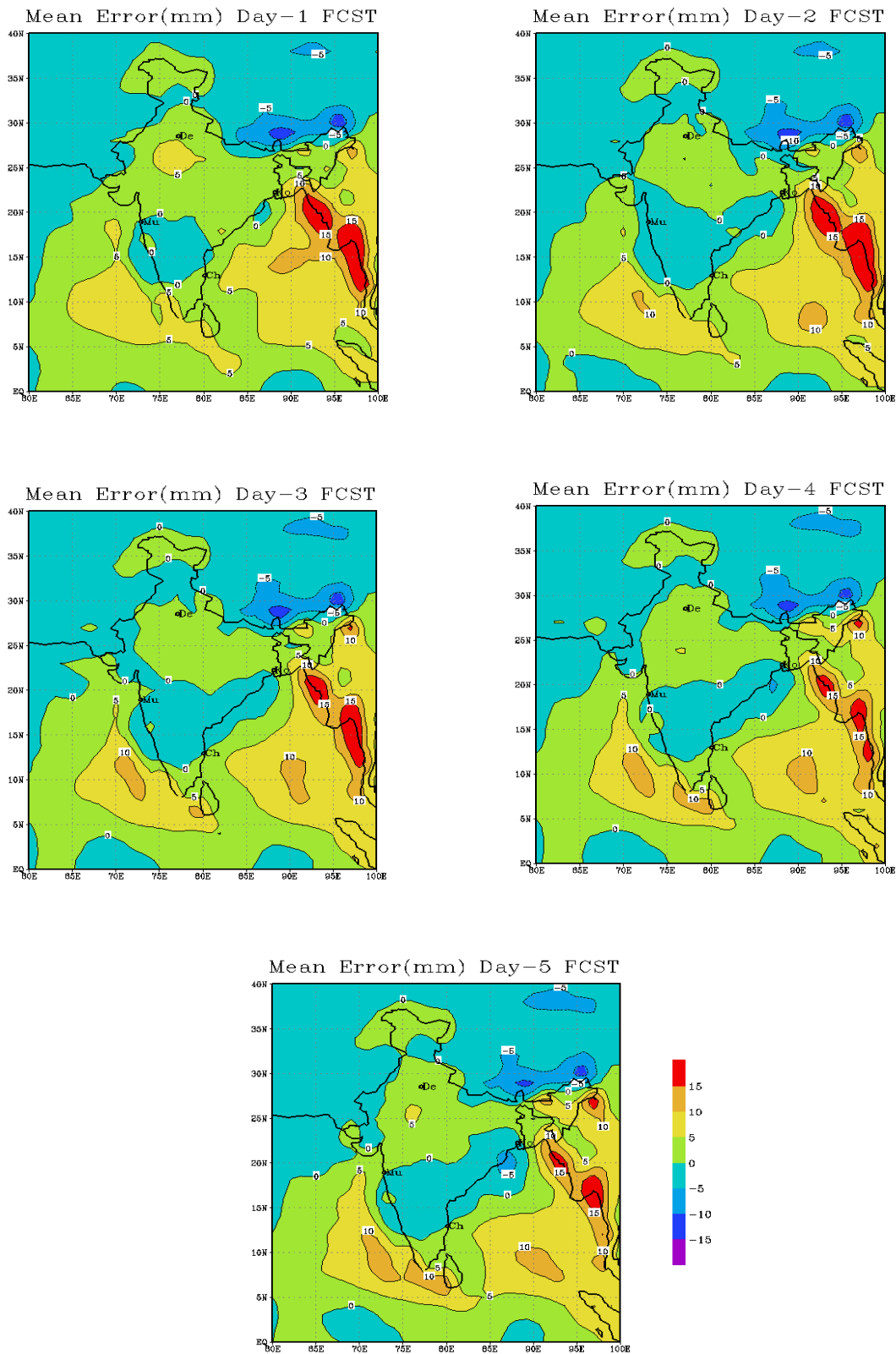


Fig. 7. Spatial distribution of mean Error (forecast-observed) rainfall (mm/day) based on GFS day-1 to day-5 forecasts for the period from 1 June to 30 September 2008

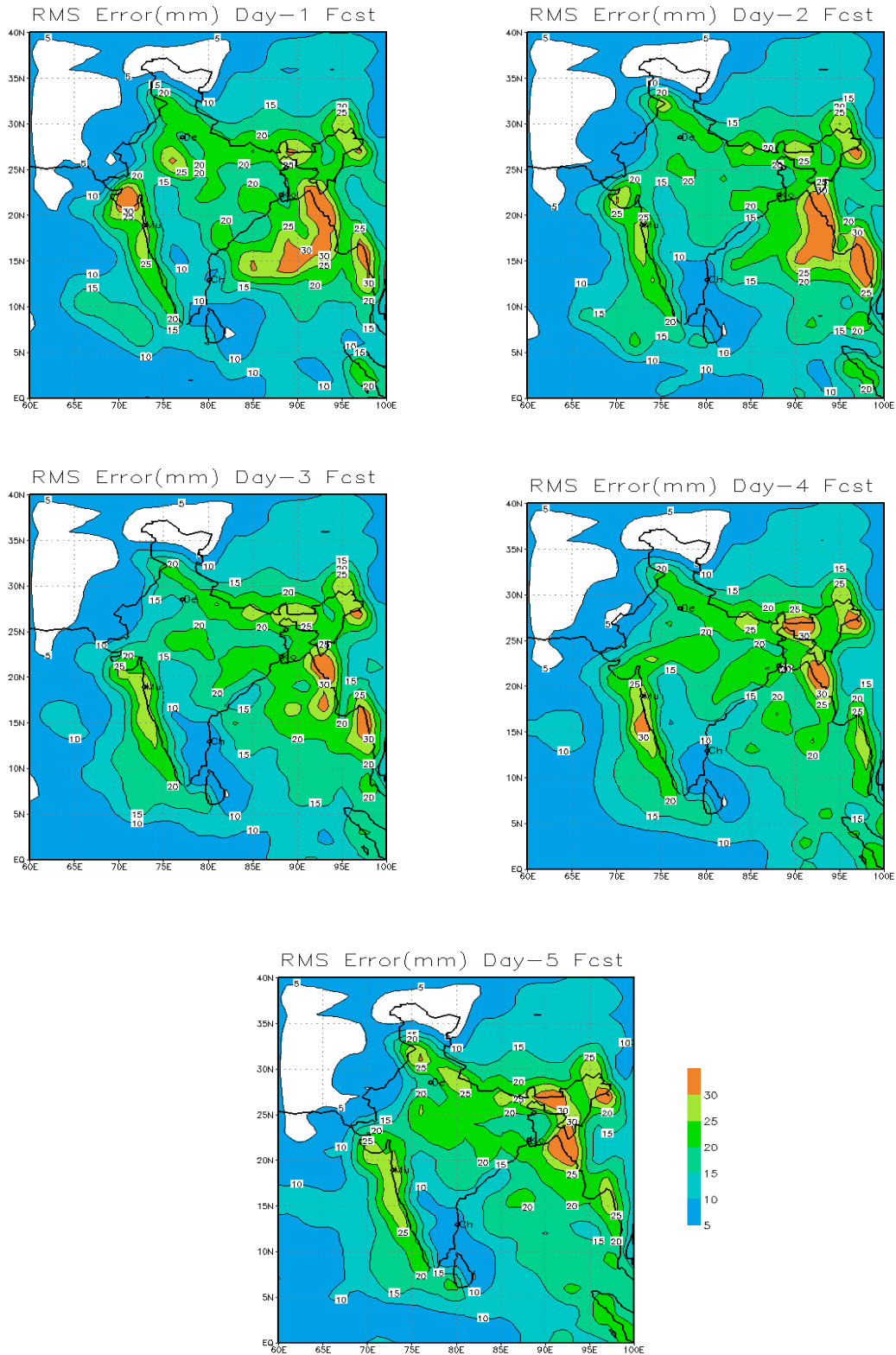


Fig. 8. Spatial distribution of root mean square error (rmse) of rainfall based on GFS day-1 to day-5 forecasts for the period from 1 June to 30 September 2008

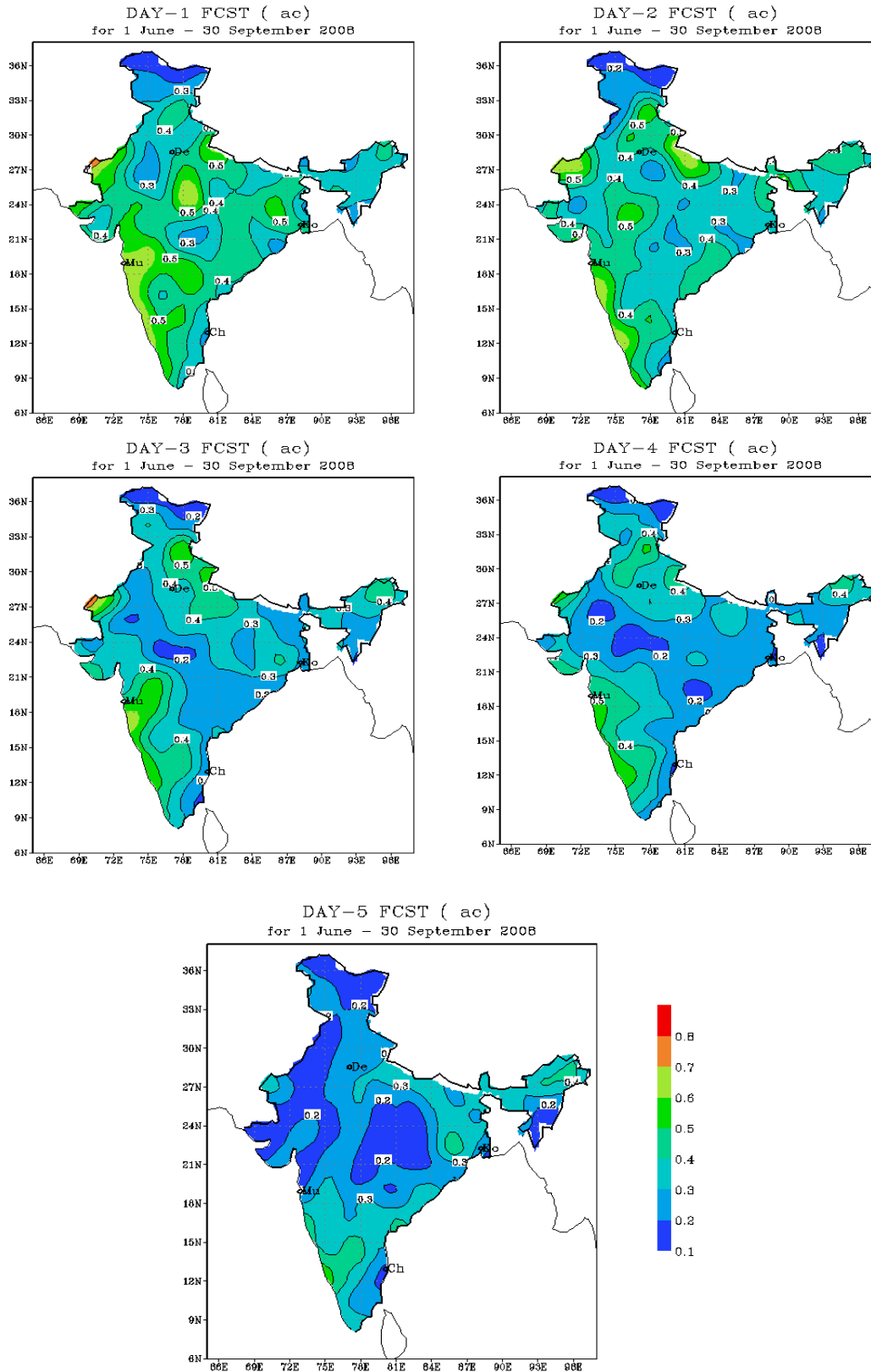
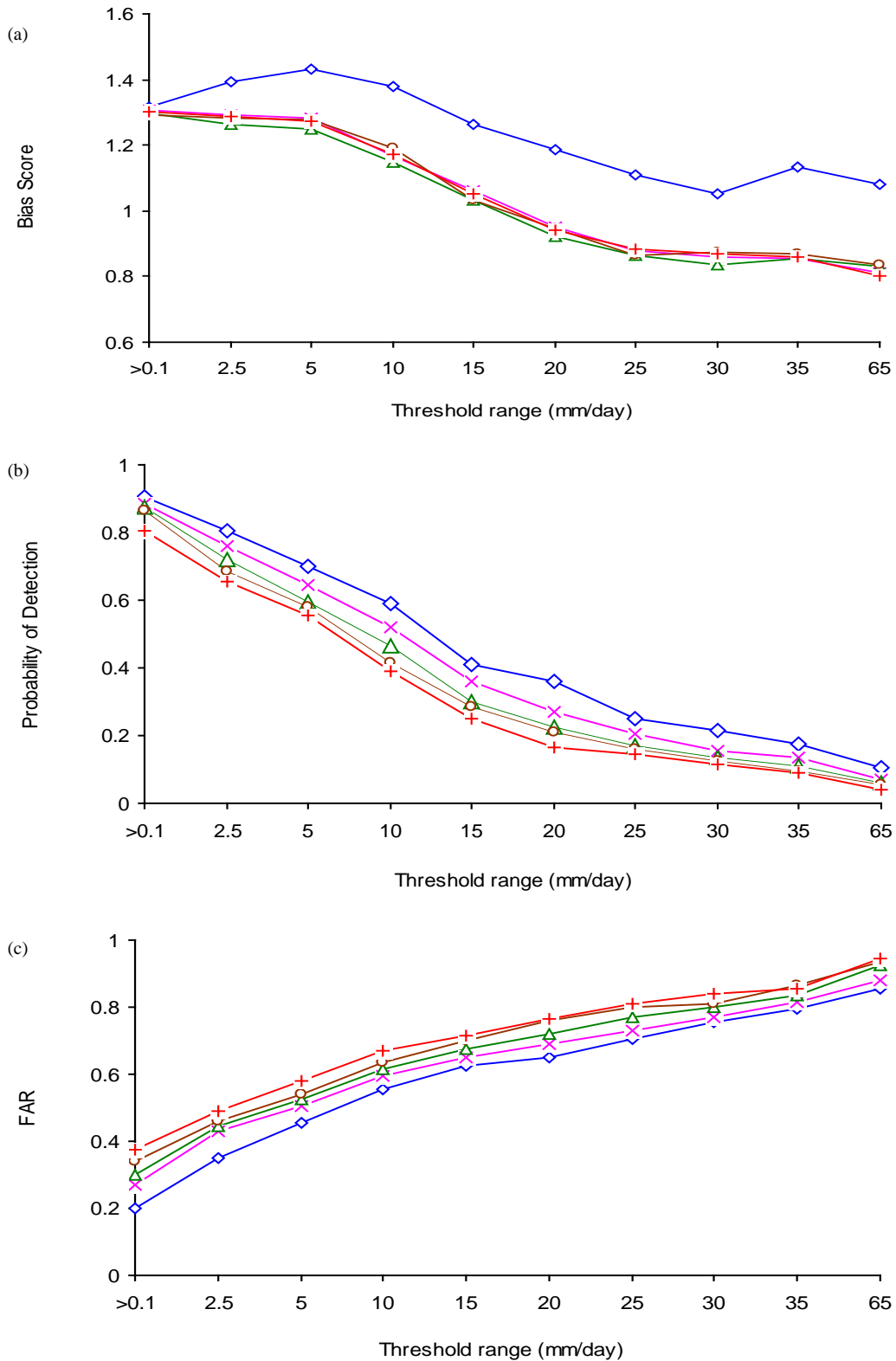


Fig. 9. Spatial distribution of anomaly CC of rainfall based on GFS day-1 to day-5 forecasts for the period from 1 June to 30 September 2008



Figs. 10(a-c). Space-time average values of (a) Bias score (b) probability of detection and (c) false alarm ratio for different threshold range (0.1, 2.5, 5.0, 10.0, 15.0, 20, 25, 30, 35 and 65 mm) of day-1 to day-5 forecast of GFS model over Indian region for the period from 1 June - 30 September 2008

5 mm/day for all the day-1 to day-5 forecast (~ of the order -5 to +5 mm/day) over most parts of the country except over Myanmar coast, where it is in the order of +10 to +15 mm/day. The maximum error over Myanmar coast may be due to under estimation of the satellite derived QPE data over the region. The spatial pattern of the areas of positive (excess) and negative (deficient) errors are more or less uniform from day-1 to day-5 forecast. The spatial distribution of root mean square error (rmse) of rainfall based on GFS day-1 to day-5 forecasts for the period from 1 June to 30 September 2008 is shown in Fig. 8. The rmse of day-1 to day-5 forecasts of the model has a magnitude between 10 and 25 mm, except over the Myanmar coast where the magnitude of rmse exceeds 35 mm. The spatial pattern of rmse of the model day-1 to day-5 forecast shows that the errors are of a more systematic in forecasts lead time.

The Anomaly correlation coefficient (ac) between the observed and the model forecasts precipitation for day-1 to day-5 is shown in Fig. 9. Over most of the country, the magnitude of day-1 and day-2 anomaly CC lies between 0.3 and 0.5, while over a large part of west coast of India, the magnitude of anomaly CC exceeds 0.6. A small area over west Rajasthan has a magnitude of anomaly CC exceeding 0.6. The anomaly CC exceeding 0.3 is considered to be good for precipitation forecast. This indicates that the trend in precipitation in the day-1 forecasts of the model is in good phase relationship with the observed trend over a large part of the country. The magnitude of anomaly CC decreases with the forecast lead time and by day 5 anomaly CC values over most of India are between 0.2 and 0.4, except in pockets near the west coast and Arunachal Pradesh in North east India where the anomaly CC values still exceed 0.4. The spatial distribution of the values of anomaly CC decreases with longer forecast length.

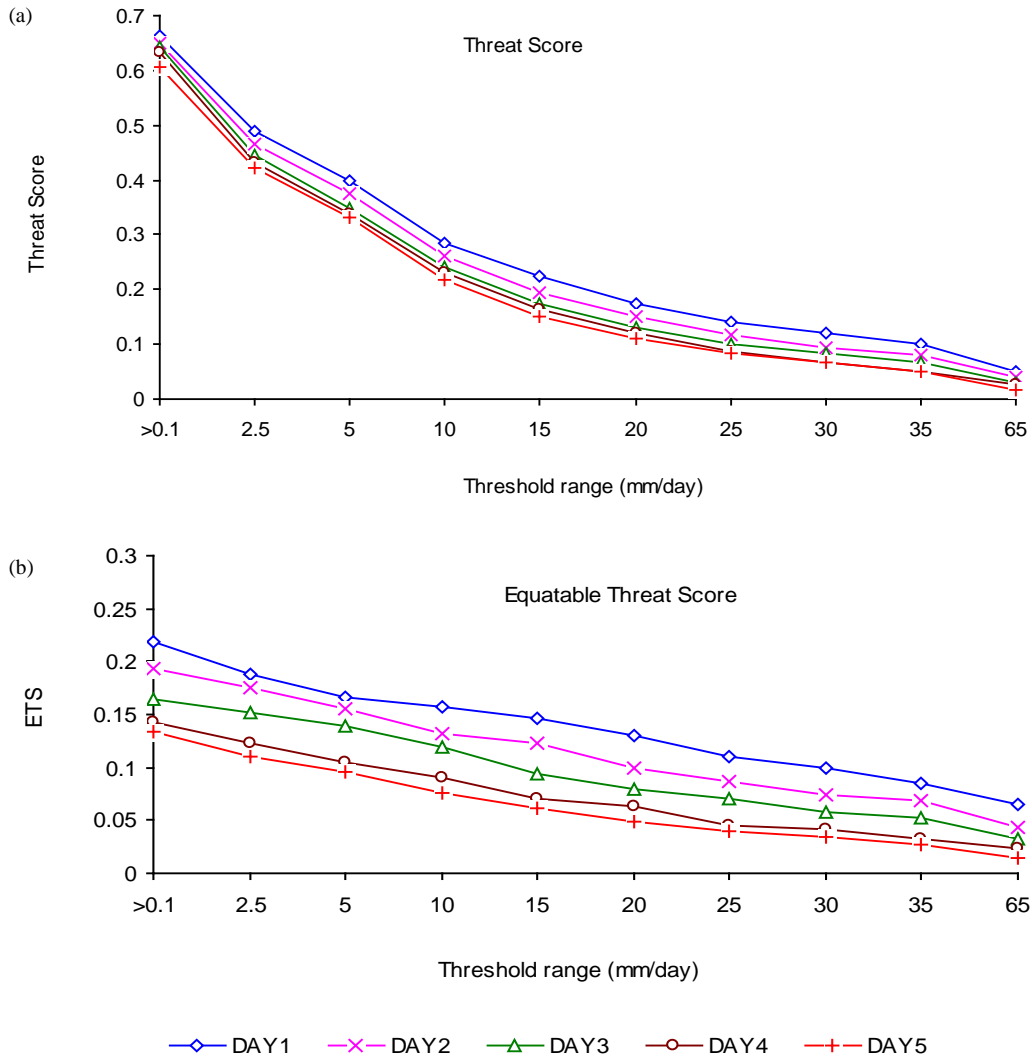
The standard WMO method of the verification of outputs (WMO 1992) is not adequate for precipitation due to its great temporal and spatial variability. The statistical parameters based on the frequency of occurrences in various classes are more suitable for determining the skill of a model in predicting precipitation. The aspect of model behaviour is further explored in Fig. 10(a) the bias, Fig. 10(b) probability of detection (POD) and Fig. 10 (c) false-alarm rate (FAR) for classes with class marks of 0.1, 1, 2, 5, 10, 15, 35,65 mm/day are presented.

The bias of a model forecast is the ratio of the predicted number of occurrences of an event to the number of occurrences of the same event actually realized in nature. It measures the ratio of the frequency of forecast events to the frequency of observed events. Indicates whether the forecast system has a tendency to under

forecast (BIAS<1) or over forecast (BIAS>1) events. It does not measure how well the forecast corresponds to the observations, only measures relative frequencies. The day-1 bias [Fig. 10(a)] of the model continuously over predicts (bias >1) rainfall event in all the threshold ranges up to 65 mm, while, the day-2 to day-5 bias over predict (bias <1) rainfall event only up to 20 mm and above 20 mm the bias score down to below 1.0. And also, the values of day-1 bias are high as compared to day-2 to day-5 bias in all the threshold ranges. In general, the model rainfall forecasts (except day-1) over predicts events of a lower magnitude, but the crossover to under prediction occurs at a higher value close to 25 mm.

The Probability of Detection (POD) is equal to the number of hits divided by the total number of rain observations; thus it gives a simple measure of the proportion of rain events successfully forecast by the mode. From Fig. 10(b), it is seen that the probability of detection is more than 50% for class marks below 10 mm/day for day-1, day-2 and day-3 forecast, while it is further below for day-3 and day-5 forecast. False Alarm Ratio (FAR) gives a simple proportional measure of the model's tendency to forecast rain where none was observed. For perfect prediction, the value of this parameter should be 0.0. In the present case, FAR is smaller for classes with a lower class mark, but increases markedly with an increase in class mark, and is practically 1 for class marks above 65 mm. From Figs. 10 (b & c), it is seen that skill is a strong function of threshold as well as forecast lead time (day-1 to day-5), with the probability of detection (POD) [Fig. 10(b)] decreasing from about 80-90% for rain/no rain (> 0.1 mm/day) to about 20% or 30% for rain amounts above 30 mm/day. Consistent with this the false alarm ratio Fig. 10(c)] increases with threshold, from about 20 or 30% at low threshold to 70-80% at high thresholds.

Threat Score (TS), also known as the Critical Success Index (CSI, *e.g.*, Schaefer, 1990); or Equitable Threat Score (ETS) which is a modification of the threat score to account for the correct forecasts due to chance (Gilbert, 1884), is for verification of the skill in precipitation forecasting. The threat score (TS) is the ratio of the number of correct model prediction of an event to the number of all such events in both observed and predicted data. It can be thought of as the accuracy when correct negatives have been removed from consideration, that is, TS is only concerned with forecasts that count. It does not distinguish the source of forecast error and just depends on climatological frequency of events (poorer scores for rarer events) since some hits can occur purely due to random chance. The higher value of a threat score indicates better prediction, with a theoretical limit of 1.0 for a perfect model. The threat score (TS) and equitable



Figs. 11(a&b). Space-time average values of (a) Threat score and (b) Equitable Threat Score for different threshold range (0.1, 2.5, 5.0, 10.0, 15.0, 20, 25, 30, 35 and 65 mm) of day-1 to day-5 forecast of GFS model over Indian region for the period from 1 June - 30 September 2008

threat score (ETS) of the model day-1 to day-5 forecasts for monsoon 2008 is shown Fig. 11. The threat score [Fig. 11(a)] starts close to 0.65 for rainfall threshold of 0.1 mm/day and then decreases to 0.3 near the 10 mm mark. Interestingly, the day-2 to day-5 threat score remains relatively constant as a function of threshold for low and moderate threshold values and the day-1 score is slightly higher in all the threshold ranges.

Among the wide variety of performance measures available for the assessment of skill of deterministic precipitation forecasts, the equitable threat score (ETS) might well be the one used most frequently. The ETS is

often used in the verification of rainfall in NWP models because its “equitability” allows scores to be compared more fairly across different regimes. If the ETS = 1, it indicates that there is no error in the forecasting. ETS = 0 indicates that none of the grid points are correctly predicted. One disadvantage perceived by the current authors is that the reference accuracy for a random forecast in the ETS is dependent on the properties of the model being verified. The ETS [Fig. 11 (b)] skill for the model, day-1 and day-2 forecasts of precipitation have significant skill for precipitation in lower threshold and it falls off rapidly for larger precipitation amounts and also for longer lead time (day-3 to day-5).

4. Conclusions

In this study, the NCEP GFS model performance is evaluated for day-1 to day-5 forecasts of 24-hr accumulated precipitation over Indian region during summer monsoon 2008 by computing the quantitative parameters prescribed by the WMO, the statistical parameters related to skill, based on the realization or non-realization of an event and intra-seasonal variability of all-India rainfall. The relative advantages of various measures of skill are a complex issue, however and are beyond the scope of the current study. From the result presented above, the following, is concluded.

(i) Model day-1 to day-5 precipitation forecasts, when accumulated over the whole season (June - September), reproduce the observed pattern (Fig. 1) with two large areas (along the west coast, North East India) with a total precipitation in excess of 200 cm; and two large areas one over West Rajasthan and another over south Tamilnadu with a total precipitation of less than 20 cm.

(ii) The observed variability of daily all-India mean precipitation is reproduced remarkably well by the day-1 to day-5 forecasts of the model. This implies that though the short-to medium-range forecasts have errors in the spatial distribution, the spatial average of daily precipitation over the whole of India (Fig. 3) and over four broad homogeneous regions of India (Fig. 5) is in reasonable agreement with that observed.

(iii) This study has also shown the usefulness of categorical statistics, calculated as a function of rain thresholds, in forecast verification. The model has a tendency to over predict the frequency of occurrence of precipitation events in the light and moderate categories and to under predict events in higher categories. The model bias changes from overestimation to underestimation at the threshold of 25 mm/day except for day-1 forecast (Fig. 10).

(iv) Model skill falls dramatically for occurrence thresholds greater than 10 mm/day. This implies that the model is much better at predicting the occurrence of rain than they are at predicting the magnitude and location of the peak during the summer monsoon season over India.

(v) The results show that the model, in general, is able to capture daily ups and downs of all India mean rainfall. In this regard it is worth to mention that though ensemble

method is expected to provide better forecast skill compared to the deterministic model, but the ensemble model has lower resolution (T 126, in case of NCEP GFS), compared to the deterministic model (T-382). This may be one possible reason for good forecast skill by this deterministic model

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