Performance of the operational and experimental long-range forecasts for the 2015 southwest monsoon rainfall

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India experienced deficient monsoon rainfall in 2015 that followed the deficient monsoon of 2014. India Meteorological Department (IMD) correctly predicted the large rainfall deficiency (86% of long period average) in 2015. Incidentally, this was the first ever deficient monsoon forecast issued by IMD, though it had earlier issued below-normal rainfall forecasts in the previous two deficient monsoon years (2009 and 2014) and was partially correct. The fact that there were only three previous occasions of consecutive two deficient monsoon years during the last 114 years (1901–2014) was itself a challenge to IMD to issue the forecast in 2015. It may be mentioned that IMD persisted with the deficient monsoon forecast for 2015, even though there were predictions from private agencies for a normal monsoon and apprehensions from the press and media about the low probability of two consecutive deficient years. IMD was also able to correctly predict the regional distribution of seasonal rainfall during the season. IMD's first deficient monsoon forecast was based on the state-of-the-art operational statistical forecasting system, which was introduced in 2007. IMD was further confident for a deficient monsoon due to the clear indications of a strong El Niño event by June itself. Forecasts from high-resolution coupled forecasting system (CFS) developed by the Indian Institute of Tropical Meteorology, Pune, under the Monsoon Mission also suggested a deficient monsoon in 2015. In this article we provide details of the operational forecasting models and verification of these forecasts. Brief description about the experimental CFS developed under the Monsoon Mission and CFS forecast for the 2015 southwest monsoon season is also presented.

Keywords: AISMR data, long-range forecasts, IMD, monsoon rainfall.

AGRICULTURE activities in India are strongly linked to the annual cycle of rainfall dominated by the two monsoon seasons – southwest (June–September) and northeast (October–December). However, most parts of the country receive 70%–90% of the annual rainfall during the SW monsoon season. The primary feature of the annual cycle of the Indian SW monsoon is its stability and regularity with all-India season rainfall being within ± 30% of its long period average (LPA) during almost all years. However, on a regional scale, variability of the rainfall can be much more than this. As a result, even a rainfall deficiency of more than 10% in the all-India SW monsoon season rainfall (AISMR) can lead to devastating impact on the agriculture regionally and on the country's economy. Agricultural output of the county shows statistically significant association with AISMR. In general, lower (higher) than normal agricultural output is observed during a deficient (excess) rainfall monsoon year. However, too much rainfall has sometimes caused devastating floods and loss of crops. Although the contribution of the agriculture sector to the Indian gross domestic product (GDP) during 1950–2014 had decreased from about 50% to 18% due to the significant rise in the contribution from two other sectors (industry and services), the typical impact of severe droughts on the GDP has been about 2% to 5% throughout the period[1].

Frequent occurrences of deficient AISMR events (2002, 2004, 2009, 2014 and 2015) and a general improvement in the operational weather and climate forecasting skills of India in Meteorological Department (IMD) in recent years have brought monsoon forecasting in the country into limelight. Accurate forecast of monsoon is essential for better macro-level planning of finance, power and water resources. Therefore, monsoon forecast and its performance each year have now become topics of intense discussions and scrutiny by the various Government establishments, media and general public. The special attention received by the monsoon forecasting services in recent years has also attracted some private agencies to come up with their own monsoon forecasts and make high claims about their forecast accuracies. Aggressive promotion of forecasts by private agencies in a large section of the media not only brought new challenges to IMD, but also caused significant

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confusion in the minds of various users of the monsoon long-range forecasts (LRFs).

The 2015 monsoon is a typical example where such confusing scenario emerged due to diametrically opposite forecasts from IMD and SKYMET, an Indian private weather agency. The challenges faced by IMD in conveying a deficient monsoon forecast for 2015 were manyfold. First, the year 2014 was a deficient AISMR year and prior to 2015, there were only three cases of two consecutive deficient AISMR years (1904–05, 1965–66 and 1986–87) since 1901 (i.e. only about 3% probability of two consecutive deficient AISMR years). Second, nobody in the country was ready to accept another year of deficient monsoon (after 2014) and its further negative impact on the agriculture sector and overall economy of the country. Therefore, everybody hoped to have a normal rainfall as forecasted by SKYMET[2]. This resulted in questions being asked on the scientific basis and reliability of the long-range forecasting system of IMD. However, all these questions were answered by the accurate forecast by IMD. Figure 1 shows the probability forecasts for the 2015 AISMR issued by both IMD and SKYMET. It is clear that in April 2015 itself, IMD had indicated significantly large probability of below normal (90%–96% of LPA) to deficient (<90% of LPA) rainfall categories (33% and 35% respectively) compared to climatological probabilities. The update forecast of IMD issued on 2 June was more decisive with high probability (>60%) for deficient rainfall. On the other hand, SKYMET forecast issued in April was indicative of high probability (94%) for normal (96%–104% of LPA) and excess rainfall. IMD forecast helped Government planners and user communities from various sectors such as agriculture, industry, power generation, etc. to carry out appropriate mitigation plans. For example, subsequent to IMD forecast in April 2015, the entire Government machinery from central to local responded quickly and positively with multi-pronged approaches to mitigate the impacts of the deficient rainfall. The Government action included a contingency plan for about 600 districts for a sustained agriculture production through location-specific interventions. Some details of the Government action plan were also published in the news released by Press Information Bureau, Government of India on 30 April 2016.

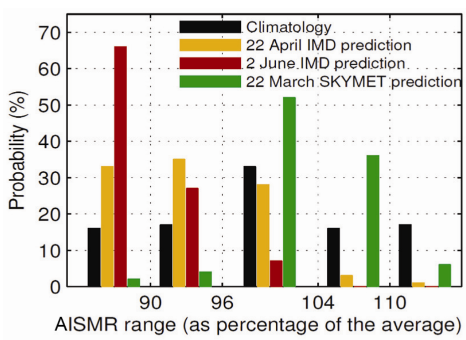

Figure 1. Comparison of five-category probability forecasts for the 2015 AISMR over the county as whole on 22 April and 2 June by IMD, the official meteorological agency and on 22 March by SKYMET, a private weather forecast agency in India. The climatological probabilities for each of the categories are shown using black bars.

In general, two methods are used to generate LRF of AISMR. The first method is based on empirical/statistical models. The statistical model uses the historical relationship between AISMR and its predictors obtained from global patterns of atmosphere and ocean parameters. The second method is based on dynamical models, which use general circulation models (GCMs) of the atmosphere and ocean to simulate the monsoon circulation and associated rainfall. The operational LRF system of IMD uses the statistical approach. For example, 16-parameter power regression and parametric models were used for general operational forecasts of AISMR during the period 1988–2002. In 2007, IMD introduced the new, state-of-the-art LRF models following review of old forecasting systems. At present, IMD also issues operational forecasts for the SW monsoon season rainfall for four broad geographical regions of the county (northwest India, northeast India, central India and south peninsula). In addition, it issues forecasts for monthly rainfall (for July and August) and for the second half of the season (August + September) over the country as a whole using models based on the latest statistical techniques with useful skill[3,4].

Since 2012, as additional forecast guidance, IMD started using the experimental forecasts for monsoon rainfall generated by the dynamical model approach developed by the Indian Institute of Tropical Meteorology (IITM), Pune. The present dynamical model forecasting system is based on the global climate forecasting system version 2 (CFSv2). The CFSv2 is a fully coupled general circulation model (CGCM) implemented by IITM under Monsoon Mission project launched by the Ministry of Earth Sciences (MoES), Government of India. The global monthly and season forecasts for rainfall and temperature prepared using CFS model are updated on the 15th of every month and are now available through IMD, Pune (www.imdpune.gov.in) and IITM (www.tropmet.res.in) websites.

Operational monthly and seasonal forecasts for the SW monsoon rainfall were issued in three stages, i.e. on 22 April, 2 June and 3 August. In April, forecast only for the season (June–September) rainfall over the country as a whole was issued. The forecast issued in June consisted of an update for the April forecast, as well as forecast for the season rainfall over the four broad geographical regions of the country (northwest India, central India, south Peninsula and northeast India) and that for all-India monthly rainfall for July and August. In August, forecast only for the all-India rainfall for the second half of the monsoon season was issued. In addition to the operational forecast, all-India experimental seasonal rainfall forecasts based on the CFSv2 model were also included in the press releases.

This article provides a brief account of the main rainfall features of the 2015 SW monsoon, the operational statistical and experimental dynamical forecasting system of IMD used for generating various LRFs for the 2015 SW monsoon rainfall and its verification.

Important features of the 2015 SW monsoon rainfall

In 2015, India experienced large deficiency in AISMR (86% of LPA) during the monsoon season (June–September). This deficiency was distributed among subdivisions from all the four broad geographical regions (Figure 2). The highest rainfall deficiency was over northwest India (83% of LPA) and lowest over NE India (92% of LPA). Of the total area of the country (36 meteorological subdivisions), 55% (18 subdivisions) received normal season rainfall, 39% (17 subdivisions) received deficient season rainfall and only 6% received excess rainfall (only west Rajasthan). In spite of a slight delay of 4 days in the onset of monsoon over Kerala (actual 5 June and normal 1 June), it covered the entire country well in advance (by 26 June), 20 days earlier than its normal date (15 July). Withdrawal of the SW monsoon started on 4 September from west Rajasthan three days later than its normal date (1 September). The SW monsoon withdrew from the mainland on 19 October subsequently giving rise to the NE monsoon. Month-wise, the all-India rainfall was above normal (116% of LPA) in June and below normal during the other three months of the season (84%, 78% and 74% of LPA respectively, in July, August and September).

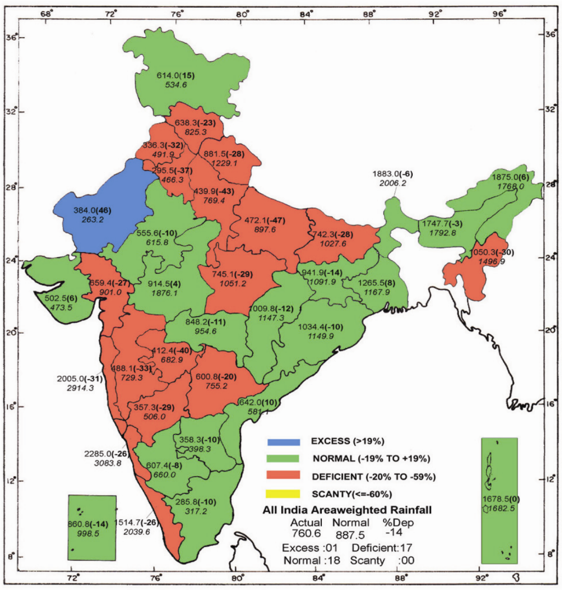

Figure 2. Subdivision-wise rainfall anomaly map for the 2015 southwest monsoon season (June–September). The subdivision rainfall anomalies are expressed as percentage departure from the normal rainfall of the respective subdivision.

The 2015 monsoon was preceded by the formation of weak El Niño conditions in April. The event reached strong level in July, peaked in December 2015 and started declining thereafter. This was the 29th El Niño event during the last 115 years (1901–2015) and was one of the strongest with peak anomaly reaching +2.3°C matching with the strength of the 1997–98 event. During 19 of these 29 El Niño years (66%), AISMR was either deficient (15 years) or below normal (4 years), indicating strong inverse monsoon–El Niño relationship.

In spite of the formation of El Niño conditions prior to the monsoon season and delayed monsoon onset over Kerala, the June rainfall was above normal due to two important factors. The first factor was the phases of Madden Julian Oscillation (MJO) just after monsoon onset over Kerala that were favourable for triggering of the northward propagation of the monsoon trough resulting in stronger than normal monsoon conditions over the Indian region. Within the season, monsoon was generally found to be weaker (stronger) than normal during MJO phases of 7, 8, 1 and 2 (3–6) (ref. 5). The second factor was the formation of a pair of depressions in the Indian seas (a deep depression in the Arabian Sea and depression in the Bay of Bengal) during the third week of June that interacted with the western disturbances across North India. However, associated with MJO phases turning unfavourable from the last part of June to middle of July and strengthening of the El Niño conditions, large deficiency was observed in the rainfall during this period. Though monsoon revived slightly in the second half of July due to the formation of two depressions, one each over southwest Rajasthan and northeast Bay of Bengal (the latter depression became cyclonic storm), July ended with large rainfall deficiency (84% of LPA). Large rainfall deficiency (77% of LPA) was also experienced in the latter half of the monsoon season in association with moderate to strong El Niño conditions and absence of any favourable conditions other than the formation of one low pressure and one depression in the Bay of Bengal.

Models used for operational long range forecasts statistical ensemble forecasting system

Statistical ensemble forecasting system (SEFS) for AISMR used a set of eight predictors having stable and strong statistical and physical association with AISMR (Table 1). The first five predictors were used in the April SEFS and the last six predictors including three predictors used in the April SFES were used for June SEFS[3,4]. The standard errors of April and June SEFS were taken as ± 5% and ± 4% respectively. Figure 3 is a schematic diagram of SEFS for AISMR. As depicted in Figure 3, the forecast of AISMR is estimated as the ensemble average of the best few models out of all possible models constructed using two methods – multiple regression (MR) and projection pursuit regression (PPR); the

Table 1. Details of the eight predictors used for the ensemble forecast system

Sl no.	Predictor	Used for forecasts in	Correlation coefficient (1981–2010)
1	Europe land surface air temperature anomaly (January)	April	0.42
2	Equatorial Pacific warm water volume anomaly (February + March)	April	–0.35
3	SST gradient between Northwest Pacific and Northwest Atlantic (December + January)	April and June	–0.48
4	Equatorial SE Indian Ocean SST (February)	April and June	0.51
5	East Asia MSLP (February + March)	April and June	0.51
6	NINO 3.4 SST (MAM + (MAM–DJF) Tendency)	June	–0.45
7	North Atlantic MSLP (May)	June	–0.48
8	North Central Pacific zonal wind gradient 850 hPa (May)	June	–0.57

Table 2. Details of the operational models used for various monthly and seasonal forecasts for the Indian summer monsoon rainfall

Forecast period	Forecast region	Model (training window period)	Correlation coefficient between actual and forecasted rainfall (period)	Root mean square error in % of LPA (period)
June–September	All India	5-P Statistical Ensemble Forecast System (SEFS) (23 years)	0.71 (1981–2014)	6.56 (1981–2014)
June–September	All India	6-P SEFS (23 years)	0.80 (1981–2014)	5.64 (1981–2014)
July	All India	6-P Principal Component Regression (PCR) (23 years)	0.70 (1981–2014)	10.20 (1981–2014)
August	All India	5-P PCR (23 years)	0.29 (1998–2014)	11.70 (1998–2014)
August and September	All India	5-P PCR (23 years)	0.57 (1981–2014)	10.83 (1981–2014)
June–September	Northwest India	5-P PCR (30 years)	0.65 (1988–2014)	12.70 (1988–2014)
June–September	Northeast India	5-P PCR (30 years)	0.56 (1988–2014)	10.97 (1988–2014)
June–September	Central India	5-P PCR (30 years)	0.44 (1988–2014)	12.1 (1988–2014)
June–September	South Peninsula	6-P PCR (30 years)	0.51 (1988–2014)	13.31 (1988–2014)

LPA, Long period average.

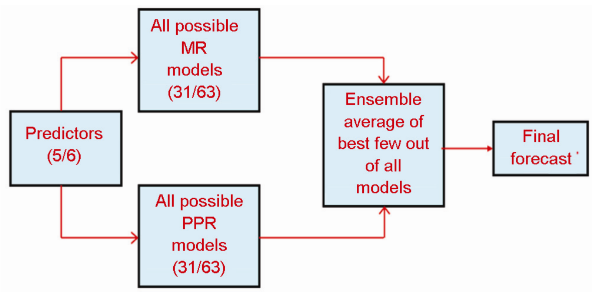

Figure 3. Schematic diagram of the new ensemble forecasting system for the monsoon season rainfall over the country as a whole. The average of the ensemble forecasts from the best out of all possible multiple regression (MR) and projection pursuit regression (PPR) models gives the final forecast.

latter being a nonlinear technique. All possible MR and PPR models were construed with all possible combinations of predictors (corresponding to n predictors, $(2n - 1)$ combinations of the predictors are possible). Figure 4 *a* and *b* shows the scatter plots of forecasted against observed AISMR for the April and June SEFS respectively, for the independent test period of 1981–2014. As seen, most of the past deficient monsoon years have been correctly predicted by both the April and June SEFS. The root mean square error (RMSE) of the April and June SEFS for the period 1981–2014 is 6.56% of LPA and 5.64% of LPA respectively (Table 2). The correlation coefficient (CC) between observed and forecasted rainfall of the April and June SEFS for the period 1981–2014 is 0.71 and 0.80 respectively.

In addition to the quantitative forecast, the ensemble forecasting system was also used to generate a five-category probabilistic season rainfall forecast based on the forecast error distribution of the ensemble forecasting system. The five categories defined based on the observed AISMR data for the period 1901–2005 are deficient (<90% of LPA), below normal (90%–96% of LPA), normal (96%–104% of LPA), above normal (104%–110% of LPA) and excess (>110% of LPA). The climatological probabilities of these five categories are 16%, 17%, 33%, 16% and 17% respectively. The five-category probability forecast was prepared using normal probability distribution with the ensemble average of forecast from the ensemble forecasting system as the mean and RMSE of the independent test period as the standard deviation. For verification purpose, the most probable category was the one that had the highest forecast probability compared to its climatological value. A forecast validating within the

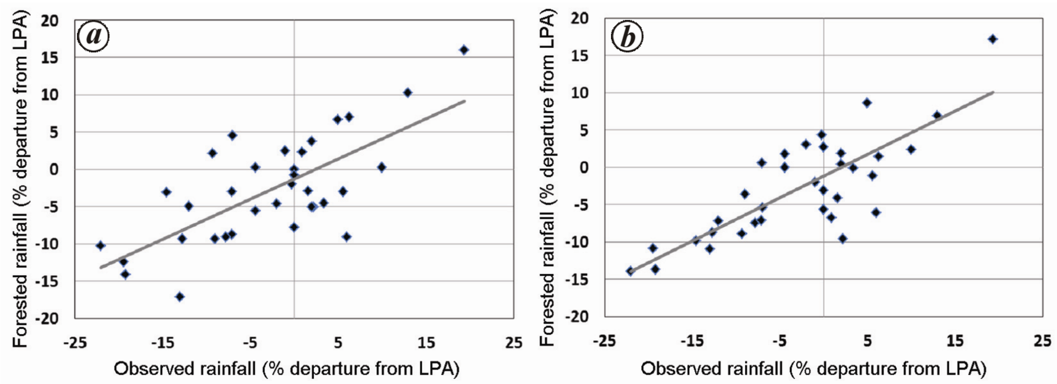

Figure 4. Scatter plots of the forecasted AISMR anomalies against observed AISMR anomalies during the period 1981–2014 for (***a***) five-parameter April and (***b***) six-parameter June forecasting systems. The anomalies are expressed as percentage departure from the long period average (LPA).

Table 3. The tercile category probability forecasts rainfall during the peak monsoon months (July and August) and those for the second half of the monsoon season (August + September) over the country as a whole based on PCR models

Category	July model		August model		August + September model	
	Rainfall range (% of LPA)	Forecast probability (%)	Rainfall range (% of LPA)	Forecast probability (%)	Rainfall range (% of LPA)	Forecast probability (%)
Below normal	<94	58	<94	61	<94	86
Normal	94–106	33	94–106	28	94–106	13
Above normal	>106	9	>106	11	>106	01

same category was considered as 'correct (C)', within one category as 'usable (U)' and beyond one category as 'unusable/not usable (NU)'.

The probabilistic forecast for the period 1981–2014 obtained based on the April SEFS showed that the model forecast was correct during 13 years (38%), usable during 15 years (44%) and not usable during 5 years (15%). The corresponding probabilistic forecast obtained based on the June SEFS showed that the model forecast was correct during 16 years (47%), usable during 15 years (44%) and not usable during 3 years (9%). Examination of probabilistic forecast during the recent four deficient monsoon years (2002, 2004, 2009 and 2014) showed that both April and June SEFS indicated correct category (deficient) during 2002, 2004 and 2009 and one category out (normal) during 2014. Figure 1 provides the five-category probability forecasts based on the April and June SEFS for the 2015 monsoon season.

Principal component regression model

Separate principal component regression (PCR) models were used for generating forecasts for the all-India rainfall for the primary rainfall months of July and August, and second half of the monsoon season (August and September). PCR models were also used for forecasting the season rainfall over the four broad geographical regions of the country. Details of the various PCR models, including their forecast skill and (CC and RMSE between the model forecast and actual rainfall anomaly) for the test period are shown in the last two columns of Table 2. In the PCR method, principal component analysis (PCA) was applied on the predictor data of the training period and the first few principal components (PCs) that explain 80% of the total variability of the predictors were retained. Multiple linear regression analysis was then used to find the relation between the retained PCs and the predictor series for the same training period. The PC loading matrix and the predictor values corresponding to the year just succeeding the training period (reference year) were then used to compute the scores of the selected PCs for the reference year. The coefficients of the trained regression equation along with the score values for the reference year were then used to calculate the predictor value in that year.

As seen in Table 2, the skills of the models for the four broad regions are relatively less than those of the models for the country as a whole. The skill of PCR model for July was better than that for August. Among the models for the broad regions, the one for northwest India showed the highest skill and that for central India showed the lowest skill.

The PCR models were also used to generate tercile (three-category) probability forecasts based on the respective model forecast error distributions. For this purpose, the tercile rainfall categories with equal climatological probabilities (33.33% each) were defined based on the period 1951–2010. The tercile probability forecast was prepared

Table 4. The tercile category probability forecasts for the monsoon season (June to September) rainfall over the four broad geographical regions based on the PCR models

	NW India		Central India		South Peninsula		Northeast India	
Rainfall category	Range (% of LPA)	Forecast probability (%)	Range (% of LPA)	Forecast probability (%)	Range (% of LPA)	Forecast probability (%)	Range (% of LPA)	Forecast probability (%)
Below normal	<92	73	<94	63	<93	53	<95	68
Normal	92–108	25	94–106	28	93–107	35	95–105	24
Above normal	>108	2	>106	9	>107	12	>105	8

Table 5. Performance of the operational forecast issued for the 2015 southwest monsoon rainfall

		Forecast (% of LPA)			
Region	Period	22 April	2 June	3 August	Actual rainfall (% of LPA)
All India	June–September	93 ± 5	88 ± 4		86
Northwest India	June–September		85 ± 8		83
Central India	June–September		90 ± 8		84
North East India	June–September		90 ± 8		92
South Peninsula	June–September		92 ± 8		85
All India	July		92 ± 9		84
All India	August		90 ± 9		78
All India	August and September			84 ± 8	77

using normal probability distribution with the forecast from the PCR model as the mean and the model standard error during the training period as the standard deviation.

Tables 3 and 4 show the tercile probability forecasts based on various PCR models for the 2015 monsoon season.

Verification of operational forecasts

Table 5 depicts the various operational monthly and seasonal forecasts issued for the 2015 SW monsoon along with the realized rainfall. The forecasts for AISMR issued in April and its update issued in June were 93% ± 5% of LPA (below normal) and 88% ± 4% of LPA (deficient) respectively. The actual AISMR was 86% of LPA, which was less than the April and June forecasts by 7% and 2% of LPA respectively, and within the limits of the June forecast. The season rainfall forecast for the geographical regions (northwest India, central India, northeast India and south peninsula) was 85%, 90%, 90% and 92% of LPA respectively, all with model errors of ± 8%. On the other hand, the realized rainfall was 83%, 84%, 92% and 85% of LPA respectively. Thus, the realized rainfall over all the regions was within the forecast limits.

The forecast for the July and August rainfall was 92% and 90% respectively, with a model error of ± 9%. The realized July (August) rainfall was 84% (78%) of LPA, which was 8% (12%) of LPA less than its forecast value. Thus the realized July rainfall was within the forecast limit and the actual August rainfall was 3% of LPA below the lower forecast limit (90 – 9% = 81% LPA). Similarly, rainfall during the second half of the monsoon season (August + September) was 77% of LPA against the forecast of 84% ± 8% of LPA, and therefore was within the forecast limits.

Experimental dynamical forecasting system

The basic modelling framework of CFSv2 implemented by IITM was initially developed by the National Centers for Environmental Prediction (NCEP), USA. IITM is coordinating the work on further improvement of CFSv2 for LRF through collaboration with different climate research centres from India and abroad. The horizontal resolution of IITM CFSv2 is approximately 38 km (T382), which is higher than that of its original version (about 100 km; T126). However, the dynamics and physics of the models remain the same. Both models used the initial conditions from NCEP climate forecast system for generating the hindcasts. Hindcasts runs were made using initial conditions (ICs) of 0 and 12 UTC at every five-day interval starting from 1 January with model outputs also at 0 and 12 UTC. Thus, every month there were 10–12 ICs (ensembles). Hindcasts corresponding to ICs of each month were made for the subsequent 9-month period. Since 2012, IMD is utilizing the experimental forecasts generated using the latest high-resolution research version of CFSv2, as an additional guidance to the operational forecasts of AISMR. The model initialized with February and April initial conditions is being used for generating experimental forecasts. Hindcast analysis of CFSv2 T126 temperature simulations (1982–2008) showed basin-wide cold bias over the Indian Ocean region and in the entire troposphere over the South Asian monsoon region[6].

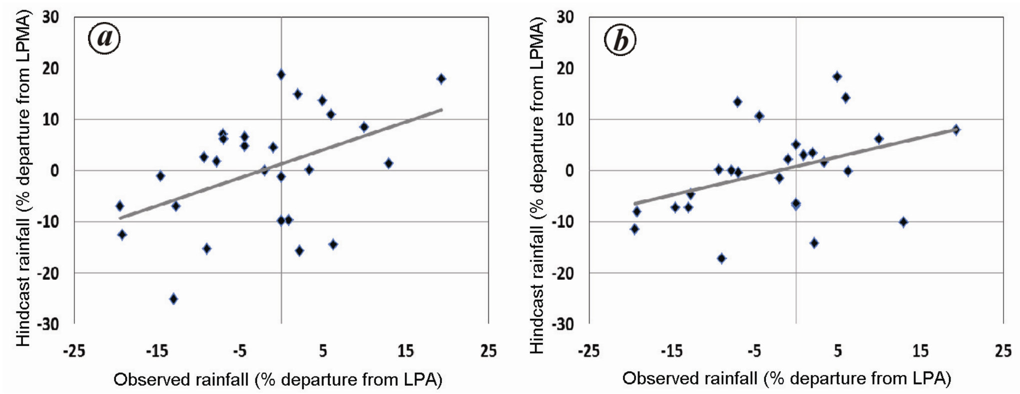

Figure 5. Scatter plots of the CFSv2 T382 hindcast AISMR anomalies (expressed as percentage departure from the long period model average (LPMA)) against observed AISMR anomalies (expressed as percentage departure from LPA) during the hindcast period (1982–2008) for (***a***) February and (***b***) April initial conditions respectively.

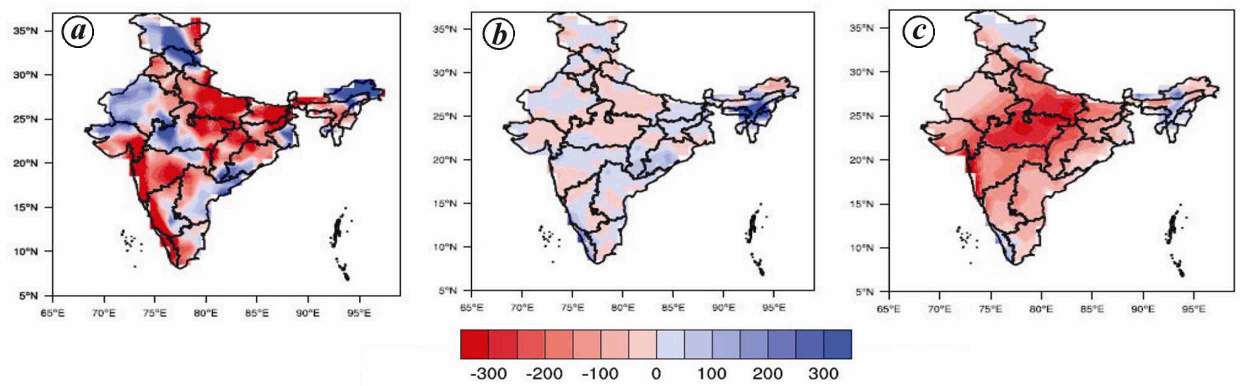

Figure 6. Rainfall anomalies (mm) for the 2015 southwest monsoon season (JJAS) from (***a***) observation (IMD) and CFSv2 T382 forecast based on (***b***) February initial conditions and (***c***) April initial conditions.

Similarly, rainfall simulations showed dry bias over Indian monsoon region and wet bias over north Indian Ocean. In addition, intra-seasonal oscillation (ISO) propagation was slower in CFSv2 T126, which could be due to the weak vertical shear of zonal wind in the model. However, considerable reduction in the temperatures and rainfall biases was observed in CFSv2 T382, resulting in better skill in the forecasting of AISMR[7]. CFSv2 T382 hindcasts also showed realistic representation of ENSO and its teleconnection, and improved ISO propagation features[6]. On comparing the skill scores of both versions of CFSv2 for forecasting of AISMR based on February and April ICs, CFSv2 T382 was found to have better skill. CC between hindcast and observed AISMR of CFSv2 T126 (T382) version for the hindcast period (1982–2008) was 0.49 and 0.38 (0.55 and 0.4) for the February and April initial conditions respectively. Figure 5 *a* and *b* shows the scatter plots of the CFSv2 T382 hindcast AISMR anomalies (percentage departure from the long period model average; LPMA against observed AISMR anomalies (percentage departure from LPA) during the hindcast period for February and April ICs respectively.

For generating the 2015 forecast using CFSv2 T382, 40 ensemble members corresponding to 40 different initial conditions of the same month were used. Figure 6 shows the spatial distribution of JJAS seasonal forecasted rainfall anomalies based on the February and April ICs along with that of observed seasonal rainfall anomalies. The AISMR forecast based on February ICs (91% of LPMA) was 5% of LPA more than the observed AISMR (86% of LPA) and that based on the April ICs was exactly equal to the actual value. This suggests that the model was able to make accurate indication of the below normal/deficient AISMR in February itself. Figure 6 shows that the large scale pattern of forecasted rainfall anomaly based on April ICs is also closer to the realized rainfall anomaly. The probabilistic forecasts (<90% of LPA) based on both February and April ICs (50% and 60% respectively) also strongly indicate deficient AISMR. It may be mentioned that the model forecast based on February IC was also able to correctly indicate establishment of strong El Niño conditions during the 2015 monsoon season. The ENSO-monsoon teleconnection in the model is strong and therefore it may be one of the possible reasons for predicting below-normal rainfall. It may also be mentioned that other leading climate centres, including NCEP and ECMWF failed to predict below-normal rainfall with the February IC, even though strong El Niño signal was indicated by these models. CFSv2 T382 was also able to obtain better simulation of extratropical sea-surface temperatures over north Pacific and its adverse impact on AISMR than other coupled models[8].

Conclusions

The realized seasonal rainfall over the country as a whole (AISMR) and that over the four broad geographical regions of the country during the 2015 SW monsoon were within limits of the respective forecasts issued in June, and therefore the forecasts were accurate. The all-India rainfall forecast for July and that for the second half of the monsoon season were also accurate. However, forecast for the all-India August rainfall was an overestimate to the realized rainfall and was not accurate. The experimental forecasts of AISMR using CFSv2 T382 based on both February and April ICs were also accurate.

The deficient AISMR forecast for 2015 was the first ever deficient monsoon forecast issued by IMD though it had partial success in some earlier deficient monsoon years like 2009 and 2014 while issuing a below-normal AISMR forecast. This forecast was also significant because of the fact that AISMR in the previous year (2014) was also deficient and there was a small probability (only 3%) for two consecutive deficient monsoon years. The above normal rainfall during June 2015, in spite of moderate El Niño conditions over the Pacific during that time had also resulted in considerable skepticism amongst meteorologists as well as media regarding the accuracy of the IMD forecast. However, IMD could withstand the intense public and media scrutiny and come out successful.

The forecast of AISMR in 2015 was prepared based on new state-of-the-art statistical ensemble forecasting technique that was first introduced in 2007. This technique uses eight predictors that represent various important physical mechanisms like ENSO, Indian Ocean dipole, northern hemispheric land heating, mid latitude wave activity, etc. which are known to have significant historical association with the inter-annual variability of AISMR. This indicates that the new monsoon forecasting system has a strong scientific basis. The forecast skill of the present ensemble forecasting system for AISMR has also improved significantly compared to that of the previous models. The mean absolute error in AISMR forecast during the last 8 years (2007–2014) was about 6% of LPA compared to that of about 9% of LPA during the previous 8 years (1999–2006). The improvement in the forecasting skill of the present system is one of the factors that gave confidence to IMD to issue deficient AISMR forecast in 2015. Another factor is that currently AISMR is going through a below-normal epoch (that started in early 1990s). Further, in recent years, global models (both statistical and dynamical) from world over have shown substantial improvement in their skill to predict ENSO phases (El Niño/La Niña). From early 2015, model forecasts from several global climate centres had indicated strong probability for the development of moderate to strong El Niño conditions during the monsoon season, which finally turned out to be true. It may also be mentioned that prior to June 2015, forecasts from many of these global climate centres were also indicating below normal to deficient AISMR during the year. All these factors gave confidence to IMD to persist with deficient monsoon forecast in 2015, in spite of above-normal rainfall in June. Thus the success of IMD in 2015 forecast can be attributed not only to the improvement in the skill of its own operational models, but also to the overall improvement in the understanding of the El Niño–monsoon relationship and to the improved capability of global coupled models (including monsoon mission CFSv2) to simulate these phenomena and their interactions.

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