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Forecasts of Rainfall (Departures From Normal) Over India By Dynamical Model

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Abstract

Intra-seasonal lack(excess) of rainfall that lead to situations of meteorological drought (flood) in one or other part of country every year apart from inter-annual variability of rainfall(Krishnamurthy, 2000). India received 88% of long period average (normal) rainfall 886.9 mm during southwest monsoon season(monsoon) in 2014. Northwest(NW), central, northeast (NE) and south peninsula of India received 79%, 90%, 88% and 93% of normal rain respectively. Twelve meteorological subdivisions i.e. about 30% area of country received deficient category(below 19% of normal) by the end of monsoon. Forecasts of Global Forecasting System(GFS/ T574L64) at ESSO-NCMRWF have been studied for all the thirty six meteorological subdivisions(subdivisions) of India during monsoon(June to September) 2014. Predicted values of weekly percentage departure of rainfall from normal are found in good agreement with observed kind of departures(-ve or less than normal) on more than about 80% of the cases at sub divisional spatial scales. Model forecasts for monsoon season were consistently found reasonably good for both the recent years 2009 and 2014 when India received 22% and 12% less rainfall than normal respectively. Scores of models forecasted weekly rainfall over meteorological subdivisions for monsoon 2014 are found improved compared to those for monsoon in 2009.

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Keywords: Rinfall; Model; Forecast; Meteorological subdivisions; Monsoon; % departure of rainfal (weekly) from normal

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1. Introduction

Impact of weather has always been there on all the sectors. Rainfall prediction in different temporal and spatial scales have become one of important inputs to not only planners and policy maker but farmers as well for management to minimize(maximize) the loss(gain), accordingly. Similarly forecasts of other atmospheric parameters are important for various applications including health and agriculture. It is required to understand atmospheric processes, enhancing of observations and do continuous research and development for obtaining accurate weather forecasts. In India, there are all efforts by ESSO-MoES for improvement in forecasts through its various programs and departments. It is the result of efforts that the forecasts of weather and rainfall are reasonably accurate. Now, ESSO-MoES programs aim for improvement of accuracy of forecasts over various spatial scale range from meteorological subdivisions to agro-climatic zones and six hundred fifty five districts. ESSO-India Meteorological Dept(IMD) has also started experimental location specific forecasts for sixty five hundred blocks of India in 2014, after pilot mode 'multi model ensemble (MME)' based forecasts issued for 342 blocks of 37 districts(one from each state) and two districts from each of two states namely Haryana and Uttar Pradesh in 2013. Simultaneously, validation of model forecast is equally important and carried out regularly to understand the gaps.

India received 777.50 mm during entire monsoon season(June to September) in 2014 that was 88% of normal(1941-1990) rainfall 886.9 mm. From year 2000 till 2014, such lack of rain during monsoon occurred in 2002 and 2009 when it was 19% and 22% less than normal respectively and caused all India meteorological drought. So far, India suffered from meteorological drought on 29 occasions during past 138 years (1877 to 2014) when more than 20% of its total area was under moderate or severe drought. Observed percentage departure of rainfall from the normal for each month of monsoon season (June, July, August, September) and season as whole for the three drought years are given in Table.1(IMD Monsoon Reports 2009, 2014).

Cases of both the opposite kind(less and more than normal) rainfall over different regions namely NW, Central, South Peninsula and thirty six subdivisions are studied for monsoon season 2014(Tables 2). Synoptic weather conditions and weather systems which caused less and excessive rainfall are narrated below(2). Global forecasting system(model) version at ESSO-NCMRWF used for forecasting is as follows(3). Models forecasts of rainfall for subdivisions which received either of the less or more rainfall than normal are described (4), followed by the summary of results.

Table 1. Monthly rainfall distribution of monsoon (% departure from normal for the country as a Whole) of major lack of rainfall years during past 15 years period (2000-2014).

Years	June	July	August	September	June-September
2002	+4	-49	-4	-10	-19
2009	-47	-4	-27	-21	-22
2014	-43	-10	-10	+8	-12

Table 2. Scores of correct (-/-; +/+) and incorrect (-/+; +/-) models forecast of for all observed cases of % departure of rainfall from normal for all weeks and subdivisions of India during monsoon season 2014

MONTHS	-OB/-FC	-OB/+FC	+OB/-FC	+OB/+FC	TOTAL
JUNE	122	23	16	19	180
JULY	68	27	27	22	144
AUG	95	18	26	41	180
SEP	89	9	16	30	144
TOTAL	374	77	85	112	648

2. Monsoon 2014

Monsoon trough's shifting to foothills of Himalayas, apart from other synoptic conditions lead to break like situations of monsoon(Gadgil, 2003). The monsoon trough mostly remained north of its normal position close to foot hills of Himalayas during August2014. Seasonal 'heat low' was less demarcated since second half of August except for first half of September, when it became noticeable. Thereafter, it became less apparent and weakened. Even it became monsoon break like situation during 15-21 August 2014. These synoptic conditions led to deficient rainfall during first half of monsoon season (June, July and first fortnight of August).
But, the axis of monsoon trough mostly remained normal or south of its normal position during July and first half of September. Also,13 low pressure systems formed during season. These included 10 low pressure areas, one cyclonic storm, a land depression and a deep depression. IMD reported, out of the 10 low pressure areas formed during the season (against the season normal of 6), 8 (3 of them well marked) formed over the Bay of Bengal and two (as well marked) over the Arabian Sea. The monthly break up is 1 in June, 3 in July, 3 in August and 3 in September (IMD's gazette publications and weekly reports 2014). Formation of depressions and low pressure systems cause major amount of rain during monsoon(Koteswaram, 1963).

2.1. Subdivision wise rainfall, monsoon 2014

2.1.1 Observed weekly rainfall for 648 cases of entire monsoon season 2014; comprised of 145 occasions of negative percentage (-ve %) departure of rainfall from normal, for July total 95 occasions, for August 113 occasions, September 98 occasions and total 451 cases of –ve% departure of rainfall from normal for entire weeks and subdivisions were studied(Table 2).
2.1.2 Similarity, weekly rainfall observation for subdivisions of NW India with numbers cases 37 in June, 27 in July, 35 in August, 28 in September and total number of observed cases 127 were studied(Table 3).

Table3. Scores of correct and (-/-) and incorrect (-/+) models forecast of for all observed cases of -ve % departure of rainfall from normal for all weeks and subdivisions of India during monsoon season 2014

MONTHS	Total -Ve OB	Number of Correct FC -OB/-FC	Score of Correct FC (%)	Number of Incorrect FC -OB/ +FC	Scores of Incorrect FC %
JUNE	145	122	84.13	23	15.86
JULY	95	68	71.57	27	28.42
AUG	113	95	84.07	18	15.92
SEP	98	89	90.81	9	9.18
TOTAL	451	374	330.58	77	69.38
Total score %			82.64		17.34

2.2. Monsoon 2009

Country received rainfall 22 % less than normal during entire season. NW India was more affected with 35% less than normal rain. June, July, August and September months received 53%, 96%,73% and 80% of normal rain. Rainfall was deficient or scanty over 58% of districts.

3. GFS (Model) Forecasts

3.1. Models

Forecasts of primitive equation based general circulation global spectral models namely; Global forecast system model T574 version of numerical weather prediction model(Kanamitsu M, 1989; Parrish D.E. and Derber J.C., 1992) operational at ESSO-NCMRWF were used for studying the rainfall during monsoon 2014. There are seven equations including five prognostic equations and two diagnostic equations. Prognostic equations are: equation of pressure, momentum equation, Thermodynamic equation, Divergence equation and Vorticity equation. Diagnostic equations are: Hydrostatic equation and equation of Vertical velocity. Mathematical expressions of equations are as given below.

Prognostic equations:

i) Surface Pressure Equation:

This equation is obtained from the continuity equation by integrating over the full sigma (σ)domain:-

$$\frac{\partial}{\partial t}\ln p_{\bullet} = -\sum_{k=1}^{K}\left(\nabla\cdot\vec{V}_k + \vec{V}_k\cdot\nabla\ln p_{\bullet}\right)\Delta_k \tag{1}$$

ii) The Momentum Equation:

$$\frac{d\vec{V}}{dt} = -RT\nabla\ln p_{\bullet} - \nabla\phi - f\,\vec{K}\times\vec{V} + \vec{F} \tag{2}$$

∇ The operator is the horizontal gradient in the system.

$\vec{F}$ Represents dissipative process in the model.

iii) Thermodynamic Equation:

$$\frac{\partial T_k}{\partial t} = -\vec{V}_k\cdot\nabla T_k + \kappa\,T_k\left(\frac{\partial}{\partial t} + \vec{V}_k\cdot\nabla\right)\ln p_{\bullet} + \frac{H}{C_p} - \frac{1}{2\Delta_k}\left[\hat{\dot{\sigma}}_{k+1}\left(\frac{\pi_k}{\pi_{k+1}}T_{k+1} - T_k\right) + \hat{\dot{\sigma}}_k\left(T_k - \frac{\pi_k}{\pi_{k-1}}T_{k-1}\right)\right]$$

where, (3)

$$T_k = \pi_k\cdot\theta_k \tag{4}$$

$$\pi_k = \left(\frac{p}{p_0}\right)^{\kappa} \tag{5}$$

$$\kappa = \frac{R}{C_p} \tag{6}$$

iv) Divergence Equation:

If we take operator □ on the momentum equation, then we get divergence equation:-

$$\frac{\partial D_k}{\partial t} = \frac{1}{a\cos^2\phi}\left(\frac{\partial B_k}{\partial \lambda} - \cos\phi \frac{\partial A_k}{\partial \phi}\right) - \nabla^2 \left(E_k + \phi_k + RT_{0_k} \ln p_{\bullet}\right) \tag{7}$$

$$D_k = \nabla \cdot \vec{V}_k = \frac{1}{a\cos^2\phi}\left[\frac{\partial U_k}{\partial \lambda} + \frac{\partial V_k}{\partial \phi}\cos\phi\right] \tag{8}$$

This is horizontal divergence in k layer.

$$A_k = \eta_k U_k + \frac{RT^1{}_k}{a}\cos\phi \frac{\partial \ln p_{\bullet}}{\partial \phi} + \frac{1}{2\Delta_k}\left[\hat{\dot{\sigma}}_{k+1}\left(V_{k+1} - V_k\right) + \hat{\dot{\sigma}}_k\left(V_k - V_{k-1}\right)\right] - \cos\phi F_{\phi k} \tag{9}$$

$$B_k = \eta_k V_k - \frac{RT_k^1}{a}\frac{\partial \ln p_{\bullet}}{\partial \lambda} - \frac{1}{2\Delta_k}\left[\hat{\dot{\sigma}}_{k+1}\left(U_{k+1} - U_k\right) + \hat{\dot{\sigma}}_k\left(U_k - U_{k-1}\right)\right] + \cos\phi F_{\lambda k} \tag{10}$$

$$E_k = \frac{\vec{V}_k \cdot \vec{V}_k}{2} \tag{11}$$

$$T_k = T_{0k} + T_k^1 \tag{12}$$

$$\eta_k = f + \varsigma_k \tag{13}$$

$$U_k = \cos\phi\, u_k \tag{14}$$

$$V_k = \cos\phi\, v_k \tag{15}$$

v) Vorticity Equation:

If we operate k□ □ on the momentum equation, we get vorticity equation.

$$\frac{\partial \eta_k}{\partial t} = -\frac{1}{a\cos^2\phi}\left(\frac{\partial A_k}{\partial \lambda} + \cos\phi \frac{\partial B_k}{\partial \phi}\right) \tag{16}$$

Diagnostic equations:

vi) Hydrostatic Equation:

$$\Phi_{k-1} - \Phi_k = \frac{C_p}{2}\left(T_{k-1}\left(\frac{\pi_k}{\pi_{k-1}} - 1\right) + T_k\left(1 - \frac{\pi_{k-1}}{\pi_k}\right)\right) \tag{17}$$

Φ is geopotential.

vii) Vertical Velocity Equation:

$$\hat{\dot{\sigma}}_{k+1} = \hat{\dot{\sigma}}_k + \Delta_k \left[\sum_{k=1}^{K} \left(\vec{V}_k \cdot \nabla \ln p_\bullet + \nabla \cdot \vec{V}_k \right) \Delta_k - V_k \cdot \nabla \ln p_\bullet - \nabla \cdot V_k \right] \tag{18}$$

(Vertical levels in atmosphere, $\sigma = p/p_s$ where Ps is surface pressure; q-specific humidity, T-Temperature, V-wind comprising u,v,w components)

Here, semi-implicit time integration scheme is applied to the equations of divergence, temperature and surface pressure. Explicit integration scheme is applied to the vorticity and moisture equations. Calculation of the development or change in aforesaid is done with definite time integration steps. Maximum length of time steps depends on the resolution of model and method in use. But, equations being non-linear, provide approximated solutions.

The global model, originally is a version of National Center for Environmental Prediction(NCEP)'s Global model of USA. It has spatial resolution, approximately 24 Kilometer with 64 vertical sigma layers in atmosphere. Basically, a simple land-surface scheme is used which includes; exchange coefficients computations based on Monin Obukhov similarity theory, Penman Monteith method of evapotranspiration over land which includes vegetation effects (Pan, 1995), prognostic surface temperature equation of Arakawa, 3 layer of surface and soil temperature prediction, interactive bucket hydrology, evaporation by bulk method over ocean and Charnock's roughness length computation of ocean. The model is with mean topography; boundary layer processes(Non-local closure), deep and shallow cumulus convection(Kuo modified scheme and Tiedtke method), large scale precipitation(Manabe modified scheme), radiation(short wave-Lacis,Hansen and Harshvardhan et al. and long wave-Fels and Schwarzkopf) and gravity wave drag etc. Basic model consists of Surface Fluxes (Monin-Obukhov) similarity; Turbulent Diffusion Non-local Closure scheme; Short Wave Radiation–invoked hourly; Long wave Radiation- Rapid Radiative Transfer Model; Deep Convection- SAS convection(Pan and Wu, 1995); Shallow Convection- Shallow convection), Large scale condensation-Large Scale Precipitation based on Zhao and Carr, Cloud Generation; Rainfall Evaporation -Kessler's scheme; Land Surface Processes-NOAH LSM with 4 soil levels for temperature & moisture; Soil moisture values are updated every model time step in response to forecasted land-surface forcing (precipitation, surface solar radiation, and near-surface parameters: temperature, humidity, and wind speed); Air-Sea Interaction Roughness length determined from the surface wind stress; Observed Sea surface temperature (SST); Thermal roughness over the ocean is based on a formulation derived from TOGA COARE and Gravity Wave Drag. Availability of global and regional initial conditions of atmosphere for assimilation to be used by model are crucial for forecast.

3.2. Model products

Main model forecast products are as follows. Rainfall(in term of accumulated total precipitation for 24 hours), Mean Sea Level Pressure (MSLP), surface wind, humidity, maximum and minimum temperatures etc. Wind (Flow Pattern), Vertical Velocity, Temperature, Geopotential Height and Specific Humidity are the parameters produced(analysis and forecast) by the Model at 12 standard pressure levels in atmosphere *viz*. 1000hPa, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70 and 50hPa levels. In addition to the aforementioned, specific forecasts like location/regional specific at various temporal scales (24 hours to 168 Hours in advance) are obtained from the Model for certain applications. Weekly rainfall forecast (% departure from normal) of computed for different spatial scales by area average of the grid point values. Weekly model rainfall forecasts of excessive rain (+ve % departure compared to normal) of meteorological subdivisions due to certain low pressure systems and synoptic conditions during monsoon 20014 were obtained(4). It is followed by model(T254) forecast for subdivisions during monsoon 2009(NCMRWF report, 2009).

4. Forecasts

Area-averaged sub divisional rainfall forecasts of model were computed on the week temporal scale. Percentage departure of week's cumulative rainfall forecasts for meteorological subdivisions from normal were taken corresponding to the excessive and above normal rainfall observations of IMD. As per criteria of IMD, it is termed, excess, normal, deficient and scanty rains, if it is, '20% or more', '19% to -19%', '-20% to -59%' and 'less than -

60%' respectively. These categories of rain are also shown on the maps and in table by color; blue, green, orange and yellow for excess, normal, deficient and scanty types of rain respectively, conventionally. Model forecasts for June, July, August September 2014 and 2009 were as following.

4.1. Forecasts (2014)

Sub-divisional percentage departure (from normal) of week's cumulative rainfall forecasts of 180 occasions in June for the five weeks(29May-4June, 5-11June, 12-18June, 19-25June, 26June-2July), 144 occasions for four weeks in July(3-9July,10-16July, 17-23July, 24-30July), 180 cases for five weeks of August(31July-6Aug, 7-13ug, 14-20Aug, 21-26Aug, 27-Aug-3Sep) and 144 cases for four weeks in September(4-10Sep, 11-17Sep, 18-24Sep, 25Sep-1October) for all the thirty six subdivisions are as shown in Table 5(a-b). There were total 648 cases(Table.2).

4.1.1 There were total 451 cases of -ve% departure when forecasts were found to be correct corresponding to their observed value of –ve % departures. But, there were 77 incorrect cases of forecasts of +ve% departure against corresponding observed value of –ve % departures(Table.3). Further, 112 cases were found correct out of total 127 occasions of –ve % departures from normal for NW India (Table.4).

Table 4. Scores of correct and (-/-) and incorrect (-/+) models forecast of cases –ve % departure weekly rainfall from normal for meteorological subdivisions of northwest India during monsoon season 2014

Months	Total cases -Ve OB	Number of correct FC -OB/-FC	Score of correct FC (%)	Number of Incorrect FC -OB/+FC	Scores of Incorrect FC (%)
JUNE	37	32	86.48	5	13.51
JULY	27	22	81.48	5	18.51
AUG	35	32	91.42	3	8.57
SEP	28	26	92.85	2	7.14
TOTAL	127	112	352.23	15	47.73
Total score %			88.05		11.93

4.1.2 Scores of such correct forecasts of the occasions of –ve% departures were found to be about 81% for selective eleven subdivisions of west & NW India during June-August 2009(Jagvir Singh, 2009).

5. Results

Score of correct forecasts of –ve% departures from normal were found to be 82.64 % for monsoon season 2014. Same time, score of incorrect forecasts that is +% departure cases of forecasts against corresponding observations of -ve % departures were found to be 17.34% (Figure.1). Score of correct forecasts of –ve% departures from normal were found to be 88 % for subdivisions of NW India during monsoon 2014(Figure.2). Same time, differences were found magnitude wise. But, improvements can be seen in corrects forecasting of –ve% departure of rainfall (drought like situation) on weekly scale for all subdivisions and entire season by 1.26 % of occasions, and for subdivisions of NW India by about 7% compared to those in 2009.

6. Summary

It is found that score of forecast are reasonably good and improvement are observed by 1.26 % to 7 % of correct forecast of occasions(-ve% departures) in 2014 compared to forecasts in 2009. Forecasts are becoming more useful to planners of various sectors. But there have been wrong (opposite: -/+; +/-) forecast on about 17% occasions. Also it can be seen that the magnitudes of forecasts were differing from observed values. Apart from limitations of model and non-linearity giving approximate solutions (forecasts), observations are also not available at finer spatial temporal scales. It is quite challenging to have accurate forecasts. More observations, understanding of atmospheric

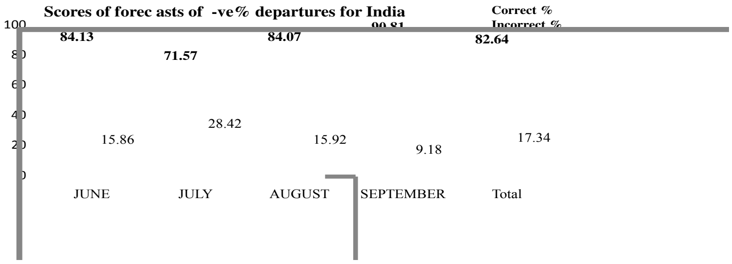

Fig 1. Scores of weekly rainfall forecasts against corresponding observed (-ve% departure from normal) for all weeks and meteorological subdivisions of India during monsoon 2014

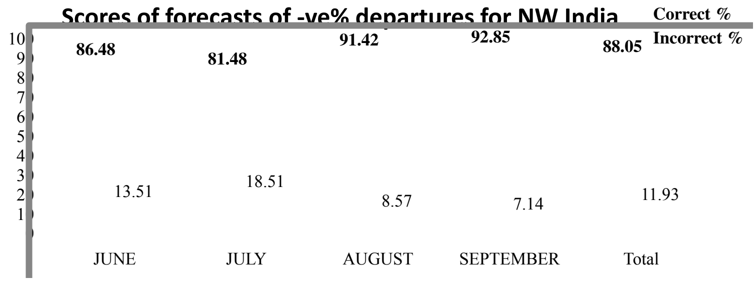

Fig 2. Scores of weekly rainfall forecasts against corresponding observed (-ve% departure from normal) for subdivisions of northwest(NW) and all weeks of India during monsoon 2014

processes and R& D on models is required towards filling the gap and reducing the errors of forecast.

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