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RESEARCH REPORT

Verification of Probabilistic Forecast of Rainfall and Snow Depth during DJF 2014-15

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10	Abstract	During the winter of 2014-2015 (December to March) the Indian subcontinent experienced a total of 9 Western Disturbances (WDs) from December (2014) to middle of March (2015). In the last week of March 2015, the state of Jammu and Kashmir received an average rainfall of about 91.1 mm which was 243% more than the weekly normal of 26.6 mm in this region. The focus of the current study is the verification of the probabilistic forecast for rainfall and snowfall (in the form of snow depth) obtained from the NCMRWF Global Ensemble Forecast System (NGEFS) over the northern parts of India (J&K and adjoining areas). This verification was carried out for winter season of 2014-15 (December 2014 to March 2015). *Reliability* Diagram, Relative Operating Characteristic (ROC and area under ROC), Brier Score and Brier Skill Score were computed for the purpose of verification. It was found that rainfall forecasts with lower (higher) probabilities showed better (lower) *reliability* but were under (over) forecasted. The ROC curves show that the forecasts with higher (lower) probabilities have a

		low (high) false alarm rate and low (high) hit rate. Brier Scores values of 0.13 and 0.05 for 5 and 10 mm rainfall thresholds respectively, in the day 5 forecasts indicate promising skill of the forecast. From decomposition of BS, it is seen that the *reliability* and *resolution* values are low. Similarly the area under the ROC curve for 5 and 10 mm rainfall threshold are 0.73 and 0.68 respectively. These values once again indicate the potential capability of the model in giving a better forecast. For snow depth verification, the BS values are seen to be increasing with increase in lead time indicating decreasing accuracy at higher lead time. The area under the ROC however remains close to 1 and is almost similar for both the ranges of snow depth.
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Abstract

During winter of 2014-2015 (December to March) the Indian subcontinent experienced a total of 9 Western Disturbances (WDs) from December (2014) to middle of March (2015). In the last week of March 2015, the state of Jammu and Kashmir received an average rainfall of about 91.1 mm which was 243% more than the weekly normal of 26.6 mm in this region.

The focus of the current study is the verification of the probabilistic forecast for rainfall and snowfall (in the form of snow depth) obtained from the NCMRWF Global Ensemble Forecast System (NGEFS) over the northern parts of India (J&K and adjoining areas). This verification was carried out for winter season of 2014-15 (December 2014 to March 2015). *Reliability* Diagram, Relative Operating Characteristic (ROC and area under ROC) and Brier Score were computed for the purpose of verification. It was found that rainfall forecasts with lower (higher) probabilities showed better (lower) *reliability* but were under (over) forecasted. The ROC curves show that the forecasts with higher (lower) probabilities have a low (high) false alarm rate and low (high) hit rate. Brier Scores values of 0.13 and 0.05 for 5 and 10 mm rainfall thresholds respectively, in the day 5 forecasts indicate promising skill of the forecast. From decomposition of BS, it is seen that the *reliability* and *resolution* values are low. Similarly the area under the ROC curve for 5 and 10 mm rainfall threshold are 0.73 and 0.68 respectively. These values once again indicate the potential capability of the model in giving a better forecast. For snow depth verification, the BS values are seen to be increasing with increase in lead time indicating decreasing accuracy at higher lead time. The area under the ROC however remains close to 1 and is almost similar for both the ranges of snow depth.

Verification of Probabilistic Forecast of Rainfall and Snow Depth during DJF 2014-15

1. Introduction

In the winter of 2014-2015 (December to March) the Indian subcontinent experienced a total of 9 Western Disturbances (WDs) from December (2014) to middle of March (2015) (Table 1). The rainfall associated with the WDs resulted in flood like conditions in the state of Jammu and Kashmir. In the last week of March 2015, the state of Jammu and Kashmir received an average rainfall of about 91.1 mm which was 243% more than the weekly normal of 26.6 mm. Timely prediction of the amount of rainfall/snowfall due to these WDs is of great importance especially for preparedness in case of associated floods and landslides. NCMRWF provides real time rainfall forecast (day 1 to day 10) based on deterministic (NGFS and NCUM) and ensemble (NGEFS) models. The ensemble model at NCMRWF is also used to provide the probability of rainfall and snowfall over the Indian subcontinent.

The focus of the current study is the verification of the probabilistic forecast for rainfall and snowfall (in the form of snow depth) obtained from the NCMRWF Global Ensemble Forecast System (NGEFS) over the northern parts of India (Jammu and Kashmir and adjoining areas). The region considered for verification of probabilistic forecast of rainfall is (70-80E; 27-37N). However, for snow depth verification the area under consideration was much smaller (74-79E; 31-34N). A reason for choosing a much smaller area was that, snowfall takes place over a much smaller region as compared to rainfall. Choosing a larger area would result in a large number of grids having zero snowfall probability. A spatial average of both the rainfall and snow depth were taken in the respective regions for verification.

No	Start Date	End Date	Maximum rainfall observed (cm/day)
1	13/12/14	15/12/14	6.5
2	21/12/14	26/12/14	20.9
3	20/01/15	22/01/15	7.8
4	1/2/2015	3/2/2015	5.9
5	6/2/2015	7/2/2015	2.5
6	15/02/15	16/02/15	5.9
7	18/02/15	26/02/15	7.4
8	1/3/2015	4/3/2015	11.3
9	8/3/2015	10/3/2015	6.5

Table 1: WD observed over the Indian subcontinent during Dec 2014 to Mar 2015

This report is divided into the following sections: Section 2 gives a brief description about NGEFS model at NCMRWF. Definitions of the verification methods used for probabilistic forecasts is provided in Section 3. Section 4 briefly describes 3 WD cases from DJF 2014-15. Salient results from this study are discussed in detail in Section 5. Finally in Section 6 important conclusions based on the study are listed.

2. Model Description

NGEFS has a *resolution* of T190L28 i.e., approximately 70 km in the horizontal with 28 vertical levels. It is a global ensemble model consisting of 21 members and is initialized by the method of Ensemble Transform with Rescaling (ETR) (Wei et al., 2008) and Stochastic Total Tendency Perturbation (STTP). The ETR makes use of the operational high *resolution* (T574L64) deterministic analysis from NGFS (NCMRWF Global Forecast System) and forecast outputs (Rajagopal et al., 2007 and Prasad et al., 2011). The NGEFS's atmospheric model is a low *resolution* model of NGFS. The model is initialised in four cycles daily (00, 06, 12, and 18 UTC). However, only the 00 UTC cycle is run daily up to 240 hours and the 06, 12 and 18 UTC cycles are used only for shorter runs (till 18 hours). The model outputs are post-processed at 6 hour interval to a 1° x 1° regular latitude-longitude grid. More details about NGEFS can be found at (Ashrit et al., 2012).

3. Verification method for probabilistic forecasts

A probabilistic forecast gives a probability of an event occurring, with a value between 0 and 1 (or 0 and 100%). In general, it is not possible to verify such kind of forecasts using the standard metrics (RMSE, BIAS, ETS etc) used for a deterministic forecast. Instead, a set of probabilistic forecasts, p_i, is verified using observations that those events either occurred (o_i=1) or did not occur (o_i=0).

Verification of a single probabilistic forecast is also not possible. Verification is always based on a sufficiently large sample. There are several scores available for the verification of probabilistic forecasts like *Reliability*, Relative Operating Characteristic (ROC), Brier Score (BS) etc. These scores are used not just for verifying the probability of occurrence of a particular event but different aspects of forecasts obtained from an ensemble model. For example, the simple difference between the forecast probabilities and observed frequencies is calculated using the Brier Score. Given an observed event whether the corresponding forecast was a hit or a miss is measured by using the ROC. Detailed description of these scores is given below.

- **Brier Score (BS)**: This score measures mean squared error in probability space and is given by the formula:

$$BS = \frac{1}{N}\sum_{i=1}^{N}(p_i - o_i)^2 \tag{1}$$

Where, p_i is the forecast probability and o_i is the observed frequency. A perfect BS value is therefore 0.

The Brier score can be decomposed into 3 additive components (Murphy 1973):

- *Reliability*: measures the average agreement between the forecast values and the observed values.
- *Resolution*: is defined as the ability of the forecast to resolve the set of events into subsets with different frequency distributions.
- *Uncertainty*: is the variability of the observations. The greater the *uncertainty*, the more difficult the forecast will tend to be.

$$BS=REL-RES+UNC$$

Where REL is the *reliability,* RES is the *resolution* and UNC is the *uncertainty* of the forecast.

$$BS = \frac{1}{N}\sum_{k=1}^{K}(p_i - o_i)^2 = \frac{1}{N}\sum_{k=1}^{K} n_k\left(p_k - \bar{o}_k\right)^2 - \frac{1}{N}\sum_{k=1}^{K} n_k\left(\bar{o}_k - \bar{o}\right)^2 + \bar{o}\left(1-\bar{o}\right) \quad (2)$$

Where, N is the total number of forecasts issued, K is the total number of unique forecasts issued,

$\bar{o} = \sum_{t=1}^{N} o_t / N$ is the observed climatological base rate for the event to occur, n_k the number of forecasts with the same probability category.

The *reliability* term measures how close the forecast probabilities are to the true probabilities. For a good forecast the *reliability* should be small. If the *reliability* is 0, the forecast is perfectly reliable. This term can also be explained via the **Reliability Diagram**. This diagram plots the observed frequency against the forecast probability. *Reliability* in this diagram is indicated by the proximity of the plotted curve to the diagonal which is a case when the observed frequency is the same as the forecast probability (i.e., *reliability* = 0 in equation (2)). The deviation from the diagonal gives the conditional bias. If the curve lies below the line, this indicates *over forecasting* (probabilities too high); points above the line indicate *under forecasting* (probabilities too low). The flatter the curve in the *reliability diagram*, the less *resolution* it has.

The *resolution* term is the difference between the observed frequency and the overall sample average frequency (base rate). This term measures the ability of the model to differentiate among several events. This means that the distribution of outcomes when "A" was forecast should be different from the distribution of outcomes when "B" is forecast. Even if the forecasts are wrong, the forecast system has *resolution* if it can successfully separate one type of outcome from another. The higher this term is the better. In the worst case, when the climatic probability is always forecast, the *resolution* is zero. In the best case, when the conditional probabilities are zero and one, the *resolution* is equal to the *uncertainty*. *Resolution* can also be visualized by using the **Relative Operating Characteristic (ROC)** curve. It is created by plotting the hit rate (probability of detection) versus the false alarm rate (probability of false detection). A good ROC is indicated by a curve that goes close to the upper left corner (low false alarm rate, high probability of detection). Diagonal line indicates no skill. ROC measures the ability of the forecast to discriminate between two alternative outcomes (i.e., either the forecast was a hit or a false alarm), thus measuring *resolution*.

The **area under the ROC** curve is frequently used as a score. The ROC area ranges from 0 to 1, 0.5 indicates no skill and 1 is a perfect score. ROC is not sensitive to any biases in the forecasts and therefore a forecast with high bias can still have a good ROC curve and the corresponding area under the curve will also be high.

The *uncertainty* term measures the inherent *uncertainty* in the event. For binary events, it is at a maximum when the event occurs 50% of the time and the *uncertainty* is zero if the event always occurs.

Table 2 gives the list of above mentioned scores, the range in which they vary and their values for best and worst forecasts.

Score	Range	Perfect Score	No Skill
BS	**0 to 1**	**0**	**1**
Area Under ROC	**0.5 to 1**	**1**	**0.5**

Table 2: Range, Perfect Score and No Skill values for BS and Area under ROC

4. WD cases and the NGEFS Forecasts:

In this section a brief discussion of three WD cases is presented. The dates chosen for this discussion are:

a. Day 6 forecast valid on 14-12-2014 and based on 8-12-2014 initial conditions

This was the first spell of WD observed during this season and lasted from 13th to 15th December 2014. The maximum rainfall observed (over a station) for this WD spell was 6.5 cm/day (NMSG). The time series plot, showing all the ensemble members, their mean and the observed rainfall, based on 8-12-2014 initial conditions is presented in Figure 1(a). The rainfall is averaged over the region mentioned in section 1. From this figure it is seen that most of the ensemble members are showing a peak in the rainfall suring 13th to 15th of December and it is matching well with the observations.

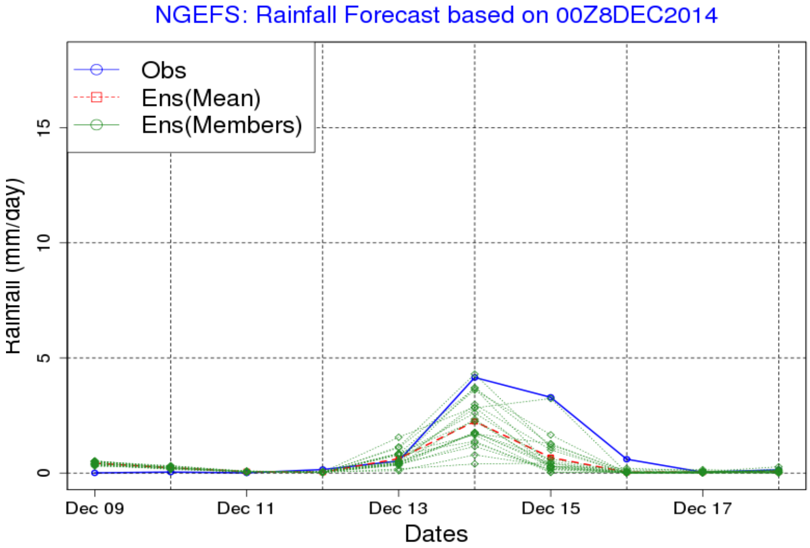

Figure 1(a): Time series plot of spatially averaged rainfall over northern India showing WD case observed during 13-12 to 15-12-2014

The spatial distribution of the observed/forecast rainfall and the probabilistic estimates are shown in Figure 1(b). These plots are valid for 14-12-2014 based on initial conditions of 8-12-2014. The first panel (*top left*) shows the average rainfall based on 20 NGEFS members. The second panel (*bottom left*) shows the probability of having 1-2 cm/day of rainfall. The third panel (*top right*) shows the probability of having 2-5 cm/day rainfall. The fourth panel (*bottom right*) shows the observed (NMSG) rainfall on 14th Dec2014. It is seen from the observed rainfall that the rainfall maxima over Himachal Pradesh is captured with reasonable accuracy in the mean rainfall plot. Also, this maxima is predicted with a high probability (upto 65%) in panel 3.

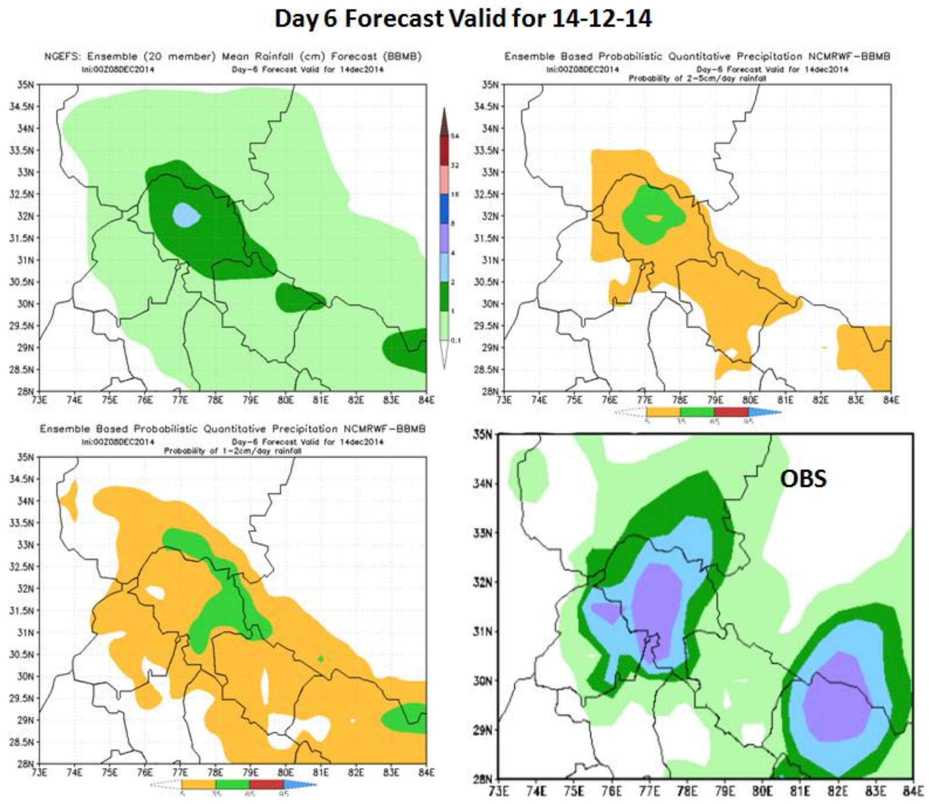

Figure 1(b): Probability of rainfall in 1-2 cm/day and 2-5 cm/day ranges valid for 14-12-2014 based on the initial conditions of 8-12-2014.

b. Day 7 forecast valid for 26-02-2015 based on 20-02-2015 initial conditions.

Figure 2(a) shows the time series plot (observed, NGEFS members and mean) of the rainfall spell associated with WD observed during 24th to 26th February 2015. This rainfall is based on the initial conditions of 20th February 2015. The maximum rainfall observed over a station for this WD spell was around 7.4 cm/day. The peak of rainfall in the observations is predicted by most of the ensemble members, but it has a lag of about one day.

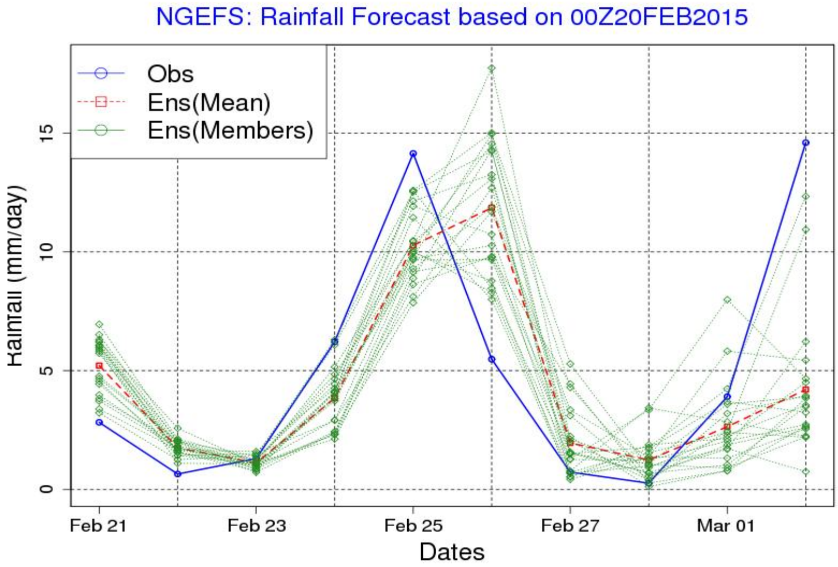

Figure 2(a): Time series plot of spatially averaged rainfall over northern India showing WD case observed during 24-2 to 26-2-2015

Figure 2(b) shows the observed and ensemble mean rainfall and the probability of rainfall in the 1-2 cm/day and 2-5 cm/day ranges over northern India. These plots are based on 18-02-2015 initial conditions and are valid for 26-02-2015. From these plots is seen that the location of the observed rainfall is predicted well by the model. It is also seen that the this rainfall over Himachal Pradesh, Uttarakhand and adjoining areas is predicted with more than 65% probability in the Day 8 forecast.

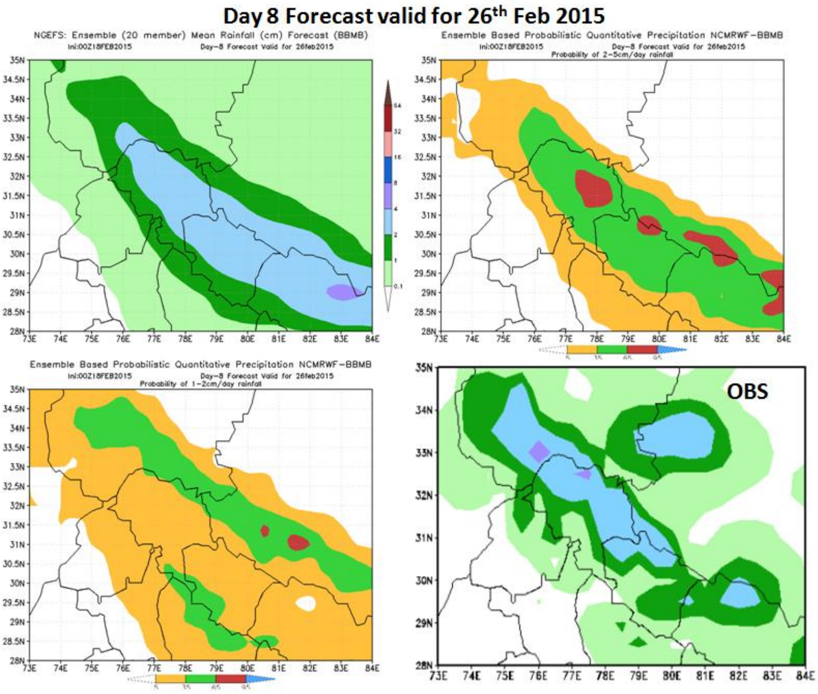

Figure 2(b): Probability of rainfall in 1-2 cm/day and 2-5 cm/day ranges valid for 26-2-2015 based on the initial conditions of 18-2-2015

Figure 3(a) shows the time series plot of the spell of WD observed during 2nd to 4th March 2015. The peak in the rainfall during 2nd March is seen in the figure, which corresponds with the WD episode. The maximum rainfall observed at a station was 11.3 cm/day. The peak rainfall in the observations is predicted by most of the ensemble members. However, some members are predicted this maxima with a lag of about one day.

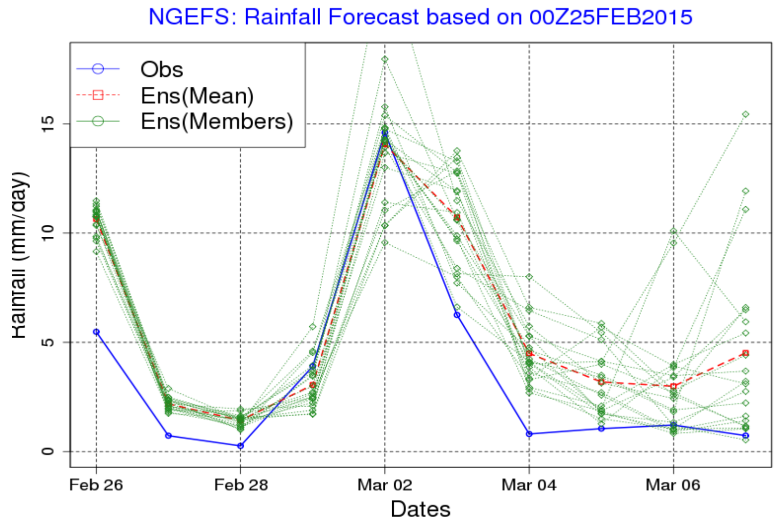

Figure 3(a): Time series plot of spatially averaged rainfall over northern India showing WD case observed during 2-3 to 4-3-2015

Figure 3(b) shows the spatial map of probability of rainfall in the 1-2 cm/day and 2-5 cm/day ranges. These plots are valid for 2-3-2015 based on initial conditions of 23-2-2015. The observations show a band of rainfall stretching from Jammu and Kashmir all the way to Uttarakhand. This pattren is captured reasonably well by the forecasts and the rainfall is predicted with up to 95% probability in the Day 7 forecast. The first panel (*top left*) shows the average rainfall based on 20 NGEFS members.

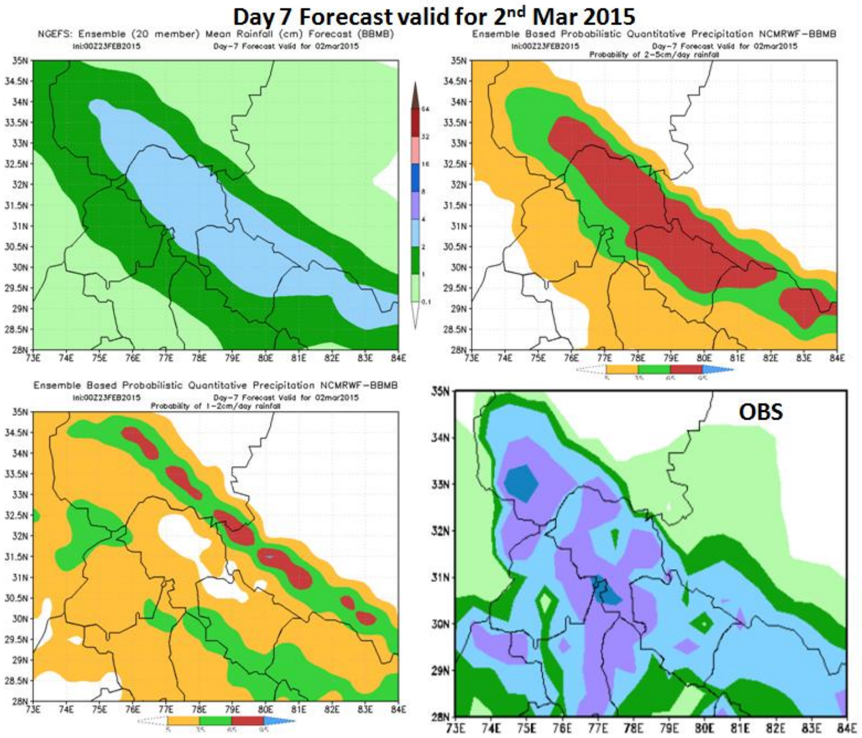

Figure 3(b): Probability of rainfall in 1-2 cm/day and 2-5 cm/day ranges valid for 2-3-2015 based on the initial conditions of 23-2-2015

5. Results and Discussion

For the purpose of verification we have chosen two variables i.e., the rainfall over northern India (70-80E; 27-37N) and snowfall over Jammu and Kashmir (74-79E; 31-34N).

5.1 Verification of Probabilistic Rainfall Forecast:

For the purpose of verification, the 24 hour accumulated Rainfall from December 2014 to March 2015 over northern India was chosen. The observed rainfall used for verification is the IMD-NCMRWF merged satellite gauge data (NMSG) (Mitra et al., 2009; 2013). The 24 hour accumulated rainfall (from all the 20 NGEFS members and observations) in this area was averaged over all the grid points for each day from December 2014 to March 2015. For verification different rainfall thresholds were chosen as 0.1mm, 1mm, 2mm, 5mm and 10mm.

The scores were calculated for all the thresholds. However, we are just presenting some of the scores and their interpretations as follows:

i. Brier Score

Figure 4 shows the BS values for all the rainfall thresholds and all forecast lead times. It is seen from the figure that higher thresholds have a better BS value (closer to 0) as compared to lower thresholds. It is also seen that except for 1 mm threshold the BS value remains almost comparable for all forecast lead times. However, for 1 mm threshold the BS value is increasing with increase in time. 10mm threshold has the lowest BS value followed by 5mm and 1 mm has the highest BS value.

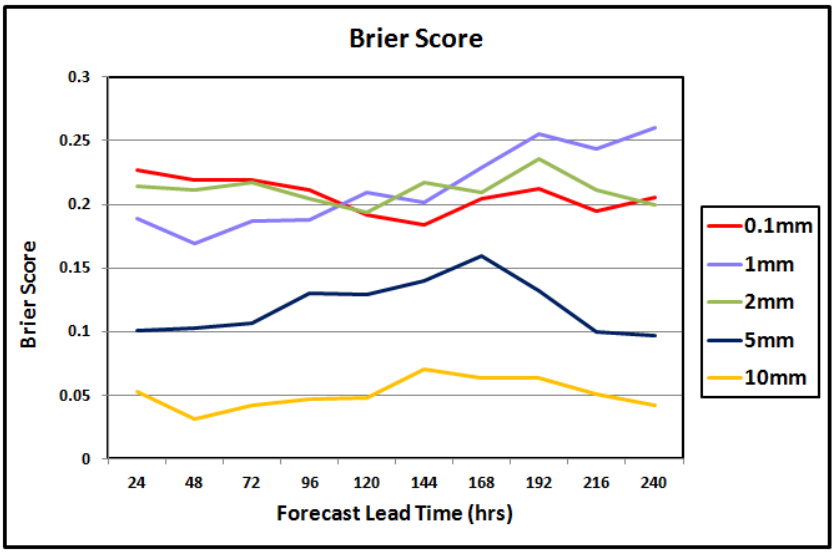

Figure 4: Brier Score for 0.1, 1, 2 5 and 10 mm rainfall thresholds

The components of the BS i.e., *reliability*, *resolution* and *uncertainty* for Day 8 to Day 10 forecasts are given in table 3 for 1 and 2mm/day rainfall threshold.

(a)	Day 8	Day 9	Day 10
BS	0.25	0.24	0.26
Rel	0.05	0.05	0.05
Res	0.04	0.04	0.03
Unc	0.24	0.24	0.24

(b)	Day 8	Day 9	Day 10
BS	0.24	0.21	0.20
Rel	0.07	0.05	0.03
Res	0.03	0.03	0.04
Unc	0.20	0.20	0.21

Table 3: Day 8 to Day 10 BS components for (a) 1 and (b) 2 mm/day rainfall threshold

From table 3 (a) it is seen that the *reliability* value is close to zero; which implies that the forecast probabilities are close to the observed frequencies. On the other hand the low *resolution* values indicate that the forecasts are not very different from the climatology.

Uncertainty values are seen to be high, which leads to a high BS value. From table 3(b) it is also seen that the BS values decrease with increase in forecast lead time, this implies that the model performs better with increase in lead time. This decrease in BS can be attributed to the decrease in the *reliability* term as the *resolution* and *uncertainty* terms remain the same from Day 8 to Day 9 and then increase from Day 9 to Day 10 forecasts.

Reliability Diagram

(a) For 1mm rainfall threshold Day 9 forecast

From Figure 5(a), which shows the attributes diagram (*reliability diagram*) it is seen that the curve in not flat which implies that the forecast has good *resolution* which implies potential skill associated with the forecast. It is also seen that for lower probabilities the points are lying closer to the diagonal as compared to higher probabilities. Fraction of verified cases are annotated by the numbers along the *reliability* curve. For example for the lowest forecast probability the fraction of verified cases is 21%, which are also significant. This shows that the model has better *reliability* in forecasting events with lower probabilities. Also, for these probabilities the line is slightly above the diagonal which implies under forecasting. As we move to higher probabilities it is seen that the model has a tendency to over forecast as the points are always below the diagonal.

(b) For 2mm Rainfall threshold Day 10 forecast

The *reliability* diagram for this threshold is seen in Figure 5(b). As in the previous case, here also it is seen that although the forecasts with lower probabilities have better *reliability* (as they lie closer to the diagonal line), they are still underforecasted. On the other hand, the forecasts with higher probabilities are being overforecasted.

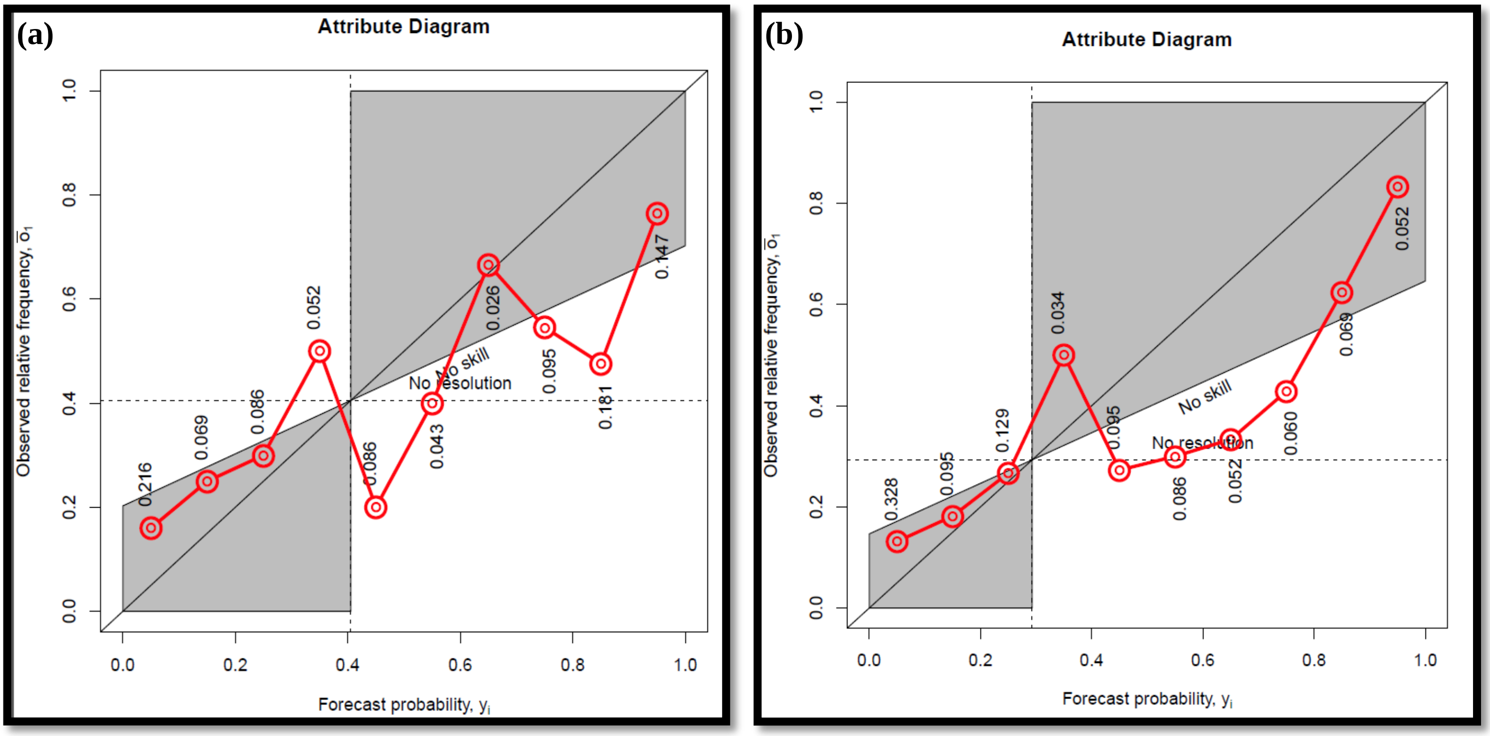

Figure 5: Attributes Diagram for (a) 1mm threshold Day 9 forecast and (b) 1mm threshold and Day 10 forecast

ROC

(a) For 1mm rainfall threshold Day 9 forecast

From Figure 6(a) which shows the ROC for 1mm threshold and Day 9 forecast, it is seen that the forecasts with lower probabilities have a high hit rate but also a higher false alarm rate. However, as the forecasts probabilities increase it is seen that the hit rate as well as the false alarm rate decreases.

(b) For 2mm Rainfall threshold Day 10 forecast

Figure 6(b) shows the ROC for 2mm threshold and Day 10 forecast. The figure and its interpretation are very similar to that of the previous case.

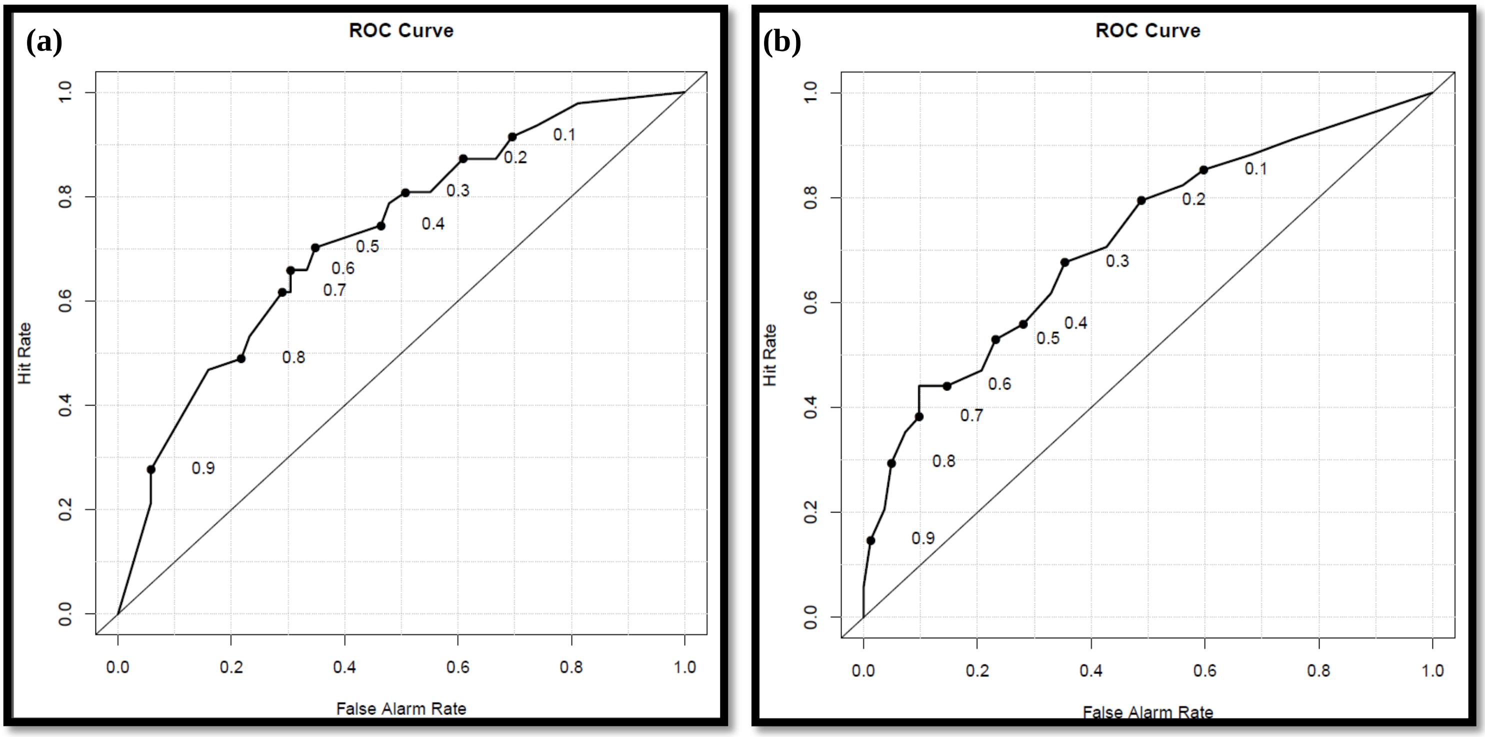

Figure 6: ROC for (a) 1mm threshold Day 9 forecast and (b) 2mm threshold and Day 10 forecast

Area under ROC curve

The area under the ROC curve should be maximum (1) for a perfect ROC curve. In the present case the area was calculated for all the rainfall thresholds and all forecast lead times. The results are presented in Figure 7.

It is seen from this figure that both the lowest (0.1mm) and the highest thresholds (10mm) show the lowest area among the 5 rainfall thresholds chosen for verification. The area under the ROC curve is seen to be the maximum for 1 mm (closest to 1). It is also seen that except for 5 and 10mm threshold the area under the ROC is decreasing with increase in forecast lead time. For 5 and 10 mm thresholds the area is increasing especially after day 7 forecast (168 hour).

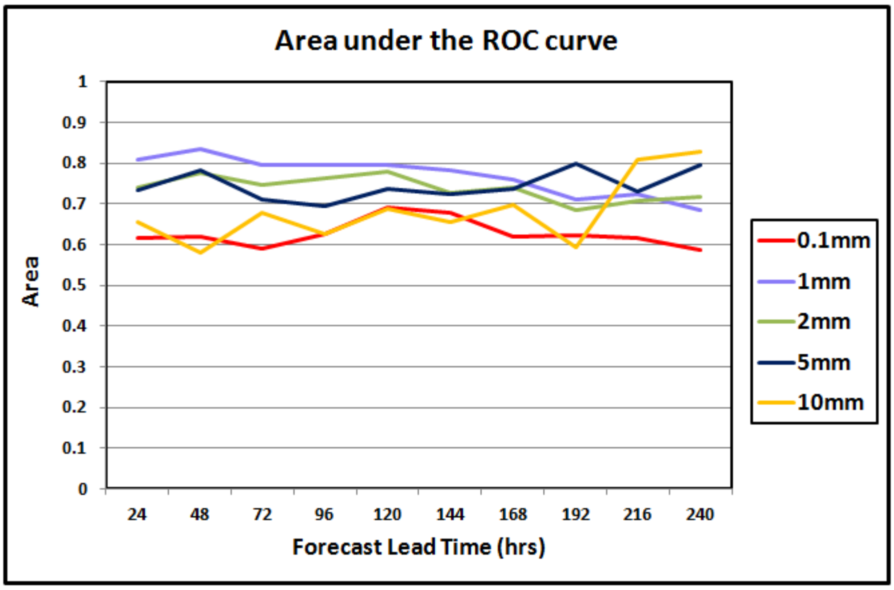

Figure 7: Area under the ROC for 0.1, 1, 2 5 and 10 mm rainfall thresholds

5.2 Verification of Probabilistic Snowfall Forecast:

For the purpose of verification of probabilistic snowfall forecast, the area considered is much smaller (74-79E; 31-34N). The snowfall probabilities are calculated using the forecast for snow depth variable from NGEFS for December 2014 to March 2015. The analysis for snow depth is taken from the corresponding NGEFS analysis for the same time period. For the purpose of verification snow depth forecast between 0.1 to 0.4 m and 0.5 to 0.9 m were considered. The verification is presented in the terms of Brier Score and Area under the ROC curve.

i. Brier Score

Figure 8 shows the BS for snow depth in the above mentioned ranges and for all forecast lead times. It is seen from the figure that the BS increases with the increase in forecast lead time. The BS is higher for the 0.5-0.9 m snow depth range as compared to 0.1-0.4 m snow depth. This implies that the performance of the model is better in the lower snow depth values as compared to the higher snow depth.

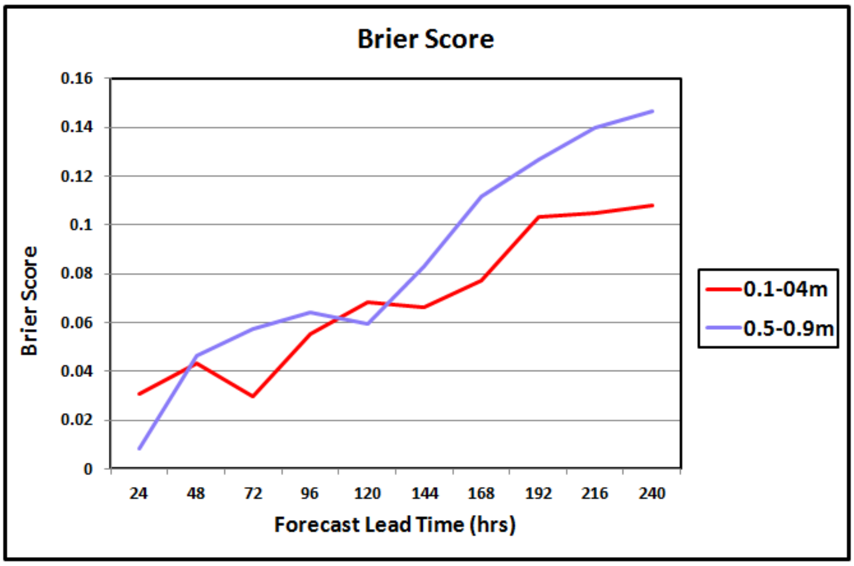

Figure 8: Brier Score for 0.1-0.4 m and 0.5-0.9m snow depth

ii. Area under the ROC curve

The area under the ROC curve for snow depth (both the ranges) is given in Figure 9. From this figure it is seen that the area under the curve for both the ranges is almost the same and very close to 1 (perfect score). This once again implies that even for a forecast which is not perfect the ROC and the area under the ROC curve can be good.

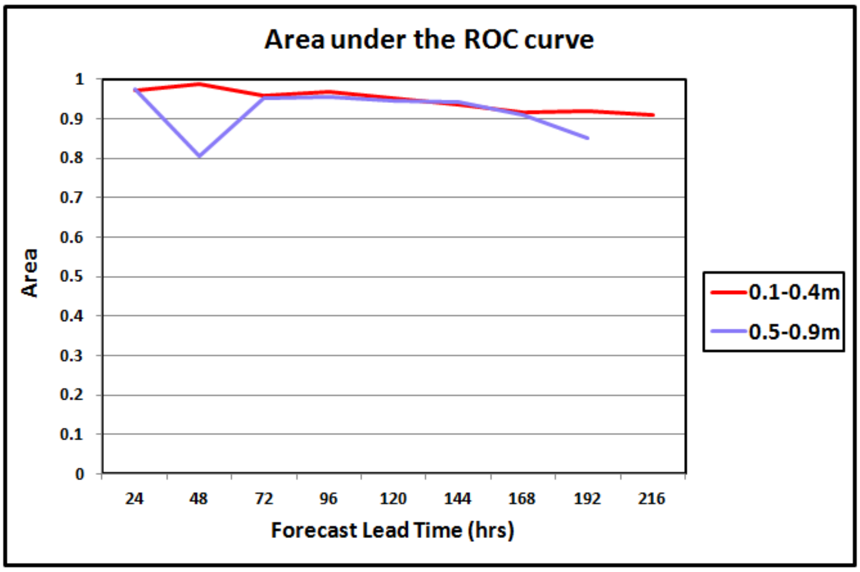

Figure 9: Area under ROC for 0.1-0.4 m and 0.5-0.9m snow depth

6. Conclusions:

Verification of probabilistic forecast for rainfall and snow depth was carried out for winter season of 2014-15 (December 2014 to March 2015). Some salient points from this study are:

1. Rainfall forecasts with lower probabilities (<0.4) have better *reliability* as compared to forecasts with higher probabilities (≥0.4). As indicated by the *reliability* diagram the

forecasts with lower probabilities are *under forecasted* and those with higher probabilities are *over forecasted*.

2. The ROC curves show that the forecasts with higher probabilities (≥0.7) have a low false alarm rate but also a low hit rate. On the other hand forecasts with lower probabilities (<0.4) have high hit rate but its effect is nullified because of a high false alarm rate.
3. Brier Scores values of 0.13 and 0.05 for 5 and 10 mm rainfall thresholds respectively, in the day 5 forecasts indicate promising skill of the forecast.
4. From decomposition of BS, it is seen that the major contribution to BS comes from the *uncertainty* term. The *reliability* values are low (~0.05 for 1 mm threshold) at all lead times, indicating promising skill of the forecast.
5. Similarly the area under the ROC curve for 5 and 10 mm rainfall threshold are 0.73 and 0.68 respectively. These values once again indicate the potential skill of the forecast.
6. Area under the ROC curve features relatively higher values (0.8) at higher lead times (beyond day 9) for 10 mm rainfall threshold. This indicates that for heavy rainfall forecasts at higher lead times have better predictability.
7. For snow depth verification, the BS values are seen to be increasing with increase in lead time indicating decreasing accuracy at higher lead time. .
8. The area under the ROC however remains close to 1 and is almost similar for both the ranges of snow depth.

This report is a preliminary effort to compile the verification results for ensemble based raw forecasts for rain and snow for one winter season. The present analysis reveals that there is potential skill in the forecasting system as indicated by the ROC and *Reliability* diagrams. The skill of the forecasts can be further improved via calibration. It should be noted that the results are constrained by the small sample size of one single season. Inclusion of higher number of forecasts will help in making the results robust. Further statistical post processing and application of downscaling methods will also help in generating value added products.

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