NMRF/RR/02/2023

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RESEARCH REPORT

Verification of Probabilistic Rainfall Forecasts of NCMRWF over Indian River Basins during Southwest Monsoon 2021

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Ministry of Earth Sciences
National Centre for Medium Range Weather Forecasting
Document Control Data Sheet

1	Name of the Institute	National Centre for Medium Range Weather Forecasting
2	Document Number	NMRF/RR/03/2022a
3	Date of Publication	February 2022
4	Title of the document	Verification of Probabilistic Rainfall Forecasts from NCMRWF over Indian River Basins during Southwest Monsoon 2021
5	Research Report	Verification Report
6	Number of pages, figures, and Tables	33 pages, 16 Figures
7	Authors	Anumeha Dube, Raghavendra Ashrit, Kondapalli Niranjan Kumar, Ashok K. Das, B.P. Yadav, A.K. Mitra
8	Originating Unit	National Centre for Medium Range Weather Forecasting (NCMRWF)
9	Abstract (brief)	In India River basins are lifelines for the agriculture dominated society. However, heavy rainfall events can cause flooding in these river basins and lead to heavy damage to life and property. In order to accurately forecast the stream flow from the rivers an accurate forecast of rainfall is required. In the current study we have carried out a verification of the probabilistic rainfall forecasts obtained from Global Ensemble Prediction system of NCMRWF (NEPSG) during the southwest monsoon of 2021. 14 FMOs and 3 river basins spread over the Indian land region are considered in this study. The observations are obtained as basin averaged values from IMD. Standard verification scores like BS, BSS, Reliability Diagram, ROC and AROC are used in the study to assess the performance of NEPSG forecasts. It was seen from the study that the model is better able to predict rainfall over most of the FMOs in the northern parts of India as compared to north-eastern or southern parts as they show a lower BS for both 10-25 and 25-50 mm/d thresholds. The BSS for the FMOs in the northern part is positive for all lead times. In the north-eastern part of India the heavier rainfall is better predicted. The model is also better able to forecast rainfall over the Ganga and Mahanadi river basins as compared to the Brahmaputra. Also, the CRPS of NEPSG is lower than MAE of NCUM indicating the better performance of EPS than the deterministic model in forecasting rainfall over river basins
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12	Distribution	

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Abstract

In India River basins are lifelines for the agriculture dominated society. However, heavy rainfall events can cause flooding in these river basins and lead to heavy damage to life and property. In order to accurately forecast the stream flow from the rivers firstly, an accurate forecast of rainfall over the river basins is required. In the current study we have carried out an in depth verification of the probabilistic rainfall forecasts obtained from Global Ensemble Prediction system of NCMRWF (NEPSG) during the southwest monsoon of 2021. 14 FMOs and 3 river basins spread over the Indian land region are considered in this study. The observations are obtained as basin averaged values from IMD. A comparison of MAE from NCUMG and CRPS from NEPSG shows that the CRPS is lower at all lead times than the MAE which is indicative of superior skill of the ensemble system as compared to the deterministic model at NCMRWF in predicting rainfall over the three river basins. Also, Ganga basin showed the lowest CRPS followed by Mahandi and finally Brahmaputra. This shows that the model has better capability in predicting rainfall over northern and central Indian River basins as compared to northeastern basins. Basin wise comparison of rainfall forecasts for Ganga, Brahmaputra and Mahanadi basins shows that the model is better able to predict rainfall over the Ganga and Mahanadi compared to Brahmaputra, which is seen from lower BS, higher BSS and better aligned reliability and ROC curves.

For the core monsoon region the verification of rainfall forecasts over the FMOs show that the model shows good forecasting skills in the northern region particularly for New Delhi, Agra, Lucknow. Rainfall forecasts for FMOs in the central part of India i.e., Ahmadabad, Hyderabad and Bhubaneswar show a higher BS. The model skill in predicting rainfall over these regions is also quite good in terms of having a high BSS. In the central parts namely:

Patna and Lucknow the model shows better skill in predicting heavier rainfall amounts (25-50 mm/d). Verification of rainfall forecasts in the FMOs of the northeastern parts of India show that lower rainfall is better predicted in FMO Guwahati whereas heavier rainfall events are better forecasted in Jalpaiguri and Asansol FMOs. For southern India it is seen that Bengaluru FMO shows a much better ROC and reliability as compared to Thiruvananthapuram.

Keywords: Ensemble Prediction System, River Basins, Probabilistic forecast verification

1. Introduction

Rivers and their tributaries are a lifeline for agriculture and livelihood over the Indian land region. They also provide water for the purpose of irrigation, hydroelectricity generation, fishing and aquaculture etc. The river basins of India are primarily classified as the Himalayan, Peninsular, coastal and inland-drainage basin rivers (Rai et al., 2011) .The main river basins of the Himalayas are the Indus, Ganga, and the Brahmaputra. These rivers are primarily snow-fed; however, higher monsoon rainfall amounts in these river catchments further add to their flow and may result in floods in several parts of North India during the monsoon season. On the other hand, the peninsular rivers such as the Godavari, Krishna, Cauvery, Narmada, Tapti, Narmada, Mahanadi, Damodar, etc are rain fed, and hence have a major flow during the monsoon season only. The coastal rivers found primarily on the west coast are short consisting of small catchments and episodic due to scant rainfall in drought years. The inland-drainage river basins are very few in numbers and they flow for a very short period. For example, the Sambhar River that vanishes in the desert sands, and the Luni that drains into the Rann of Kutch.

Being blessed with many rivers, it is also quite important to accurately provide hydrological forecasts over all the river catchments specifically for drought and flood information services. Quantitative Precipitation Forecast (QPF) from the numerical weather prediction (NWP) models remains the primary source of rainfall data for input into hydrological forecasting models. However, the performance of flood forecasts from such hydrological models is highly dependent on the accuracy of the rainfall distribution and intensity forecasts. It is well known that rainfall forecasts exhibit high spatial and temporal variability compared to other variables. This is especially observed during the southwest monsoon season over India. The India Meteorological Department (IMD) is the nodal agency for issuing the QPF for river basins/sub-Basins whereas the Central Water Commission (CWC) is the nodal agency for issuing the flood forecast in India. IMD issues the QPF forecasts through their field offices called 'Flood Meteorological Offices' (FMOs) during the flood season. There are nearly 14 FMOs along with DVC met service stations throughout the country. Through these FMOs IMD issues the sub-basin-wise QPF on an operational basis daily for the next 5 days (Yadav et al., 2022). The high resolution ensemble predictions systems (EPS) provide location specific probabilistic rainfall forecasts. These rainfall forecasts can be used in hydrological models to generate a probabilistic hydrological forecast which can provide a good insight into the uncertainty associated with these forecasts. Therefore in this report we evaluate the probabilistic rainfall forecasts obtained from NCMRWF Ensemble Prediction System (NEPSG) over the different river basins/sub-basins during the 2021 southwest monsoon.

1.1 Data and Methodology

1.1.1 Forecast and Observed Rainfall

The operational EPS at the NCMRWF (NEPSG) is adapted from the Met Office Global and Regional Ensemble Prediction System (MOGREPS). NEPSG, which is a global EPS, has been operational at NCMRWF since 2015. The current version of the NEPSG is a 23 member EPS with a horizontal resolution of ~12 km (N1024L70) with 70 vertical levels (Mamgain et al., 2018). The analysis perturbations in NEPSG are generated by Ensemble Transform Kalman Filter (ETKF) (Bowler et al., 2009) method four times a day i.e., for 00, 06, 12 and

18 UTC. Analysis perturbations are added to the reconfigured analysis obtained from the flow dependent, hybrid four-dimensional variational data assimilation system (hybrid-4DVar; Clayton et al., 2013) of Unified Model version 10.8 (UM10.8) operational at NCMRWF. Uncertainties in the forecasts also arise due to the parameterization of various physical processes and these are incorporated in the NEPSG using stochastic physics schemes that consist of "random parameters" (RP) (Bright and Mullen, 2002) and "Stochastic Kinetic Energy Backscatter" schemes (Tennant et al., 2011). The NEPSG model is integrated to produce a 10.5 day forecast only using 11 perturbed members from 00 UTC and again from 12 UTC (which is another set of 11 perturbed members) which is due to computational constraints. A 22 members lagged EPS is constructed at time 'T' by using 11 members from the current forecast and 11 members from the 'T+12' hour forecast (obtained from the 12 UTC run of the previous day). To this lagged ensemble the control member from the 00 UTC run is added to finally obtain a 23 members EPS. Further details about NEPSG can be obtained from Mamgain et al. (2018). NEPSG provides hourly rainfall forecasts which are then accumulated from 03 UTC to 03 UTC (to make a 24 hour accumulated rainfall). The rainfall forecasts from NEPSG are at a resolution of 12 km X 12 km over the Indian land region. These gridded rainfall forecasts are averaged over the individual sub-basins to obtain a rainfall forecast over these areas. For the purpose of verification of these rainfall forecasts the observed rainfall is obtained as a basin averaged value from the India Meteorological department. The spatial domain considered in the current work ranges from 68.0 ° to 97.0 ° E and from 8.0 ° to 38.0 ° N (Figure 1) which is the Indian land region.

2.2 Verification area

The forecast performance of NEPSG in predicting the probabilistic rainfall over different FMOs and three river basins, namely the Ganga, Brahmaputra and Mahanadi, is evaluated in this study. There are 14 different FMOs along with DVC met service stations. The boundaries defined for various FMOs throughout the country by the IMD are depicted in Figure 1. Figure 1 also indicates the boundaries of different basin/sub-basins. The names of these different basins and sub-basins categorized under each FMO are given in Annexure-I. A detailed account of river basins/sub-basins in respective FMOs/DVC can be found in Yadav et al., 2022.

The verification is carried out by comparing the sub-basin wise observed and forecasted rainfall within each of the FMOs listed in Figure 1. The results of verification are further summarized by comparing the river basins within FMOs which may receive homogeneous rainfall and are affected by similar weather patterns causing rainfall during the southwest monsoon season. For example: FMO Agra, Ahmadabad, Bhubaneswar, Lucknow, New Delhi, Patna and Hyderabad are included in the Core Monsoon region. This zone is more affected by the monsoon depressions and lows and consists of flat regions. FMOs Bengaluru and Thiruvananthapuram are mostly affected by the monsoon current and rainfall in these regions is also affected by orography. Similarly the FMOs Guwahati, DVC, Asansol and Jalpaiguri are affected by the monsoon depressions but the rainfall in these regions is also affected by orography.

2.3 Verification methodology

In general, it is not possible to verify the probabilistic forecasts using standard metrics (root mean squared error, bias, equitable threat score (ETS)) routinely applied for deterministic forecasts. Also, probabilistic forecasts cannot be verified directly against observed quantities; instead, they are verified against binary observations, i.e. based on the occurrence of an event the observation is 1, and for non-occurrence it is 0. For forecast verification, the sample set should always be sufficiently large in order to get more reliable statistics.

Several scores are available for the verification of probabilistic forecasts. However, in the present study, the BS, BSS, ROC curve, A_{ROC} and the reliability diagram were used. A brief description of these scores is presented here.

The BS measures the mean squared error in probability space (Brier, 1950) and is given by the formula:

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

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

The BS measures the accuracy of the forecast and does not convey any information about its actual skill. The BSS, on the other hand, measures the improvement of the probabilistic forecast relative to a reference forecast (usually the long term or sample climatology). In the present study the sample climatology was used for calculation of the BSS.

The BS can also be decomposed into three components: reliability, resolution and uncertainty (BS = REL − RES + UNC) (Murphy, 1973). The reliability term measures how close the forecast probabilities are to the observed frequencies; hence, reliability is 0 for a perfect forecast. This term can also be explained via the reliability diagram which plots the observed frequencies against the forecast probabilities. Reliability in this diagram is indicated by the proximity of the plotted curve to the diagonal. Over forecasting is indicated if the curve lies below the diagonal, whereas a curve lying above the diagonal indicates under forecasting. A flat curve implies lesser resolution.

The resolution term measures the ability of the model to differentiate (resolve) between several events. For a perfect forecast, the resolution is equal to the uncertainty. The resolution can also be visualized by using the ROC curve which plots hit versus false alarm rate, hence discriminating between two different outcomes (Swets, 1973). A good ROC is indicated by a curve that is close to the upper left corner of the diagram (low false alarms, high hits). When the ROC curve lies close to the diagonal the hit and false alarm rates are equal and the forecast system has no skill. If the curve lies below the line, negative skill is indicated (Mason and Graham, 1999).

The AROC can be defined as the likelihood that the forecast probability issued for the occurrence of an event is greater than that for the non-occurrence (Mason and Graham, 2002). The AROC ranges from 0 to 1, 0.5 indicating no skill and 1 being a perfect score. The third term in the decomposition of BS is the uncertainty, which depends only on the observations and does not convey any information about the forecast quality.

The Continuous Ranked Probability Score (CRPS) is a much used measure of performance of the probabilistic forecast of a scalar observation. It is a quadratic measure of difference between the forecast cumulative distribution function (CDF) and the empirical CDF of the observations (Zamo et al., 2018 and Hersbach, 2000).

Let X be a random variable. Let F be the cumulative distribution function (CDF) of X, such as $F(y) = P[X \leq y]$.

Let x be the observation, and F the CDF associated with an empirical probabilistic forecast. The CRPS between x and F is defined as:

$$CRPS(F,x) = \int_{-\infty}^{\infty} (F(y) - \mathbb{1}(y-x))^2 \, dx \qquad (2)$$

Where $\mathbb{1}$ is the Heaviside step function and denotes a step function along the real line that attains:

- the value of 1 if the real argument is positive or zero,
- the value of 0 otherwise.

The CRPS generalizes the mean absolute error; in fact, it reduces to the mean absolute error (MAE) if the forecast is deterministic.

3. Results and Discussions

In the current study we have tried to verify basin-wise rainfall forecasts with the available observations for the southwest monsoon season of 2021. We have used standard verification metrics i.e., BS, ROC and reliability curve (defined above) for the purpose of verification of the NEPSG forecasts. The two events considered for verification are rainfall lying in the ranges 10 - 25 mm/d and 25-50 mm/d.

a) Region wise comparison

Core Monsoon Region

Figure 2 shows the comparison of BS obtained for the Day-1, 3 and 5 forecasts among the FMOs present in the Core Monsoon region. It is seen from this figure that the BS is smaller for the heavier rainfall events (25-50 mm/d) for all lead times and all FMOs. Among the FMOs it is seen that the lowest BS is exhibited by New Delhi and Agra FMOs. On the other hand the highest BS is seen in the Ahmedabad, Bhubaneswar and Hyderabad FMOs. In order to assess the skill of the model we have also compared the BSS (calculated by using the sample climatology) for the different FMOs (Day-1, 3 and 5 forecasts). These results are presented in Figure 3. From this figure it is seen that the BSS values decrease with increasing lead time. Also, the New Delhi FMO which showed one of the lowest BS values shows the highest BSS for rainfall in the range 10-25 mm/d. However, for heavier rainfall lying in the range 25-50 mm/d the Day-3 and 5 BSS for New Delhi is negative showing poorer skill than climatology. Negative BSS values are also seen for Ahmedabad in the Day-1 forecast for rainfall in 10-25 mm/d range. Negative BSS values are also seen for Bengaluru, Thiruvananthapuram, Guwahati and Hyderabad and these FMOs also showed higher values of the BS (Figure 2).

The ROC and reliability for the 10-25 and 25-50 mm/d rainfall thresholds in the Core monsoon region are presented in Figure 4 and 5 (a,b). Although the ROC and reliability curves are obtained for all lead times, we are only presenting these curves only for Day-1, 3 and 5 forecasts. It can be seen from this figure that the ROC curves for all the FMOs at all lead times and both rainfall thresholds are away from the diagonal line of no skill. This implies that the model has good resolving skills. Also for the lower rainfall thresholds i.e., 10-25 mm/d the curves for FMOs New Delhi and Agra are closer to the top left whereas, the curves for Bhubaneswar and Lucknow FMOs are closer to the no skill line. For the higher rainfall thresholds the curves for Bhubaneswar, Patna and Lucknow are closer to the top left whereas New Delhi and Agra show a poorer ROC curves. This shows that the lower rainfall amounts are better predicted in the Northern parts of India whereas heavier rainfall amounts are better predicted in the east central parts of India. Figure 5(a,b) shows the reliability curves for the above mentioned FMOs, thresholds and lead times. For lower rainfall thresholds the model is underpredicting rainfall for lower probabilities (<0.6) (line above the diagonal) for most of the FMOs except Hyderabad and Ahmedabad. Reliability curve for the rest of the FMOs lie very close to the diagonal line of perfect reliability particularly for Patna and Lucknow. Also, the curves follow a zig-zag shape which is typical for a small data set. For higher rainfall amounts it is seen that only for very low probabilities (<0.3) the reliability curve lies closer to the diagonal line particularly for Lucknow, Patna and Agra FMOs. New Delhi and Hyderabad FMOs show over prediction for forecasts made with probabilities exceeding 0.2 for all lead times. One reason for the over-confidence noted in the reliability diagram may be attributed to the finite size of the ensemble. The contribution is more significant for smaller ensemble size and for events with smaller probability (Richardson, 2001).

Northeast India

The FMOs included within the region are: Guwahati, Asansol, Jalpaiguri and DVC. It is seen from Figure 2 that the BS for DVC is the lowest for both rainfall thresholds followed by Asansol. Guwahati and Jalpaiguri both have higher BS which are comparable to each other at all lead times. BSS presented in Figure 3 shows that the values are negative for FMO Guwahati for all lead times and both thresholds which is indicative of a very poor skill of the model in predicting rainfall over this region. The FMO DVC shows positive BSS for lower rainfall thresholds but negative BSS for higher rainfall. In contrast the Jalpaiguri FMO shows better skill (positive BSS) for higher rainfall amounts at all lead times and negative BSS for lower rainfall (except in the day-1 lead time). For Asansol the BSS is positive for both teh thresholds except in the Day-3 forecast.

Figures 6 and 7 show the ROC and the reliability diagram for the FMOs in the Northeast region. It is seen from Figure 6 that for 10-25 mm/d rainfall threshold the FMO Guwahati shows better ROC (away from the diagonal line) and Jalpaiguri shows the curve which is closest to the diagonal line. For 25-50 mm/d rainfall amounts the ROC curve for all the FMOs is further away from the diagonal as compared to the lower rainfall amounts. Out of all the FMOs Jalpaiguri shows the best ROC curve (closer to the top left corner). This shows that the model has better resolving capabilities in the case of higher rainfall in the Northeastern parts of India. The reliability diagrams of Figure 7, for FMOs in Northeast India for the above two ranges shows that for lower rainfall amounts the model is overpredicting the events forecasted with higher probabilities. Whereas for events made with lower probabilities the reliability curve is aligned along the diagonal line of perfect reliability. For 25-50 mm/d range the FMO Asansol shows the reliability curve which is very close to the diagonal line whereas Guwahati and Jalpaiguri FMOs show over prediction for events forecasted with high probabilities.

This shows that heavier rainfall events are better forecasted in the Northeast regions particularly in Jalpaiguri and Asansol FMOs.

South India

The FMOs included within this region are Bengaluru and Thiruvananthapuram. From Figure 1 it is observed that the BS for Bengaluru is lower than Thiruvananthapuram for all lead times and rainfall thresholds. The BS for 25-50 mm/d range is lower than 10-20 mm/d rainfall amount. The BSS (Figure 2) shows that for Bengaluru the score is positive for higher rainfall amounts and negative for lower rainfall. Also, for Thiruvananthapuram the BSS is negative at all lead times and both thresholds. This implies that the model shows more skill in predicting higher rainfall amounts over Bengaluru.

The ROC and reliability for FMOs in this region are presented in Figure 8 and 9 respectively. From Figure 8 it is clearly seen that the model has no skill in predicting rainfall over Thiruvananthapuram as the ROC curve is aligned along with the diagonal line of no skill. Similarly in the case of reliability seen in Figure 9, the curve for Bengaluru is closer to the diagonal line of perfect reliability particularly for both rainfall ranges (except Day-3 forecasts for 25-50 mm/d range). For forecasts made with lower probabilities the reliability curve is almost perfectly aligned with the diagonal but for events associated with higher probabilities the model tends to over forecast for lower rainfall amounts and under forecast for heavier rainfall.

b) Basin wise comparison

In this study we have also carried out the verification of probabilistic rainfall forecasts over three individual river basins namely; Ganga, Brahmaputra and Mahanadi. The analysis is carried out for three ranges i.e., rainfall < 10mm/d, 10<rainfall<25 mm/d and 25<rainfall>50 mm/d. Figure 10 shows the BS, reliability and resolution as components of BS, AROC and BSS for the Ganga river basin. It is seen from the figure that the model shows lowest BS for the 25-50 mm/d rainfall. Highest BS is shown for the lowest rainfall amount. The AROC for heavier rainfall ranges from 0.95 to 0.85 at all lead times which is higher than the other two rainfall thresholds. The BSS on the other hand shows higher values for low rainfall amounts (<10mm/d). BSS for the other two ranges is comparable. As expected all the verification scores show decay with lead time. Figure 11 (a and b) shows the reliability and ROC curve for the above three thresholds respectively. It is seen from the figure (11(a)) that the reliability curves of the events forecasted with lower probabilities for all three ranges shows a good alignment with the diagonal line of perfect reliability. However, for 25-50 mm/d range particularly in the Day-1 and 3 forecasts the events forecasted with higher probabilities are over forecasted (the observed probability is very low and the forecast probability is around 0.3). For lower rainfall amounts the curve is well aligned with the diagonal for all forecast probabilities and lead times. The ROC curves as seen from Figure 11(b) indicate that the model has good resolving skills for all thresholds but the curve for the heavier rainfall amounts is further away from the diagonal line of no skill.

Figure 12 shows the various verification scores for the Brahmaputra river basin. It is seen from this figure that similar to the Ganga river basin the model shows higher skill in predicting heavier rainfall amounts with lower BS and higher AROC as well as BSS. Figure 13 (a and b) shows the reliability and ROC curves for this basin and it is seen that except for the lowest rainfall threshold (<10 mm/d) all the other rainfall amounts show poor reliability (over forecasting and flat curves) and ROC curves (close to the diagonal line of no skill).

Figure 14 shows the verification scores for the Mahanadi river basin. The results are very similar to the Ganga river basin with the model performing better in predicting heavier rainfall amounts. Also, from Figure 15 (a and b) it is seen that the reliability curve for all thresholds is much closer to the diagonal line and the ROC curve is also further away from the no skill line.

It can be concluded from this analysis that in all the three basins NEPSG model shows better skill in predicting heavier rainfall amounts.

Figure 16 shows a comparison of the MAE obtained from rainfall forecasts over the river basins from the NCMRWF Unified Model (NCUMG) and the CRPS obtained for the probabilistic rainfall forecasts obtained from the NEPSG. It is clearly seen from the figure that the MAE from NCUMG is higher than the CRPS from NEPSG at all lead times indicating that the ensemble prediction system shows more skill in predicting rainfall over river basins as compared to the deterministic NCUMG model. Among the river basins the CRPS and the MAE for the Ganga river basin is the lowest followed by Barhmputra and finally Mahanadi has the highest scores. This indicates that the model has better skill in predicting rainfall over the Ganga river basin and poorer skill in forecasting rainfall over the Mahanadi river basin.

4. Conclusions

In the current study we have carried out an in depth verification of the probabilistic rainfall forecasts obtained from NEPSG during the southwest monsoon of 2021. For this purpose the basin wise average of the daily rainfall forecasts from NEPSG were obtained for the 14 FMOs and 3 river basins i.e., the Ganga, Brahmaputra and Mahanadi. For this purpose the observations are obtained as basin averaged values from IMD. Standard verification scores like for probabilistic forecast verification are used in the study to assess the performance of NEPSG forecasts. Salient conclusions drawn from this study are presented here:

A comparison for forecasting capabilities of the deterministic model NCUMG and EPS NEPSG in predicting rainfall over three river basins i.e., Ganga, Mahanadi (in the core monsoon region) and Brahmaputra (northeastern region) has been carried out. In this a comparison of the MAE obtained from NCUMG and CRPS from NEPSG have been compared. It was seen that at all lead times in the three river basins the CRPS from NEPSG was lower than the MAE from NCUMG. Also among the three river basins the Ganga river basin has the lowest CRPS followed by Mahanadi and finally Brahmaputra. It can be concluded from this study that for the rainfall forecasts during the southwest monsoon season of 2021, NEPSG has better forecasting skills till day-5 lead time in the three river basins as compared to NCUMG. Basin wise comparison of rainfall forecasts for Ganga, Brahmaputra and Mahanadi basins shows that the model is better able to predict rainfall over the Ganga and Mahanadi which are included in the core monsoon region as compared to Brahmaputra which is included in the northeastern region, which is seen from lower BS, higher BSS and better aligned reliability and ROC curves.

For the core monsoon region the verification of rainfall forecasts over the FMOs show that the FMOs in the northern region namely: New Delhi, Agra, Lucknow show the lowest BS which is indicative of a good match between forecast probabilities and observed frequencies for low as well as high rainfall amounts. FMOs in the central part of India i.e., Ahmadabad, Hyderabad and Bhubaneswar show a higher BS as compared to the FMOs in northern regions. The model skill in predicting rainfall over these regions is also quite good in terms of having a high BSS. Also, the analysis of ROC and reliability curves shows that the model has good skill in predicting lower amounts of rainfall in the northern parts of India. Whereas in the central parts namely: Patna and Lucknow the model shows better skill in predicting heavier rainfall amounts (25-50 mm/d).

Verification of rainfall forecasts in the FMOs of the northeastern parts of India show that lower rainfall is better predicted in FMO Guwahati whereas heavier rainfall events are better forecasted in Jalpaiguri and Asansol FMOs due to better reliability and ROC curves. This is also seen in the higher BSS and lower BS for heavier rainfall events for Jalpaiguri and Asansol as compared to Guwahati.

For southern India it is seen that Bengaluru FMO shows a much better ROC and reliability as compared to Thiruvananthapuram which is also seen in a negative BSS and highest BS Thiruvananthapuram. Therefore it can be concluded that the model has no skill in predicting rainfall over the Thiruvananthapuram region.

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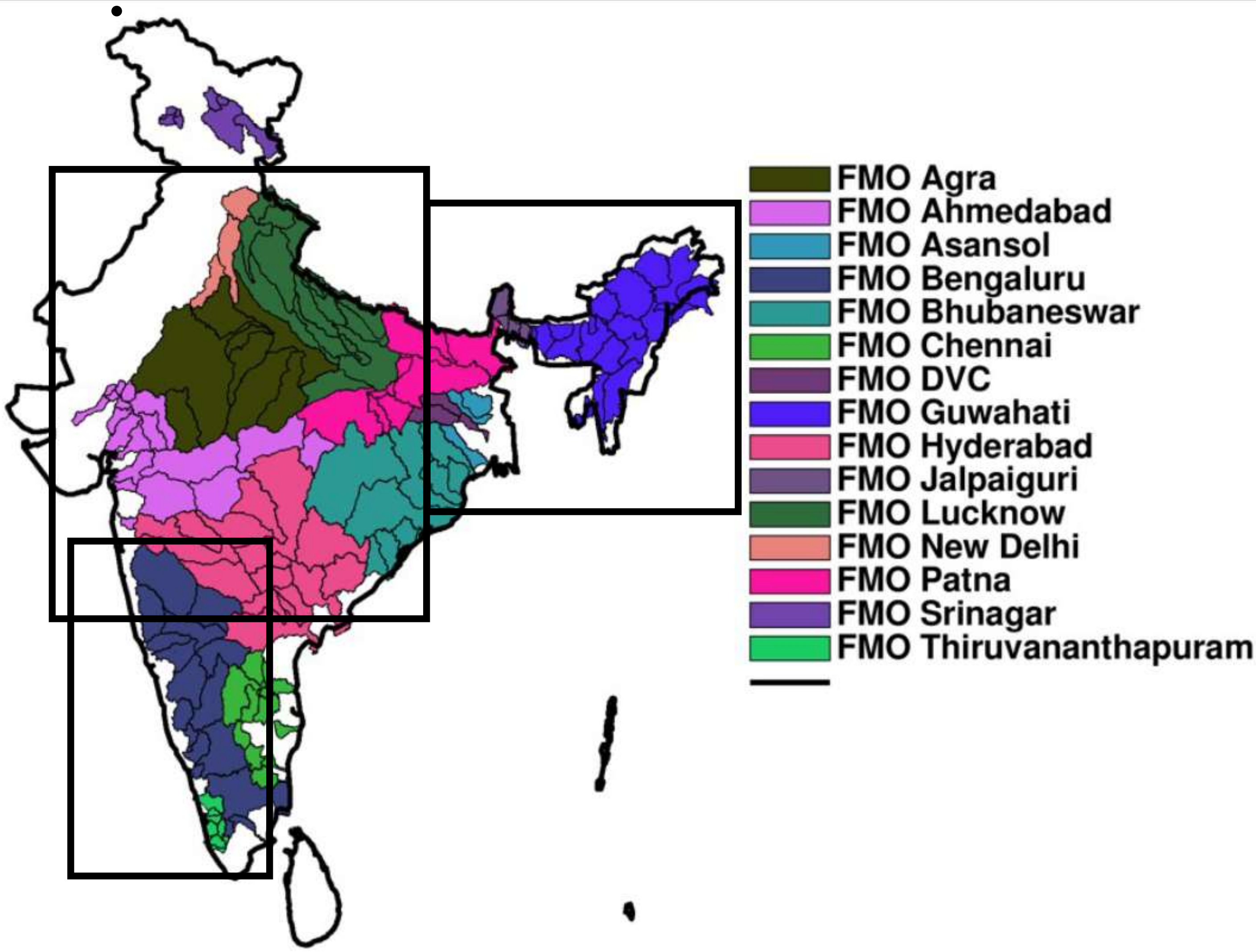

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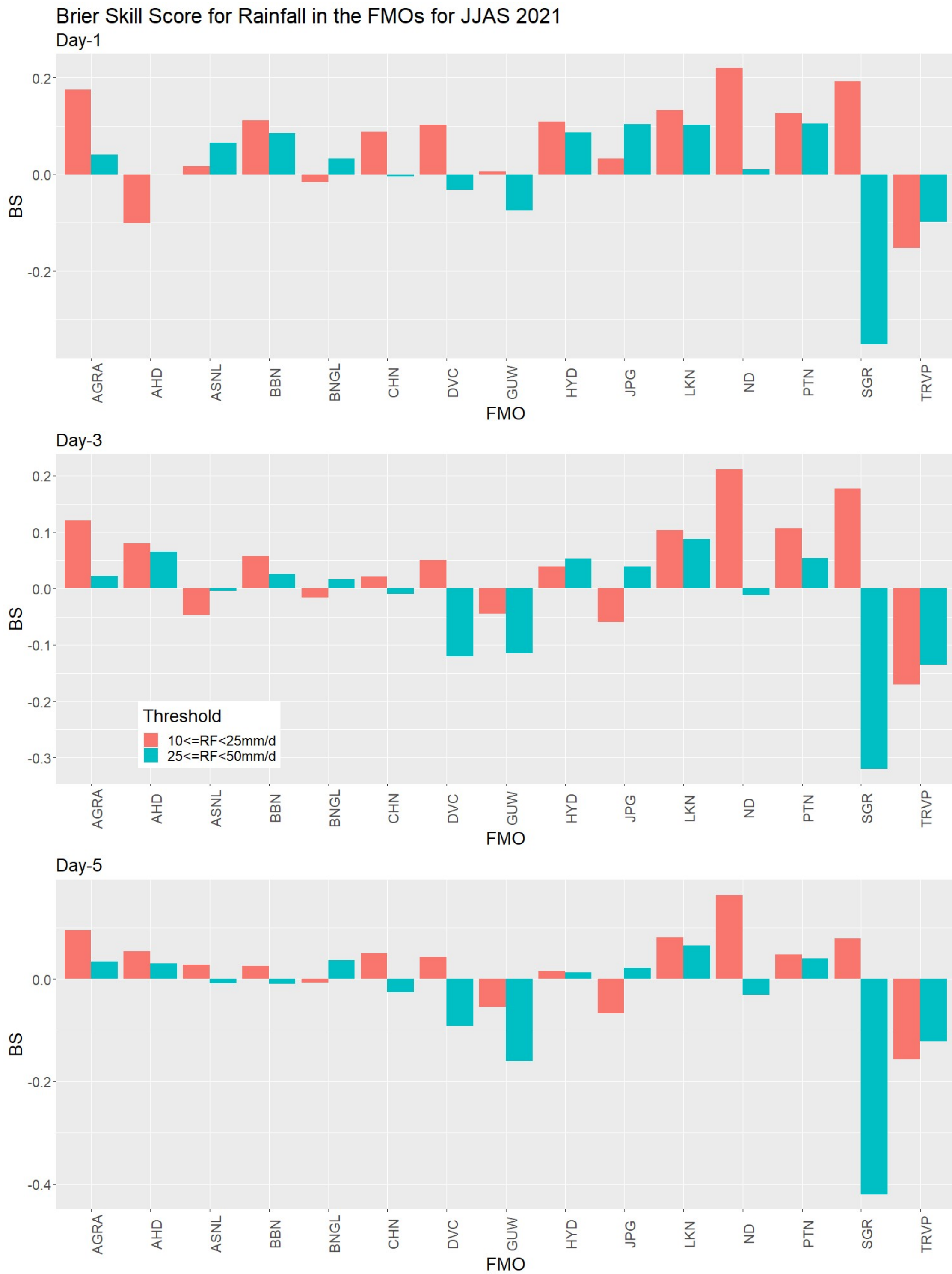

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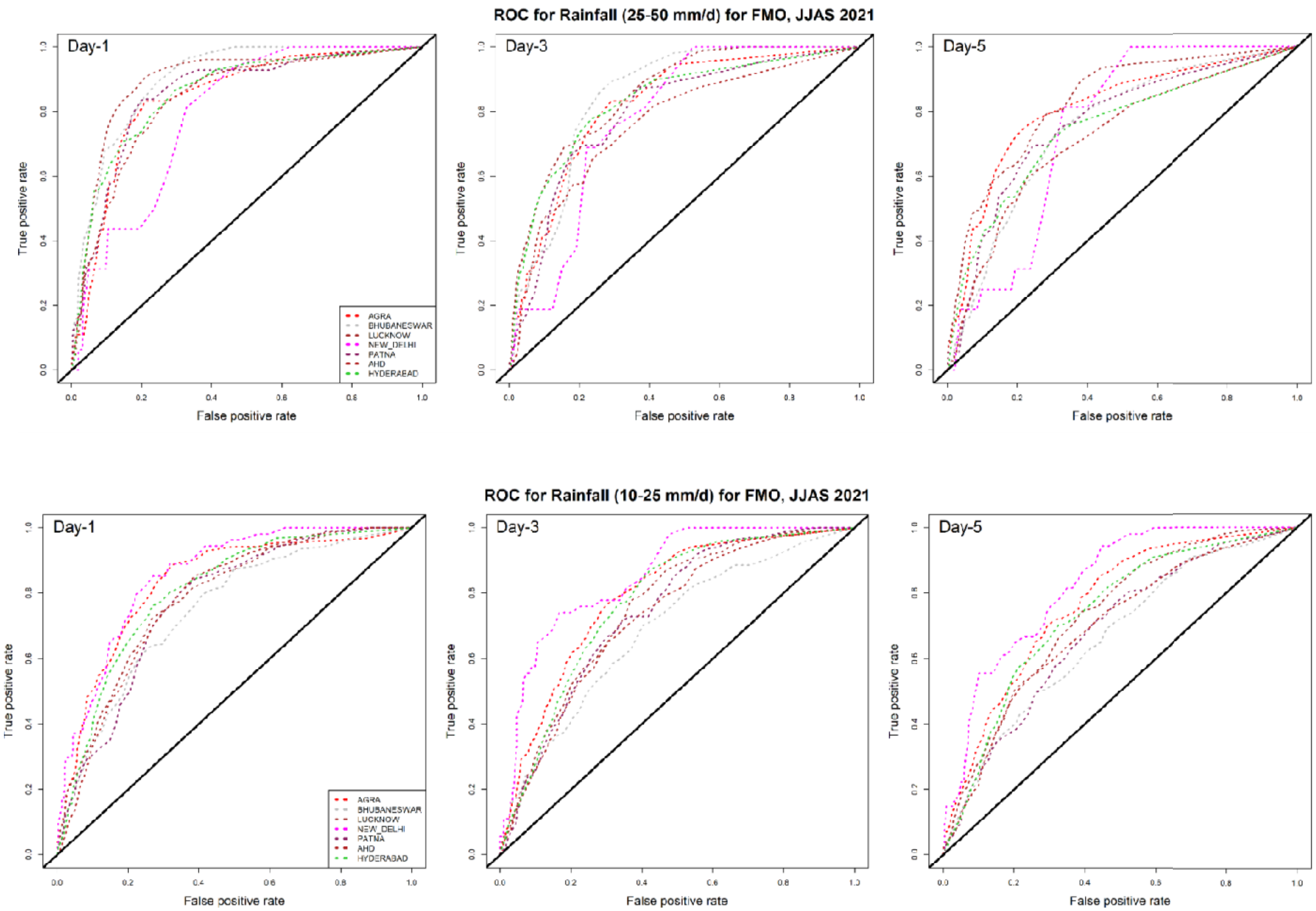

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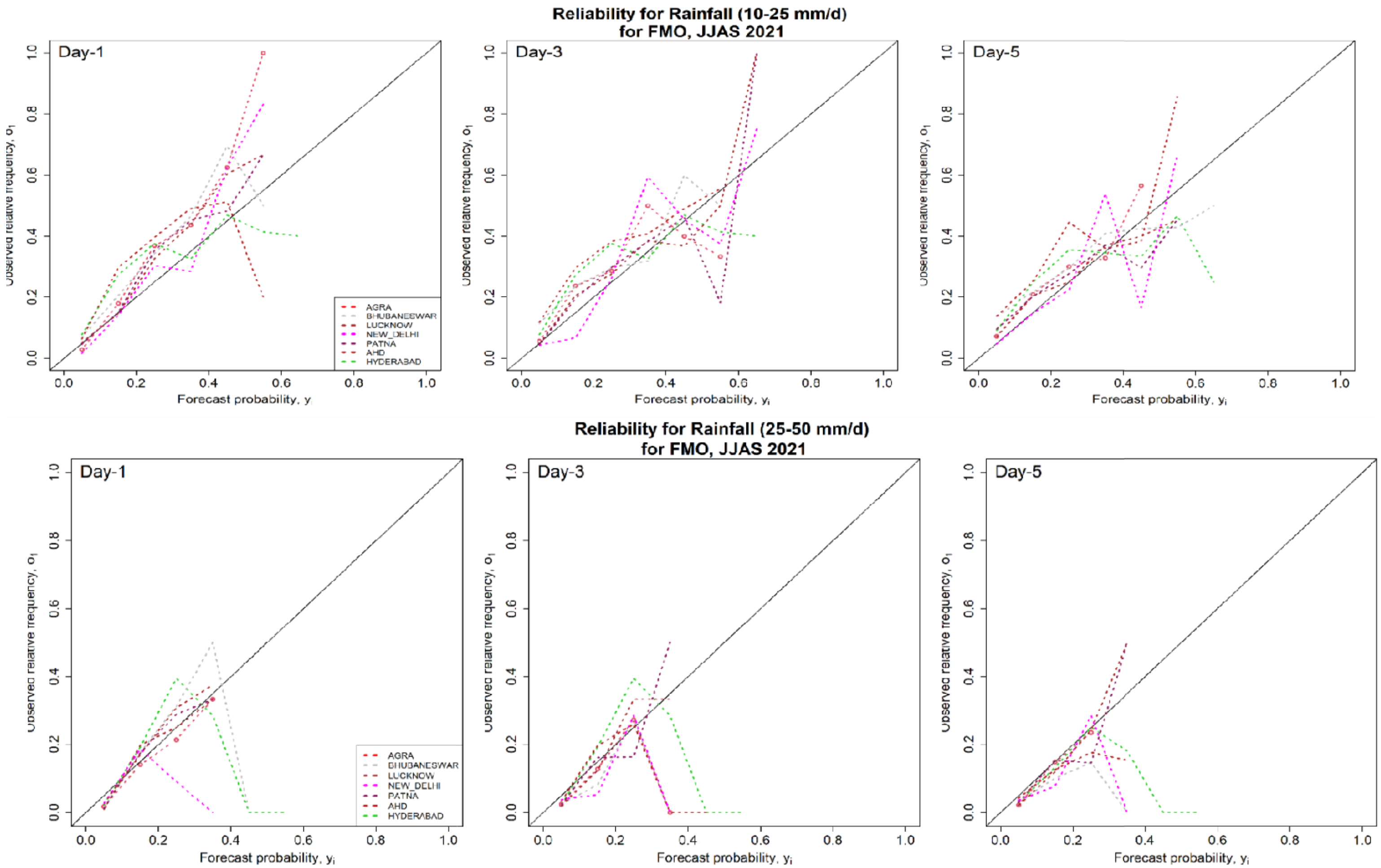

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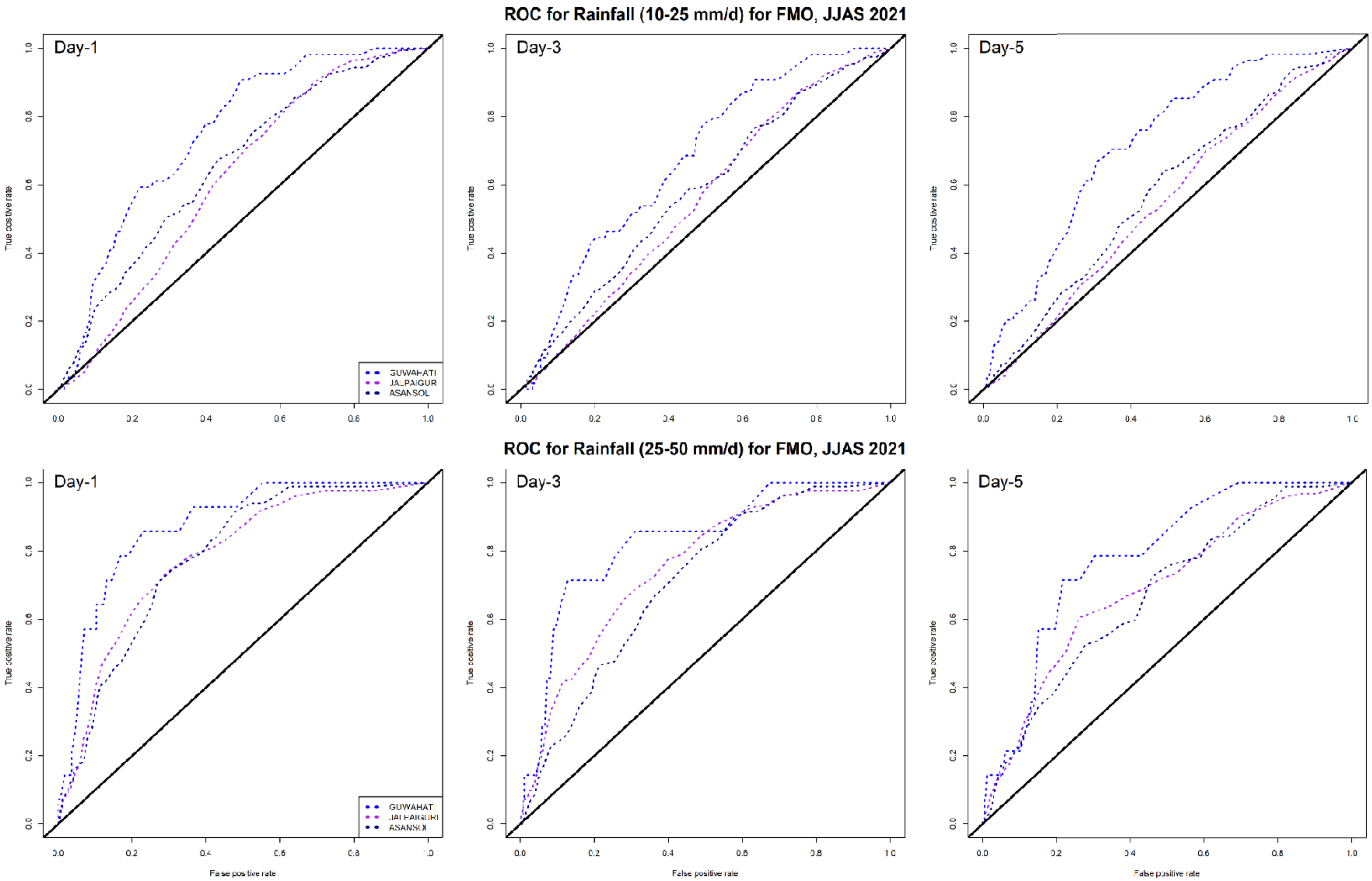

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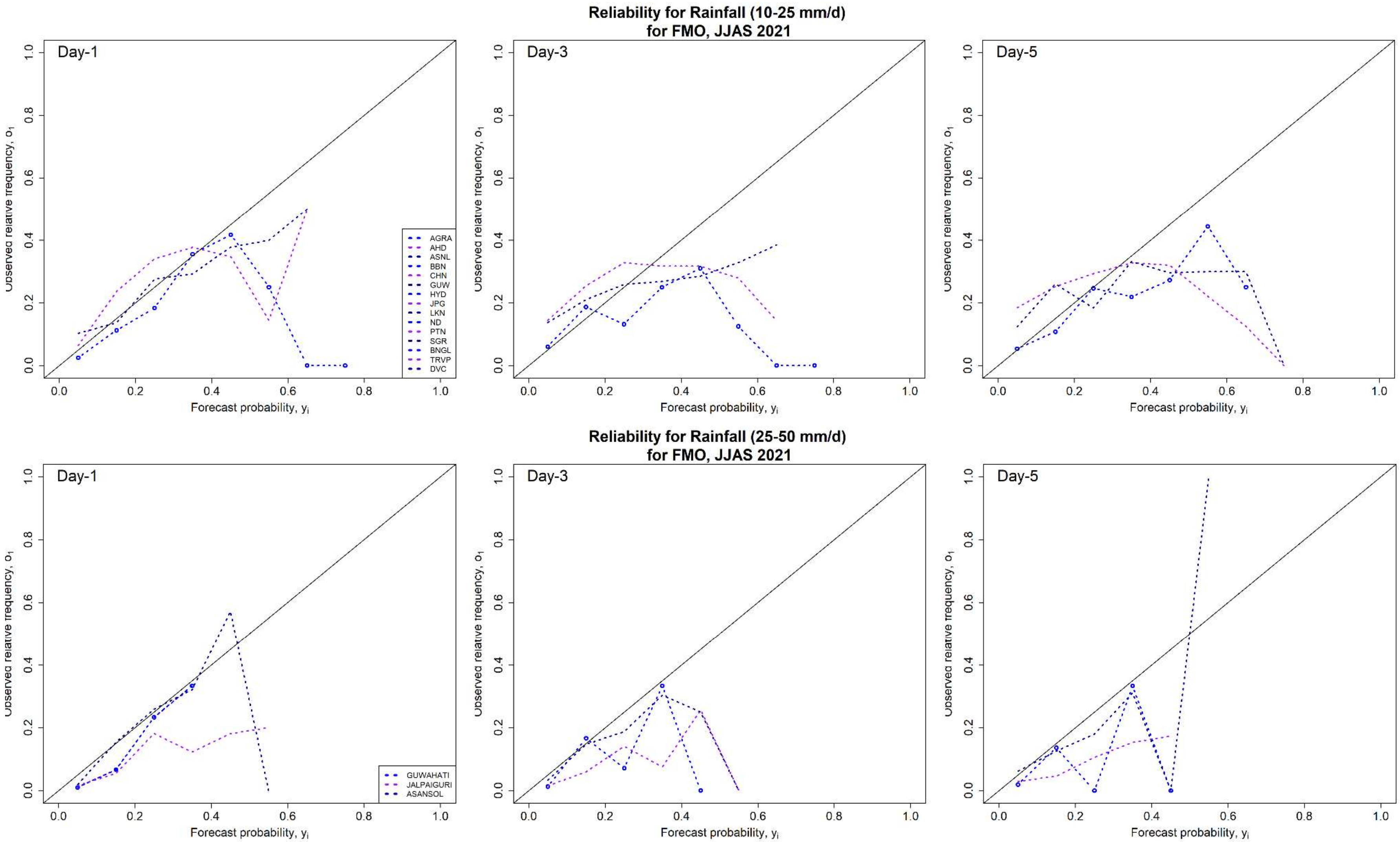

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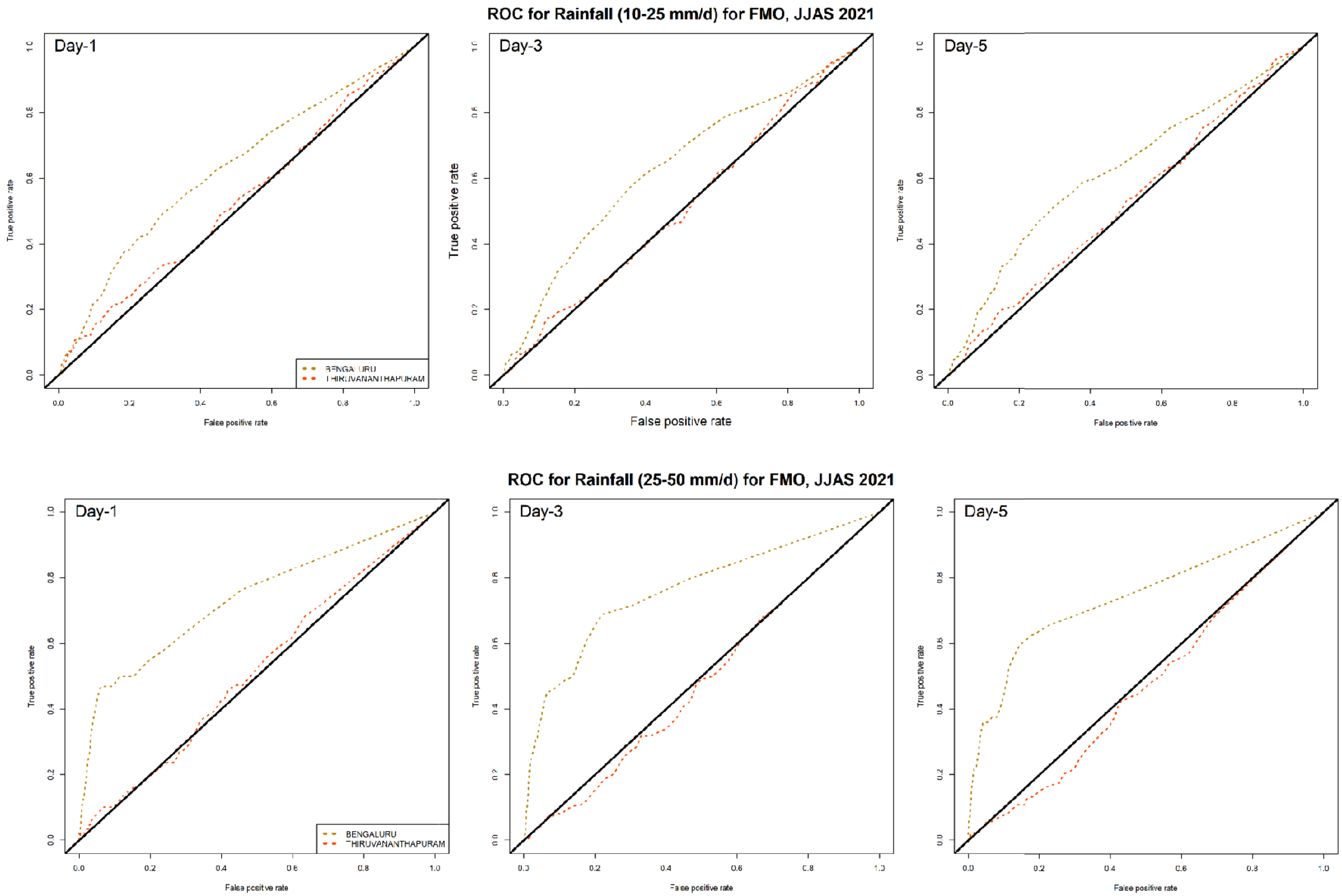

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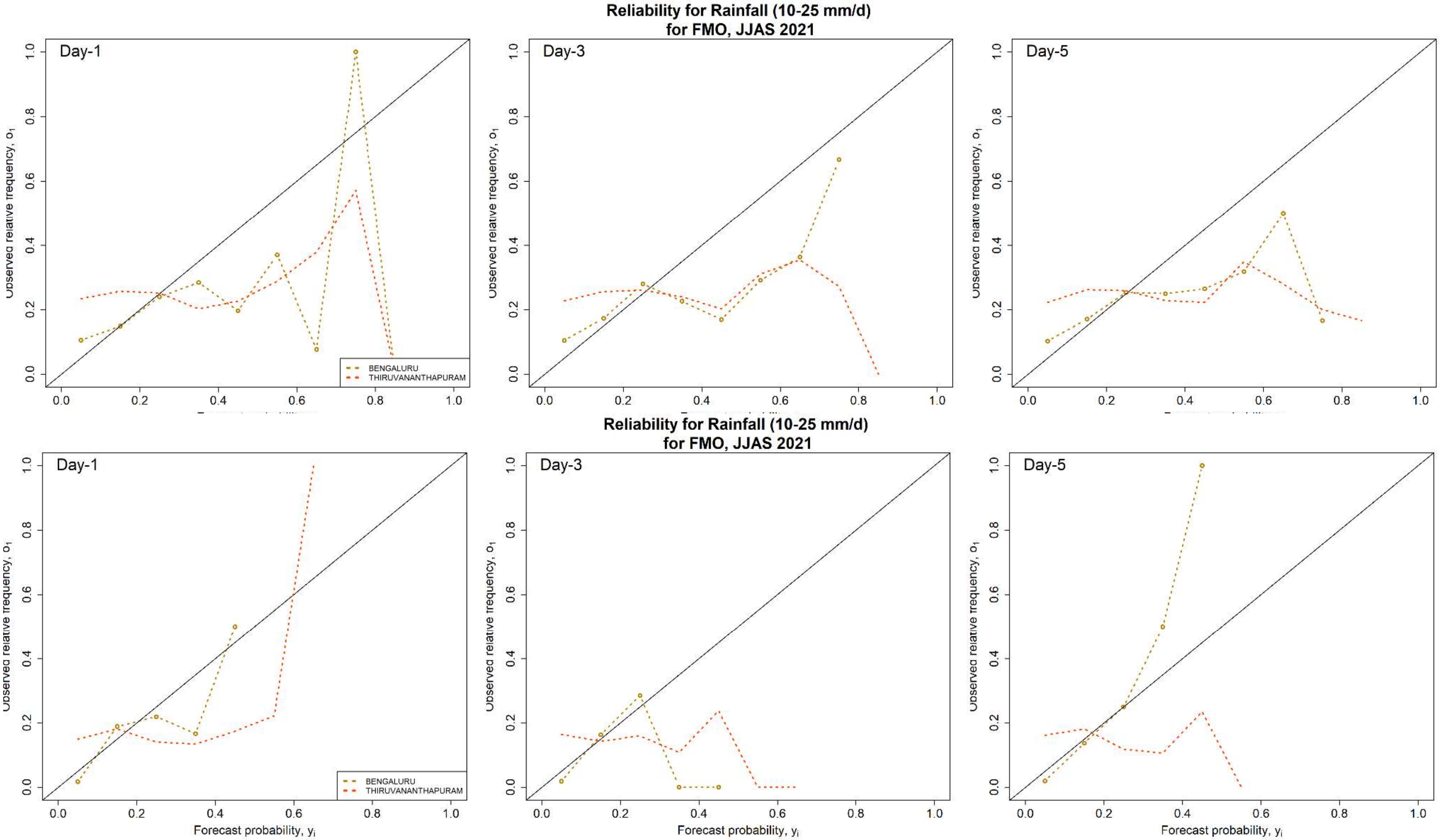

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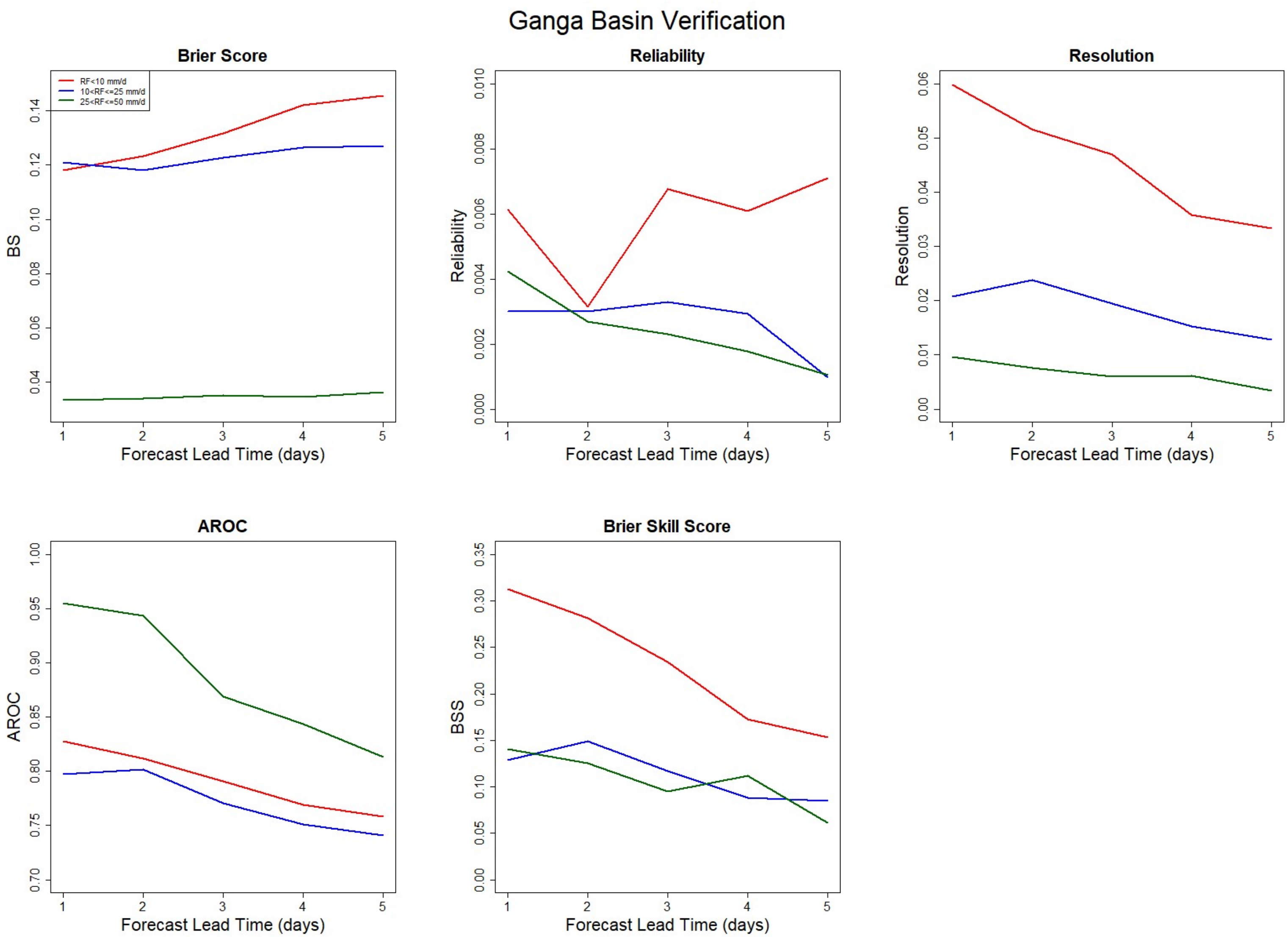

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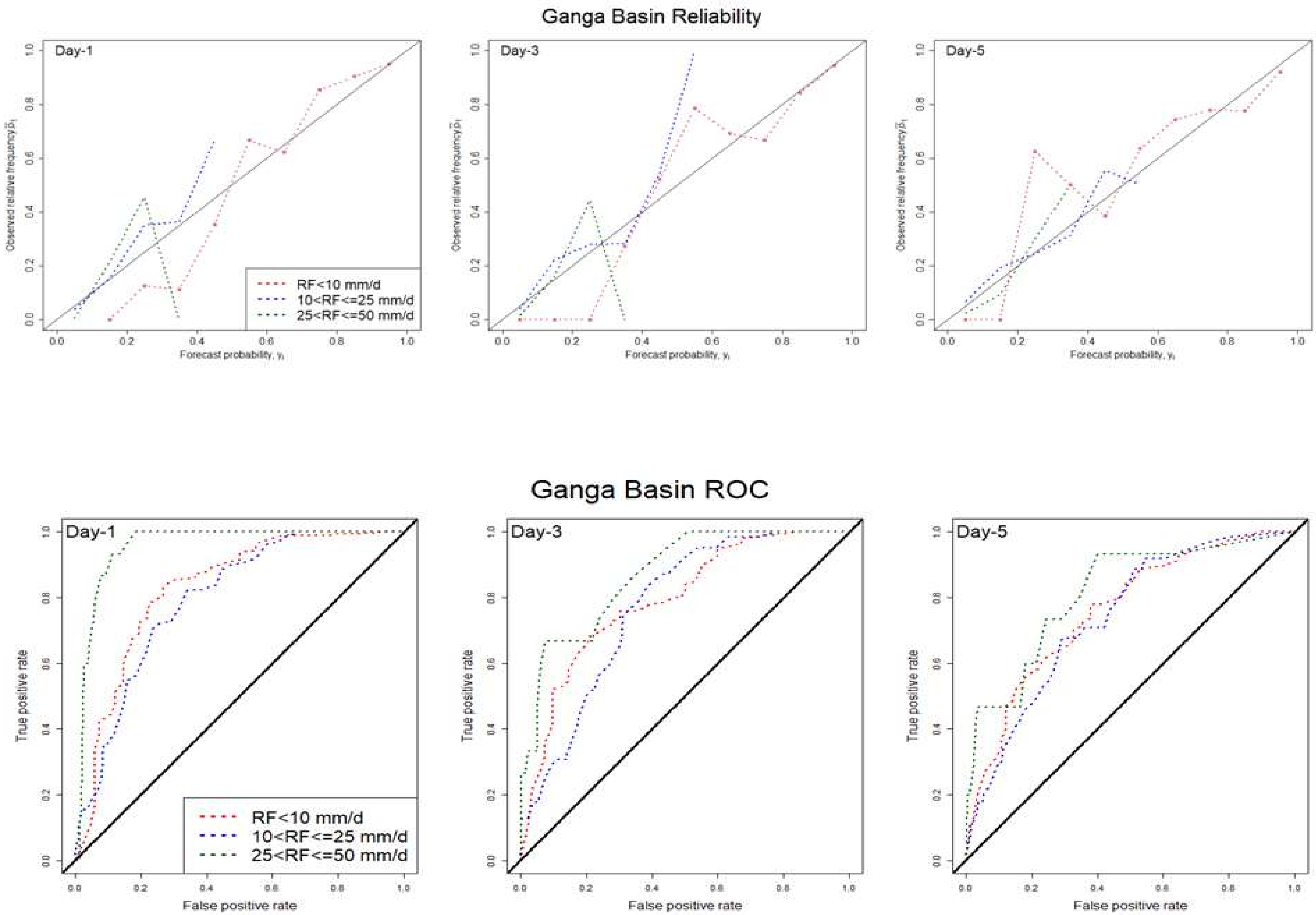

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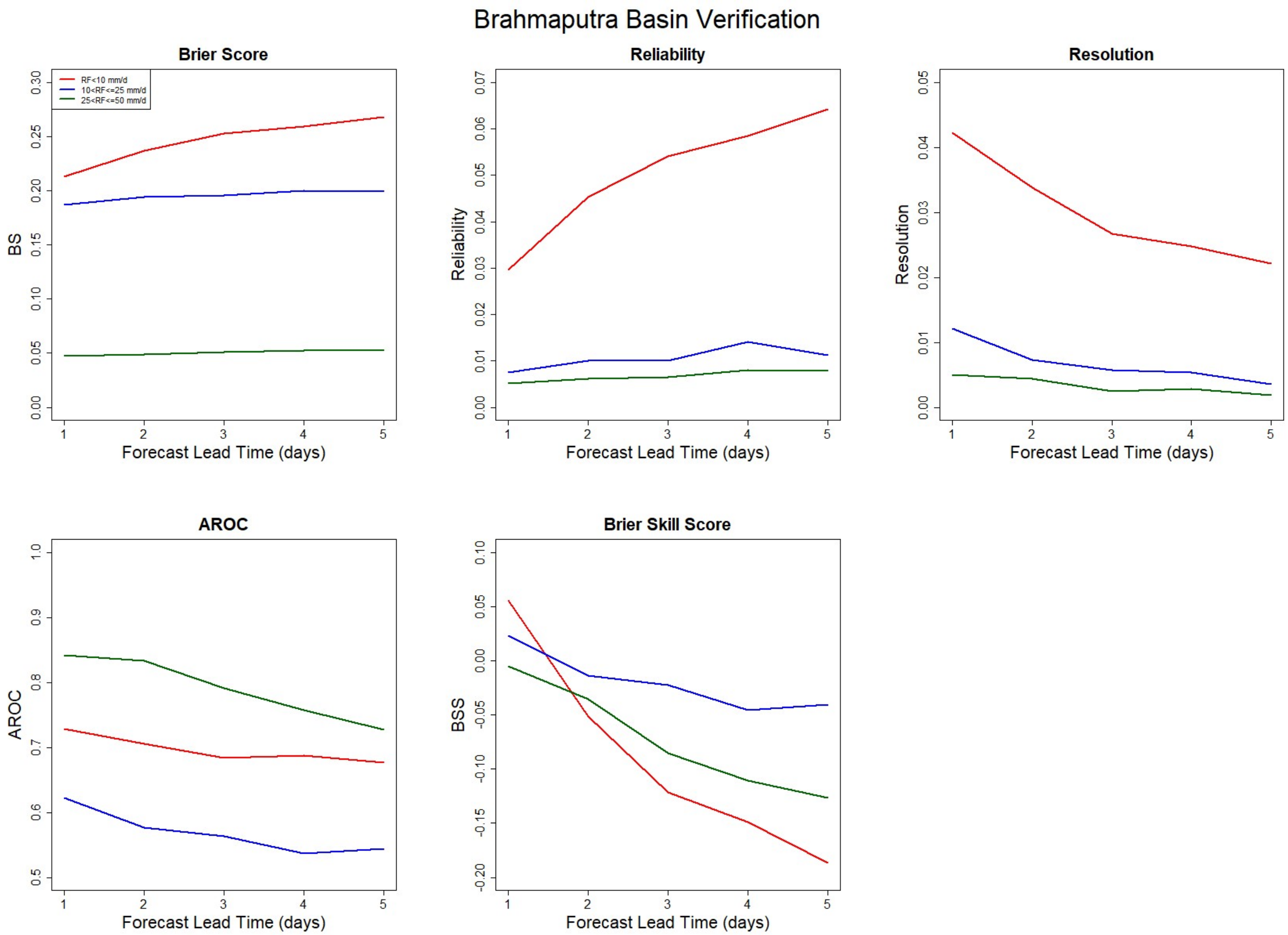

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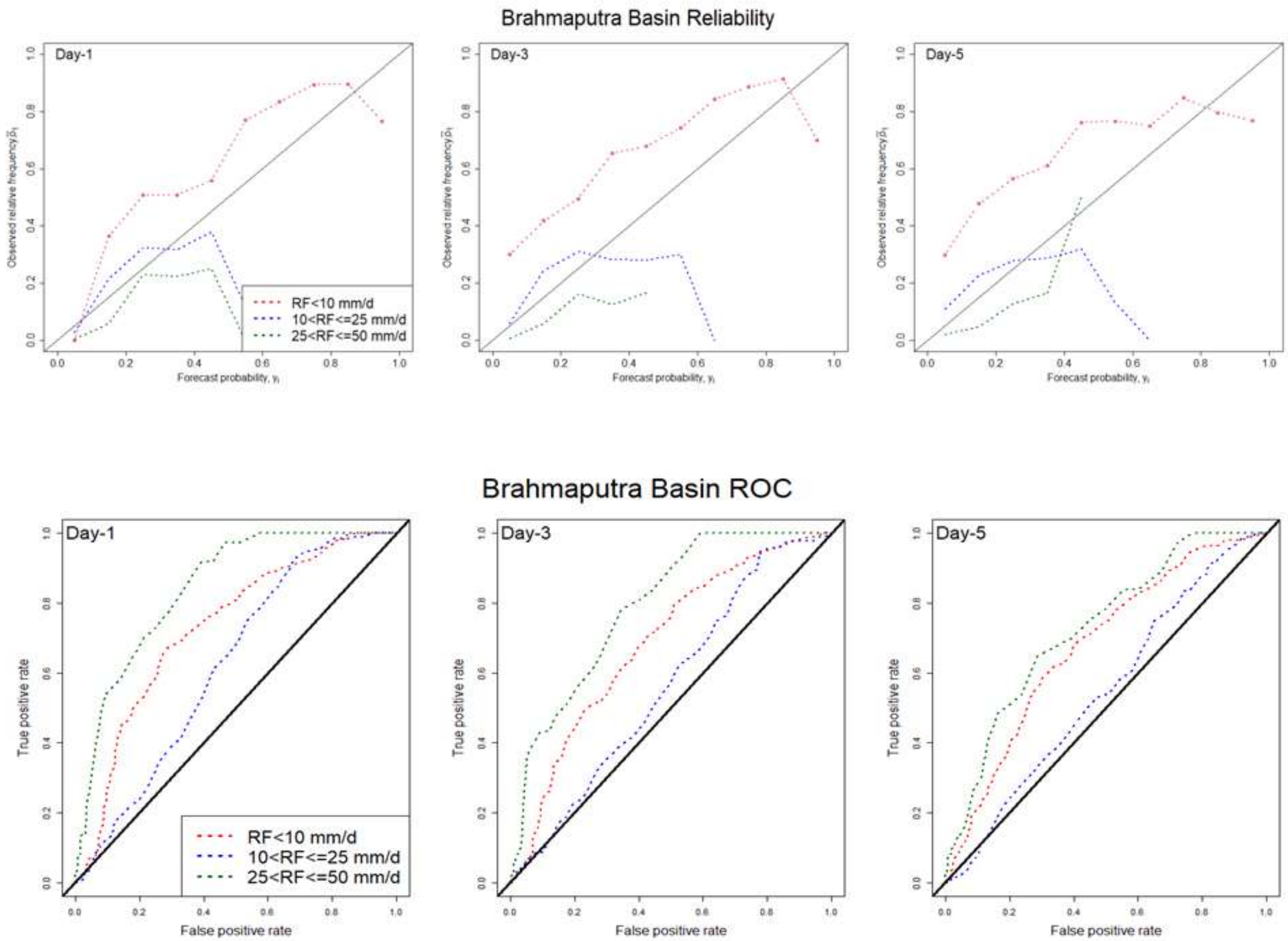

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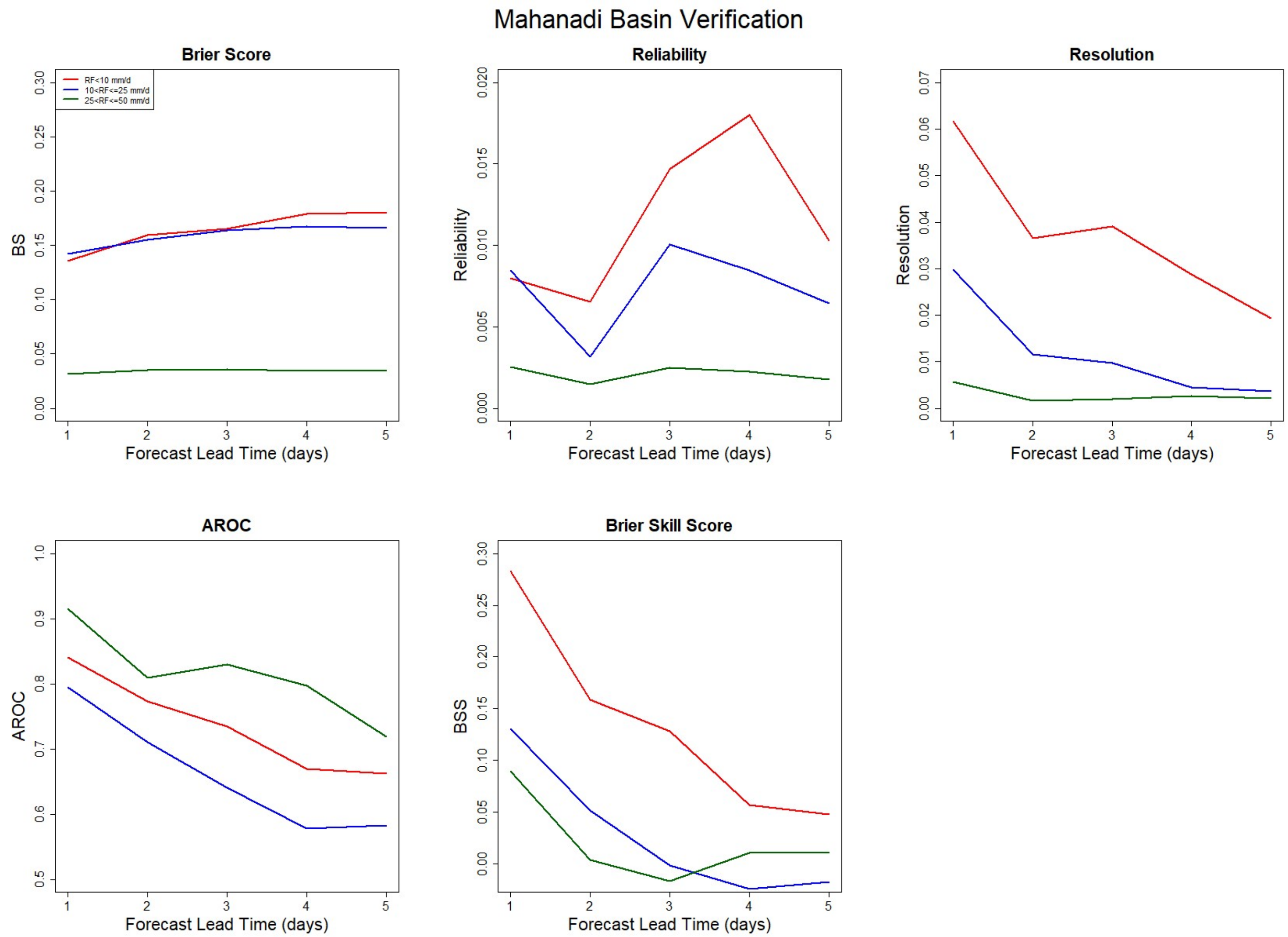

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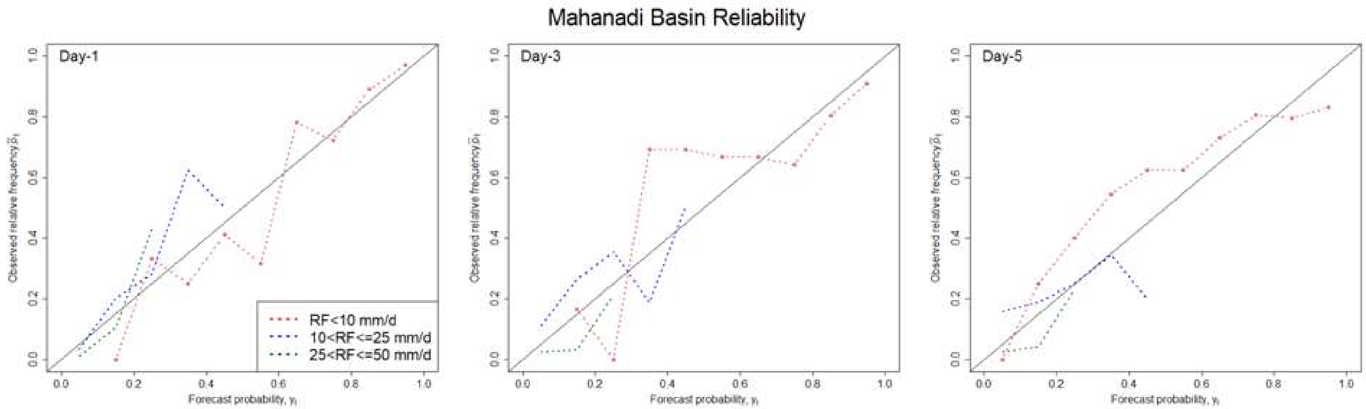

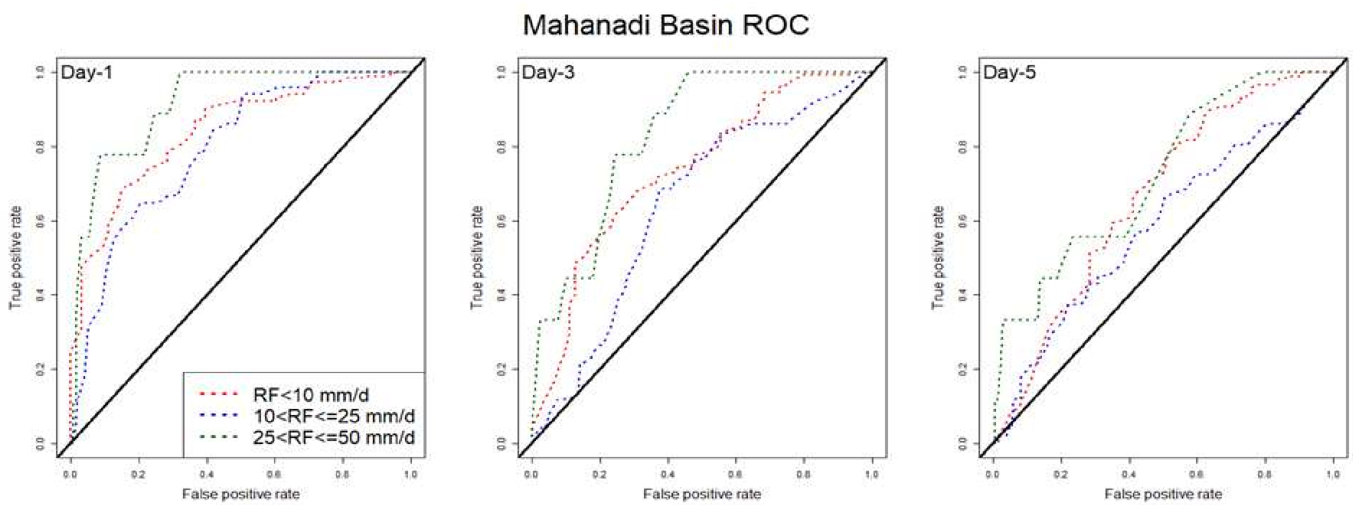

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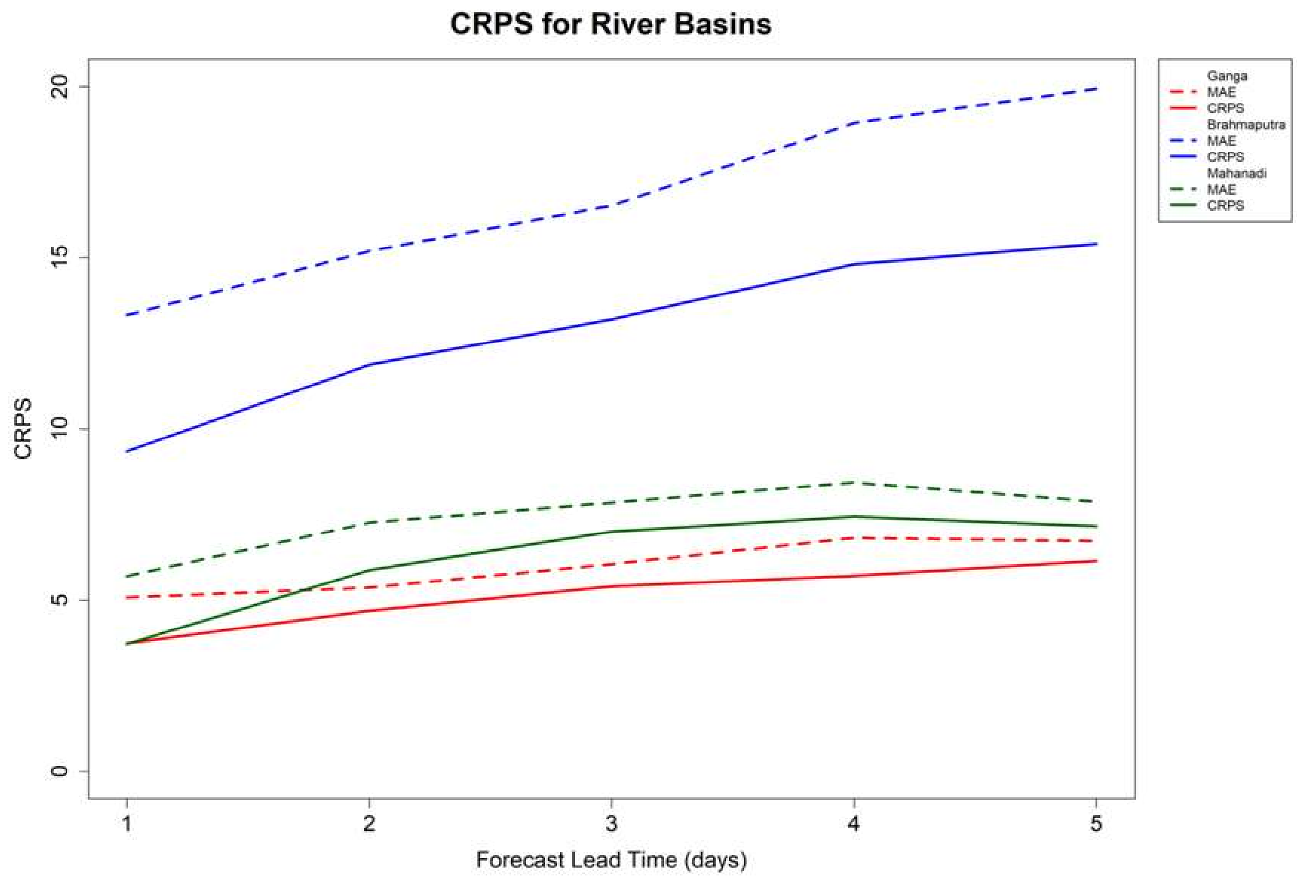

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