Chapter-8

Numerical Weather Prediction Guidance

Numerical Weather Prediction (NWP) Models are extensively used to prepare forecasts for short to medium range forecasts (up to 10 days) and extended range forecasts (up to one month). Over the years, the skill of NWP systems has improved substantially due to a) better assimilation methods of more quantity of data including non-conventional data b) higher resolution NWP models c) improved model Physics and d) better methods of post-processing of model output data. At the Ministry of Earth Sciences (MOES), there are two global forecasting systems which are now operational. The first system is based on the NCEP Global Forecasting System (GFS) model, which IMD uses to prepare the forecasts, four times a day (0000, 0600, 1200 and 1800 UTC). These are deterministic forecasts up to 10 days. The GFS model is a global model with 12 km horizontal resolution. Using the same model, an ensemble prediction system was also developed by IITM scientists and put on operational work by IMD. This system operational since 2017, provides probability forecasts of different parameters. All these IMD forecast products are available at the IMD website https://nwp.imd.gov.in/gfsproducts_cycle00_mausam.php.

Another operational system is used by NCMRWF, Noida for generating forecasts (both deterministic and ensemble) twice a day. The NCMRWF Unified Model (NCUM) was implemented in 2012 with a grid resolution of 25km (NCUMG:V1) which was upgraded to 17km (NCUM-G:V3) in 2015, 12km (NCUM-G:V5) in 2018. The present version (NCUM-G:V6) of NCUM-G has a horizontal grid resolution of ~12 km with 70 levels in the vertical reaching 80 km height. An advanced data assimilation method of Hybrid 4-Dimensional Variational (4D-Var) is used for the creation of NCUM global analysis. The NCMRWF forecast products are available at https://www.ncmrwf.gov.in/

There are not enough studies on systematic verification of weather forecasts for the NE monsoon season, except the two reports brought out by NCMRWF for 2020 and 2021 seasons.

Salient aspects of verification of forecasts during November 2021 using the NCMRWF model are given below.

November 2021 witnessed unprecedented rainfall activity over south peninsula during the NE monsoon season. Fig 8.1 shows the monthly accumulated rainfall during November 2021 and its anomalies. This shows above normal rainfall activity over South Peninsula with more than 100 mm excess rainfall over parts of Tamil Nadu and Rayalaseema.

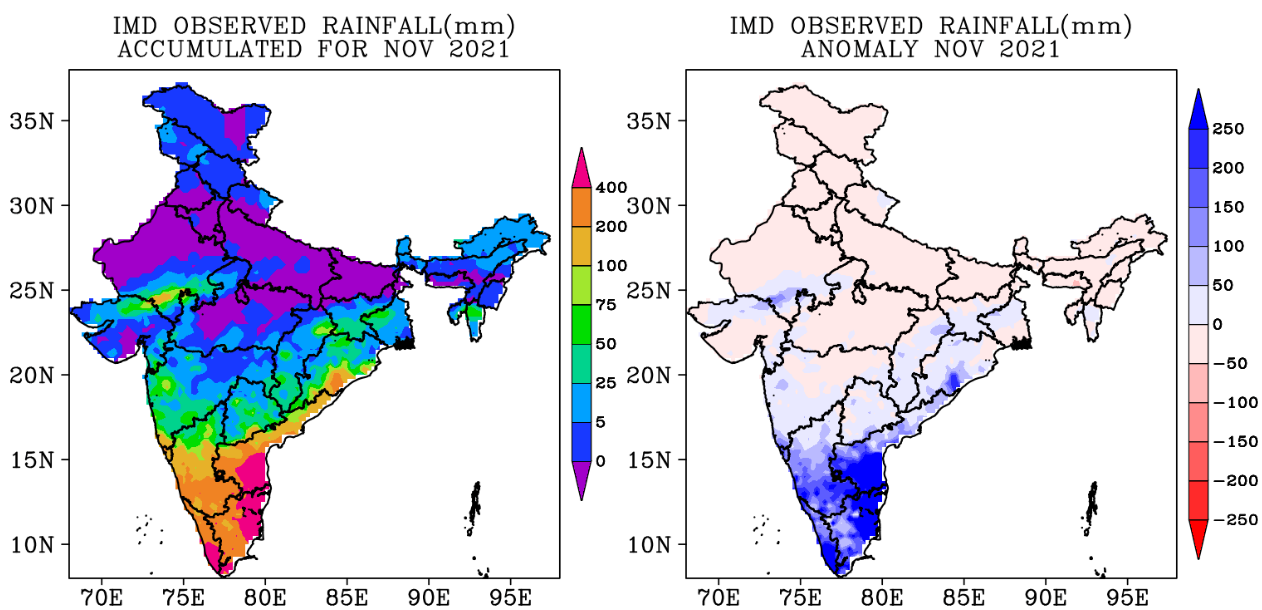


Fig. 8.1. Observed monthly rainfall (IMD) during November 2021 (left) and its anomaly (right). Unit: in mm.

Fig. 8.2 shows the vertically integrated moisture transport (VIMT) integrated up to 300 hPa level. The NCUM analysis shows strong easterlies bringing abundant moisture towards south Peninsula. However, the NCUM model predictions underestimated this large-scale moisture transport towards South Peninsula. The anomalies are much bigger in Day-5 forecast. The moisture transport was much weaker than observed. This has resulted in negative bias in rainfall over south Peninsula (Fig. 8.3). Rainfall predicted by the model was less than that observed, even though the model predicted the spatial distribution of rainfall very well. The underestimation of rainfall could be related to under-estimation of moisture transport to the region in the lower tropospheric levels.

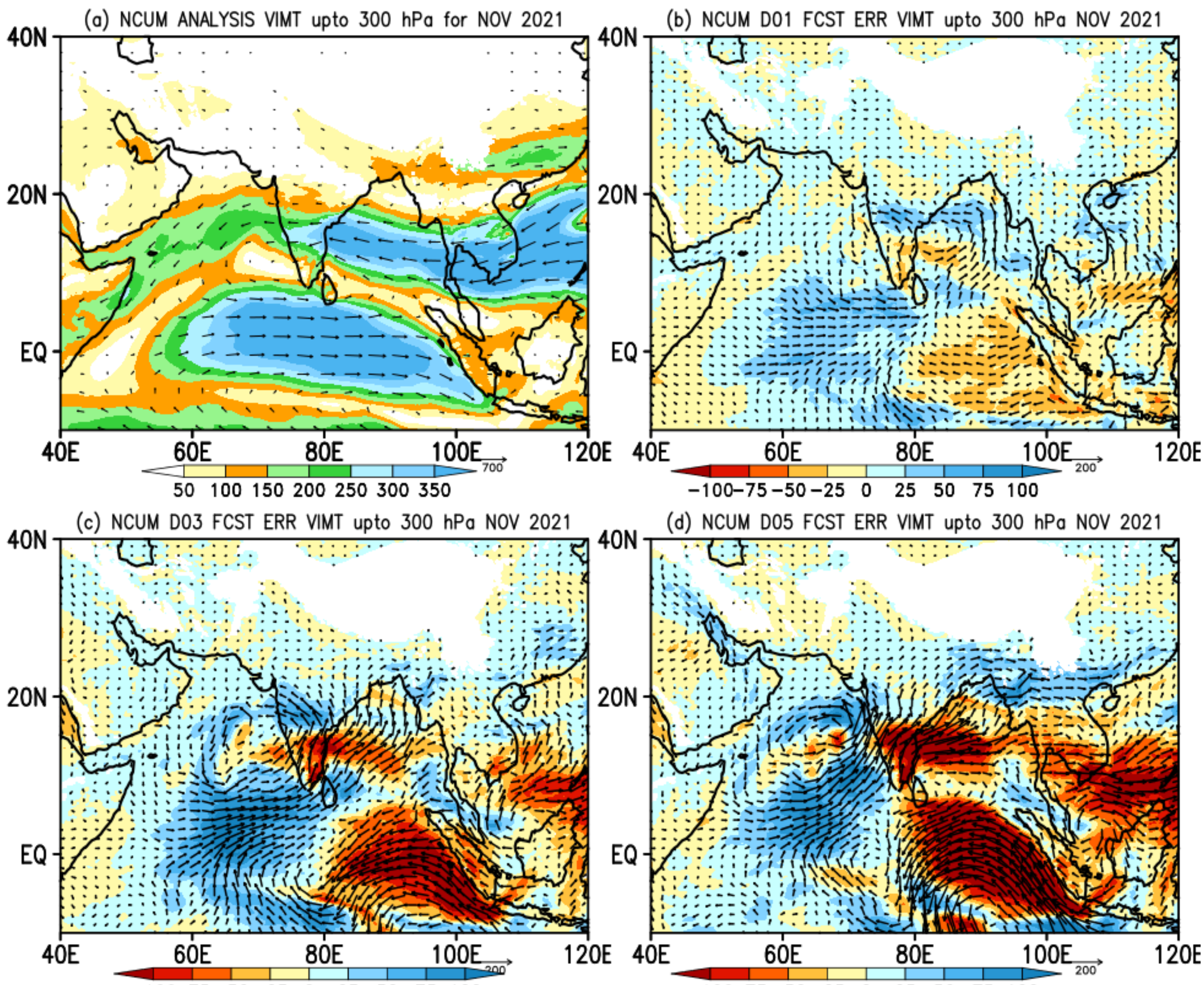


Fig. 8.2. a) The NCUM model analysis of vertically integrated (up to 300 hPa) moisture transport (VMT) during Nov 2021. The forecast error in VMT for day-1 (b), day-2(c) and day-3(d).

The Skill scores of forecast categories with the NCUM model are given in Fig 8.4.

The Skill Scores are defined as follows:

1) Probability of Detection (POD): hits/(hits+misses)
2) False Alarm Rate (FAR)= False alarms/ (Hits+false alarms)
3) Critical Success Index (CSI)= Hits/ (hits+false alarms+misses)
4) BIAS= (hits+false alarms)/(total number of observed events)
5) Pierce's Skill Score (PSS)= hits/(hits+misses) – false alarms/(false alarms+correct negatives)
6) Symmetric Extreme Dependency Index (SEDI) is defined as

SEDI = (log F-log H-log (1-F)+log (1-H))/ (log F+ Log H+ log(1-F)+log (1-H)

Where, H is Hit rate and F is false alarm rate.

Probability of Detection (POD) is larger for lower rainfall thresholds, but it drastically reduces for larger amount of rainfall. POD for 2 cm rainfall at Day-1 forecast is close to 0.30, but it is around 0.1 for Dady-5 forecast. False Alarm Rate (FAR) is larger for higher amount of rainfall thresholds. FAR is more than 0.7 for larger amount of rainfall. Therefore, the model has tendency of over predicting frequency of higher amount of rainfall. The other skill scores (like CSI, BIAS, PSS and SEDI) are better for Day-1 and Day-3 forecasts but reduces sharply for Day-5 forecasts.

Next, a discussion is made on the fidelity of the NCUM model in predicting two weather systems which developed in November 2021 and affected South Peninsula. The first weather system was a low-pressure system that formed over the Bay of Bengal and moved northwestwards. It crossed the border of Tamil Nadu and Andhra Pradesh on 12 November 2021.

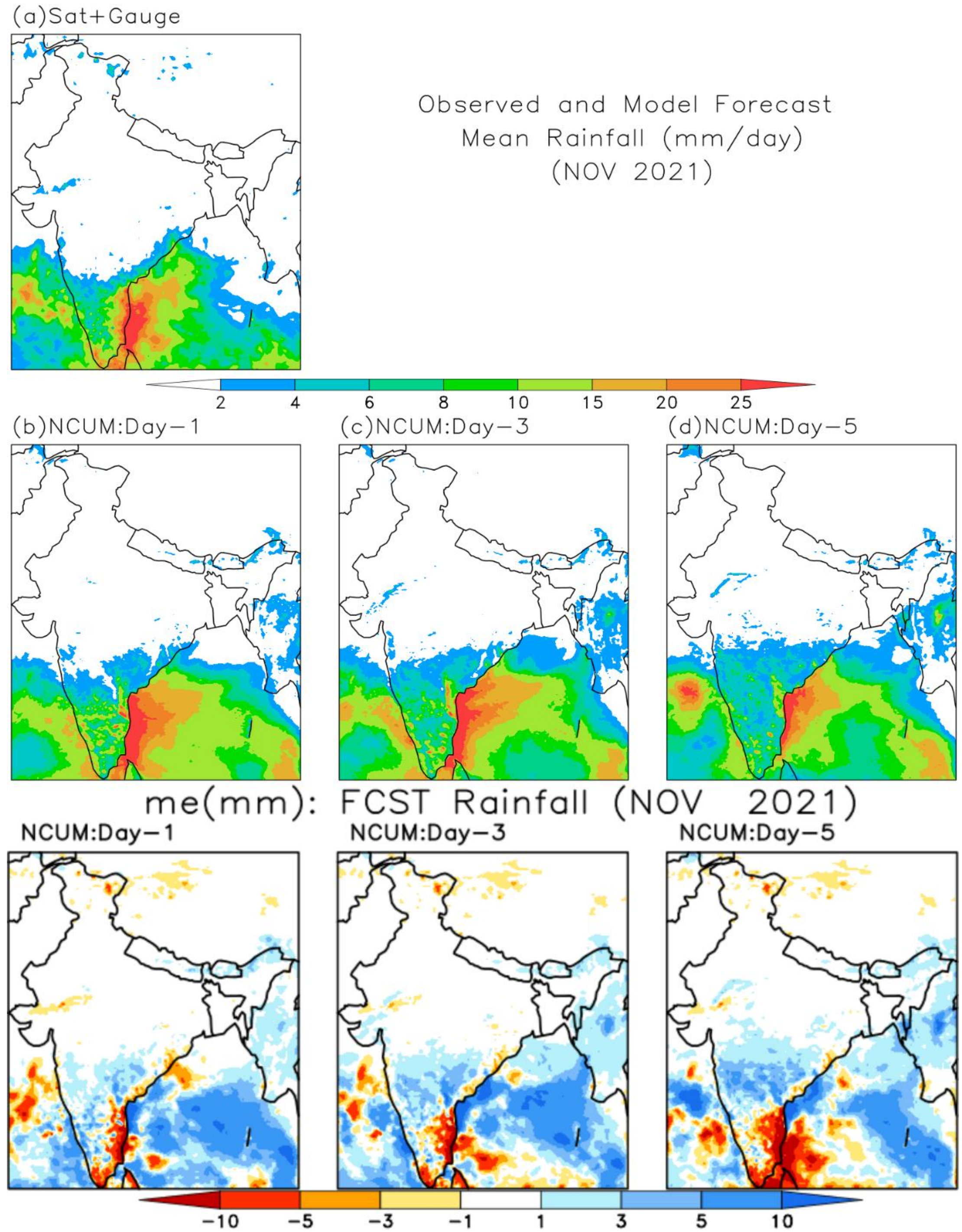


Fig. 8.3. Observed and Model Forecast Mean rainfall (mm/day) during November 2021. a) Observed merged rainfall in mm/day. b) to d) represent model forecasts for day-1 to day-3. Bottom three plots show model forecast errors for day-1 to day-3 forecasts.

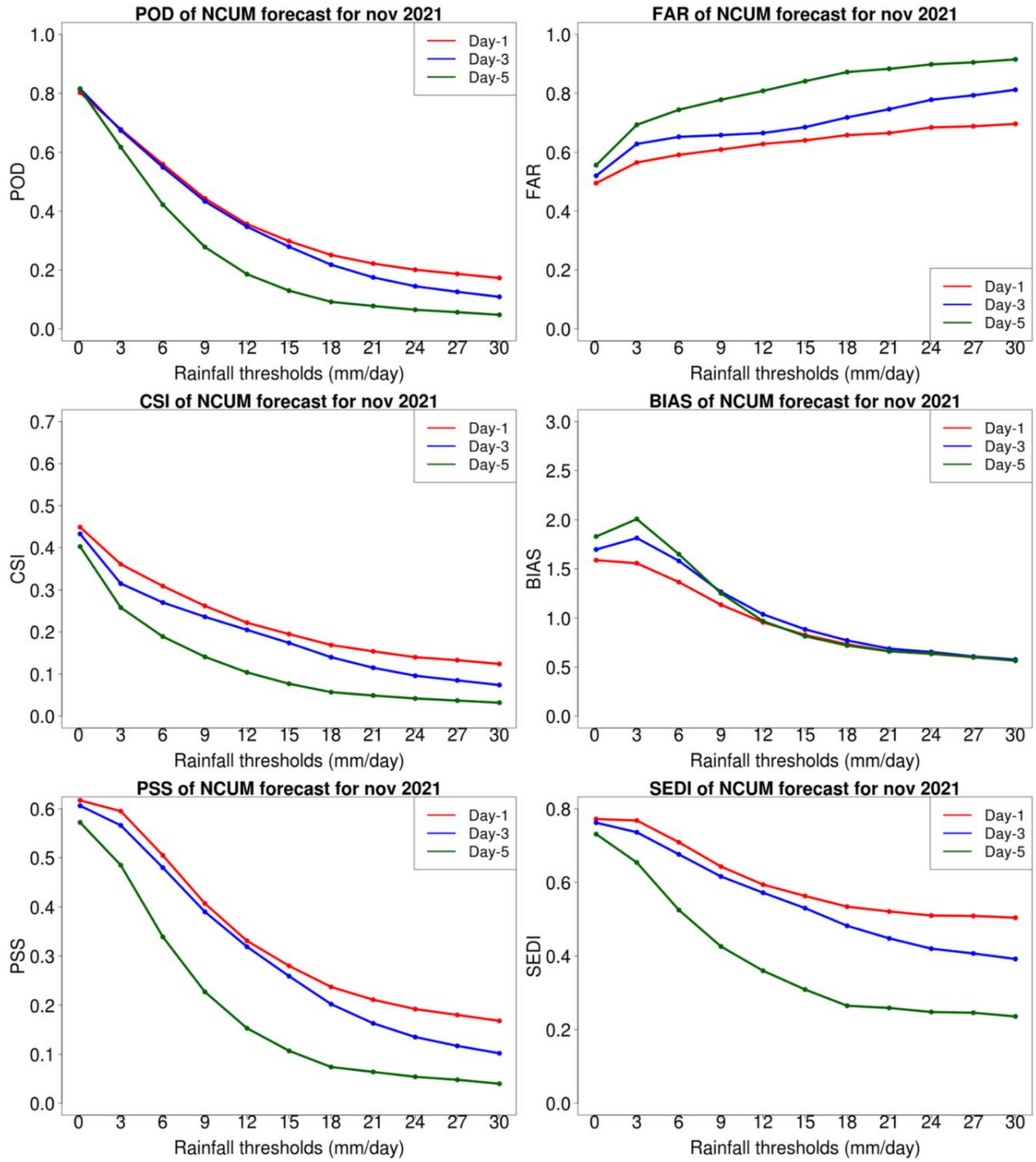


Fig. 8.4. Statistical Skill Scores for the NCUM forecasts of rainfall during November 2021, a) POD b) FAR c) CSI d) BIAS e) PSS and f) SEDI for day-1 to day-3 forecasts.

Fig. 8.5 shows the 850 hPa wind analysis of 11 Nov 2021 and NCUM forecasts up to 120 hrs in advance. The low pressure system with cyclonic circulation was clearly seen in the analysis off Tamil Nadu coast on 11 November. It is interesting to see the

NCUM model is able to predict the presence of cyclonic circulation off the Tamil Nadu coast with similar intensity up to 72 hours in advance. However, beyond 72 hours, model could not predict the cyclonic circulation correctly. Accordingly, the rainfall activity is also well predicted by the model up to 72 hours in advance (Fig 8.6). Beyond 72 hours, the model under-predicted the intensity of rainfall and the model forecasts have shown large biases.

Fig. 8.7 and Fig. 8.8 show the same details but for another weather system which crossed the land near north Andhra Pradesh on 19 Nov 2021. As in the previous case, the model could predict the presence of cyclonic circulation off Andhra coast up to 72 hours in advance. Rainfall was also well predicted by the model up to 72 hours in advance.

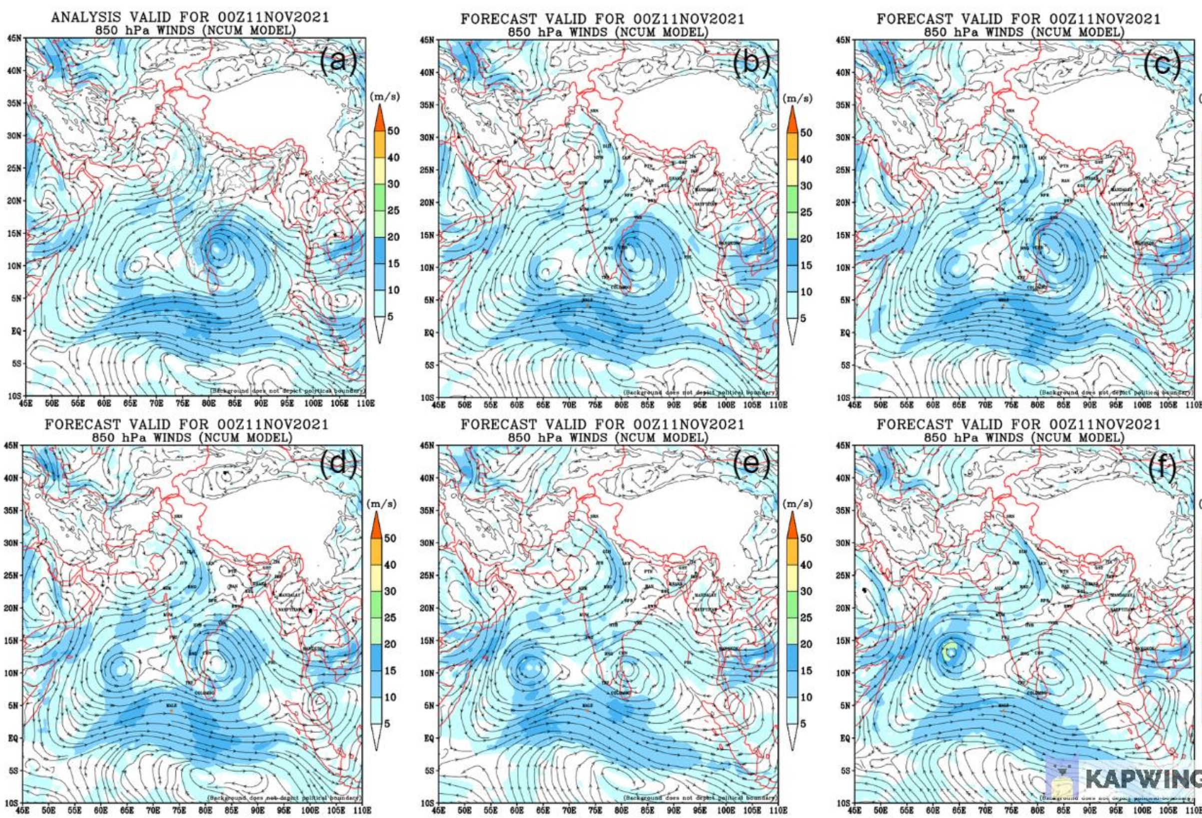


Fig. 8.5. NCUM model analysis of 850 hPa winds at 0000 UTC, 11 November 2021 (a) and model forecast for day-1 (b), day-2 (c), day-3 (d), day-4 (e) and day-5 (f).

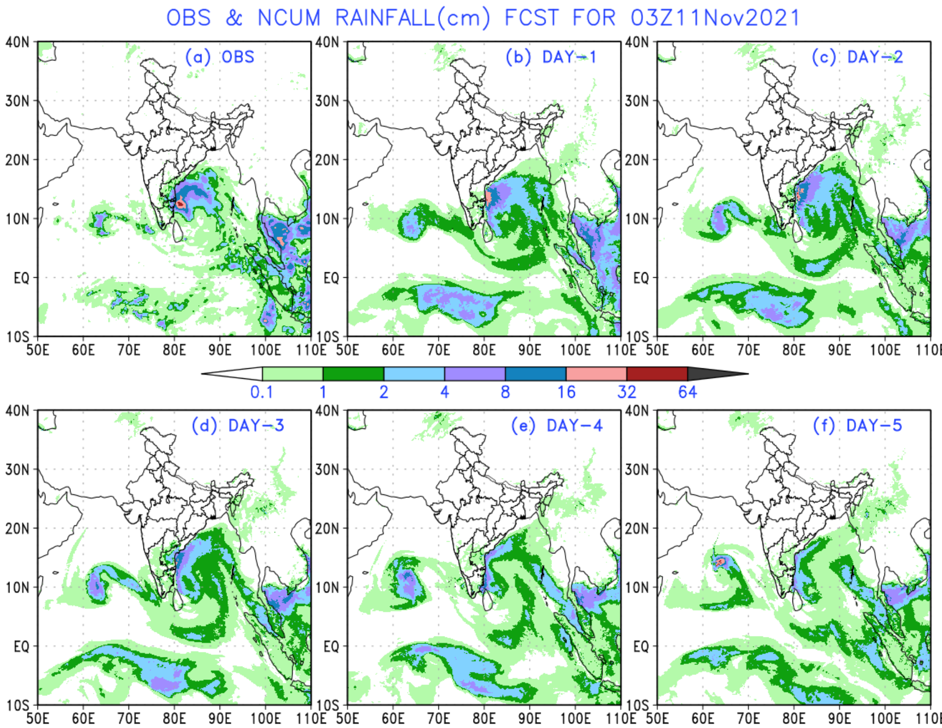


Fig. 8.6. Observed and NCUM model predictions of rainfall (cm) for 03 UTC 11 November 2021. a) observed, b) to f) represent forecasts of day-1 to day-5.

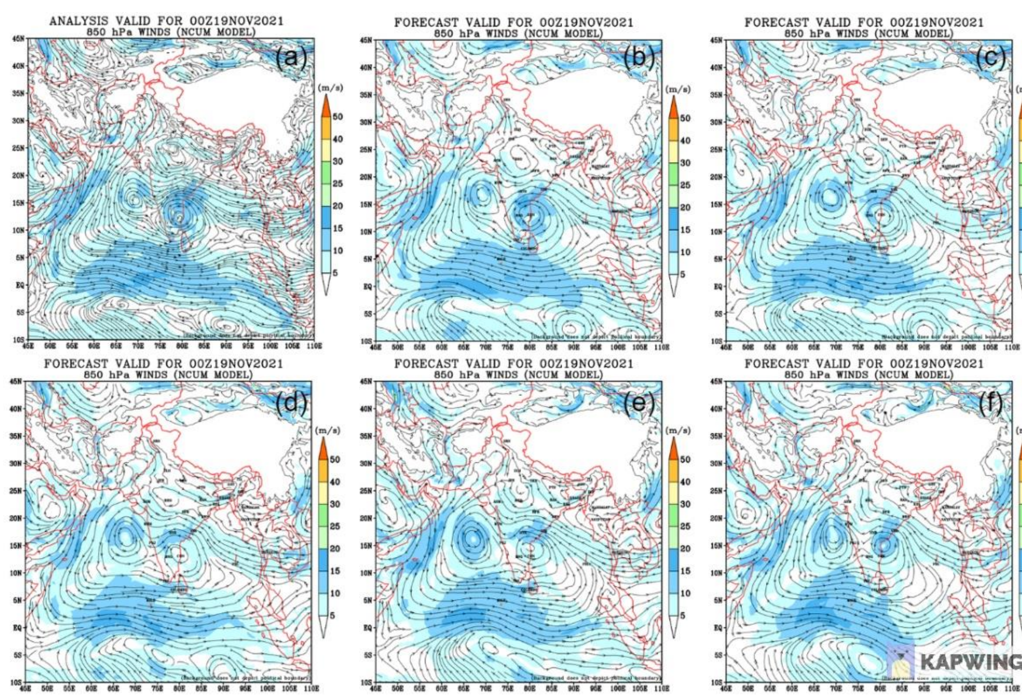


Fig. 8.7. NCUM model analysis of 850 hPa winds at 0000 UTC, 19 November 2021 (a) and model forecast for day-1 (b), day-2 (c), day-3 (d), day-4 (e) and day-5 (f).

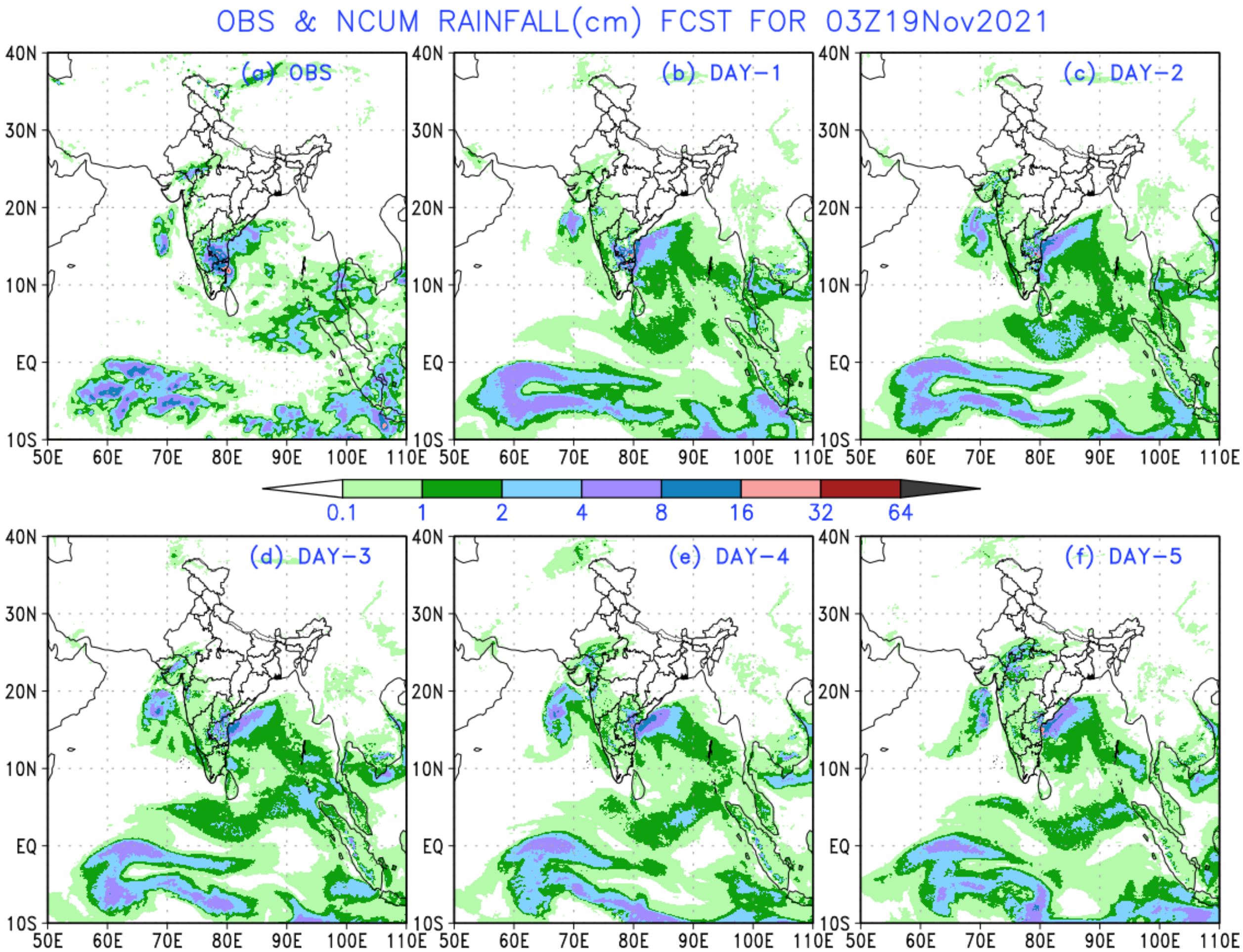


Fig. 8.8. Observed and NCUM model predictions of rainfall (cm) for 03 UTC 19 November 2021. a) observed, b) to f) represent forecasts of day-1 to day-5.

Thus, the NCUM models have shown some useful skill in predicting large scale circulation and rainfall patterns associated with weather systems during the NE Monsoon season, at least up to 72 hours in advance.

In the next section, analysis of forecast verification using IMD/IITM GFS and GEFS models is presented.

The categorical statistical scores for verification of precipitation forecasts based on GFS T1534 for south peninsula are shown in Fig 8.9 for Day-1, Day-3 and Day-5 forecasts. This verification is made for three NE monsoon seasons, 2019-2021.

Probability of Detection (POD) is larger for lower rainfall thresholds, but it drastically reduces for larger amount of rainfall. POD for 2 cm rainfall at Day-1 forecast is close to 0.35, but it is around 0.2 for Dady-5 forecast. False Alarm Rate (FAR) is larger for higher amount of rainfall thresholds. FAR is more than 0.7 for larger amount of rainfall. Therefore, the model has tendency of over predicting frequency of higher amount of rainfall. The other skill scores (like CSI, BIAS, PSS and SEDI) are better for Day-1 and Day-3 forecasts but reduces sharply for Day-5 forecasts.

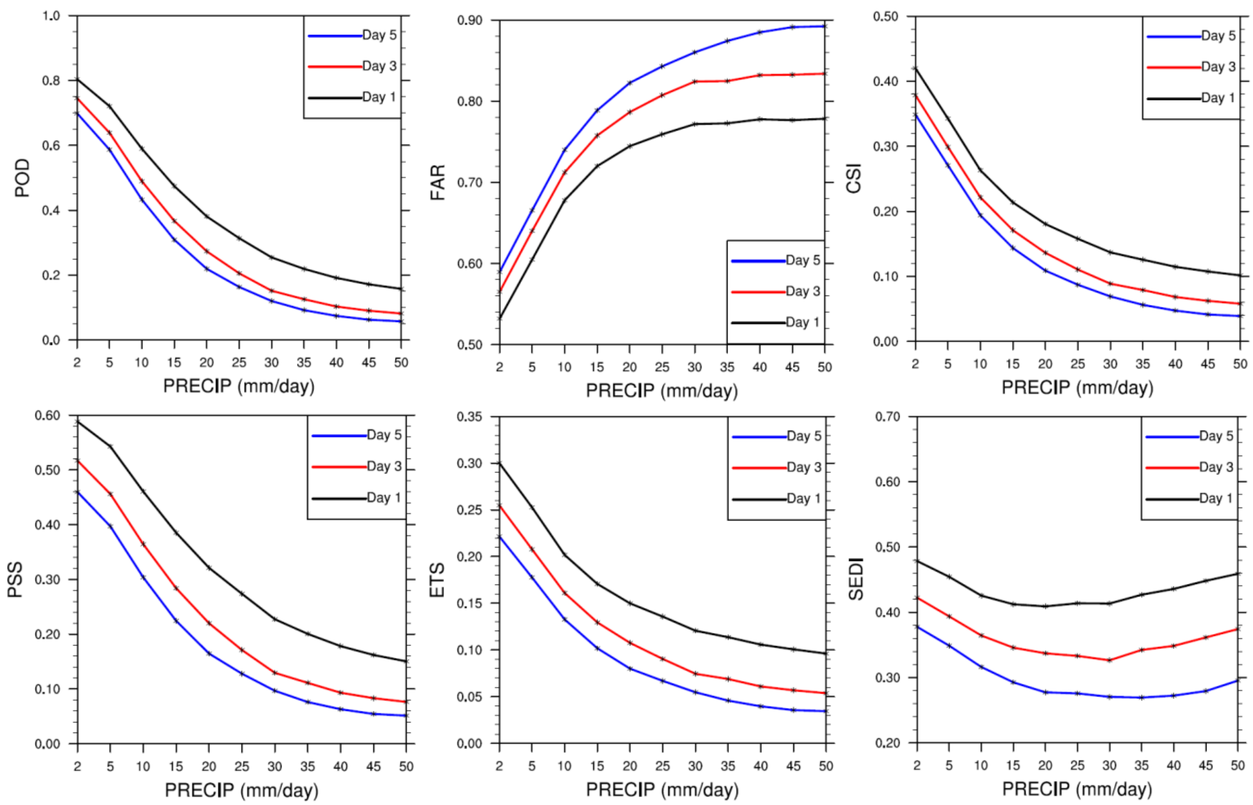


Fig. 8.9. Categorical skill scores for rainfall forecast of OND 2019-2021 from GFS T1534 for the Southern Peninsula region (8°-20°N, 68°-97.5°E, land only)

Fig. 8.10 shows the Reliability Diagram of prediction of rainfall during the NE monsoon season (OND) (2019-2021) from the model GEFS T1534 for the southern Peninsula region (8°-20°N, 68°-97.5°E, land only). The observed merged (satellite-rain-gauge) rainfall data are taken from Mitra et al. (2009). The columns are for Day 1, 2, and 3, respectively, and the rows are for rainfall thresholds of 2.5 mm/day, 15.6 mm/day, and 65.5 mm/day, respectively. A reliability diagram is a graph where the conditional distribution of the observations, given the forecast probability, is plotted against the forecast probability. The distributions of perfectly reliable forecasts are plotted along the 45- degree diagonal. If the curve falls in the grey-shaded region, it indicates a skilful forecast. The curve obtained below the diagonal indicates over-forecasting and vice-versa. Fig 46 shows that the model can display a skilful forecast which decreases with increasing thresholds. For a threshold of 2.5 mm/day rainfall, the forecast shows a consistent skill through Day 1 to 3 as the curve is in the grey shaded region of the graph. For the threshold of 15.6 mm/day of rainfall, the curve falls just below the grey region for higher forecast probability categories for all lead times. For the threshold of 65.5 mm/day, the Day 1 curve shows a comparatively reliable forecast. However, the type of curve obtained for Day 2 and 3 forecasts indicates under-sampling. As all the curves are below the diagonal, we can say that the model forecast is over-confident or under-spread.

Fig. 8.11 shows the Relative Operating Characteristic (ROC) for the rainfall forecast of OND 2019-2021 from the model GEFS T1534 for the Southern Peninsula region (8°-20°N, 68°-97.5°E, land only). The columns are for Day 1, 2, and 3, respectively, and the rows are for rainfall thresholds of 2.5 mm/day, 15.6 mm/day, and 65.5 mm/day, respectively. The ROC is conditioned on the observations and gives a measure of the resolution of the forecast. Here resolution of the model forecast means the distinguishing capacity between events and non-events. The ROC shows the forecast in terms of Hit Rate and False Alarm Rate. The perfect forecast displays the curve along the bottom left to the top left and then to the top right corner. A curve along the diagonal indicates no skill, and a curve below the diagonal shows negative skill. Fig. 8.11 shows a near-perfect ROC for the 2.5 mm/day threshold and at all lead times. The skill decreases for the 15.6 mm/day rainfall threshold, but there is a considerable dip in skill for the 65.5 mm/day threshold, but it still shows a positive skill of the forecast. Hence the ROC gives a measure of the potential skill of the forecast.

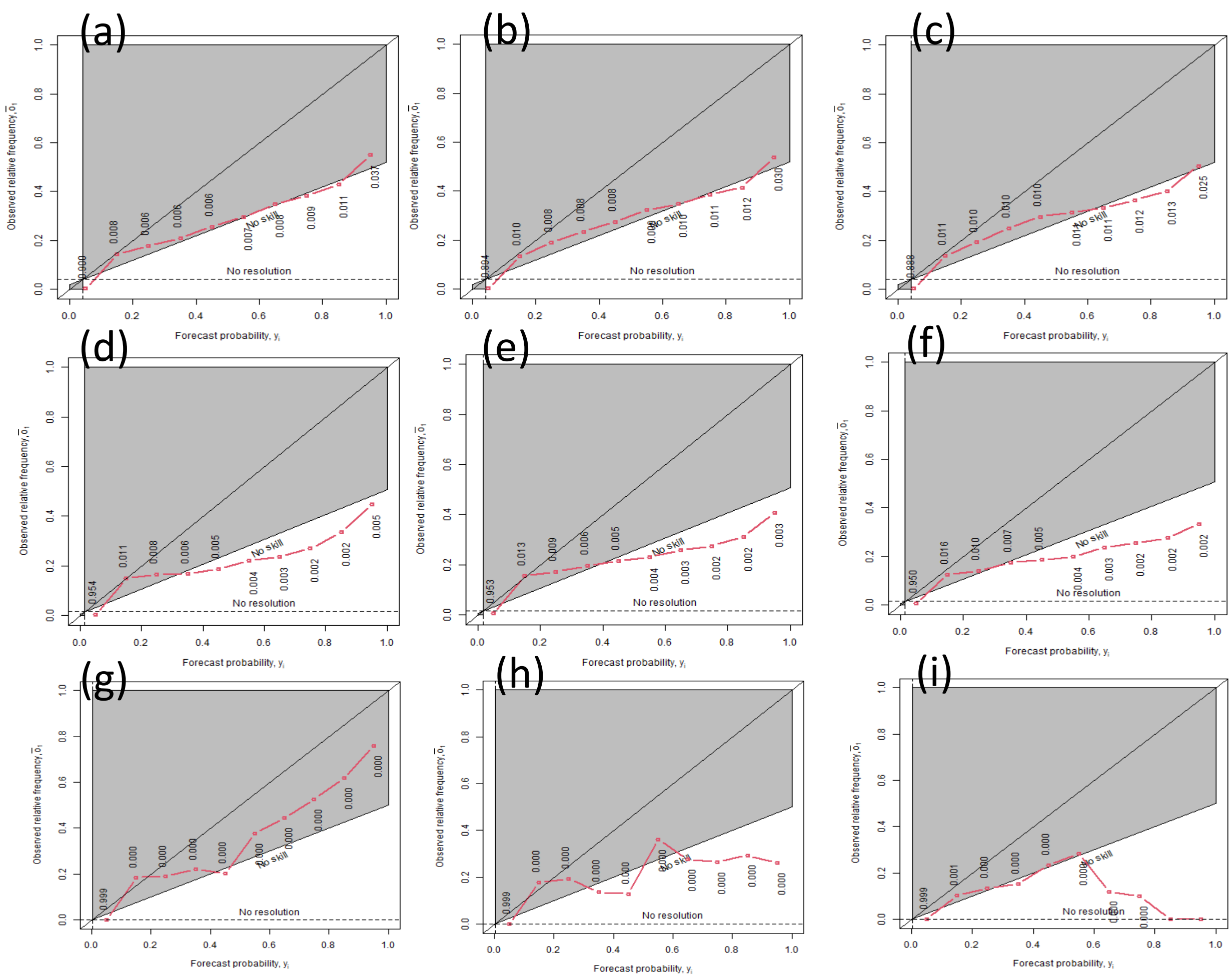
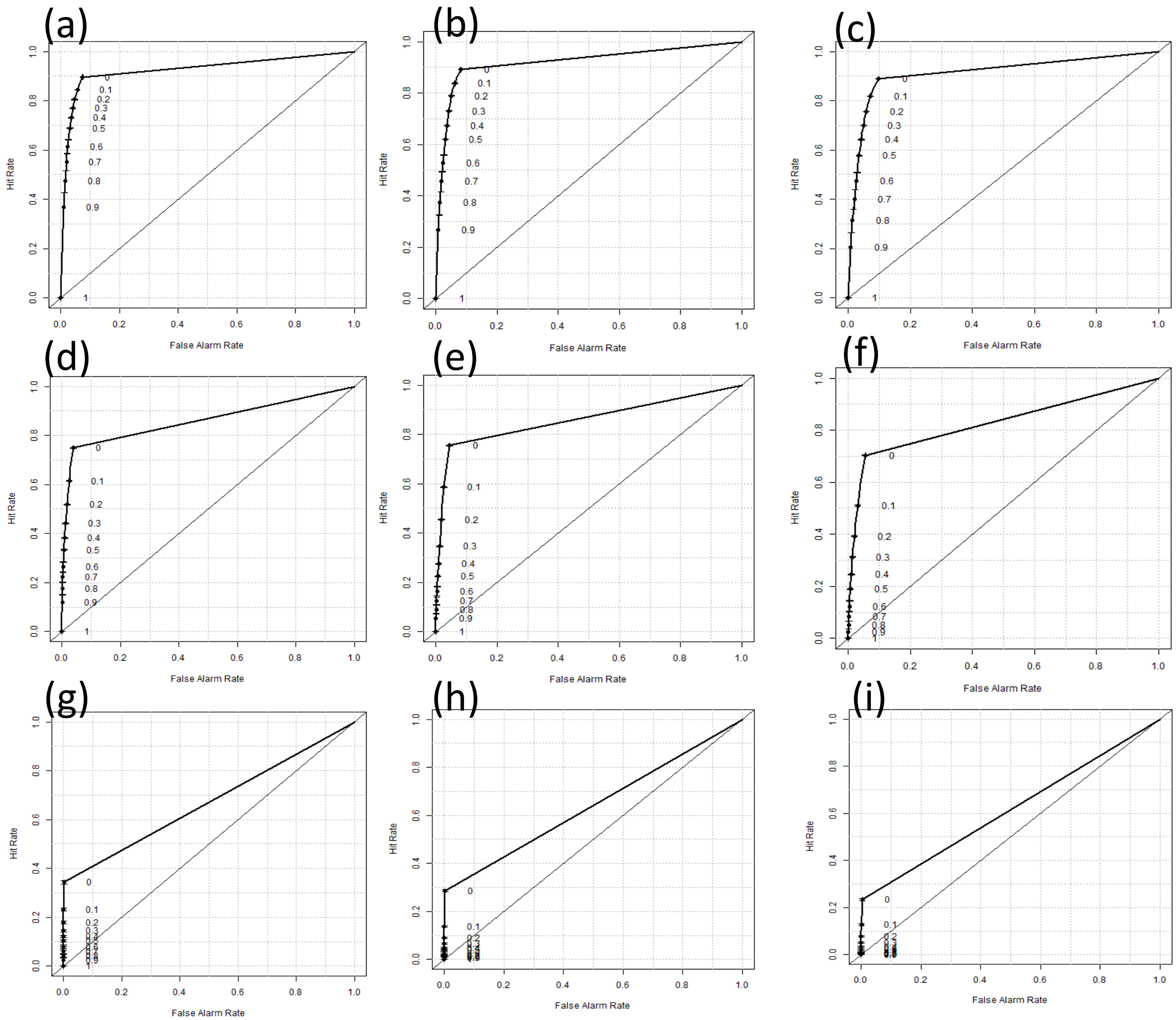


Fig. 8.10. Reliability Diagram for rainfall forecast of OND 2019-2021 from GEFS T1534 for the Southern Peninsula region (8°-20°N, 68°-97.5°E, land only). The columns are for Day 1, 2 and 3 respectively and the rows are for rainfall thresholds of 2.5 mm/day, 15.6 mm/day and 65.5 mm/day respectively.



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In the earlier section, it was shown that the deterministic forecast skill is reduced for rainfall of larger thresholds. Since we need to predict heavy rainfall events, depending upon the deterministic forecasts alone will not be fruitful. We need to refer to Ensemble forecasts to understand the uncertainties involved in the forecasts and thus to prepare probabilistic forecasts.

An ensemble weather forecast is a set of forecasts that present the range of future weather possibilities. Multiple simulations are run, each with slight variation of its initial conditions and with slightly perturbed weather models. These variations represent the inevitable uncertainty in the initial conditions and approximations in the models. They produce a range of possible weather conditions. The uncertainty associated with every forecast means that different scenarios are possible and the forecast should reflect that. Single "deterministic" forecasts can be misleading as they fail to provide this information.

Under the Monsoon Mission project of the MoES, two ensemble forecasting systems have been developed and put on operational use. One system is based on UK Met office weather prediction model and the second one is based on the NCEP Global Forecasting System (GFS) weather prediction model. The details of these weather prediction models are available in the papers by Sarkar et al. (2016), Chakraborty et al. (2020), Deshpande et al. (2020, and Mukhopadhyay et al. (2022).

Here, a case study is discussed to demonstrate the utility of ensemble weather forecasts during the NE monsoon season. The case study pertains to a heavy rainfall event (exceeding 10 cm) which occurred over Tamil Nadu-South Andhra coast on 7 Nov 2021. Fig. 8.12 a, b and c show rainfall forecast from Global Ensemble Forecasting System (GEFS) T1534 model of IMD/IITM valid for 7 Nov 2021 for Day-1, Day-3 and Day-5 forecasts. The IMD-GPM observed rainfall is shown in Fig. 8.12 a, which shows heavy rainfall over the east coast of Tamil Nadu/Andhra coast. The forecasts show higher probabilities of rainfall of even 15.6 mm/day. It is interesting to note the GEFS model indicated a chance of heavy rainfall exceeding 65 mm/day even at Day-3 and Day-5 forecasts. This ensemble forecast product thus provides an additional tool for forecasters on the possibility of extreme events like heavy rainfall and therefore such ensemble forecast products should be extensively used.

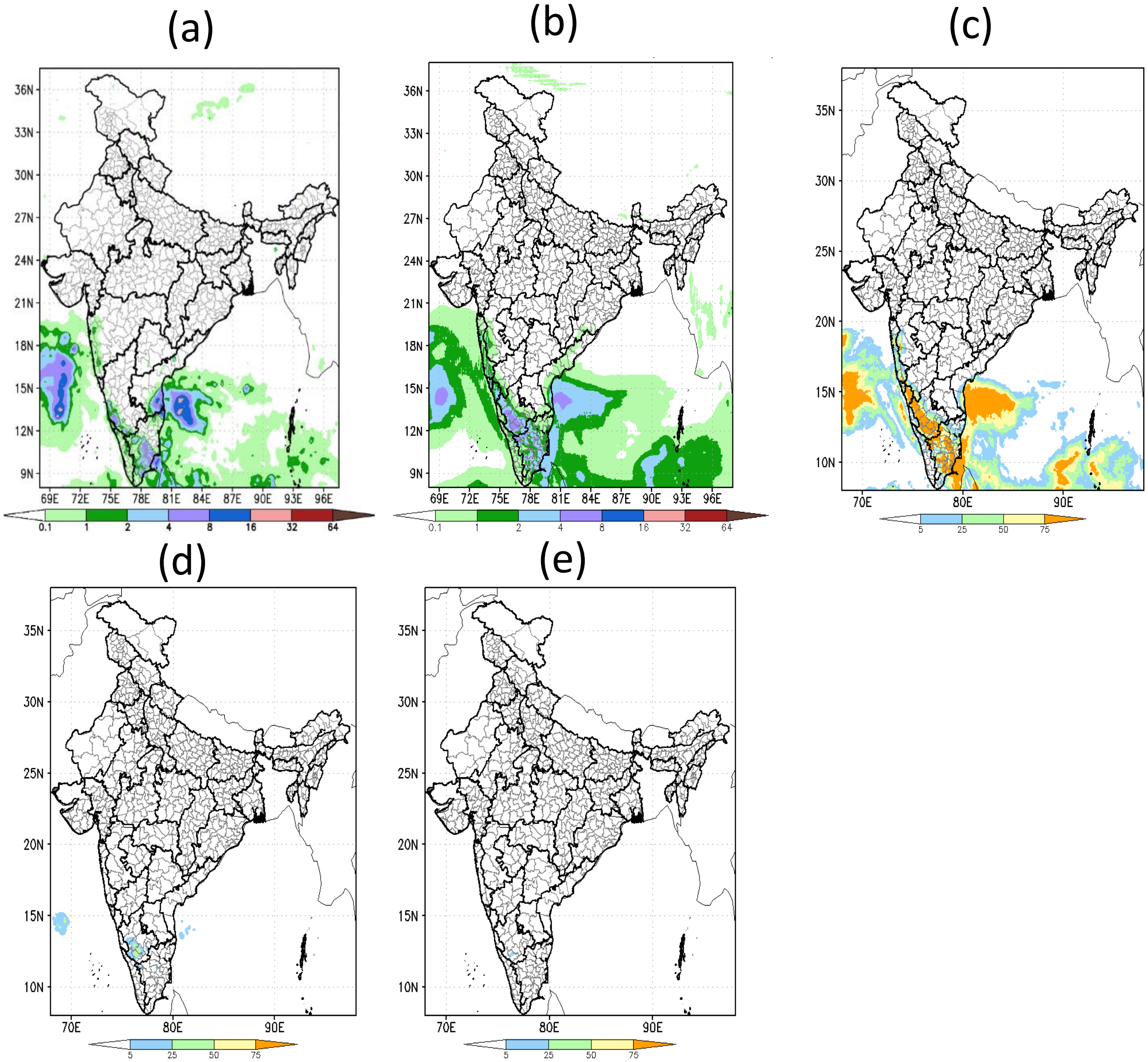

Fig. 8.12 a. Day 1 rainfall forecast from GEFS T1534 valid for 7 November 2021 with (a) IMD-GPM (b) Ensemble mean and forecast showing probability of exceedance from (c) 15.6 mm/day (d) 65.5 mm/day (e) 115 mm/day rainfall threshold.

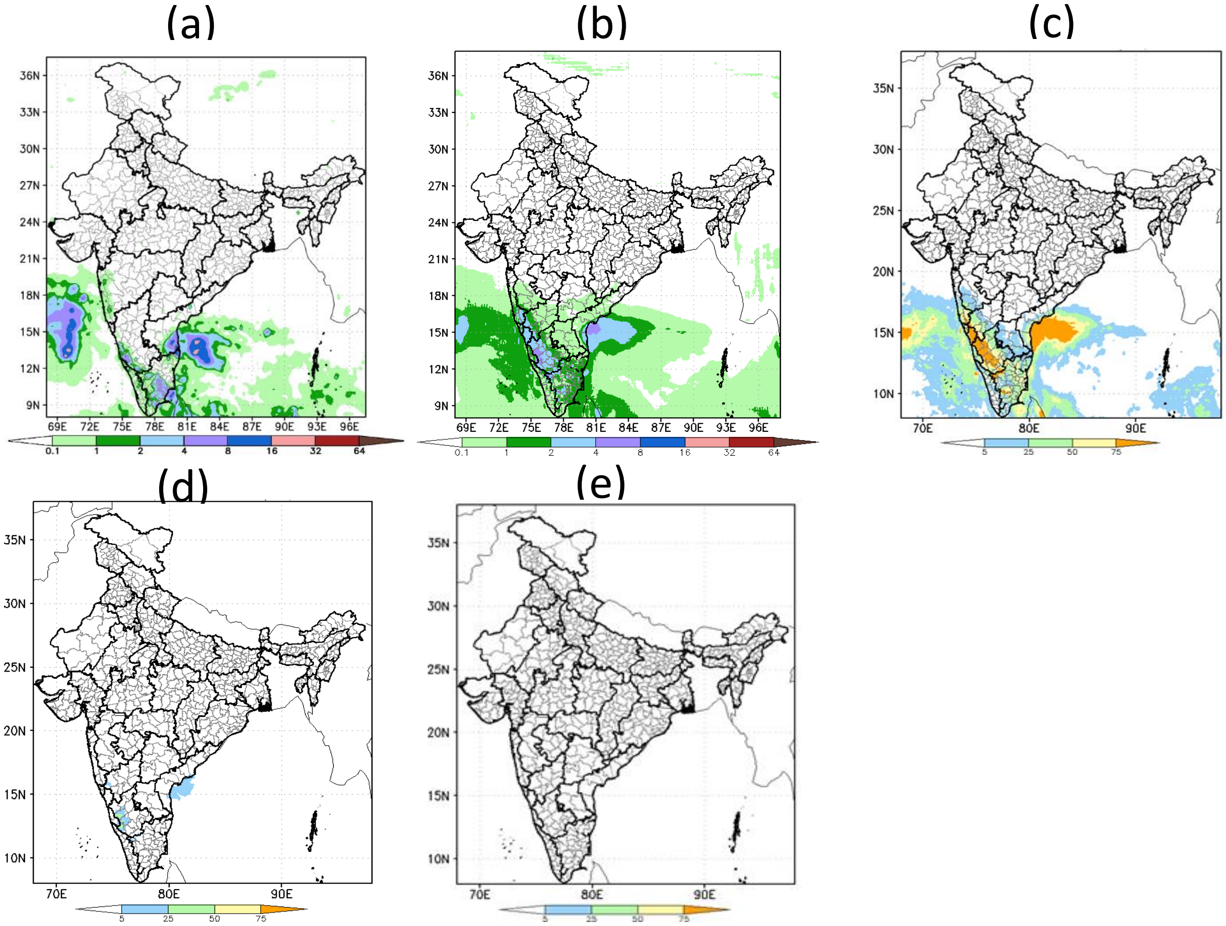

Fig. 8.12 b. Day 3 rainfall forecast from GEFS T1534 valid for 7 November 2021 with (a) IMD-GPM (b) Ensemble mean and forecast showing probability of exceedance from (c) 15.6 mm/day (d) 65.5 mm/day (e) 115 mm/day rainfall threshold.

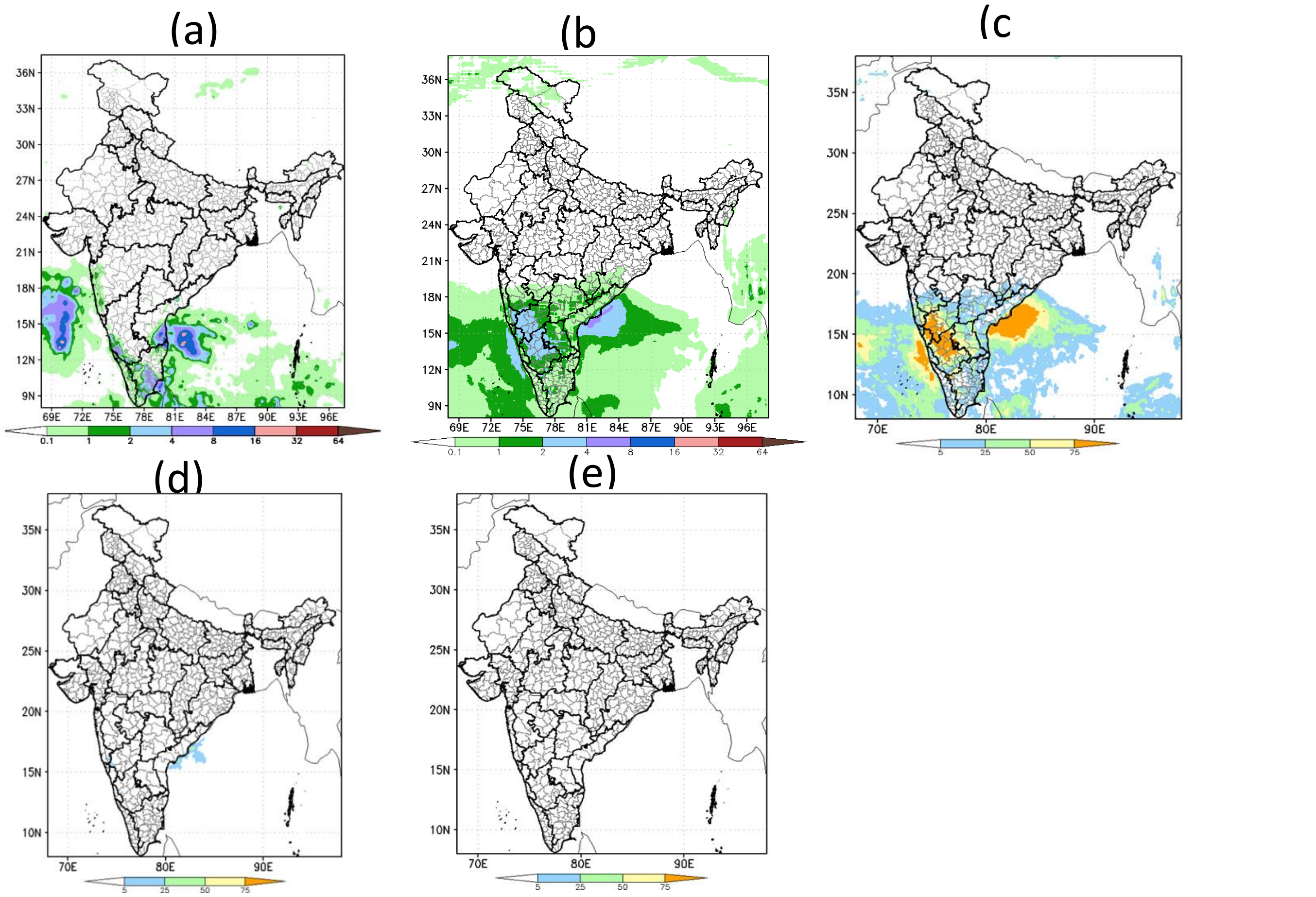

Fig. 8.12 c. Day 5 rainfall forecast from GEFS T1534 valid for 7 November 2021 with (a) IMD-GPM (b) Ensemble mean and forecast showing probability of exceedance from (c) 15.6 mm/day (d) 65.5 mm/day (e) 115 mm/day rainfall threshold.

Thus, from the above discussions, we can conclude that the present-day NWP model forecasts have some useful skill in predicting various aspects of the NE Monsoon season. Forecasters should make use of the NWP model forecasts along with other forecasting tools like satellite pictures, radar data etc for preparing more skillful forecasts during the NE monsoon season. The ensemble forecasts are very useful for preparing probability forecasts to account uncertainties involved in the forecasts.