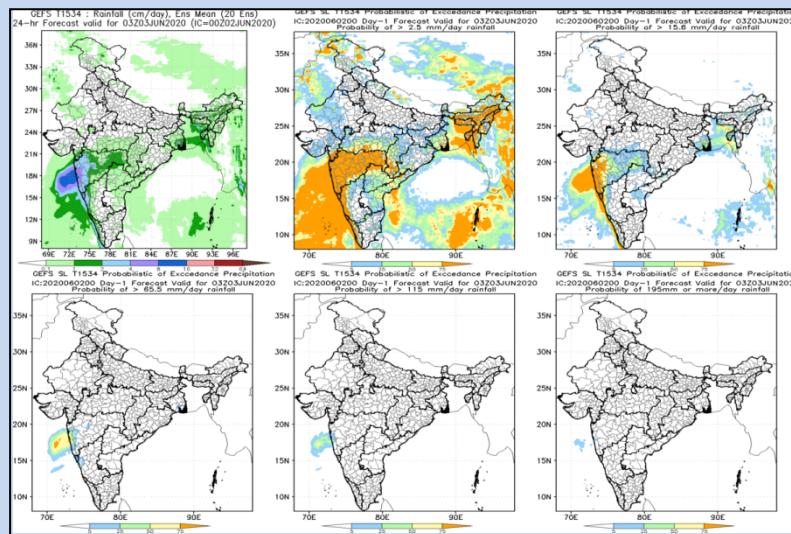


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Abstract

To improve the weather forecasts and services across India, Global Ensemble Forecast System (GEFS) model has been implemented on MoES HPCS system. The model has been ported on two HPCS systems which has 21 ensembles (21) and runs at 12 Km resolution with 64 vertical levels. The model runs twice a day on Operational mode. Various products are generated from this model for the Indian region. This document gives a glimpse on the implementation of the GEFS model.

Summary

Many efforts are being done to increase the prediction skill of the high-impact weather systems using the state-of-art models. With an intuition to improve the weather forecasts and services, we have implemented Global Ensemble Forecast System (GEFS) model on the MoES HPCS system. The high-resolution (~12Km) and the number of ensembles (21) make this GEFS system unique in the world. This system is based on the deterministic GFS system of NCEP operationalized in 2018. The initial conditions are generated from the Ensemble Kalman Filter (EnKF) method. The Ensemble Transform methods are used to combine the perturbed ensembles and the ICs from the GDAS assimilation system. Near Real-time SST (NSST) is also perturbed along with the other fields. 12Km GEFS model suggests that the RMSE doesn't change with the lead time. The model is able to predict heavy precipitation events and the cyclonic storms more realistically. The EPSgram, Skew-T plot and the QPF are very useful for the forecasters.

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1. Introduction

The scientific insights gained from the research work based on numerical experiments by Smagorinsky, 1963; Leith, 1965; Mintz, 1965 and others in 1960s and further the epochal work of Lorenz (1963) on limited predictability of deterministic forecast due to inherent chaotic nature of the environment, have set the basis for ensemble prediction system (EPS). As a consequence to these path breaking concepts, the EPS system for medium range forecast was established in European Center for Medium Range Weather Forecast (ECMWF), UK (Buizza et al., 1993; Buizza and Palmer, 1995) since 1992 (Palmer et al., 1992; Molteni et al., 1996). Contrary to the singular vector approach of ECMWF, around same time NMC/NCEP, USA introduced the medium range ensemble prediction system based on breeding vector approach (Toth and Kalnay, 1993; 1997). In India, the ensemble prediction system for medium range weather was started at National Center for Medium Range Weather Forecast (NCMRWF) at a moderate resolution of T190 in the year 2012 (Ashrit et al., 2012). However, with the pressing demand of stake holders and for different societal need for a forecast at higher resolution, Indian Institute of Tropical Meteorology implemented a global high resolution (T1534~12.5km) ensemble prediction system with 21 ensemble members for a ten day forecasts. This was done under the “Monsoon Mission” programme of Ministry of Earth Sciences, Government of India in collaboration with NCMRWF for the perturbed initial conditions and NCEP, USA for the model. The details of the model, porting and the perturbation techniques are discussed in subsequent sections. The IITM GEFS system is operationalized by IMD on 1 June 2018. The current GEFS system is supposed to be the highest resolution global EPS system in the world at present that is being used for 10 days forecast.

2. Methodology

2.1 Description of GEFS model

Global Ensemble Forecast System (GEFS) was upgraded from ~27 km (T574 with GEFS v11.3) to ~12 km (T1534) resolution in year 2018. It is based on Global Forecast System (GFS v14.1) which is a part of the ‘Operational Model’ developed at NCEP, USA in 2018. Table 1.0 gives the difference in the versions of the model which was newly implemented. The dynamics, horizontal resolution, representation of physics processes and the Near surface SST (NSST) are among the few to be mentioned which has significant changes in the new version. Apart from the more number of observations, surface perturbations (NSST) are also included in the Initial Conditions (ICs). The total number of 21 Ensembles (20 perturbed forecasts + 1 control forecast) constitutes the ensemble system. These 20 ensembles analysis are generated by Ensemble Kalman Filter (EnKF) method from the forecast perturbation of the previous cycles four times a day (00, 06, 12 and 18 UTC) at all 64 model vertical levels. These analysis perturbations are added to the reconfigured analysis obtained from the hybrid four-dimensional Ensemble variational data assimilation system (GDAS-Hybrid4DEnVar) as part of the suite. The 243 hour forecast of GEFS is routinely generated based on 00UTC and 12UTC initial conditions which include a control forecast starting from GDAS assimilation and 20 (20 perturbations) ensemble members with each perturbed initial conditions.

Figure 1 gives the details of the 12Km GEFS model flow chart.

Model Version	V14.1.1.3	V11.1 (Older version)
No. of ensembles members	20 + 1	20 + 1
No. of Levels (Sigma)	64	64
Description about the Model	a) Spectral model, with Semi-Lagrangian dynamics and Semi-implicit time scheme b) With Near surface SST	a) Spectral model with semi-Lagrangian dynamics
Grid description	Reduced Gaussian Linear Grid	Reduced Gaussian Linear Grid
Resolution	T1534 (3072 x 1536) ~ 12.5KM	T 574 (1152 x 576)
Model time-steps	Dynamics : 900 sec(450) Physics : 450 sec(225)	Dynamics : 450 sec Physics : 225 sec
Radiation time-steps	1 Hour for both LW and SW	1 Hour for both LW and SW
Deep Convective Parameterization	Scale- and Aerosol-aware deep convection (SAS)	New- Simplified Arakawa Scheme
Shallow Convective parameterization	Scale- and Aerosol-aware shallow scheme based on mass-flux	Mass-flux based Shallow convection
Radiation	RRTMG	RRTM

PBL	EDMF	EDMF
Microphysics	Zhao – Carr Microphysics	Zhao – Carr Microphysics
Surface Model	NOAH Land Surface Model	NOAH Land Surface Model
Forecast Length	243 Hours with 3 hourly interval (cycles: 00UTC and 12 UTC)	240 Hours with 6 hourly interval (only 00 UTC cycle)
Initial Condition Perturbations	Ensemble Kalman Filter (ENKF)	Ensemble Kalman Filter (EnKF)
Model I/O format	Nemsio	Sigma spectral
Space requirement for 243 hrs forecasts (21 ens)	21 TB / cycle	4 TB / cycle
Post-Processing	Grib2	Grib1

Table 1: GEFS T1534 model description and the older version of the model

2.2 Computational details of the Model

The GEFS model was made operational first at Pratyush HPCS of IITM and, later at Mihir HPCS of NCMRWF. Pratyush and Mihir HPCS are Cray-XC40 Liquid Cooled System with 3315 nodes and 2320 nodes running with a peak performance of 4.006 PF and 2.8 +PF with a total system memory of 414TB and 290 TB respectively. The deterministic model (GFS v14) takes around 90 minutes on Cray XC-40 with 23 nodes. Out of the 23 nodes, 4 nodes are used as I/O. Similarly, separate nodes are allocated for writing the I/O as each ensemble writes nearly 10GB at each model output frequency. The 21 member ensemble forecast takes nearly 90 minutes on 483 nodes of the same system. Table 2 gives the specification of the complete details of the timing used for the GEFS model.

Configuration	Start Time	Wall Clock Time (Minutes)	Number of Nodes	Details of the run
Global Ensemble Initialization (10)	0900, 2100	2	84	enkf.track
Vortex Separation (12)	After 10	2	84	init.seperate
Ensemble Transform with Rescaling (13)	After 12	10	84	init.et
Ensemble Vortex Combine (14)	After 13	20	84	init.combine
Forecast (100)	After 14	90	483	Fest
Post-Processing (102 – 182)	After 100	20	540	ncep.post
Ensemble Average/Spread (194)	After Post processing	10	84	Ensstat
Ensemble Tracker (396 – 397)	After Ensemble average	10	21	Getrk

Table 2: Timings/Nodes usage of the GEFS T1534 model. The number in the bracket indicates the configuration number and the starting time depends on the completion of this number

2.3 Ensemble Kalman Filter (Data assimilation)

NCMWF GFS data assimilation system employs hybrid Ensemble Variational (EnsVar) technique with 80 member EnKF ensembles. The hybrid assimilation system is based on grid point statistical interpolation (GSI), with background error covariance modified by inclusion of flow dependent background error information from ensembles. In the background error, 87.5 % contribution is provided by flow dependent error covariance and 12.5 % by static error covariance. Here EnKF formulation uses ensemble square root filter (EnSRF) for generating ensembles as a part of the hybrid GSI analysis system (Liu et al, 2015). EnKF uses observation operator in GSI to compute observation innovations with respect to each ensemble. So all the observations used in the GSI are available for assimilation in EnKF and observation selection and other quality control procedures are done with in GSI operator. The assimilation system uses conventional and satellite observations including many Indian observations. **Table 3** gives details of observations used in NCMWF GSI assimilation system. In EnSRF formulations model analysis state is updated by representing analysis variables as two terms, the ensemble mean and as a deviation from mean (Liu et al, 2015). Ensemble analyses are re-centered around deterministic analysis from GSI using recentering procedures and short forecasts are generated. The process is repeated 4 times a day corresponding to 00, 06, 12 and 18 UTC. Twenty members of these EnKF ensembles are utilized in GEFS forecasts utilizing different members in each cycle. At present GEFS is run at 00 UTC and 12 UTC using member 1-20 and 41-60 respectively.

Conventional observations	Non Conventional observations	
Tropical cyclone bogus	MHS	MLS ozone
Rawinsonde	HIRS-4	OMPS (NP & TC8) ozone
PIBAL	AIRS	AHI
Dropsonde	IASI	GPSRO
AIREP	SSM/IS UPP radiances	AMV
AMDAR	GOES sounder radiances	Scatterometer (ASCAT/SCATSTAT)
U.S./Mexican/ADS-C MDCRS	SEVIRI/CSR	GMI
Canadian AMDAR	ATMS	
S. American AMDAR	CrIS	
GPS-IPW (ground based)	SAPHIR radiances	
NPN wind profiler	GOES img cloud products	
VAD winds	GOES sndr cloud products	
JMA wind profile	SBUV ozone	
SYNOP METAR	GOME ozone	
Ship buoy platforms	OMI ozone	

Table 3: Details of observations assimilated in GSI

3. Results and Discussion

The new GEFS model at 12Km is operationalized on 01 June 2018. Many products are generated from this model and are made available operationally at https://srf.tropmet.res.in/srf/hires_gefs/index.php. Some of them and their skill scores are being mentioned below.

3.1 Verification of GEFS with Probabilistic Skill scores

To evaluate the statistical reliability of the ensemble forecast we have plotted the Root Mean Square Error (RMSE) and spread of precipitation for June-September of 2018 and 2019 in **Figure2**. RMSE of the ensemble mean measures the distance between forecast and IMD GPM Gridded rainfall data. The spread measures the deviation of ensemble members from the ensemble mean. In a perfect ensemble forecast system, where all of the uncertainties associated with initial errors and model errors are represented, the verifying analysis is statistically indistinguishable from the ensemble members and the spread would be equal to RMSE uncertainty (Zhu 2005, Buizza et al. 2005). The discrepancy between the RMSE of ensemble mean and ensemble spread is a measure of the statistical reliability of an ensemble forecast system (Buizza et al. 2005). For a reliable ensemble forecast system, this discrepancy should be low. The large difference between the two indicates statistical inconsistency. For the Indian Landmass (**Figure2**) the spread is less than RMSE which indicates precipitation forecast is under-dispersed. Also the growth in the RMSE is less than growth in the spread with forecast lead time.

Brier Score (BS) is used for the verification of probabilistic forecasts (Brier 1950). It measures the mean-square error between the probabilistic forecasts and the subsequent categorical observation. It is given by,

$$BS = \frac{1}{n} \sum_{k=1}^n (y_k - o_k)^2$$

Where the difference is between the forecast probabilities and binary observations ($o_k=1$, event occurs and $o_k=0$, event does not occur). The score ranges from 0 to 1 with 0 showing perfect forecasts.

BS can be decomposed into reliability (REL), resolution (RES) and uncertainty (UNC) components (Murphy, 1973, Wilks, 1995).

$$BS = \text{Reliability} - \text{Resolution} + \text{Uncertainty}$$

Reliability measures the statistical consistency between *a priori predicted* probabilities and *a posteriori observed frequencies* of the occurrence of the event. For a perfectly reliable system, REL should be 0.

Resolution measures how the different forecast events are classified by a forecast system. Larger the RES is, better is the forecast system at identifying whether an event is likely to occur in the future.

Uncertainty is the variance of the observations.

Figure 3 shows the Brier score and its decomposition for precipitation forecast for JJAS of 2018-2019. The forecast shows skill as it does not deteriorate with increasing lead times. The decomposition shows that lower reliability and higher resolution holds true for lower thresholds.

3.2 Ensemble mean features of GEFS model

Various parameters like Ensemble Mean and Spread for Mean Sea Level Pressure (MSLP), Wind at different levels (850, 500, 200), Geopotential Height (700, 500, 200) along with Ensemble Mean Rainfall and Rain probability are extracted and plotted operationally after post-processing. Ensemble mean is a simple mean of the parameter value between all ensemble members and Ensemble spread is calculated as the standard deviation of a model output variable which provides a measure of the level of uncertainty in a forecasted parameter. Here in this section, we are discussing a case during monsoon 2020. On 25th June, monsoon trough was located near the foothills of Himalaya, which gave heavy rainfall along with thunderstorms and lightning over Bihar and Uttar Pradesh. The movement of the trough towards foothills of Himalaya was very well predicted by the GEFS at the lead time of 5 days. **Figure 4 (a)** INSAT3D IR Brightness Temperature Image indicates the band of deep clouds near the foothills on 25th June. Corresponding Mean Sea Level Pressure (MSLP) from the analysis is shown in **Figure 4 (b)** wherein the blue dashed line indicates the location of the trough. The forecast of MSLP and the wind at 850 hPa level valid for 00Z 25 JUNE 2020 based on 00Z 20 JUNE IC is shown in **Figure 4 (c)** and **(d)**. Due to the presence of trough there was heavy rainfall over Himalayan foothills which caused floods in Uttar Pradesh, Bihar and the Northeastern States like Assam and Meghalaya. **Figure 5** shows the 24 hr

accumulated rain from **(a)** IMD-GPM merged Gridded data, 48 hr forecast from **(b)** GFS and **(c)** GEFS ensemble mean along with the probability of rain with a threshold of **(d)** >2.5 mm/day **(e)** >15.6 mm/day **(f)** >65.5 mm/day **(g)** >115 mm/day **(h)** >195 mm/day all valid for 28th June 2020. The probability of heavy rain over Uttar Pradesh, Bihar, Assam and Meghalaya predicted by the model very well matches with the observed Rainfall.

3.3 Tropical Cyclone Prediction

GEFS based intensity and strike probability forecast is provided to the operational centre (IMD) which helps in providing and managing guidance on the impact of tropical cyclone on coastal population. The prediction of Super Cyclonic Storm (SuCS,) AMPHAN is discussed in this section. AMPHAN formed as a depression over Bay of Bengal on 16th May 2020 and intensified to its maximum strength as SuCS (maximum wind speed of 130 kts) on 18th May. It weakened slightly and crossed West Bengal – Bangladesh Coasts on 20th May. **Figure 6 (a)** is the Strike probability (%) forecast which is the probability of the storm passing within 65nm (approximately 120 kms) during the forecast period. Forecast of maximum surface wind speed (knots) is shown in **Figure 6 (b)**. Both these plots are based on 12Z 17MAY 2020 Initial Condition. Here Black line is for IMD best track data, blue line (AC00) is for the control run (deterministic GFS) and red lines are for the ensemble members with dark Red line (AEMN) for Ensemble mean. **Figure 6 (c)** is the verification of the forecast of track and intensity from all the ICs during the lifespan of the cyclone. Verification clearly brings out the advantage of ensemble prediction system as RMSE for track from Ensemble Mean is always less than that of the deterministic one. Regarding intensity prediction RMSE is less for deterministic forecast for shorter lead time, but at higher lead time both are almost same.

3.4 Rainfall Probability Forecasts at Block Level

With the increase in horizontal resolution of the operational probabilistic weather forecast model, the demand for block level probabilistic forecast grows quite naturally. Therefore, we started issuing block level probabilistic forecast since 2019 monsoon season. One such example is provided in **Figure 7**. As discussed earlier, super cyclonic storm AMPHAN has made landfall on 20th May 2020 over coastal region of Orissa and West Bengal, which brought huge amount of rainfall and caused severe economic damage over the region. The various stations around Kolkata and other coastal districts of West Bengal reported heavy rainfall. It is found that GEFS T1534 was able to capture the heavy rainfall associated with the cyclonic storm over various blocks within the coastal districts with day-2 lead time (**Figure 7**). The block level forecast indicates that majority of the blocks shows up to 25%

probability of having heavier category rainfall. It is worth to note that skillful prediction on block level will eventually help to minimize the damage caused by the heavy and extreme rainfall events.

3.5 EPS Gram

Figure 8 shows the EPS Meteogram (EPSgram) computed from the output of GEFST1534 based on 18th May initial condition over Kolkata. The EPSgram is a probabilistic interpretation of the forecasts from the Ensemble Prediction System (EPS) for a given location. It displays the time evolution of the distribution of atmospheric variables in the ensemble forecast. The red line corresponds to the median of 20 member ensemble, i.e, it is showing the middle member of the upper and lower half of the distribution. The top part of the blue bar is showing the maximum value of that given variable amongst the 21 member ensemble and the lower part of it showing the minimum value of the same variable. The lower line of the green box shows the value represented by the bottom 25% of the members and the top line represents the value within which 75% of the members are laying. So here we have chosen the EPSgrams from a recent cyclone AMPHAN that made the landfall on 20th May 2020 over Sundarbans and eventually moved to Kolkata city and made massive destruction. The figure shows that the 2m air temperature gradually decreases and becomes minimum between 20th to 21st May. After 21st it rises again. The rainfall also reaches maximum between 20th to 21st May and decreases thereafter. It is to be noted that during the maximum rainfall the members are showing great variation with the minimum value of no rain to a maximum value of more than 160 mmhr⁻¹. It implies that atleast one of the ensemble member indicates very heavy rainfall on 20th May over Kolkata. Similar feature is also evident in the mean sea level pressure (MSLP) plot (bottom panel). MSLP shows a minimum value during the same time as in the case of rainfall and 2m air temperature. Some members even show MSLP as low as 970 mb. The EPSgram based on GEFS ensemble forecast provide additional guidance over selected cities across India particularly during extreme events.

3.6 Skew-T plots

Figure 9 shows the skew T-log P chart using GEFST1534 model forecast outputs based on 3rd July 2020 IC valid for 18, 24, 30 and 36 hours respectively over Delhi. This region was selected because of monsoon onset on the national capital. The blue line represents the dew point temperature of a parcel. Red line represents environmental temperature and cyan line represents the temperature profile of a parcel lifted adiabatically from the surface. They are enclosed by the red and cyan curve (enclosed by a black ellipse on the top right panel) represent CAPE. It is to be noted that a cape value more than 1000 Jkg⁻¹ is conducive for the development of thunderstorms. We have

picked a thunderstorm case over Delhi on 4th July to show the evolution of skew T-log P charts. We can see on 3rd July 18hrs the CAPE value increases to 1125 Jkg⁻¹ but on 4th July 00 hrs it has become almost double to 2311 Jkg⁻¹. **Figure 10** shows that the CAPE even further increases to 2368 Jkg⁻¹ at 06hrs of the same day and then at 12 hrs it started reducing showing a value of 1763 Jkg⁻¹. The evolution of CAPE based on GEFS forecast thus demonstrates how this diagram can be very useful to the forecasters to predict thunderstorm events in advance.

3.7 Probabilistic rainfall prediction over river basins for Flood Meteorological Office (FMO)

Increasing flood risk is recognized as one of the important threats in the changing climate scenario especially in the perspective of extreme heavy rainfall events. In order to issue a warning for flood, an appropriate quantitative precipitation forecast (QPF) system was required. Probabilistic QPF (PQPF) provides the best estimate of the chances that any given location will receive an amount of rain that equals or exceeds a certain threshold value. In view of the above, PQPF based on GEFS over different river basins has been operationalized recently. Twenty four FMO (Flood Meteorological Office)/agencies those are responsible for issuing the QPF in the respective regions. The said regions are Agra, Asansol, Ahmedabad, Bengaluru, Bengaluru-Kerala, Bhubaneswar, Chennai, DVC, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi, Patna, Srinagar, Cauvery, Hirakud, Narmada, Krishna, Idamalayar, Idukki, Maithon, Tapi and Panchet. GEFS based PQPF is produced daily for the above FMO basins in six different precipitation ranges (viz. 0-0.1, 0.1-10, 10-25, 25-50, 50-100 and >100 mm).

Figure 11 shows **(a)**day-1, **(b)**day-3 and **(c)**day-5 PQPF forecast based on GEFS valid for 26 June 2020 over FMO Patna region which predicted a heavy rainfall, and created havoc/floods over the region. There is more than 50% probability of rainfall between 10 to 25 mm with all the lead time over the region. The model is also able to capture 25% probability of rainfall more than 100 mm with 120hr lead time in few river catchments. PQPF forecasting is useful in issuing a flood warning during monsoon season and extreme weather events.

4. Conclusions and Future works

The GEFS model is ported on Pratyush and Mihir HPCS systems and has been in operational mode from 01 June 2018. The model is run twice (00UTC and 12UTC) a day with 10 days lead

time. Various products are generated from this model for the forecasters. While it is demonstrated in the above sections that ensemble prediction system based on GFS (GEFS) at the globally highest resolution of 12.5 km is providing skillful predictions of a variety of weather systems with longer lead time, there is a need to improve the fidelity of individual member in the ensemble and also improve the performance of the GEFS system further. Mostly it is noted that the ensemble system has a reasonable skill up to 5 days but for the disaster mitigation and early warning, there is a need to extend the skill up to 7 days or beyond. Considering this societal need into account, the GFS/GEFS system would be developed at a global 6 km resolution (over tropics) using cubic-octahedral dynamical core. Along with the change of dynamical core, the future system would be using Stochastic Physics Perturbation Tendencies (SPPT) in place of Stochastic Total Tendency Perturbation (STTP). The present system uses 64 hybrid vertical levels which will be increased to 91 hybrid levels. The convection is currently being done using a scale-aware approach. The convection and cloud microphysics would be further improved to incorporate the stochastic physics. More data from remote sensing sensors and in-situ would be ingested to improve the initial conditions.

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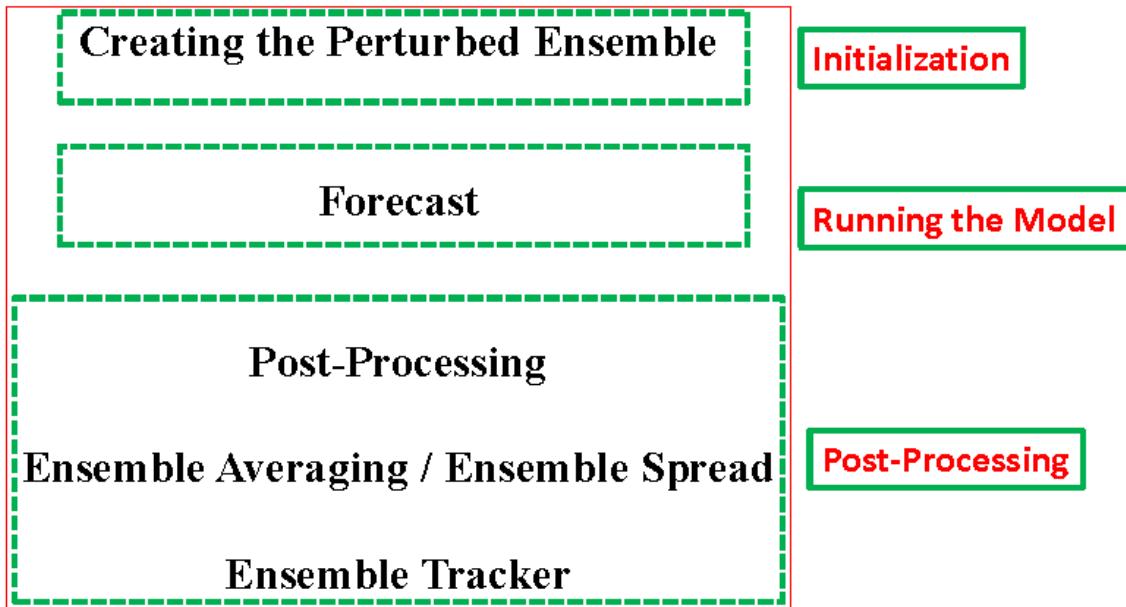


Figure 1 Schematic view of the GEFS T1534 model

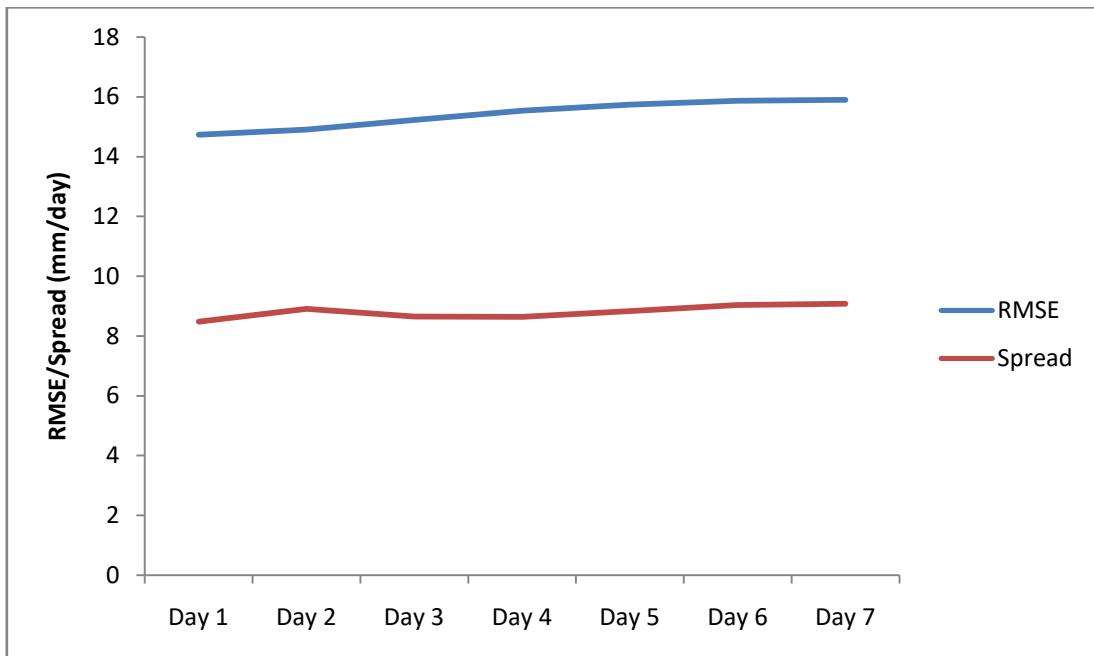


Figure 2: RMSE and spread of precipitation forecast (mm day^{-1}) over Indian landmass for JJAS of 2018 and 2019



Figure 3: Brier Score and its decomposition of precipitation forecast (mm day^{-1}) over Indian landmass for JJAS of 2018 and 2019 for various thresholds with lead times.

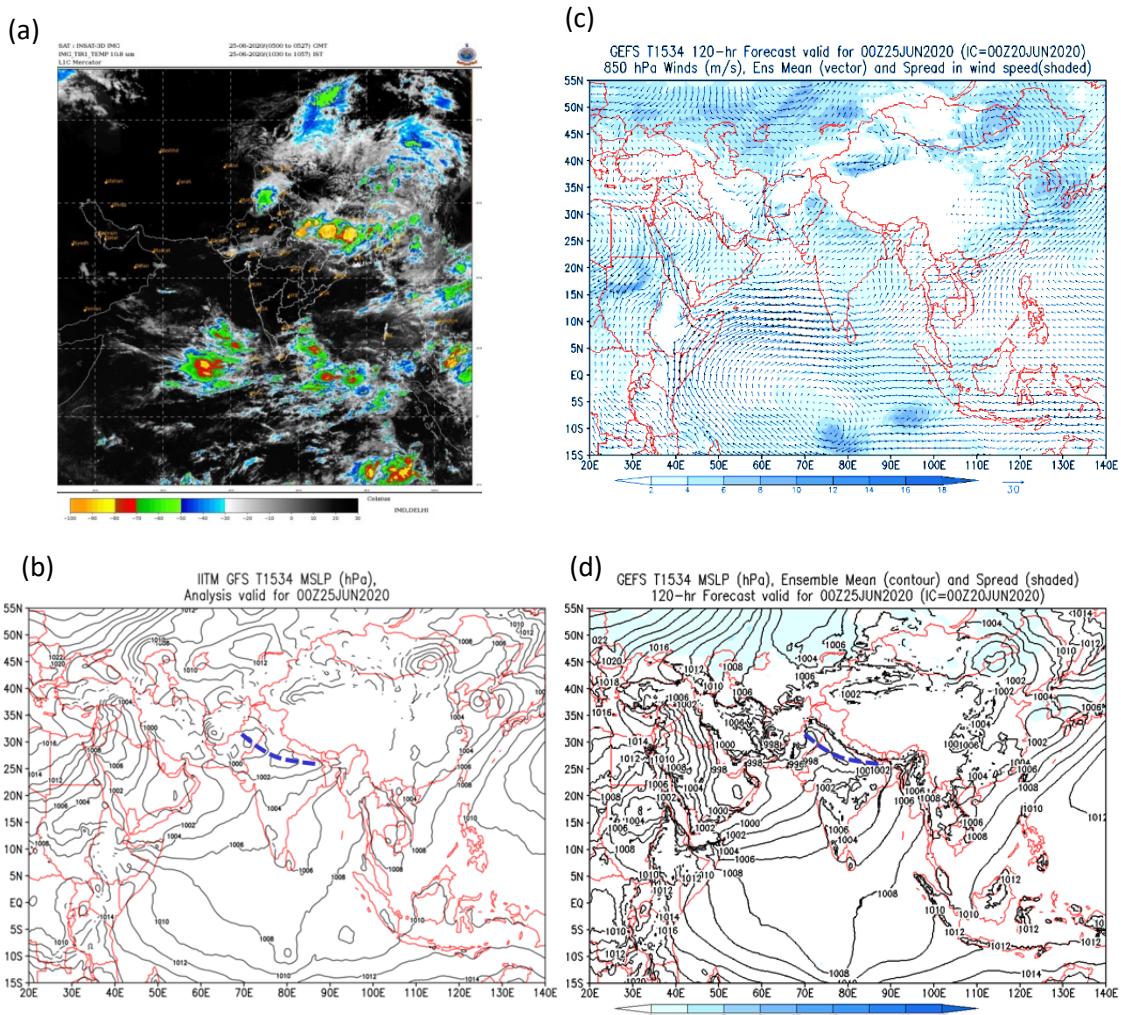


Figure 4 a) INSAT 3D IR Brightness Temperature Image, (b) Mean Sea Level Pressure from the analysis, (c) GEFS T1534 120 hr Forecast of Ensemble Mean and Spread (shaded) for wind speed (vectors) at 850 hPa level and (d) Mean Sea Level Pressure (contour) all valid for 00Z 20 JUNE 2020

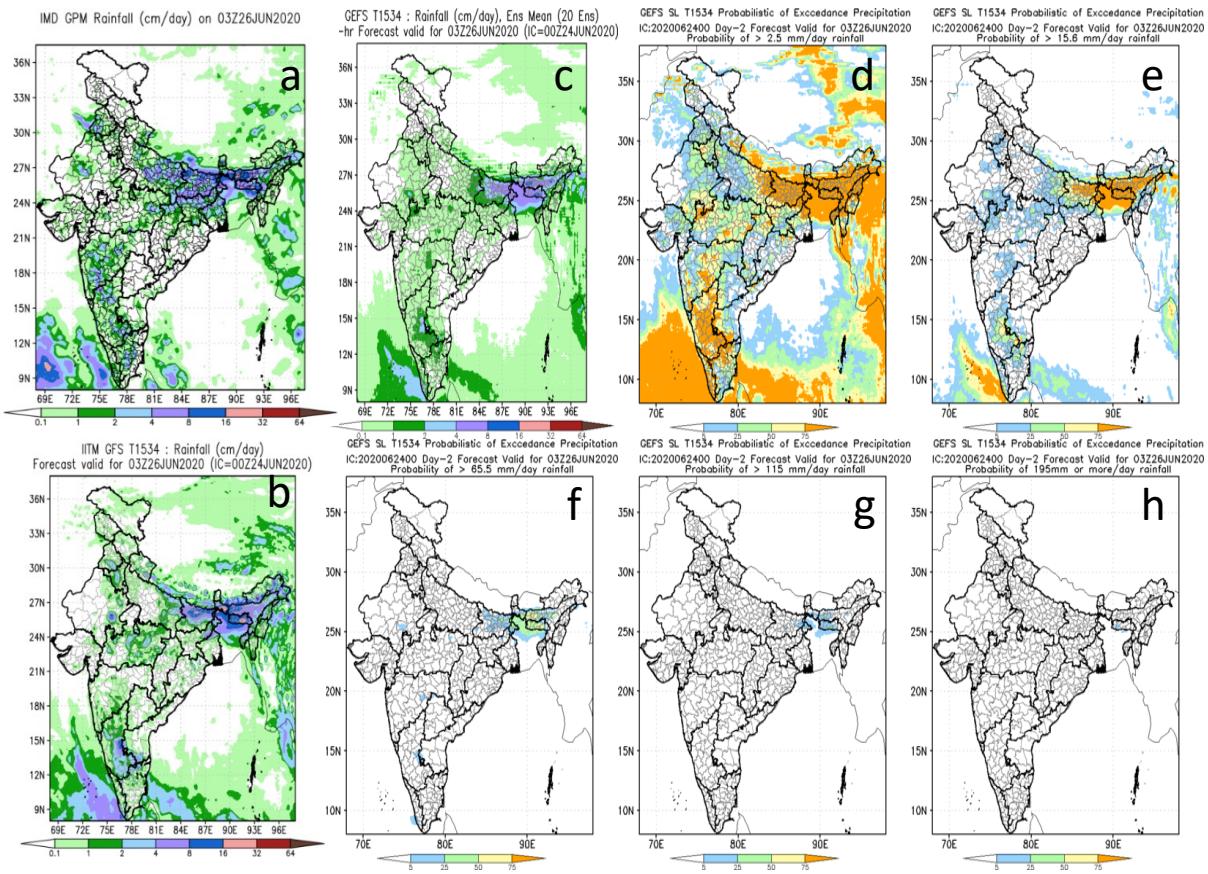


Figure 5. 24 hr accumulated rain from (a) IMD-GPM merged Gridded data, 48 hr forecast from (b) GFS and (c) GEFS ensemble mean along with the probability of rain with various thresholds (d) $> 2.5 \text{ mm/day}$ (e) $> 15.6 \text{ mm/day}$, (f) $> 65.5 \text{ mm/day}$, (g) $> 115 \text{ mm/day}$ and (h) 195 mm/day or more all valid for 26th June 2020.

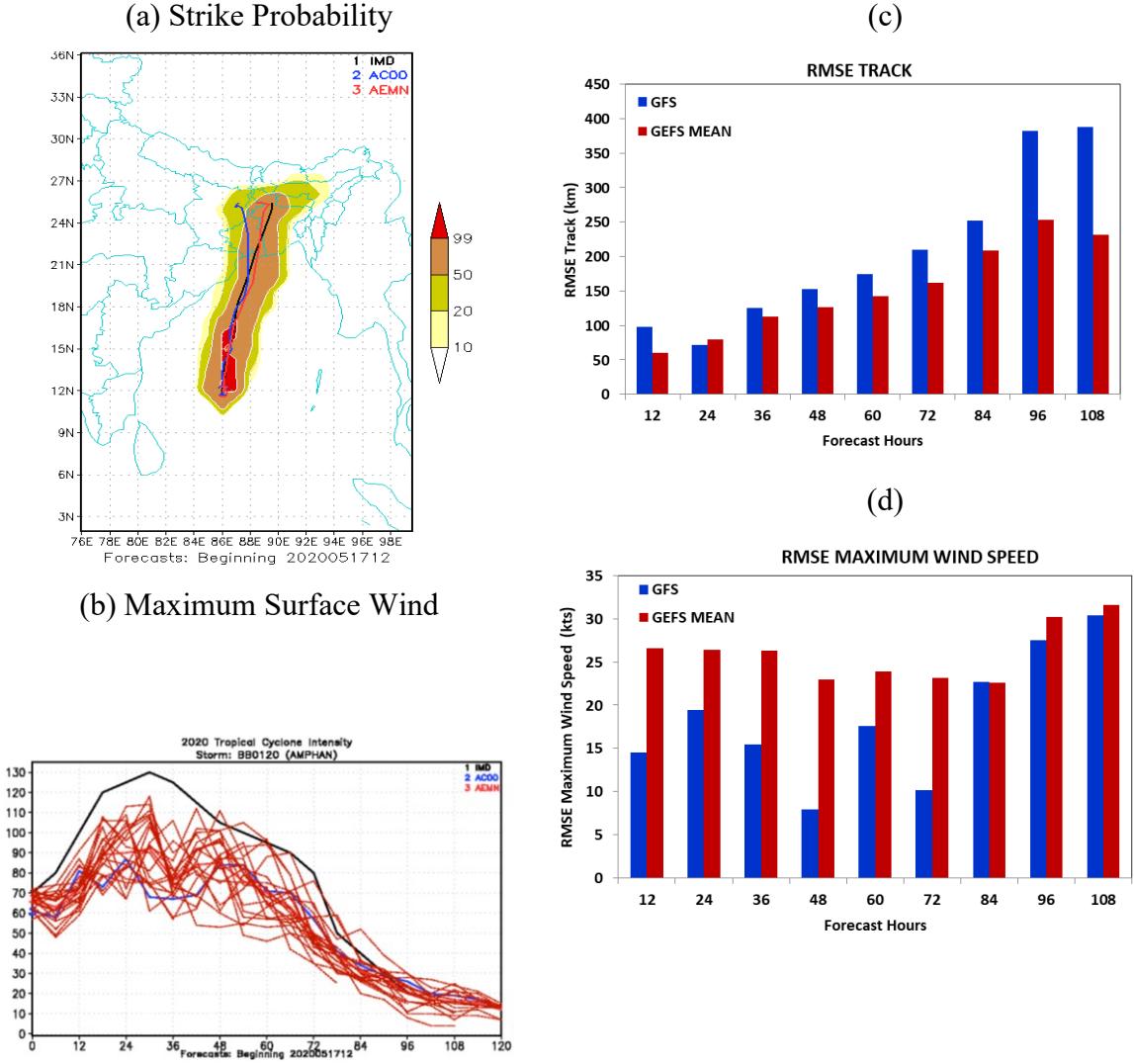


Figure 6. (a) Strike probability forecast, (b) Forecast of maximum surface wind speed (knots) for Super Cyclone AMPHAN both based on 12Z 17MAY 2020 Initial Condition. Here Black line (IMD) is from IMD best track data, blue line (AC00) is for the control run and red lines are for the ensemble members with dark Red line (AEMN) for Ensemble mean. Verification of the forecast of (c) track and (d) intensity from all the ICs during the lifespan of the AMPHAN.

IC: 18th May 2020, valid for 20th May

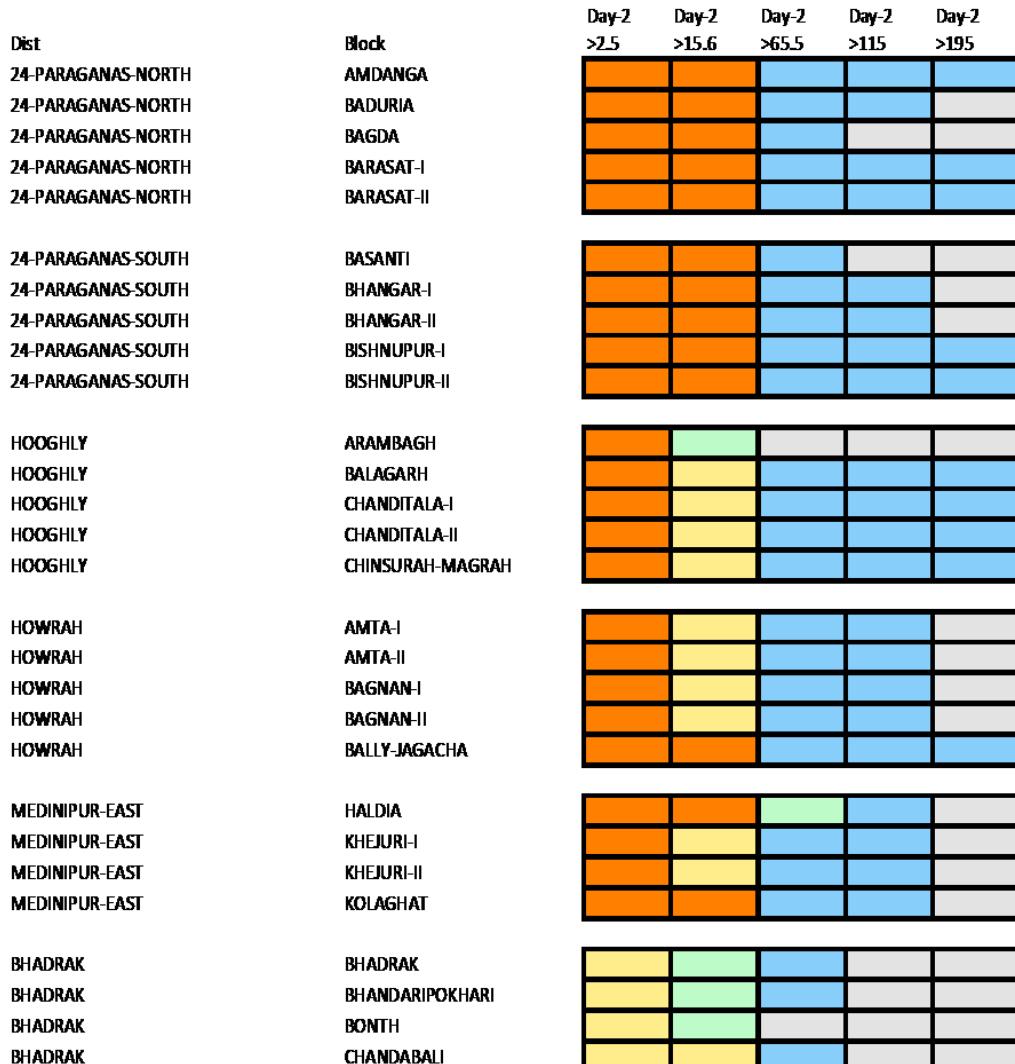


Figure 7. Block level forecast of precipitation probability for different rainfall category (mm day^{-1}) valid for 20th May 2020 based on GEFS T1534 model forecast with 18th May 2020 IC. Different blocks with corresponding districts names are mentioned. Orange (yellow) color indicates precipitation probability more than 75% and yellow color represents probability 50%-75%. Aqua color and sky-blue color represent probability (25%-50%) and (5%-25%) respectively.

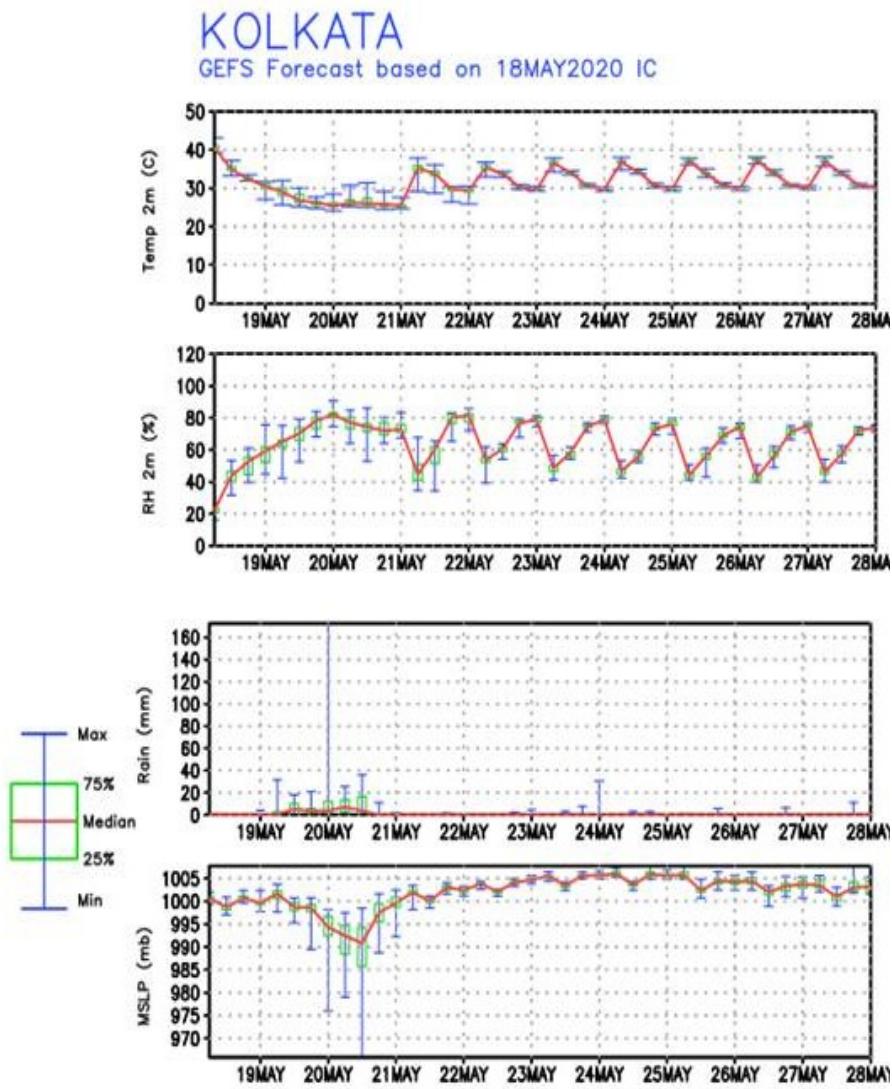


Figure 8.EPSgrams (Top panel to bottom panel) of 2m temperature ($^{\circ}\text{C}$), RH(%) at 2m, Rain (mm/hr) and MSLP(mb) based on GEFST1534 outputs with 18th May 2020 initial condition over Kolkata.

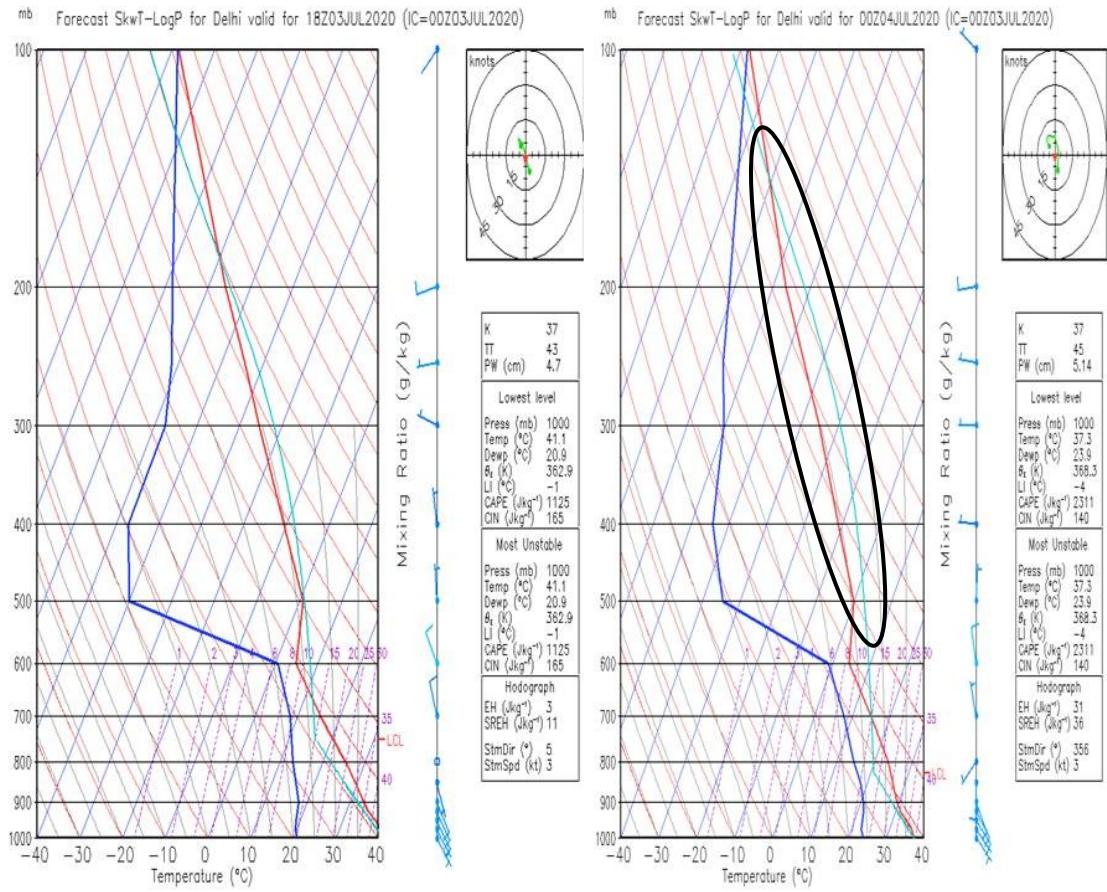


Figure 9. Skew T-log P charts using GEFST1534 forecast products based on 3rd July 2020 initial condition valid for 18hr, 24hr respectively from the top left to bottom right panel over Delhi.

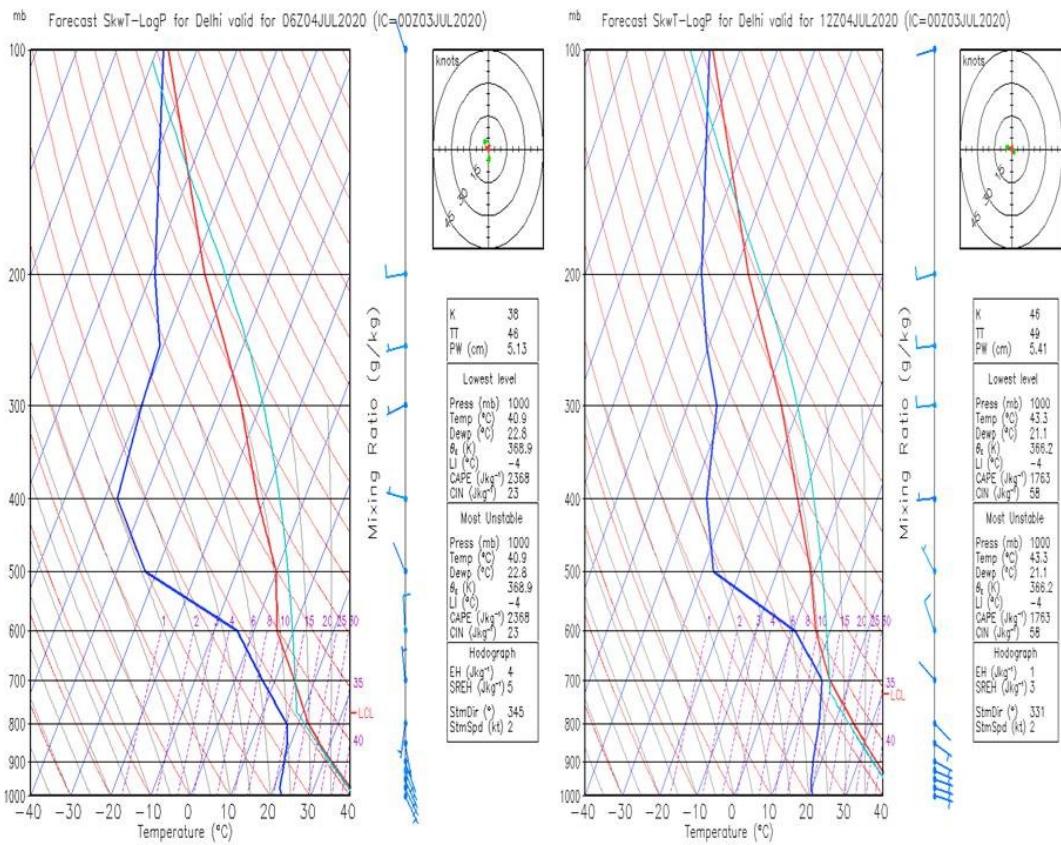


Figure 10. Skew T-log P charts using GEFST1534 forecast products based on 3rd July 2020 initial condition valid for 30hr and 36 hr respectively from the top left to bottom right panel over Delhi.

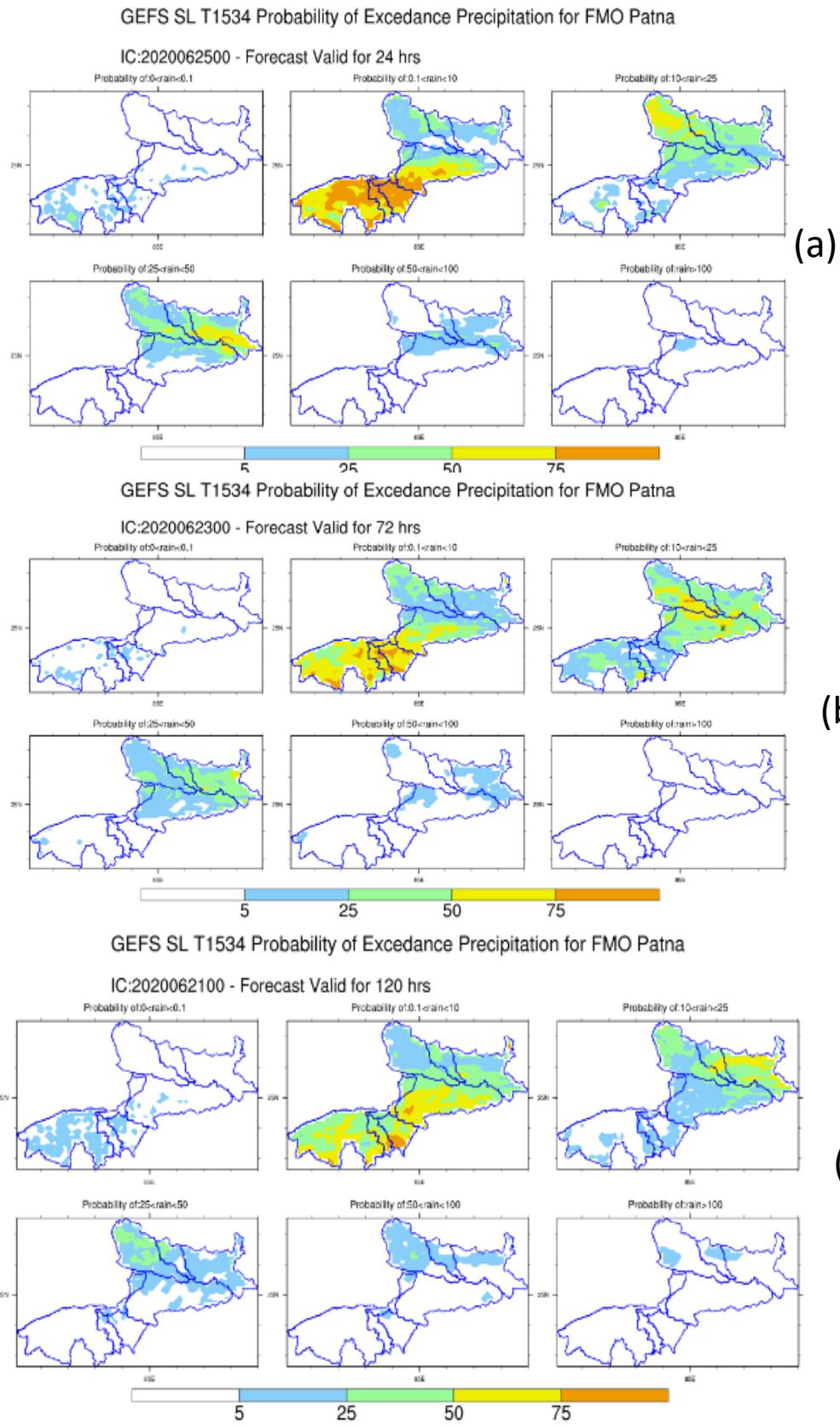


Figure 11.QPF plot for the Patna river basin from the GEFS model on 26June 2020 for a) one day lead b) three days lead and c) five days lead. The PQPF of more than 75 percentage is shown with 5 days lead.