# *Ensemble Prediction System in NCMRWF: its performance and future goals*

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**9th NOAA ENSEMBLE USERS WORKSHOP, 22–24 August 2023,**
**23 August, Session 5b**

# *Schematic representing a seamless modelling system operational at NCMRWF*

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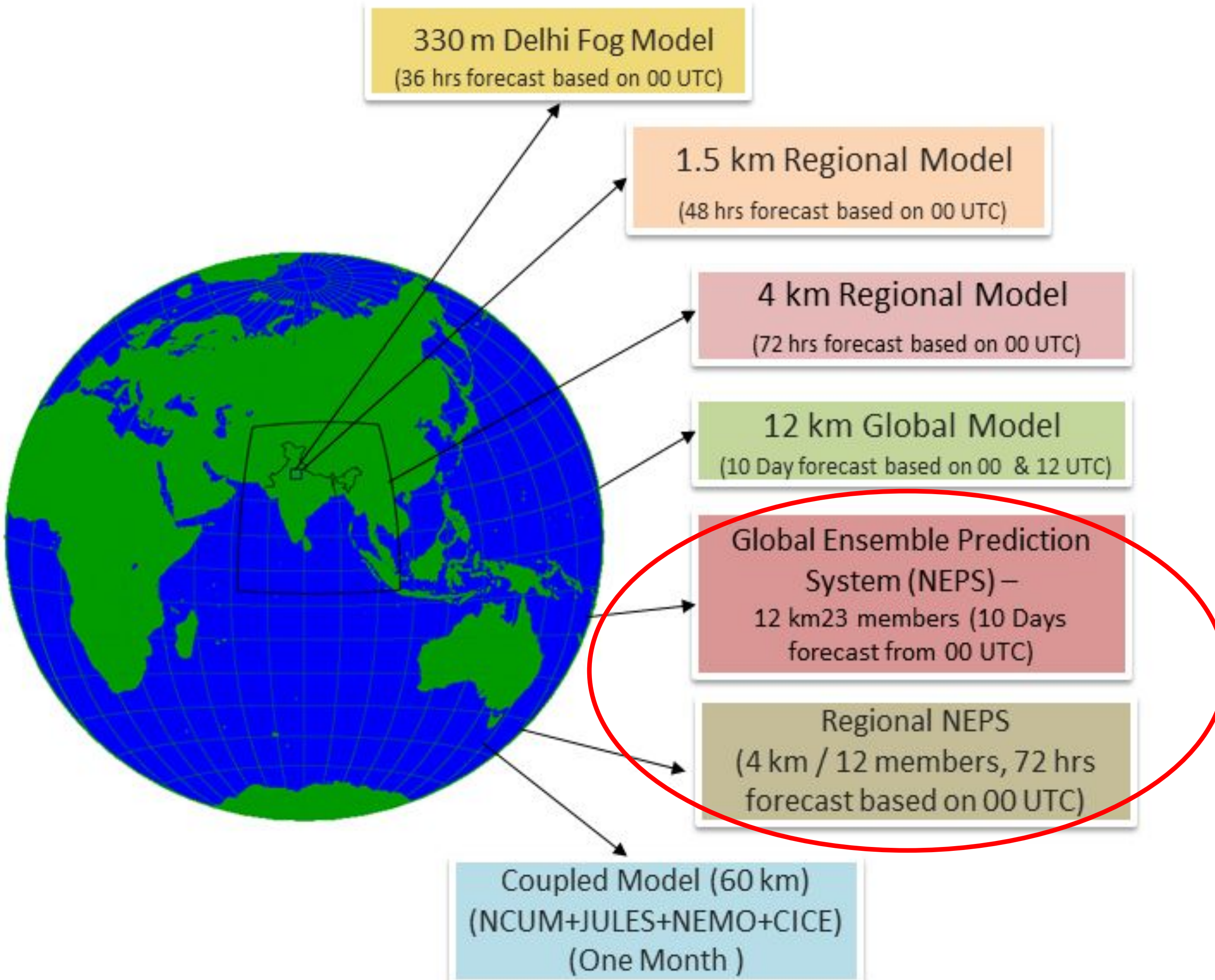

# Details of the NCUM Assimilation-Forecast system (NCUM-G)

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| Model | Atmospheric Data Assimilation | Surface analysis |
|---|---|---|
| **Model:** Unified Model; Version 11.2<br>**Domain:** Global<br>**Resolution:** 12 km, Levels 70 (Top of the model: 80 km)<br>**Grid:** 2048x1536<br>**Time Step:** 5 minutes<br>**Physical Parametrizations:** Based on GA7.2<br>**Dynamical Core:** ENDGame<br>**Forecast length:** 10 days (forecasts are produced based on 00 UTC and 12 UTC initial conditions) | **Resolution:** N320L70 (~40 km) with N144L70 Hessian based pre-conditioning<br>**Method:** Hybrid 4D-Var. Information on "errors of the day" is provided by NEPS ensemble forecasts at every data assimilation cycle<br>**Data Assimilation Cycles:** 4 analyses per day at 00, 06, 12 and 18 UTC are produced. Observations within +/- 3 hrs from the cycle time is assimilated in the respective DA cycle<br>**Observations:** List of observations assimilated are given in Table | **Soil Moisture analysis:** *Method:* Extended Kalman Filter *Analysis time:* 00, 06, 12 and 18 UTC *Observations assimilated:* ASCAT soil wetness observations, Screen Temperature and Humidity (pseudo observations from 3D-Var screen analysis)<br>**SST**: Updated at 12 UTC DA cycle with OSTIA based SST and sea-ice analysis<br>**Snow Analysis:** Satellite-derived snow analysis. Updated at 12 UTC DA cycle |

# Observations Assimilated in Global Data Assimilation System

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| Observation Type | Observation Description | Assimilated Variables |
|---|---|---|
| **AHIClear** | Advanced Himawari Imager radiances from Himawari-8 | Brightness Temperature ($T_b$) |
| **ABIClear** | Advanced Baseline Imager radiances from GOES third generation satellites | $T_b$ |
| **Aircraft** | Upper-air wind and temperature from aircraft | u, v, T |
| **AIRS** | Atmospheric Infrared Sounder of MODIS | $T_b$ |
| **AMSR** | Radiances from AMSR-2 onboard GCOM-W1 satellite | $T_b$ |
| **ATOVS** | AMSU-A (including cloud affected radiances), AMSU-B/MHS from NOAA-18 &19, MetOp-B&C | $T_b$ |
| **ATMS** | Advanced Technology Microwave Sounder in NPP& NOAA20 satellites | $T_b$ |
| **CrIS** | Cross-track Infrared Sensor observations in NPP&NOAA20 satellites | $T_b$ |
| **MWHS** | MicoWave Humidity Sounder onboard FY3C and FY3D | $T_b$ |
| **MWTS** | MicroWave Temperature Sounder onboard FY3D | $T_b$ |
| **MWRI** | MicroWave Radiation Imager onboard FY3D | $T_b$ |
| **GMI** | Global Precipitation Measurement (GPM) Microwave Imager (GMI) instrument | $T_b$ |
| **GPSRO** | Global Positioning System Radio Occultation observations from various satellites | Bending Angle |
| **GroundGPS** | Ground based GPS observations from various locations | Zenith Total Delay |
| **IASI** | Infrared Atmospheric Sounding Interferometer from MetOp- B&C | $T_b$ |
| **IN3DImgr** | INSAT-3D Imager Radiances | $T_b$ |
| **Satwind** | Atmospheric Motion Vectors from various geostationary and polar orbiting satellites (including INSAT-3D& INSAT-3DR) | u, v |
| **Scatwind** | Advanced Scatterometer in MetOp-B & C | u, v |
| **SEVIRIClear** | Cloud clear observations from SEVIRI onboard Meteosat Prime and Indian Ocean Data Coverage (IODC) services | $T_b$ |
| **Sonde** | Radiosonde (TAC & BUFR),Pilot balloons, Wind profiles | u, v, T, q |
| **Surface** | Surface observations over Land and Ocean (TAC & BUFR), TC bogus (Surface Pressure) | u, v, T, q, $P_s$ |
| **SSMIS** | SSMIS Radiances | $T_b$ |

# NCMRWF Global Ensemble Prediction System (NEPS-G)

# *Present Operational EPS in NCMRWF (NEPS-G)*

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| **Horizontal grid resolution** | ~ 12km (N1024e) |
|---|---|
| **Initial perturbation strategy** | Ensemble Transform Kalman Filter (ETKF) |
| **Surface Perturbations** | Sea Surface Temperature |
| **Physics Perturbation method** | Stochastic Perturbation of Tendencies (SPT), Stochastic Kinetic Energy Backscattering (SKEB) |
| **Data assimilation method for control analysis** | Hybrid 4D-Var |
| **Members** | Forecast perturbations from 6 hr short forecasts, are based on 22 perturbed ensemble members and each of those are updated by the ETKF four times a day (0000, 0600, 1200 and 1800 UTC).<br><br>Ten days long forecast provided by NEPS-G at 00 UTC is the combination of 11 members from 00 UTC cycle and lagged 11 members from 12 UTC cycle. 22 members (00UTC+12UTC) |

*2020 NEPS Configuration that is based on PS42 with UM11.2 of UK metoffice*

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RESEARCH ARTICLE

Meteorological Applications | RMetS

# Medium-range global ensemble prediction system at 12 km horizontal resolution and its preliminary validation

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**Abstract**

Forecasts of high-impact weather systems require sufficiently high resolution of state-of-the-art numerical models in order to resolve the small-scale features. At the National Centre for Medium Range Weather Forecasting (NCMRWF) in India, a global ensemble prediction system (EPS—called the NEPS) has been implemented operationally at 12 km horizontal grid size. The NEPS configuration is based on the UK Met Office Global and Regional Ensemble Prediction System (MOGREPS). Initial condition perturbations are generated by the ensemble transform Kalman filter (ETKF) method. Model uncertainties are taken care of by stochastic kinetic energy backscatter (SKEB) and random parameters (RP) schemes. Forecast perturbations obtained from 6 hr short forecasts of 22 ensemble members are updated by the ETKF four times a day (0000, 0600, 1200 and 1800 UTC). Perturbations of surface parameters such as sea-surface temperature, soil moisture content and soil temperature are also included in the new NEPS. The NEPS aims to provide 10 day probabilistic long forecasts using 23 ensemble members (22 perturbed plus one control). The long forecast provided at 0000 UTC is the combination of 11 members from the 0000 UTC cycle and lagged 11 members from the 1200 UTC cycle. The new NEPS shows improvements in terms of forecast agreement among the members in comparison with the previously operational NEPS that was running at 33 km horizontal grid size with 44 perturbed members. The ratio between the root mean square error of the ensemble mean and ensemble spread as a function of lead time has improved in both the Northern and Southern Hemispheres in the new NEPS.

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NCMRWF

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# NCMRWF Global Ensemble Prediction System (NEPS-G)
# 33km vs 12km

**Both NEPSs, n1024 (12km) and n400 (33km) were operational during the period**

**1st June 2018 – 16th July 2018**

# *Key distinction among*
# *33km NEPS and 12km NEPS*

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| | 33km NEPS (N400) | 12km NEPS (N1024) |
|---|---|---|
| **Grid Points** | 800 x 600 | 2048 x1536 |
| **Members** | 44 perturbed + 1 cntl | 22 perturbed +1 cntl |
| **Initial condition perturbations** | Perturbations in θ, π, q, u, & v by ETKF method | Perturbations in θ, π, q, u, & v by ETKF method and **perturbations in SST , SMC & Deep Soil Temp** |
| **Model Physics Perturbations** | Stochastic Kinetic Energy Backscattering and Random Parameter Schemes | Stochastic Kinetic Energy Backscattering and Random Parameter Schemes |
| **Observations Assimilated in NEPS** | AIRS, ATOVS, Aircraft, GOESClear, GPSRO, IASI, Satwind, Scatwind Sonde, Surface | AIRS, ATOVS, Aircraft, GOESClear, GPSRO, IASI, Satwind, Scatwind Sonde, Surface, **SEVIRIClear, SSMIS** |
| **Long Forecast Start time** | 44 members at 00 UTC | 11 members and Cntl at 00 UTC and 11 members at 12UTC of previous day |

**This table is based on 2018 configurations of the NEPSs**

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# Verification of high resolution (12 km) Global Ensemble Prediction System

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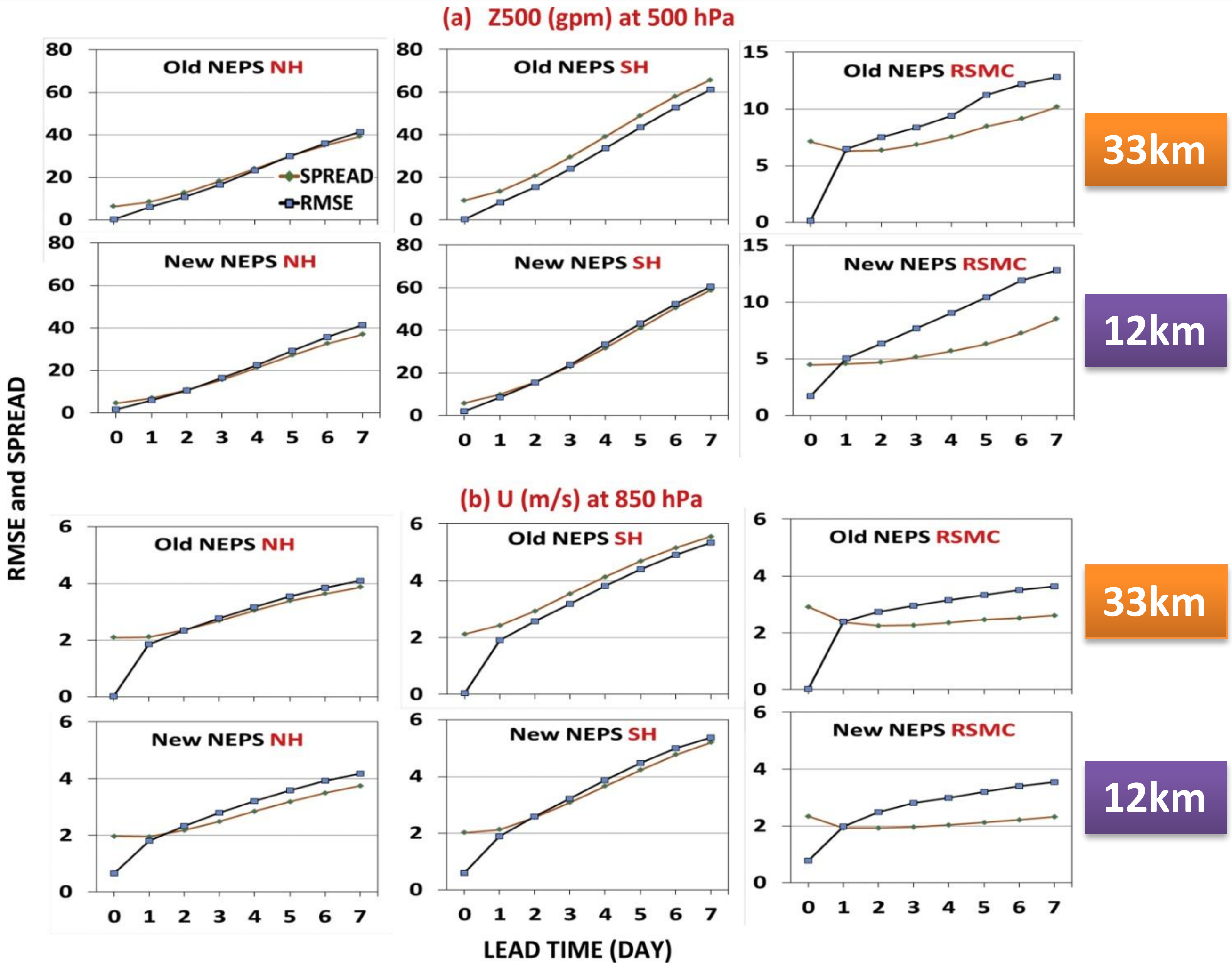
## ARTICLE INFO

*Keywords:*
Ensemble Prediction System
Ensemble member
Probabilistic forecasts
Ensemble-spread
Brier score
Reliability diagram

## ABSTRACT

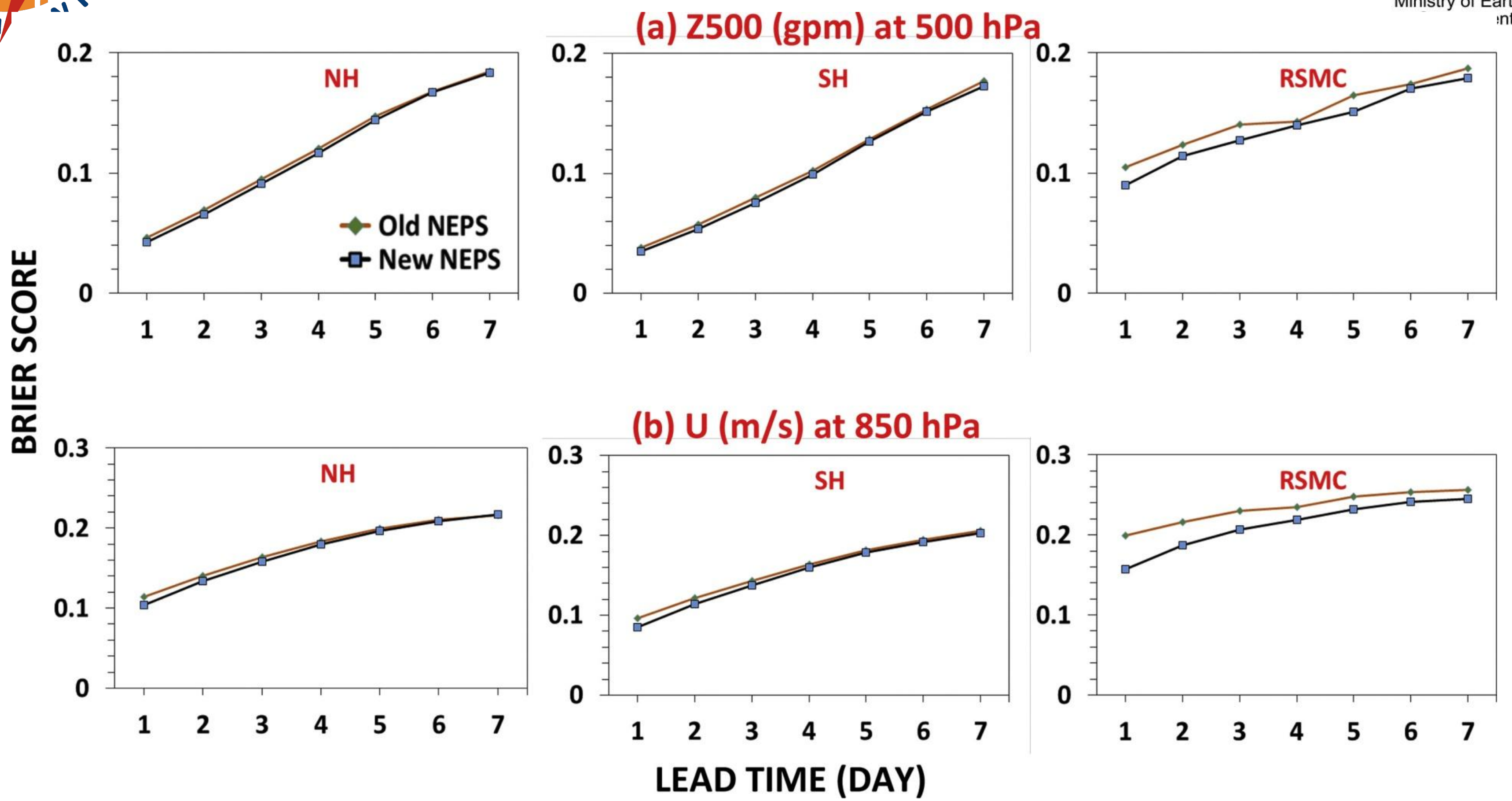
Ensemble Prediction Systems (EPSs) are used to estimate the uncertainty in a weather forecast as well as the most likely outcome. To improve weather forecasts and services, the global EPS at the NCMRWF has been upgraded to 12 km horizontal resolution (with 22 perturbed +1 control members). Although the upgraded version of EPS had become operational from 1st June 2018 in the newly acquired high-performance computing system (HPCS), the previous EPS at 33 km horizontal resolution (with 44 perturbed +1 control members) was also running in the old HPCS till 16th July 2018. As compared to the old EPS in NCMRWF, the new EPS includes perturbations in initial state of sea surface temperature, soil moisture content and deep soil temperature. The analysis of the new EPS also includes some more sources of observations. The perturbed 22 members long forecast of the new EPS provided at 00 UTC is the combination of 11 members from 00 UTC cycle and lagged 11 members from 12 UTC cycle of previous day. In the present study, the performances of the new and old EPS are compared for the period from 1st June to 16th July 2018. Performances of both the systems are assessed considering different attributes of probabilistic forecasting. The verification of precipitation, geopotential height at 500 hPa and zonal wind at 850 hPa has been carried out over the northern hemisphere, southern hemisphere and a smaller tropical region which includes India. The metrics used for verification are ensemble-spread, ensemble root-mean-square error, brier score, brier skill score, relative operating characteristics, reliability, sharpness diagrams, rank histogram, ranked probability score, continuous ranked probability score and continuous ranked probability skill score. Two heavy rainfall events have also been considered for subjective comparison of probabilistic prediction capabilities of both the systems. The results show that the new EPS is more skilful in probabilistic forecasts especially over the Indian region and it significantly outperforms the old EPS in probabilistic forecasts of the selected extreme weather events.

# RMSE-SPREAD Relationship




RMSE and ensemble spread of the old and new NEPSs as a function of forecast lead time over NH, SH and RSMC regions for (a) geopotential height at 500 hPa and (b) zonal wind at 850 hPa.
RSMC region (0 – 40 N & 50 - 100 E)

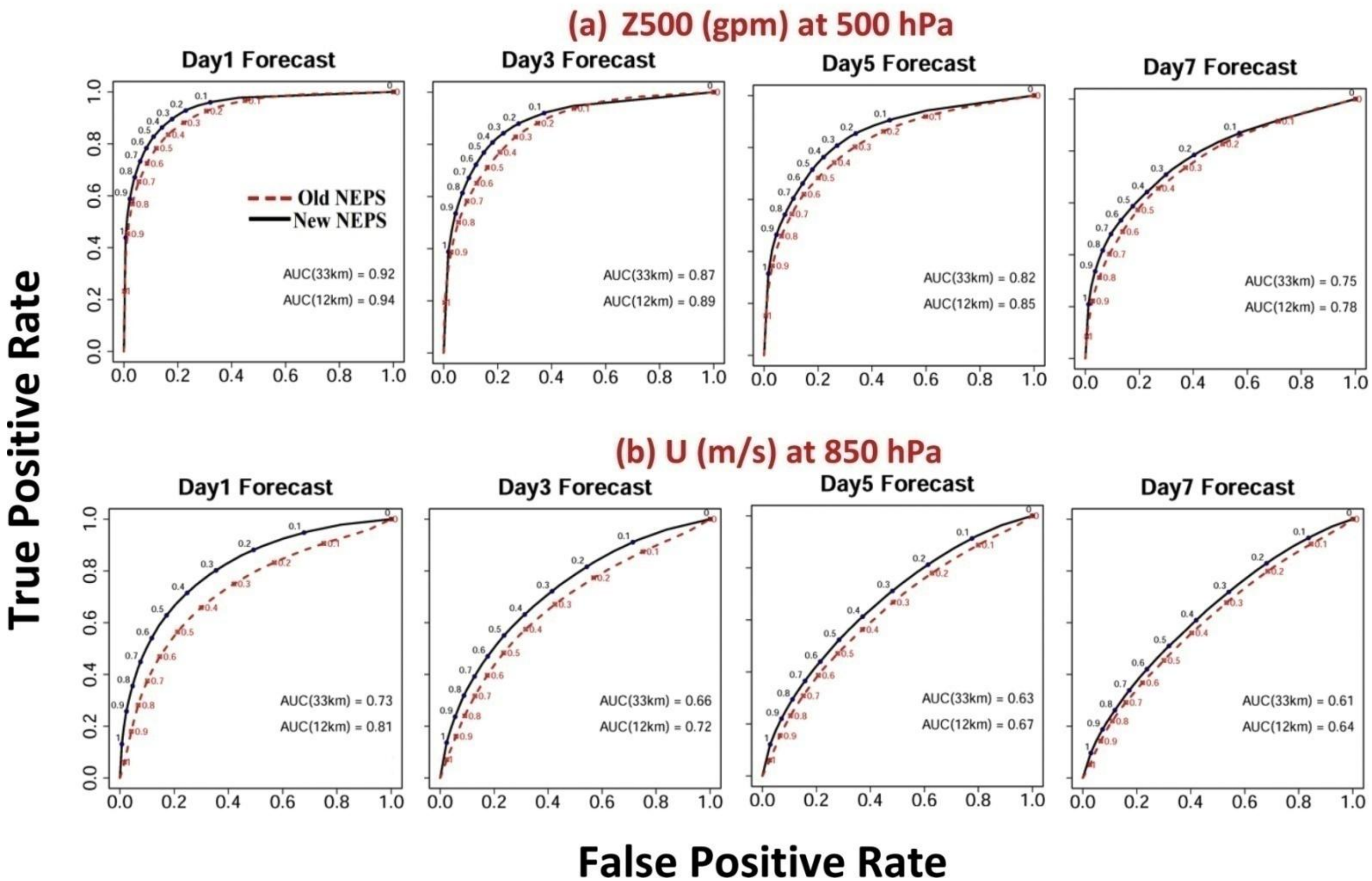
# BRIER SCORE




Brier Scores of old and new NEPSs as a function of forecast lead time over NH, SH and RSMC regions for (a) geopotential height at 500 hPa and (b) zonal wind at 850 hPa. One standard deviation greater than the sample data climatology has been used as threshold.

# Relative Operating Characteristic (ROC)

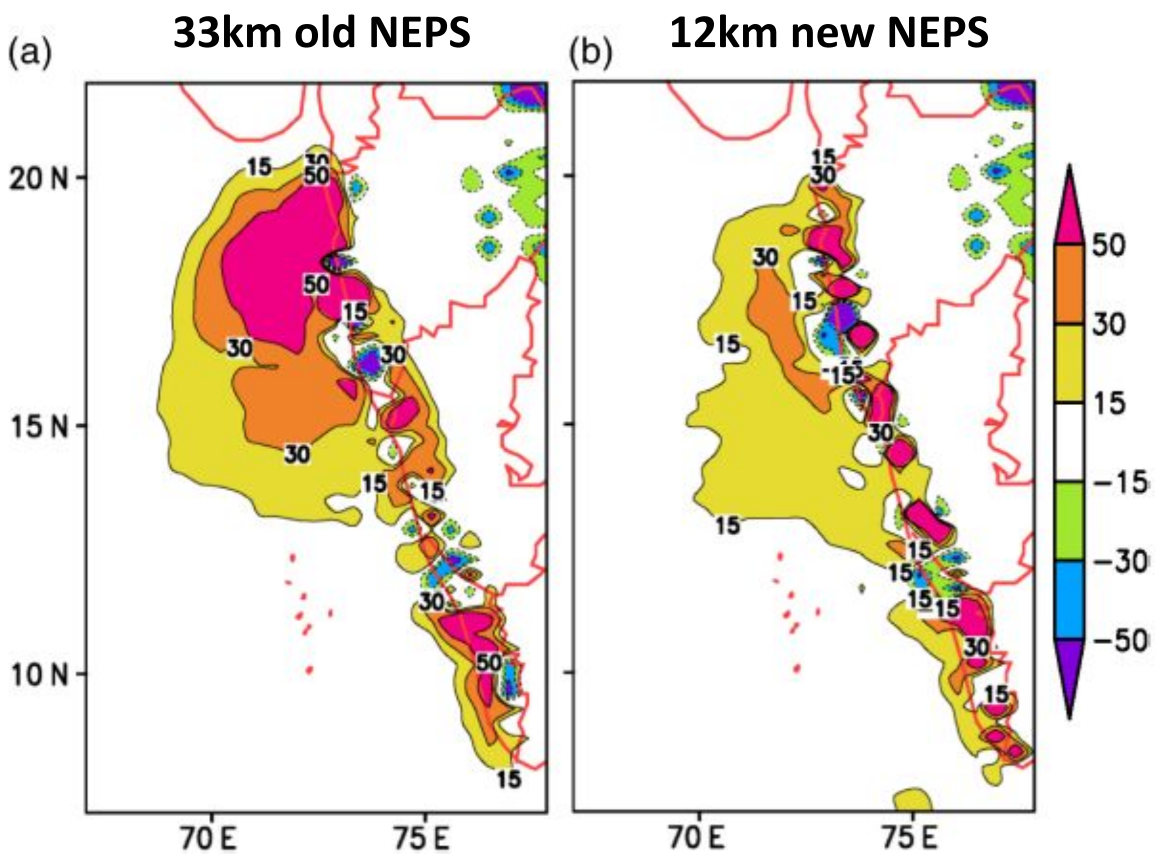
## ROC RSMC




ROC curves of old and new NEPSs over RSMC region for Day 1, 3, 5 & 7 forecasts for (a) geopotential height at 500 hPa and (b) zonal wind at 850 hPa forecasts. One standard deviation greater than the sample data climatology has been used as threshold.

# *Spatial distribution of rainfall difference*






Spatial distribution of rainfall difference ($mm \cdot day^{-1}$) between Day 5 control forecasts valid for June 10, 2018, and the observations

# Probability of rainfall exceedance

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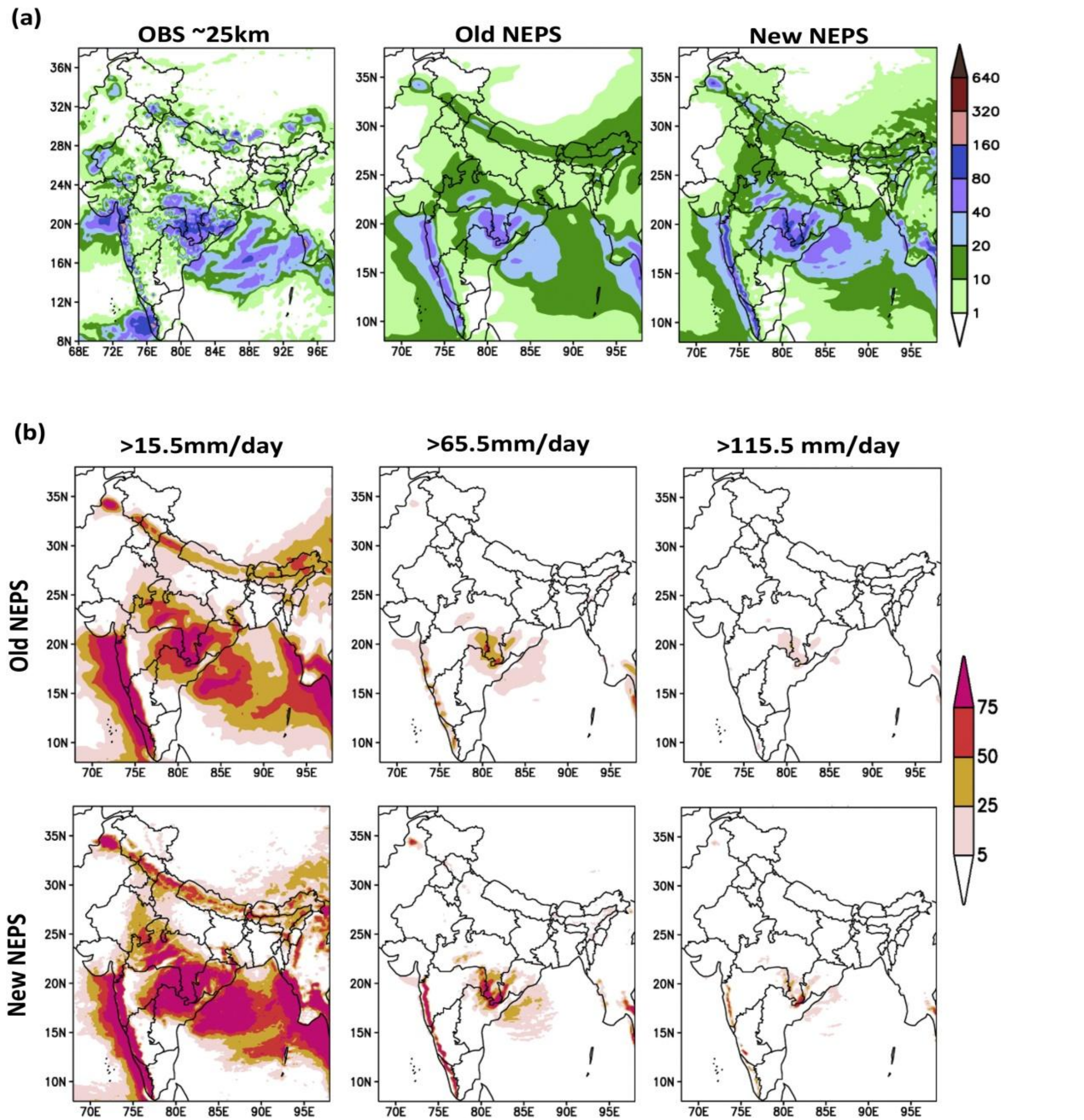
(a) Day 7 Forecast of old and new NEPS ensemble mean rainfall (mm/day) valid on 16th July 2018 along with observed rainfall

(b) Probability of precipitation forecast of old (33km) and new (12km) NEPSs exceeding the threshold values of 15.5, 65.5 and 115.5 mm/day.



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Tropical Cyclone Research and Review 9 (2020) 106–116

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# Improvements in tropical cyclone forecasting through ensemble prediction system at NCMRWF in India

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Available online 8 May 2020

## Abstract

This paper deals with the comparison of cyclone forecasts from the two versions of the operational global ensemble prediction system (EPS) at the National Centre for Medium Range Weather Forecasting (NEPS). The previous version had a horizontal resolution of 33 km with 44 ensemble members (NEPS) whereas the updated version of this EPS has a resolution of 12 km with 11 members (NEPS-UP). The ensemble mean forecasts from both the models are compared using the direct position (DPE), along (ATE) and cross track (CTE) errors. For the verification of strike probability, Brier Score (BS), Brier Skill Score (BSS), Reliability Diagram, Relative Operating Characteristic (ROC) Curve and Root Mean Square Error (RMSE) in mean Vs Spread in members are used. For verification of intensity, RMSE in maximum wind speed from the ensemble mean forecasts are compared.

Comparison of ensemble mean tracks from both models showed lower errors in NEPS-UP for all forecast lead times. The decrease in the DPE, ATE and CTE in NEPS-UP was around 38%, 48% and 15% respectively. NEPS-UP showed lower BS and higher BSS values indicating a better match between observed frequencies and forecast probabilities as well as higher prediction skills. The reliability diagram showed higher accuracy for NEPS-UP as compared to NEPS. The ROC curves showed that for forecasts with higher probabilities the hit rate was high in NEPS-UP. There was a greater consensus between the RMSE and Spread for NEPS-UP at all lead times. It was also seen that the RMSE in mean showed a 41% decrease from NEPS to NEPS-UP. On comparing maximum wind, it was found that for all lead times the RMSE in maximum wind speed for NEPS-UP was lower than NEPS.

# NEPS: 33km 44 mem Vs NEPS-UP: 12km 22 mem Tropical Cyclone

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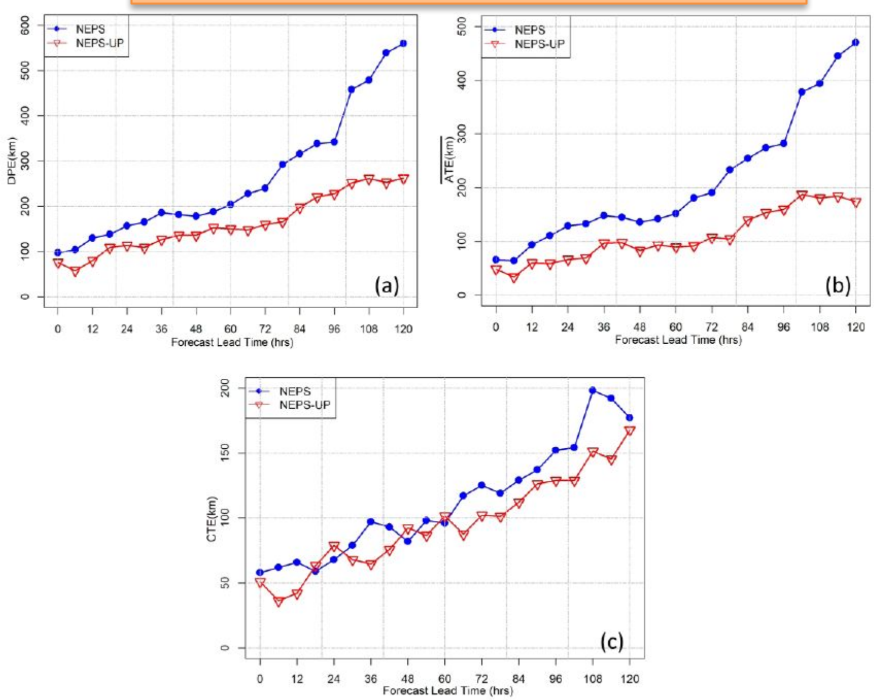
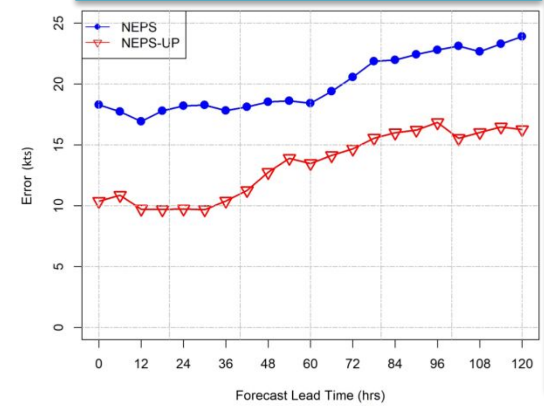
## Track Errors



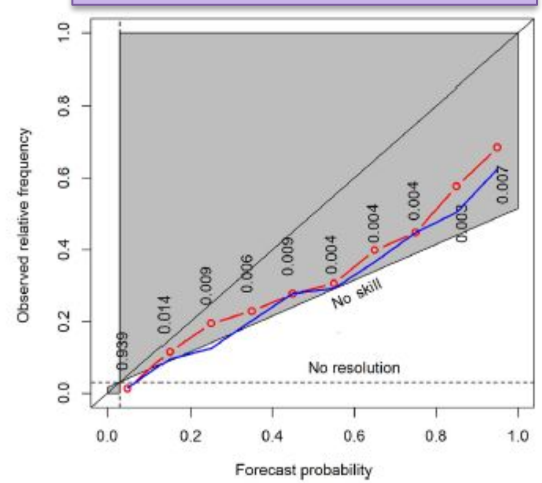

Comparison of (a) DPE, (b) ATE and (c) CTE for tropical cyclone forecasts obtained from NEPS-33km and NEPS-12km with respect to forecast lead time.

## RMSE of 10m Max Wind Speed



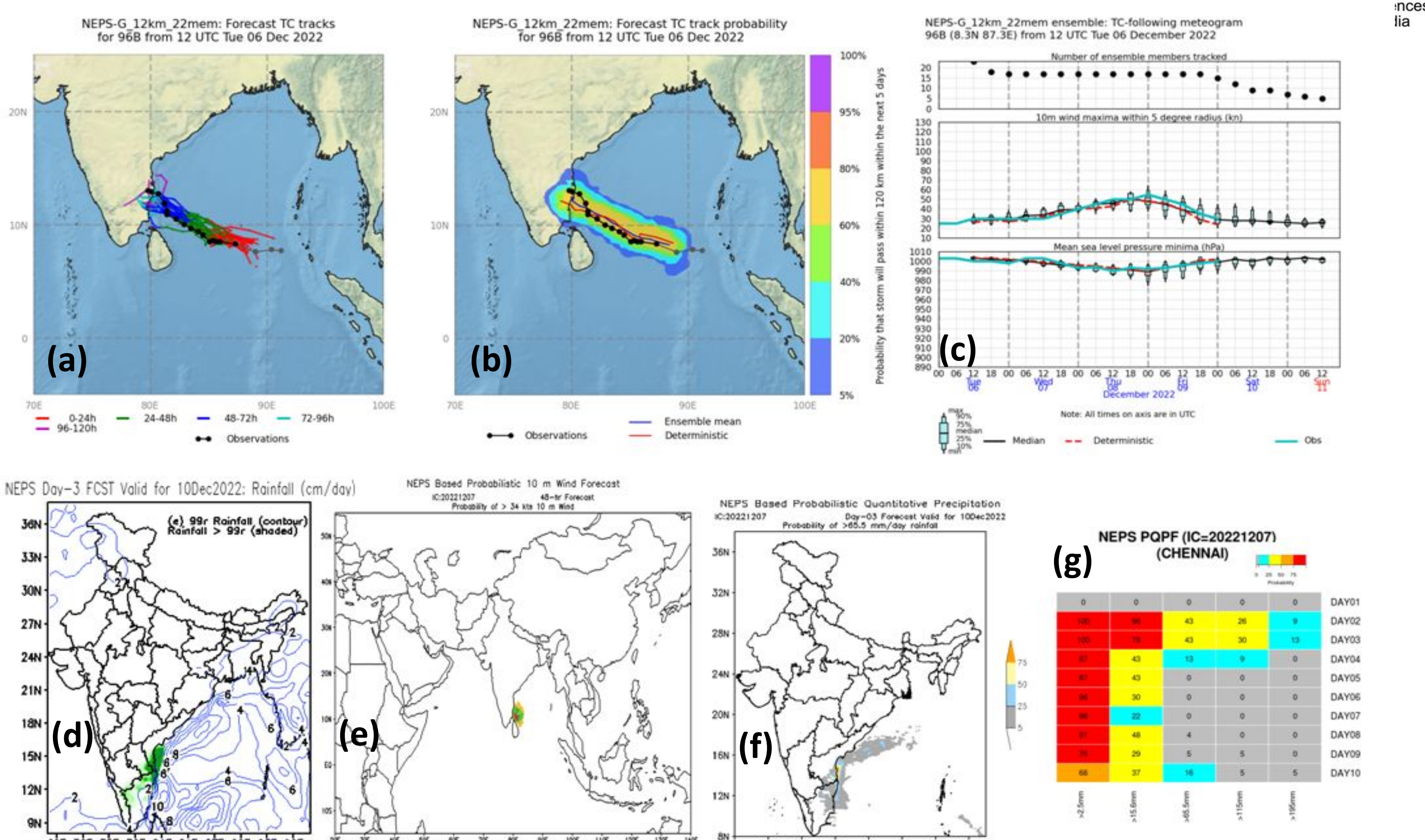

Comparison of the RMSE in the maximum wind speed forecasts for a tropical cyclone obtained from NEPS-33km and NEPS-12km with respect to forecast lead time

## Reliability diagram Strike probability




Comparison of the Reliability diagram for the strike probability forecasts from NEPS-33km and NEPS-12km

# Some of the NEPS-G products based on a cyclone case MANDOUS




Rainfall > 99 percentile

Probability > 34 knots 10m wind

Probability > 65.5 mm/day rainfall

Probabilistic quantitative precipitation forecasts (PQPFs)

# 12-km NCMRWF-EPS in TIGGE Portal

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## News

Created by Richard Mladek, last modified about an hour ago

[ 2018 ] [ 2017 ] [ 2016 ] [ 2015 ] [ 2014 ] [ 2012 ] [ 2011 ] [ 2010 ] [ 2008 ] [ 2007 ] [ 2006 ]

### 2018

**24-07-2018 NCMRWF forecast system change**
Update of NCMRWF forecast system. A new version of NCMRWF model was introduced. The first archived updated model runs are from the 1$^{st}$ of July. The main changes are:

- reduced number of the ensemble size from 45 to 12
- two model runs 00 and 12 UTC at very high resolution (0.12x0.18 degree)

Click here for more details.

**18-06-2018 Usage statistics**
A new page with TIGGE data usage statistics was added.

### 2017

**20-12-2017 New model (NCMRWF, India) added to TIGGE archive**
New model outputs (NCMRWF, India) were added to TIGGE archive. The first starting date available thanks to the back-archiving is the 1st of August 2017. Click here for more details.

**11-07-2017 ECMWF forecast system change**
Update of ECMWF forecast system. A new version of ECMWF model (IFS cycle 43r3) was introduced. Click here for more details.

# GSI-GFS Data Assimilation System in NCMRWF

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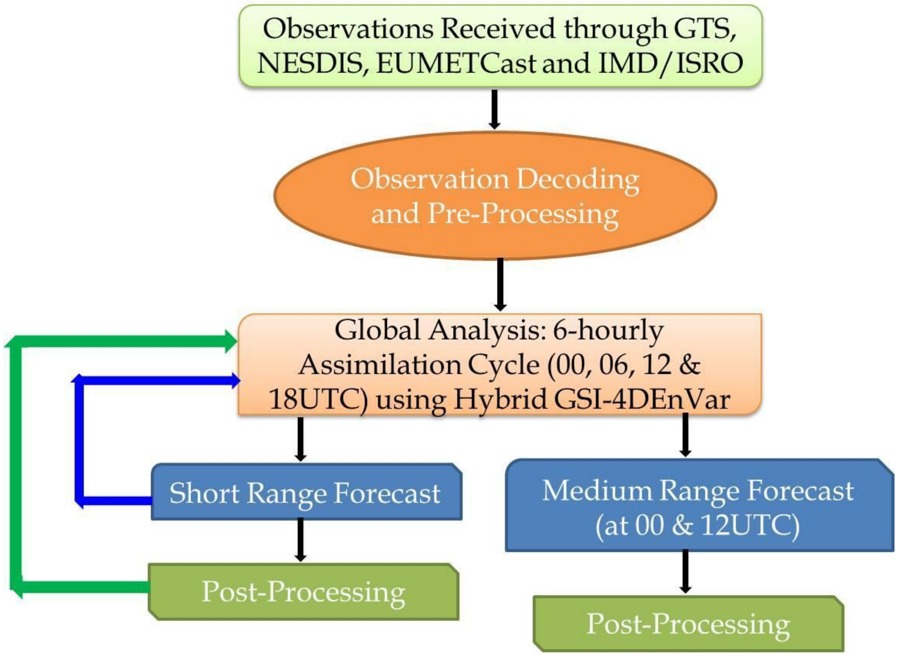
Another global DA systems operational at NCMRWF is the GFS (Global Forecast System) based GSI-4DEnVar (Global Statistical Interpolation – 4 Dimensional Ensemble Variational) system which provides initial conditions for the IMD GFS NWP system.

The NCEP (National Centre for Environmental Prediction) based DA system implemented at NCMRWF has been upgraded periodically and improved with in-house R&D efforts.




The GSI-4DEnVar at NCMRWF uses 80 member ensembles for updating the error covariances.

# MoES Global Grand Ensemble (NEPS-G) + (GEFS)

*Operationally, two high resolution (~12 km horizontal resolution) Global Ensemble Prediction Systems (EPS), viz, NEPS & GEFS are running in Mihir HPC in the NCMRWF*

**To determine any added benefit that can be obtained from a super-ensemble consisting of the union of the members from:**

1. NCMRWF global EPS named as NEPS, is based on UK Met Office MOGREPS system

2. IMD GEFS based on National Centers for Environmental Prediction (NCEP) system

# Configurations of the Global EPSs used in this study

| | NEPS (NCMRWF) | GEFS (IMD) |
|---|---|---|
| **Members** | 22 (00UTC+12UTC) | 20 (00UTC) |
| **Horizontal grid resolution** | ~ 12km (N1024) | ~ 12km (T1534) |
| **Vertical levels** | 70 (~80 km) | 64 (~2.73hPa) |
| **Initial perturbation strategy** | Ensemble Transform Kalman Filter (ETKF) | Analysis perturbation from ETR (Ensemble Transform with Rescaling) and forecast perturbation comes from EnKF ensemble |
| **Surface Perturbations** | SST, Deep soil temperature and Soil Moisture Perturbations | NSST |
| **Physics Perturbation method** | Stochastic Kinetic Energy Backscattering (SKEB) and Random Parameter (RP) schemes | Stochastic total tendency perturbation (STTP). Stochastic perturbation to account for random model errors. |
| **Data assimilation method for control analysis** | Hybrid 4D-Var | Hybrid 4D-Ens-Var(GSI) |

# Reliability Diagram

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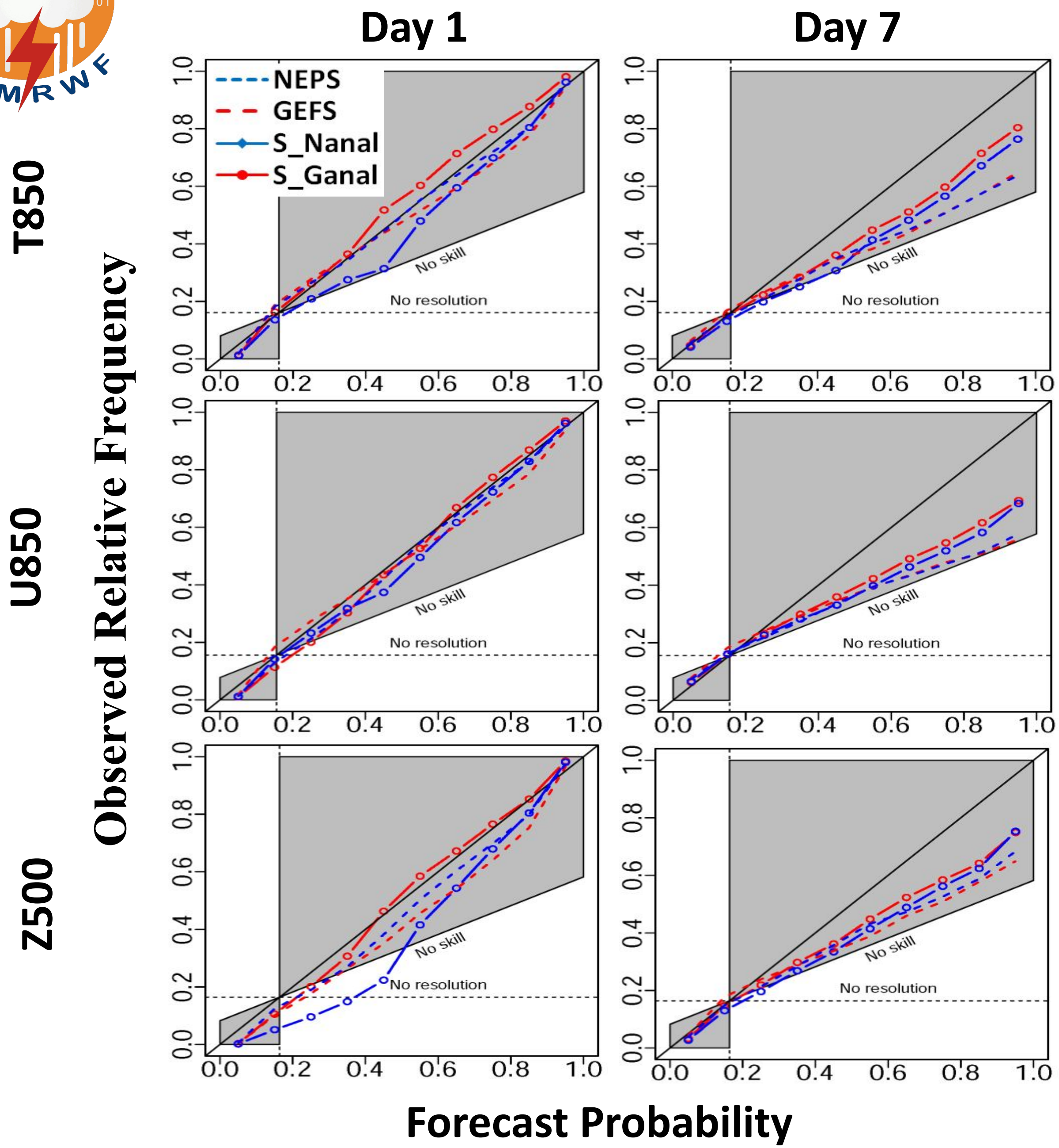


A measure of agreement between the probabilistic forecasts and the observations

- greater than 1 standard deviation from the sample climatology is considered as event.
- With an increase in the forecast probability of the occurrence of events, the verified chance of observing the event is also increasing.
- Reliability curve is mostly indicating over forecasting
- Super ensemble shows better reliability for Day 7 forecast for probability greater than 40%

# Brier score

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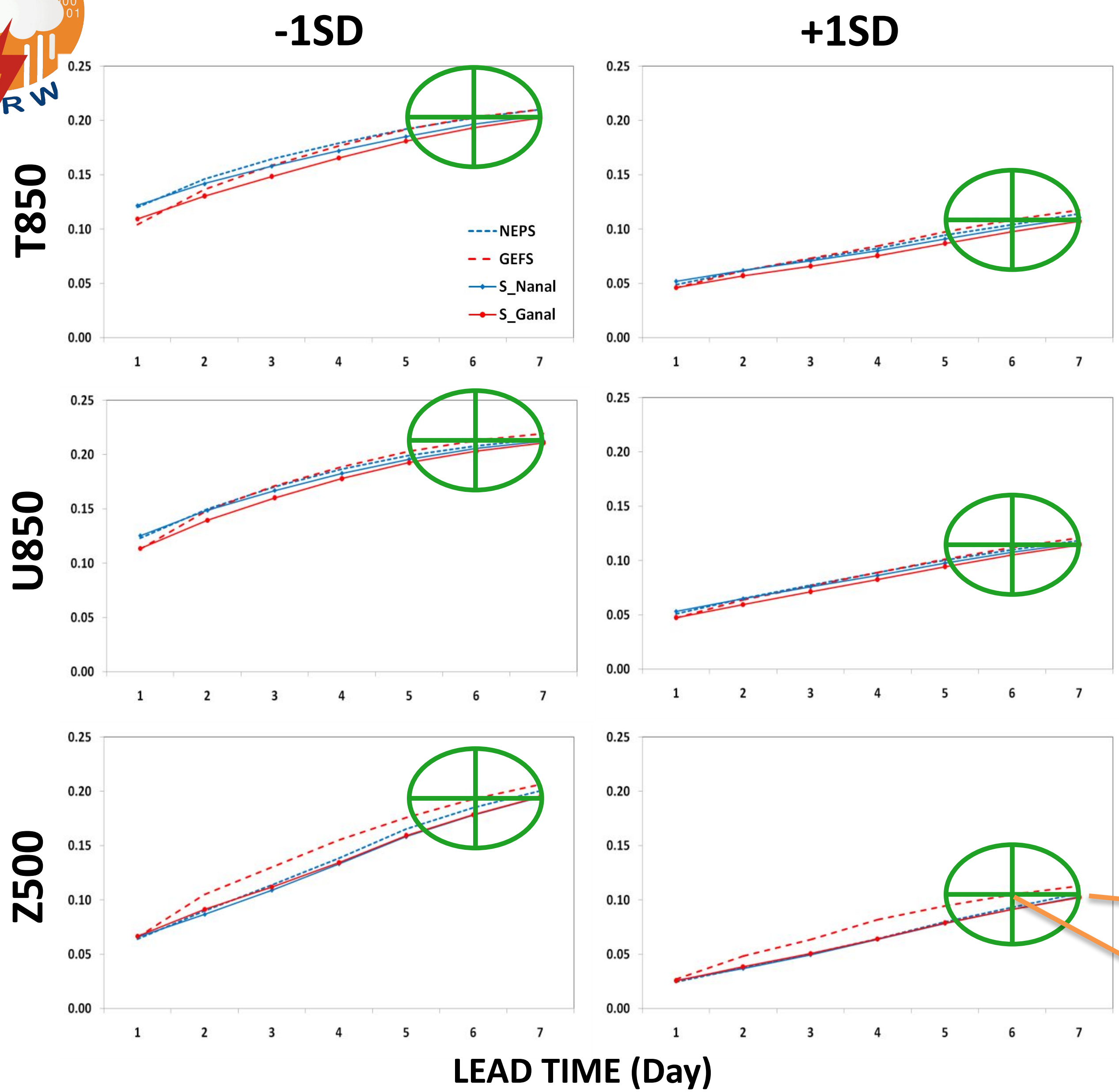


- The Brier Score is a measure of probability forecast accuracy for dichotomous events
- The best possible value of the Brier Score for total accuracy is 0 and the worst value is 1
- Nearly one day improvement in predictability has been noticed with increase in the ensemble size

**Day 7 BS of Super Ensemble are comparable to Day 6 BS of single EPS**



Brier scores for the values above +1 and below -1 standard deviation (SD) of the sample climatology

# Continuous Ranked Probability Score

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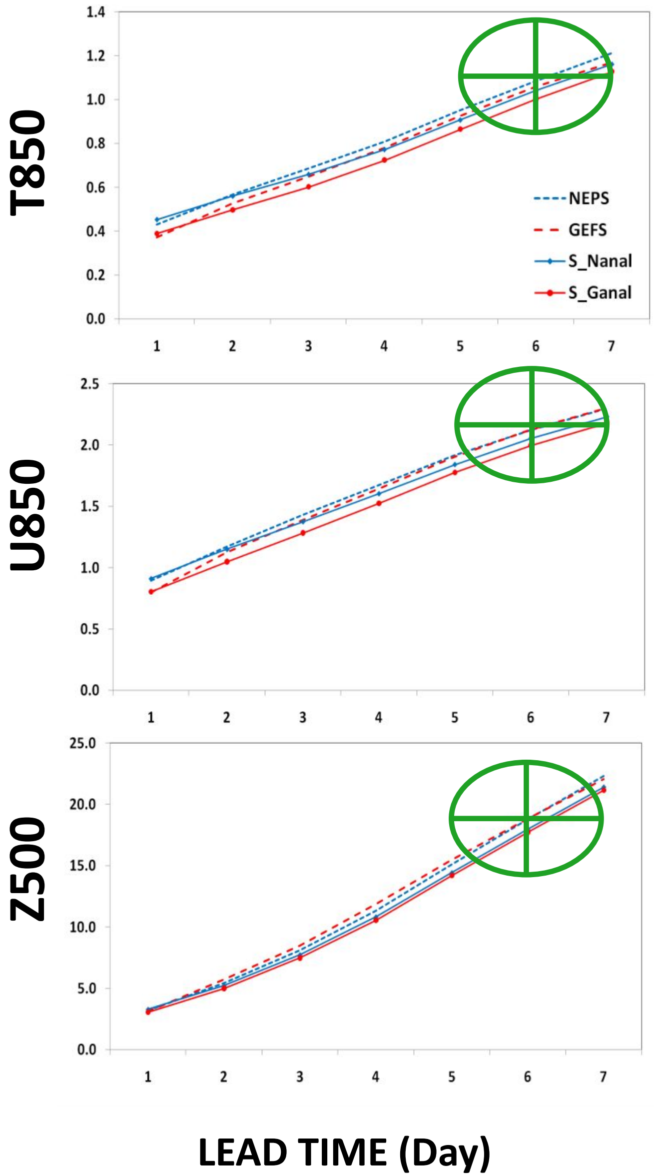


-  CRPS is analogous to Brier Score with an infinite number of continuous classes

-  It is an integral of the Brier score over a continuum set of all possible thresholds of the selected variables

-  For a perfect case it reaches a minimum value of zero.

-  Results indicate Improved CRPS for super ensemble as compared to the individual models

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# NCMRWF Regional Ensemble Prediction System (NEPS-R)

# NEPS-R Running operational since July 2019

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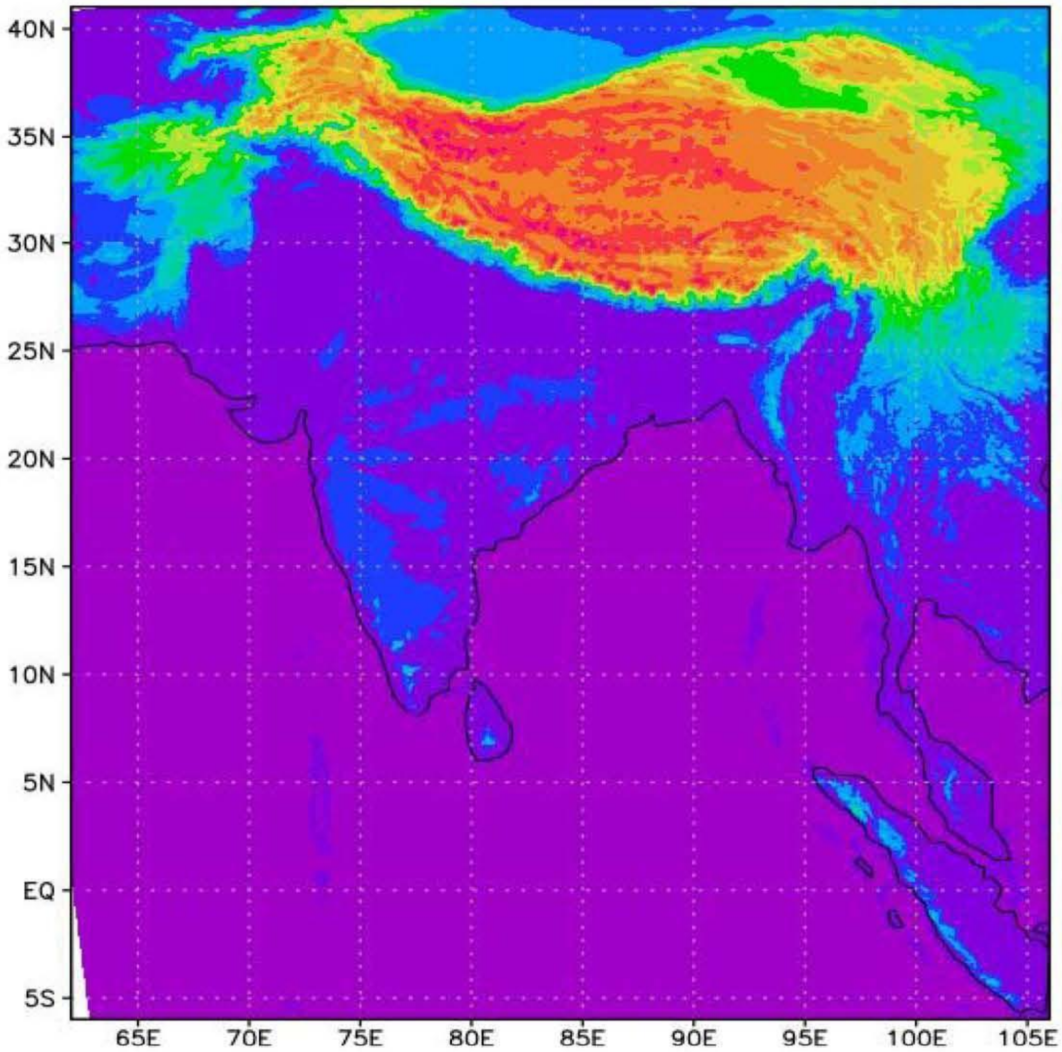
| | |
|---|---|
| Current UM version | : 11.1 |
| Science Configuration | : Pre-chill RA2T ( conserve) |
| Horizontal resolution | : ~4 km |
| Vertical levels | : 80 levels up to 38.5 km |
| Model Domain | : $62^0$ E -$106^0$ E and $6^0$ S - $41^0$ N |
| No. Of grid points | : 1200 x 1200 |
| Model time step | : 60 seconds |
| Ensemble size | : 12 (1 control + 11 perturbed) |
| Initial Conditions (IC) | : Downscaled from NEPS-G (12 km resolution) |
| Convection | : Explicit |
| Physics Perturbation | :Random Parameter scheme |
| LBC frequency | : 3 hourly |
| Forecast length | : 75 hrs (once per day at 00 UTC) |
| Resources (Cray XC-40) | : 30 nodes /member completes 75hrs forecast in 3 hrs |

# NEPS–R Operational Domain



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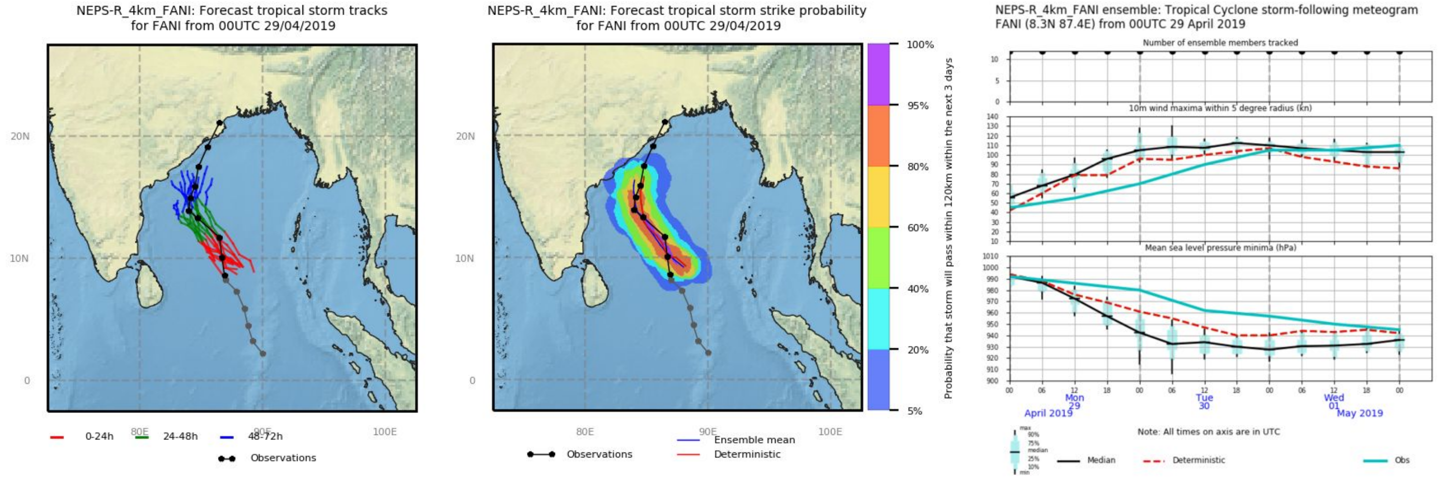
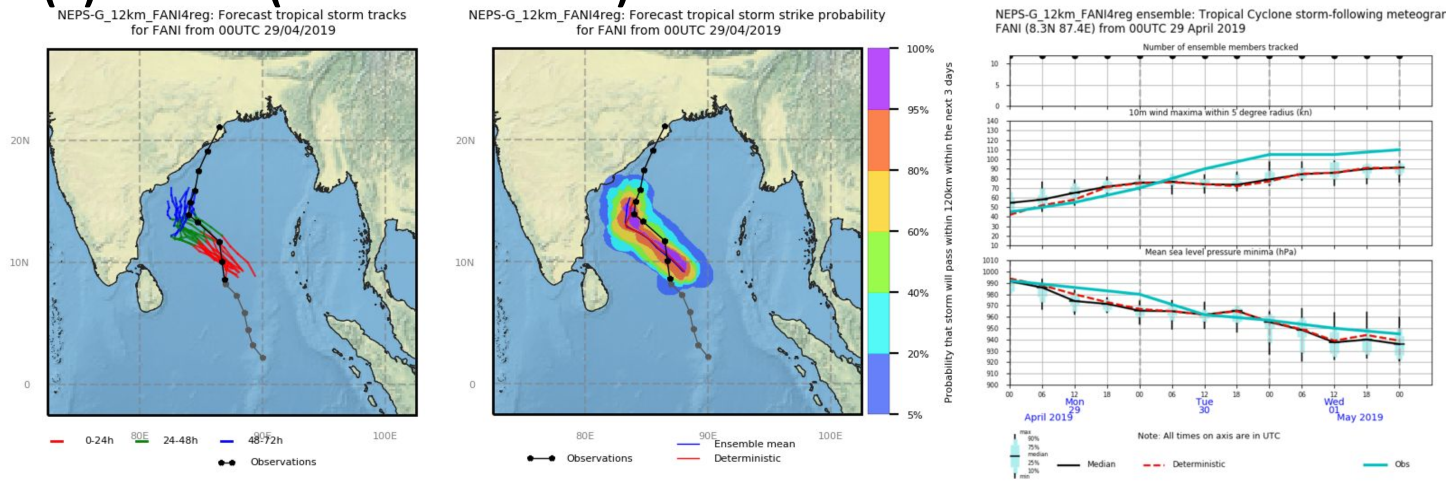
## (a) NEPS-R (4km Regional EPS)




## (b) NEPS-G (12km Global EPS)




Tropical cyclone FANI, intensified into an extremely severe cyclonic storm and reached its peak intensity on 2nd May 2019. The rapid intensification in wind speed has been nicely captured by NEPS-R as compared to NEPS-G as shown in storm following meteograms. However, NEPS-G performs better in initial stage of cyclone development

# RMSE and ensemble spread

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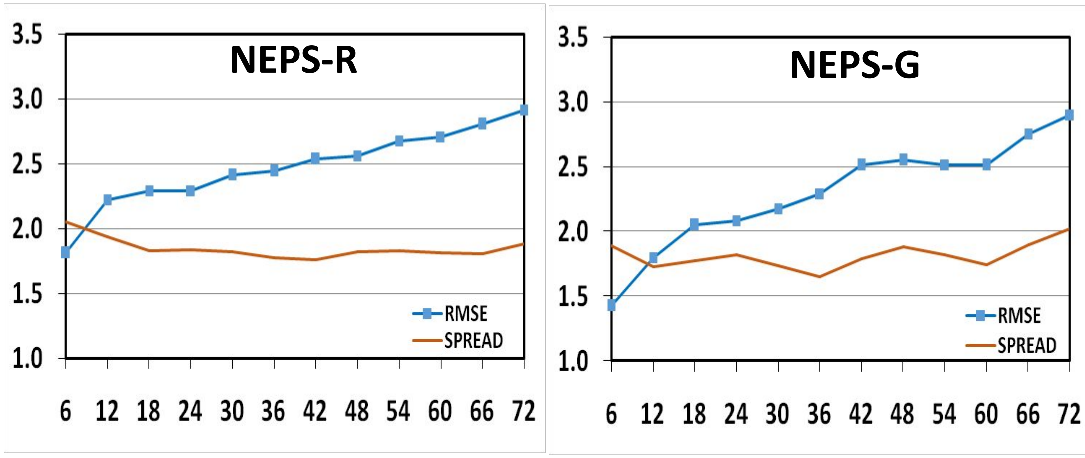
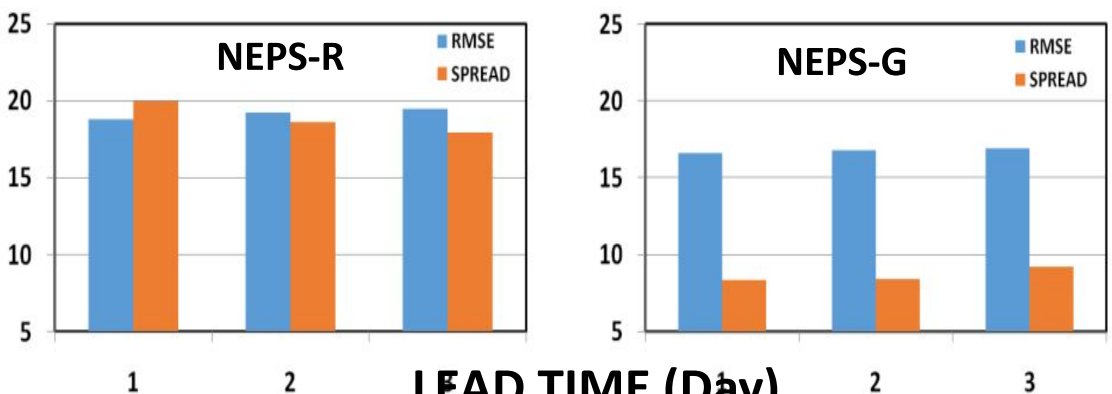
## Zonal wind 850 (m/s) or U850




LEAD TIME (Hour)

**Fig.1** NEPS-R spread in U850 is slightly higher than that in NEPS-G during starting hours only and after that it is nearly constant. U850 ensemble spread of NEPS-G is varying between 1.6 and 2 (m/s) and not increasing with forecast lead time.

## Precipitation (mm/day)




LEAD TIME (Day)

**Fig.2** RMSE and spread in precipitation are much closer to each other in NEPS-R as compared to NEPS-G. RMSE is slightly better in case of NEPS-G. A larger spread is noticed in NEPS-R. Whereas in NEPS-G, precipitation values are more under-dispersed.

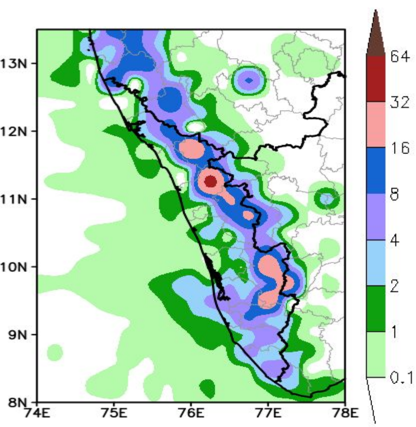
# Probabilistic Quantitative Precipitation
## Day-3 valid for 03Z09AUG2018

Ministry of Earth Sciences
Government of India

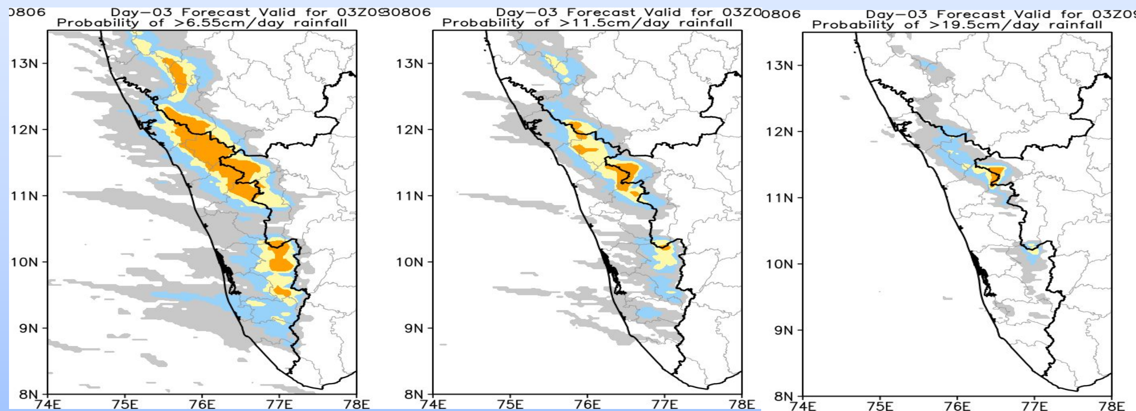
**IC:20180806-00UTC**

**>65.5mm/day** **>115mm/day** **>195mm/day**

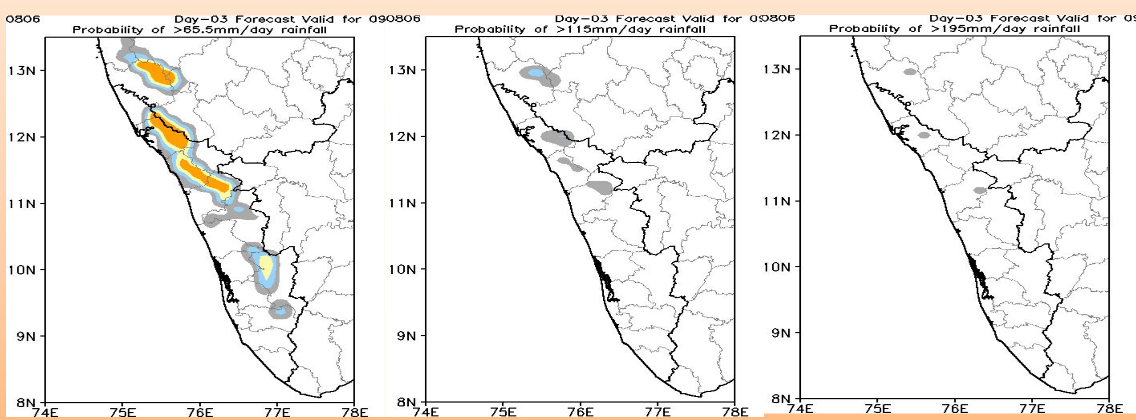
### Observation

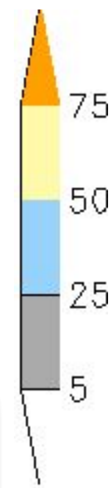



### 4km NEPS-R

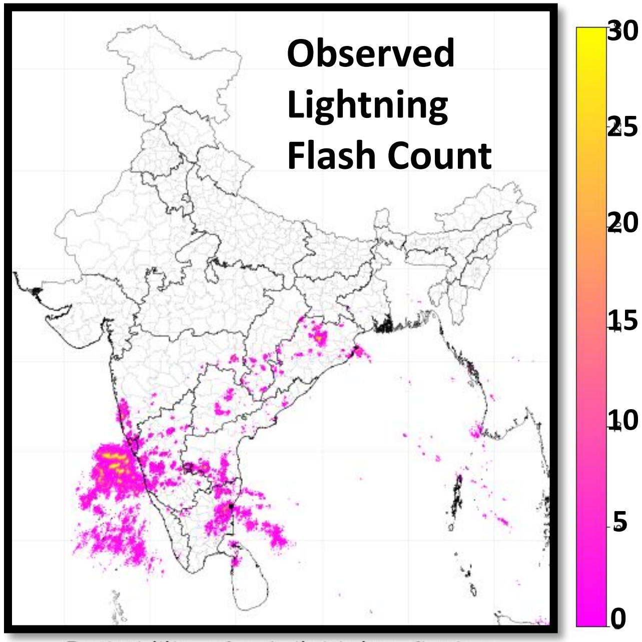



### 12km NEPS-G

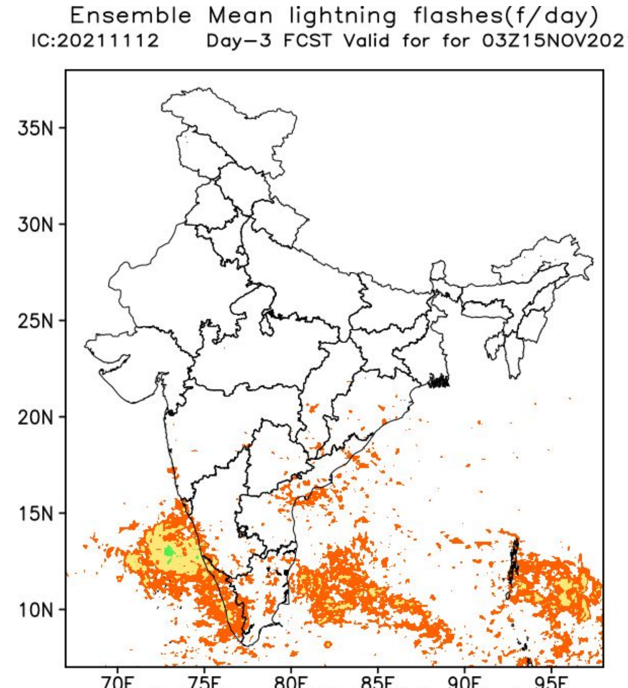


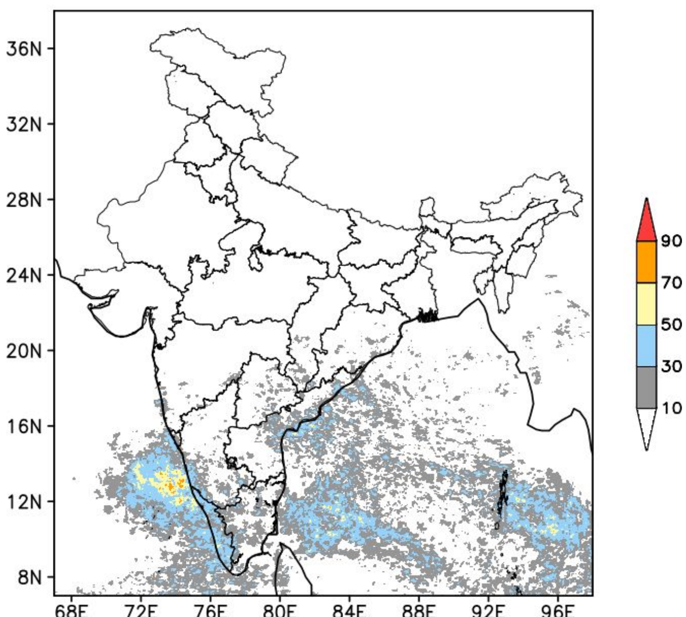
# Probabilistic lightning forecast of NEPS-R



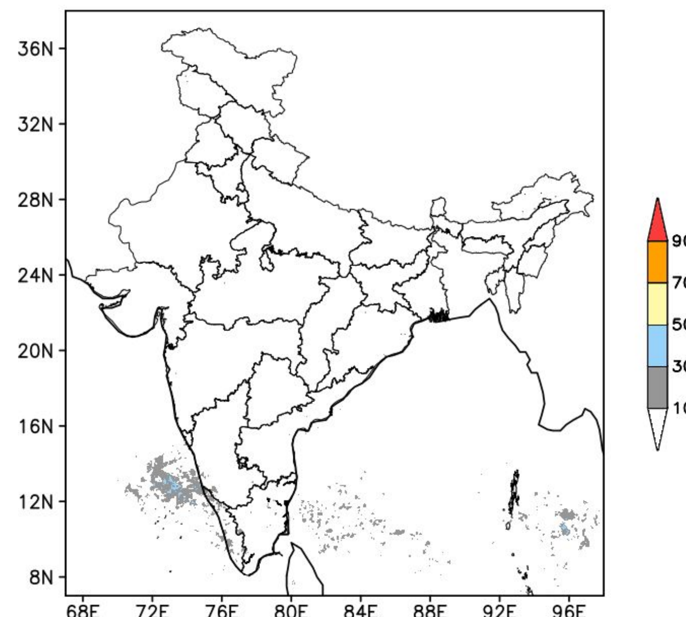

**Day-3**




Probability of >1 lightning flashes




Probability of >10 lightning flashes



## *Future Objectives:*

- Currently, NCMRWF, MoES is in the process of acquiring a 9 PFLOPS machine for the centre, which will help to improve the weather forecasting in India of different temporal scales.

- En-4DEnVar that is an ensemble of initial conditions which are generated through their own data assimilation cycles and provides a more sophisticated and stable method of producing probabilistic forecasts than the present ETKF scheme.

- “additive inflation” scheme to controls the growth of ensemble spread during the forecast. The scheme also includes a bias-correction term in the ensemble forecasts which is a new and effective way to reduce systematic forecast errors and thus improve forecast verification scores.

- Increase in the Ensemble size for both global and regional EPS

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Ministry of Earth Sciences
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National Centre for Medium Range Weather Forecasting

# Thank You