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Global Ensemble Forecast System (GEFS T1534) evaluation for tropical cyclone prediction over the North Indian Ocean

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सार – भारतीय उष्णकटिबंधीय मौसम विज्ञान संस्थान (IITM) द्वारा जून 2018 में उच्च-वियोजन एन्सेम्बल पूर्वानुमान तंत्र कार्यान्वित किया गया तथा भारत मौसम विज्ञान विभाग (IMD) को प्रचालनात्मक कार्य के लिए सौंप दिया गया। उत्तर हिंद महासागर में उष्णकटिबंधीय चक्रवात (TC) ऋतुके दौरान, भारत मौसम विज्ञान विभाग को उष्णकटिबंधीय चक्रवात एन्सेम्बल मार्ग, तीव्रता और टकराने की संभावना का वास्तविक समय पूर्वानुमान प्रदान किया जाता है। प्रस्तुत शोधपत्र में वर्ष 2018, 2019 के दौरान उष्णकटिबंधीय चक्रवातों और 2020 की दो घटनाओं का पूर्वानुमान करने में इस मॉडल के कौशल का मूल्यांकन किया गया है। कुल 13 मामलों पर विचार किया गया और उष्णकटिबंधीय चक्रवातों के पूर्वानुमानों के लिए विभिन्न कौशल स्कोर की गणना की गई। यह अध्ययन उष्णकटिबंधीय चक्रवातों के पूर्वानुमान के लिए एन्सेम्बल पूर्वानुमान प्रणालीके महत्व का मूल्यांकन करता है और उस पर प्रकाश डालता है। इस विश्लेषण से लंबी अवधि के GEFS पर आधारित एन्सेम्बल पूर्वानुमान प्रणाली के अत्यधिक कुशल होने का पता चलता है जो प्रचालनात्मक पूर्वानुमानकर्ताओं के लिए आरंभिक चेतावनी जारी करने हेतु बहुत लाभकारी है।

ABSTRACT. The high-resolution global ensemble prediction system was implemented at IITM (Indian Institute of Tropical Meteorology) in June 2018 and handed over to India Meteorological Department (IMD) for operational running. During the Tropical Cyclone (TC) season over the North Indian Ocean, real time forecasts of ensemble tracks, intensity and strike probability of TCs are provided to IMD. This paper evaluates the skill of the model in predicting TCs during 2018, 2019 and two cases in 2020. A total of 13 cases are considered and various skill scores are calculated for the TC predictions. This study evaluates and highlights the importance of the Ensemble Prediction System for Tropical Cyclone forecasting. The key finding from this analysis is that, the higher skill of ensemble prediction system based on GEFS at longer lead time compared with the deterministic prediction. This is particularly beneficial for operational forecaster for issuing early warnings.

Key words – Tropical cyclone, North Indian Ocean, GEFS, Verification.

1. Introduction

Prediction of Tropical Cyclone's (TC's) track, intensity, landfall location, associated wind and rainfall is a challenge to numerical weather prediction (NWP) community. Accurate forecasts of these high impact weather events minimize the possible damage of life and property by implementing pre-decided mitigation plans. Short and medium range weather forecast being an initial value problem is sensitive to initial state of the atmosphere from which models are initialized for prediction. In the tropics, weather is controlled by fast growing convective instabilities and is thus less predictable than that in the extra-tropics (Shukla, 1981). In spite of significant progress in the field of NWP, the variability of track and intensity forecasts from one day to the next, pose a major problem to the forecaster due to the uncertainties of individual model forecast. This issue has greatly been resolved by introduction of ensemble prediction systems in the operational centres. (Toth and Kalnay, 1997; Houtekamer *et al*., 1996; Molteni *et al*., 1996; Palmer *et al*., 1997; Puri *et al*., 2001). Hence, many leading meteorological centers use Ensemble Prediction System (EPS) for real-time probabilistic forecasts of TC tracks (Hamill *et al*., 2011; Buckingham *et al*., 2010; Heming *et al.*, 1995; Heming and Radford, 1998; Chung Tsai and Elsberry, 2013; Yamaguchi and Komori, 2009; Kehoe *et al.*, 2007). The ensemble prediction was initiated at a

TABLE 1

Description of operational Global Ensemble Forecast System (GEFS) T 1534

Model Description	Two-time level semi-implicit, Semi-Lagrangian linear grid
Time-steps	Dynamics: 900, Physics: 450, Radiation: 1Hour for SW/LW
No of members	21 (20 perturbed + 1 Control)
Perturbation Method	Ensemble Kalman Filter
Parameters	Critical Relative Humidity = 0.9,0.9,0.9 Auto Conversion(Ice to snow) = 6.0e-4,3.0e-4 Auto conversion (cloud to rain) = 1.0e-4, 1.0e04 Threshold (ice/water) = 1.0e-5,1.0e-5 coefficient for evaporation of large scale rain = 2.0e-5 Factors for CDMB and GWD : 2.0, 0.25
Resolution	T1534 (3072 × 11534) ~ 13km at poles
Land Surface Model	NOAH Land Surface Model
PBL	Hybrid Eddy-diffusivity Mass-flux Scheme
GWD	Orographic and Convective Gravity Wave Drag
Deep Convection	scale- & aerosol-aware mass-flux deep conv scheme
Shallow Convection	New Mass flux based shallow convection
Microphysics	Zhao-Carr Microphysics scheme
Radiation	Optimized versions of RRTMG for Long-wave and Short-wave

TABLE 2

Classification of low pressure system over NIO*

System	Associated wind speed in knots (kmph)
Low Pressure Area	< 17 (<31)
Depression	17-27 (31-49)
Deep Depression (DD)	28-33 (50-61)
Cyclonic Storm (CS)	34-47 (62-88)
Severe Cyclonic Storm (SCS)	48-63 (89-117)
Very Severe Cyclonic Storm (VSCS)	64-89 (118-166)
Extremely Severe Cyclonic Storm (ESCS)	90-119 (167-221)
Super Cyclonic Storm	≥120 (≥ 222)

*Adopted from http://www.rsmcnewdelhi.imd.gov.in/images/pdf/cyclone-awareness/terminology/faq.pdf" http://www.rsmcnewdelhi.imd.gov.in/images/pdf/cyclone-awareness/terminology/faq.pdf

moderate resolution of T190 in the National Centre for Medium Range Weather Prediction (NCMRWF) (Ashrit *et al*., 2013). However, there was a need for an ensemble based forecast system for region specific probabilistic prediction of weather over India particularly for disastrous weather events, *e.g*., tropical cyclones, heavy rainfall events etc. Considering the societal need into account, under 'Monsoon Mission' program of Ministry of Earth Sciences (MoES), Government of India, we successfully implemented NCEP Global Ensemble Forecast System (GEFS) (semi-Lagrangian T574 L64 resolution) at IITM (Indian Institute of Tropical Meteorology) for seven days weather prediction (Rao *et al*., 2019). This model was running operationally at IITM from June 2016 till May 2018. Further as per the need of forecast at block level (~12 km), the high resolution ensemble prediction system (GEFS T1534) was implemented at IITM in June 2018 (Deshpande *et al*., 2020) and subsequently handed over to India Meteorological Department (IMD) for operational implementation. This was done under the initiative of Niti Aayog and 'Monsoon Mission' programme of the MoES, Government of India in collaboration with NCEP, USA for the model and NCMRWF for the perturbed initial condition. In order to gain the confidence in the forecasting system it is essential to evaluate and carry out the verification of the operational forecast. Recently Dube *et al*. (2020) evaluated TC prediction skill of operational NEPS (resolution 12 km with 11 member) running at NCMRWF. In this paper we are evaluating and documenting the performance of the GEFS (at horizontal resolution ~12 km with 21 ensemble members) in predicting Tropical cyclones formed during 2018-2020 over north Indian oceans.

2. Data and methodology

2.1. *GEFS and TC tracker*

Global Ensemble Forecast System (GEFS) is a semi-lagrangian global spectral model with a horizontal resolution of T1534 or approximately 12 km at the poles with 64 hybrid sigma-pressure layers (Deshpande *et al*., 2020). Detailed information of the GEFS model is provided in Table 1. A total of 21 (20 perturbed forecasts + 1 control forecast) ensemble members constitute the GEFS system suite. Each of these ensemble members are generated from the Ensemble Kalman Filter (EnKF) method with the forecast perturbation of the previous cycles four times a day (0000, 0600, 1200 and 1800 UTC) at all 64 model vertical levels. To simulate better, the Cyclones/Hurricanes vortex initialization is performed for all the ensemble members. If the storm location from the Tropical Cyclone Vitals Database (TCVitals) matches with the analysis files, then there are no changes to the

TABLE 3

List of cases with description

S. No.	TC Name (basin)	CSLP hPa (MSW kt) and classification	Duration (D to D)	Landfall location and time	Areas affected
1.	Luban (AS)	980 (70) VSCS	0900 UTC 6 Oct - 0000 UTC 15 Oct, 2018	15.8° N / 52.2° E 0530-0600 UTC 14 Oct	Yemen, Oman
2.	Titli (BoB)	972 (80) VSCS	0300 UTC 8 Oct - 2100 UTC 12 Oct, 2018	18.8° N / 84.5° E 2300 UTC 10 Oct - 0000 UTC 11 Oct	Andhra Pradesh, Odisha, West Bengal, Bangladesh
3.	Gaja (BoB)	976 (70) SCS	0300 UTC 10 Nov - 1200 UTC 19 Nov, 2018	10.45° N / 79.8° E 1900-2100 UTC 15 Nov	Andaman Islands, Tamil Nadu, Sri Lanka
4.	Phethai (BoB)	992 (55) SCS	0000 UTC 13 Dec - 1800 UTC 17 Dec, 2018	16.55° N / 82.25° E 0800-0900 UTC 17 Dec	East India, Northeast India
5.	Fani (BoB)	932 (115) ExSCS	0300 UTC 26 Apr - 1200 UTC 4 May, 2019	19.75° N / 85.7° E 0230-0430 UTC 3 May	Nicobar Islands, East India, Sumatra, Sri Lanka, Bangladesh, Bhutan
6.	Vayu (AS)	970 (80) VSCS	0000 UTC 10 Jun - 1200 UTC 17 Jun, 2019	Weakened over ocean before landfall	Northern Maldives, India, South Pakistan, East Oman
7.	Hikaa (AS)	978 (75) VSCS	0300 UTC 22 Sep - 0600 UTC 25 Sep, 2019	19.7° N / 57.7° E 1400-1500 UTC 24 Sep	Western India, Oman, Saudi Arabia, Yemen
8.	Kyarr (AS)	922 (130) SuCS	0300 UTC 24 Oct - 1500 UTC 2 Nov, 2019	No landfall	Western India, Oman, Yemen, Somalia
9.	Maha (AS)	956 (100) ExSCS	0000 UTC 30 Oct - 0900 UTC 7 Nov, 2019	No landfall	Southern and Western India, Oman, Maldives, Sri Lanka,
10.	Bulbul (BoB)	976 (75) VSCS	0000 UTC 5 Nov - 0000 UTC 11 Nov, 2019	21.55° N / 88.5° E 1500-1800 UTC 9 Nov	Andaman and Nicobar Islands, Eastern India, Myanmar, Bangladesh
11.	Pawan (AS)	998 (40) CS	1200 UTC 2 Dec - 0900 UTC 7 Dec, 2019	7.4° N / 49.6° E 0200-0300 UTC 7 Dec	Somalia
12.	Amphan (BoB)	920 (130) SuCS	0000 UTC 16 May - 1200 UTC 21 May, 2020	21.65° N / 88.3° E 1000-1200 UTC 20 May	Sri Lanka, India, Bangladesh, Bhutan
13.	Nisarg (AS)	984 (60) SCS	0000 UTC 1 Jun - 0600 UTC 4 Jun, 2020	18.35° N / 72.95° E 0700-0900 UTC 3 June	West India

background fields, else depending on the TC Vitals, modifications are done for the relocation, size correction and the intensity (Quingfu, 2020). Using Ensemble Transform (ET) these analysis perturbations are added to the reconfigured analysis obtained from the hybrid four-dimensional Ensemble variational data assimilation system (GDAS-Hybrid-4DEnsVar) as a part of the suite (Deshpande *et al*., 2020) with vortex initialization. During the pre-processing, vortex-separate and Vortex-combine are run for every cycle. Near-surface SST (NSST) is also perturbed along with the Initial Conditions (ICs). The GEFS model is run for 0000 UTC and 1200 UTC for 10 days. In this study 0000 UTC IC is considered for evaluation. Ensemble mean and the spread of ensembles are calculated from the 21 ensembles. The suite also includes the ensemble tracker (v1.1.14) of NCEP (Marchok, 2002) which has been used for the estimation of tracks for each ensemble, track uncertainty (from ensemble spread) and the intensity of the cyclones. The GEFS tracker was specific to Indian, Atlantic and pacific regions but was modified to take the Bay of Bengal and the Arabian Sea cyclones.

2.2. *IMD data used for verification*

All the verification in the current study is carried out against the best track data issued by India Meteorological Department (IMD) (Mohapatra *et al*., 2012). As per the cyclone manual published by IMD (2013), based on maximum sustained wind (MSW) speed, cyclonic disturbances in the NIO are classified into different categories as mentioned in Table 2. The TC is named when it reached the Cyclonic Storm (T2.5) Stage. In this study GEFS forecast of track and intensity is verified for a total 13 named tropical cyclones in the North Indian Ocean occurred during 2018, 2019 and 2020. The detailed

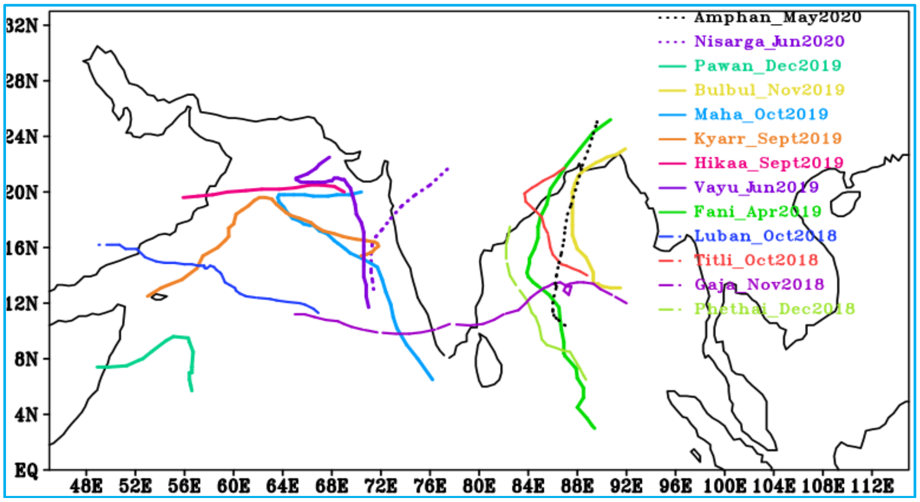


Fig. 1. Observed tracks of tropical cyclones during 2018, 2019 and 2020

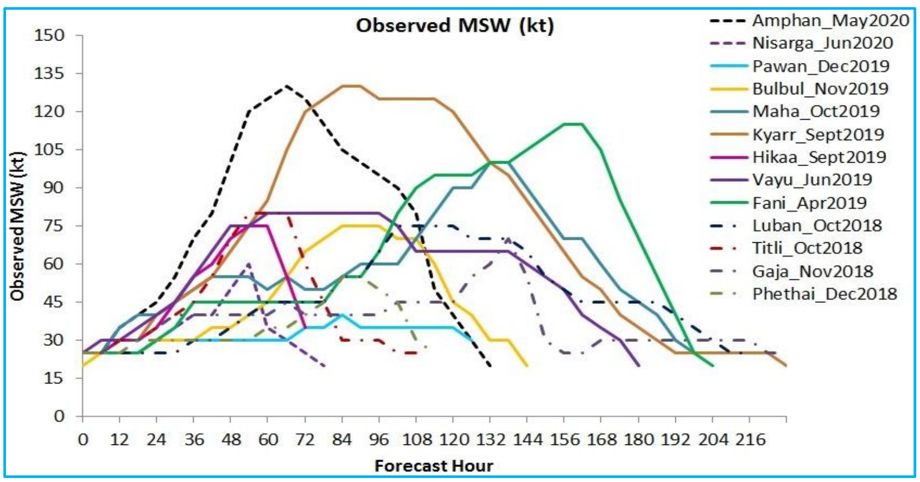


Fig. 2. Observed intensity in terms of MSW (kt) of cyclones during 2018, 2019 and 2020

description of the cases with name, basin, intensity, duration from the formation as a Depression till dissipating Depression, landfall location and time along with the area affected are described in Table 3. The observed tracks and intensity (MSW in kts) of all the cyclones considered in the present study are shown in Figs. 1&2 respectively. During the study period, TCs affected India (East and West Coast; islands like Andaman, Nicobar), Bangladesh, Bhutan, Yemen, Oman, Saudi Arabia, Somalia, Maldives. Out of 13 TCs, 7 formed over Arabian Sea (AS) and remaining 6 formed over Bay of Bengal (BoB). All together there were two SuCS, two ExSCS. Five VSCS, three SCS and only one CS. Historically rare events like TCs Luban and Titli simultaneously active over AS and BoB happened during October 2018 and both underwent rapid intensification. In November 2018, TC Gaja originated in BoB crossed Indian peninsula and entered into AS. In 2019, AS was more active than BoB, moreover there were two intense TCs (Kyarr and Maha) one after the other over AS in October. In June 2020 TC Nisarga had a landfall near Mumbai, which is considered as rare. So in all, the variety of cases are considered while evaluating the performance of operational prediction of TCs.

2.3. *Verification method*

The GEFS forecast includes tracks for each member and ensemble mean along with the strike probability. It also provides the intensity of the cyclone in terms of minimum mean sea level pressure (*P*min) and maximum surface wind speed (*V*max) for each member and ensemble mean. In the current study, we evaluated the skill of GEFS T1534 in predicting TC tracks and intensity against the IMD best track data. Strike probability is the chance of a given location (grid point) being within a

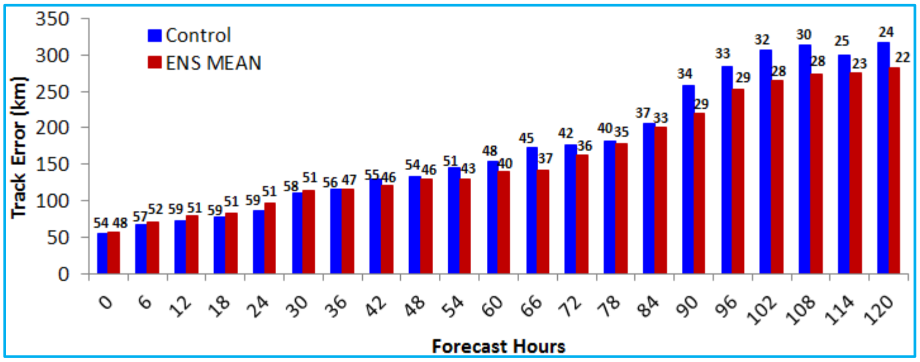


Fig. 3. Track Error for ENS mean and control with forecast lead hours

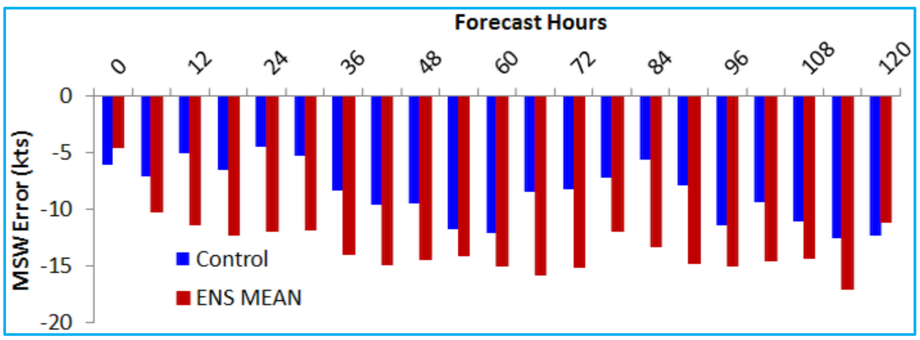


Fig. 4. MSE Error for ENS mean and control with forecast lead hours

specified distance (~120 km) of an ensemble mean track point. Strike probability is calculated both individually for each forecast hour and for the total accumulated probability upto 168 hr (7 days) forecast. The probabilistic track prediction for the cyclones obtained from the model is verified using standard metrics like ensemble mean error *versus* spread in members for track and intensity, Brier Score (BS), Reliability diagram and Relative Operating Characteristic (ROC) curve for the Strike Probability Products. The RMSE in the maximum sustained wind speed is calculated for the ensemble mean at each forecast lead time. The BS is the mean squared difference between the forecast probability and binary observation (Brier, 1950). It is calculated by the following-

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

where, n is the total forecast event pairs, y_k and o_k are the forecast probability and binary observation at k^{th} sample respectively. As the BS is an error score, the lesser the BS better is the forecast. Hence a BS value of 0 indicates a perfect forecast. The Reliability Diagram accounts for how much the predicted probabilities and observed frequencies are in tandem. Thus a curve along the diagonal shows a perfectly reliable forecast. Curve over the diagonal indicates the forecast to be under confident as it means that the forecast probability of an event occurring is less than the observed frequency. A vice versa condition renders the forecast to be overconfident. If the curve follows along the no resolution line, it indicates that the forecast is not resolved or distinguished amongst the forecast probability categories. The ROC displays the success of the forecast as it plots the hit rate against the false alarm rate with increasing probability thresholds. A perfect ROC curve extends from the bottom left to the top left and then to the top right indicating that the forecast has the ability to discriminate among the forecast probability thresholds. A ROC curve along the diagonal indicates that the hit rate and false alarm rate are equal and hence the forecast has no skill. A curve below the diagonal indicates negative skill.

3. Results and discussion

3.1. *Track and intensity prediction skill for all the cases (2018, 2019, 2020)*

Fig. 3 is the plot of the track error for GEFS Ensemble Mean (ENS MEAN) and Control run with forecast lead time. The number on each color bar indicates the sample size for respective error calculation which

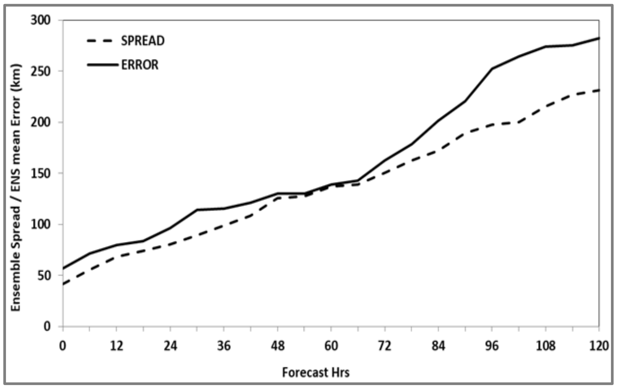


Fig. 5. Ensemble Spread and ENS Mean Error

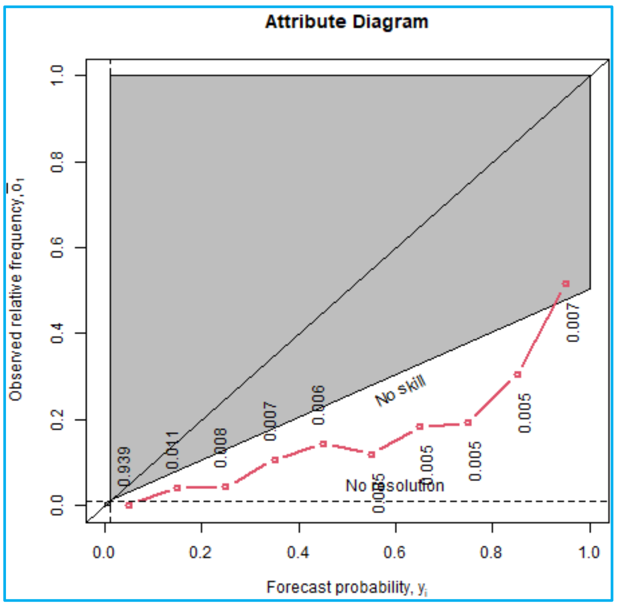


Fig. 6. Reliability Diagram for strike probability forecast for all TC cases

reduces with the lead time. The track error increases with lead time for both the models. For the initial 48 hrs the track error is the same for ENS MEAN and Control which is of the order of 100 kms. There after the track error is less for ENS Mean which is 282 km and 316 km for Control on day 5 (120 hrs).

TC intensity prediction from GEFS ENS mean and control run in terms of Maximum Sustained Wind (MSW) speed is evaluated against IMD best track data and MSW error (Forecasted - Observed) is presented in Fig. 4. Both ENS Mean and Control underestimate the intensity and the error is larger for GEFS ENS Mean. Error is maximum (-17 kts for ENS Mean and -12 kts for the Control) at 114 hrs. Track is basically driven by the large scale flow which the model could reproduce but intensity is mainly influenced by the core processes like eye and eyewall

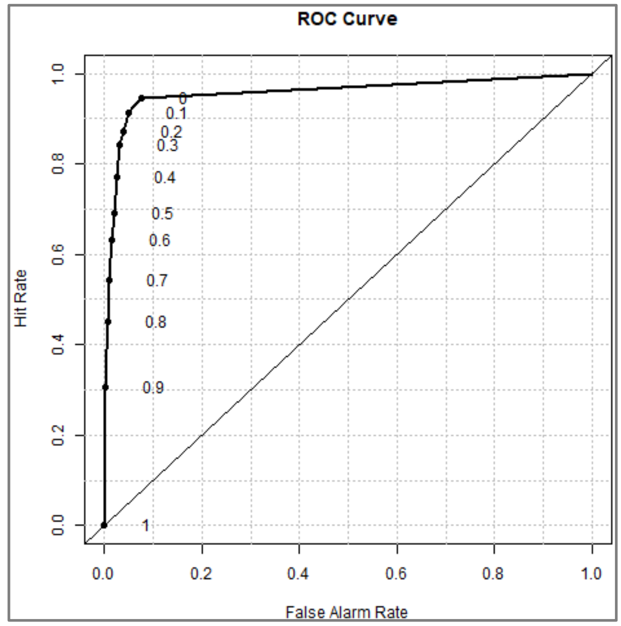


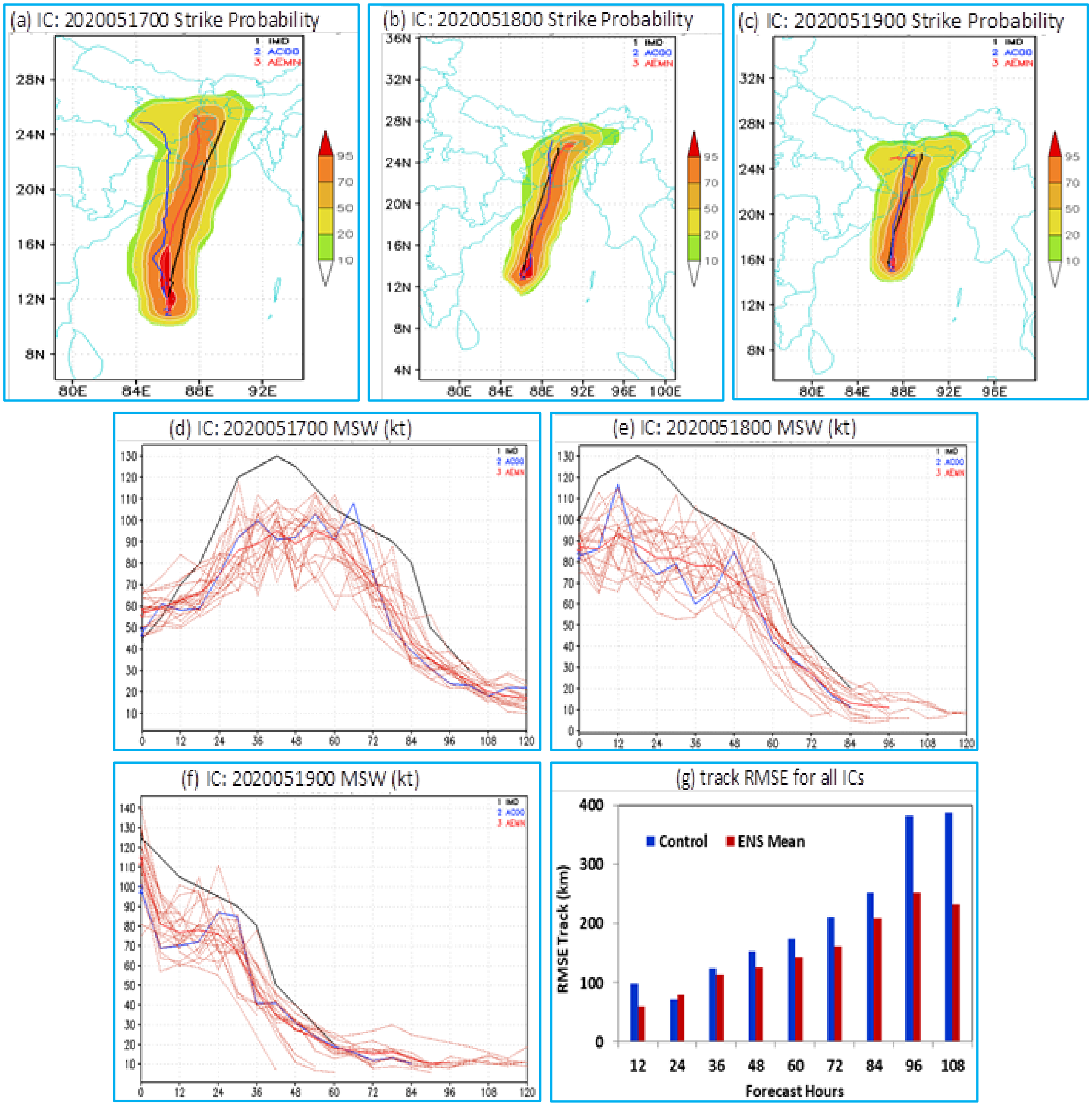
Fig. 7. Relative Operating Characteristic (ROC) curve for strike probability forecast for all TC cases

formation, eyewall replacement cycle etc. Prediction of these processes is still a challenge for GFS and GEFS at 12 km resolution.

3.2. *Track probability prediction skill*

Ensemble spread is a measure of dispersion among members and determines the expected uncertainty or forecast error. It is the standard deviation with respect to ensemble mean. Fig. 5 shows Error (ENS Mean) and Spread variation with forecast lead hours for GEFS. Both Error and Spread are increasing with forecast hours. Both are almost equal till 72 hrs (Day3), thereafter spread is less than error. Spread smaller than error indicates the forecast is over confident and thus the ensemble system is under spread for higher lead time.

The accumulated strike probability is verified against the IMD best track data using skill scores such as Brier Score, Reliability diagram and ROC. The forecast shows a BS of 0.02 indicating very less error between the forecast probabilities and observed occurrence or non-occurrence of events. Though a near perfect BS is obtained, Fig. 6 shows the reliability diagram with a curve below the no skill line. Despite the position of the curve, it is not flat and rises with increasing forecast probability categories. This indicates the ability of the forecast to be more skillful than the climatology. As the curve is below the diagonal, we can deduce that the forecast is overconfident implying that with increasing forecast probability categories, it produces more forecasts than the observed occurrences.

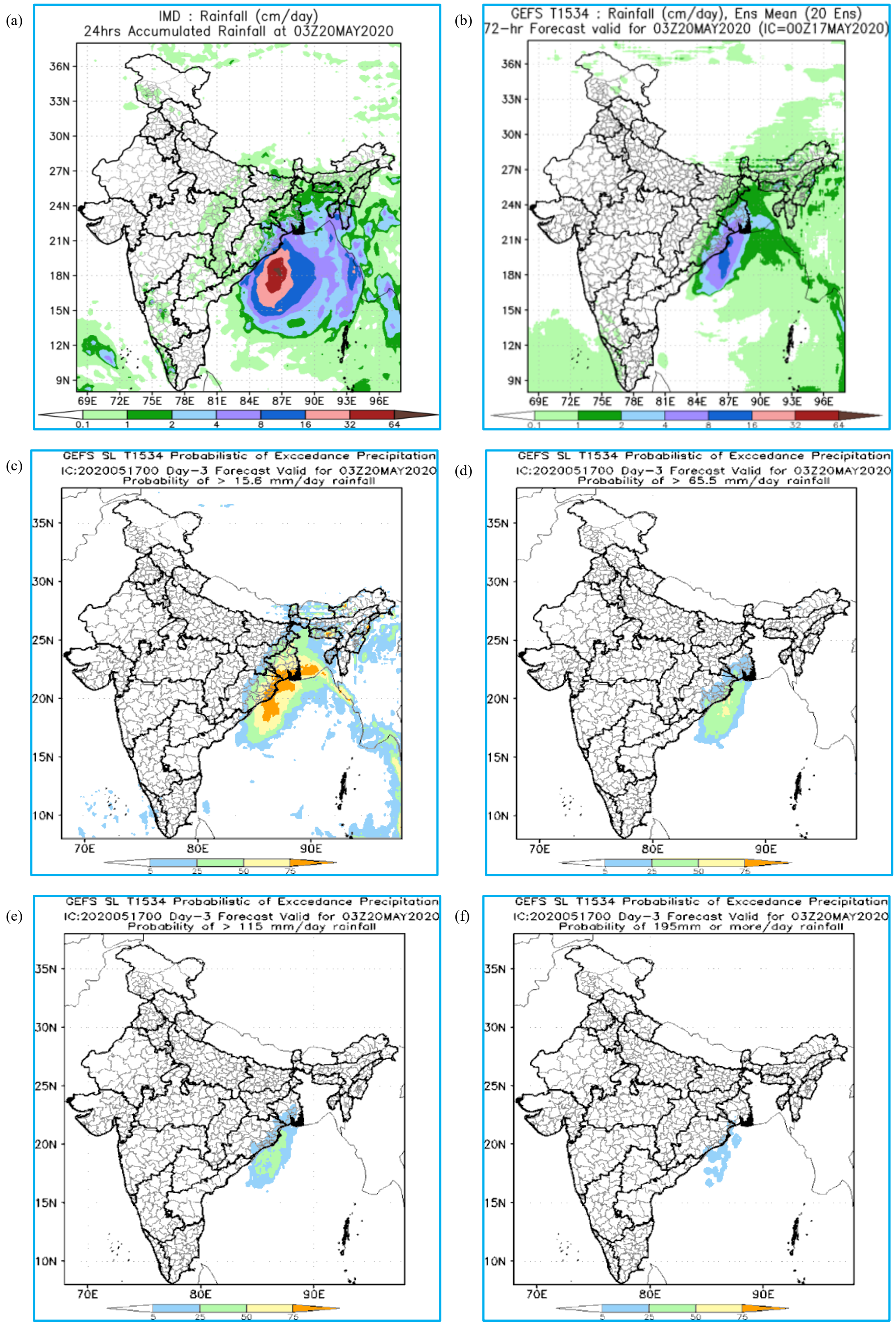


Figs. 8(a-g). TC Amphan (a-c) strike probability, (d-f) maximum sustained wind and verification of the forecast of (g) track from all the ICs during the lifespan of the Amphan

Although the reliability diagram indicates an overconfident and under spread forecast, the ROC in Fig. 7 shows a near perfect curve. Such a curve shows high resolution in the forecast indicating the ability of the forecast to discriminate among the different forecast probabilities. Since ROC is independent of forecast bias, it shows the potential skill of the forecast. A measure of this skill is given by the area under the ROC curve. For the present figure the area under the curve is 0.96 thus quantifying the skillful forecast.

3.3. *Verification of SuCS Amphan prediction*

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. Probabilistic prediction of SuCS AMPHAN is discussed in this section. Figs. 8 (a-c) are the Strike probability (%) forecast based on 0000 UTC 17th May, 18th May and 19th May IC. As



Figs. 9(a-f). 24 hr accumulated rain from (a) IMD-GPM merged Gridded data; 72 hr forecast from (b) GEFS ensemble mean along with the probability of rain with various thresholds (c) > 15.6 mm/day, (d) > 65.5 mm/day, (e) > 115 mm/day and (f) 195 mm/day or more; all valid for 20th May, 2020 explained before, strike probability is the probability of the storm passing within 65 nm (approximately 120 km) during the forecast period. 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. From 17th May IC the deterministic track is towards Odisha and shows early landfall. But the AEMN is towards West-Bengal which is close to the observed track.

This is a clear example of the Ensemble system being advantages over the deterministic (Control) one. This performance of AEMN remains consistently better than Control for all the ICs. Fig. 8(g) is the verification of the forecast of track 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. Forecast of maximum sustained surface wind speed (knots) is shown in Figs. 8(d-f) for corresponding ICs. The intensity is underestimated by all the members and the control run but the weakening of intensity before and after the landfall is captured by majority of the members and thus by AEMN. The improvement in the prediction of track and intensity with lead time is also clearly seen in the plots of consecutive ICs.

Prediction of heavy rainfall associated with the cyclone is also a great challenge to the NWP community. Figs. 9 (a-f) show 24 hours accumulated rainfall from observations (IMD), AEMN as well as its probabilistic forecast for different thresholds valid at 0000 UTC 20 May. The observed rainfall was more than 64 cm/day, whereas rainfall is underestimated by AEMN (<16 cm/day). As the modeled cyclone was having high translational speed, some location error is clearly seen in the AEMN. The probability of heavy rain greater than 195 mm/day is well captured by the model 3 days in advance. Thus, along with the track and intensity, GEFS has the ability of predicting the heavy rainfall with 72 hrs lead.

4. Summary and conclusions

In this paper we have evaluated the skill of the operational model in predicting the tracks, intensity and strike probability for named Tropical Cyclones (TCs) over the North Indian Ocean during 2018, 2019 and 2020. The forecast is verified against IMD best Track data. This includes 13 cases in which 7 formed over Arabian Sea and 6 over the Bay of Bengal. All together there were two SuCS, two ExSCS, five VSCS, three SCS and only one CS. This includes TCs with a variety of tracks (recurving, non-recurving) and intensity variations (weak and intense storms). The Track error for Ensemble Mean (ENS Mean) and Control are increasing with time. Overall ENS mean track error is comparable with that of the control run till Day 2 (48 hrs) and thereafter track error is less for ENS Mean. On Day 5 (120 hrs) track error is 282 km for ENS Mean and 316 km for Control. Intensity error in terms of Maximum Sustained Wind (MSW) is not varying uniformly with time. It is underestimated and error in MSW by Control is less than ENS Mean. The Ensemble Mean Error and Spread variation with time indicate GEFS is over confident after 72 hrs. Verification of accumulated Strike probability is carried out using probabilistic skill scores like Brier Score (BS), Reliability diagram and ROC (Relative operating characteristic). The BS is 0.02 which is near perfect but the reliability diagram curve is below no skill line and above no resolution line. Hence we conclude that the forecast is overconfident and thus with increasing forecast probability categories, it produces more forecasts than the observed occurrences. The ROC curve shows high resolution in the forecast indicating the ability of the forecast to discriminate among the different forecast probabilities. Since ROC is independent of forecast bias, it shows the potential skill of the forecast. Area under ROC curve is 0.96 thus quantifying the skilful forecast. Further verification of a Super Cyclonic Storm Amphan (May 2020) over Bay of Bengal is discussed. The model predicted the track, rapid intensification and weakening of Amphan before crossing land well in advance. The spatial distribution of heavy rainfall associated with the cyclone is also well predicted by the model with 72 hrs lead. This brings out the advantage of Ensemble Prediction System over the Deterministic forecast.

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