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Predictive skill of DEMETER models for wind prediction over southern subtropical Indian Ocean

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The ensemble mean prediction of winds at 850 hPa from individual models of DEMETER project has been compared from NCEP observation over southern subtropical Indian Ocean during summer monsoon season (JJAS) for the time domain 1980-2001. Predictability of U850 hPa (U850) and V850 hPa (V850) has been tested by different statistical approach like root mean square error (RMSE) for the region between Madagascar and western Australia in view of the importance of this region in anomalous variation of south central African rainfall variability as evidenced by some recent studies. A dichotomous forecast skill measure has been performed by calculating predictive skill measures like accuracy, bias, probability of detection (POD), false alarm ration (FAR), probability of false detection (POFD), threat score (TS), equivalent threat score (ETS) and Heidke skill score (HSS) for model produced U850 and V850 from all the individual models and multi model ensemble (MME). It has been found that the root mean square error has been reduced by applying MME but there is no effect on dichotomous predictive skill measures.

[**Key words:** ECMWF, DEMETER Project, wind, Indian Ocean, forecast skill]

1. Introduction

The association of rainfall variability with south west Indian Ocean Sea Surface Temperature (SST) has been reported by Walker[1] and Mason[2]. The warming in south west Indian Ocean is associated with strengthening of easterlies producing moisture convergence over tropical to subtropical regions of the eastern boundary of African subcontinent. These modulations of the tropical and mid-latitude atmosphere leads to the formation of tropical-temperate troughs across South Africa and hence leading to increased precipitation[1].

The wet conditions over southern African continent was found to be associated with warm SST anomalies in the south west Indian Ocean and *vice versa*[3]. Behera & Yamagata[4] discussed the interannual occurrence of the Indian Ocean subtropical dipole using the observational and reanalysis data and they also provided evidence of a link between this dipole and summer rainfall over central southern Africa. The response of these SST anomalies on the Atmospheric circulation was simulated by atmospheric general circulation models[3,5]. The south west Indian Ocean SST anomaly may result in changes to amount of moisture advected towards coastal regions by prevailing south easterly winds which is important for southeast African rainfall[3,5]. It has also been shown that the model response would be larger if the positive SST anomaly was closer to the African coast. The intertropical convergence zone (ITCZ) in the western Indian Ocean lies along 10°S. The mean surface winds north of 35°S are predominantly southeasterly due to subtropical high. During positive subtropical Indian Ocean Dipole (SDP) event the cold SST anomalies were found to be elongated obliquely from the eastern subtropical region (roughly 110°E, 25°S; off Australia) to the western tropical region (roughly 65°E, 10°S) in the Southern Indian Ocean region. These cold anomalies weaken the maritime ITCZ by suppressing the atmospheric convergence which spreads the southeasterlies in the Somalia region in the equatorial region. The enhanced lower tropospheric southeasterlies transport surplus moisture towards far regions of south-central Africa which gives increased convective activity and anomalous rainfall over those regions[4].

In recent years further improvement in seasonal prediction has been made possible using multimodel ensemble approach which removes the errors associated with spread of ensemble prediction with different initial conditions and the uncertainties associated with the model parameterizations[6,7]. European Centre for Medium-Range Weather

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Forecasts (ECMWF) has established **D**evelopment of a **E**uropean **M**ultimodel **E**nsemble system for seasonal to in**TER**annual (DEMETER) based on the seven coupled models (CERF, ECMW, INGV, LODY, UKMO, MAXP and METF) used in European countries [7]. The aim of DEMETER project was to develop a multimodel seasonal prediction system and to evaluate the skill of the prediction system.

In the present work we have studied the predictive skill of each model and, the multimodal ensemble of the DEMETER system for the zonal and meridional winds for the region between Madagascar and western Australia covering some parts of the recently discovered subtropical Indian Ocean Dipole[4]. The area of domain for the predictive skill of zonal wind at 850 hPa has been chosen as the ocean between two land masses of Australian and African continent and covers the positive (partial) and negative poles of recently discovered subtropical Indian Ocean dipole (SDP)[4] . The choice of the domain is based on the relative importance of low level winds in the anomalous variation of south-central African rainfall variability as inferred from some recent studies[4,5].

2. Model and Data

The data utilized in the present study is the model output for 22 years (1980-2001) of DEMETER project which have been obtained from International Centre for Theoretical Physics (ICTP), Trieste, Italy (ftp://clima-ftp.ictp.trieste.it) under joint collaboration between ICTP and Centre of Ocean-Land-Atmosphere Studies (COLA), USA through Targetted Training Activity (TTA) Program. The DEMETER system comprises seven global coupled ocean-atmosphere models. A brief summary of the different coupled models is given in Table 1. The DEMETER hindcasts were started from 1 February 1, May 1, August 1 and November 1 to assess the seasonal dependence on skill. Each hindcast comprises an ensemble of 9 members so in its simplest form, the multimodel ensemble is formed by merging all the ensemble members of seven models thus comprising 7 × 9 ensemble members.

The predictive skill of zonal and meridional component of wind at 850 hPa was studied for the region south of Madagascar covering the positive pole of recently discovered subtropical Indian Ocean Dipole[4,8]. We will focus on the deviation (anomaly) from mean for the 22-year predicted climatology of each model. The anomalies thus obtained should not contain the systemic error of climatology of each model. The observed wind data of National Centre of Environmental Prediction (NCEP)[9] reanalysis data was used for verification.

3. Categorical Forecast Skill measures of Discrete Predictions

The easiest way to understand forecast verification of discrete prediction is the different categorical

Table 1—Brief description of the seven ocean atmosphere coupled models of DEMETER [7]

Institute	AGCM	Resolution	Atmosphere IC	OGCM	Resolution	Ocean IC
CERFACS (CERF)	ARPEGE	T63 31 levels	ERA-40	OPA 8.2	2.0° × 2.0° 31 levels	Ocean Analysis Forced by ERA-40
ECMWF (ECMW)	IFS	T95 40 levels	ERA-40	HOPE-E	1.4° × 0.3°-1.4° 29 levels	Ocean Analysis Forced by ERA-40
INGV	ECHAM-4	T42 19 levels	Coupled AMIP-type experiment	OPA 8.1	2.0° × 0.5°-1.5° 31 levels	Ocean Analysis Forced by ERA-40
LODYC (LODY)	IFS	T95 40 levels	ERA-40	OPA 8.2	2.0° × 2.0° 31 levels	Ocean Analysis Forced by ERA-40
Meteo-France (METF)	ARPEGE	T63 31 levels	ERA-40	OPA 8.0	182 GP × 152 GP 31 levels	Ocean Analysis Forced by ERA-40
Met Office (UKMO)	HadAM3	2.5° ×3.75° 19 levels	ERA-40	Glo Sea OGCM based on HadCM3	1.25° × 0.3°-1.25° 40 levels	Ocean Analysis Forced by ERA-40
MPI (MAXP)	ECHAM-5	T42 19 levels	Coupled run relaxed to observed SSTs	MPI-OMI	2.5° × 0.5°-2.5° 23 levels	Coupled run relaxed to observed SSTs

forecast skill measures. To verify this type of forecast we start with a contingency table that shows the frequency “yes” and “no” for forecast and real event. For calculating the contingency table, the area average has been calculated in the spatial domain 30°E-120°E; 30°S-5°S for observational as well as model produced U850 and V850 anomaly data and has been normalized by dividing its respective standard deviation (SD). Obviously the SD of normalized data set will be 1 so the condition for “yes” is defined as if the forecast is greater (less) than 1.0 (-1.0) and the condition for “no” is defined as if forecast is less (greater) than 1.0 (-1.0). In this way there will be four combinations of forecasts (yes or no) and event (yes or no) given below:

(h) Hit: Forecast to occur and did occur

(m) Miss: Forecast not to occur but did occur

(f) False alarm: Forecast to occur but did not occur

(n) Correct negative: Event forecast not to occur and did not occur.

In this way a contingency table will be generated for each individual model and MME. Several scalar measures are in common use which are defined below.

$$\text{Accuracy} = \frac{h+n}{total} \quad \ldots (1)$$

where $total = (h+m+n+f)$

$$\text{Bias} = \frac{(h+f)}{(h+m)} \quad \ldots (2)$$

$$\text{Probability of detection } (POD) = \frac{h}{(h+m)} \quad \ldots (3)$$

$$\text{False alarm ratio } FAR = \frac{f}{h+f} \quad \ldots (4)$$

Probabality of false detection or false alarm rate

$$(POFD) = \frac{f}{(n+f)} \quad \ldots (5)$$

Threat score or critical success index

$$(TS) = \frac{h}{(h+m+f)} \quad \ldots (6)$$

Equitable threat score or Gilbert skill

$$\text{score } (ETS) = \frac{h-h_{random}}{h+m+f-h_{random}} \quad \ldots (7)$$

where $h_{random} = \frac{(h+m)(h+f)}{total}$

$$\text{Heidke skill score } (HSS) = \frac{(h+n)-(correct_{random})}{total-(correct_{random})} \quad \ldots (8)$$

where

$$correct_{random} = \frac{1}{total}\left[(h+m)(h+f)+(n+m)(n+f)\right]$$

The details of the above skill score measures, their importance can be found in Wilks[10].

4. Results and Discussion

The mean prediction of winds at 850 hPa for the region (30°E-120°E and 30°S to 40°N) covering tropical Indian Ocean and Indian subcontinent has been studied here. The mean June-August (JJA) climatological prediction for the period 1980-2001 from all the seven models and the observed NCEP climatology for the same time domain is shown in Fig. 1A. The spatial pattern of Indian summer monsoon winds at 850 hPa is predicted well from Istituto Nazionale de Geofisicae Vulcanologia, Italy (INGV), (European Centre for Research and Advanced Training in Scientific Computation, France) (CERF) and Centre National de Recherches Météorologiques, Météo-France, France (METF). The direction of winds near south equatorial band (EQ-20°S) from all the models except CERF is slightly different from the observation. We can see that the prediction of different models vary regionally. The predictive skill of the models and their multimodel ensemble by a number of statistical measures for the Indian Ocean between land masses of Madagascar and western Australia (30°E-120°E and 5°S to 30°S) has been studied.

We will focus on deviation (anomaly component) for the 22-year predicted climatology of each individual model for zonal (U850) and meridional (V850) component wind at 850 hPa. Root mean square error (RMSE) at each year for U850 and V850 has been calculated in the region between Madagascar and western Australia The multimodel ensemble (MME) is calculated by combining individual model output with equal weight. Out of 22 years of prediction the RMSE is less than SD for 16 years implying better prediction. It is also clear that MME reduces RMSE considerably but the MME is not

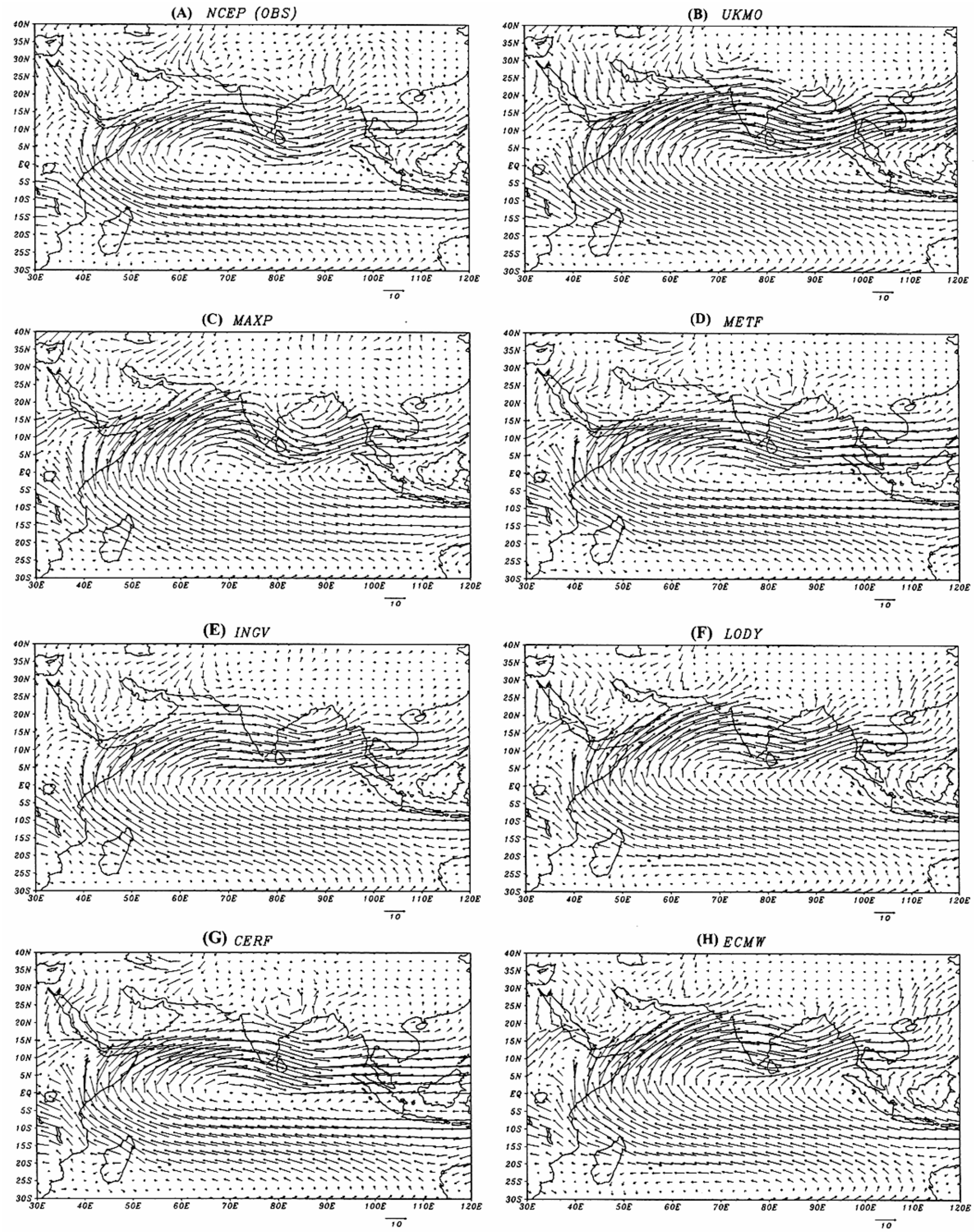

Fig. 1—Mean winds during 1980-2001 at 850 hPa for summer monsoon season (JJA) observed from (A) NCEP and forecasts from (B) UKMO (C) MAXP (D) METF (E) INGV (F) LODY (G) CERF and (H) ECMW models for the same season

always better than the best individual model (Fig. 2). Similarly for V850 the RMSE was found to be smaller than SD for 14 years. RMSE was largest for both U850 and V850 in the year 1997 although larger (smaller) error in V850 (U850) does not correspond to larger (smaller) error V850 (U850) for any particular year.

The purpose of calculating conventional skill scores is to show the improvement of forecast by applying MME although the MME is not always better than best individual model at any particular year. The dichotomous skill scores have been calculated to see the performance of individual model and MME in the forecast time domain of 22 years (1980-2001). Categorical forecast verification measures have been performed for U850 and V850 for all the individual models for June-August during forecast period of 1980-2001. Contingency table based on the definition of 'yes' and 'no' forecast has been generated and shown in Table 2. The Max-Planck Institut für Meteorologie, Germany (MAXP) for U850 as well as CERF and Laboratoire d'Océanographie Dynamique et de Climatologie, France (LODY) for V850 did not predicted any rare event during the period 1980-2001 although these models predicted normal events for more than 10 years. It is important to note that the predictability measures are strictly confined to the region between Madagascar and western Australia (30°E-120°E and 30°S to 5°S) and our observation about the forecast skill measure is true for this region only. It is also interesting to mention that the MME did not improve the categorical forecast measures.

The forecast verification has been quantified by calculating dichotomous forecast skill measures for U850 and V850 and is given in Tables 3 and 4 respectively. Accuracy of more than 0.45 has been

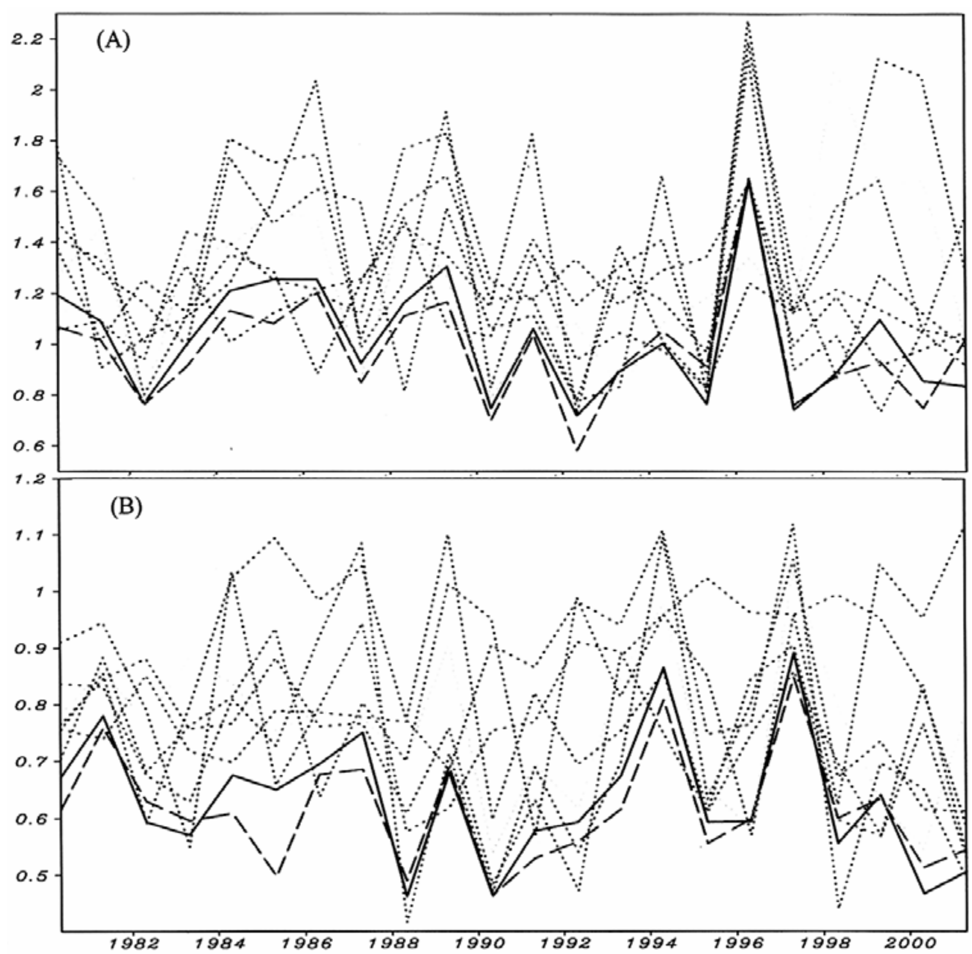

Fig. 2—Time series of the root mean square error over the region between Madagascar and western Australia (30°E-120°E and 30°S-5°S) between observed and predicted (A) U850 and (B) V850 by individual models and MME. (*Dotted lines are for individual models of DEMETER, thick line is for MME and long dash-dot is for observed standard deviation*).

found for U850 whereas it is more than 0.40 for V850 from all the individual models and MME which indicates that forecast were correct for more than 40% (45%) for V850(U850). Since bias is less than 1 for U850 from all the models, it can be argued that the models are under forecast in the case of U850 whereas all the models except CERF and LODY showed over forecasting for V850. Probability of detection (POD) was larger for European Centre for Medium-Range Weather Forecasts, United Kingdom (ECMW) and United Kingdom Met Office (UKMO) models both for U850 and V850 indicating that these models are better in predicting rare events. MAXP for U850 as well as CERF and LODY for V850 did not predict any rare events giving POD=0 and obviously the False alarm ration (FAR) was 1 for these models. FAR envisage that the models predicted rare events but actually it was not and it was found that FAR is

Table 2—Contingency Table of each individual model and MME for U850 and V850 in the region 30°E-120°E and 30°S to 5°S

Model Name			U850		V850	
			Observed		Observed	
			Yes	No	Yes	No
CERF	Forecast	Yes	2	2	0	6
		No	7	11	6	10
ECMW	Forecast	Yes	3	5	3	5
		No	6	8	3	11
INGV	Forecast	Yes	2	1	1	8
		No	7	12	5	8
LODY	Forecast	Yes	2	5	0	5
		No	7	8	6	11
MAXP	Forecast	Yes	0	2	3	8
		No	9	11	3	8
METF	Forecast	Yes	1	3	2	5
		No	8	10	4	11
UKMO	Forecast	Yes	3	2	4	6
		No	6	11	2	10
MME	Forecast	Yes	1	3	2	7
		No	8	10	4	9

Table 3—Categorical statistics computed for U850 from the contingency table of individual models and MME.

	Accuracy	Bias	POD	FAR	POFD	TS	ETS	HSS
CERF	0.59	0.44	0.22	0.5	0.15	0.18	0.04	0.08
ECMW	0.5	0.89	0.33	0.62	0.38	0.21	0.02	-0.05
INGV	0.63	0.33	0.22	0.33	0.08	0.20	0.09	0.16
LODY	0.45	0.78	0.22	0.71	0.38	0.14	0.08	-0.16
MAXP	0.5	0.22	0	1.	0.15	0	0.08	-0.17
METF	0.5	0.44	0.11	0.75	0.23	0.08	-0.06	-0.13
UKMO	0.64	0.56	0.33	0.40	0.15	0.27	0.11	0.19
MME	0.50	0.44	0.11	0.75	0.23	0.08	0.06	-0.13

Table 4—Categorical statistics computed for V850 from the contingency table of individual models and MME.

FAR	Accuracy	Bias	POD		POFD	TS	ETS	HSS
CERF	0.45	1.	0	1.	0.37	0	1.5	-0.26
ECMW	0.64	1.33	0.5	0.62	0.31	0.27	1.22	0.17
INGV	0.41	1.5	0.17	0.89	0.5	0.07	1.32	-0.29
LODY	0.5	0.83	0	1.	0.31	0	1.58	-0.32
MAXP	0.5	1.8	0.5	0.73	0.5	0.21	1.21	0
METF	0.59	1.17	0.33	0.71	0.31	0.18	1.29	0.02
UKMO	0.63	1.67	0.67	0.60	0.37	0.33	1.17	0.24
MME	0.5	1.5	0.33	0.78	0.44	0.15	1.27	-0.09

larger for V850 as compared to U850. It could be said that failure of rare events are larger for V850 as compared to U850. Probability of false detection (POFD) is very small (0.08) from INGV for U850 which indicates that the fraction of 'no' events which were incorrectly forecast as 'yes' is negligible for this model whereas it is largest from ECMW and LODY (0.38 each). Since FAR was larger for V850 as compared to U850 so as the POFD is larger for V850. Threat Score (TS) measures accuracy when the correct negatives have been removed from the forecast and it was found to be 0.27 and 0.33 for U850 and V850 from UKMO model which indicates that UKMO model is better than other member of DEMETER in predicting rare events for our domain of study and for the forecasting period of 1980-2001.

Since ETS and HSS are also larger as compared to other models, it strengthens our argument that UKMO model is better as compared to other models. But it is also true that these skill scores are very less. TS of 0.27 and 0.33 indicate that slightly more than ¼ rare events for U850 and more than 1/3 rare events for V850 have been predicted by UKMO, which was the best score among the seven models and MME. HSS which is a measure of fraction of correct forecast after eliminating those forecast which are purely due to random chance and it is found to be 0.19 and 0.24 for U850 and V850 respectively from UKMO model.

5. Conclusion

The mean prediction of winds during Indian summer monsoon season (JJA) at 850hPa has been compared from observation (NCEP) for the time domain of 1980-2001 for the region (30°E-120°E and 30°S to 40°N). It has been found that the prediction of direction of Indian summer monsoon winds from INGV, CERF and METF is better as compared to other models. The direction of winds for the region 0-20°S has been found to be slightly different from observation from almost all the models. So we have performed the statistical predictive skill measure for the region 30°E-120°E and 30°S to 5°S to come up with a model which is better than others. It has been found the MME technique reduces the RMSE but it is not always better than the best individual model.

Forecast verification with respect to observation has been performed by categorical forecast techniques by calculating different scalar skill score measures. It has been found that the UKMO model is better in predicting rare events as compared to other models for U850 and V850 both. The MME technique did not improve the categorical skill score measures for our study of domain and this may be due to giving equal weights to bad as well as good models. So in the future we will try to perform the multi model ensemble by applying "super ensemble" method [6, 11]. The model errors could also be reduced by statistical correction methods by incorporating statistical relationship between predicted and observed anomalies. The most commonly used methods of statistical corrections are based on singular value decomposition (SVD) [12] based on canonical correlation analysis (CCA). Since it has been found that the results after error correction were not sensitive to choice of correction method [13] so any available error correction technique may be used.

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