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Impact of resolution and vertical coordinate on ETA model forecast over Indian region

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ABSTRACT
A version of Eta model is used to study the orography induced rainfall along the west coast of India. The model is integrated with Eta and Sigma as vertical coordinate in three horizontal resolutions (0.5 deg, 0.33 deg and 0.25 deg). The 1.5 deg grid point analyses of 25 July 1996, 0000 UTC and 1200 UTC are used as initial condition and twelve hourly analyses are used to update the boundary condition. The root mean square error and bias error of different prognostic fields are calculated to see the growth of errors with increasing horizontal resolution and for the different choice of vertical coordinate. The skill e. g. Equitable threat score (ETS) and Bias are calculated for different threshold values of precipitation. Experiments in general show qualitative and quantitative agreement with verification analyses. Skill of the model in forecasting precipitation for a threshold of 3 cm/day is found higher in case of Eta compared to Sigma for all the three chosen horizontal resolutions.

INTRODUCTION

The physiographical complexity of the west coast region with Western Ghat hill to the east and Arabian Sea to the west, makes it conducive for several meteorological systems to occur. One of these phenomena is the presence of off shore trough during southwest monsoon regime. This off shore trough often produces enhanced rainfall activity over the stations located near the wind ward side of the Western Ghat hill. Where as the lee side remains a rain shadow zone. Thus a prominent spatial variability in the precipitation pattern evolves in this region. The spatial variabilities are also seen among the stations in the wind ward side of the mountain range implying spatial heterogeneity of rainfall. Very little work has been done to study such phenomenon using numerical model. A variety of numerical models are available which generally use Sigma as the vertical coordinate. Experience shows that conventional sigma coordinate limited area models do not properly simulate the meteorological fields due to errors arising in the computation of pressure gradient forces in the regions of steep topography (Janjic 1977; Mesinger; 1982). To overcome this problem arising due to steep orography Eta model has been developed (Mesinger 1985, Mesinger & Janjic 1986). Eta model is a widely used regional model and has been extensively applied operationally in many mid-latitude countries with good forecast skill (Mesinger et al. 1990). Mesinger & Black (1992) first showed a comparative study of Eta and Sigma coordinate over United States. Mesinger, Black & Baldwin (1996) in another study has shown the impact of resolution and vertical coordinate on the skill of precipitation forecast of Eta model. Paccagnella et al. (1992) carried out a study for Northern Italy with similar objective using Eta model. Driven by this idea, it is intended to study the impact of increased horizontal resolution and different choice of vertical coordinates namely Eta and Sigma, on the prediction of the meteorological parameters associated with the monsoonal flow over West Coast of Peninsular India. The Eta model is chosen here to study the synoptic/ subsynoptic orography induced weather of West Coast of India.

DATA USED

The twelve hourly gridded analyses provided by Global Data Assimilation System (GDAS) of National Centre for Medium Range Weather Forecasting (NCMRWF), New Delhi for the period of 25 July 1996 to 28 July 1996 are used as the model input. Model boundary condition is updated twelve hourly using this analyses. Albedo, sea surface temperature (SST) and soil wetness are taken from National Centre for Environmental Prediction (NCEP) climatology. Station reports of twenty four hour accumulated rainfall valid for 0300 UTC of each day are provided by India Meteorological Department (IMD). The routine IMD station reports are augmented by the state agricultural station's raingauge reports with the purpose of increasing the number observations within each model grid.

SYNOPTIC FEATURES

During 25 July 1996 to 28 July 1996, the major synoptic systems are, presence of west coast trough in the surface analyses with vertical extension upto 1.5 km above sea level and a Deep Depression crossing Indian land mass in a northwestward direction (IDWR). All these perturbations in the large-scale flow, act in favour of establishing the southwest monsoonal flow which in turn enhances the rainfall activity over the entire country and especially over the west coast. The recorded rainfall over west coast has been found to have large spatial variability with some stations receiving very heavy (> 5cm/day) rainfall.

MODEL DESCRIPTION

The Eta (h) coordinate following Mesinger (1984) is defined as,

$$\eta = \frac{p - p_{top}}{p_{sfc} - p_{top}} \frac{p_{ref}(Z_{sfc}) - p_{top}}{p_{ref}(0) - p_{top}}$$

Where p_{top} = Pressure at the top of the domain
p = Pressure at any point
p_{sfc} = Surface pressure at $(x, y, z=Z_{sfc})$
$p_{ref}(Z) = p_{ref}(0)[1-Z/T]^{-g/R\Gamma}$
$g = 9.81\ m/s^2$
$R = 287.04\ JK^{-1}Kg^{-1}$
$T = 288\ K$
$\Gamma = 0.0065Km^{-1}$

The above expression can be written as $\eta = \sigma\,\eta_s$

η_s = Eta at the surface

If the value of η_s is made unity i. e. $\eta_s = 1$, then η (Eta) becomes σ (Sigma) coordinate and the model with same code and same physics can be run in the sigma coordinate mode. Sigma coordinate is terrain following and therefore sigma levels gets congested near the steep terrain where as Eta levels are quasi-horizontal levels (Black 1994), coinciding with the chosen steps of the step mountain and thus do not tend to converge near the steep terrain. Thus it helps reducing the slope of the model levels near mountainous region. The surface heights Z_{sfc} are allowed to take only a discrete set of values in the case of step mountain. The chosen steps in meter for the present study are 140.0, 299.07, 477.36, 675.07, 892.5, 1130.01, 1388.02, 1667.09, 1967.82, 2290.97, 2637.38, 3008.06, 3404.16, 3827.04, 4278.28, 4759.73, 5273.56, 5822.4, 6409.32, 7038.15, 7713.509, 8441.239, 9228.77, 10085.84, 11025.54, 12066.21, 13234.77, 14573.39, 16154.43, 18120.35, 20828.23, 25915.93 respectively. The model is used with 32 vertical levels with top of the domain at 10 hPa. Eta model uses transformed rotational coordinate system to increase the stability irrespective of the shrinking of the latitudinal circle polewards. Model runs on equal latitude and longitude grid. Arakawa-E type of grid staggering is used in the model. Silhouette type of topographic averaging is used. Mellor-Yamada level 2.5 closure is used for PBL and Mellor-Yamada level 2.0 closure is used for surface layer. The model's simulation of surface processes include the calculation of surface temperature, specific humidity and the accumulation/loss of water (Black 1988) using a two layer soil model. Large scale precipitation is estimated using cumulus parameterization of Betts (1986). Shallow and deep convection are incorporated by modified Betts & Miller (1986) scheme by Janjic (1994). The routines which incorporate the effects of short wave and long wave radiation are by Davies (1982) and Harshavardhan & Corsetti (1984). The model is integrated for 84 hours and the domain covers 2N to 22N and 65E to 85E. The centre of the domain is fixed at 12N, 75E. For further detail on Eta model, studies of Mesinger (1973, 1977, 1985); Mesinger et al. (1988), Janjic (1984, 1990, 1994); Janjic, Mesinger & Black (1995); Lazic & Telenta (1990) ; Black (1988, 1994) can be referred. The present study uses 1995 workstation version of ETA model.

Table 1. Details of experiment conducted with different horizontal and vertical coordinate (Eta and Sigma).

Exp Name	Vertical Coordi-nate	Horizontal Resolution (Deg)	No. of vertical levels	Intial Condition (25July1996) time in UTC
E50L3200	ETA	0.50	32	0000
E33L3200	ETA	0.33	32	0000
E25L3200	ETA	0.25	32	0000
S50L3200	Sigma	0.50	32	0000
S33L3200	Sigma	0.33	32	0000
S25L3200	Sigma	0.25	32	0000
E50L3212	ETA	0.50	32	1200
E33L3212	ETA	0.33	32	1200
E25L3212	ETA	0.25	32	1200
S50L3212	Sigma	0.50	32	1200
S33L3212	Sigma	0.33	32	1200
S25L3212	Sigma	0.25	32	1200

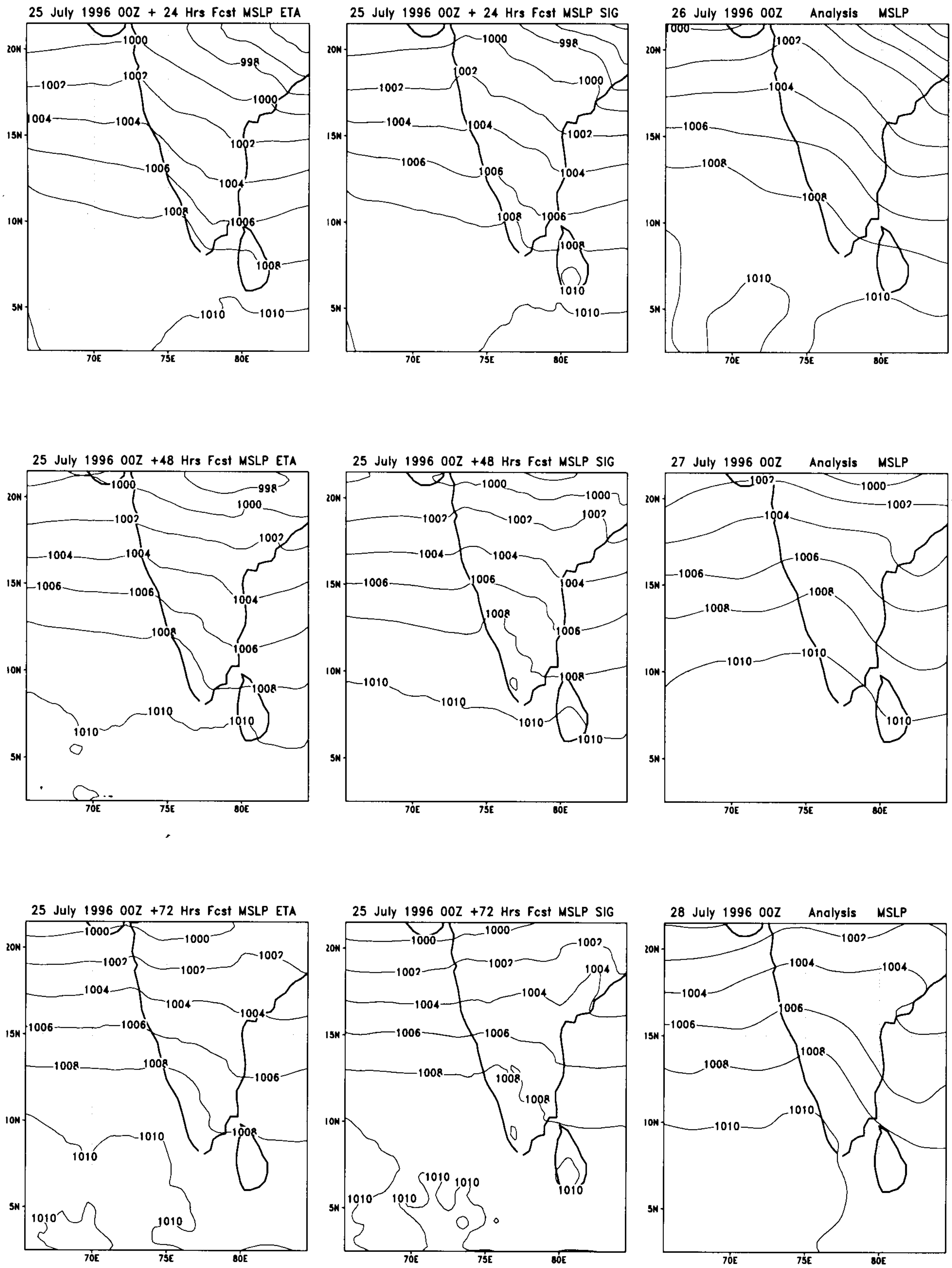

Figure 1. Eta model forecast (Eta and Sigma mode) and analysis of mean sea level pressure (hPa) for 0.25 Deg horizontal resolution.

EXPERIMENTS

Eta model is integrated for 84 hours with Eta and Sigma mode using 25 July 1996, 0000 UTC and 1200 UTC initial condition. This has produced four sets of forecast. The model produced 24 hour accumulated rainfall is verified with 0300 UTC rainfall observation. The West Coast and surrounding areas are considered in the model domain to study the spatial variability of the precipitation which arises mainly due to the north-south orientation of Western Ghat hill. During the south-west monsoon regime, south-westerly wind prevails in the lower troposphere and the Western Ghat hill stands as a barrier to it. The windward side of the hill gets more rainfall than lee side but large variability is seen even in the rainfall at windward side. This possibly happens depending upon the extension of off shore trough. The details of numerical experiments carried out, are given in Table 1. To estimate the accuracy of the model forecast, root mean square (rms) error and bias of different meteorological parameters are calculated at three representative levels. Further to study the skill of the model in forecasting such heterogeneous precipitation pattern of west coast, skill scores namely equitable threat score (ETS) and bias are computed for the three horizontal resolutions 0.5 deg, 0.33 deg and 0.25 deg with Eta and Sigma as vertical coordinate.

DISCUSSION

The rms error and bias error of wind, geopotential height and temperature for 24, 48 and 72 hour forecast at grid resolutions of 0.5, 0.33 and 0.25 deg are shown in Table 2, Table 3 and Table 4 respectively. The rms errors and bias are calculated for three representative levels 850 hPa, 500 hPa and 200 hPa representing the lower, middle and upper troposphere. The rms errors are calculated as follows :

$rms(x) = [1/N \Sigma(X_f - X_a)^2]^{0.5}$

for wind

$rms(x) = [1/N \Sigma \{(U_f - U_a)^2 + (V_f - V_a)^2\}]^{0.5}$

The bias (B) are calculated as follows

$B(x) = 1/N \Sigma (X_f - X_a)$

For wind

$B(x) = [1/N \{\Sigma (U_f - U_a)^2 + \Sigma (V_f - V_a)^2\}]^{0.5}$

Where X_f = Forecasted parameter

X_a = Analysed parameter

N = Total number of forecast of a particular variable

The rms errors for wind, geopotential and temperature at the three representative levels are found to be in general lesser in Eta mode than Sigma mode for all the three horizontal resolutions. However the rms error in general has increased for each variable with the increase of horizontal resolution e. g. the rms error for wind at 850 hPa in 0.5 deg grid, with Eta as vertical coordinate is 3.1 (Table 2), for 0.33 deg resolution, the error is 3.3 (Table 3) and that for 0.25 deg, the error becomes 3.5 (Table 4). Similar trend is seen for the geopotential and temperature also for both the vertical coordinates (Eta and Sigma).

So far as growth of error with time is concerned, it can be seen from Table 2, Table 3 and Table 4 that errors have not increased remarkably. The 200 hPa wind forecast in 0.5 deg grid (Table 2) shows reduction of rms error from 3.5 at 24 hour forecast to 2.0 at 48 hour forecast and finally becomes 3.2 in the 72 hour forecast (for Eta mode). Similar variation is seen for 200 hPa wind forecast in Sigma mode of 0.5 deg grid. In case of 850 and 200 hPa temperature forecast, rms errors have consistently decreased from 24 to 72 hour forecast for all the resolutions and for both the vertical coordinates. However the 500 hPa temperature forecast has shown marginal increase in rms error for 0.33 and 0.25 deg grid.

The bias of each forecast variable with respect to its value in the corresponding analysis is shown in Table 2, 3, and 4 within bracket as bold numbers. The Eta mode run has shown lesser positive bias error in all the resolutions for 850 and 200 hPa wind compared to that of Sigma for 24, 48 and 72 hour forecast. The forecast of 500 hPa wind field incase of Eta mode has shown marginally larger positive bias than that of Sigma e. g. bias for 500 hPa wind in Eta mode at 0.5 deg resolution is 1.1 whereas that for Sigma, it is 1.0 in the 24 hour forecast (Table 2). From the analysis of the bias error of wind for Eta and Sigma, it can be said that the wind field simulation by Sigma mode run is much stronger than the corresponding analyses and in comparison to Eta simulation. So far as bias error of temperature is concerned, Eta and Sigma both have persistently shown negative bias for temperature forecast at 200 hPa, however the absolute value of bias is less in Eta than Sigma. The negative temperature bias suggests that model simulated upper troposphere is cooler than analyses and extent of cooling is more in Sigma than Eta. Bias of temperature at 850 and 500 hPa in Eta and Sigma mode are lying within 0.5 to 0.8 deg celcius for all the three resolutions. This implies that lower and middle troposphere of the model atmosphere has a warm bias and thus can have more thermal instability than the observation.

The three day forecasts of mean sea level pressure (mslp) in Eta and Sigma mode for 0.5, 0.33 and 0.25 deg horizontal resolution are analysed. Here only the 72 hour mslp forecast by Eta and Sigma and

Table 2. Comparison of rms and bias error of Wind, Geopotential height and Temperature forecast for 0.50 Deg resolution.

RMS Error and Bias error (within bracket) for 24 hour forecast

.	ETA (0.5 Deg)			SIGMA (0.5 Deg)		
	850hPa	500hPa	200hPa	850hPa	500hPa	200hPa
Wind	3.1 (**1.8**)	2.8 (**1.1**)	3.5 (**1.1**)	3.4 (**2.0**)	2.7 (**1.0**)	4.2 (**1.3**)
Geo Potential	6.3 (**-3.8**)	7.2 (**6.2**)	12.2 (**-6.8**)	6.8 (**-4.1**)	6.7 (**5.5**)	13.0 (**-8.8**)
Temperature	0.9 (**0.8**)	1.0 (**0.4**)	1.6 (**-1.1**)	1.0 (**0.8**)	1.0 (**0.8**)	1.9 (**-1.6**)

RMS Error and **Bias error** (within bracket) for 48 hour forecast

.	ETA (0.5 Deg)			SIGMA (0.5 Deg)		
	850hPa	500hPa	200hPa	850hPa	500hPa	200hPa
Wind	3.1 (**2.2**)	3.0 (**1.4**)	2.0 (**0.3**)	3.4 (**2.3**)	2.8 (**1.2**)	3.1 (**0.9**)
Geo Potential	7.5 (**-5.9**)	4.0 (**-1.7**)	11.8 (**10.8**)	7.7 (**-6.5**)	4.3 (**-2.5**)	13.0 (**11.1**)
Temperature	0.9 (**0.8**)	0.8 (**0.4**)	1.2 (**-1.1**)	0.9 (**0.7**)	0.8 (**0.5**)	1.5 (**-1.3**)

RMS Error and **Bias error** (within bracket) for 72 hour forecast

.	ETA (0.5 Deg)			SIGMA (0.5 Deg)		
	850hPa	500hPa	200hPa	850hPa	500hPa	200hPa
Wind	3.8 (**2.4**)	3.3 (**1.9**)	3.2 (**1.9**)	3.9 (**2.4**)	3.4 (**1.8**)	3.9 (**2.3**)
Geo Potential	4.4 (**1.0**)	3.7 (**0.8**)	11.8 (**-5.9**)	4.3 (**0.7**)	3.7 (**0.5**)	11.0 (**-7.4**)
Temperature	0.7 (**0.5**)	0.7 (**0.1**)	1.1 (**-1.0**)	0.8 (**0.6**)	0.7 (**0.0**)	1.6 (**-1.4**)

Table 3. Comparison of rms and bias error of Wind, Geopotential height and Temperature forecast for 0.33 Deg resolution.

RMS Error and Bias error (within bracket) for 24 hour forecast

.	ETA (0.33 Deg)			SIGMA (0.33 Deg)		
	850hPa	500hPa	200hPa	850hPa	500hPa	200hPa
Wind	3.3 (**1.8**)	2.9 (**1.1**)	3.7 (**1.1**)	3.6 (**2.2**)	2.8 (**1.1**)	4.3 (**1.2**)
Geo Potential	6.5 (**-4.1**)	6.9 (**5.9**)	12.0 (**-5.4**)	6.6 (**-3.5**)	6.7 (**5.3**)	13.9 (**-9.1**)
Temperature	1.0 (**0.8**)	0.9 (**0.7**)	1.7 (**-1.4**)	1.0 (**0.8**)	0.9 (**0.7**)	1.8 (**-1.5**)

RMS Error and **Bias error** (within bracket) for 48 hour forecast

.	ETA (0.33 Deg)			SIGMA (0.33 Deg)		
	850hPa	500hPa	200hPa	850hPa	500hPa	200hPa
Wind	3.0 (**1.7**)	2.7 (**1.1**)	2.8 (**0.4**)	3.5 (**2.1**)	2.8 (**1.3**)	3.7 (**0.9**)
Geo Potential	9.5 (**-8.9**)	7.3 (**-6.0**)	25.7 (**24.7**)	10.2 (**-8.8**)	8.2 (**-6.9**)	26.5 (**24.6**)
Temperature	0.9 (**0.7**)	1.2 (**0.7**)	1.3 (**-1.1**)	1.0 (**0.7**)	1.3 (**0.9**)	1.5 (**-1.3**)

RMS Error and **Bias error** (within bracket) for 72 hour forecast

.	ETA (0.33 Deg)			SIGMA (0.33 Deg)		
	850hPa	500hPa	200hPa	850hPa	500hPa	200hPa
Wind	3.8 (**2.1**)	3.7 (**1.8**)	4.0 (**1.8**)	4.1 (**2.1**)	3.7 (**1.7**)	3.9 (**1.7**)
Geo Potential	4.1 (**0.4**)	6.2 (**-3.5**)	14.4 (**10.8**)	4.8 (**-1.1**)	6.3 (**-3.3**)	14.9 (**9.3**)
Temperature	0.8 (**0.6**)	1.3 (**-0.8**)	1.0 (**-0.8**)	0.9 (**0.7**)	1.2 (**-0.5**)	1.2 (**-0.9**)

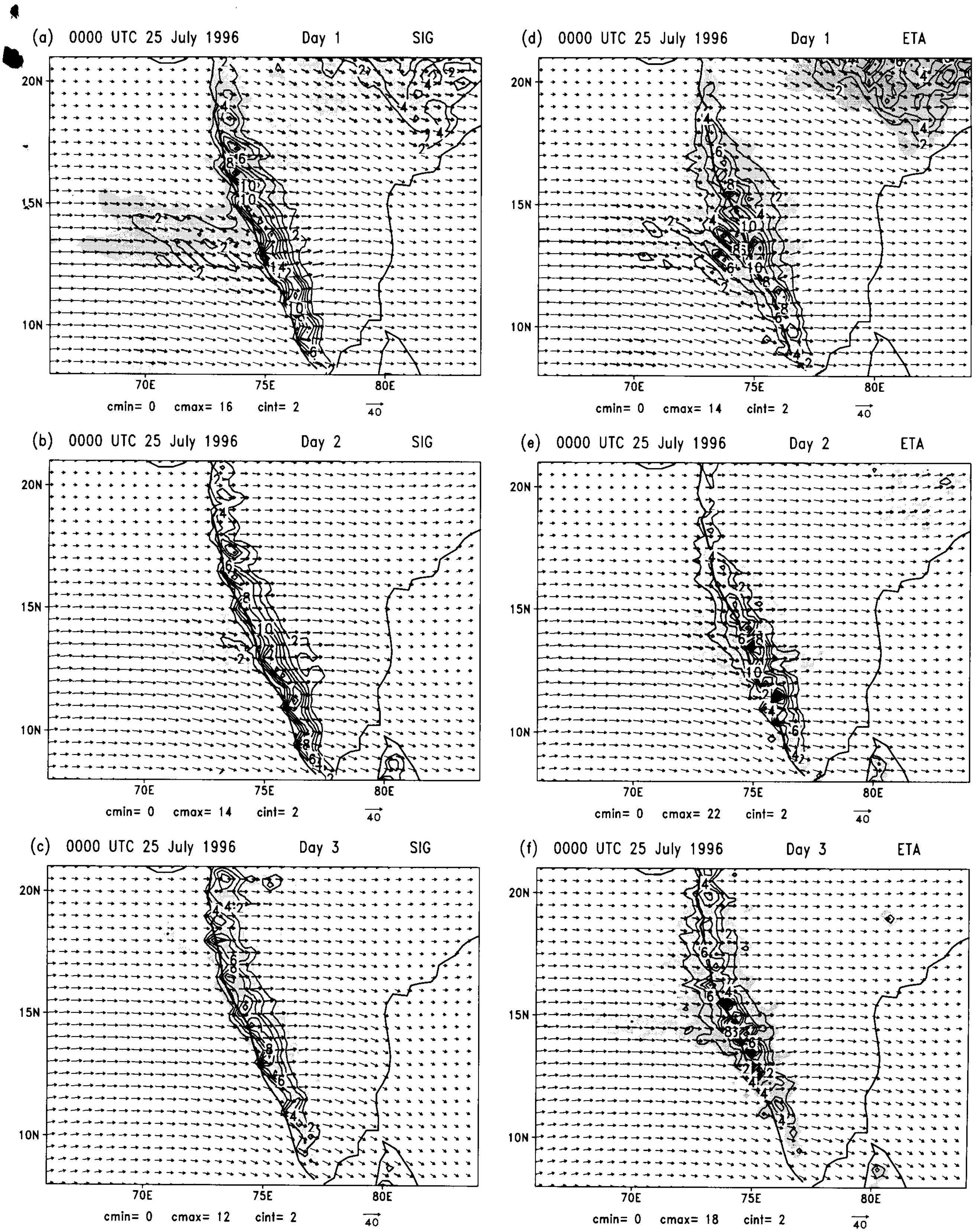

Figure 2. Predicted 850 hPa wind (m/s) and 24 hour rainfall (cm/day) for 0.25 Deg resolution; Input: 0000 UTC 25 July.

Table 4. Comparison of rms and bias error of Wind, Geopotential height and Temperature forecast for 0.25 Deg resolution.

RMS Error and Bias error (within bracket) for 24 hour forecast

	ETA (0.25 Deg)			SIGMA (0.25 Deg)		
	850hPa	500hPa	200hPa	850hPa	500hPa	200hPa
Wind	3.5 (**1.9**)	2.9 (**1.2**)	4.0 (**1.2**)	3.7 (**2.1**)	2.8 (**1.1**)	4.2 (**1.1**)
Geo Potential	6.8 (**-4.1**)	6.6 (**5.5**)	12.8 (**-6.4**)	6.6 (**-3.5**)	6.8 (**5.3**)	14.8 (**-6.9**)
Temperature	1.0 (**0.9**)	0.9 (**0.6**)	1.7 (**-1.4**)	1.1 (**0.9**)	0.9 (**0.6**)	1.7 (**-1.4**)

RMS Error and **Bias error** (within bracket) for 48 hour forecast

	ETA (0.25 Deg)			SIGMA (0.25 Deg)		
	850hPa	500hPa	200hPa	850hPa	500hPa	200hPa
Wind	3.02 (**1.9**)	2.7 (**1.2**)	2.8 (**0.7**)	3.6 (**2.5**)	3.1 (**1.6**)	3.2 (**1.1**)
Geo Potential	9.4 (**-4.2**)	7.2 (**-7.8**)	24.4 (**23.0**)	6.7 (**-1.3**)	3.6 (**-1.6**)	7.3 (**-0.3**)
Temperature	1.0 (**0.8**)	1.2 (**0.6**)	1.3 (**-1.1**)	1.1 (**0.1**)	0.8 (**0.1**)	1.4 (**-1.5**)

RMS Error and **Bias error** (within bracket) for 72 hour forecast

	ETA (0.25 Deg)			SIGMA (0.25 Deg)		
	850hPa	500hPa	200hPa	850hPa	500hPa	200hPa
Wind	4.0 (**2.1**)	3.9 (**1.8**)	4.1 (**1.8**)	4.2 (**2.3**)	3.4 (**1.7**)	3.5 (**2.0**)
Geo Potential	4.4 (**-0.8**)	7.0 (**-4.8**)	17.1 (**14.1**)	5.4 (**-1.9**)	5.9 (**-4.1**)	12.4 (**9.8**)
Temperature	0.9 (**0.6**)	1.3 (**-0.7**)	0.9 (**-0.7**)	0.9 (**0.7**)	1.0 (**0.6**)	1.4 (**-1.3**)

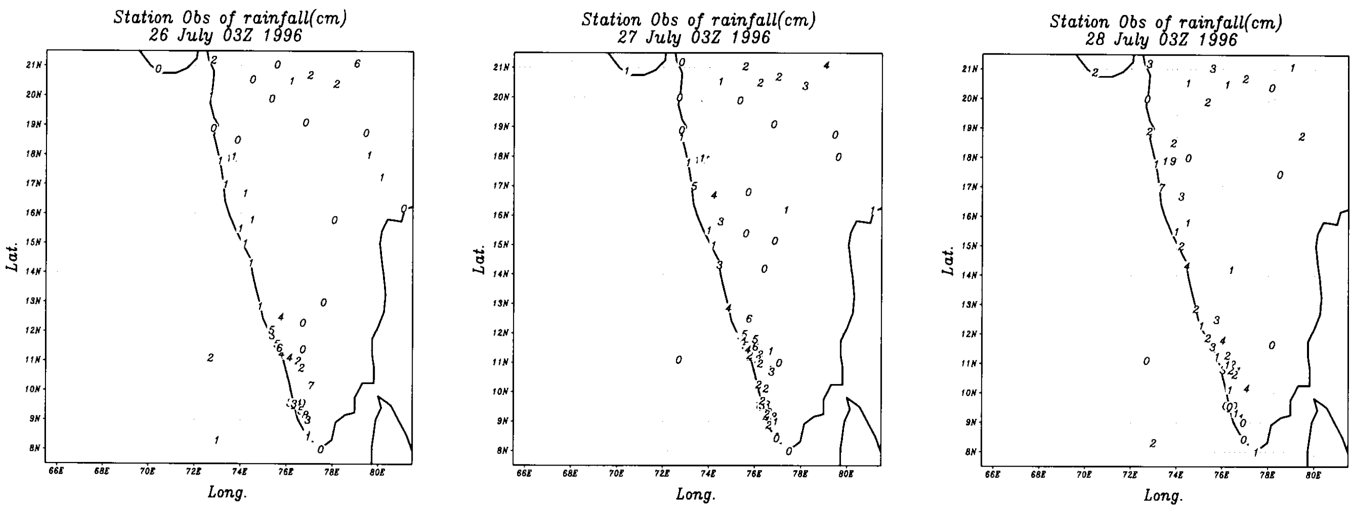

Figure 3. Station report of observed rainfall in cm for 26, 27 and 28 July 1996.

corresponding analyses for 0.25 deg grid resolution is shown in Fig 1. It can be seen from the isobar analyses (right panel, Fig1) of 26, 27 and 28 July that a weak off shore trough persists along the west coast. The Sigma forecast (middle panel, Fig 1) and the Eta forecast (left panel, Fig 1) in general have been able to show a weak trough in the west coast in 24 and 48 hour but in 72 hour forecast the trough becomes less marked in case of Eta. However a week trough is seen to persist in 72 hour forecast of Sigma. In comparing the predicted mslp by three different horizontal resolutions, it is found that the model has predicted the off shore trough along the west coast reasonably well (plot for 0.5 and 0.33 deg are not shown here) till 48 hours of forecast by both Eta and Sigma and on 72 hour forecast a weak trough is seen in Sigma mode run of the model with 0.5 deg resolution.

The predicted wind fields at 850 hPa and twenty four hour accumulated forecast rainfall with 0.25 deg resolution are shown in Fig 2. This is compared with predicted 850 hPa wind field and accumulated precipitation by 0.5 and 0.33 grid (figures not shown). The corresponding observed twenty four hour accumulated rainfall from IMD station rain gauges valid for 0300 UTC of 26, 27 and 28 July 1996 are plotted in Fig 3. In comparing the results with the three mentioned horizontal resolutions, the rainfall activity is found to decrease in the 72 hour forecast with respect to the realized distribution (Fig 3). This reduction in rainfall activity appears to be consistent with the weakening of the off shore trough in the 72 hour forecast. However comparing the Sigma and Eta prediction, it appears that the rainfall forecast in Sigma mode for the third day (28 July) is more than the rainfall forecast in Eta mode for all the three horizontal resolutions. This is due to the fact that in Sigma mode mslp forecast, a weak off shore trough is present in 72 hour forecast in contrast to Eta. The horizontal inhomogeneity of west coast precipitation is prominently simulated by the model. Qualitative comparison of simulated spatial distribution of rainfall further suggests that larger area of heavy rainfall (~ 6 cm) is predicted by Sigma mode run of the model compared to Eta.

To estimate the sensitivity of horizontal resolution and different vertical coordinates in a quantitative manner, Equitable threat score (ETS) and bias are calculated. The predicted rainfall accumulated for last 24 hour in both (Eta and Sigma) mode is verified for the periods ending 27 July 0300 UTC and 28 July 0300 UTC. Mainly to incorporate the 0300 UTC prediction, the model is integrated for 84 hours. Four sets of forecast comprising 0000 and 1200 UTC initial condition in Eta and 0000 and 1200 UTC in Sigma are considered for the calculation of skill scores. The steps in calculating precipitation skill scores are as follows:

- The grid points where atleast one rainfall observation is reported, are selected and rest are not considered for the skill calculation. Fig 4 shows the distribution of grid boxes and the stations within each grid box for 0.25 deg grid.
- These rainfall observations within each grid box are averaged (arithmetic) so as to get a single representative value of rainfall for each grid.
- This box averaged rainfall is then used to verify the model predicted 24 hour accumulated rainfall for all such boxes.

ETS and bias (B) are calculated following Mesinger (1996). ETS is defined as follows

$$ETS = \frac{H - E}{F + O - H - E}$$

Where

H: Number of Hits (forecast matching observations)

F: Total number of forecast

O: Total number of observation

E: Expected number of hits for a random forecast

$$E = \frac{F.O}{N}$$

N: Total number of points in the verification domain.

In descriptive terms ETS implies the fractional number of correctly forecast points of a precipitation event above random, normalized by the total number of observed and/or forecast points, also above the number of hits in a random forecast.

The bias score is defined as follows:

$$B = \frac{F}{O}$$

ETS is zero for a random forecast of any areal coverage and one for a perfect forecast. Bias score for precipitation suggest whether the model is forecasting larger or lesser area of rainfall compared to observation. Bias for precipitation exceeding one would mean model having a moist bias. The ETS and bias for the verification period ending 27 July 0300 UTC and 28 July 0300 UTC are shown in Fig 5. The threshold values of rainfall are mentioned in abscissa. The ETS for 0.5 deg grid resolution is higher for all the threshold values of rainfall in comparison to Sigma, however the ETS for Eta and Sigma has become coincident for threshold of 3cm/day and 5cm/day. But with the increase of grid resolution ETS score of ETA becomes better than Sigma e. g. ETS for threshold rainfall of 5cm/day in 0.25 deg grid is 0.1 for Eta and is less than 0.05 for Sigma. Thus it can be seen that even for a threshold of 5cm/day the skill of precipitation forecast in 0.25 deg grid is considerably high in case of ETA mode. It can be seen from Fig 5 that Eta has shown considerably high forecast skill for predicting low as well as high threshold values of rainfall. This suggests that Eta is able to predict light as well as heavy rainfall events with better accuracy than Sigma.

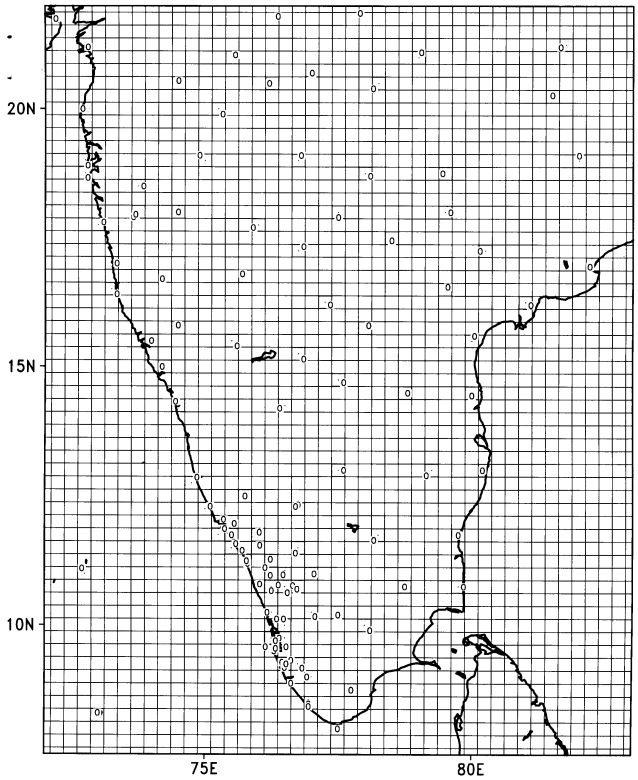

Figure 4. Location of raingauge stations and 0.25 Deg Eta grid used for calcualtion of Skill scores.

So far as bias of 0.5 deg grid is concerned, Eta is showing a steady bias varying between 1 and 2 for threshold rainfall range between 0.25 cm/day to 5cm/day. Sigma on the contrary shows large moist bias in the precipitation forecast which has reached a value 4.0 for the threshold 5cm/day. For 0.33 deg grid resolution also Eta has shown lesser bias than Sigma at all the threshold. However the bias is found to increase for 0.33 deg resolution in Eta and Sigma mode with the increase of threshold values of rainfall. For 0.25 deg grid resolution, the bias of Eta and Sigma are not much different from each other. Both are showing large moist bias and the bias is increasing for both the mode with the increase of threshold rainfall. Thus it is seen that Eta is showing better skill as reflected by ETS compared to Sigma for all the three resolutions in general. Where as in case of bias the tendency of the model in forecasting larger area of heavy rainfall is seen for Eta and Sigma and for 0.25 deg grid resolution in particular. This tendency of large moist bias could be controlled by tuning some of the convective parameterization scheme. The number of observations are not uniform over the verification domain, this can also adversely affect the forecast skill by increasing the number of false alarm.

CONCLUSIONS

The impact of horizontal resolution of the Eta model and the suitability of vertical coordinate between Eta and Sigma in simulating heavy precipitation over Western Ghat region of Peninsular India has been investigated. It is seen from the present study that the rms error of the predicted fields like wind, geopotential height and temperature are less in general for the Eta mode run of the model than Sigma. It has also been noted that the rms error has increased marginally with the increase of horizontal resolution, however it has not increased remarkably with time of integration. Both Eta and Sigma mode run of the model has shown positive bias for wind and temperature in the lower troposphere suggesting a warmer model atmosphere with stronger wind field strength compared to the analyses. In case of bias also the magnitude is less in case of Eta than Sigma. The lower tropospheric geopotential has shown a negative bias for Eta and Sigma that implies the intensity of the system is more in the forecast than the analyses. The mslp forecast by Eta and Sigma have shown weak offshore trough in the 24 and 48 hour forecast. The 72 hour forecast of Eta has not shown any trough in the 0.5 or 0.25 deg resolution however the Sigma forecast has shown a weak trough in the 72 hour forecast in 0.5 deg resolution. The skill of precipitation forecast measured in terms of ETS clearly suggests that Eta mode has predicted low and high magnitude of rainfall with better accuracy than Sigma. The skill of Eta in predicting 5cm/day threshold precipitation has not deteriorated from its value 0.1 for 0.5 deg, 0.33 and 0.25 grid whereas the skill of Sigma has remarkably deteriorated from 0.1 to less than 0.05. The bias for precipitation has increased with the increase of horizontal resolution for Eta and Sigma and this suggests that in both the modes there is a tendency for the model to predict larger area of precipitation or more number of moist grid points than the observation. This could be improved by suitable tuning of Cumulus parameterization scheme of the model. It can also be inferred that mere increase of horizontal resolution of the model may not necessarily improve the forecast in general and skill of precipitation forecast in particular.

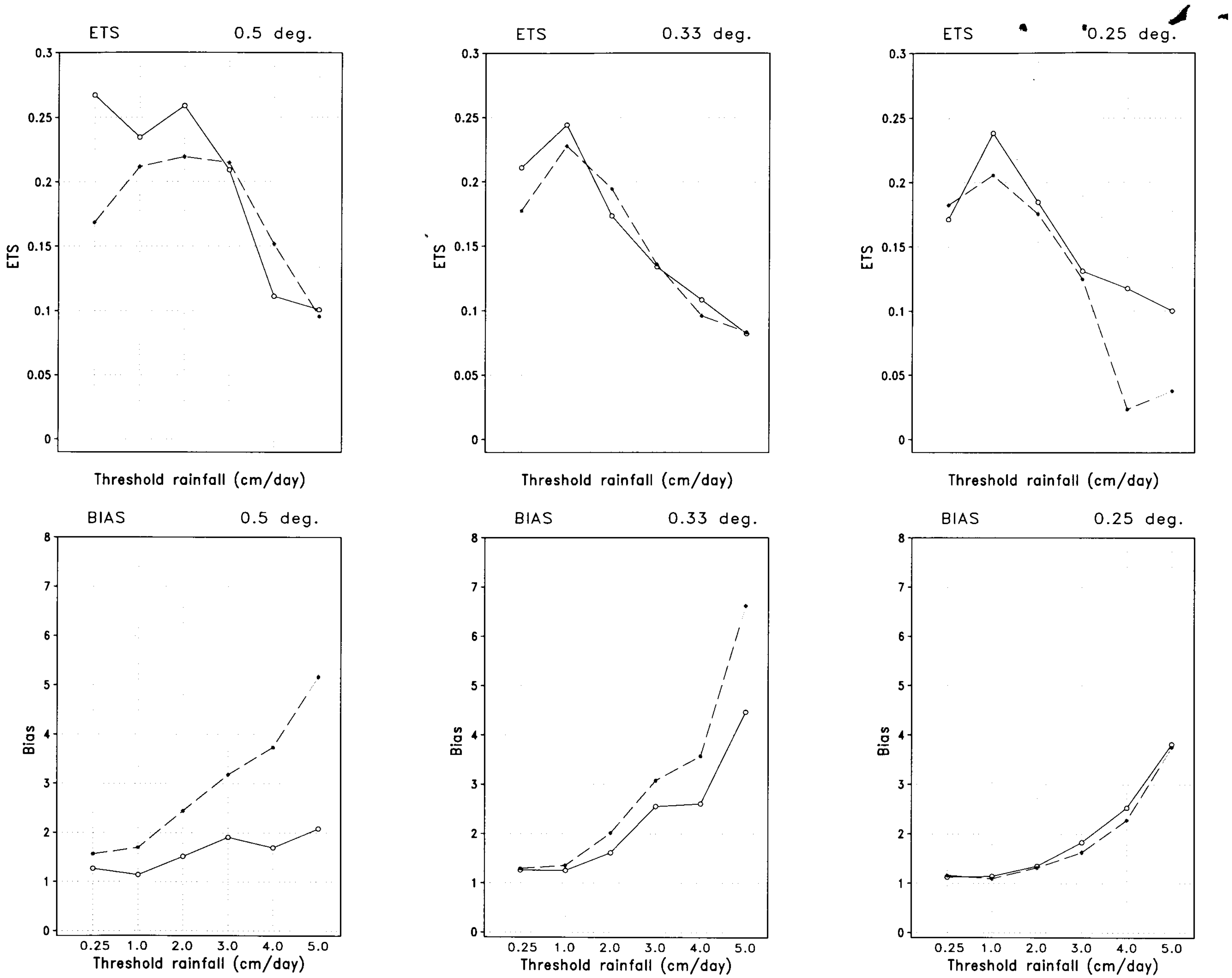

Figure 5. Equitable Threat Score (ETS) and Bias Score for Eta model at 0.5, 0.25 and 0.25 deg resolutions; Sum of 4 verifications ending 0300 UTC of 27 and 28 July 1996. Eta Mode (Solid lines) and Sigma Mode (dashed lines)

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