Mesoscale forecasts with Eta model over Indian region

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NCEP's mesoscale Eta model (Workstation Version 0.2) which was released in March 2000 has been installed on a SGI-Origin 200 workstation at National Centre for Medium Range Weather Forecasting (NCMRWF). The analysis and forecasts of the operational global spectral model (T80L18) are used as the initial and boundary conditions for the Eta model runs. Since 1 January 2002, the Eta model is being run for 72 h daily and the model forecasts are displayed on the NCMRWF website (www.ncmrwf.gov.in). The Eta model forecasts for a few recent cases of monsoon systems are discussed in this study. In general, it is found that Eta model forecasts of the position and intensity of the weather systems are in reasonable agreement with the observations. Furthermore, it is found that the Eta model gives better orography-induced rainfall. Impact of model's horizontal resolution on the prediction of a monsoon system is also studied. Finally, the performance of the Eta model for the month of June 2002 is evaluated.

THE National Centers for Environmental Prediction (NCEP), USA developed a step-mountain eta (η) coordinate model, generally known as the Eta model, and was made operational in 1993 (ref. 1). A workstation version of Eta model (Version 0.2) which was released in March 2000 has been installed on a SGI-Origin 200 workstation at NCMRWF[2–5]. The analysis and forecasts of the operational global spectral model (T80L18) are used as the initial and boundary conditions for the Eta model runs. Since 1 January 2002, the Eta model is being run for 72 h daily and the model forecasts are displayed on the NCMRWF website (www.ncmrwf.gov.in).

Brief description of the Eta model

The Eta model is a hydrostatic mesoscale weather forecast model with an accurate treatment of complex topography using eta (η) vertical coordinate system and step-like mountains[6], which eliminates errors in computation of pressure gradient force over steeply sloped terrain present in sigma (σ) coordinate[7] system. The model version used here follows that described by Black[1] and Mesinger[8]. The model employs a semi-staggered Arakawa E-grid in which wind points are adjacent to the mass points[9], configured in rotated spherical coordinates. The mesoscale Eta model is run operationally with a horizontal grid spacing of 48 km and 38 vertical levels, with layer depths that range from 20 m in the planetary boundary layer to 2 km at 50 mb. The model top is at 25 hPa. Split explicit time differencing is used with a time step of 120 s. Spatial differencing is done with a conserving Arakawa type scheme[10]. The model's step mountains are derived using the official United States Geological Survey (USGS) topographical data.

The model physics as described by Janjic[11] includes a modified Betts-Miller scheme for deep and shallow convection[11,12] and predicted cloud water/ice[13]. The GFDL scheme is used for radiation[14,15]. Free atmospheric turbulent exchange above the lowest model layer is computed using a Mellor-Yamada level 2.5 closure[1] and the surface layer similarity functions are derived from Mellor-Yamada level 2.0 closure[16]. A viscous sub-layer is used over water surfaces[11]. The land surface scheme is a version of the OSU scheme modified by Chen *et al.*[17]. A more detailed description of the model as implemented at NCMRWF can be found in refs 4, 5.

Model inputs

Initial and lateral boundary conditions

NCMRWF global (T80L18) analysis and 6 hourly global model forecasts are used for initial and lateral boundary conditions. Wind, temperature, relative humidity and geopotential height interpolated to 26 pressure levels at $1° \times 1°$ global resolution are used.

Time-dependent surfaces fields

Daily NCEP 1° global SST analysis, 47-km daily USAF global snow depth analysis and 23 km daily NESDIS/NOAA snow cover (NH only) downloaded from ftp.ncep.noaa.gov are used. Soil moisture at 2 layers (surface and root zone), soil temperatures at 3 layers and global sea–land–ice mask are extracted/generated from surface analysis of NCMRWF global analysis–forecast system.

Results and discussions

Select cases

The forecast results of (1) off-shore trough (19–21 June 2002) and (2) low pressure area (25–28 June 2002) cases are discussed below.

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Off-shore trough (19–22 June 2002). During this period a trough of low pressure prevailed off the west coast extending from Gujarat to Karnataka due to which spells of heavy rainfall migrated from south to north as can be seen from the description given below. The chief rainfall amounts (in cm) during this period were Karwar 13, Agumbe 9, Honavar 9, Mangalore 8, Kannur 7, Kozhikode 5, Panaji 4, Ratnagiri 3 on 19 June, Dahanu 6, Goa 6, Mumbai 4, Mangalore 4, Ratnagiri 3 on 20 June, Dahanu 25, Ratnagiri 22, Panaji 16, Honavar 14, Colaba 7, Alibag 6, Surat 4, Karwar 3 on 21 June and Alibag 8, Ratnagiri 7, Panaji 4, Surat 3, Honavar 3 on 22 June.

Figure 1 shows the Eta model forecasts for 1000 hPa winds and geopotential height valid for 20–22 June 2002. The signature of the trough of low pressure along the west coast can be seen in the wind field in all the 3 forecast charts. Figure 2 shows the Eta model rainfall forecasts valid for 20–22 June 2002. It can be seen that the northward progression of rainfall maxima along the west coast has been predicted quite

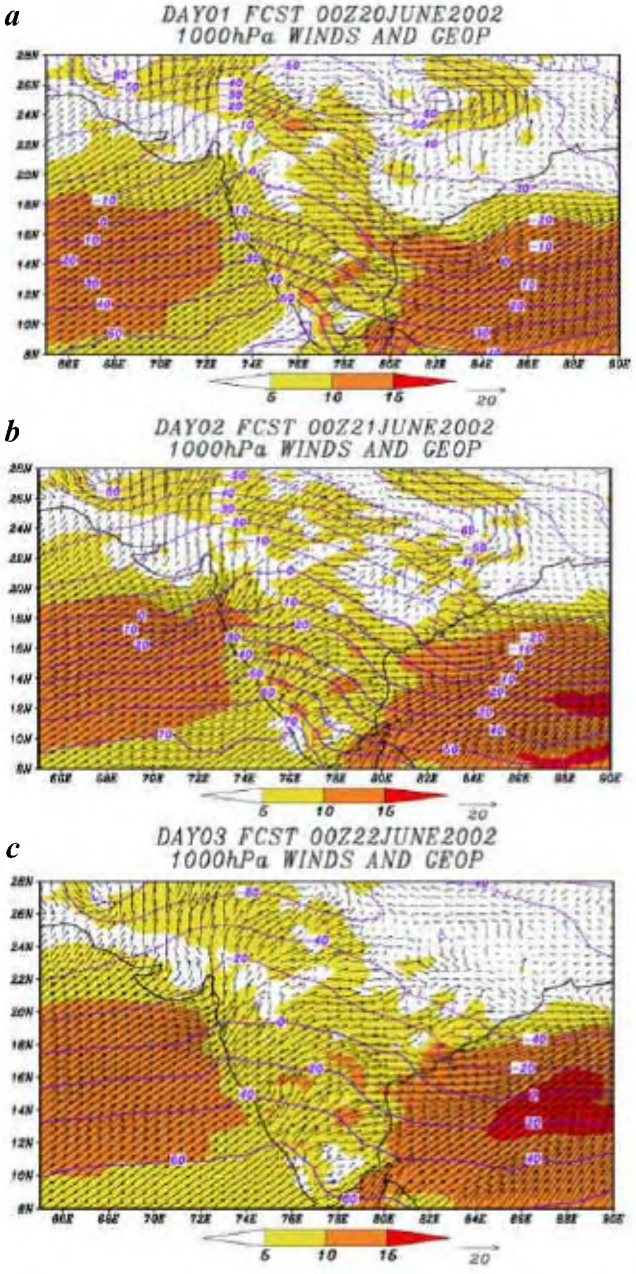

Figure 1. 1000 hPa wind (ms^{-1}) and geopotential (m) forecasts. ***a***, Day 1 valid for 20 June 2002; ***b***, Day 2 valid for 21 June 2002; ***c***, Day 3 valid for 22 June 2002. Note: Readers may obtain colour figures from the authors by sending an e-mail request to them.

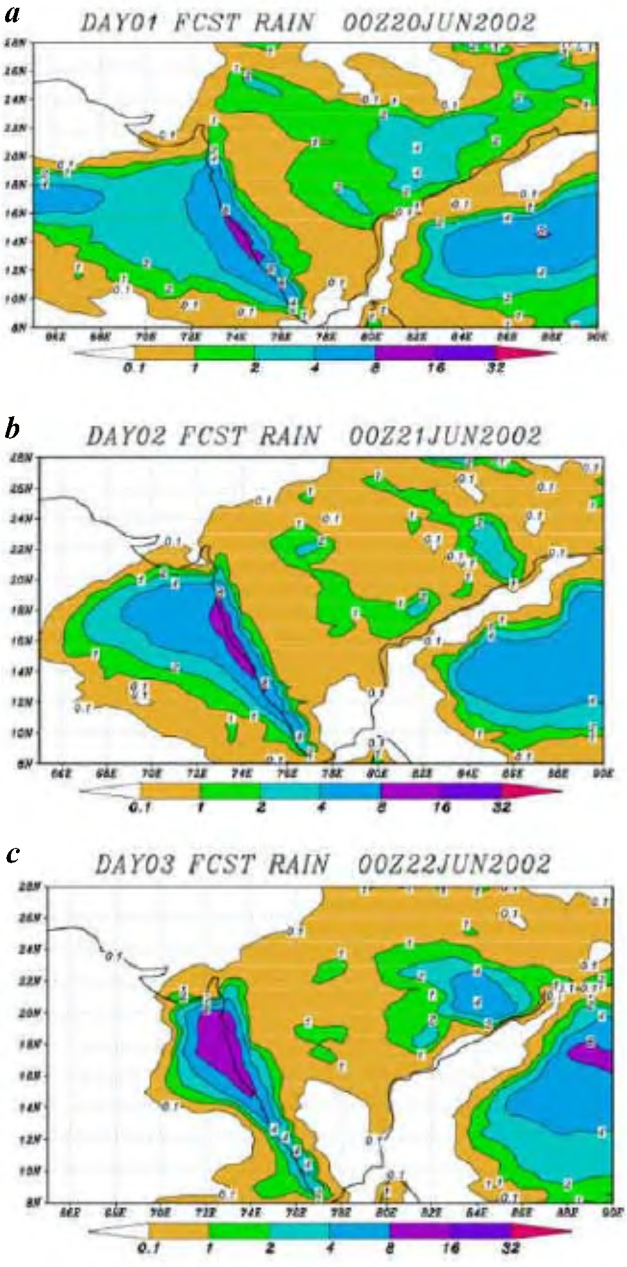

Figure 2. Rainfall forecasts. ***a***, Day 1 valid for 20 June 2002; ***b***, Day 2 valid for 21 June 2002; ***c***, Day 3 valid for 22 June 2002.

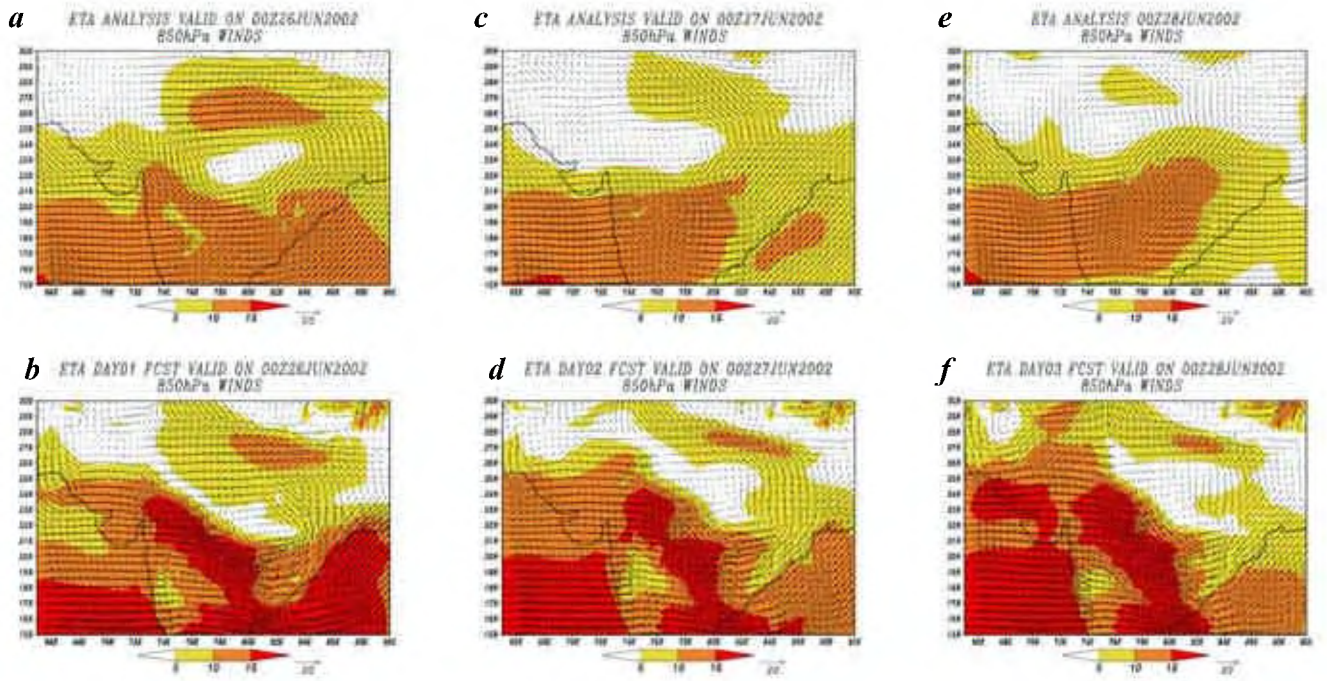

Figure 3. ***a***, 850 hPa wind analysis valid for 00z 26 June 2002; ***b***, Day 1 forecast valid for 00z 26 June 2002; ***c***, 850 hPa wind analysis valid for 00z 27 June 2002; ***d***, Day 2 forecast valid for 00z 27 June 2002; ***e***, 850 hPa wind analysis valid for 00z 28 June 2002; ***f***, Day 3 forecast valid for 00z 28 June 2002.

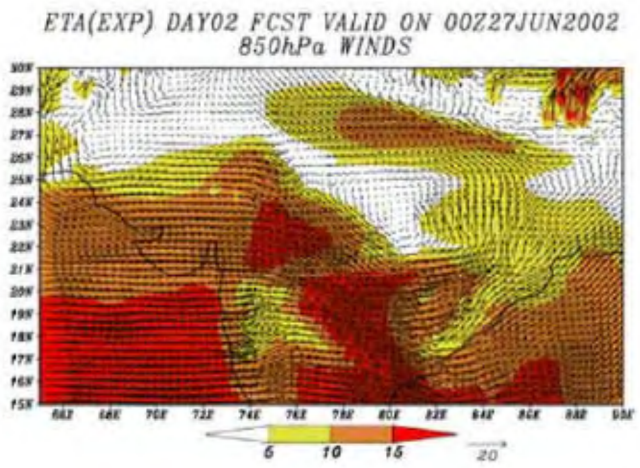

Figure 4. Day 2 forecast wind at 850 hPa from 32-km model.

well. However, model predicted rainfall maximas are much less than the observed amounts.

Low pressure area (25–28 June 2002). During this period a low pressure area (LPA) moved from Chattisgarh to Gujarat giving heavy rainfall over Vidarbha, West MP, Maharashtra and Gujarat. The chief rainfall amounts (in cm) were Vadodara 10, Aurangabad 7, Surat 7, Nasik 5, Akola 5 on 26 June, Pardi 61, Valsad 54, Lonavla 49, Dawadi 43, Shirgaon 36, Surat 15, Mahabaleshwar 12, Nasik 10, Bhavnagar 9 on 27 June and Bhavnagar 43, Vadodara 11, Rajakot 6, Porbunder 4, Mangalore 2 on 28 June.

Figure 3 shows the 850 hPa wind analysis for 26–28 June 2002 and Eta model forecasts valid for the same period. The westward movement of the LPA can be clearly seen in the analysis charts (Figure 3 *a*, *c*, *e*), however, in the model forecasts (Figure 3 *b*, *d*, *f*) the westward movement is not predicted well. The reason for the model's failure could be due to the overprediction of the monsoon winds south of the LPA and generation of a ridge west of the system.

High resolution experiment. Eta model is currently run operationally at 48 km horizontal resolution to meet the operational time limits and to get a larger model domain. For the same horizontal model domain 48-km model takes ~5 h of CPU time for a 72 h forecast, while for the 32-km model time taken is ~15 h. As the model's prediction for the LPA of 25–28 June 2002 was not satisfactory, the high-resolution experiment at 32 km was attempted for the same case. A time step of 90 s is used for the 32 km resolution model run.

Figure 4 shows Day 2 forecast of 850 hPa winds from 32-km model run valid for 00 UTC 27 June 2002. On comparison with analysis (Figure 3 *c*) it is found that the position of the LPA in this run is also far too east of the actual position as was noticed in the 48-km run (Figure 3 *d*). The speed of the winds around the predicted LPA is slightly

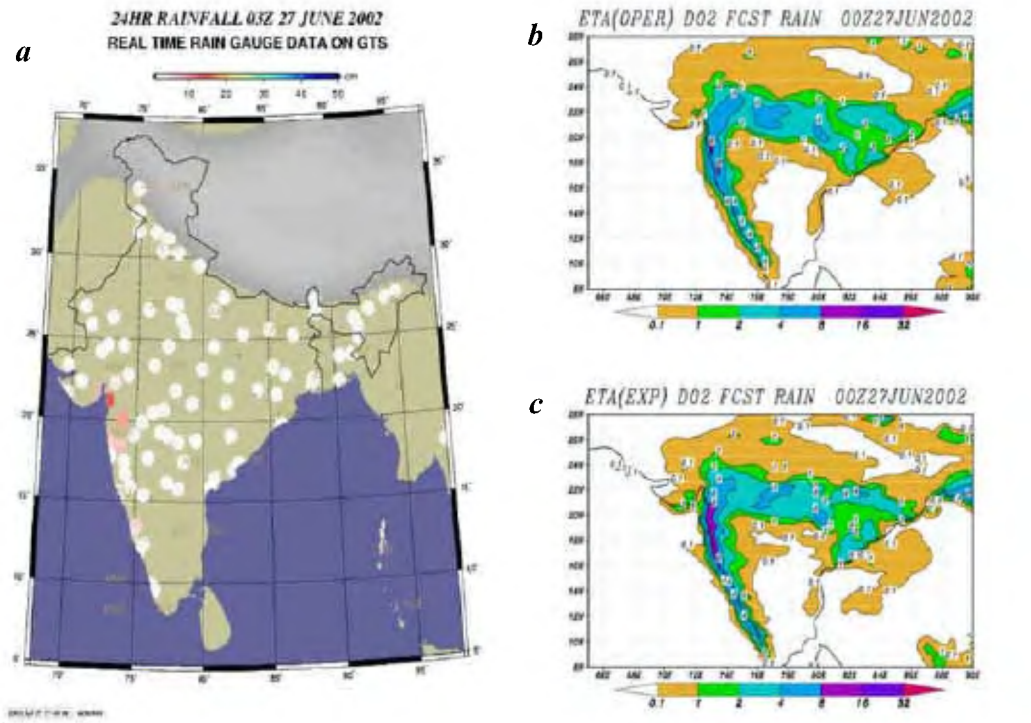

Figure 5. ***a***, Observed rainfall valid for 03z 27 June 2002; ***b***, Day 2 forecast from 48-km model; ***c***, Day 2 forecast from 32-km model.

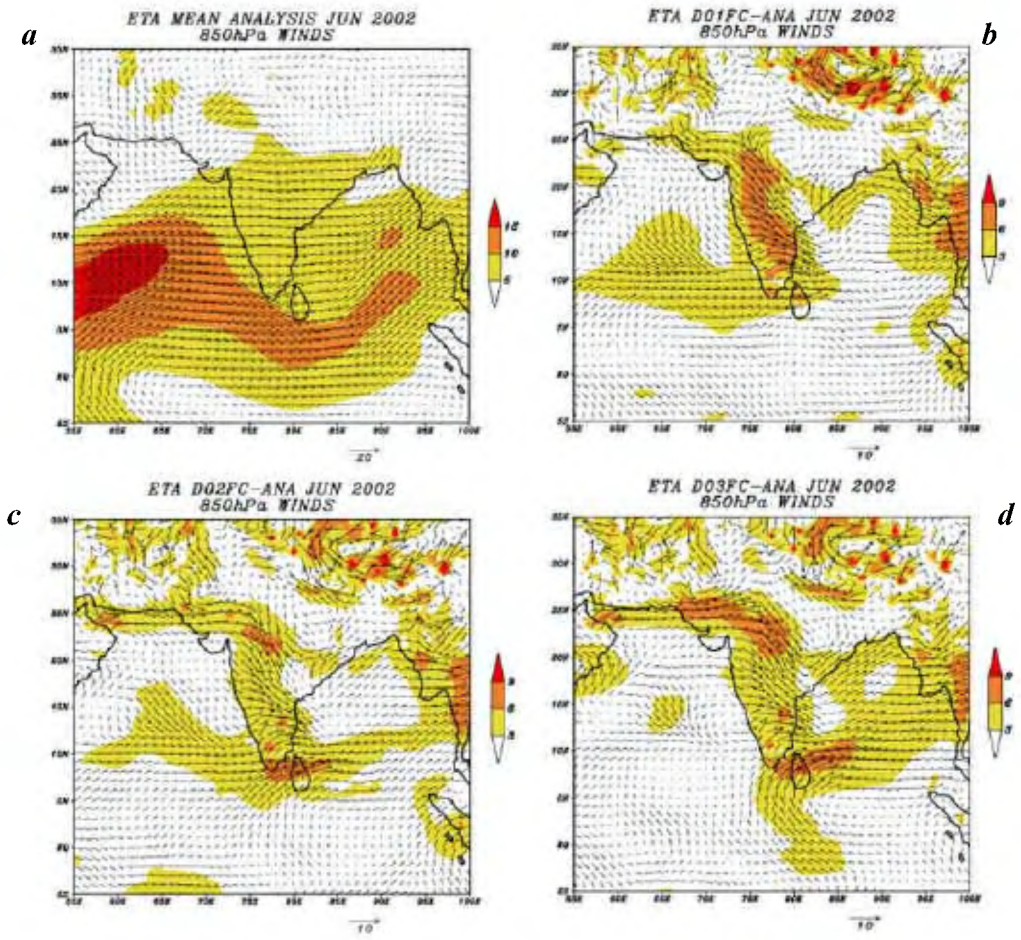

Figure 6. ***a***, Mean June 2002 analysis of 850 hPa winds; ***b***, Day 1 systematic error; ***c***, Day 2 systematic error; ***d***, Day 3 systematic error.

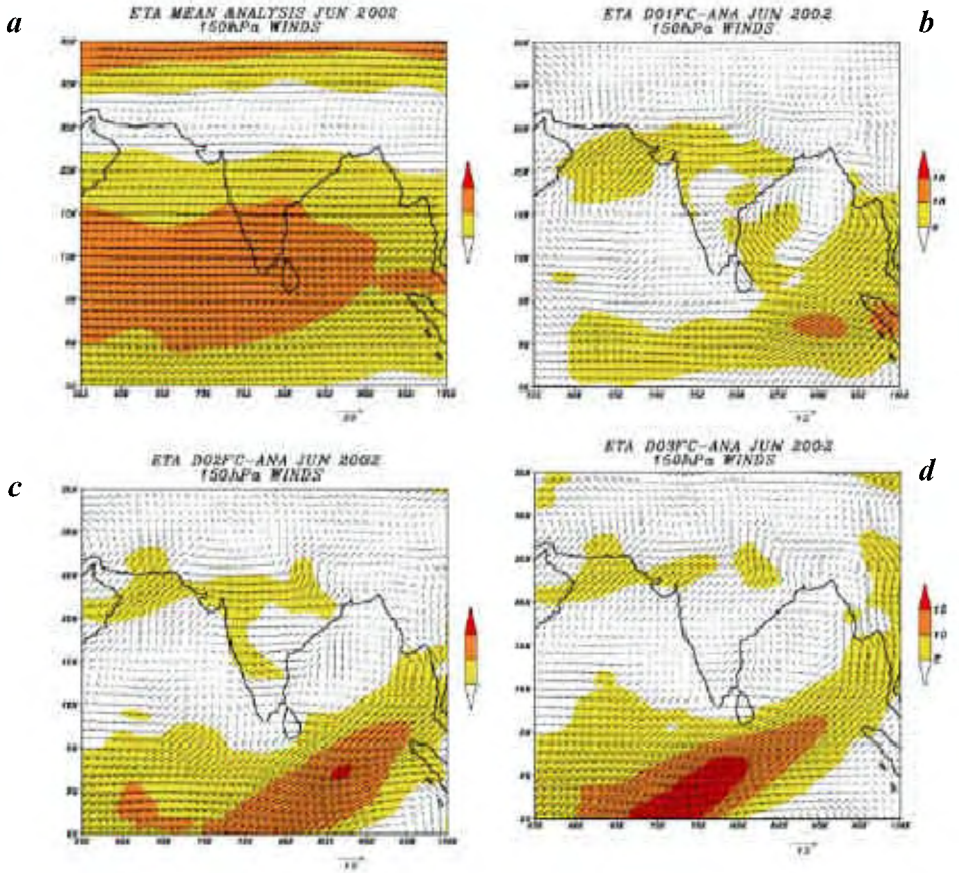

Figure 7. ***a***, Mean June 2002 analysis of 150 hPa winds; ***b***, Day 1 systematic error; ***c***, Day 2 systematic error; ***d***, Day 3 systematic error.

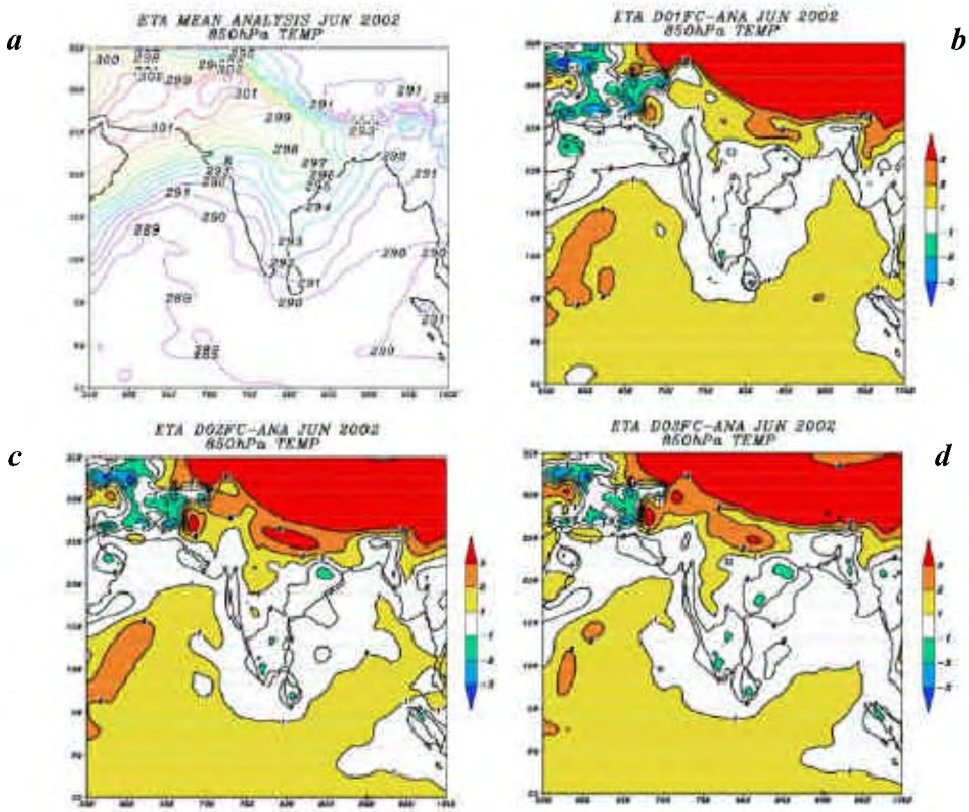

Figure 8. ***a***, Mean June 2002 analysis of 850 hPa temperature (K), ***b***, Day 1 systematic error; ***c***, Day 2 error; ***d***, Day 3 error.

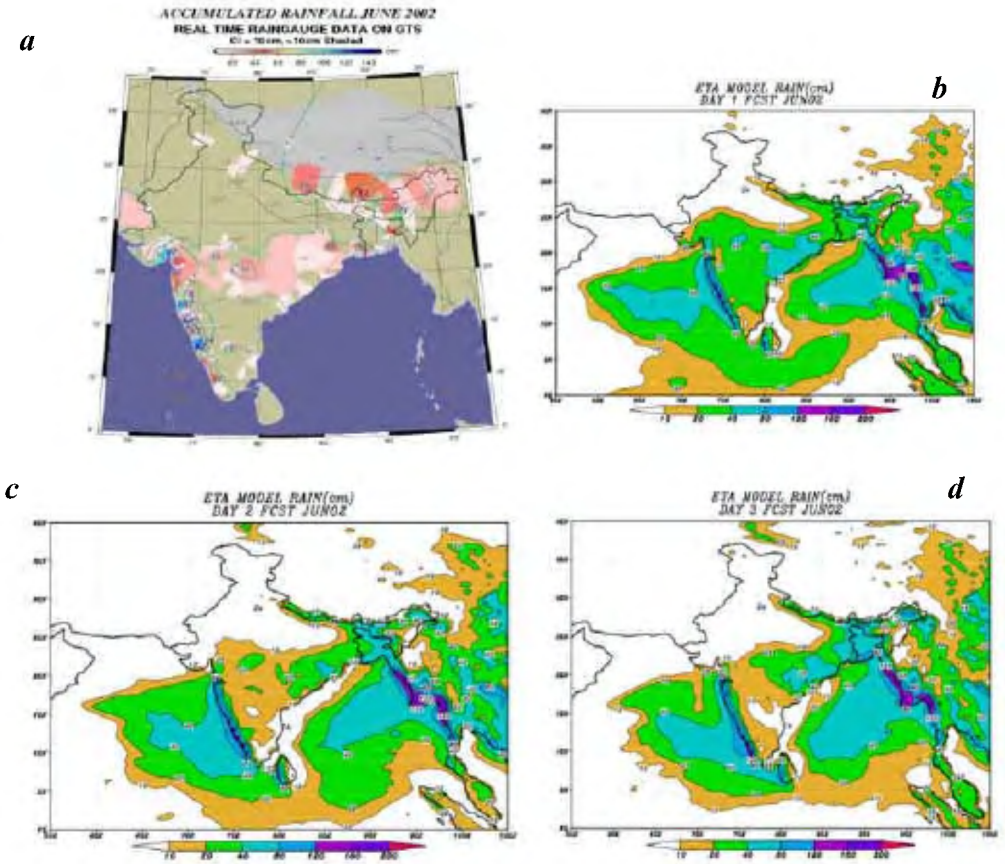

Figure 9. Accumulated rainfall (cm) for June 2002. ***a***, Observed; ***b***, Day 1 forecast; ***c***, Day 2 forecast; ***d***, Day 3 forecast.

more in 32-km compared to 48-km run. Hence, the model run at higher horizontal resolution also could not predict the westward movement of the LPA correctly.

Figure 5 shows Day 2 forecast of rainfall from 48-km and 32-km model runs and rainfall observations of 03UTC 27 June 2002. It can be seen that predicted rainfall maxima (> 8 cm) along the west coast shows more latitudinal extent in the 32-km run compared to 48-km and quite comparable to the observations. The reason for better rainfall prediction in 32-km case in spite of the failure to predict the movement of LPA rightly, could be due to intensification of monsoon winds over that region and better representation of the Western Ghats.

Monthly means and errors

As the Eta model is being operationally run for the first time over Indian region, the monthly means and model systematic errors for the month of June 2002 were computed to evaluate the model's prediction skill. The monthly mean 850 hPa wind analysis for the month of June 2002 and the model's systematic errors (mean forecast – mean analysis) for Day 1, 2, 3 are shown in Figure 6. It can be seen that the model errors are increasing with the forecast lead time especially over peninsular India and the Bay of Bengal.

The monthly mean 150 hPa wind analysis for the month of June 2002 and the model's systematic errors for Day 1, 2, 3 are shown in Figure 7. It can be seen that the model errors are increasing with the forecast lead time especially over Indian Ocean which could be due to propagation of errors from the southern boundary. The monthly mean 850 hPa temperature analysis for the month of June 2002 and the model's systematic errors for Day 1, 2, 3 are shown in Figure 8. Temperature forecast errors are larger over Gangetic plains and they penetrate southward with forecast lead time.

Figure 9 shows the observed and model predicted accumulated rainfall (cm) for the period 1–30 June 2002. The observed maximas at west coast stations range between 50 and 150 cm. It can be seen from Figure 9 *b–d* that the model predicted accumulated rainfall maxima range from 40–120 cm along the west coast, which compares quite well with observations. The rain shadow effect on the leeside of Western Ghats is also predicted quite well by the model.

Conclusions

In general, Eta model forecasts are found to be quite successful in the cases mentioned here. As the Eta model predicts orographic rainfall better, the model predicted rainfalls along the west coast of India are found to be quite close to

observations. The model has been able to predict the monthly total rainfall reasonably well. However, the study on model errors revealed that the model errors are increasing as forecast time increases. Increasing the model's horizontal resolution had very little impact on the forecasts.

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