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Systematic errors of IMD Operational NWP model

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सार – इस शोध–पत्र में शीत और ग्रीष्म ऋतु के समय, 48 घंटों के पूर्वानुमान फील्डों का उपयोग करते हुए भारतीय क्षेत्र में भारत मौसम विज्ञान विभाग के सीमित क्षेत्र निदर्श की नियमित त्रुटियों की जाँच की गई है। इस अध्ययन से यह पता चलता है कि पवन के क्षेत्रीय घटकों में उपउष्णकटिबंधीय पश्चिमी धारा (जेट) आरै उष्णकटिबंधीय पूर्वी प्रवाह (जेट) के क्रोड अच्छी तरह से अनुकरित होते हैं। पवन के याम्योत्तरी घटक के विषय में पूर्वानुमान और विश्लेषण के बीच महत्वपूर्ण अंतर देखने में आया है। ऊपरी क्षोभमंडलीय स्तरों में (100 है.पा. से ऊपर) उत्तराभिमुखी बायसों का पता चला है। निदर्श की तापीय संरचना उत्तरी अंक्षाशों पर मध्य और निम्न क्षोभमंडलीय स्तरों में शीतल बायस दिखाती है। भूविभव उँचाई के निदर्श बायस की प्रकति ऋतु के साथ–साथ बदलती है। इस शोध पत्र में सभी ऋतुओं के दौरान पाई जाने वाली उष्णकटिबंधीय पट्टी पर निदर्श की शुष्कता और उत्तरी अक्षांशों के आस–पास की आर्द्रता का अध्ययन किया गया है।

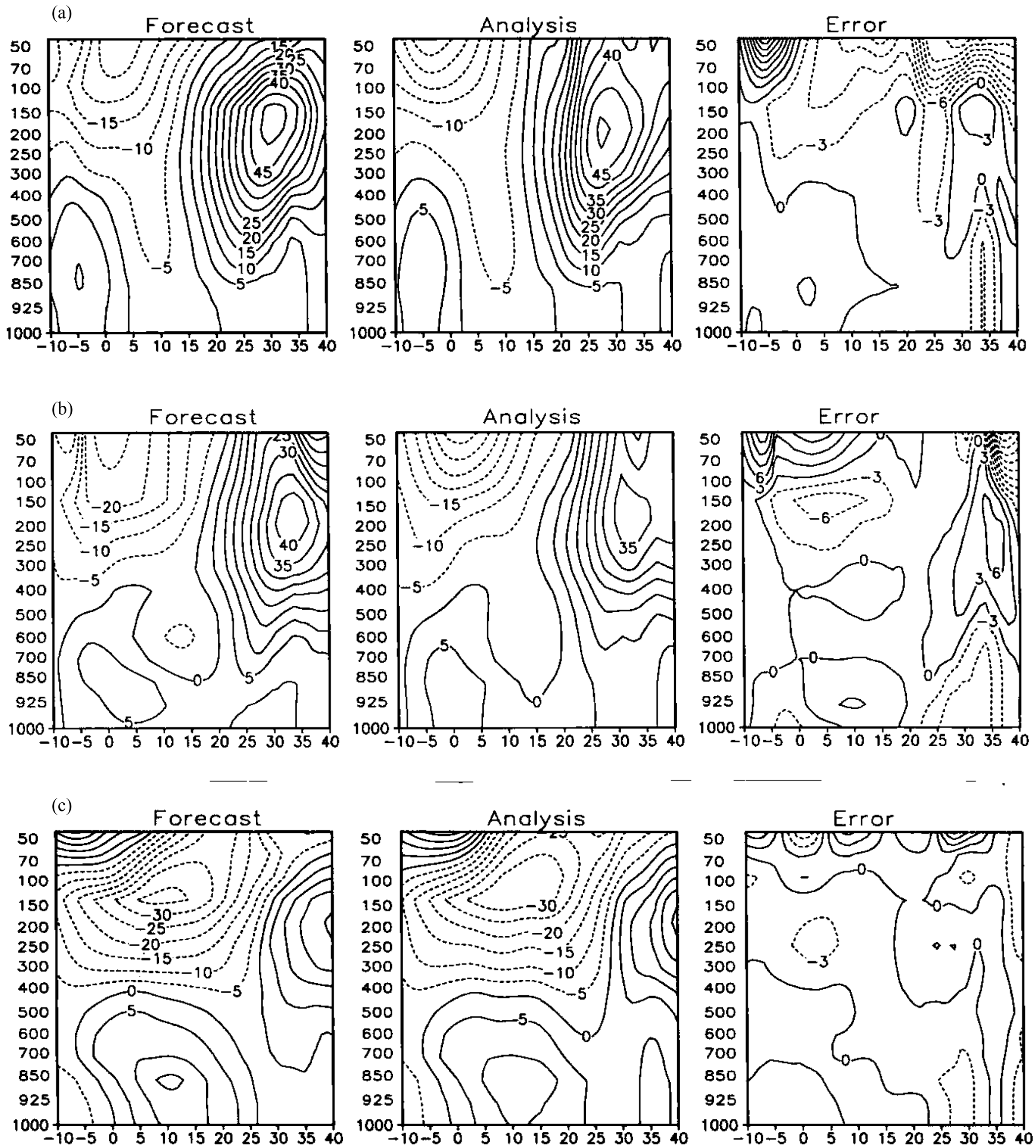
ABSTRACT. The systematic errors of IMD (India Meteorological Department) limited area model over Indian region using 48 hours forecast fields for winter and summer seasons are examined in this paper. The study reveals that the core of the sub tropical westerly jet and tropical easterly jet are well simulated in the zonal component of wind. In case of meridional component of wind significant difference is noticed between forecast and analysis. In the upper tropospheric levels (above 100 hPa) northerly biases are noticed. Thermal structure of the model exhibits cool bias in middle and lower tropospheric levels over the northern latitudes. The nature of model biases of the geopotential height changes with the season. Model drying over the tropical belt and moistening towards the northern latitudes are found in all the seasons studied.

Key words – Limited area model, Model biases, Systematic errors.

1. Introduction

A Limited area Analysis and Forecast System (LAFS) is in operational use at India Meteorological Department (IMD). It consists of real time processing of data received on Global Telecommunication System (GTS), objective analysis by three dimensional multivariate optimum interpolation scheme and a multi level primitive equation model. The Numerical Weather Prediction (NWP) model is Florida State University (FSU) based Limited Area Model (LAM). The horizontal resolution of the model is 1º × 1º Lat./Long. with 16 sigma levels in the vertical. The model includes number of physical processes such as cumulus convection (modified Kuo; Krishnamurti *et al*., 1983), large scale condensation (Kanamitsu, 1975), atmospheric boundary layer (Monin-Obukhov formulation of surface layers with stability dependent vertical diffusion in mixed layer), radiation (Harshvardan and Corsetti, 1984; Lacis and Hensen, 1974) and envelope orography. The other features of the model include time dependent lateral boundary conditions and dynamical normal mode initialization (Sugi, 1986). The forecast domain of the model covers the area between Lat. 30º S to 50º N and Long. 25º E to 130º E. The details of the model can be found in Krishnamurti *et al*. (1989). The model is run upto 48 hours twice daily initiated with 0000 UTC and 1200 UTC observations. Lateral boundary conditions of the model are obtained from the global spectral model (T-80) run of the National Center for Medium Range Weather Forecasting (NCMRWF), New Delhi and updated every 6 hours. The first guess field of the model is also provided by NCMRWF forecast.

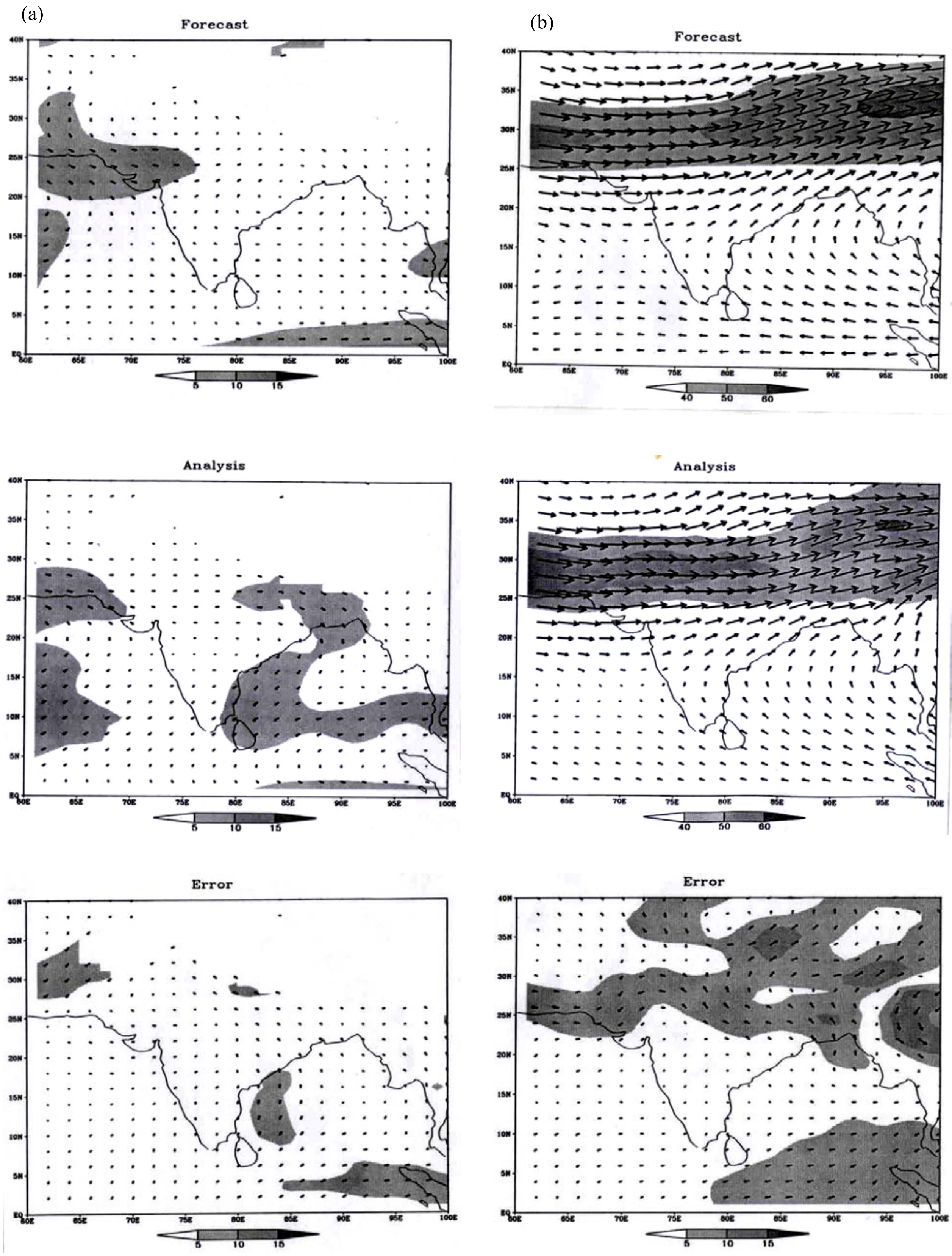
Roy Bhowmik and Prasad (2001) studied performance statistics for precipitation forecast of this model over Indian region. Performance of the model for cyclone track prediction was evaluated by Prasad *et al*. (2000). These studies show that the performance of the model is comparable with the performance of other models operational at various national centers. Studies of Kanamitsu (1985) and Laurent *et al*. (1989) revealed that 50 to 80% of the total errors in the ECMWF global model



Figs. 1(a-c). Vertical cross section of zonally averaged monthly mean of zonal wind (ms^{-1}) based on 48 hours forecast field, model analysis and mean error (forecast-analysis) for the month of (a) January, (b) April and (c) July. Dotted lines indicate easterlies and solid lines westerlies for the analysis and forecast. The X-axis is the latitude from 10° S to 40° N. and Y-axis is the pressure levels in hPa

were due the systematic errors of the model. Therefore, it is important to carry out research on analysis of structures and magnitudes inherent to the model's errors and possible way of their reduction.

In this paper, systematic errors of the operational model of IMD over Indian region have been examined based on 48 hours forecast fields for winter and summer seasons. In this study, for the summer season two months



Figs. 2(a&b). Geographical distribution of monthly mean wind field (ms^{-1}) based on 48 hours forecast, analysis and mean error (forecast-analysis) for the month of January at (a) 850 hPa and (b) 200 hPa. Shaded regions indicate higher wind speed are considered namely, April as the representative of pre-monsoon and July as the representative of monsoon, whereas for the winter season January is considered.

2. Data and methodology

The systematic errors are obtained by computing the time average difference between forecast and analysis. In this study, the systematic errors are simply the difference between 48 hours forecast field and corresponding analysis averaged over one month. The forecast and analysis domain considered for this study is from Lat. 10° S to 40° N and Long. 60° E to 100° E. Vertical cross section of longitudinal average of mean errors are computed to assess the nature of their latitudinal variation over Indian region. This exercise is carried out with the data of January, April and July for the year 1999. The meteorological elements considered for computation of systematic errors are zonal and meridional component of winds, temperature, geopotential height, and relative humidity. For the purpose of comparison, the climatological features of these parameters are described based on the studies of Asnani (1993) and Rao (1976).

3. Structure of systematic errors

(*i*) *Zonal wind*

During winter season, the sub-tropical westerly jet lies near 200 hPa with core of maximum winds close to Lat. 30° N. Fig. 1(a) shows the latitude height section of longitudinal mean zonal wind based on 48 hours forecast, analysis and the mean errors (forecast-analysis) for the month of January. The forecast shows subtropical westerly jet along 150 hPa near Lat. 31° N, whereas in the analysis the jet is seen along 200 hPa at Lat. 27° N. The forecast core of maximum wind around 150 hPa between Lat. 30º - 35º N is slightly stronger than the analysis by 3ms^{-1}. Over the equatorial region, the mid and upper tropospheric winds are easterly in both forecast and analysis. The zero isopleths separating the sub tropical westerly and equatorial easterly meets near 850 hPa at Lat. 10° N in both forecast and analysis. In the forecast, between equator and Lat. 15° N, the upper tropospheric easterlies (above 100 hPa) are stronger and towards northern latitudes the westerlies are weaker. No model bias is found over the tropics south of Lat. 25º N in the lower and mid tropospheric levels. Lower tropospheric forecast westerlies between Lat. 30º - 35º N are found to be weaker.

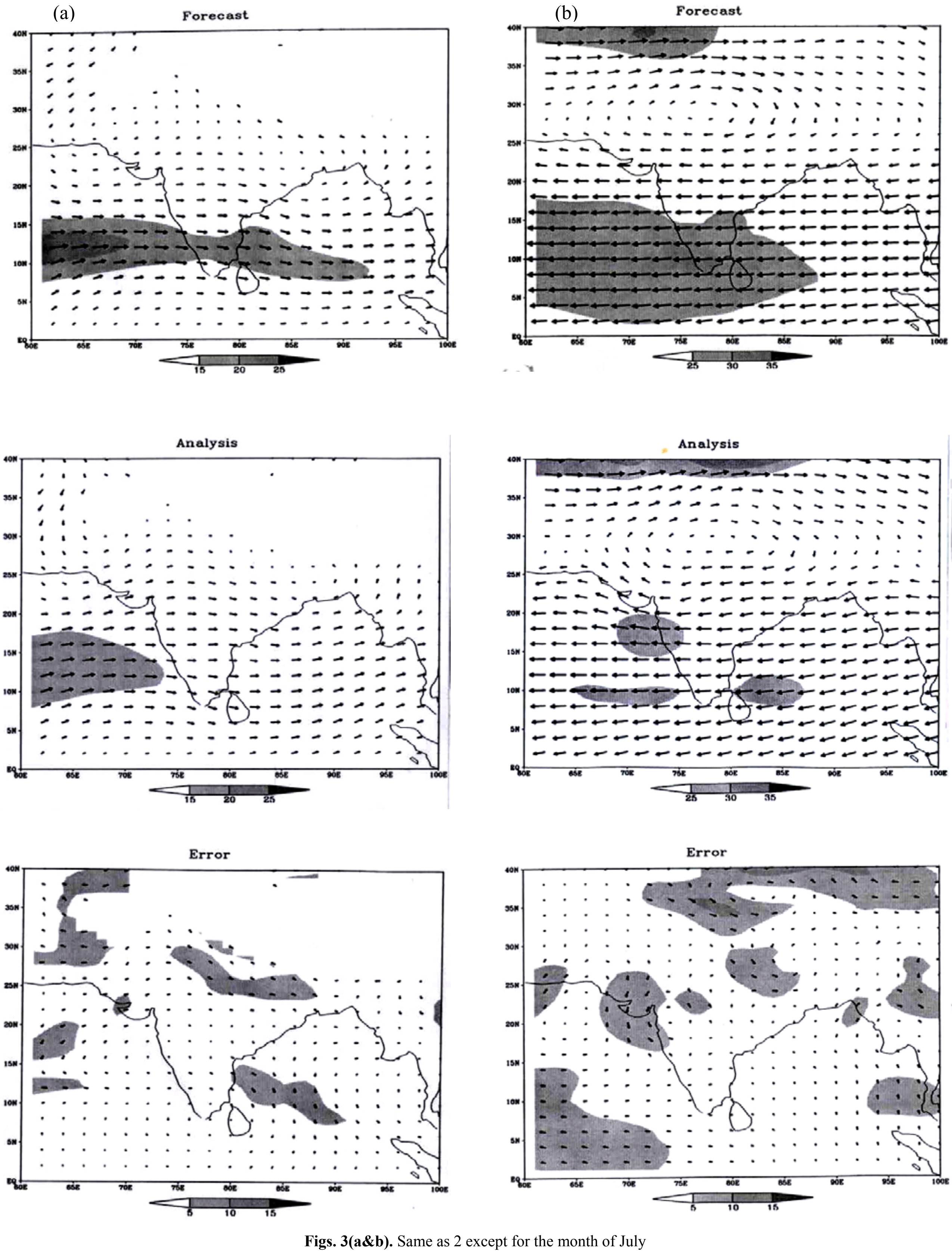
During the summer season the westerly jet becomes weaker and moves towards northern latitudes. In July the jet core lies at 200 hPa along at 45º N. Fig. 1(b) presents the latitude height section of longitudinal mean zonal wind for the month of April. In April the sub tropical westerly jet is seen at Lat. 34º N along 200 both in forecast and analysis. In the forecast the gradient is stronger and the jet is stronger by 3 - 6 ms^{-1}. The zero isopleths separating easterlies and westerlies near 850 hPa is seen along Lat. 15º N. The mean errors show that the upper tropospheric easterlies between 150 and 250 hPa over tropics north of Lat. 20º N are stronger (3 - 6 ms^{-1}) and weaker aloft. Towards the northern latitude (north of Lat. 20º N) the lower tropospheric westerlies are weaker. The upper tropospheric westerlies above 100 hPa in these latitudes are also weaker.

In July [Fig. 1(c)] the sub tropical westerly jet, both in forecast and analysis is seen along 200 hPa north of Lat. 40° N. The core of easterly jet is seen between 150 and 100 hPa from Lat. 10° N to Lat. 15° N. The low level jet lies between Lat. 10º and 15° N at 850 hPa. The comparison between forecast and analysis shows that the sub tropical westerly jet and tropical easterly jet are well simulated but strength of easterly jet around Lat. 5° N between 200 and 250 hPa is slightly over estimated (3 ms^{-1}). The low-level westerlies are found to be slightly over-estimated south of Lat. 7° N.

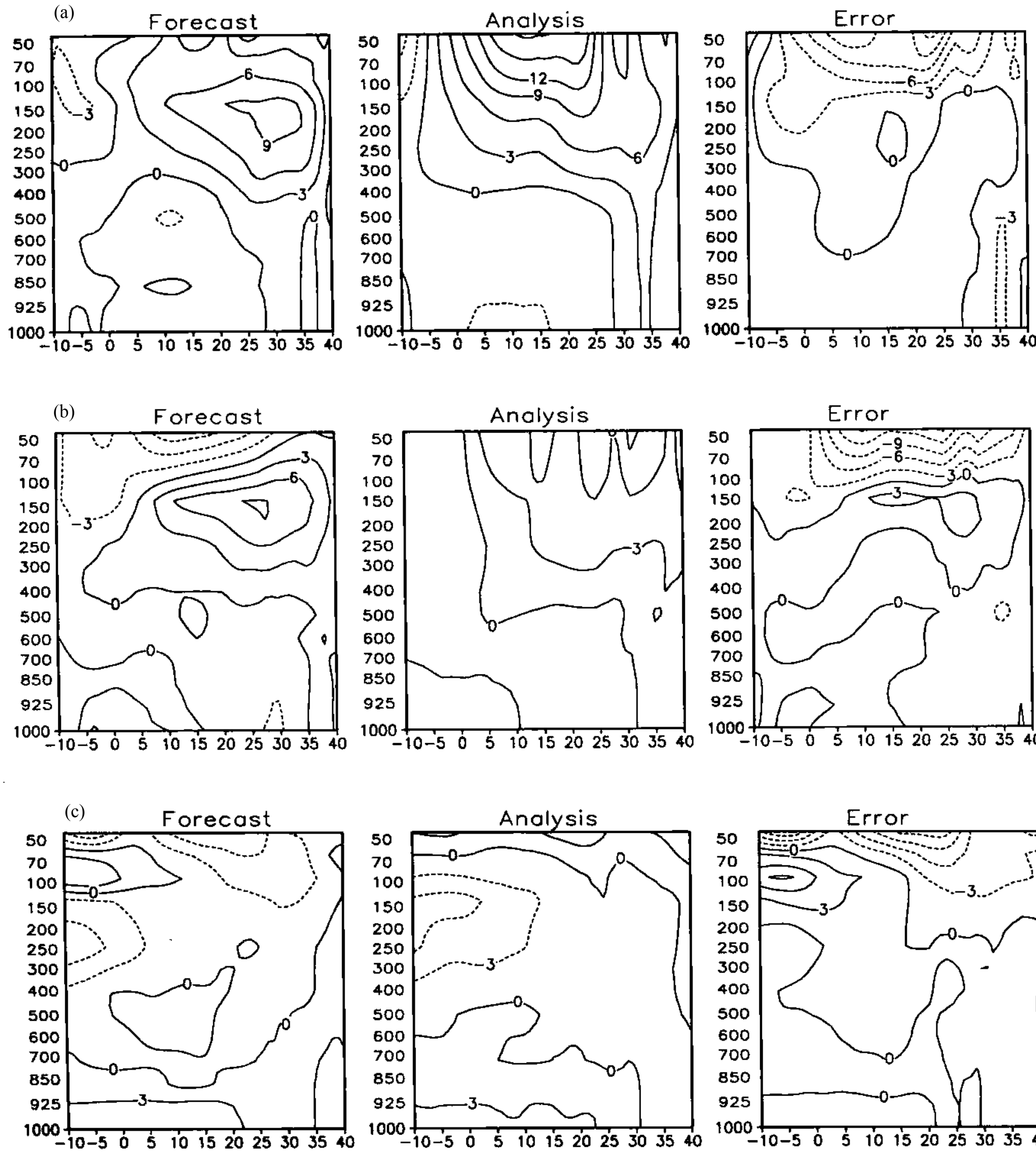
The biases like over estimation of subtropical westerly jet and tropical easterly jet are similar to those found in other models (Moorthi, 1997; Kamga *et al*., 2000).

Figs. 2 (a&b) respectively shows the geographical distribution of wind for the month of January (winter) at 850 hPa and 200 hPa based on 48 hours forecast, analysis and the mean errors. Both forecast and analysis at 850 hPa reflects features like light winds over the region with relatively stronger northwesterly winds over Gujarat region and neighbourhood. The comparison between forecast and analysis reveals that at 850 hPa model fails to capture north-easterly winds along east coast and adjoining sea areas of the Bay of Bengal. At 200 hPa the subtropical westerly jet is seen roughly between Lat. 25º and 30º N which broadens towards east. The ridgeline at 200 hPa is seen roughly along Lat. 15º N in both forecast and analysis. The strength of subtropical westerly jet to the south of Lat. 27º N is under predicted and to the north (particularly east of 80º E) is over estimated. The easterlies south of the Bay of Bengal are found to be stronger.

In order to demonstrate how the typical features of Indian summer monsoon are captured, the wind fields for the month of July are illustrated in Figs. 3(a&b). At 850 hPa the low level jet in the forecast is seen over the Arabian Sea extending east upto the Bay of Bengal, roughly between Lat. 10º and 15º N, whereas in the

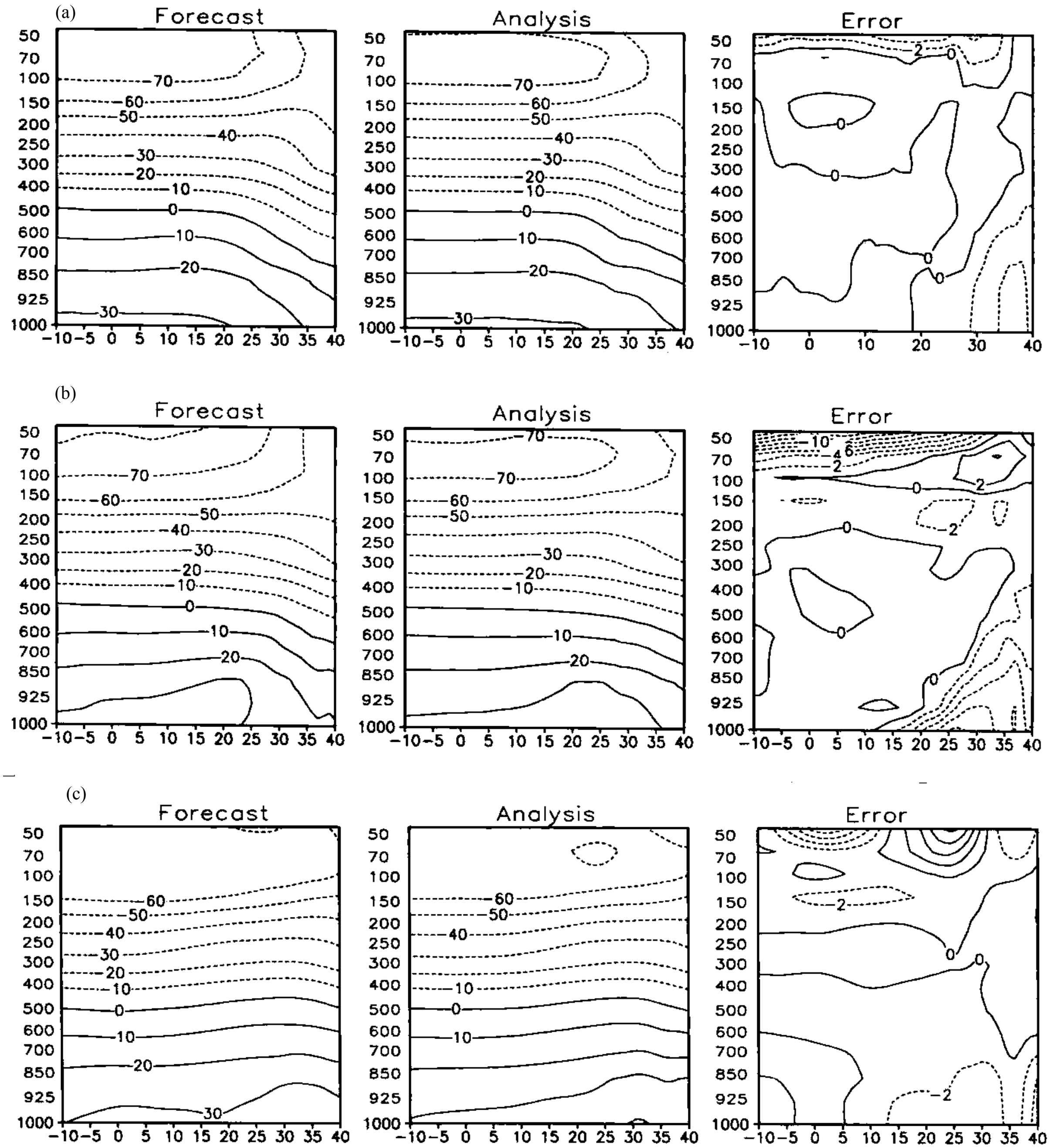


Figs. 3(a&b). Same as 2 except for the month of July



Figs. 4(a-c). Same as Fig. 1 except for the meridional wind (ms^{-1}). Dotted lines indicate northerlies and solid lines southerlies for the analysis and forecast

analysis it is seen upto the Arabian Sea roughly along the same latitude. Along Konkan coast and neighborhood the forecast westerlies are slightly weaker. The monsoon trough in the forecast is seen more prominent compared to analysis. Easterly biases along foothills of the Himalayas are noticed. These features of the mean errors are similar to the results found for the month of August with data of 1997 (Roy Bhowmik and Prasad, 2001). Our day to day experience reveals that though the model lacks to capture the initial development of monsoon low pressure system, for the well defined system, the low level circulation becomes more organized in the forecast compared to analysis. This may be a reason that monsoon trough appeared more prominent in the mean forecast field.

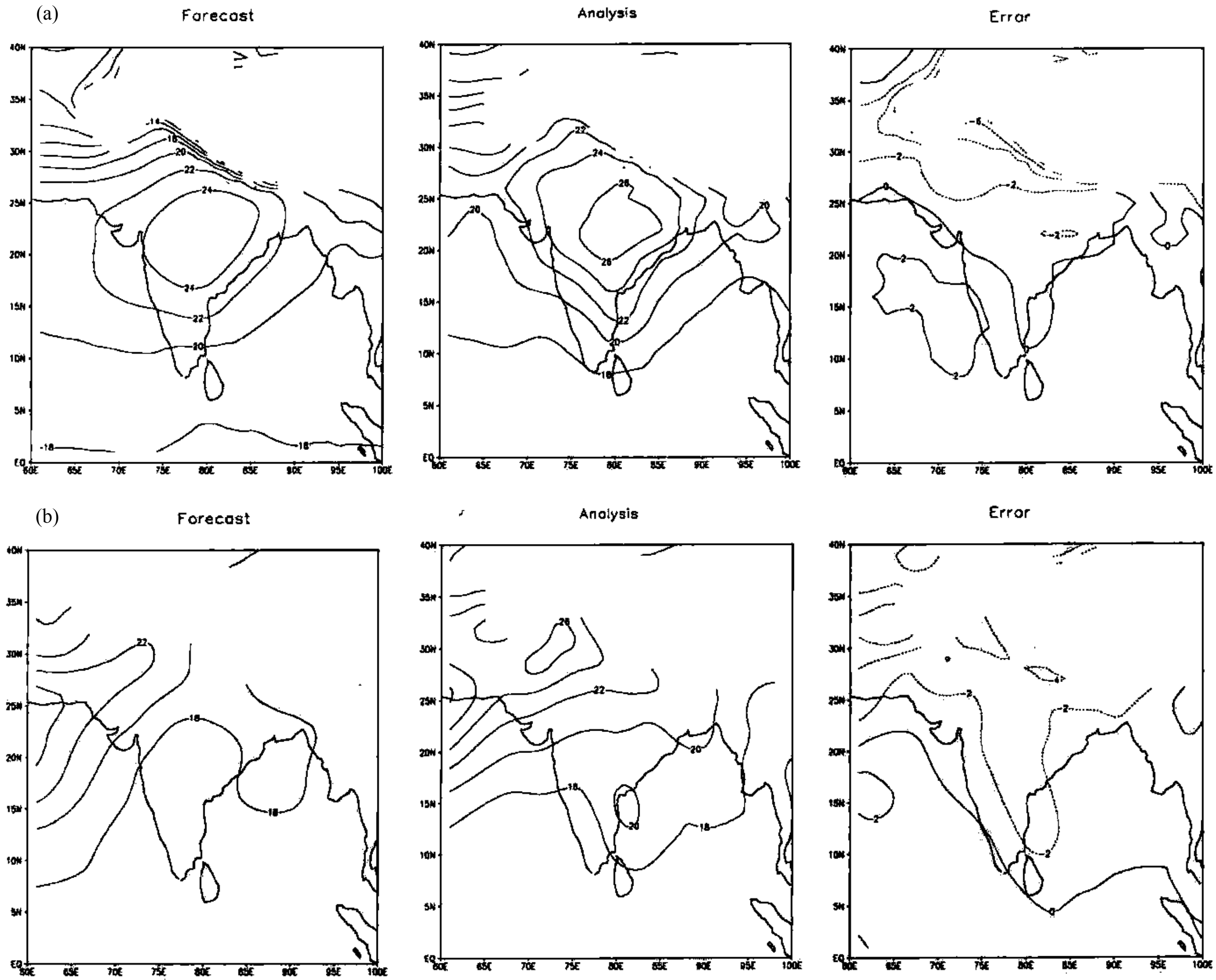


Figs. 5(a-c). Same as Fig. 1 except for the temperature (°C). Dotted lines indicates negative values and solid lines positive values

Tropical easterly jet is seen to occupy larger area over the Arabian Sea between Lat. 5º and 15º N in the forecast. In the analysis it is seen in some pockets over the southwest Bay and Arabian Sea along Lat. 10º N. Another branch is also noticed over north Konkan. The subtropical ridge is seen along Lat. 28º N both in forecast and analysis with the Tibetan anticyclone roughly near Lat. 28º N / Long. 80º E.

(*ii*) *Meridional wind*

Meridional components are usually weaker than zonal winds. In January, over Indian region south of Lat. 30º N, northerlies prevails from surface upto 300 hPa and southerlies aloft. In July, a simple circulation of southerly below and northerly aloft (reverse Hadley circulation) occurs over Indian region between Lat. 12º N and 26º N.



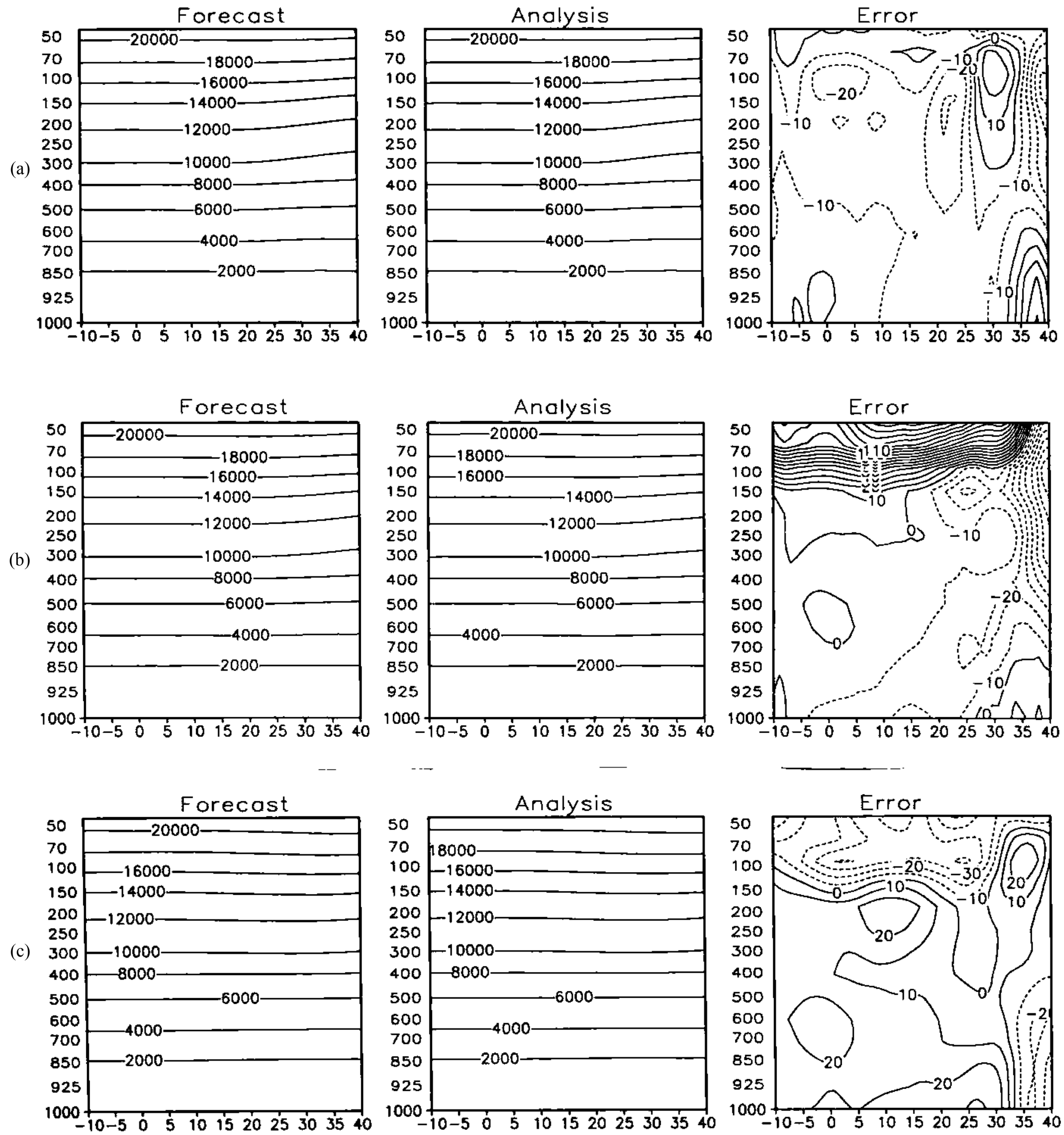
Figs. 6(a&b). Geographical distribution of monthly mean temperature field (°C) at 850 hPa based on 48 hours forecast, analysis and mean error (forecast - analysis) for the month of (a) April and (b) July

In Fig. 4(a) latitude pressure section of longitudinal mean meridional wind based on 48 hours forecast, analysis and mean errors for the month of January is shown. Significant differences in the meridional components of winds between forecast and analysis are noticed. In January stronger southerlies in the forecast are found to confine between 300 and 100 hPa from Lat. 20° N to 35° N (6 - 9 ms^{-1}). In the analysis southerlies are found strengthening from 300 hPa onwards with peak (18 ms^{-1}) at 50 hPa. The mean errors reflect that the strength of the southerlies are, in general, significantly under estimated by the model in the upper tropospheric levels above 100 hPa. Similar features are also noticed in April [Fig. 4(b)].

In July, [Fig. 4(c)] both forecast and analysis shows southerlies in the lower tropospheric levels (upto 700 hPa). In the upper troposphere, between 400 and 100 hPa south of Lat. 5° N northerlies are seen in the forecast. In the analysis, between 400 and 100 hPa south of Lat. 10° N northerlies prevail. The mean errors show northerly bias (3 - 6 ms^{-1}) above 100 hPa north of Lat. 10° N and southerly biases are seen in a pocket south of Lat. 5° N between 150 and 70 hPa.

(*iii*) *Temperature*

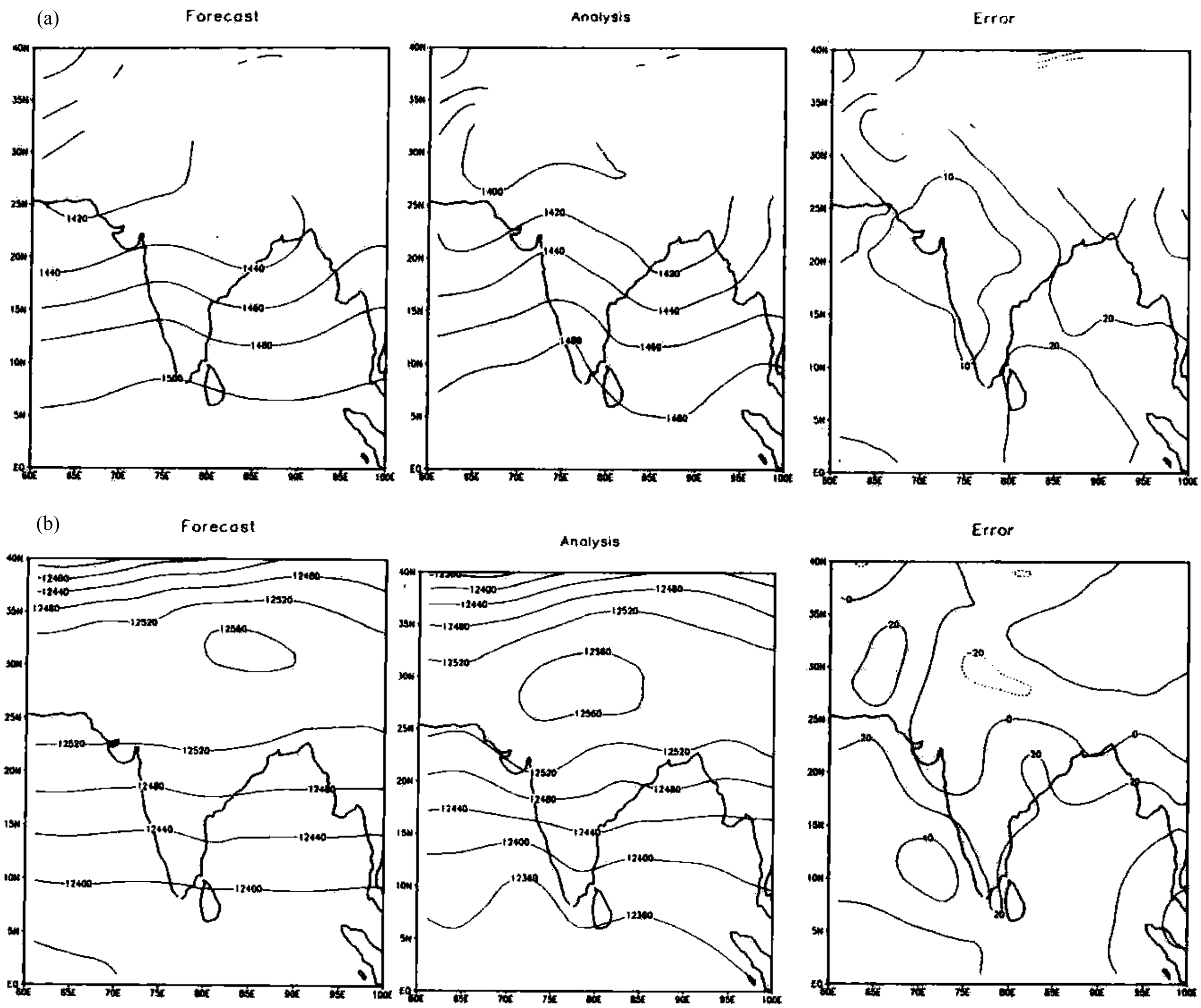
The level of tropopause near the equator is highest compared to other latitudes. The lowest temperature of



Figs. 7(a-c). Same as Fig. 1 except for the geopotential height (gpm)

–68º C or less occurs in the near equatorial region around 100 hPa. The highest temperature 25º C or more occurs in the near equatorial region close to sea level. There is a seasonal shift of latitude of lower tropospheric maximum temperature and upper tropospheric minimum temperature towards the summer season.

In Fig. 5(a) latitude height section of zonally averaged temperature field based on 48 hours forecast, analysis and mean errors for the month of January is presented. The tropopause with temperature –70º C or less is seen south of Lat. 25º N between 100 and 50 hPa both in the forecast and analysis. The higher temperature

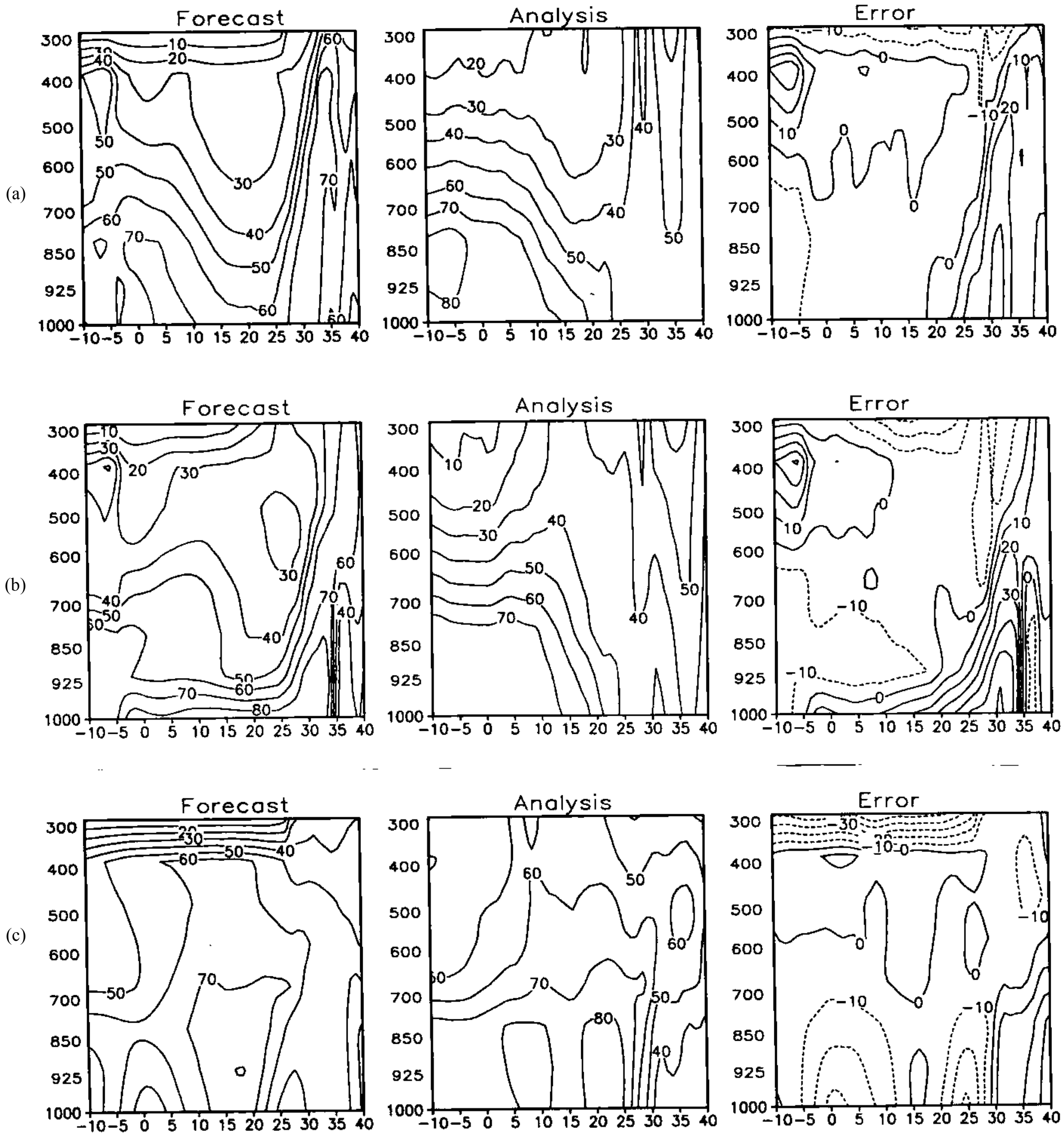


Figs. 8(a&b). Geographical distribution of monthly mean geopotential height (gpm) (a) 850 hPa and (b) 200 hPa based on 48 hours forecast, analysis and mean error (forecast - analysis) for the month July

(30º C) is seen below 925 hPa south of Lat. 20º N in the forecast and south of Lat. 22º N in the analysis. In the mean errors, positive value indicates model warming and negative error model cooling. In January, in general, model bias is very negligible in the mid tropospheric levels. A cool bias (2º to 4º C) in the lower and mid tropospheric levels is found over the northern latitudes north of Lat. 25º N and also over upper tropospheric levels (above 70 hPa) south of Lat. 35º N.

In April [Fig. 5(b)], forecast shows tropopause (–80º C or less) above 70 hPa and in the analysis it is seen (–70º C) between 100 and 50 hPa. Higher temperature (30º C) is seen below 925 hPa northwards upto 23º N in the forecast and upto 35º N in the analysis. Around Lat. 23º N some vertical extension of higher temperature upto 900 hPa is noticed both in forecast and analysis. In the mean errors, we note an erroneous model cooling in the upper tropospheric levels (above 100 hPa) with peak more than 10º C at 70 hPa. This occurs due to increase of tropopause height in the forecast. Cool model bias in the lower and mid tropospheric levels are found north of Lat. 15º N.

In July [Fig 5(c)], in both forecast and analysis the tropopause is seen above 150 hPa (–60º C or less) extending northwards upto 40º N. Below 925 hPa the higher temperature (30º C) extended northwards upto Lat. 40º N. The mean errors show cooling north of Lat. 15º N in the boundary layer and warming to the south



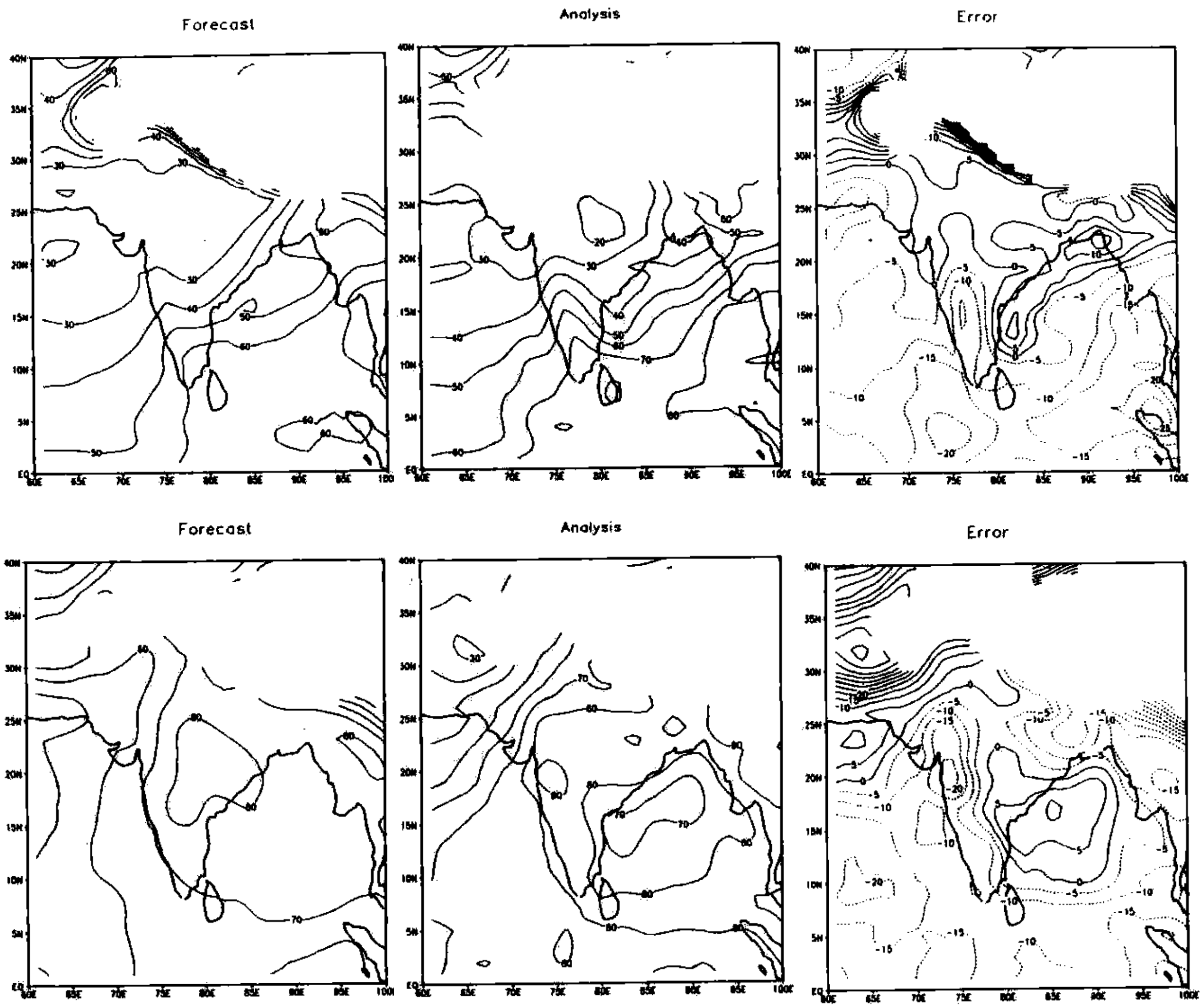
Figs. 9(a-c). Same as Fig. 1 except for the relative humidity (%) upto 300 hPa

of Lat. 5° N. Cool biases occur above 200 hPa in some pockets south of Lat. 15° N and warm bias is seen over the tropics between Lat. 15° and 30° N above 70 hPa.

In April, a thermal high develops over India at 850 hPa with center near about Lat. 22° N/Long. 80° E. In July thermal ridge runs along longitude 35° N over north India at 850 hPa. Figs. 6(a&b) respectively shows the geographical distribution of temperature based on forecast, analysis and mean errors at 850 hPa for the month of April and July. Forecast shows larger area of warmer zone (24° C) over central parts of the country. In

(a)

(b)



Figs. 10(a&b). Geographical distribution of monthly mean relative humidity (%) at 850 hPa based on 48 hours forecast, analysis and mean error (forecast - analysis) for the month of (a) April and (b) July

the analysis, the highest temperature of magnitude 26° C is seen over the central parts of India. In July thermal high is seen over northwest India north of Lat. 25° N both in forecast and analysis. The difference shows model cooling (–2° C) over most parts of the country both in April and July with peak towards the north.

(*iv*) *Geopotential height*

In Figs. 7(a-c) latitude height section of zonally averaged geopotential height fields based on 48 hours forecast, analysis and mean errors for the month of January, April and July respectively are presented.

The comparisons between forecast and corresponding analysis reveal that in January geopotential heights between 300 and 100 hPa along Lat. 30° N and at the boundary layer between Lat. 35° and 40° N have positive biases (20 gpm), whereas over the equatorial belt south of Lat. 25° N biases are, in general, negative (10 to 20 gpm). In April a systematic positive biases (30 - 90 gpm) are found in the upper troposphere (above 150 hPa) north of Lat. 30° N. In July a negative bias (20 gpm) is noticed over upper tropospheric levels (above 150 hPa) whereas positive biases are found to dominate in the mid and lower tropospheric levels north of 15° N. Another negative bias area is found in the lower levels between Lat. 35° and 40° N. The study reveals that the nature of biases usually changes with the season.

The geographical distribution of geopotential height at 850 hPa and 200 hPa for the month of July is shown in

Figs. 8(a&b). In general, both forecast and analysis show similar pattern of contour height at 850 hPa and 200 hPa. However; marginal model over-estimations of height (10-20 gpm) at 850 hPa and 200 hPa are noticed over most parts of the region in the mean errors.

(*v*) *Relative humidity*

The value of relative humidity (R.H.) above 300 hPa is very small. In general, R.H is largest at the lowest latitude and lowest levels. The maximum occurs in the neighbourhood of the equator, with a northerly shift towards summer season. The minimum occurs in the region of subtropical high with a seasonal northerly shift during July.

In Fig. 9(a) latitude height section of zonally averaged mean relative humidity based on 48 hours forecast, analysis and mean errors for the month of January is presented. In January, in the forecast the minimum value of (R.H.) at all levels occurs along Lat. 22º N., shifting slightly southwards with height. In the analysis, the minimum R.H. line is seen along Lat. 25º N. Both forecast and analysis exhibits two maxima, one over the tropics south of this minimum R.H. line and another over the northern latitudes. Over the tropics higher values of R.H. (60%) is seen upto 700 hPa in the forecast and upto 650 hPa in the analysis. Towards the northern latitudes higher values of R.H. (60 %) is seen to occupy upto 300 hPa in the forecast. In the mean errors, the positive values indicate moistening and negative drying. In January model shows erroneous moistening (20 - 30 % higher) in the northern latitude north of Lat. 20º N and drying (difference less than 10%) in the lower tropospheric levels south of the equator. Again over the tropics in the mid tropospheric levels south of Lat. 15º N model shows wet biases (20 - 30 % more).

In April [Fig. 9(b)] the minimum R.H. line is seen between Lat. 20º and 25º N in the forecast and along Lat. 25º N in the analysis. In the forecast higher R.H. (more than 60%) is confined below 925 hPa over the tropics, whereas in the analysis higher R.H. is seen upto 650 hPa. The mean errors show drying over the tropics between 925 and 650 hPa and moistening aloft and below 925 hPa. Over the northern latitudes (north of 15º N) moistening dominant is found below 600 hPa and drying aloft.

In July [Fig. 9(c)] both forecast and analysis shows higher R.H. (60%) upto 500 hPa over the tropics. The difference indicates, in general, model drying in the lower tropospheric levels south of Lat. 30º N. In the middle levels no model bias is seen, but aloft drying biases are found to dominate.

The structure of biases such as model drying over the tropics and moistening over the northern latitudes in lower and mid tropospheric levels do not significantly change with respect to season as seen in case of other parameters. The drying of the lower troposphere in the tropical region is also consistent with studies of other models (Moorthi, 1997; Kamga *et al.*, 2000).

The geographical distribution of relative humidity based on forecast, analysis and mean errors at 850 for the month of April and July are shown in Figs. 10(a&b) respectively. In April the minimum value of relative humidity is seen over central parts of country which increases towards south with maximum over the south Bay of Bengal. The mean errors reflect model drying over the Arabian Sea, Bay of Bengal and over a large domain from Maharashtra to southern peninsular India. A belt of moistening is seen over east coast and adjoining Bay of Bengal, northern parts of the region, over the area of pre-monsoon convective activities. In July the mean errors show model drying over west coast of India upto Gujarat region and moistening over the area of low pressure area in the north and east central Bay of Bengal and also over north-west of India.

4. Summary and concluding remarks

NWP system is constrained by limitations imposed by difficulties related to finite difference approximation of primitive equations and lateral boundary conditions, inadequacy of parameterization of subgrid scale physical processes, uncertainties in the initial conditions and computer resources for real time forecast. As a part of an effort to address this problem in this paper, the systematic errors of IMD operational model have been described. Many of the model biases are similar to some other models as documented by (Kamga *et al*. 2000; Surgi, 1989). The study reveals that the core of the sub tropical westerly jet and tropical easterly jet are well simulated, but in both the cases the strengths of the jet are slightly over estimated. In case of meridional components of winds significant difference between analysis and forecast is noticed. The strength of the southerly component of wind is, in general, considerably under estimated by the model in the upper tropospheric levels above 100 hPa. Low level westerlies over the Western Ghats are slightly weaker, but monsoon trough is noticed more prominent in the forecast. Model is able to capture warmer belt (heat low) at 850 hPa over central parts of country in April and over northwest India in July. Tropopause is also found well simulated. Thermal structure of the model exhibits cool bias in lower tropospheric levels over the northern latitudes. In April height of tropopause is found slightly higher than the analysis resulting enormous model cooling above 100 hPa. The nature of model biases of the geopotential height changes with the season. Model drying in the tropical belt, over the area of convective activity and moistening towards the northern latitudes, over the area of western disturbances are found in all the seasons studied. An appreciable under estimation of relative humidity at lower troposphere (850 hPa) during July occurs along Western Ghats of India.

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