THE DYNAMICAL DIAGNOSIS OF THE SYSTEMATIC ERRORS OF THE SECOND GENERATION MEDIUM - RANGE NWP MODEL AT CNMC

Liu Huanzhu Teng Qiaobian
National meteorological Center,
Beijing, China

Abstract

Upon using the dynamic statistics of the atmospheric circulation the monthly mean forecasting fields of January and July of 1996 obtained from the second generation medium - range numerical weather prediction(NWP) model(T63) have been investigated. The results indicate that the new generation model has been improved remarkably in comparison with the old one. The systematic prediction errors of model have been reduced significantly. However there still exist some differences in the distributions in wind, temperature and moisture fields between forecasts and observations.

After having diagnosed the transfers and budgets of angular momentum, heat and water vapour of the T63 model, and compared these with observations, it was suggguested that to improve the model performance, the treatments of orography, land surface processes, cloud radiation and convection parameterization in the model need to be improved further.

1. Introduction

The dynamical diagnosis of the systematic errors of numerical weather prediction (NWP) model based on the knowledge of the atmospheric general circulation can help us in understanding the model behavior and detecting its physical processes, and provide the scientic basis for improving the model' s forecasts. Zhang et al (1995) have diagnosed the mean meridional circulation (MMC) of the medium - range NWP model T42L9(T42 in short) of the Chinese National Meteorological Center (CNMC), and its systematic errors by using the non - accelaration theorem in a primitive equation system (Wu, 1989).

The second generation medium - range NWP model T63L16 (T63 short) has been routinely operating at CNMC since June 1995. The model uses not only finer resolution in the horizontal as well as in the vertical direction, but also better initialization, orography presentation and physical processes (HuanPu et al. 1995) compared with T42. In order to know the performance and systematical errors of this new generation model, we have verified the forecast results in January and July of 1996 of the T63 model by emloying dynamical diagnosis. Some assessment results are reported in this paper, and the possible ways for further improving the model are explored.

2. Data treatment

From the archieved data set, the initial values (observation) of the variables u, v, t, z, ω, and q at each standard pressure level for each day in January and July, 1996 and the corresponding 1 – day, 2 – day, upto 7 – day forecast values for the same days were withdrawed. By employing the scheme proposed by Wu and Liu (1987), various transfer properties of both toriods and eddies were calculated on a daily base. These include the zonal averaged meridional and vertical flux of angular momentum, heat and moisture. Their vertical integration and budgets were then calculated. Finally, the monthly mean quantities were obtained from the daily results. These data are then used for the following diagnoses.

3. Wind field and angular momentum transfer

In Fig. 1 is shown the vertical cross – sections of the observed zonal mean wind component in January and July, 1996, and their forecast errors of the T63 for 2 – day 4 – day and 6 – day periods. The predicted westerly jets in the upper troposphere in both hemispheres are located reasonablly well compared with the observations. However, their intensity appears stronger. This prediction error increases with integration, particulary during the first 96 hours. In both winter and summer, the error is negative in high latitudes (60 – 80°) and low latitudes (10 – 25°), but positive in middle latitudes. Except in the high latitude region of the southern hemisphere in winter, the zero lines which separat positive and negative erros are tilted towards the equator with increasing height. In addition, the errors increase in general with increasing height, and become maximized in the stratosphere. Despite these, the forecast errors are much smaller compared with those of the T42 model during the same period, and the mean forecast wind fields are more close to the climate distributions.

Fig. 2 shows the divergence of eddy horizontal flux of angular momentum in January and July, 1996, and its forecasting vulue at various forecasting times. In both the winter and summer hemispheres, there exist convergence in mid – latitudes and divergence in subtropics. However, either the convergence or the divergence in the winter hemisphere is much stronger than in the summer hemisphere. As the forecasting extends, the convergence in mid – latitudes increases, and reaches its maximum at 96 hours. This is in coordinate with the evolution of forecasting errors of the forecasted westerly jet as shown in Fig. 1, simply because the westerly acceleration in the mid – latitudes is mainly due to the convergence of the eddy angular momentum transfer there (zhang, et al., 1995).

The CNMC T63 model has included the impacts of the gravity wave drag forced by orography. This contributes to the remarkable improvement in the wind forecasts compared with those of the T42. However, as the mechanical forcing induced by orography and friction in the T63 model differs from reality, the systematic errors in wind forecasts still exist.

4. Temperature field and thermal energy budget

The cross – sections of the observed temperature in January and July, 1996 and the corresponding forecasting errors at different forecasting times are presented in Fig. 3. Forecast error in temperature also keeps similar spatial pattern and grows slowly throughout the forecast period. In January (left panel) negative errors appear in the lower troposphere, in the polar regions in the middle and upper troposphere. In the upper stratosphere, negative errors exist in the boreal mid - latitudes and in the extra - tropics of the southern hemisphere. Positive errors are observed above 700hPa in the tropics, and in the high latitudes of the boreal stratosphere. Errors in the latter region grows faster than in other regions. Such error distribution makes the temperature gradient in the northern hemisphere stronger than observation in mid - latitudes, but weaker in high latitudes, in good correspondance agreement with the distribution of systematic error of the zonal wind forecasts presented in Fig. 1. In July (right panel of Fig. 3) the whole characteristics of the error distribution is similar to that in January except the existance of negative error near 300hPa in high latitudes. The error grows with time, and results in stronger temperature gradient as well as westerlies in mid - latitudes. In addition, the vertical temperature lapse rate in high latitudes in the troposphere become larger in the forecasts than in the observation. Despite these, the forecast errors in the T63 model are much weaker than in the T42 model. This is because in the T63 model, the interaction between cloud and radiation has been better presented, when radiation flux are calculated, the gray body effects for either cloudy or clear sky, and the effects of tracer gases have been considered.

The mean meridional circulation plays an important role in the sensible heat transfer in tropics. In January, it transfers heat from the northern hemisphere to the southern hemisphere. whereas in July it transfer heat from the southern hemisphere to the northern hemisphere. The T63 model captures this characteristics (figure not shown). However, the forecasted cross - equator transfer decreases with forecast time. This is due to the forecast errors in MMC as will be discussed in the next section, and contributes to some extent the cooling of the lower troposphere in the tropics in the forecast.

5. The mean meridional circulation

In January 1996, the center of the observed Hadley cell is at 400hPa to the north of the equator. Its intensity is about 180×10^6 ton s^{-1} (Fig. 4, bottom left). The 96 - hour forecacted MMC possesses positive error only in the low level of the boreal tropics, but negative elsewhere (third panel on the left). It is much weaker than the observed. In contrast, the forecasted Hadley cell in the southern hemisphere and the direct cell in the northern high latitudes are stronger. In July, the center of the southern Hadley cell is at 300hPa near the equator, with an intensity of 240×10^6 ton s^{-1}. In the forecasts, its intensity decreases gradually, but its sinking branch in the southern hemisphere becomes stronger.

The general weakening of the forecast Hadley cell can be detected from the forecast errors in meridional and vertical wind components. Again, we focus on the 96 hour forecasts. The maximum errors in v - is negative in January and positive in July just above the main Hadley centers, and oposite in directions to the observed cell (second row in Fig. 4). The errors in vertical motion on both the northern and southern sides of the main Hadley cells in January and July are also in the oposite directions of the Hadlly cells. These together contribute to the weakening of the forecasted Hadley cells. The weaking of the Hadley cells implies the insufficient near-equatorial heating. Rising there is then suppressed, and meridional air flux reduced. The too strong sinking in the subtropics then must be attributed to the stronger Ferrel cell forecasted in the winter hemisphere.

6. Moisture and its budget

As usual, moisture is distributed in the lower troposphere with maximum near the equator. However, as forecasts proceed, the moisture contents of the model atmosphere decrease (figure not shown). To understand this, the forecast errors in the meridional divergence of moisture flux have been analized. In January positive errors exist in the poleward sides of 20°, whereas negative errors in the tropics between 20°S and 20°N, indicating too much moisture convergence towards the tropical region. In July the error distribution pattern are similar with that in January except between 30°N and 45°N in the northen hemisphere where negative errors in moisture flux divergence exist. The extra moisture convergence in the tropical region in the T63 forecasts is in favor of the increase of moisture content there. However, from the distribution of errors in the residual term by which the moisture sinks or sources are implied, we see that the main deficit of moisture source in the forecasts occurs in the tropical region. It then means that there is too much forecasted precipitation in the tropics, so that the model atmosphere in the tropics becomes drier.

7. Discussions and conclusions

(1) The analyses of the forecast errors of the T63 in January and July of 1996 show that the performance of the second generation of the medium – range numerical forecasting model of the CNMC has been improved remarkably compared with that of the first generation model. Particularly the forecasts of the westerly jets and the temperature in the low latitude region are rather satisfied. This is due to the fact that the new generation model has introduced the impact of the gravity wave drag induced by orography, treated more properly both the short – and long – wave radiation processes, and improved the parameterization of culmulus convection.

(2) The analyses in this study show that the intensity of the forecast westerly jets in the winter hemisphere are still stronger than observation. Diagnoses on the mean distribution, meridional transfer, and budget of angular momentum of the T63 model atmosphere reveal that the errors are mainly caused by the exaggeration in the convergence of eddy angular momentum flux in the mid – latitudes, and suggest that the further improvement in the treatment of external mechanical forcing, such as orography and surface friction, are required.

(3) Large errors in temperature forecasts exist in the polar region of the upper troposphere and strato-

sphere. This may be attributed to the inaccurate treatment of radiation processes, particularly the cloud – radiation interaction, near and at the two poles. The lower layer temperature in the T63 model is lower than in reality. This may be a result of insufficient heating in the lower troposphere, and can weaken the upward motion and the meridional mass exchange. The insufficient north – south heat exchange in the upper troposphere makes the temperature gradient in mid – latitudes increase, in correspondance with the increase in westerlies. The errors in temperature forecast also affect the forecast in geopotential height. The forecasted subtropical anticyclone over the north western Pacific in the T42 is too strong, whereas it is too weak in the T63. This makes the forecasted subtrpical westerlies in the lower and middle troposphere become weaker as well, and the north boundary of the forecasted rain belt shift slightly southward.

(4) The model atmosphere in the tropics is drier than in the real atmosphere. The diagnoses on the moisture budget errors show that this is partly because the moisture transfer from subtropical region to high latitudes in the T63 is too large, and partly because too much precipitation occurs in the region. The latter may be associated with either inaccurate convective parameterization or the usage of "bucket" scheme in the model for land suface processes. Further improvement should be anticipated.

(5) The mean meridional circulation is a kind of secondary circulation forced by either dynamical or thermodynamical imbalance. It reflects synthetically many important messages, and can be used as an important element in assessing the behaviors of a NWP model.

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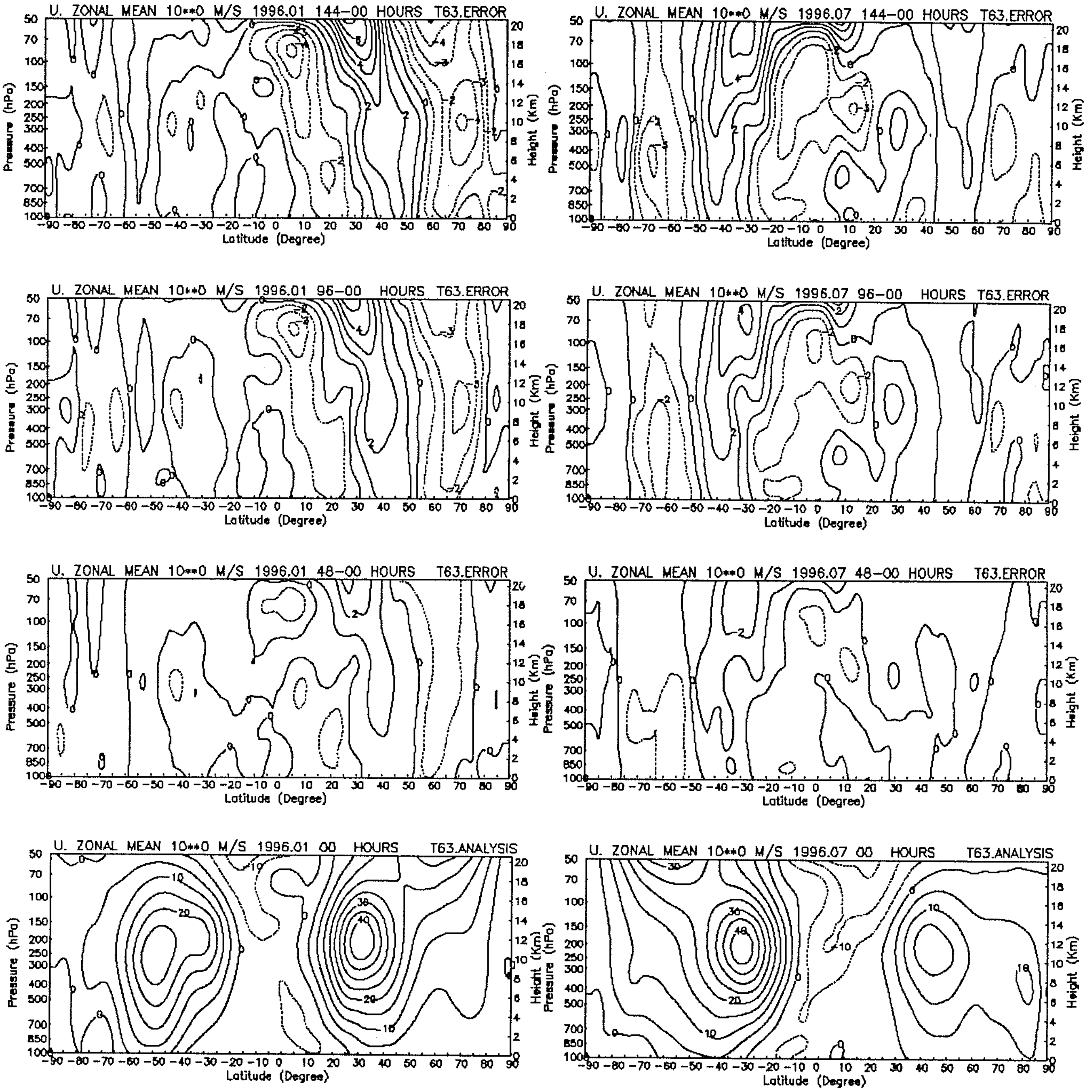

Fig. 1 The analyzed monthly mean January (left) and July (right) meridion – height cross – sections of the zonal mean westerly and the corresponding forecast errors at different forecast times of the T63 model. Unit is in ms^{-1}.

From top to bottom: errors at 144 – , 96 – , and 48 – hour forecasting time, and the analysis.

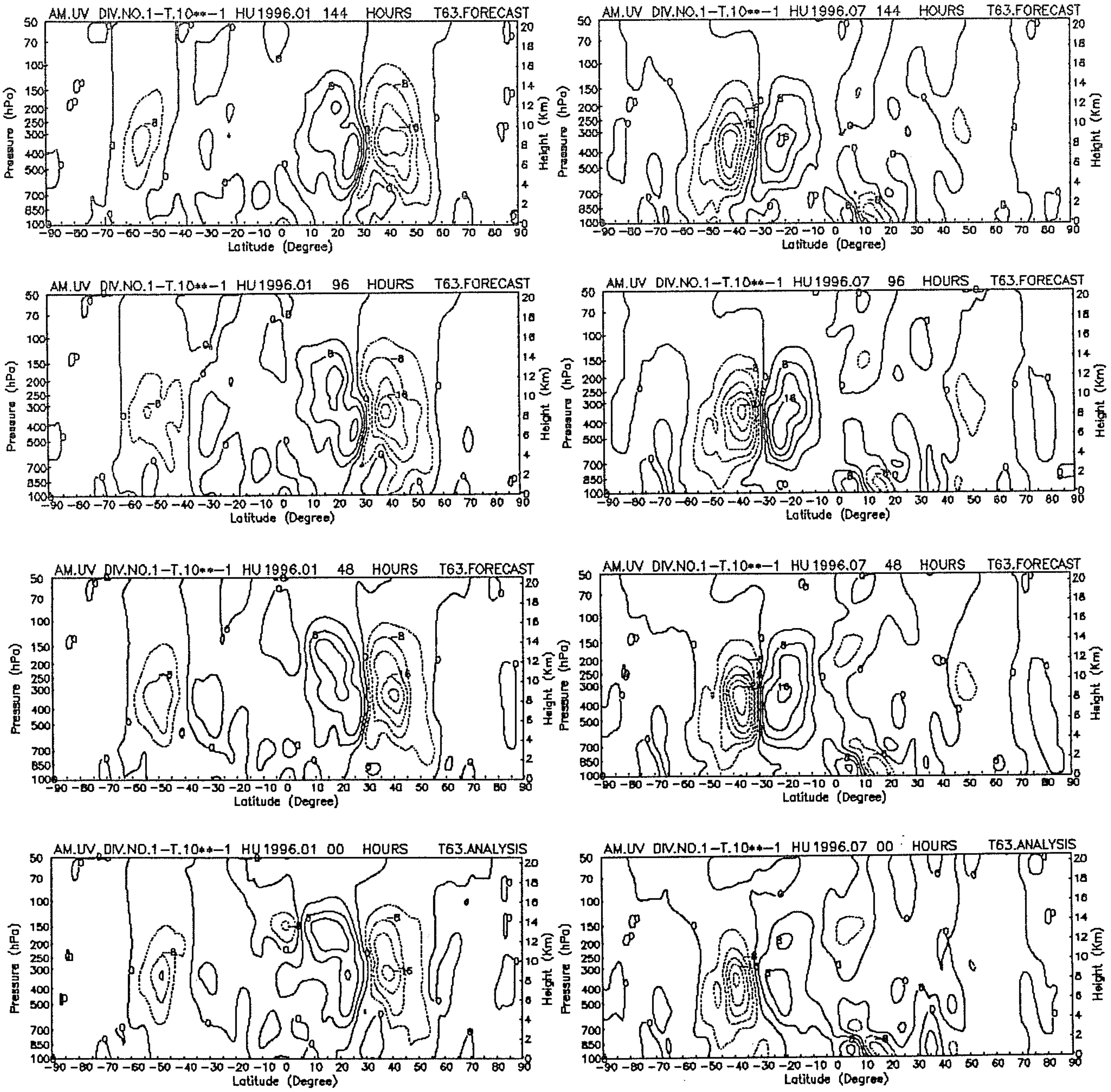

Fig.2 The same as in Fig.1, except for the divergence of eddy angular momentum flux. Unit in 10^{-1} Hadley Unit. 1 HU$=10^6$ TON/s.

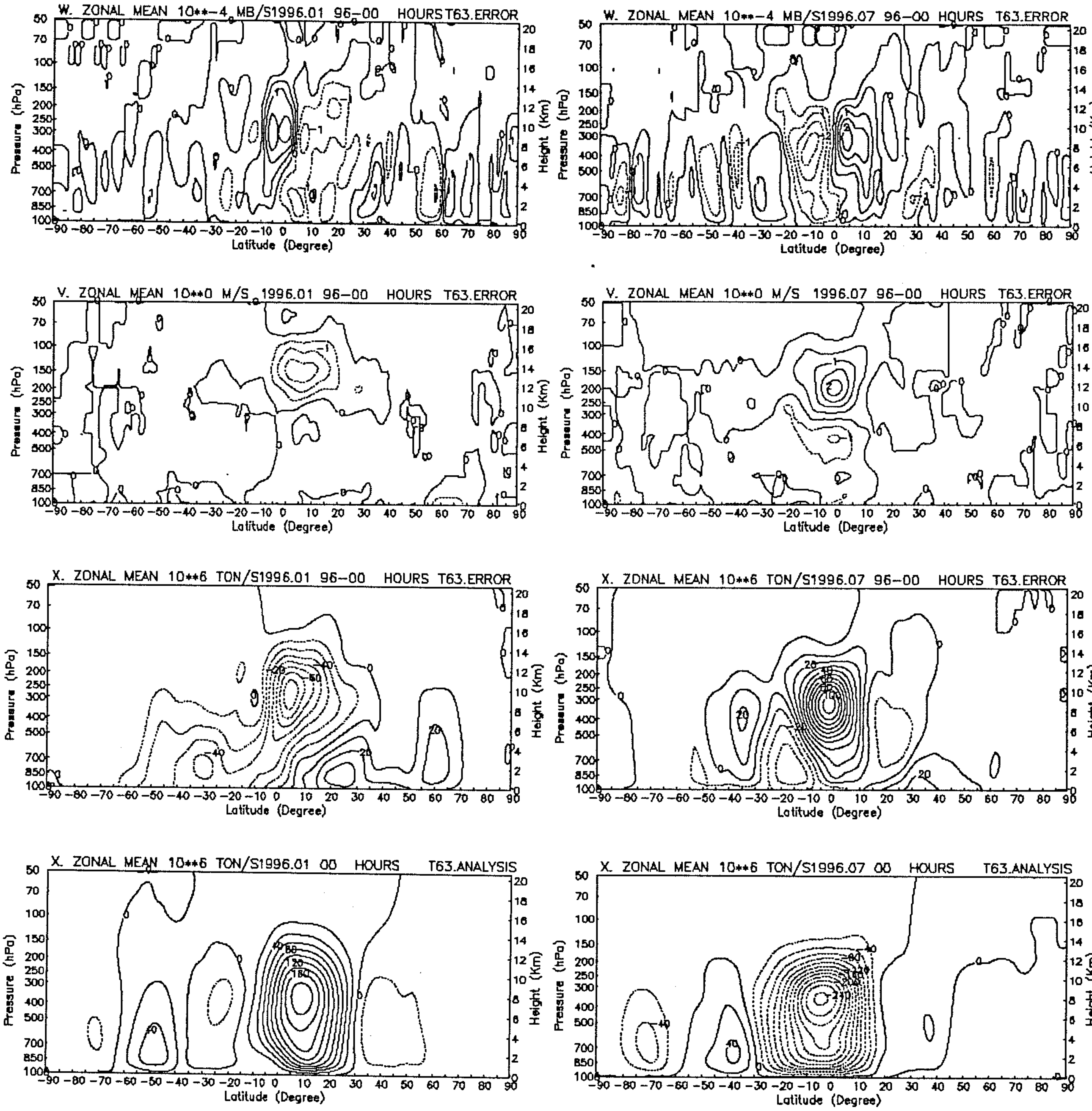

Fig. 3 The same as in Fig. 1, except for the monthly mean temperature. Unit in ℃.

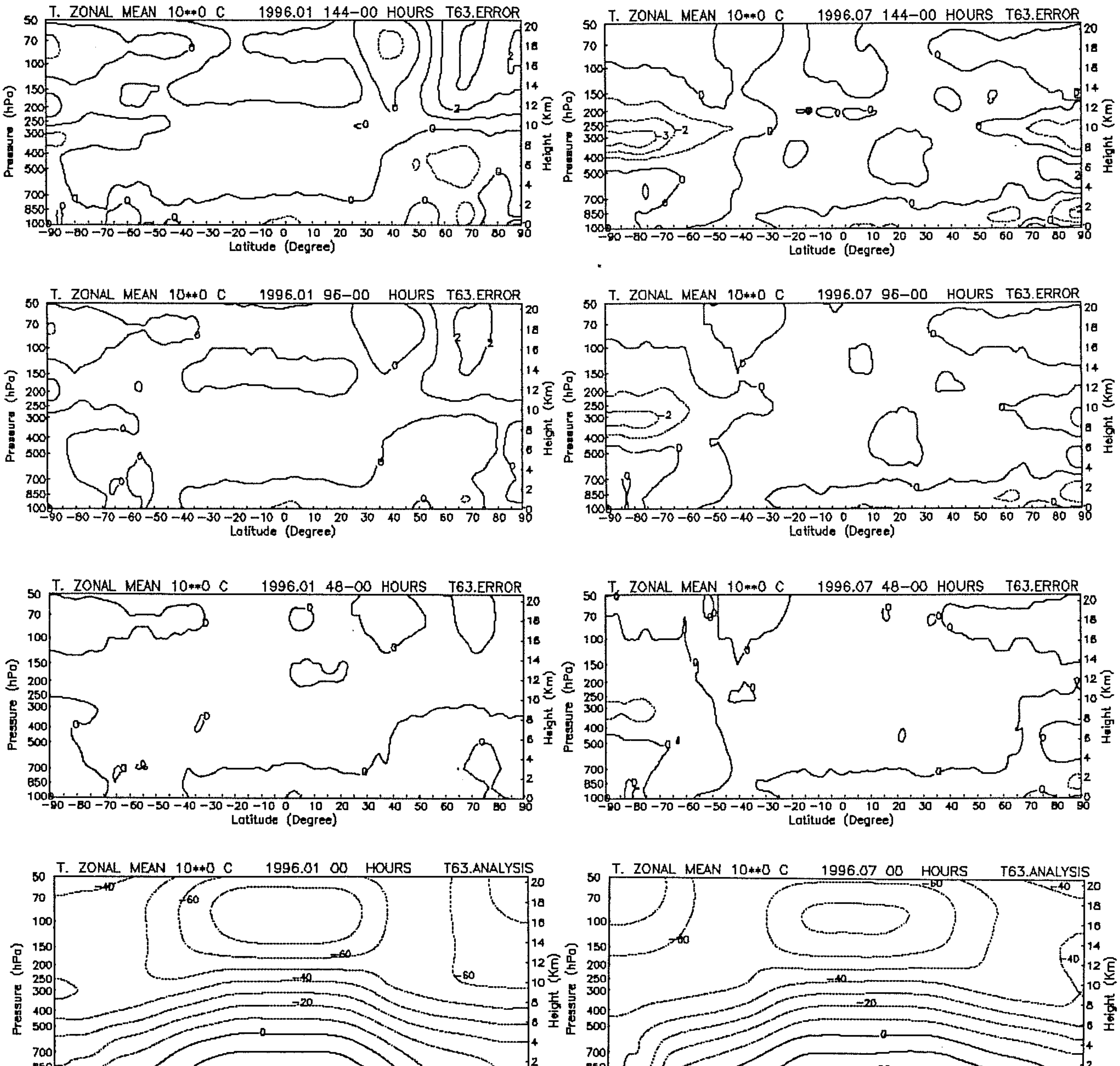

Fig. 4 The analyzed monthly mean January (left) and July (right) meridion – heigh cross – sections of the MMC and the error distributions of the associated fields forecasted at 96 hours. From top to bottom; errors in "vertical velocity" $\omega(10^{-4}$ hPa $s^{-1})$, meridional wind $V(m\ s^{-1})$, and MMC $(10^6$ ton $s^{-1})$, and the analyzed MMC $(10^6$ ton $s^{-1})$.