DIAGNOSTICS OF DIABATIC PROCESSES IN GLOBAL NUMERICAL EXPERIMENTS AT ECMWF

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1. INTRODUCTION

Numerical medium range weather forecasts are produced at ECMWF on an operational basis since September 1979. The verification of the forecasts showed that the forecast quality stayed rather high for the first 3 days but deteriorated rapidly beyond day 3 and became rather poor on average after day 5. This was found by means of objective measures as by rms errors or by correlation coefficients as well as by subjective verification from synoptical aspects. The rapid decrease in forecast quality beyond day 3 is presumably caused by

a) uncertainties in the initial flow and

b) deficiencies in the forecast model.

The verification of the forecasts revealed also the existence of systematic errors which reduces the forecast quality. The systematic errors are briefly summarised as follows:

1. Overintensified lows in the midlatitudes: i.e. there is a tendency to predict lows which develop deeper than observed, which decay at a slower rate than observed and which propagate further eastwards than in reality. As a result the model's time-mean pressure is lower over the eastern parts of the oceans and over the western continental areas. The Aleutian low and the Icelandic low are therefore also deeper and are displaced eastward.

2. Increase of zonal westerly flow at mid-latitudes and decrease of the zonal flow at low and high latitudes. This becomes evident from the zonally averaged flow.

3. Net cooling of the atmosphere during the forecasts. The largest cooling is observed in the mid-troposphere and is found over the whole northern hemisphere.

The errors were observed every month for which operational forecasts have so far been verified at the Centre, i.e. from September 1979 to February 1980. The consistency of these errors suggests strongly that they are independent of the initial flow but reflect a deficiency in the forecast model and it was suspected that they indicate a trend towards a climate in the forecasts which differ from that of the atmosphere. It was therefore that a number of extended predictions up to 50 days were carried out. These integrations proved indeed that the models climate deviates significantly from that of the atmosphere. Moreover, it became evident that the characteristic errors observed in the operational medium range forecasts are also features of the model's climate.

In the following section results will be presented from a 50-day integration using the EC operational forecast model, i.e. N48 - 15-level global gridpoint (Burridge and Haseler (1977)) with the physics as described by Tiedtke et al (1979).

2. RESULTS FROM AN EXTENDED RANGE FORECAST

The results presented here are the time-mean averages taken over the forecast period from 20 to 50 days. For verification we use the February climate and the mean flow observed in January and February 1979.

Fig. 1 shows the global distribution of the simulated 30d-mean 1000 mb height field and the February climate height field. The overall global distribution is realistic, as the main pressure systems are present in the simulation experiment. However, we notice rather large deviations over parts of the northern hemisphere. The Icelandic and Aleutian lows are far too deep and shifted to the east. The subtropical high pressure cells are also shifted eastwards and are situated over the continents, where in reality the pressure is low. The flow is however well simulated over the tropics and over the southern hemisphere, as agreement with observation is found for the tropical continental cyclones, the subtropical highs as well as to the strong flow between 40S and 60S and the low pressure belt north of Antarctica. The inferior simulation in the northern hemisphere in comparison to that of the southern hemisphere is related to the presence of larger amplitudes of the stationary long waves. Indeed, a Fourier analysis of the model's height field shows that a large part of this error is due to an eastward shift of the wave of zonal wavenumber 2 by 45°. The comparison of the simulated and observed 500 mb height fields (not shown here) leads to similar deductions, i.e. large errors in the northern hemisphere whereas again simulated and observed flow agree better in the southern hemisphere. Although the time mean flow is badly simulated in the northern hemisphere, the variance of the 1000 mb height field agrees well with the observed values (Fig. 2). Simulated and observed fields show the largest values over those parts of the oceans where cyclones appear most frequently. This indicates that the energetics of the medium long waves (zonal wavenumbers ~ 4-9) are rather well simulated.

Deficiencies in the simulation appear also in the axially symmetric part of the flow. Figs 3 to 5 show for the northern hemisphere the observed and simulated mean zonal wind and the zonally averaged temperature including their deviation from the observed values and also the mean meridional circulation. The most

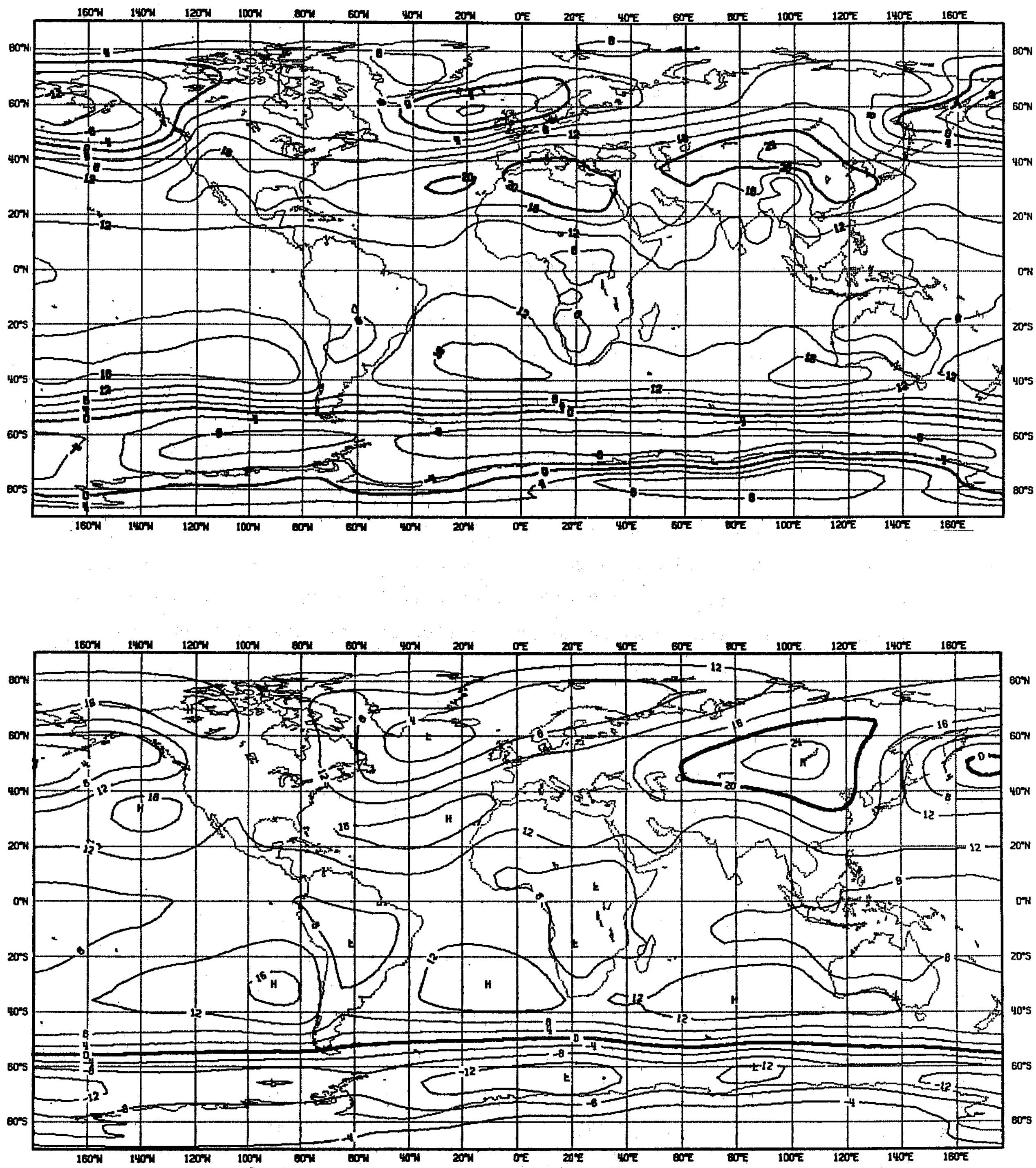


Fig. 1 Global 1000 mb height fields
upper panel: model, days 20-50
lower panel: NCAR February climatology

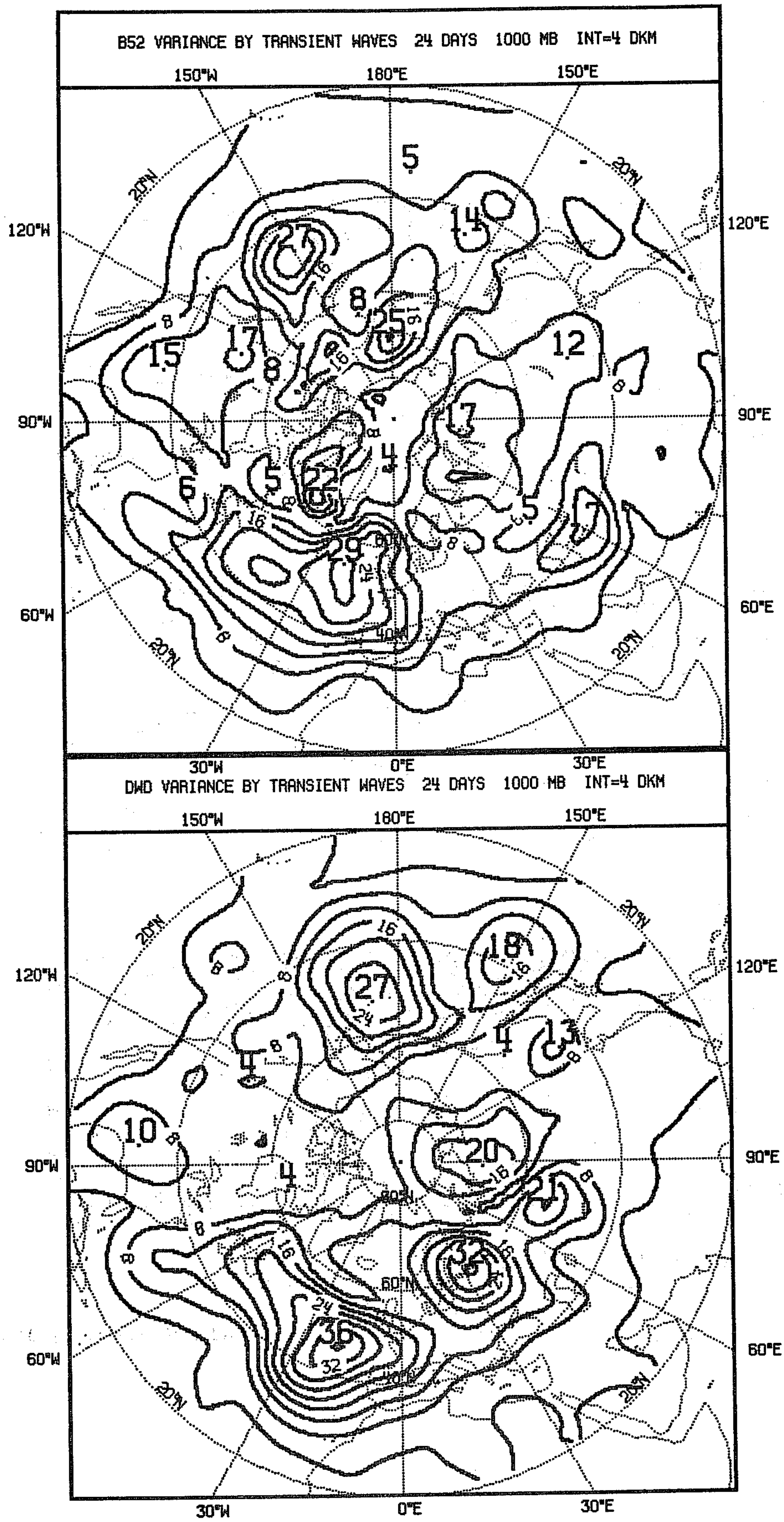


Fig. 2 Variance of the 1000 mb height field
upper panel: model days 24-48
lower panel: DWD February 1979

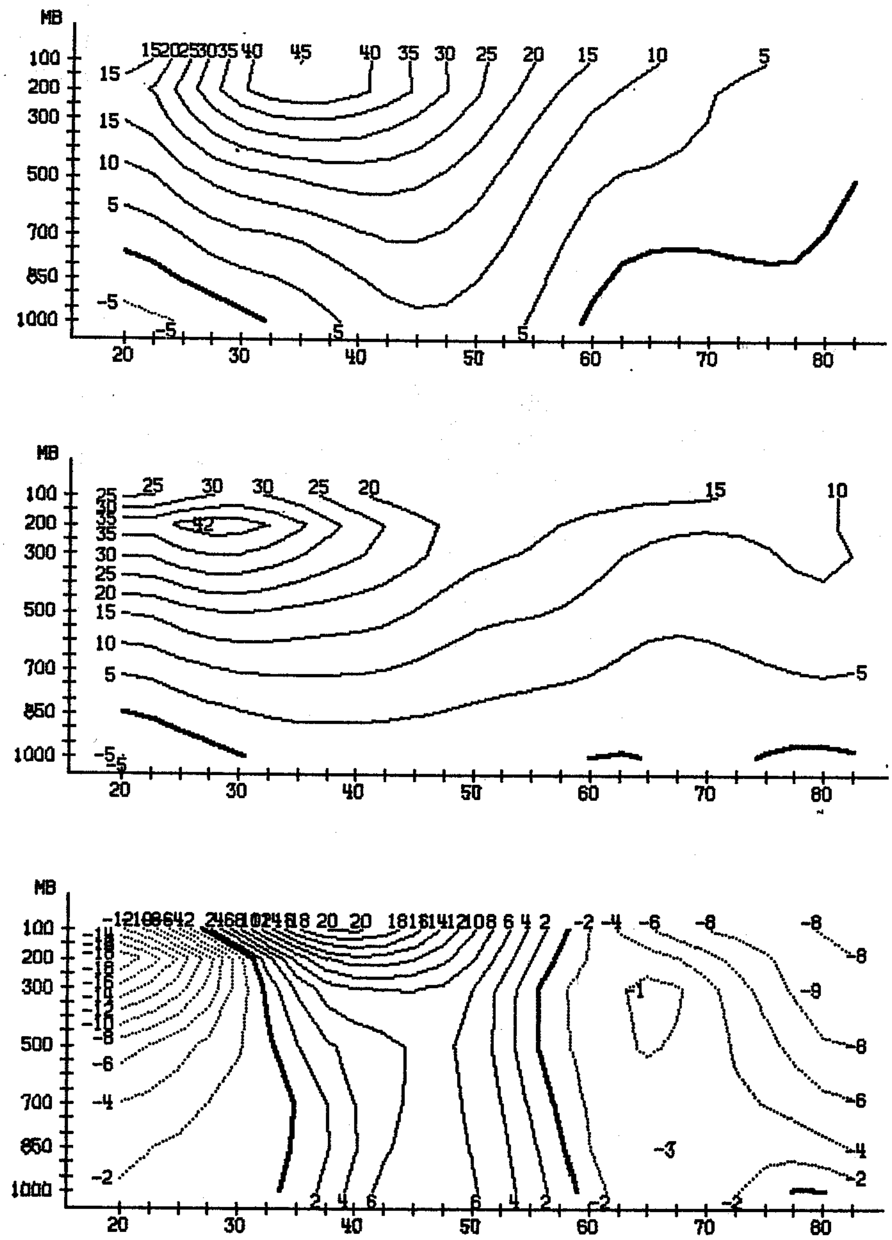


Fig. 3 Zonal mean of the geostrophic wind, m/s
upper panel: model, average of days 25-48
centre panel: DWD February 1979
lower panel: difference between model and DWD February 1979

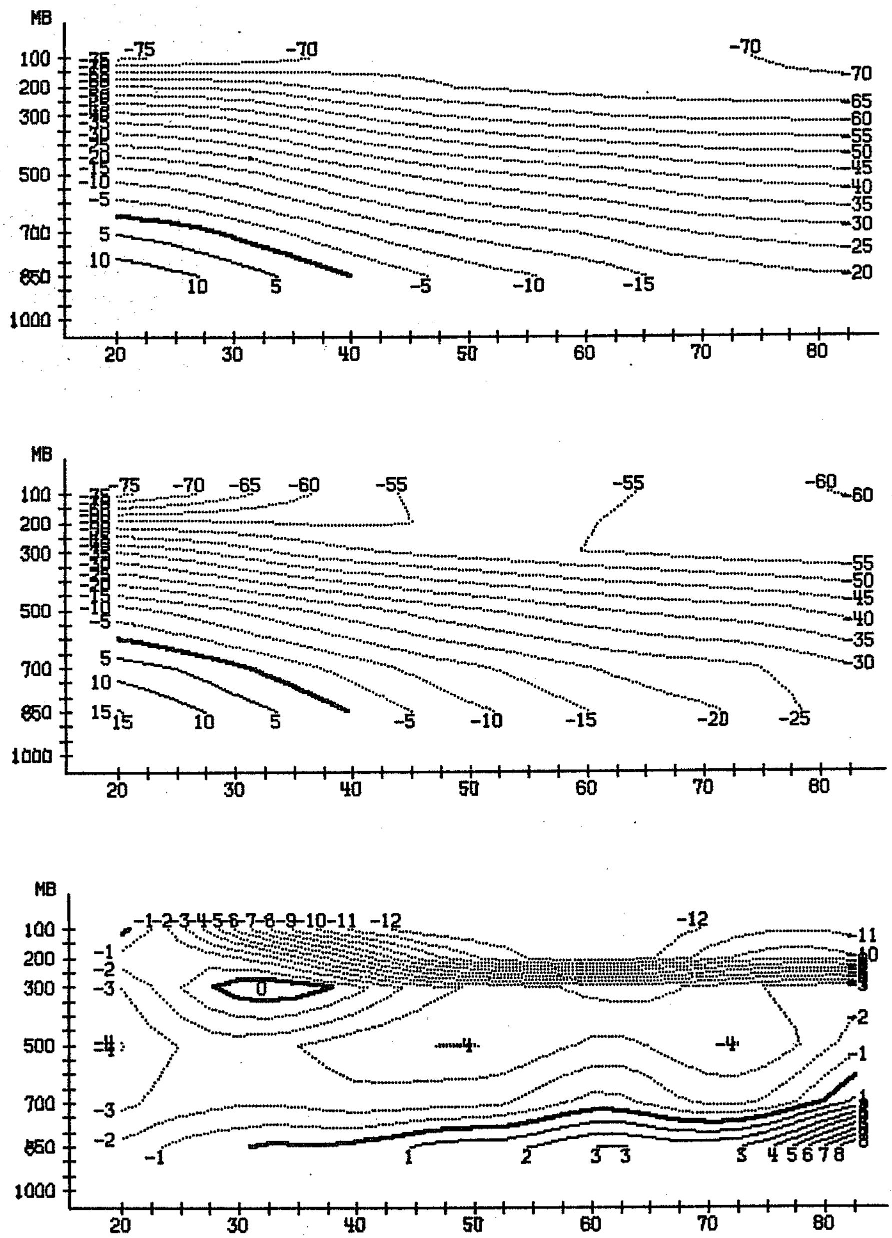
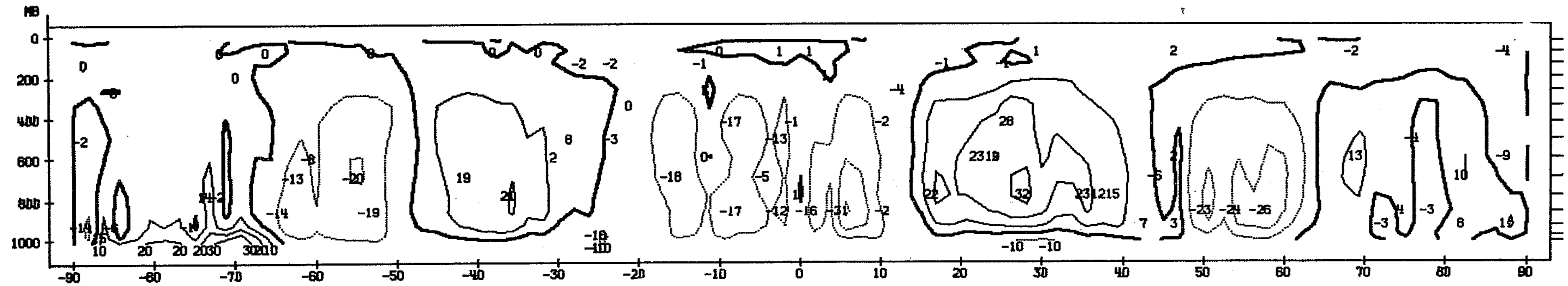
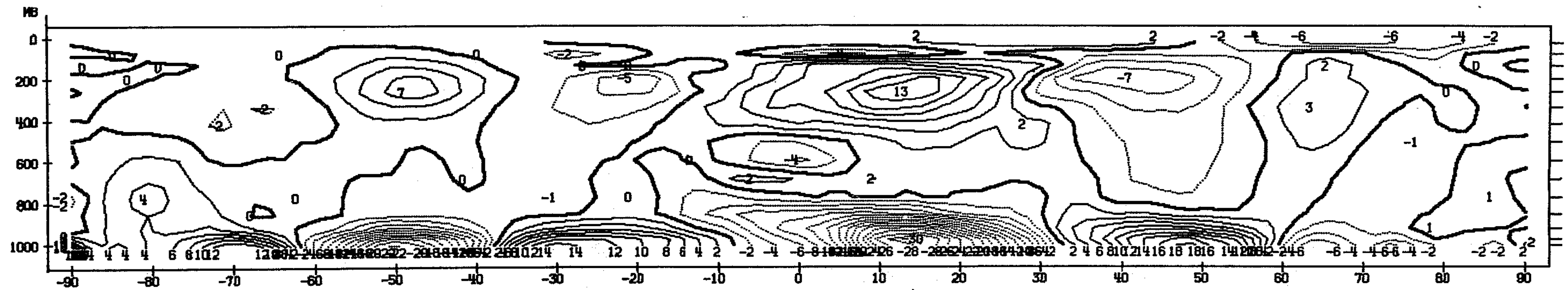


Fig. 4 Zonal mean of temperature, ^{o}C
upper panel: model, average of days 25-48
centre panel: DWD February 1979
lower panel: difference between model and DWD February 1979





50 Day forecast from 16/1/1979 0 GMT

February

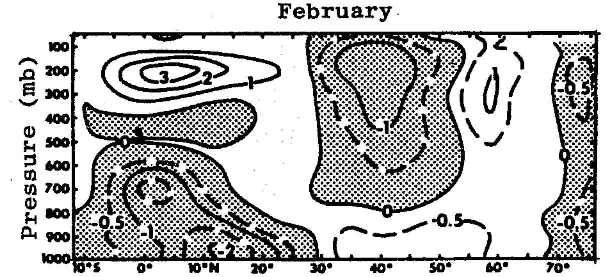


Fig. 5 Meridional circulation
upper panel: model, vertical velocity, 10^{-3} Pa/s
centre panel: model, meridional velocity, Dm/s
lower right panel: meridional velocity, cm/s after Oort and Rasmussen (1971)

notable deficiencies in the zonal wind (Fig. 3) are:

1. The substropical jet is not closed off.

2. The centre of the jet is shifted northward by about 8°.

3. The zonal flow is increased at mid-latitudes throughout the atmosphere and decreased at high and low latitudes. Notable also is the large change of horizontal shear associated with the change of the subtropical jet. This will certainly affect the barotropic energy conversion rates.

With regard to temperature (Fig. 4) we notice that:

1. The lower part of the troposphere is warmer especially at high latitudes (up to 8° in 850 mb at the north pole).

2. The middle and higher troposphere are rather uniformally too cold by 4°.

3. The stratosphere is even colder with differences up to 12° and the tropopause is therefore displaced to higher levels by almost 1000 mb.

The largest effect of these temperature errors on the adiabatic process is presumably by means of the state stability which is reduced by 50% in the mid-troposphere. This change in static stability may influence the growth rate and probably also the horizontal scale of baroclinic waves. The model's diabatic processes which cause the net cooling of the model's atmosphere are discussed below.

The model's mean meridional circulation (Fig. 5) contains the Hadley and Ferrel circulation; however, the Hadley circulation is too weak compared to Oort and Rasmusson (1971) values and in particular the depth of the equatorial region of northerly flow appears to be too shallow.

As the mean meridional circulation is only the net result of locally large and small values, the global distribution of the divergent wind in terms of the velocity potential was also studied and was compared with the monthly mean values for January 1979 as analysed at ECMWF and with the mean winter values as given by Krishnamurti et al (1973). Fig. 6 shows the simulated and observed distribution of 200 mb, where the differences between simulation and observation became most apparent. The model's distribution at 200 mb is dominated by a

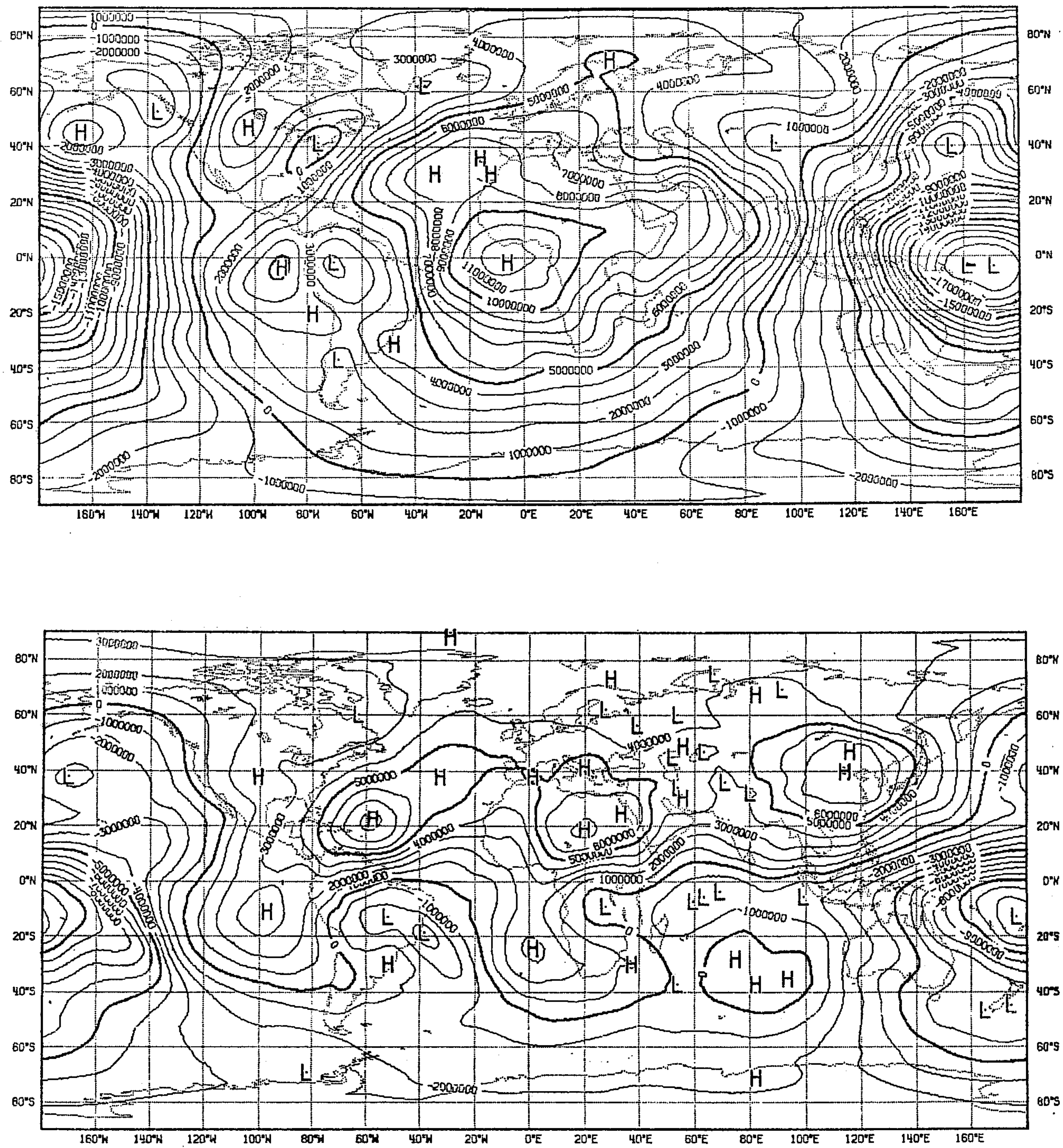


Fig. 6 Velocity potential at 200 mb
upper panel: model, days 20-50
lower panel: observed, January 1979

wave of zonal wavenumber 1 with its minimum (diffluent point) over the West-Pacific and its maximum (confluent point) over the East-Atlantic. The large source of diffluent flow over the Pacific coincides with the area of maximum convective heating in the model (Fig. 11). The observation on the other hand gives a much weaker minimum over the Pacific, but contains instead two further although weaker minima over the Indian Ocean/East Africa and over South America. The absence of these minima in the simulation experiment may be due to insufficient forcing by convection in those areas. In fact, the simulated precipitation is significantly smaller over South America and especially over East Africa than observed. The lack of convective heating over the tropical continents is probably a consequence of the elimination of the diurnal cycle in the simulation experiment. From the velocity potential distribution we can deduce the divergent part of the horizontal wind. It appears, that the east-west circulation and especially the Walker circulation over the Pacific is far too strong in the simulation.

One of the major deficiencies in the simulation is the net cooling of the model's atmosphere. This cooling is caused by an imbalance between the global radiative cooling and the global heating by surface fluxes, by large-scale condensation processes and by convection (Fig. 7). Although the imbalance is largest in the first 10 days, it holds throughout the whole integration period. Considering the different processes we find: the surface fluxes of sensible heat are smaller, on average by about 20%, probably because the lowest layers of the model are too stable (Fig. 8). The latitudinal and vertical distribution of heating by large-scale condensation processes and by convection seems reasonable, although it is difficult to verify and therefore not presented here. However, the amount of convective heating is much too small. This is confirmed by comparing the model's total precipitation rate with the February climatological values (Fig. 9), which shows differences up to 40% in the tropics. The small rate of convective precipitation is consistent with the weak mean meridional circulation mentioned before, which provides also a too small moisture convergence into the tropics compared to the moisture convergence derived from climatological data given by Oort and Rasmusson (1971) (Fig. 10).

3. SENSITIVITY EXPERIMENTS

As the deficiencies in the adiabatic flow and the non-adiabatic forcing were found to be rather coherent, a number of sensitivity tests have been carried out using the more economical spectral model. 50-day integrations have been made, where

a) the horizontal resolution and

b) the parameterization scheme have been changed.

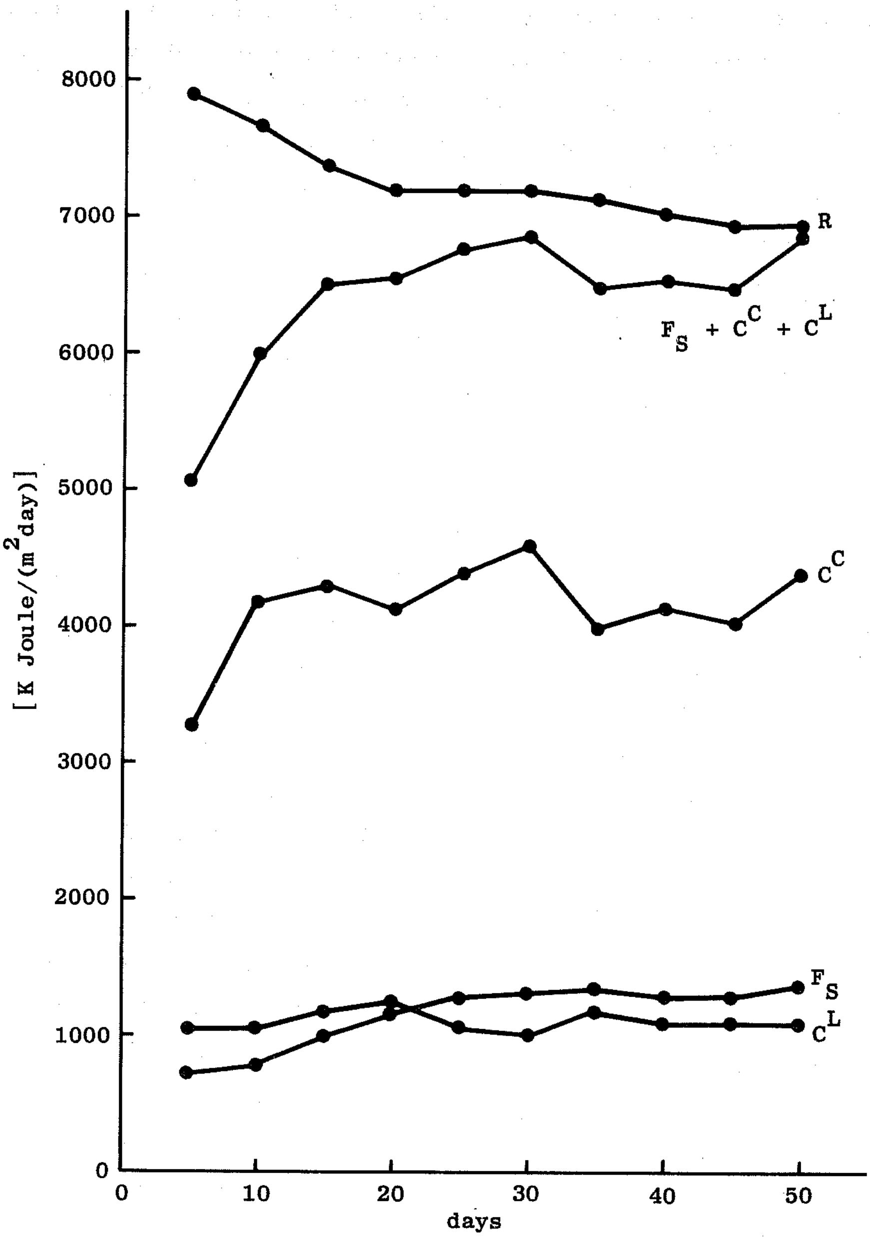


Fig. 7 Evolution of the global radiative cooling (R), and the global heating by surface fluxes (F_S), large-scale condensation (C^L) and convective heating (C^C) for Experiment B52

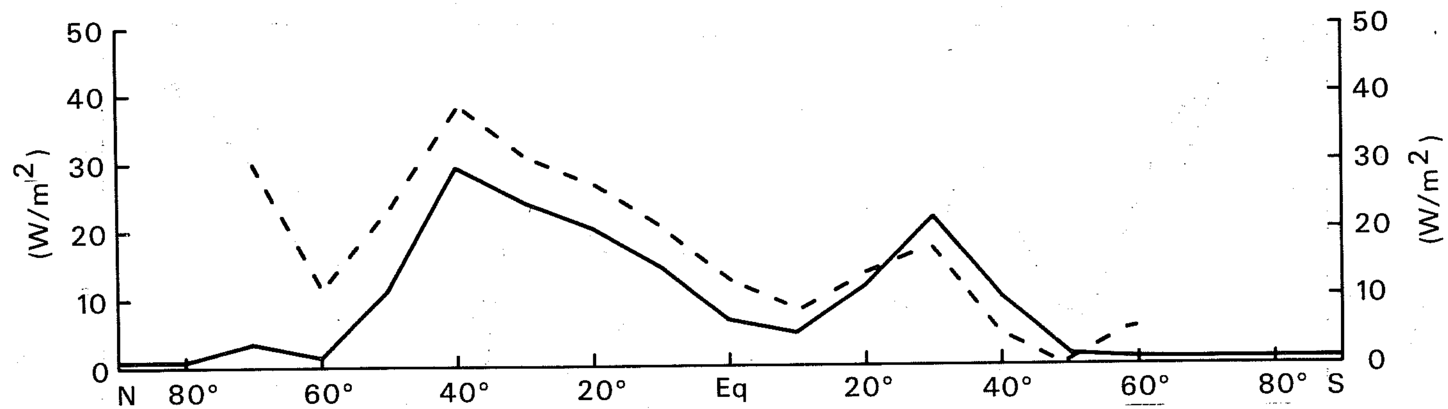


Fig. 8 Latitudinal distribution of zonal averaged surface heat flux for model (full line) and observed for January after Schutz and Gates (1971)(dashed line).

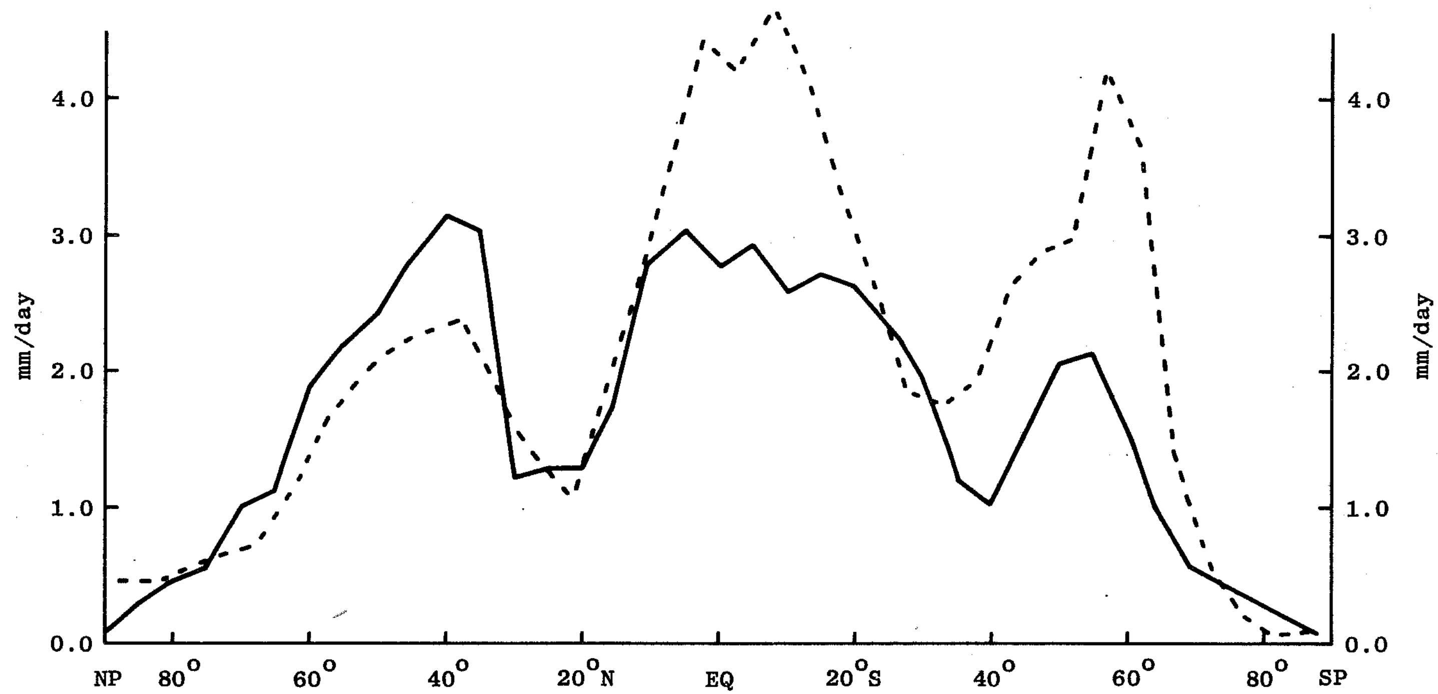


Fig. 9 Latitudinal distribution of zonal averaged rainfall rates (mm/day) for model (B52) and observed for Dec-Feb after Jaeger (1978) (dashed lines).

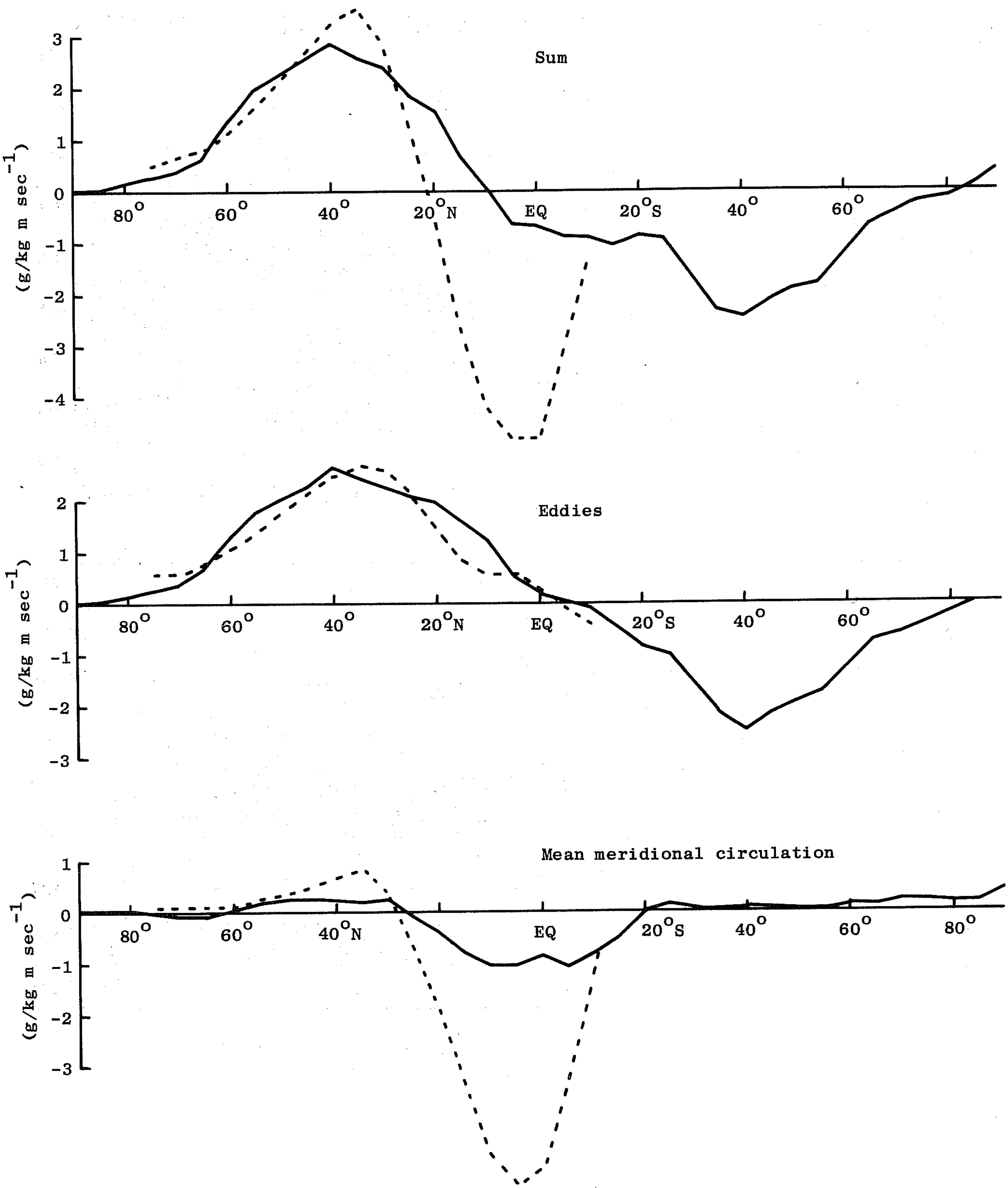


Fig. 10 Meridional transport of moisture by mean meridional circulations and eddies for experiment B52 (20-50 days) and for February after Oort and Rasmusson (1971) (dashed lines)

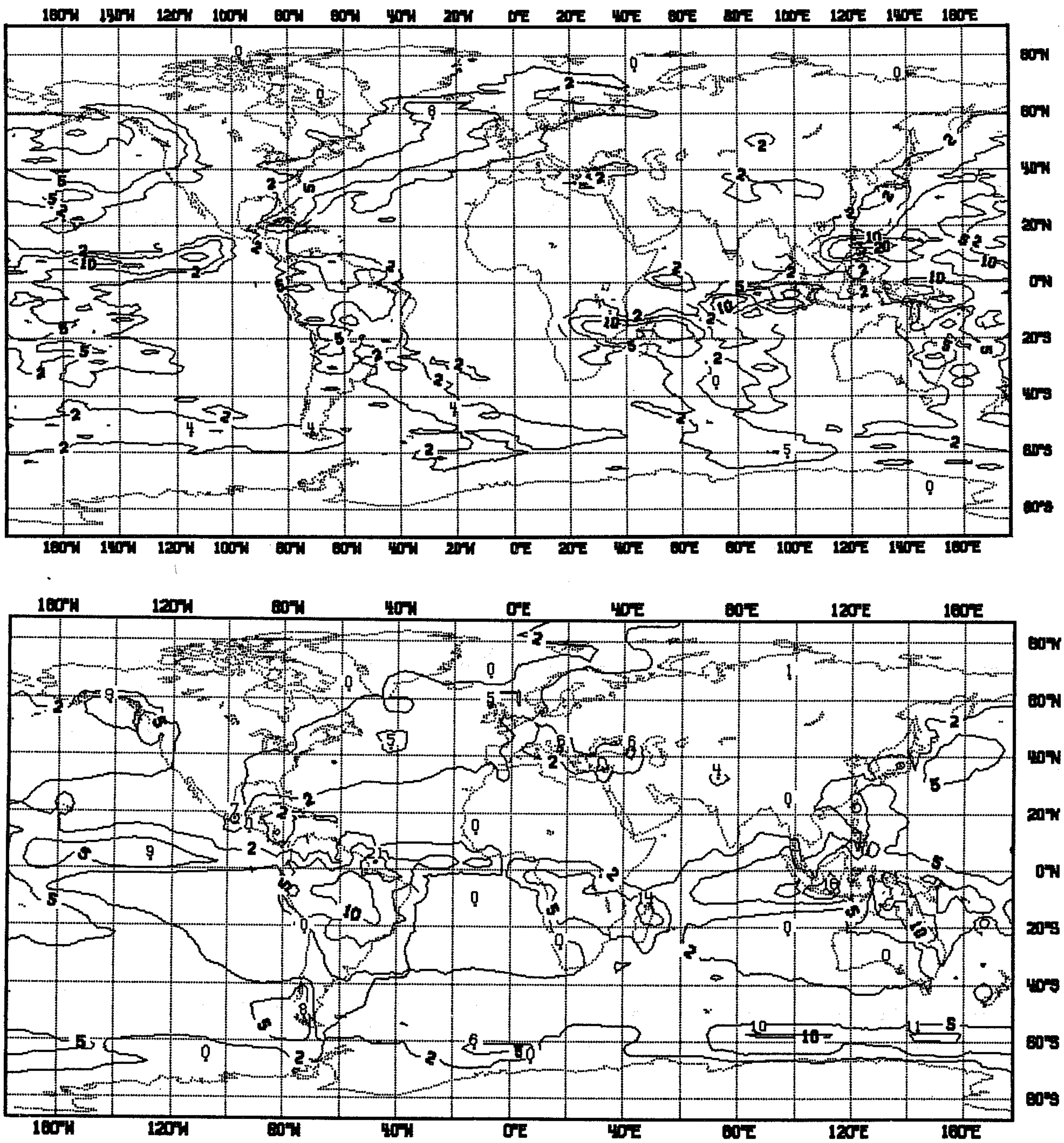


Fig. 11 Global distribution of total precipitation, mm/day
upper panel: model average over days 20-50
lower panel: after Jaeger (1976)

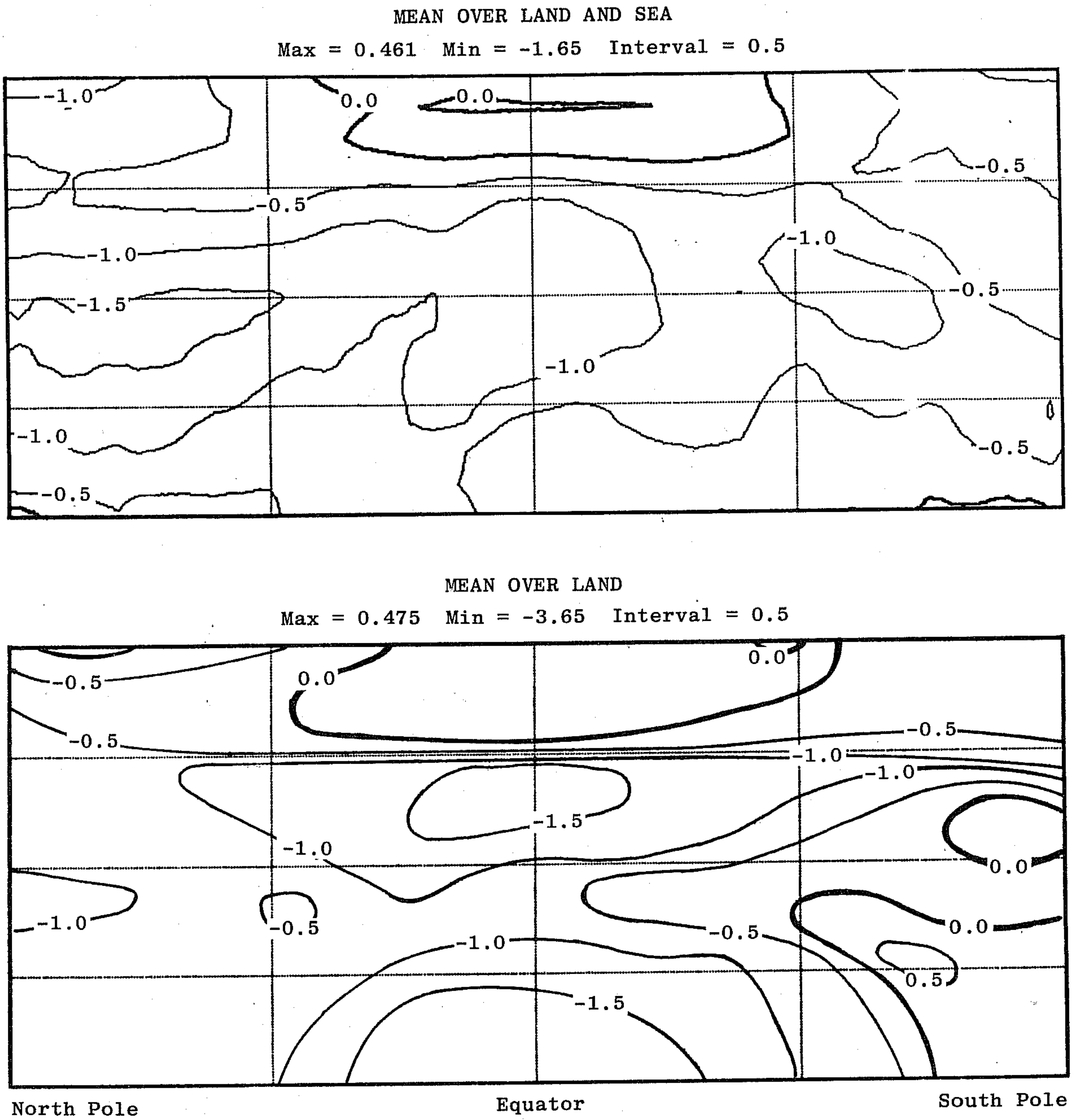


Fig. 12 Zonal mean radiative cooling °C/day
upper panel: model, average over days 0-50
lower panel: after Dopplick (1972)

The resolution sensitivity experiments (resolution T21, T40 and T63) revealed that the systematic error in the mean flow is present in every simulation, although the simulation with the lowest resolution T21 gives the smallest error. The differences in the overall atmospheric cooling are very small. The only significant impact was found, when the vertical transport of moisture for moist convectively unstable stratification was increased. This resulted in an acceleration of the hydrological cycle and in an increase of the surface moisture fluxes, whereby the non-adiabatic heating was increased and the overall cooling was removed. A further experiment where the Kuo convection scheme has been replaced by the Arakawa-Schubert (1974) scheme showed that the A-S scheme gave more convective heating (less net cooling) in the early states of the intetration but after 10 days the model's atmosphere drifted toward the same too cold state. There was also not found any significant sensitivity to the radiation scheme used, being either the interactive radiation scheme developed at the Centre or the climatologically controlled radiation scheme designed at GFDL.

References

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