TECHNICAL MEMORANDUM

12

Preliminary assessment of a 50-day run with the ECMWF operational forecast model

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Preliminary assessment of a 50 day run with the ECMWF operational forecast model

by

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1. INTRODUCTION

Hollingsworth et al. 1979 gave a first insight into the usefulness and deficiencies of the medium range forecasts by the ECMWF model. It was shown there that the troughs in the 500 mb height fields, which are normally found over the western Atlantic and the western Pacific, moved during the course of the 10 day forecast further to the east. A further deficiency was the loss of long wave eddy kinetic energy of the standing waves during the 10 days of forecast.

One reason for doing this 50 day run with the ECMWF model was to find out if those troughs go on moving after 10 days or if they would come to another equilibrium position which might then improve the energetics of the standing waves. Furthermore, we wanted to see the statistical properties of the model's atmosphere undisturbed by possible problems by initial data. This latter point could probably best be achieved by choosing initial data which give a forecast with very good skill at the beginning.
We chose, therefore, the data of the 16 January 1979 as initial day for our 50 day run. The anomaly-correlation coefficients of height fields in Fig. 1.1 for the first 20 days of this run show the good skill for the whole troposphere north of 20^{O}N. The 60% level is reached after $7\frac{1}{2}$ days at 1000 mb and on day 11 in the upper troposphere. This was taken as a measure of predictability in Hollingsworth et al. (1979).

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In spite of this good start of the forecast there are indications that major changes occur already at the start. They become obvious by the coefficients of mode one of the empirical orthogonal functions of the 500 mb height fields in Fig. 1.2. The coefficients of the forecast drops from -150 to -180 m during the first day while they stay almost constant for the analyses. From then on they stay 20 to 30 m below the observed ones for 20 days. It is not easy to see the reason for this from this single run but monthly averages of the operational two day forecasts show broadly a reduction of the 850 mb temperature by 2K over continents,while there is a slight increase over the oceans.

2. TIME AVERAGED MASS AND WIND FIELD

We will first investigate, as others have done, whether the mean maps of the 1000 and 500 mb height fields of our forecast look the same as the climatological ones. For practical reasons we took averages between day 24 and 48 of the 50 day run. We shall call these averages the model's climate. We restrict ourselves mainly to the areas north of 20^{O}N because we have only poor knowledge of the real atmosphere in the tropics and southern hemisphere.

Fig.2.1 shows at the top panels the 1000 mb height fields for the model's climate and for the observed climate as we obtained it from Crutcher and Jenne (1970). We do not know if a 25 day mean is large enough to simulate the climate and therefore we provide two 25 day averages for February 1979, using DWD analyses, and for February 1976, using NMC DST analyse in the lower panels. Two samples are certainly not enough to be statistically significant, but they give an indication of the possible variability in the atmosphere.

The low over the Atlantic in respect of its depth and its position of minimum value is simulated reasonably well.

The main deficiency here is the stretching of its centre to the east, creating very low values over Northern Europe, while all observed fields show a stretching to the north-east, allowing much higher values over Scandinavia.

This deficiency is similar to the systematic error of the 10 day forecast series by Hollingsworth et al. (1979). There a difference of 230 m between observation and 10 days' forecasts was found over Scandinavia.

The anticyclone over Siberia is simulated quite well, the cyclone south of it in the simulation is probably due to extrapolations below ground and should be disregarded.

The cyclones over the North Pacific seem to be quite variable in the real atmosphere with two favoured positions, one at about 170^{O}E and the other at about 150^{O}W. The model over-estimated the eastern cyclone so much that the western one is only indicated by a trough. At the position of the western cyclone the trough in the model's climate is still as deep as the observed lows. Despite the variability in the observations one can say that the dominating eastern cyclone in the model is much too strong by about 240 m(30mb).

A further point to look at is North America. All observations show a ridge, clearly separating the cyclones over the Atlantic and the Pacific. The model keeps quite low values over Canada and Alaska which leads to a totally different flow pattern.

These differences between the model's simulation and the observed samples are so strong that they can be seen already in the zonal means of the 1000 mb height field, which are shown in Fig. 2.2. Between 50^{O} and 70^{O}N the values of the model's atmosphere are much too low. This leads to a too strong meridional gradient south of this belt. We will come to it later when looking at the wind field.

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In Fig. 2.3 we find the means of the 500 mb height field. Here it becomes obvious that a sample of 25 days of observed data may be quite different from the climatological mean. Especially the February 1979 mean (lower left panel) deviates considerably south of 60°N from the climate showing 5 instead of 3 troughs. We will go into more detail later when we use wavenumber decomposition. At present we can only realise that the simulation by the model produced a pattern south of 60°N which lies within the variability of the atmosphere.

North of 60°N the model's climate is really different from all observed ones. The axis of low pressure areas is about 60° longitude turned to the east compared with the observed ones. Over the Bering Strait the model has a centre of low pressure which definitely cannot be found in the samples of observed data. Another problem area may be over northern Europe, as found by Hollingsworth et al.(1979) and which is connected with the deficiency we found for the 1000 mb level. The variability within the samples of observed data is too large in this area to permit a definite statement.

Fig. 2.4 shows difference maps between the model's averages and the corresponding climatological fields. The top panels for 1000mb and 500mb height fields repeat more clearly what we have already seen from Fig. 2.1 and Fig. 2.3. It is difficult to say whether the centres of differences over the eastern Pacific and eastern Atlantic are more connected with the land-sea distribution or with the positions of main mountain massifs. The extension of the Atlantic centre further east over the Continent might favour the relation with the mountain massifs. It would mean that the model does not recognise the mountain in the right way and, therefore, does not build up the ridges in front of the mountain massifs.

The lower panels show the temperature anomalies for the 850 and 500 mb level. These maps are dominated by the difference due to a turning of the axis of low temperature areas of about 45° longitude to the east, similar to that found in the height fields. The cooling over the continents at 850 mb established already after 1 day of forecast,which was mentioned in the introduction, can hardly be seen in this figure.

A closer insight into the horizontal gradients of the height fields is given by Fig. 2.5 showing zonal mean of geostrophic zonal winds in pressure-latitude cross-sections. Again we are looking at the same 25 day averages. The top panel shows the difference between both panels illustrated below. The model simulates the subtropical jet too far to the north, at least 5°. This shift is responsible for the strong deviations shown in the top panel for the upper troposphere. The deviations (up to 8m/sec) in the lower troposphere are connected with the very low values of 1000 mb heights between 50° and 70°N(see Fig. 2 which lead to very strong gradients in the height field south of the belt with low values and to weak or reversed gradients north of it.

The maximum wind speed seems to be somewhat too strong, but we have found another month (February 1978) of observations which had even a stronger wind speed maximum of 47 m/sec.

The following figures will give a further insight into the vertical and horizontal distribution of single waves. Fig. 2.6 shows the phases and amplitudes of zonal wavenumber 1 of the height field. The variability within the observed samples is quite large and makes conclusions difficult. The model has quite a high maximum value of 143 m compared with the observations. The nearest observed maximum value is 115 m for February 1978 which is not shown here. If we compare meridionally averaged amplitudes (panels with dotted lines) the model's values are not too far from those of February 1976 (second panel from below).

In the stratosphere, about 70°N, we find a strong increase of amplitude with height in the climatological mean and in the sample for February 1979. This increase is not found in the model's mean or in the February 1976 sample. This strong variability in the observed fields may be connected with occurrences of sudden stratospheric warmings, but we have not studied it yet.

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The panels on the right show the phases of wavenumber 1 height fields. Common to all samples is a tilt to the west with height and to the east with latitude. The model's phases are within the variability of the observations.

Fig. 2.7 shows the amplitudes and phases of zonal wavenumber 2 height fields. The differences between observations and the model's simulation are obvious. Above 700 mb the model's amplitudes are much too small, but again we have to ask if the differences are so large that they could not happen in the real atmosphere. Let us take the maximum values at 100 mb : the climate has 100m, the February 1976 has 200m, the February 1979 has 180m and the model only about 30m. If there are two samples which deviate so much from the climatological mean to higher values, we might also expect strong deviations to lower values. This conclusion may not be right because the smaller amplitudes in the larger sample, the climatological mean, need not result from a variability in the amplitudes in the smaller samples of single months but could also be due to a variability in the phases.

Below 700 mb the amplitudes of the model's climate are higher than the observed ones but the differences are not as dramatic as in the upper troposphere.
The phases (panels on the right) show another large difference between observations and model for wavenumber 2. We will concentrate on the latitudinal belt between 50^{o}N and 75^{o}N, which is the belt with strongest amplitudes. All samples show a westward tilt with height but only the observations show a westward tilt with latitude while the model has almost no tilt with latitude. The model's phases are up to 120^{o} (a third of a wave length or 60^{o} geographical longitude) out of phase compared with the observations. This is in agreement with the subjective impression as seen in Fig. 2.3.

To go into more detail, Fig. 2.8 shows the amplitudes and phases of the wavenumber 2 temperature fields. Above 700mb the amplitudes of temperature are also much too small.

.../7

This agrees with the fact that there is hardly any change in the height amplitude in the vertical. In the latitudinal belt with strongest amplitudes, i.e. between 45° and 75°N and below 300 mb only small tilts with height or latitude in all samples can be found. Again we find differences in the phases between the model's climate and the observed samples as we did for the height field. However, the differences are smaller ranging between 0° and 60° compared with the range 60° to 120° in the height field. Fig. 2.9 gives a sketch of the positions of maxima of temperature and height fields of wavenumber 2 for the model and the DWD observation of February 1979 at 60°N.

In Fig. 2.10 we see the mean phases and amplitudes of the wavenumber 3 height field. This wave is quite well simulated by the model. The model's result lies within the variability of the observed sample.

Fig. 2.11 displays the zonal means of temperature averaged over the same 25 days as before. The top panel gives the differences between both panels below, i.e. the model's climate minus the February 1979 sample. The model simulates the troposphere quite well except for the lower levels in the Arctic. Differences of 2K may even occur when comparing analyses by different analysis methods over the same period of time. The model's real deficiency can be found in the stratosphere where the model's climate is too cold. The variability within the observed samples is quite large too, but the model has still 5K lower values than the coldest sample at 100 mb north of 65°N.

Fig. 2.12 gives an insight into the mean meridional circulation in the model's climate (top panel), where the mean meridional wind only is shown. It is very difficult to verify this parameter, therefore we have for comparison only the observed mean, given by Oort and Rasmussen (1971) in the lower panel. Both meridional wind fields do agree reasonably well except for the lower branch of the Ferrell-cell, where the model has more than 2 m/sec. while the observed fields have only up to 0.5 m/sec. The vertical integral of the mean meridional

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wind should balance to zero. There are some doubts that this is true for the observed data.

3. THE VARIABILITY OF THE ATMOSPHERE WITH TIME

Up to now we investigated only the structure of the mean fields, i.e. the standing waves or the zonally and time averaged quantities. Now we want to see the behaviour of the transient waves. The top left panel of Fig. 3.1 shows maps of RMS deviations between the time means given in Fig. 2.1 and the daily fields for the model averaged over the same 25 days as before. The other three panels show correspondingly observed values for three February months of 1976, 1978 and 1979. The variability from year to year in the observations is considerable and makes conclusions difficult. In fact if the labels were missing it would be hard to spot the panel showing the model's simulation.

The main cyclone tracks, which are indicated by areas of larger values, are reasonably well simulated. With some reservations two areas of deficiencies could be spotted :

a) the model's cyclone tracks over the Pacific penetrate further eastward than the observations, giving high values at about 40°N, 140°W.

b) The model's simulation provides quite strong transient waves over North America, which are not found in the observations. Both failures go hand in hand with the deficiencies in the mean maps (see Figs. 2.1 and 2.4).

The corresponding maps for 500 mb height fields, shown in Fig. 3.2, have very similar patterns to those for 1000 mb height fields. Note that the contour interval is 8 dkm instead of 4 dkm for the 500 mb map.

Another way of looking at the behaviour of the model's atmosphere is by energetic properties or fluxes of momentum, or heat etc. Fig. 3.3 shows height-latitude cross-sections of geostrophic eddy kinetic energy. Here we want to compare

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the contributions by standing and travelling waves and therefore only the contributions by the very long waves with wavenumbers 1 to 3 are displayed. All panels on the right show the contribution by the standing waves alone and those on the left by both the standing and the travelling waves. The model's values are in the top panels. The variability within the observations in the lower panels is so large that no judgement about the quality of the model's simulation can be made from this point of view.

The area means north of 20°N, i.e, the dotted diagrams, show that the model's values are within the atmosphere's variability except for the lower troposphere where the model produced values mainly for the transient waves which were somewhat too high.

The eddy available potential energy (Fig.3.4) shows considerable variability, too, but there is a slight overestimate in the stratosphere which is at least partly due to a less stable stratification in the top levels, as was shown in Fig. 2.11.

For completeness Figs. 3.5 to 3.6 show the geostrophic flux of eddy momentum and of sensible heat. Furthermore, in Figs. 3.7 and 3.8 we find for wavenumbers 4 to 9 the sensible heat flux and the available potential energy. Here the contributions by both the standing and transient waves are shown, but the standing waves contribute only a small amount.

No clear-cut conclusion can be gained from any of the figures, but there is a slight indication, especially in the flux of sensible heat,that the main activities in respect of temperature waves are taking place a little too far south in the model's atmosphere.

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4. SUBGRID SCALE PROCESSES

The model's output allows quite a wide range presentation of parameters, also for subgrid scale processes. Our problem here is to verify such data and therefore we will restrict ourselves to a comparison of rainfall data.

Fig. 4.1 top panel shows a map of the rainfall of the model for the 25 day mean with which we are already familiar. The bottom panel shows a map of mean February rainfall prepared by Jäger (1976). There is quite a good resemblance between both maps. Largest values over the northern mid-latitudes are connected with areas of cyclonic activities or with major mountains. The maximum values are larger in the simulation by the model, but we do not know if it is a deficiency of the model or just a matter of sampling period. The convergence zone with maximum rainfall is well simulated in the tropics. The oceans with up-welling and the desert also in the model show a very small amount of rainfall.
It is quite astonishing to find such a good simulation in this respect after we have seen quite a few deficiencies in the other sections.

5. THE CHANGE-OVER FROM THE ATMOSPHERE'S TO THE MODEL'S CLIMATE

In Section 1 we saw that the first 10 days forecast was done with very good skill (anomaly correlation coefficients higher than 60%). That means that the model maintained the climate of the real atmosphere for a considerable time. Fig. 5.1 illustrates the change-over to its own climate, showing 10 day mean maps of the 1000 mb height field for the periods : day 1-10, 11-20, 21-30 and 31-40. The maps for the first two periods look quite similar to the observed maps given in Fig. 2.1, while those for the two last periods are similar to the model's climate in Fig. 2.1.

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The same can be said when looking at height-latitude cross-sections for the zonal mean winds in Fig. 5.2. The shift of the subtropical jet has not taken place in the period day 11 to 20 but it fully established in the period day 21 to 30.

For more details we see, in Fig. 5.3, time sequences of coefficients of empirical orthogonal functions mode 1 and 2 for the model and for DWD analyses for 40 days of forecasts. Fig. 1.2 already dealt with the evolution of empirical orthogonal functions during the first days of forecast, where the model's coefficients of mode 1 had a shift downward by about 30m. At day 19 to 22 another shift downward of at least 20m in mode 1 and a shift upward of 60m in mode 2 can be found. We do not know yet whether the single modes of the EOF's have a physical meaning and therefore we use them here only as a measure for changes in the large-scale pattern of the 500 mb height field which is clearly indicated here. This change in the pattern of 500 mb height fields seems to represent the switch over from the atmosphere's to the model's climate, i.e. the shift of the jet to the north, the increase of geostrophic wind at 1000 mb between 40^o and 50^oN, the changes in wavenumber 2 etc.

Both panels in the middle of Fig. 5.3 show the zonal means of zonal wind at 200 mb in latitude-time diagrams for the model and the observations for the same period of time. The shift of the jet can be seen between day 19 and 22.

The two lowest panels in Fig. 5.3 show that during the period of change very abnormal conversions of eddy to zonal kinetic energy are taking place in the forecast, especially for the medium scale waves with wavenumbers 4 to 9.

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6. CONCLUSIONS AND SUMMARY

We have seen that the variability in the real atmosphere is considerable. Therefore we often arrived at the conclusion that the simulation by the model gave reasonable results. Nevertheless, we could prove that the model finds its own state o equilibrium after a period of transition. After that there is no underestimation of the energetics of the standing waves as it was found by Hollingsworth et al. (1979) in their 10 day forecast experiments. The switch-over from the initially imposed atmospheric climate to the model's climate happened within a few days, probably between day 19 and 22 in this forecast. This happened so late because it was a specially chosen case with high predictability.

The following main deficiencies were made obvious :

a) The mean Icelandic low is stretching to the east instead of north-east, resulting in too low pressure over northern Europe.

b) The model's mean Pacific low at about 150°W was much too intensive.

c) Observations show a ridge over North America while the model's climate obtained strong westerly winds at the 1000 mb level over this area.

d) The mean subtropical jet (200 mb, 28°N) is shifted in the model's climate further north to 35°N.

e) Wavenumber 2 height fields are much too weak in the upper troposphere and are $1/6$ to $1/3$ of wavelength out of phase.

f) Connected with b) and c), the model produced too many transient disturbances over the eastern Pacific and over North America.

g) The stratosphere is cooling down too much in the polar night regions at 100 mb.

/13

Points a) to c) are so strong that these deficiencies can be seen already in zonal means of the 1000 mb height fields.

There are some indications that some of these deficiencies are connected with the treatment of the mountains but mostly we can only speculate about the reasons. At the present time we see one way only to solve this problem and that is by sensitivity experiments.

References:

Crutcher H.L. and Jenne, R.J., 1970; " An interim note on a northern hemisphere climatological grid data tape". NOAA Environmental Data Service, NWRC, Asheville.

Hollingsworth, A., Arpe, K., Tiedtke, M., Capaldo, M., Savijärvi, H., Åkesson, O., and J.A. Woods, 1979: " Comparison of Medium Range Forecasts made with Two Parameterization Schemes ". ECMWF Technical Report 13.

Jäger, L., 1976: "Monatskarten des Niederschlags für die ganze Erde". Berichte des Deutschen Wetterdienstes, Nr.139, Band 18.

Oort, A.H. and Rasmussen, E.M. 1971 : " Atmospheric Circulation Statistics". NOAA Professional Paper 5.

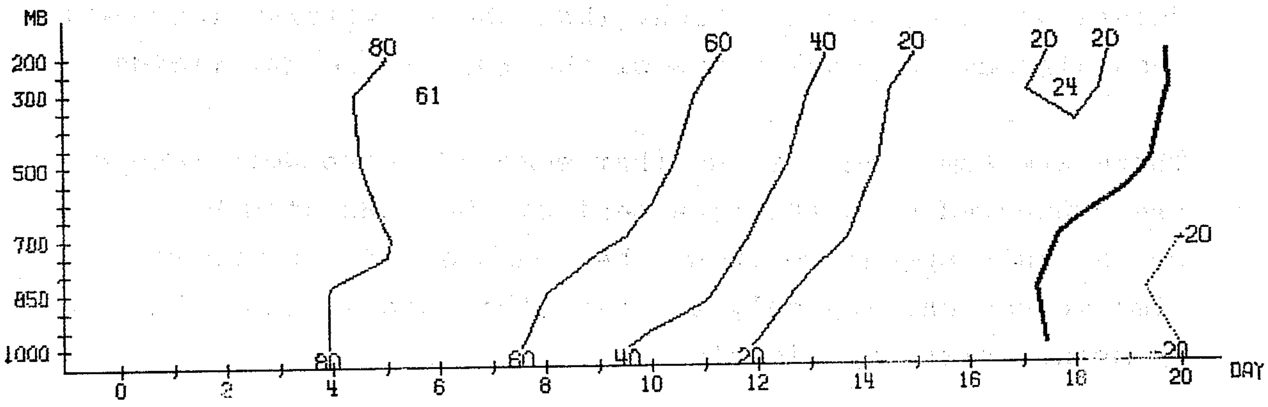


Fig. 1.1 Anomaly correlation coefficients of height (%) for the first 20 days of the model-run.

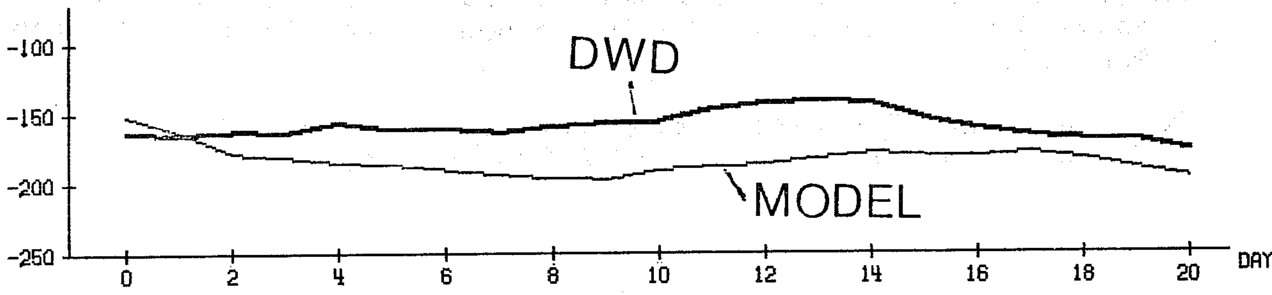


Fig. 1.2 Mode 1 empirical orthogonal function coefficients (m) for the first 20 days of the model-run and the corresponding analyses (DWD)

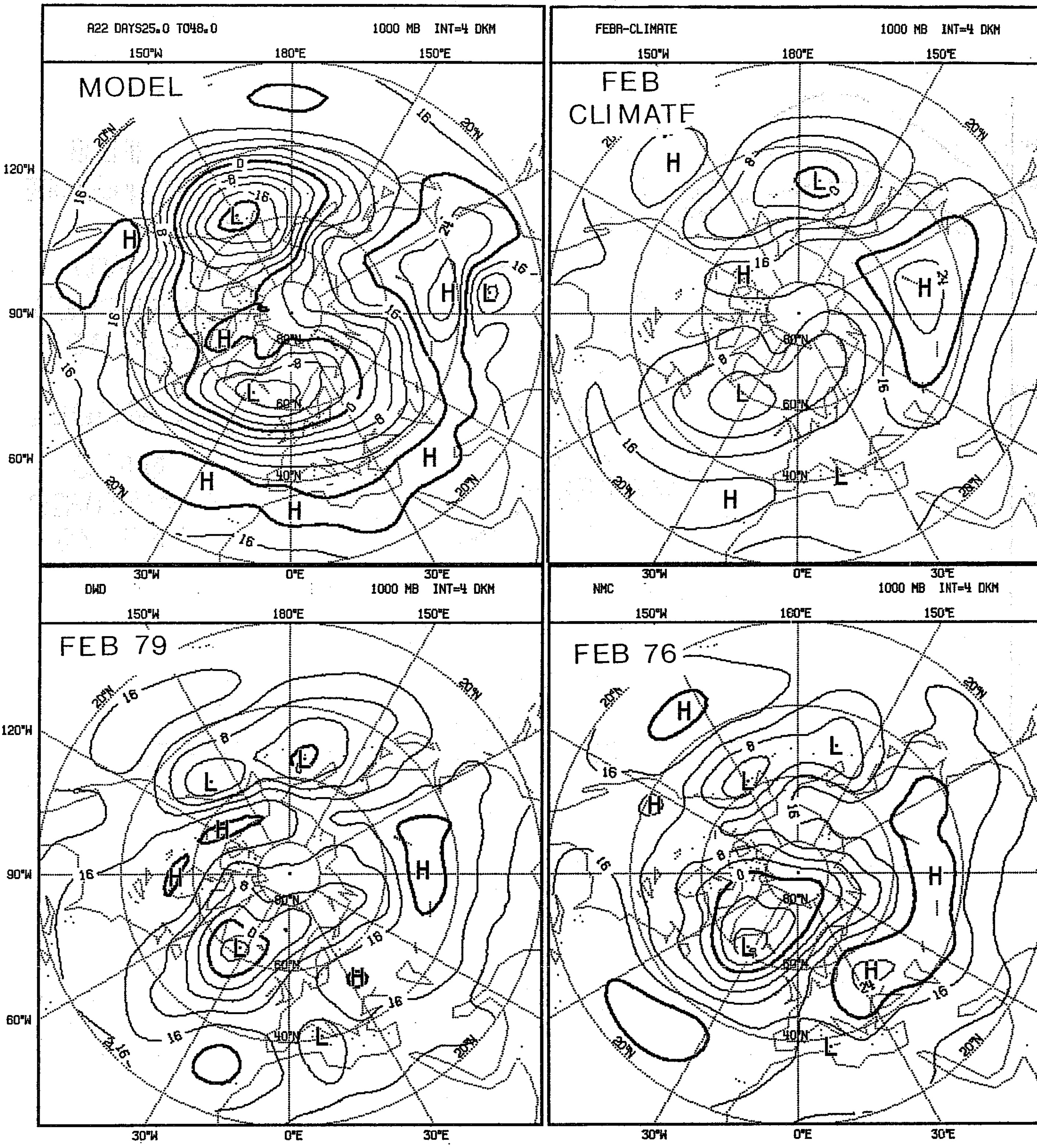


Fig. 2.1 1000 mb height mean maps.
Top left: day 25 to 48 of the model's simulation
Top right: February climate after Crutcher and Jenne (1970)

Bottom left: February 1979 mean using analyses from DWD
Bottom right: February 1976 mean using analyses from NMC

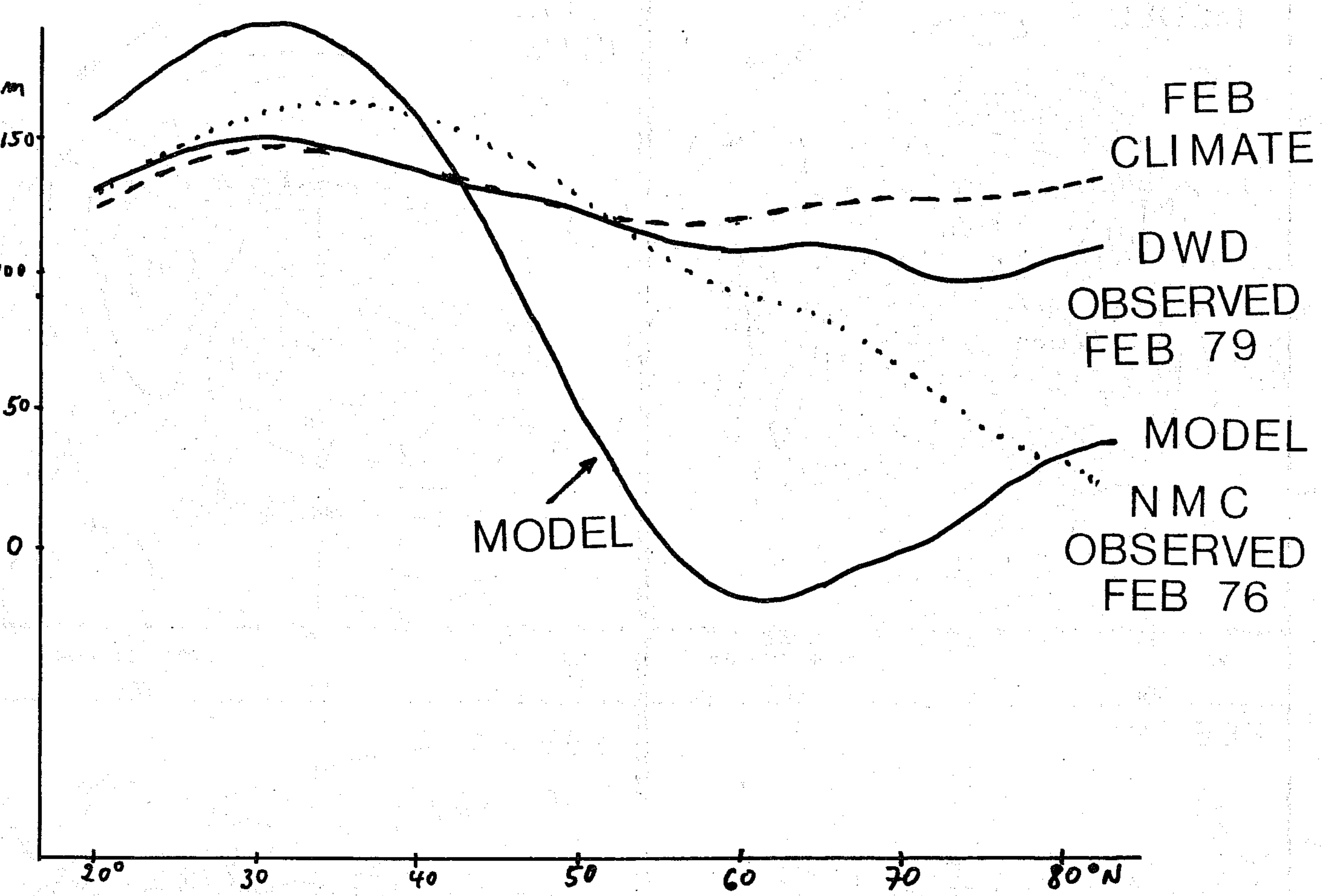


Fig. 2.2 Zonal means of 1000 mb height for the same time averages given in Fig. 2.1.

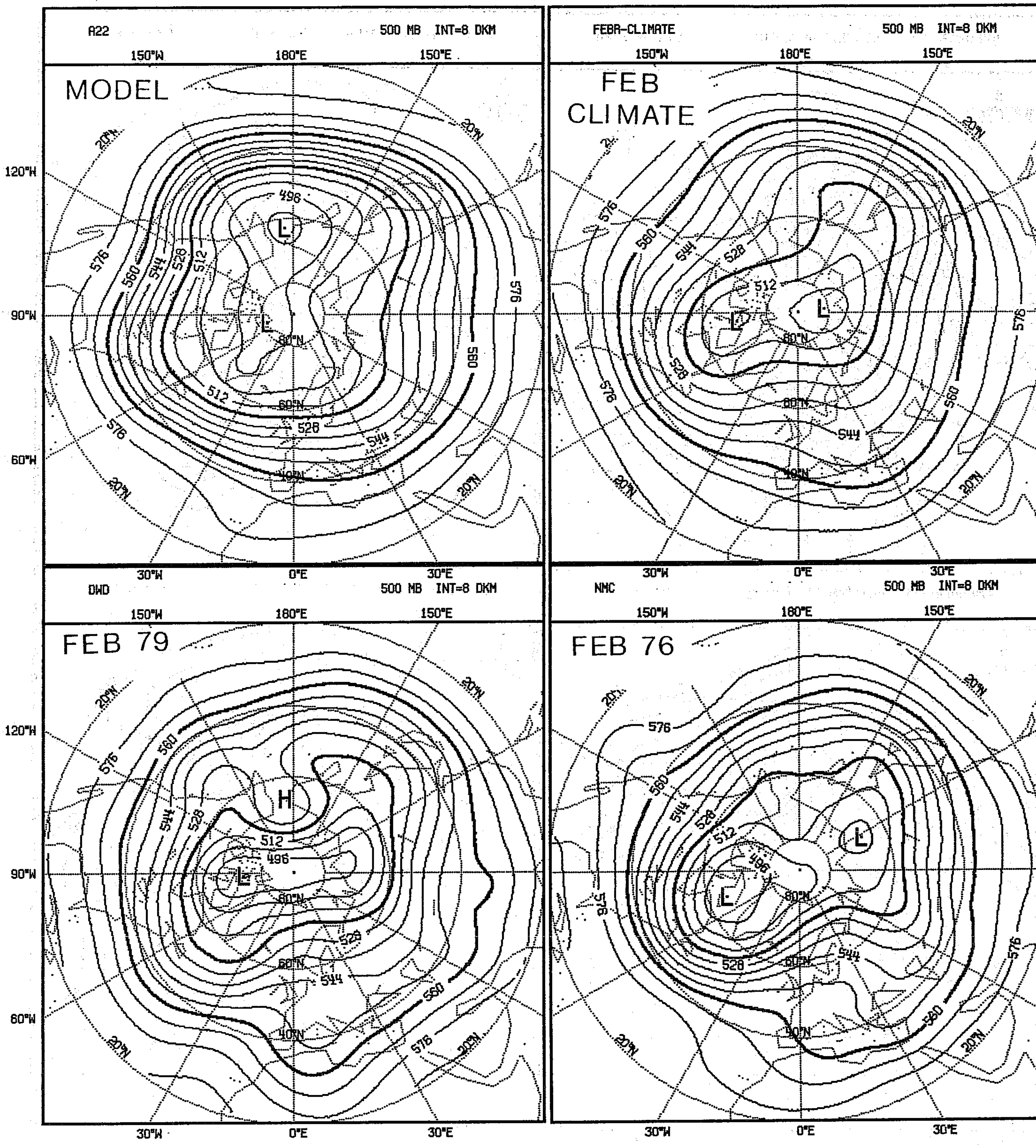


Fig. 2.3 Same as Fig. 2.1 for the 500 mb height field

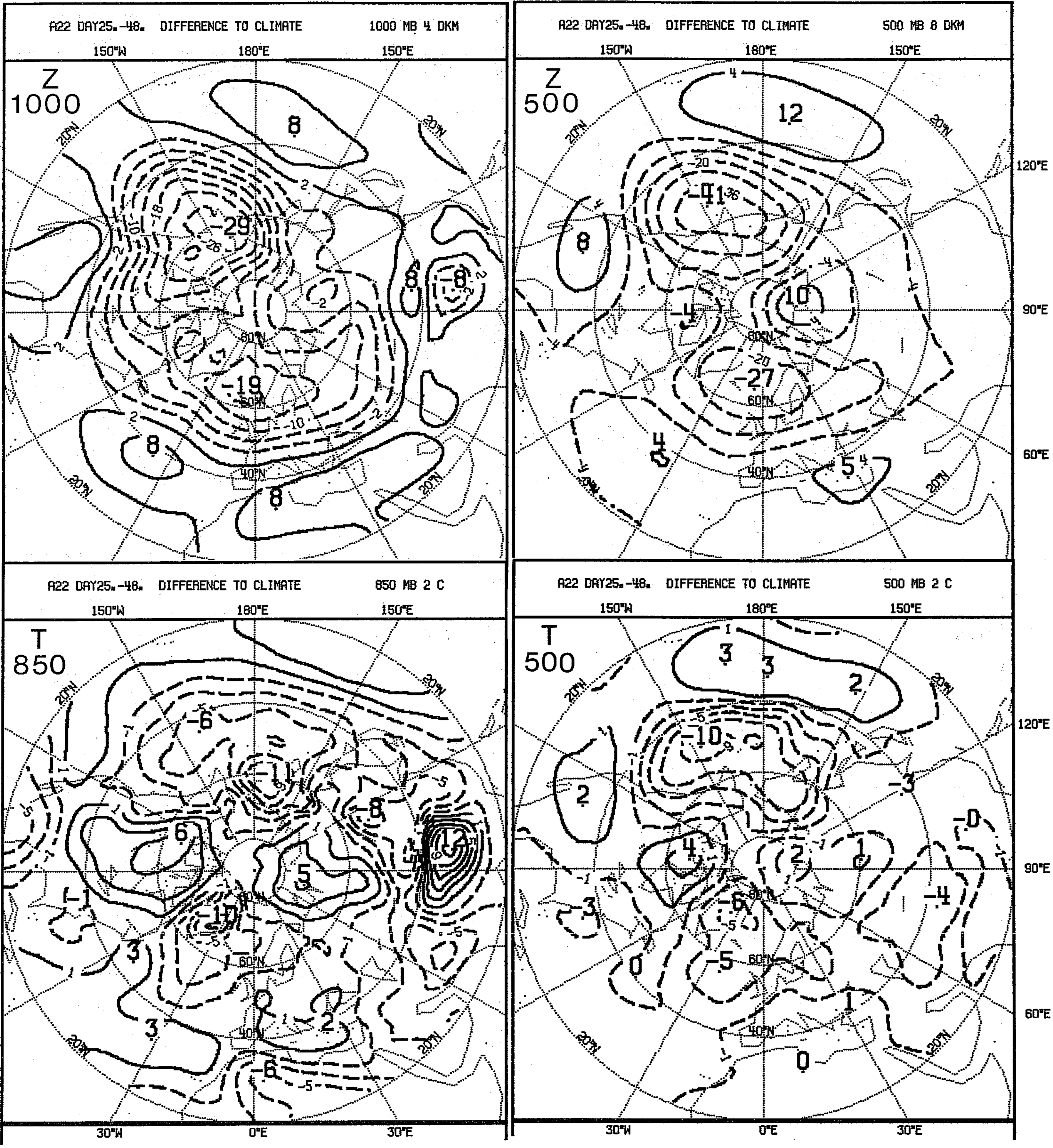


Fig. 2.4 Differences between model's 25 day means and the climatological values
Top left: 1000 mb height field, contour interval 4 dkm
Top right : 500 mb height field, contour interval 8 dkm

Bottom left: 850 mb temperature, contour interval 2 K
Bottom right:500 mb temperature, contour interval 2 K.

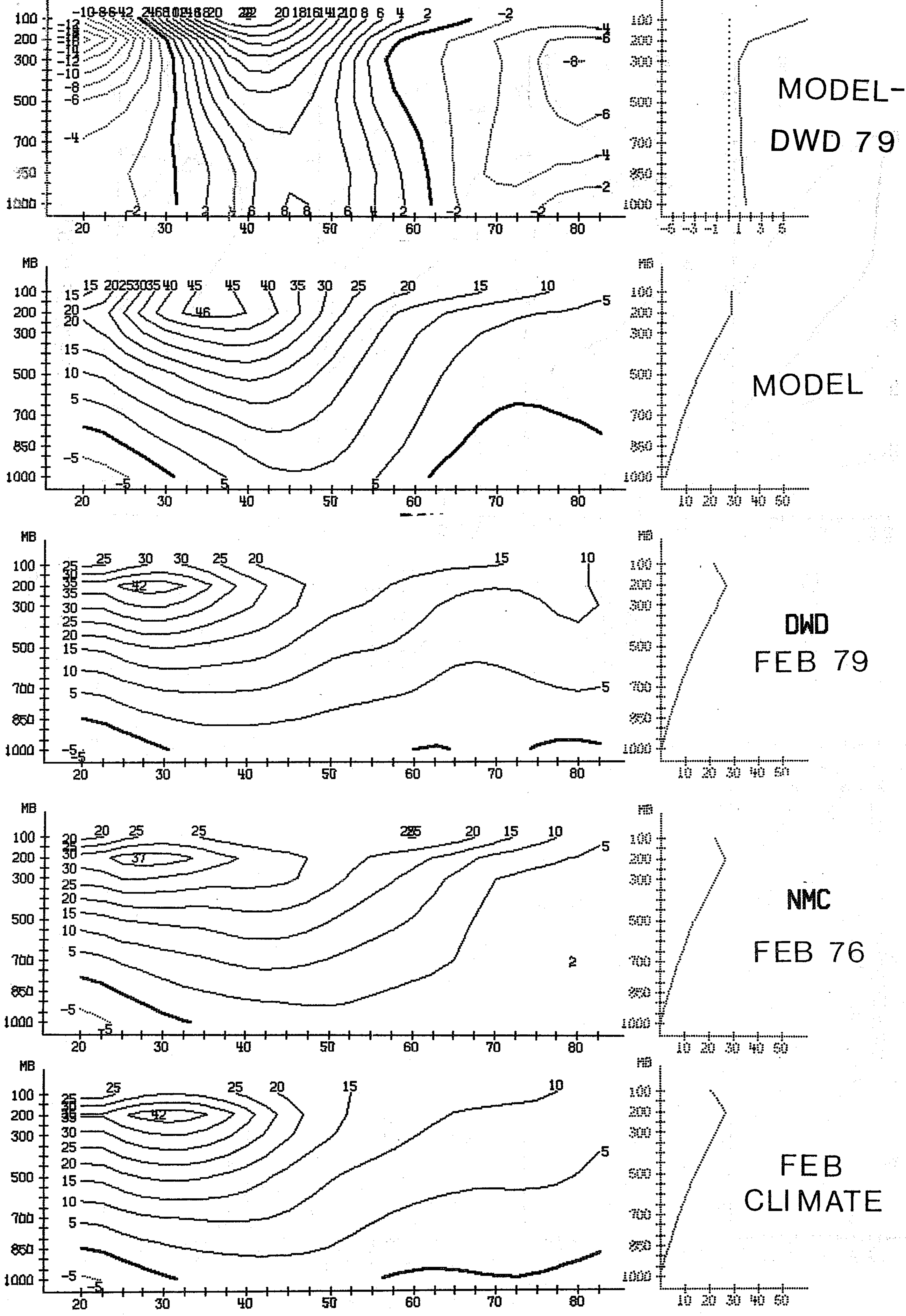
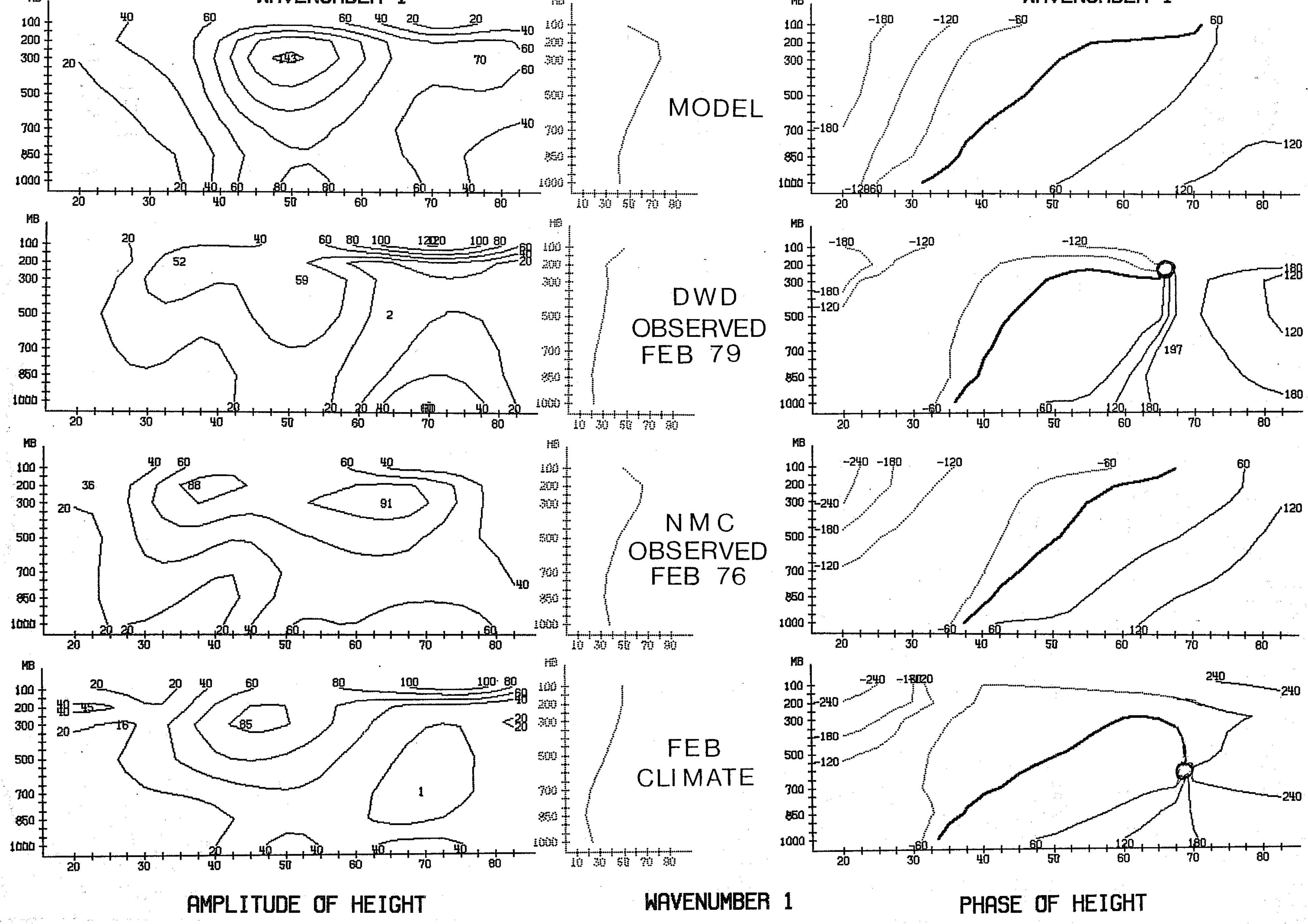


Fig. 2.5 Zonal mean of geostrophic wind (m/s) for the same time averages given in Fig. 2.1. Top panel gives differences


WAVENUMBER 1
WAVENUMBER 1
MODEL
DWD
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2
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91
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1
197
-240
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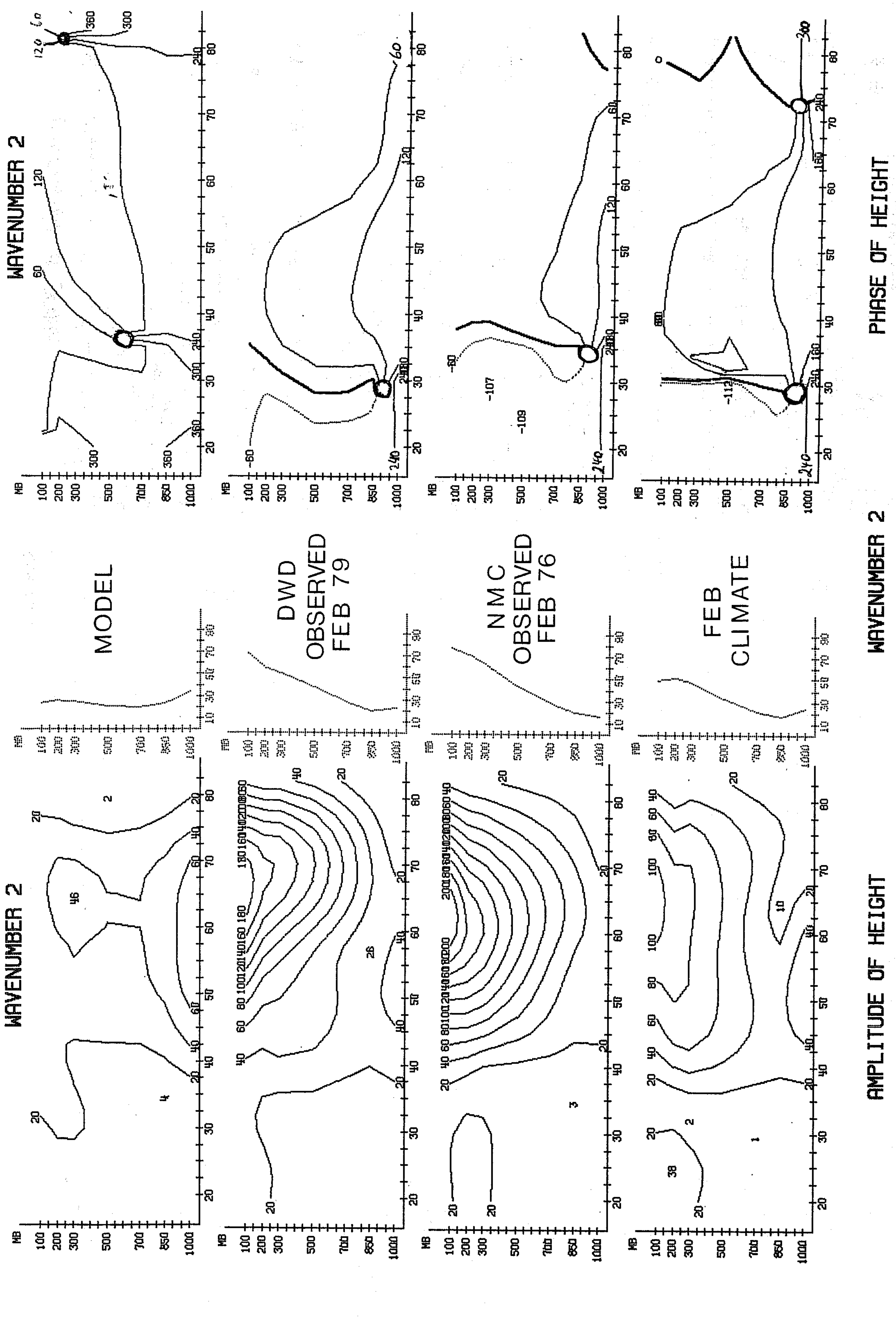
AMPLITUDE OF HEIGHT
WAVENUMBER 1
PHASE OF HEIGHT

Fig.2.6


WAVENUMBER 2
AMPLITUDE OF HEIGHT
WAVENUMBER 2
PHASE OF HEIGHT
MODEL
DWD OBSERVED FEB 79
NMC OBSERVED FEB 76
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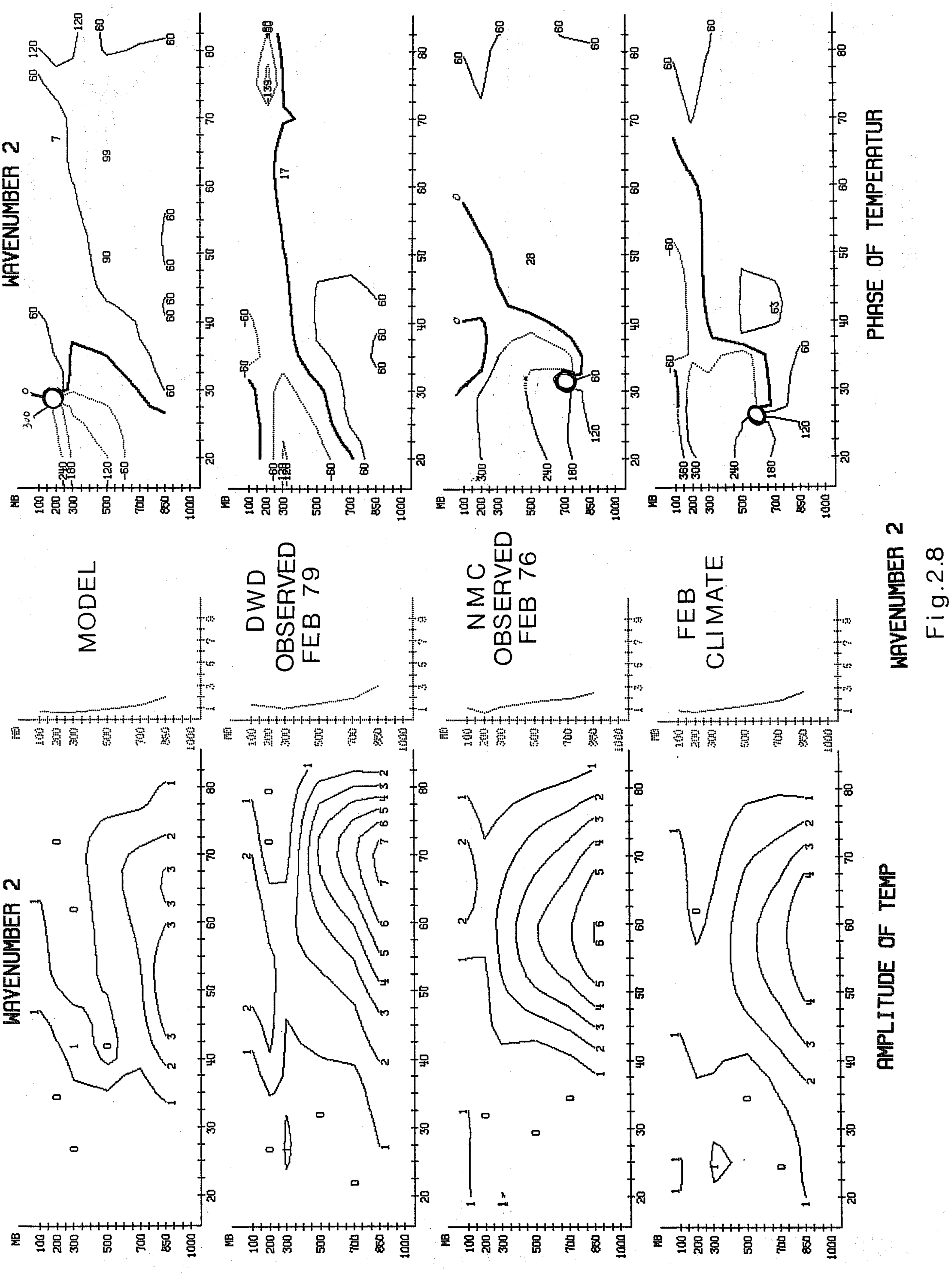


WAVENUMBER 2

Fig.2.8

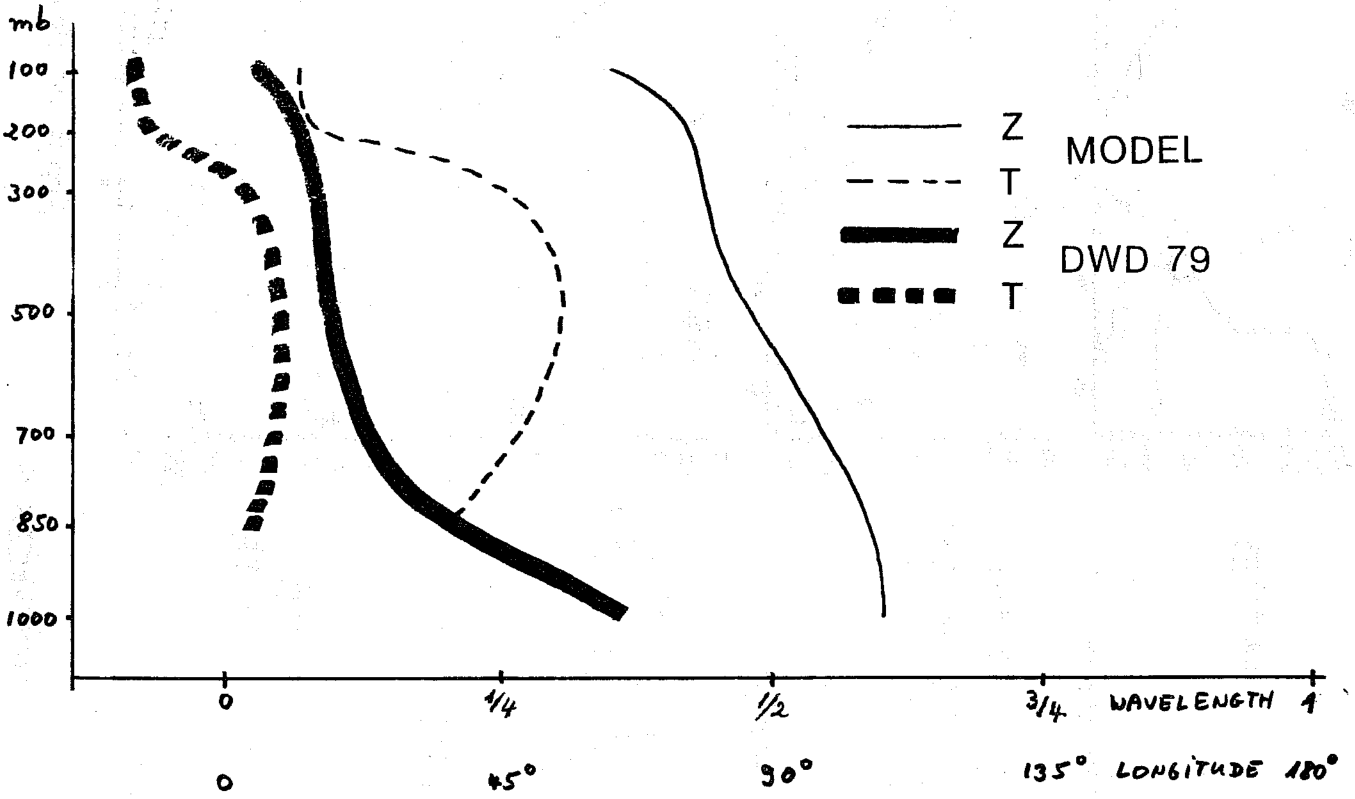
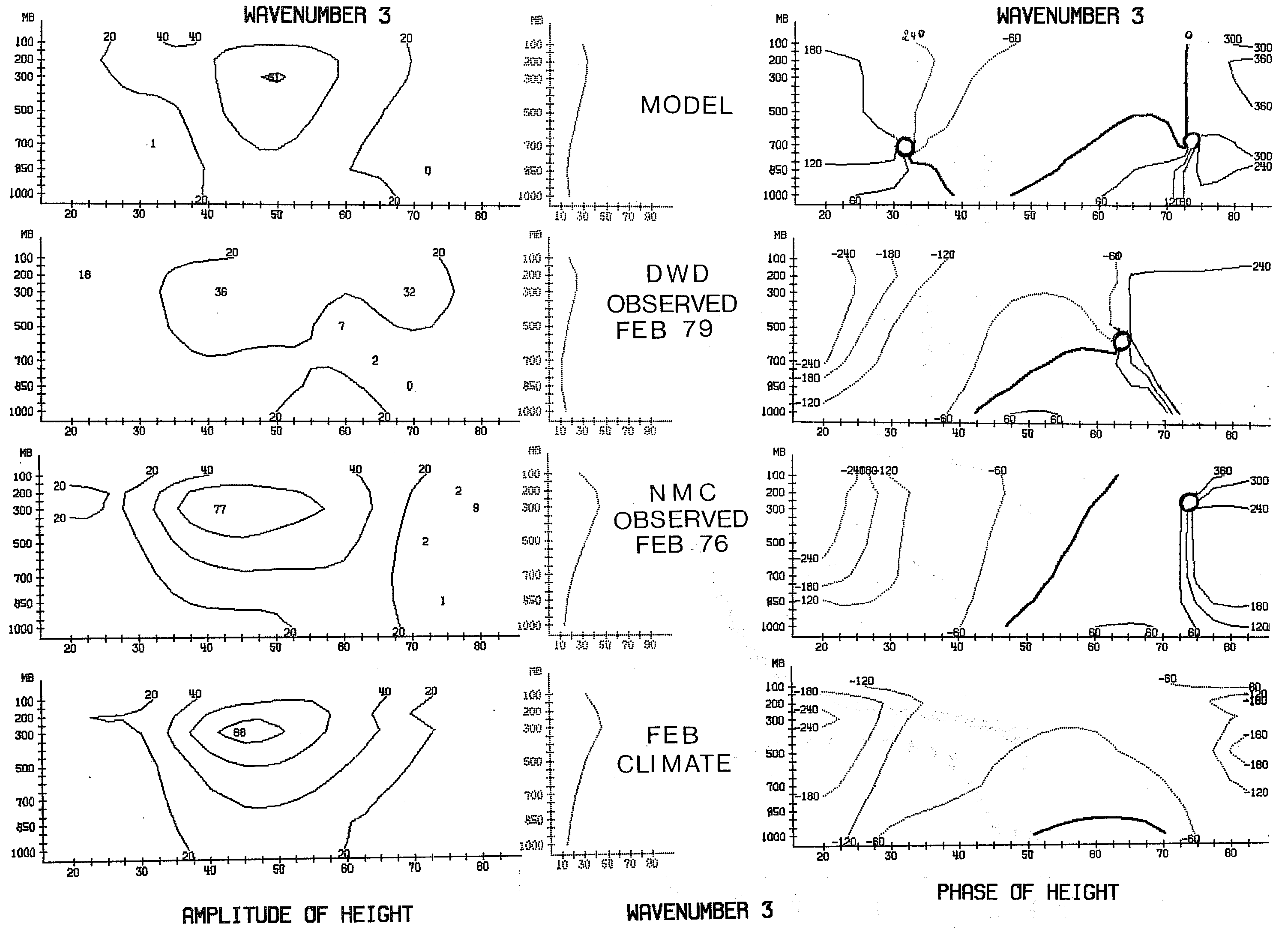


Fig. 2.9 Positions of ridges of zonal wavenumber 2 of temperature (dashed lines) and of height field (solid line) for the model's mean between day 25-48 (thin) and the corresponding analyses by DWD (thick) at 60°N


WAVENUMBER 3
WAVENUMBER 3
MODEL
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OBSERVED
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AMPLITUDE OF HEIGHT
WAVENUMBER 3
PHASE OF HEIGHT

Fig.2.10

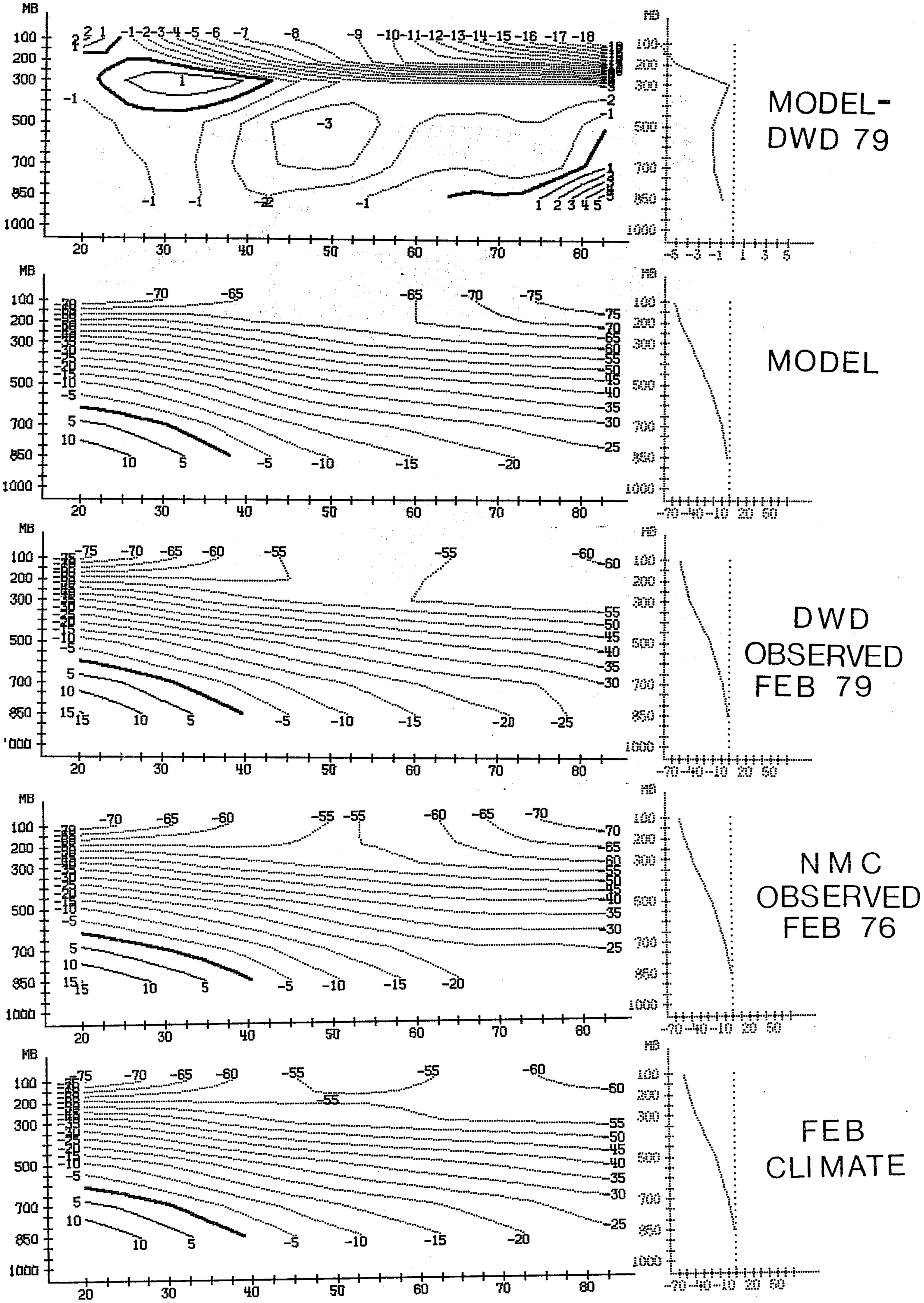


Fig. 2.11 Zonal mean of temperature (^{o}C) for the same time averages given in Fig. 2.1. Top panel is a difference between both

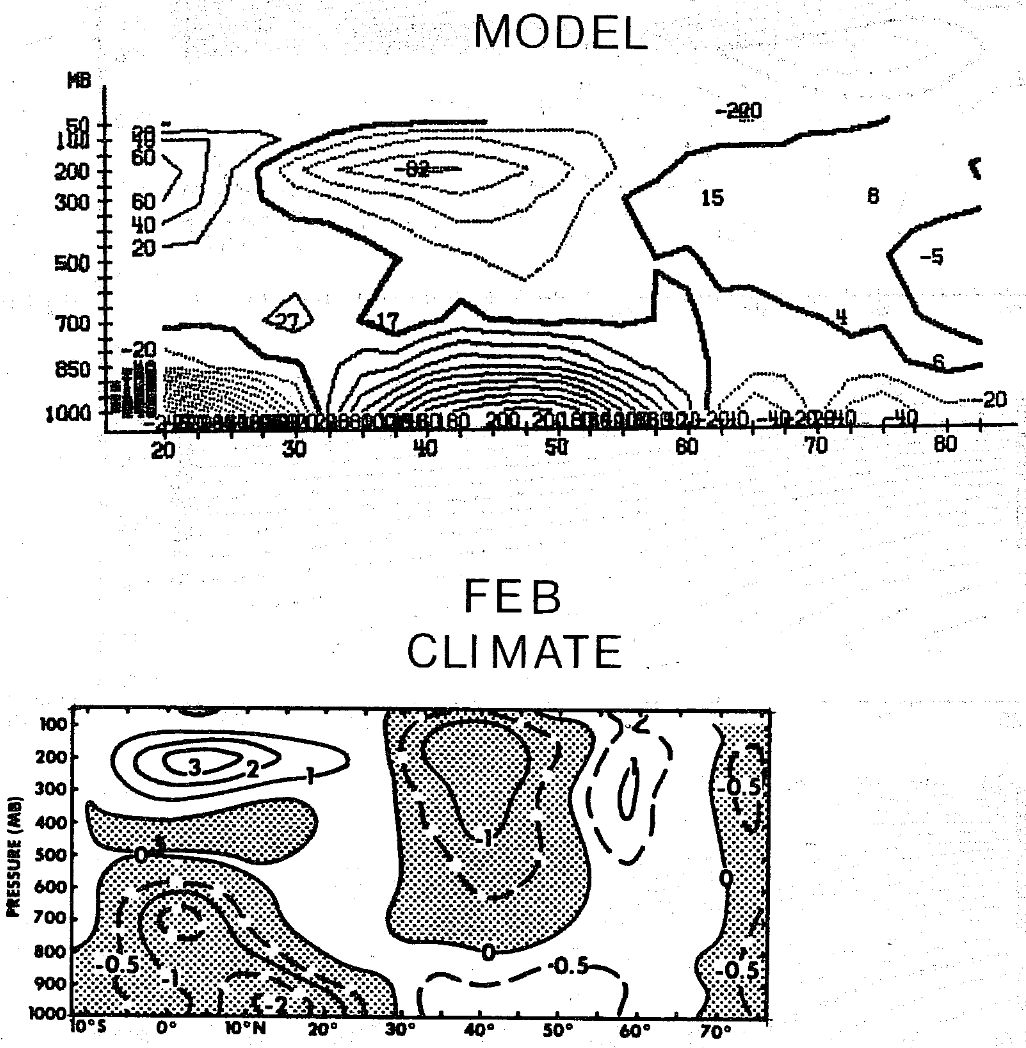


Fig. 2.12 Zonal mean of meridional wind.
Top panel: model's mean, unit (cm/sec)
Bottom panel: observations by Oort and Rasmussen (1971), units: m/sec .

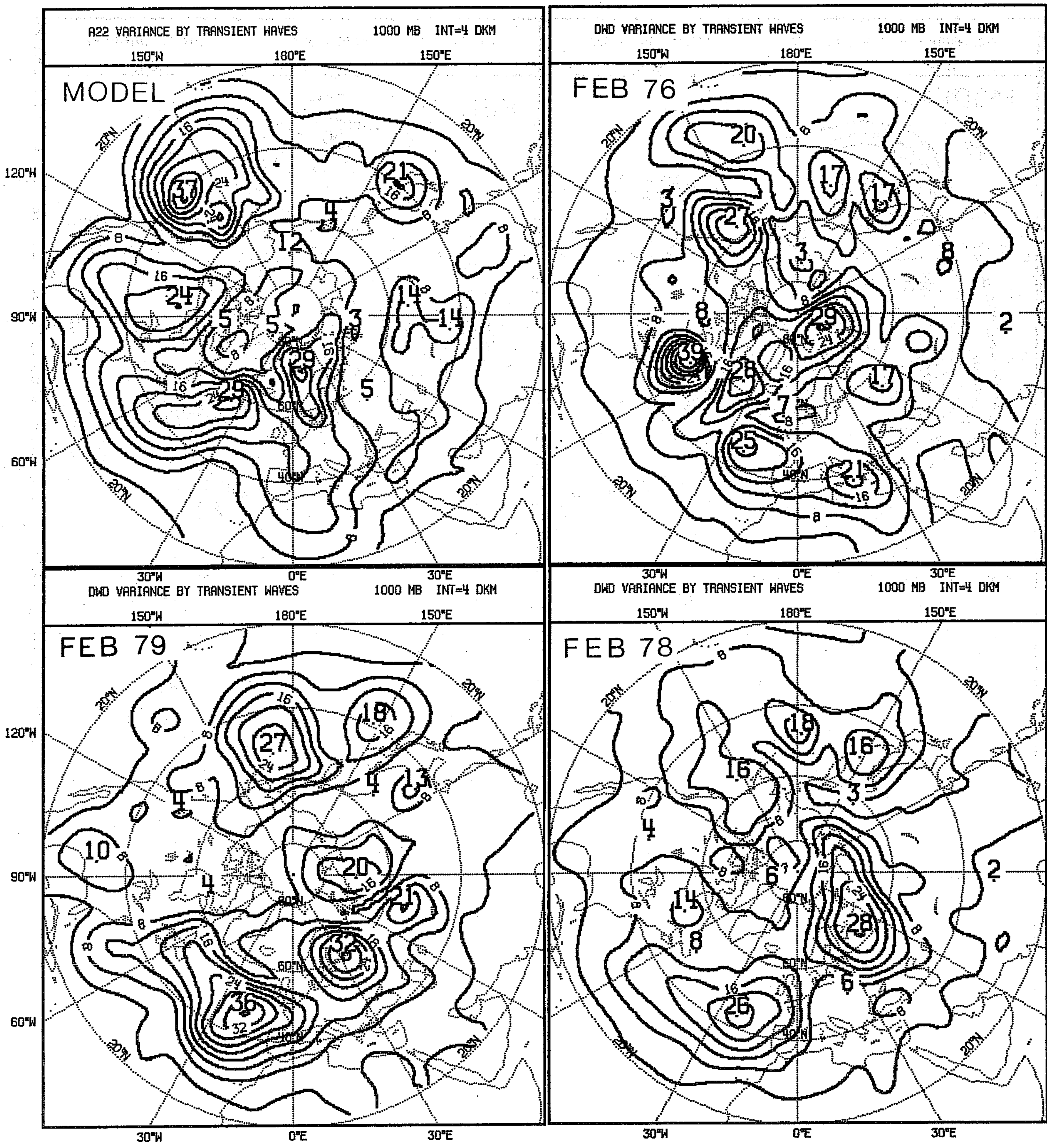


Fig. 3.1 RMS deviations between the time means given in Fig. 2.1 and the daily fields for the 1000 mb height field.
Top left: model's simulation day 25 - 48
Top right: observed for February 1976 (DWD analyses)
Bottom left: observed for February 1979 (DWD analyses)
Bottom right: observed for February 1978 (DWD analyses)

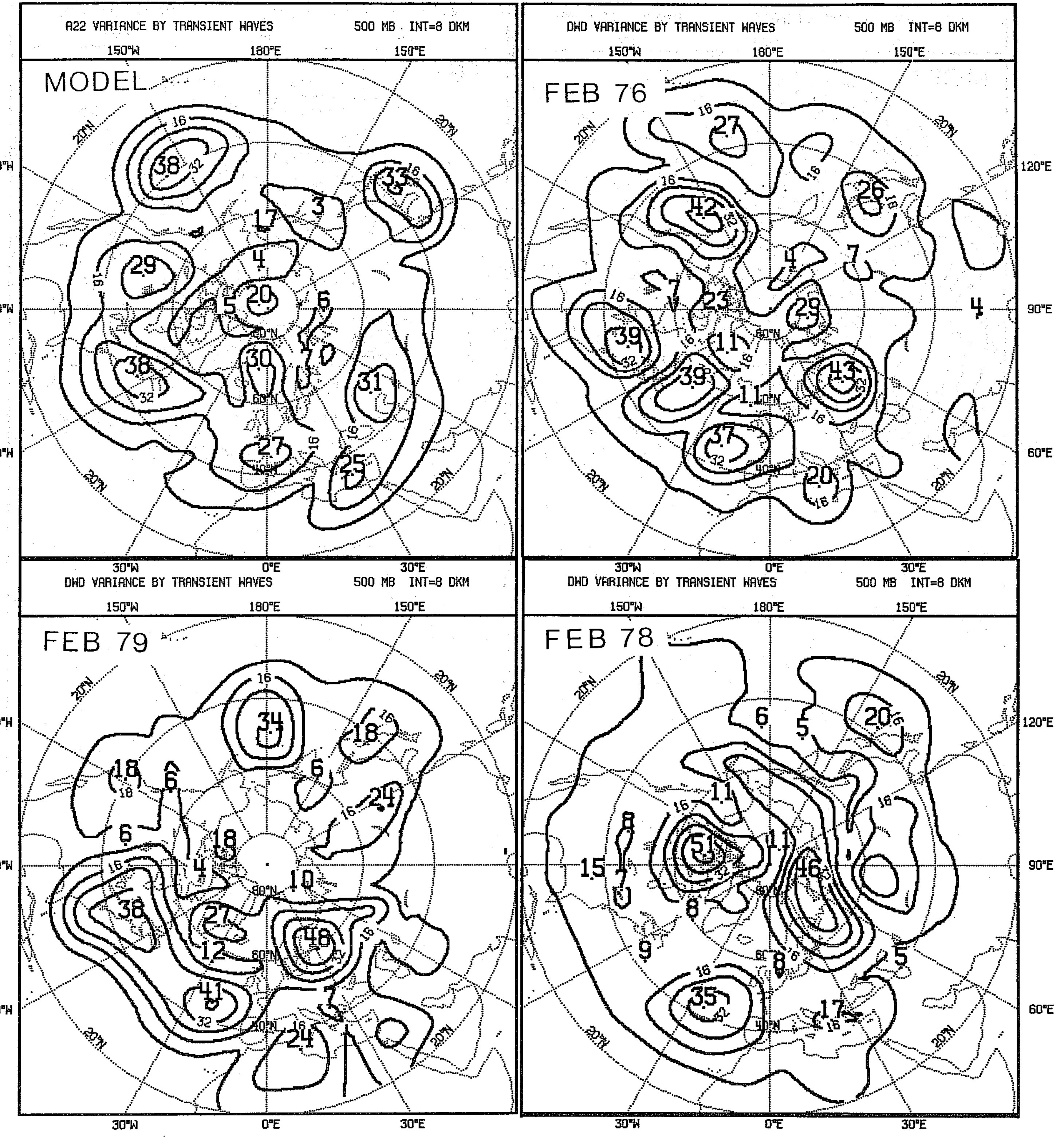
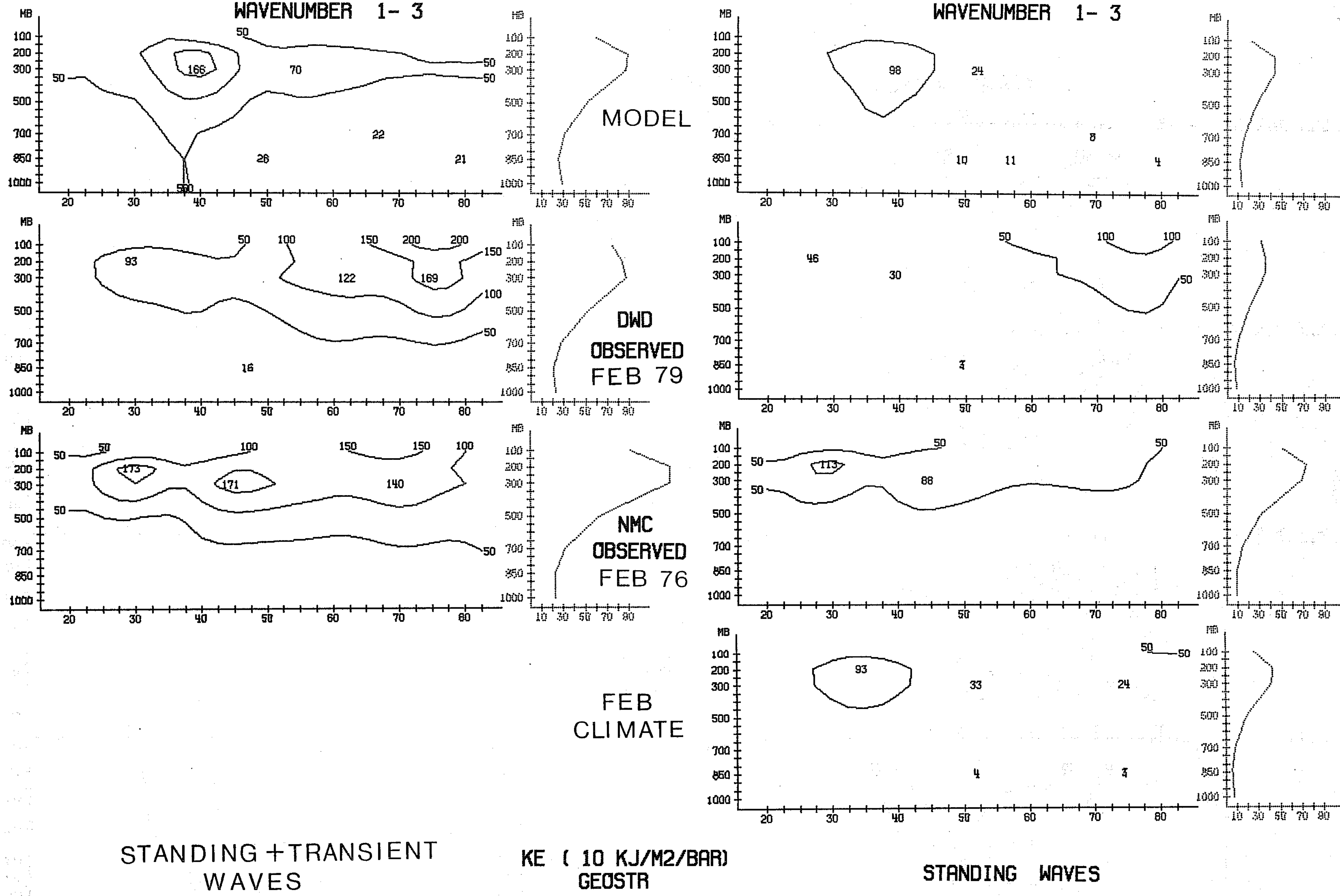


Fig. 3.2 Same as Fig. 3.1 for the 500 mb height field


WAVENUMBER 1- 3
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MODEL
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169
150
200
100
16
DWD
OBSERVED
FEB 79
173
171
140
NMC
OBSERVED
FEB 76
FEB
CLIMATE
98
24
10
11
8
4
46
30
3
113
88
93
33
STANDING + TRANSIENT
WAVES
KE (10 KJ/M2/BAR)
GEØSTR
STANDING WAVES

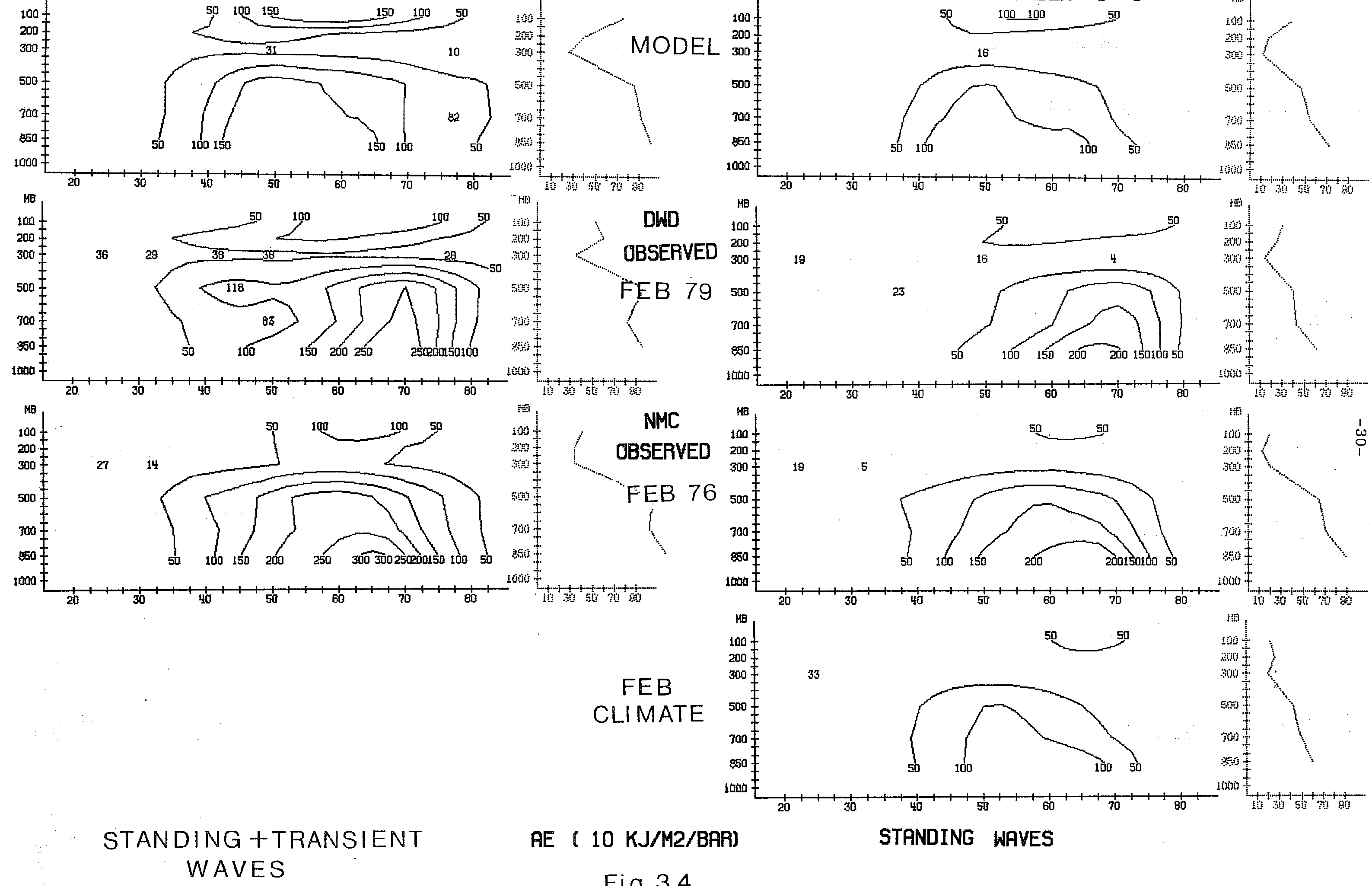
MODEL
DWD
OBSERVED
FEB 79
NMC
OBSERVED
FEB 76
FEB
CLIMATE
MB
100
200
300
500
700
850
1000
20
30
40
50
60
70
80
10
90
50
100
150
200
250
300
31
10
82
36
29
38
28
118
83
27
14
16
19
23
4
5
33
STANDING + TRANSIENT WAVES
AE (10 KJ/M2/BAR)
STANDING WAVES

Fig.3.4

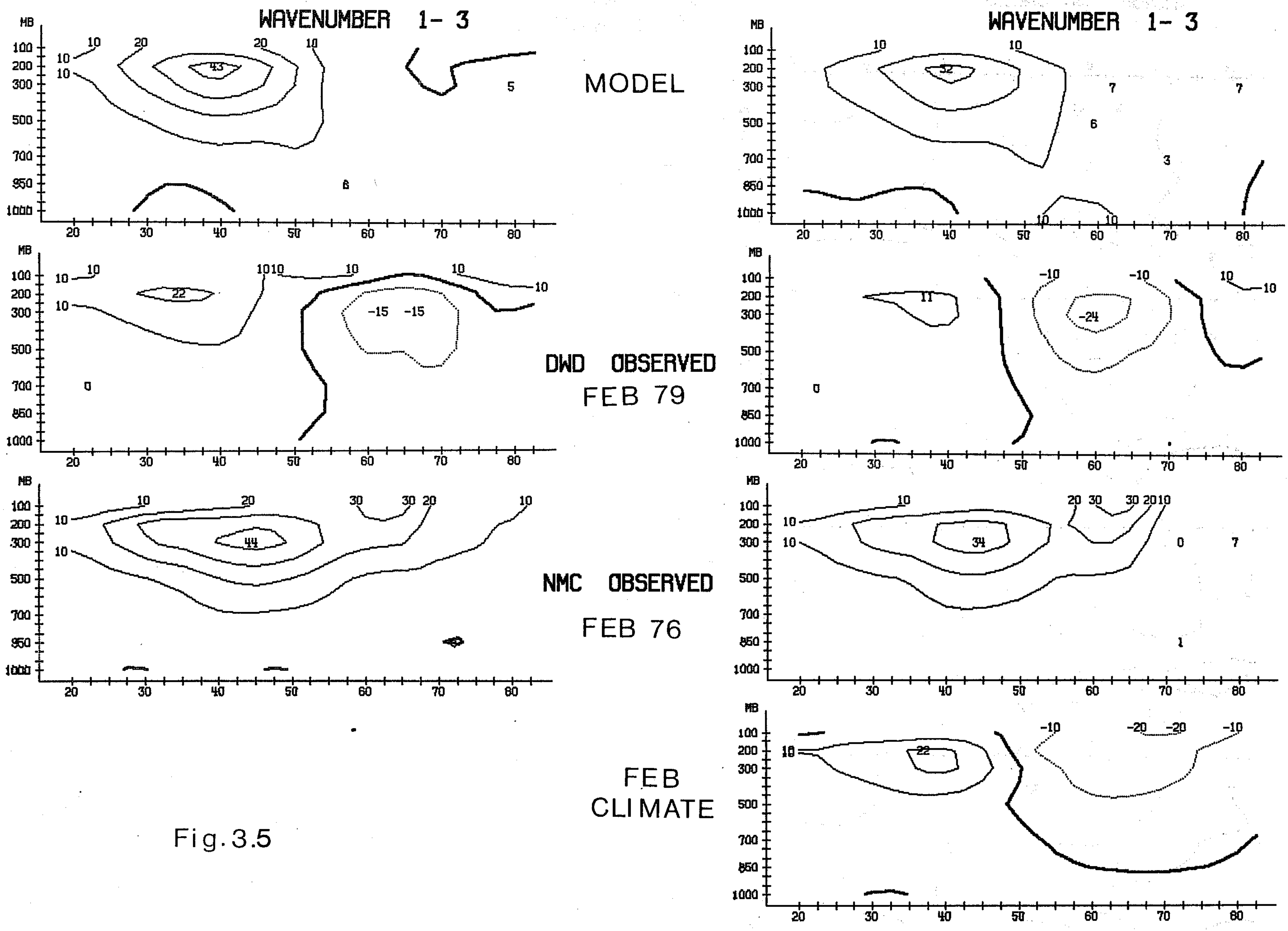

Fig.3.5

STANDING + TRANSIENT
WAVES

WAVENUMBER 1- 3
MOMENTUM-FLUX UV (M2/S2)
GEOSTR

STANDING WAVES

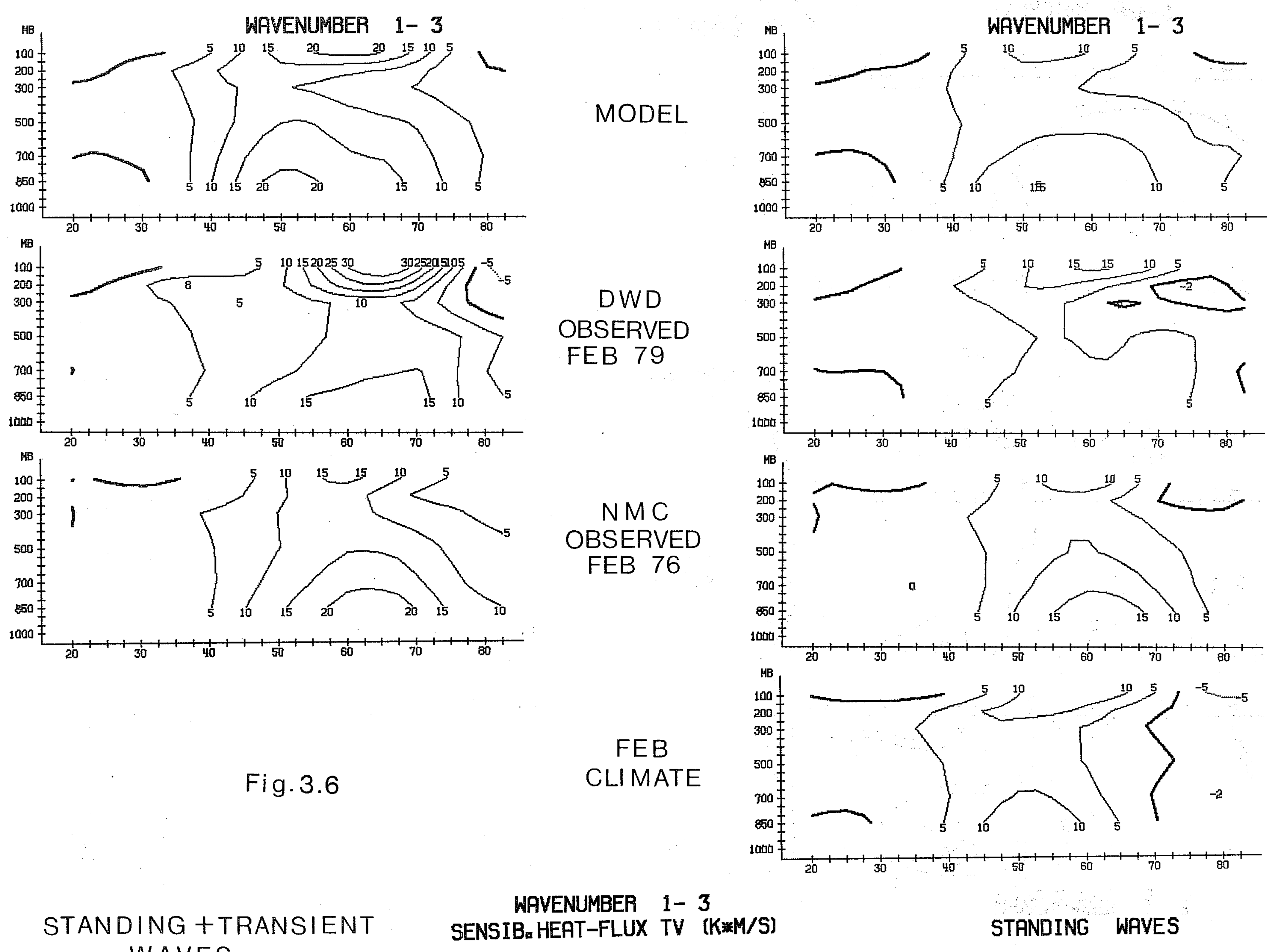
WAVENUMBER 1- 3
WAVENUMBER 1- 3
MODEL
DWD OBSERVED FEB 79
NMC OBSERVED FEB 76
FEB CLIMATE
MB
100
200
300
500
700
850
1000
20
30
40
50
60
70
80
STANDING + TRANSIENT
WAVENUMBER 1- 3
SENSIB. HEAT-FLUX TV (K*M/S)
STANDING WAVES

Fig.3.6

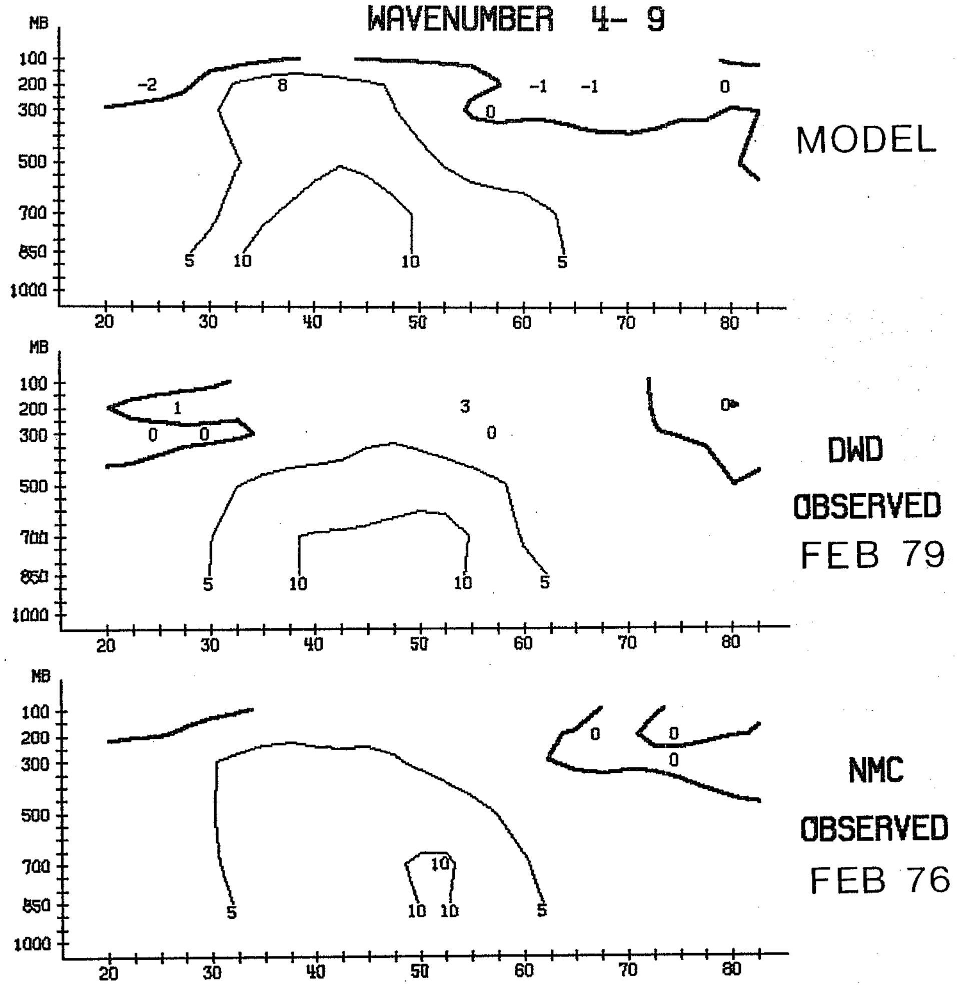

Fig.3.7

SENSIBLE HEAT-FLUX TV

GEOSTR K*M/S

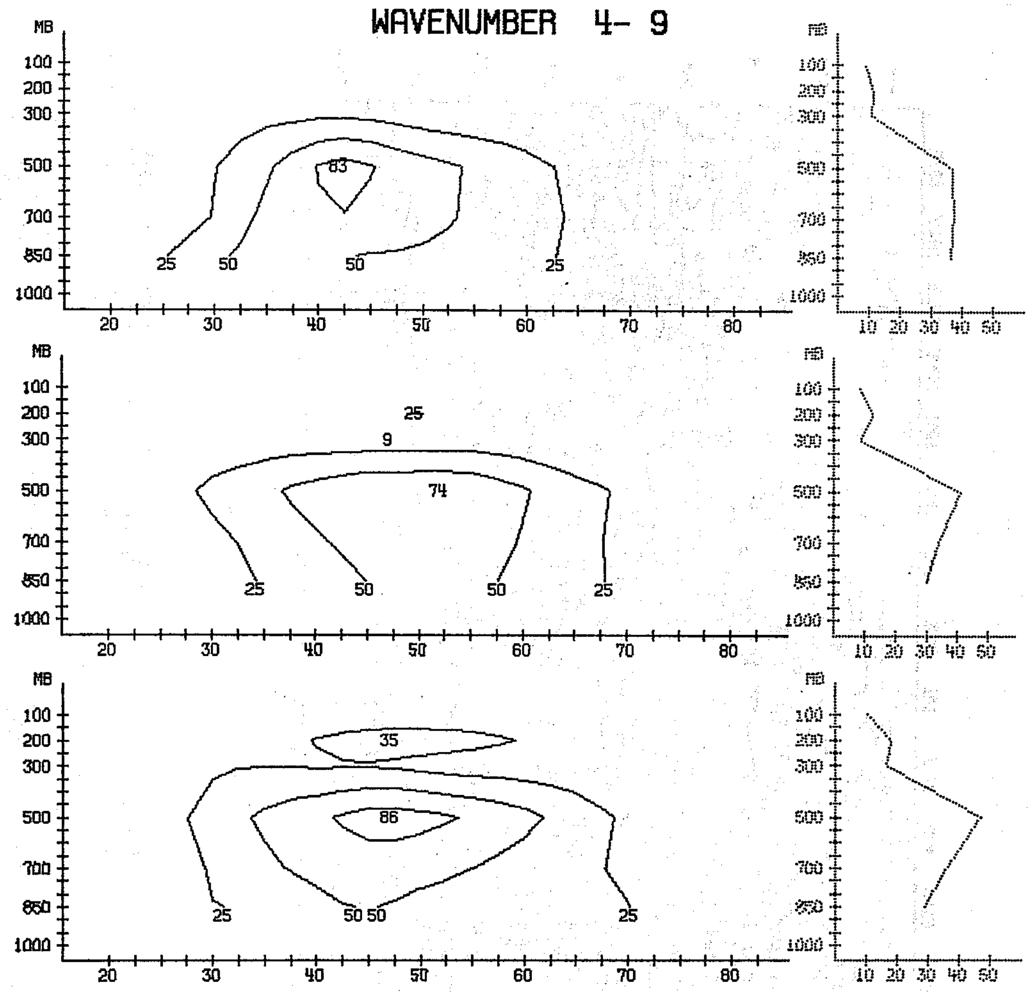

Fig.3.8

AE (10 KJ/M2/BAR)

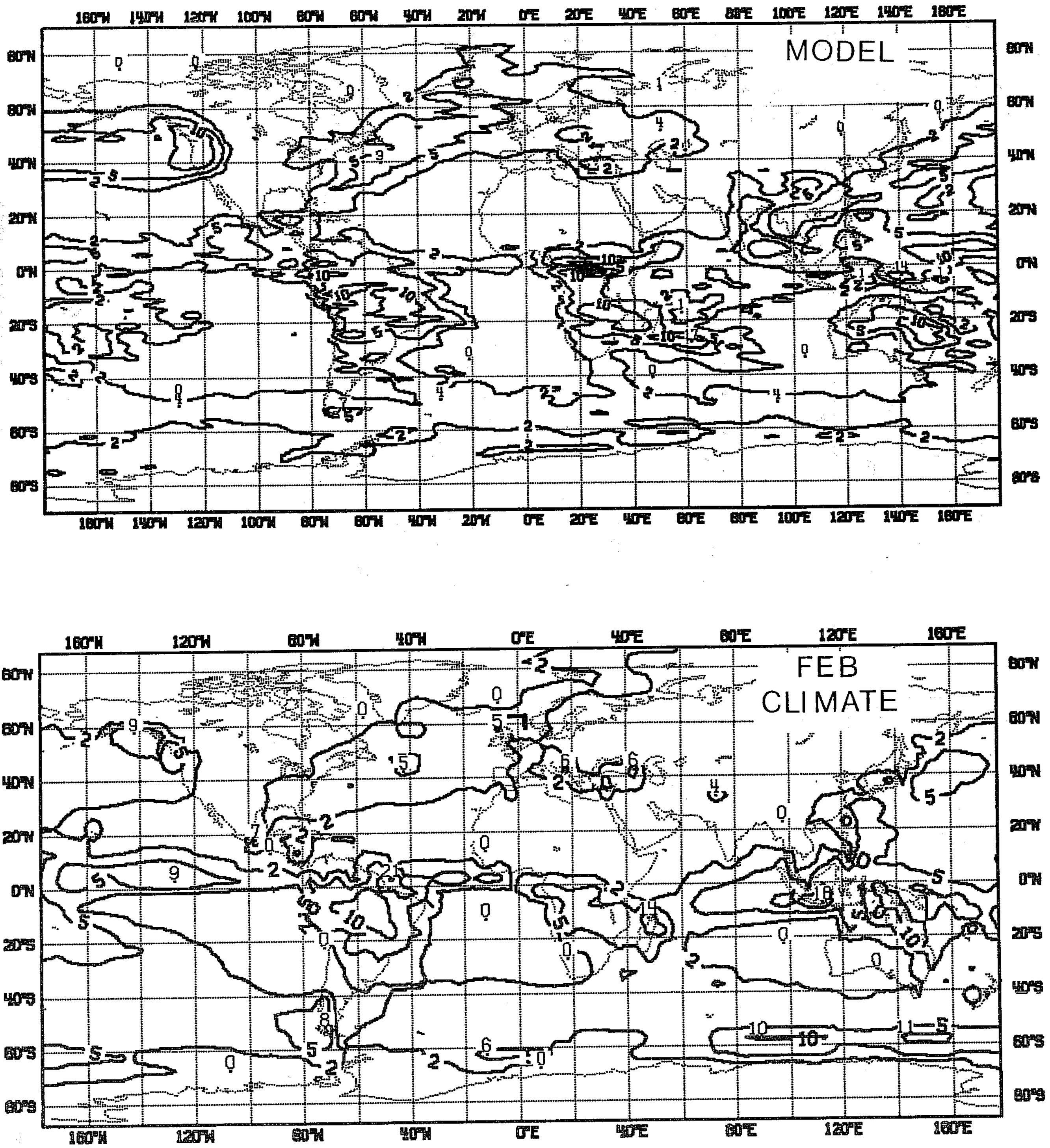

Fig. 4.1 Mean precipitation (mm/day)
Top: model's simulation day 25 - 48
Bottom : February climate after Jäger (1976)

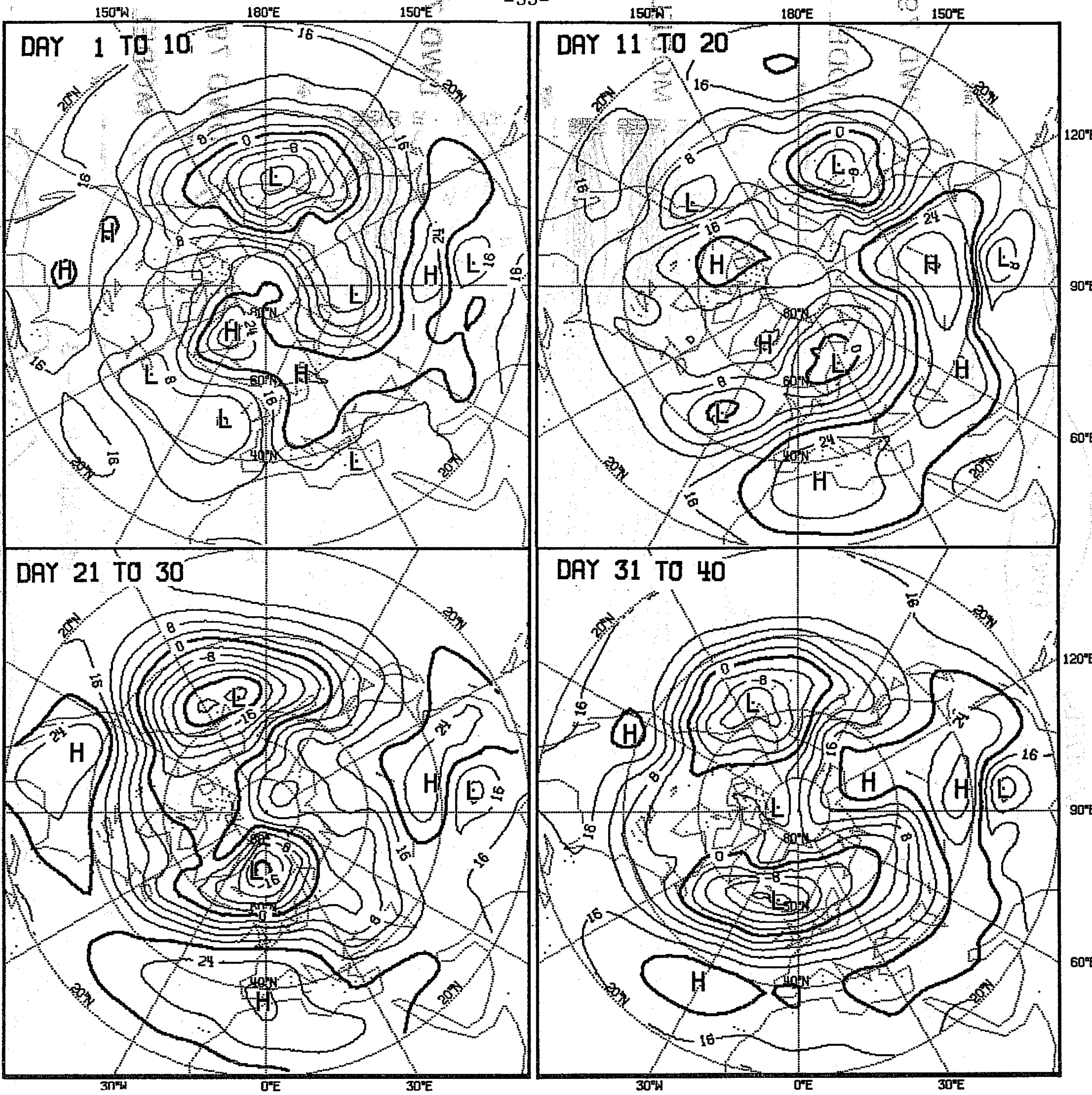

Fig. 5.1 Ten day means of 1000 mb height field of the model's simulation

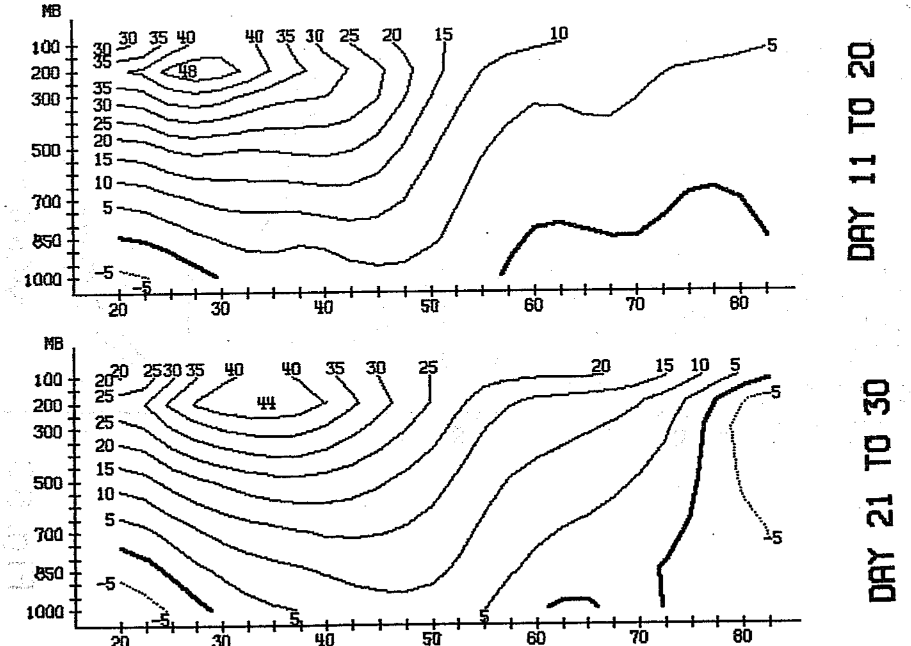

Fig. 5.2 Ten day means of zonal mean geostrophic wind (m/sec)

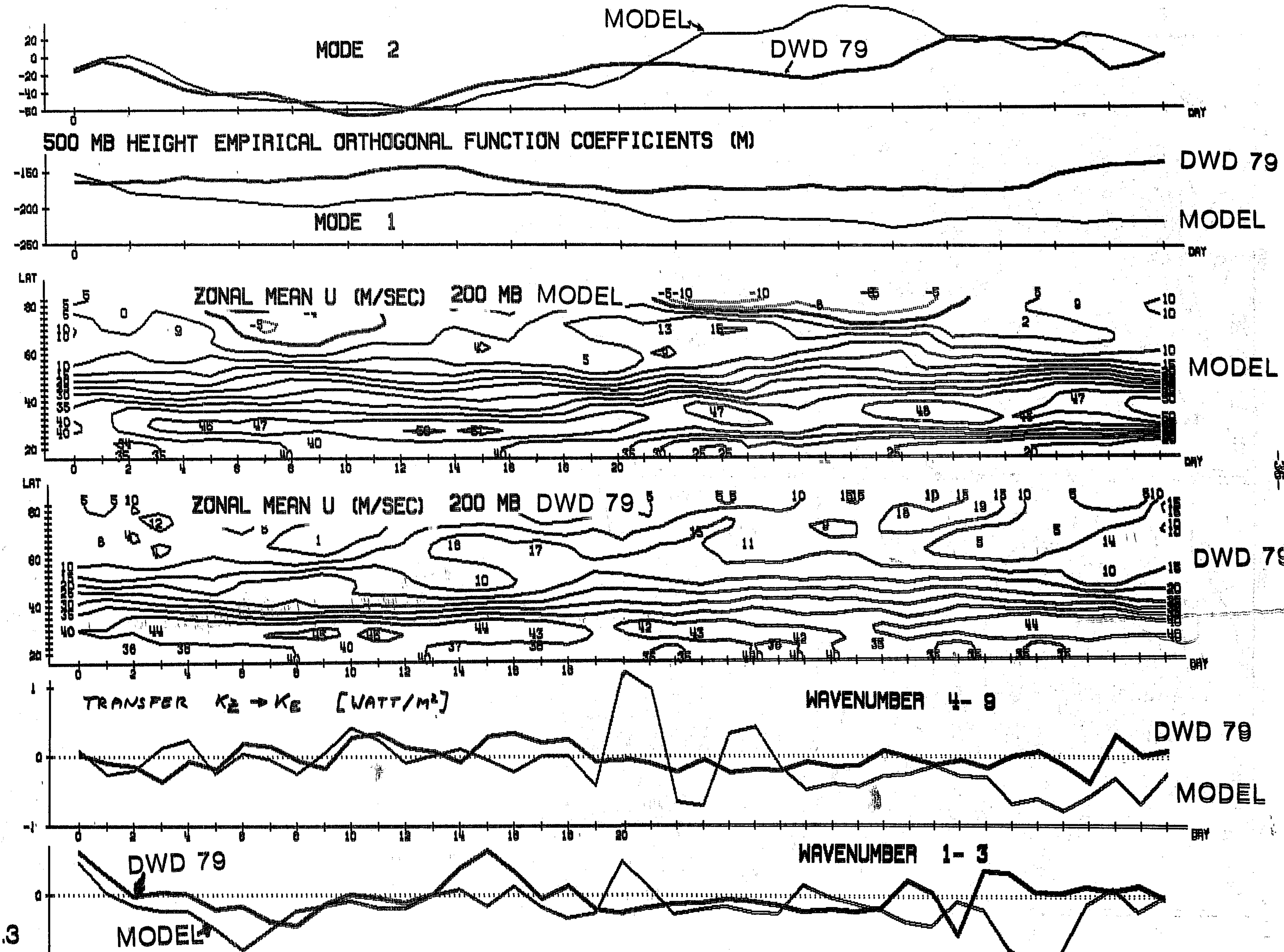
MODE 2
MODEL
DWD 79
DAY
500 MB HEIGHT EMPIRICAL ORTHOGONAL FUNCTION COEFFICIENTS (M)
MODE 1
DWD 79
MODEL
LAT
ZONAL MEAN U (M/SEC) 200 MB MODEL
MODEL
ZONAL MEAN U (M/SEC) 200 MB DWD 79
DWD 79
TRANSFER $K_Z \rightarrow K_E$ [WATT/M²]
WAVENUMBER 4- 9
DWD 79
MODEL
WAVENUMBER 1- 3
DWD 79
MODEL

Fig. 5.3