SENSITIVITY OF THE ECMWF MODEL
TO CHANGES IN THE RESOLUTION

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1. INTRODUCTION

1.1 Review of previous resolution studies

1.1.1 Climate circulation studies

Manabe et al (1979) assessed in one recent publication the performance of the GFDL spectral model of summer and winter circulation simulations using various spectral truncations and reached the following conclusions:

a. The surface westerlies in the southern hemisphere become stronger and more realistic with increased resolution.

b. The overall performance of the model simulating the sea level pressure distribution improves with increased resolution (except for the northern hemisphere in winter).

c. The high resolution model simulates the upper tropospheric flow in low latitudes better than its low resolution counterpart.

d. The geographical distribution of precipitation becomes more realistic with increased resolution.

e. In all models the eddy kinetic energy is less than observed. The stationary component has a larger share than observed, while one finds too little eddy kinetic energy in the transient component.

A similar resolution experiment was carried out using the ECMWF model (Cubasch, 1980) for a winter circulation going to even higher resolution in the horizontal and vertical than Manabe et al. The evaluation of the ECMWF experiment confirmed the results of GFDL, but gave additional information about the performance of models in climate runs.

The 1000 mb height 24-day mean height field (fig.1) pinpoints to three trends in dependence of resolution:
The pressure of the stationary depressions becomes lower with increased resolutions.
The depressions are displaced to the north with increased resolution.
The depressions shift towards the east with increased resolution.

Evaluating the zonal mean of the zonal wind (fig.2) one finds that the extremum of the subtropical jet increases with higher horizontal resolution and is displaced upwards and polewards.

The kinetic eddy kinetic energy (Fig. 3) also increases with resolution and its maximum shifts northwards.

1.1.2 Predictability case studies

While these two experiments were carried out to test the sensitivity of the model's climatology to the resolution, Bengtsson (1981) published a study investigating the impact of resolution to the direct predictability of a blocking event in the medium range time scale (up to 10 days). He concluded that a high resolution model with comprehensive physics appears to be necessary to extend the predictability.

At the "5th conference on numerical weather prediction" held in the USA in 1981, Miyakoda and Sirutis presented a case study of 30-day mean forecasts starting on 1.1.77. They were able to predict the mean flow of this situation within reasonable accuracy with a high resolution gridpoint model using a particular physical parameterization which included a second order closure scheme for turbulent processes ("E-4 - physics").

The possibility of a forecast of longer timespans for long waves had been discussed in theoretical studies (Lorenz, 1969), but the previous generation of models displayed serious deficiencies in simulating ultralong waves (Lambert and Merilees, 1978) which seemed to be mainly connected to the insufficient resolution of the older models and by the assumption of a wall at the equator in the hemispheric models. Encouraged by the results of Miyakoda particularly, and knowing that the prediction of ultralong waves seems to pose no problem to the ECMWF model (Bengtsson, 1981) it was decided to study the 1.1.77 case in more detail, also at ECMWF.Results of this study using the ECMWF grid point model have been discussed by Strüfing (1982). He indicated that the EC-model does not simulate the flow pattern as accurately as the GFDL model. A set of experiments investigating this case with the spectral version of the ECMWF model with various horizontal resolutions will be discussed below.

2. THE EXPERIMENT

2.1 Synoptic situation

The synoptic situation (Fig. 4) starting on 1.1.77. is characterised by a strong blocking high over the western part of North America, flanked by a low pressure area over the central north Pacific and one over the American east coast. This situation persisted in the mean over the 30-day period and created an abnormous warm winter in the western United States, but a very cold and severe winter in the central and eastern United States. The persistence of the severe winter situation with all its implications for the US economy in fact led to the case study done at GFDL.

2.2 The Model

The spectral model (Baede et al., 1979) used for this experiment has been developed as an alternative to the operational gridpoint model. Like the operational model it comprises 15 levels in the vertical on sigma coordinates (Fig. 5) and shares the same physical parameterization as the gridpoint model (Tiedtke et al., 1978). The horizontal resolution is determined by the triangular truncation of the spherical harmonic coefficients. The following resolutions were put on trial:

T21L15: gaussian grid of 5.6 deg; max. resolved zonal wavenr.: 21

T40L15: gaussian grid of 2.8 deg; max. resolved zonal wavenr.: 40

T63L15: gaussian grid of 1.9 deg; max. resolved zonal wavenr.: 63

A comparison of the spectral with the gridpoint model has been carried out by Jarraud et al. (1979) and indicated a comparable performance of both horizontal representations.

The dataset was provided by GFDL, initialized with the ECMWF gridpoint model and interpolated to the appropriate resolution.

Soil moisture and sea surface temperature were adjusted to their climatological value every 4th day.

The results are verified against the analysis of the German Meteorological Office (DWD).

3. RESULTS

As mentioned before, the dominating feature of this "Grosswetterlage" is a ridge over the western parts of North America accompanied by a trough over the Pacific and eastern United States with a small ridge developed over Greenland and the Kamschatka and a trough over Europe. The ridge over the American west coast has been forecast with all model resolutions, but its phase, tilt and amplitude are fairly poorly predicted with the T40 and the T63 model (Fig. 6).

A diffluent region east of the United States can only be found in the T21 model. The strength of the flow, however, is better simulated with the higher resolution models.

The skillscores (for details see Hollingsworth et al., 1979) for the 500 mb height field in the total show that with increasing resolution the predictability (correlation coefficient $> 60\ \%$) is increased. On the other hand, once passing this threshold value the anomaly-correlation drops faster with increased resolution and stays quasi-horizontal at about 40 % for the T21 model (Fig. 7). This effect is mainly caused by the better treatment of the long waves and the zonal part in the low resolution model.

The anomaly correlation for the 10-day running mean confirms the results of the single day correlation (Fig. 8). A comparison with the skillscore published by Sirutis and Miyakoda (1981) for the GFDL model shows a slight advantage of the T21 simulation over the GFDL run with "E-4" physics, except for the last time period from day 20 to 30. Noteworthy is the recovery skill of the T63 model in the late period of the prediction, a phenomenon also found in the GFDL forecast by Sirutis and Miyakoda using the "F-physics" (Arakawa-Schubert convection parameterization).

The reason for the poor performance of the high resolution models is not known, but it is possibly the consequence of an insufficient treatment of the forcing in the model, as it might be inferred from the spectrum of kinetic energy which appears to be unrealistic as it approaches the higher wavenumbers of the spectrum. This unrealistic treatment of the short waves in the T21 model might substitute effects missing in the higher resolution models.

The main differences between the high and the low resolution model in the forcing are as follows:

a) The orography is smoother with lower resolution.

b) The physical parameterization is done on more points in the higher resolution runs.

c) The diffusion is higher in the T21 model than in the other models.

It was therefore decided to launch a number of experiments to isolate the importance of these three factors.

The impact of orography has been tested by running the T40 model with the initial information and the comparatively smooth orography of the T21 model. This hybrid model performs similarly to the T40 model at the short and medium range and worse over a 30-day period. It resembles, however, more the T40 model than the T21 in respect of the circulation pattern. The orography seems therefore not to bear the main responsibility for the different performance of the high resolution models (Fig.10).

The effect of the physical parameterisation was studied by running an experiment using (a) a GFDL physical parameterisation package (Hollingsworth et al, 1979) and (b) only a basic surface friction formulation:

$$F = \text{const.} \; |\underline{V}| \; \underline{V}$$

The run containing the GFDL parameterisation predicts two ridges over North America instead of one (Fig.11). The flow in the north Atlantic region is not well forecasted. The skillscore of this experiment is lower than that of the standard T21 experiment (Fig.12).

Even though the 1000 mb height field for the run with surface friction hardly produces a reasonable flow pattern, it still displays in the 30 day mean 500 mb height field the trough and the ridge over North America with a remarkable precision. A T40 run done with surfaces friction only on the other hand again resembles more the ordinary T40 run with its deficiencies. Further experiments to clarify the role of the physical parameterisation and/or the orography seem, however, to be necessary.

The impact of the diffusion has also been investigated. A limited number of experiments indicate that the diffusion does not solve the basic problems of the increased resolution.

4. CONCLUSION

As already mentioned by Cubasch (1981) we find that the model-climate is influenced by the resolution in the following way:

Depressions tend to become deeper with increased resolution.
Depressions also shift to the north and the east and north with increased resolution.

The subtropical jet increases and shifts to the north with increased resolution.

The eddy kinetic energy increases with resolution.

These effects seem to be the cause for the inferiority of a high resolution model in an extended range prediction experiment.

Up to now only a few cases have been evaluated in respect of their extended range predictability. It appears, therefore, to be necessary to run 30-day forecasts in a semi-operational way to extablish the rules on which occasions such a forecast can be expected to be successfull.

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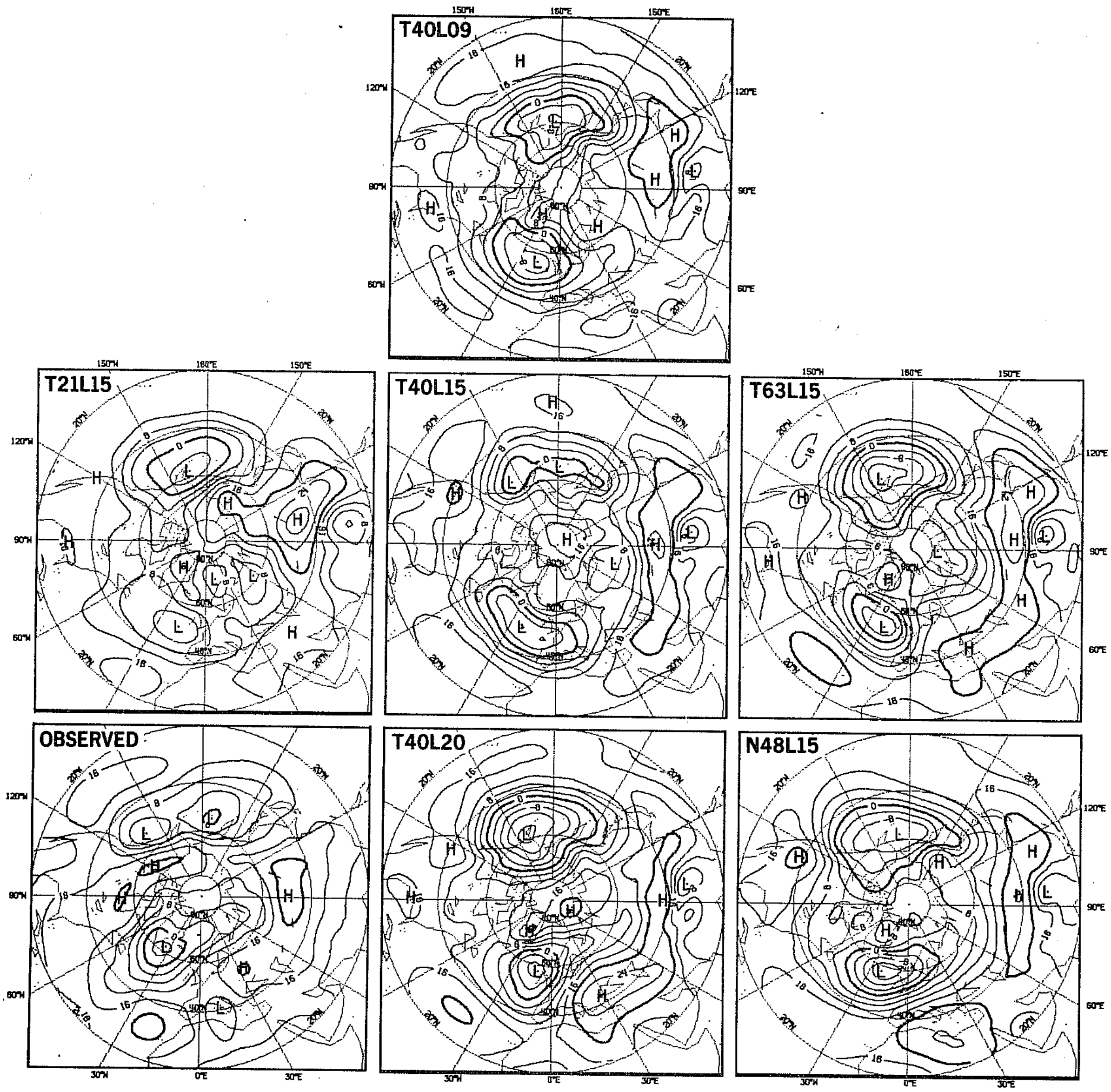


Fig. 1 The 24 day mean 1000 mb height field for a winter circulation simulation.
TnnLmm: triangular spectral truncation at wavenumber nn;
vertical resolution mm levels
N48L15: operational gridpoint model
DWD analysis

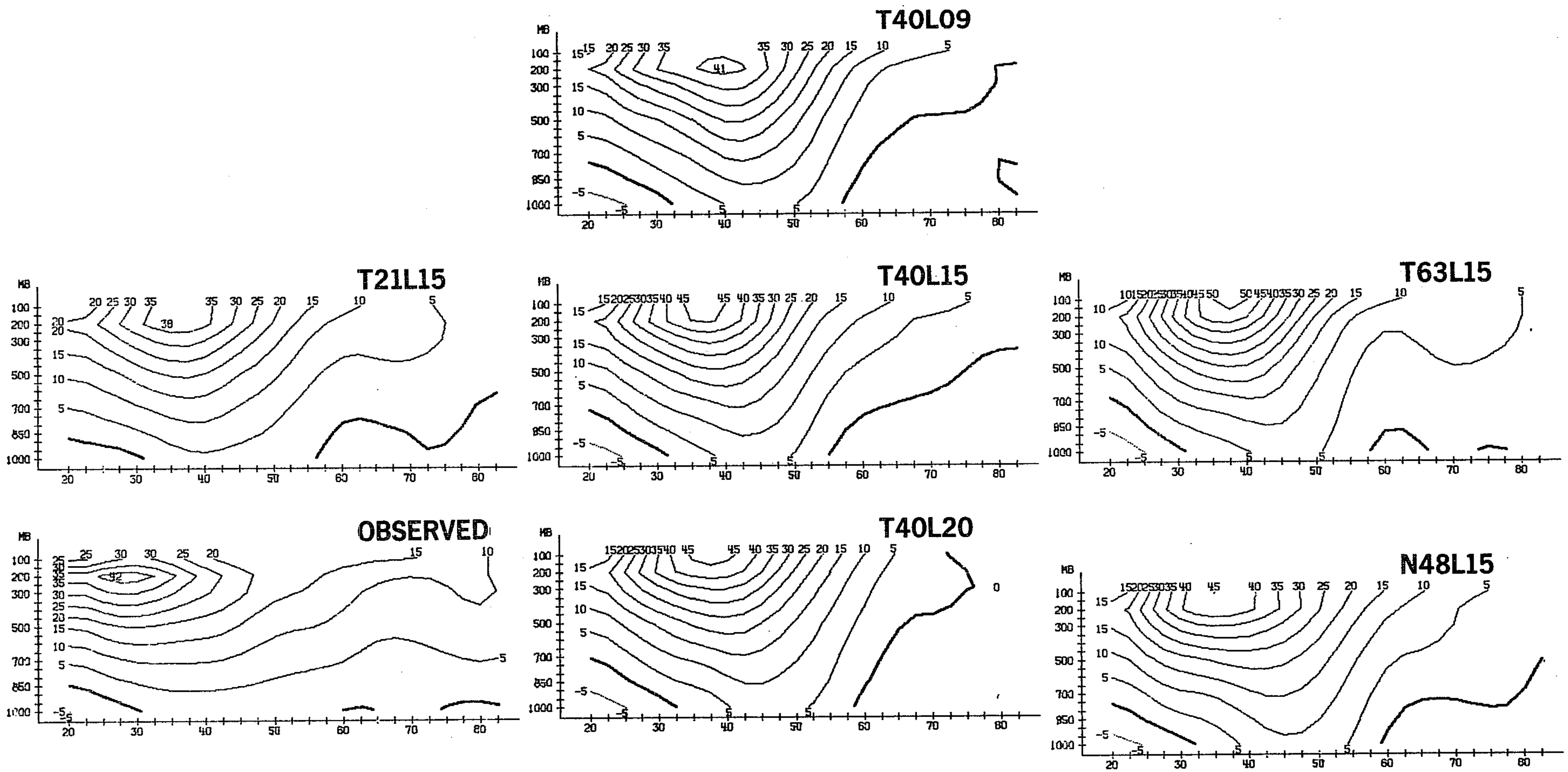


Fig. 2 The 24 day mean of the zonal mean of the zonal wind. Units: m/s. See Fig. 1 for notation.

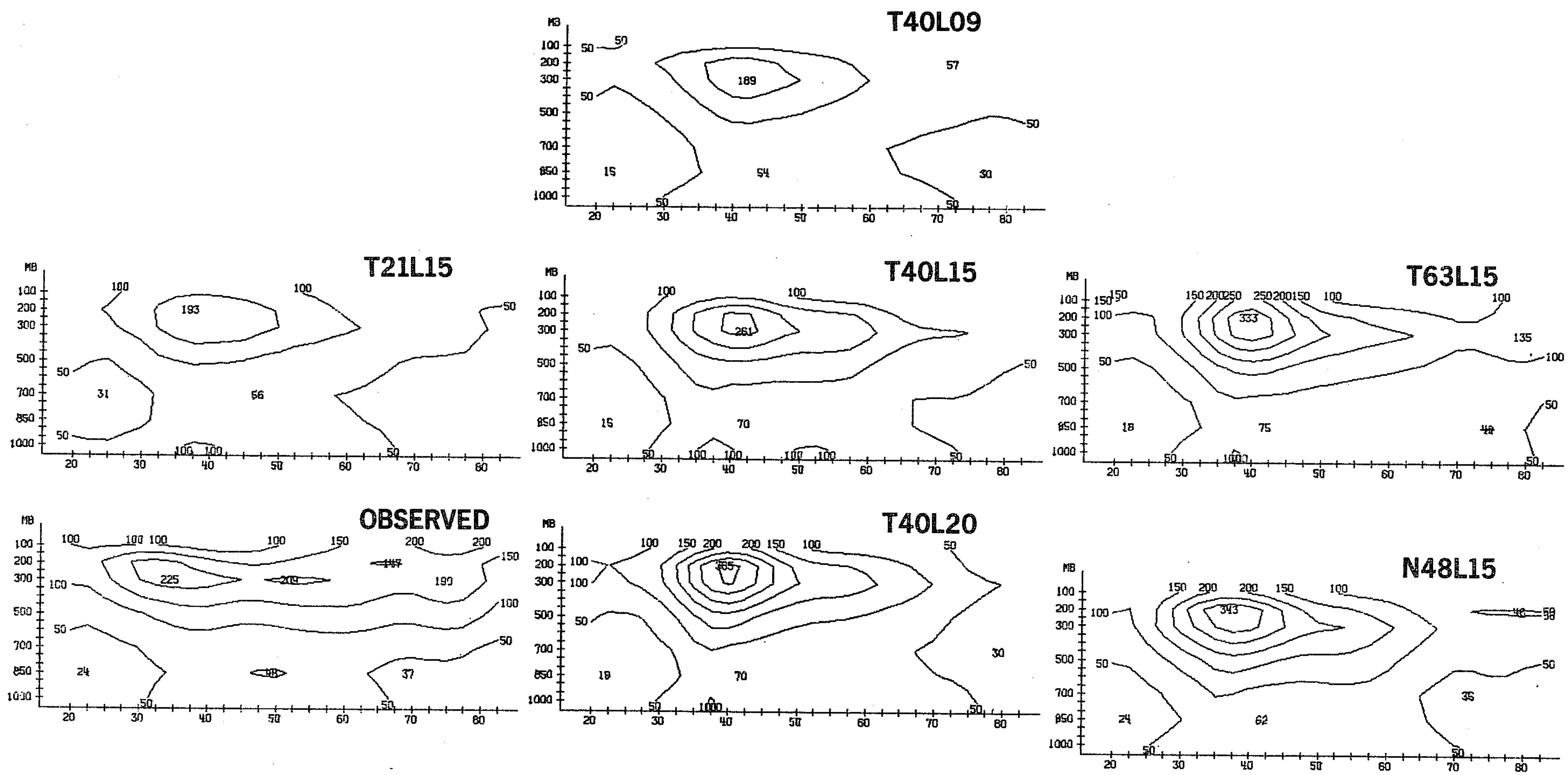


Fig. 3 The 24 day mean kinetic energy in wavenumber 1...20. Units: 10 kJ/m^2/bar. See Fig. 1 for notation.

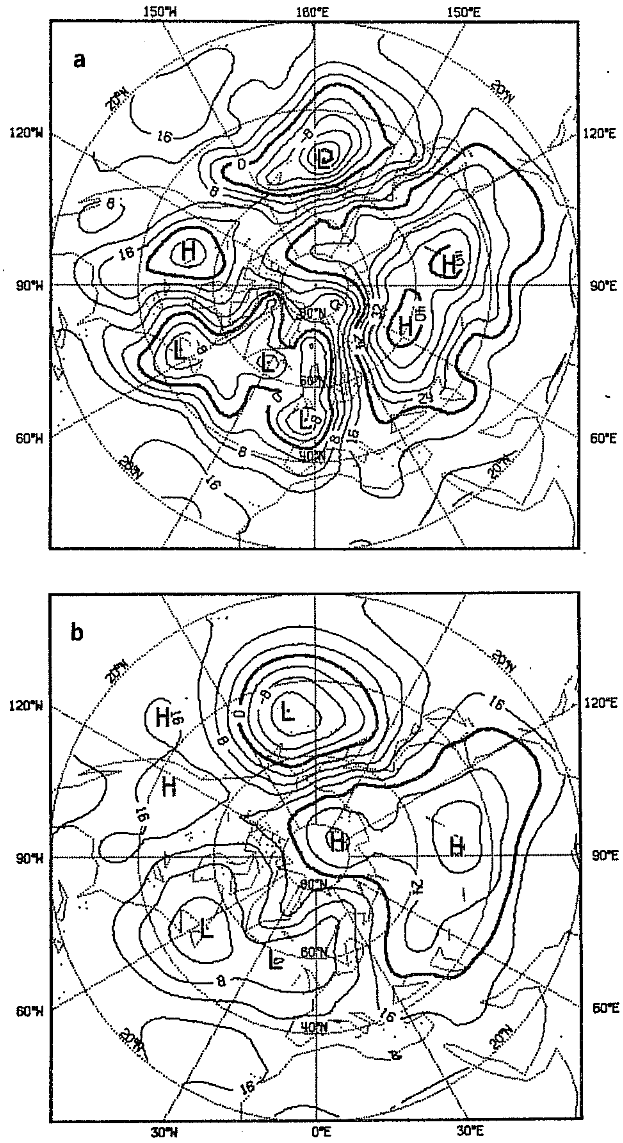
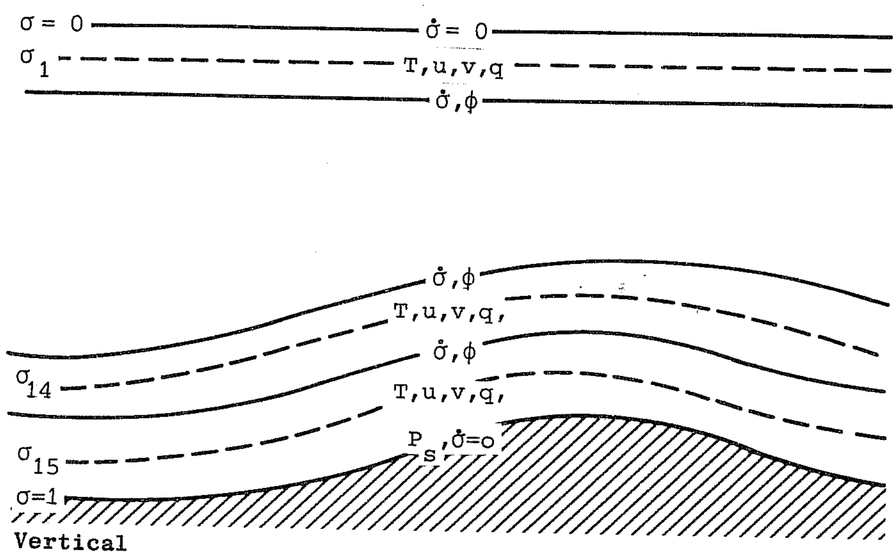


Fig. 4 a) The 1000 mb flow on 1 January 1977 and
b) The 1000 mb mean flow for January 1977.

SIGMA LEVELS

0.025(σ_s)
0.077
0.132
0.193
0.260
0.334
0.415
0.500
0.589
0.678
0.765
0.845
0.914
0.967
0.996(σ_{15})



Vertical dispositions of variables in the ECMWF models
Vertical coordinate: $\sigma = p/p_s$

Independent variables	λ, φ, ϕ, t
Dependent variables	T, u, v, q, p_s
Grid	Gaussian, resolution : T21 max. resolved zonal wave nr. 21, T40 : max. resolved zonal wave nr. 40: non-uniform spacing of vertical levels.
Finite difference scheme	Second order accuracy.
Time-integration	Leapfrog, semi-implicit (Δt: T21-2400 sec; T40-1600 sec)
Horizontal diffusion	Linear, fourth order (diffusion coefficient = T21-2.10^{15} T40-7.10^{14})
Earth surface	Albedo, roughness, soil moisture, snow and ice specified geographically. Albedo, soil moisture and snow time dependent.
Orography	Averaged from high resolution data set.
Vertical boundary conditions	$\dot{\sigma} = 0$ at $p = p_s$ and $p = 0$.
Physical parameterisation	(i) Boundary eddy fluxes dependent on roughness length and local stability (Monin Obukov)
	(ii) Free-atmosphere turbulent fluxes dependent on mixing length and Richardson number
	(iii) Kuo convection scheme
	(iv) Full interaction between radiation and clouds
	(v) Full hydrological cycle
	(vi) Computed land temperature, no diurnal cycle
	(vii) Climatological sea-surface temperature adjusted every 4th day.

Fig. 5 Characteristics of the ECMWF spectral model

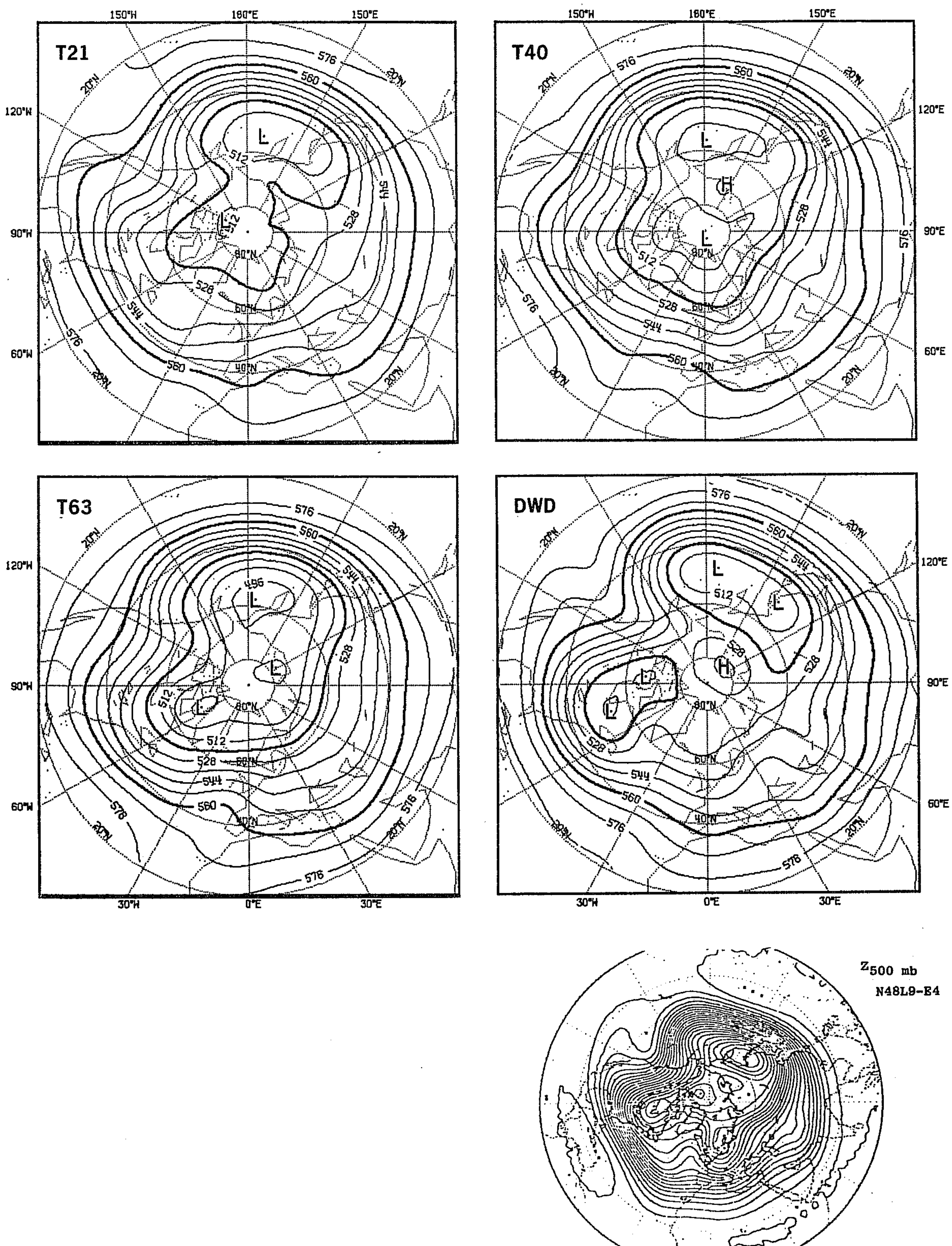


Fig. 6 The 30 day mean 500 mb flow simulation for three different horizontal resolutions of the ECMWF model and the GFDL-model (bottom right) compared to the DWD analysis.

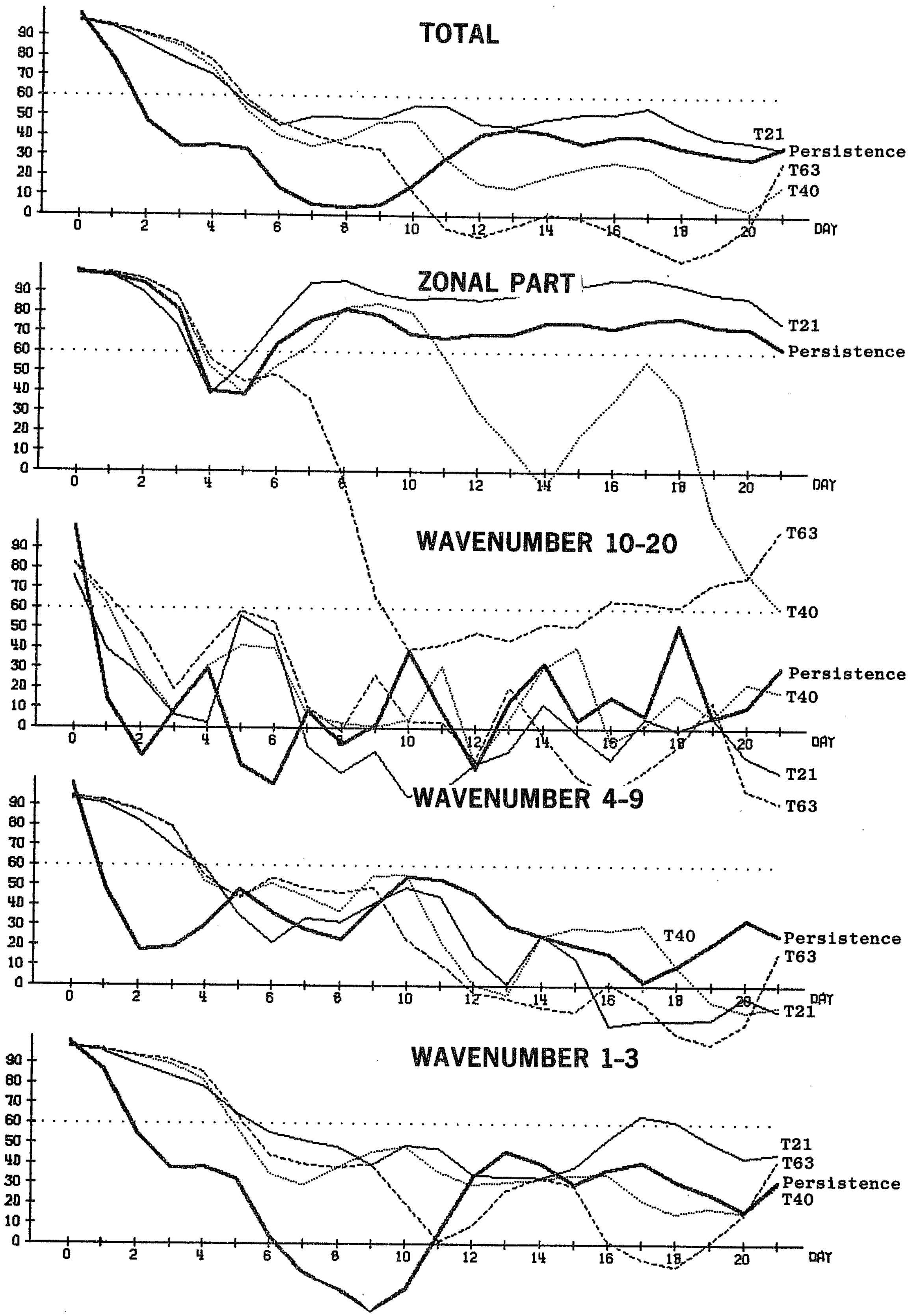


Fig. 7 The anomaly correlation for the 500 mb height field, latitude 20° to 82.5°N, as a function of resolution.

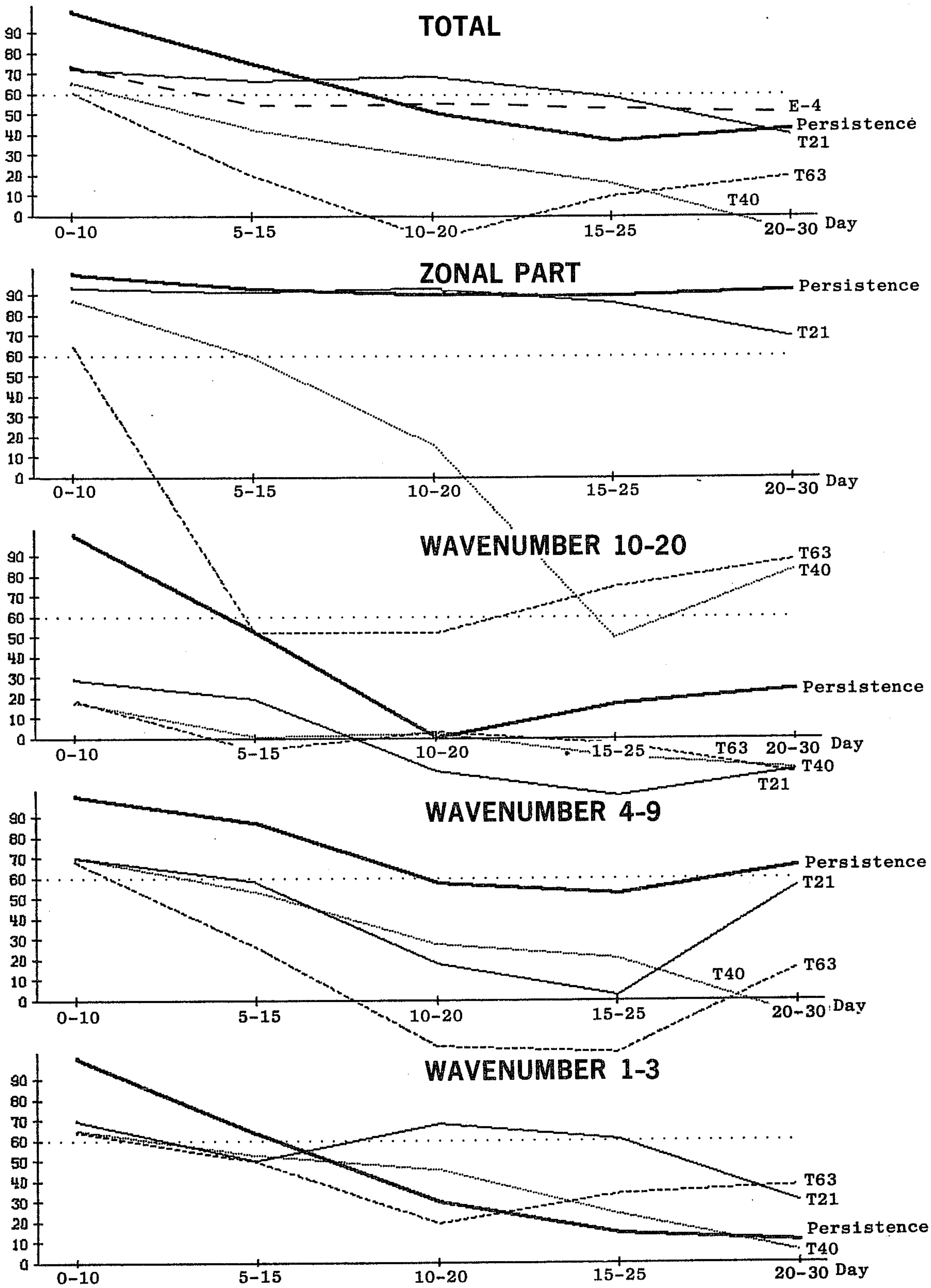


Fig. 8 The anomaly correlation for the 500 mb height field, latitude 20° to 82.5°N, as a function of resolution (running 10-day mean) and the integration performed at GFDL with E-4 physics.

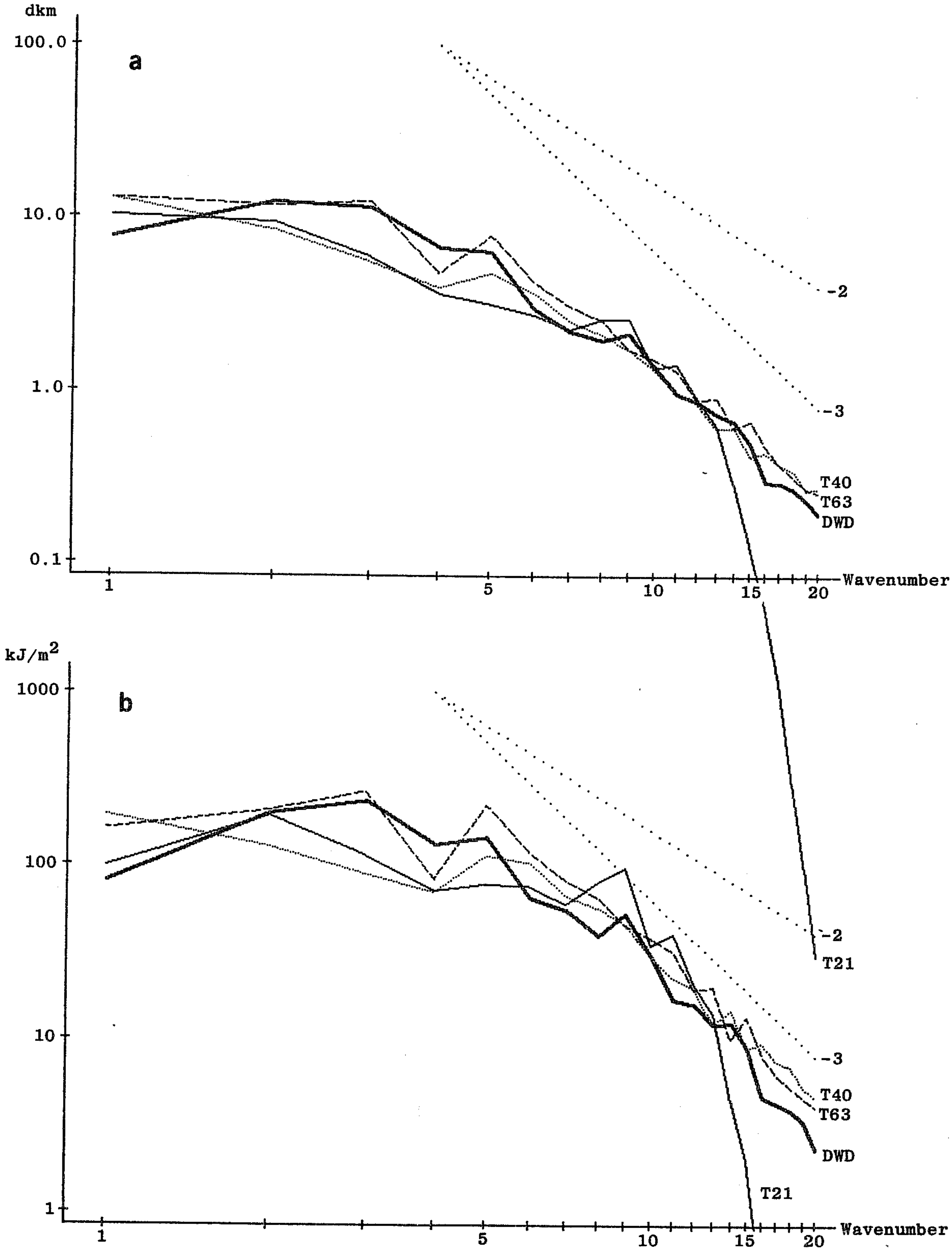


Fig. 9 a) the spectrum of height and b) the spectrum of kinetic energy in the troposphere as a function of horizontal resolution.

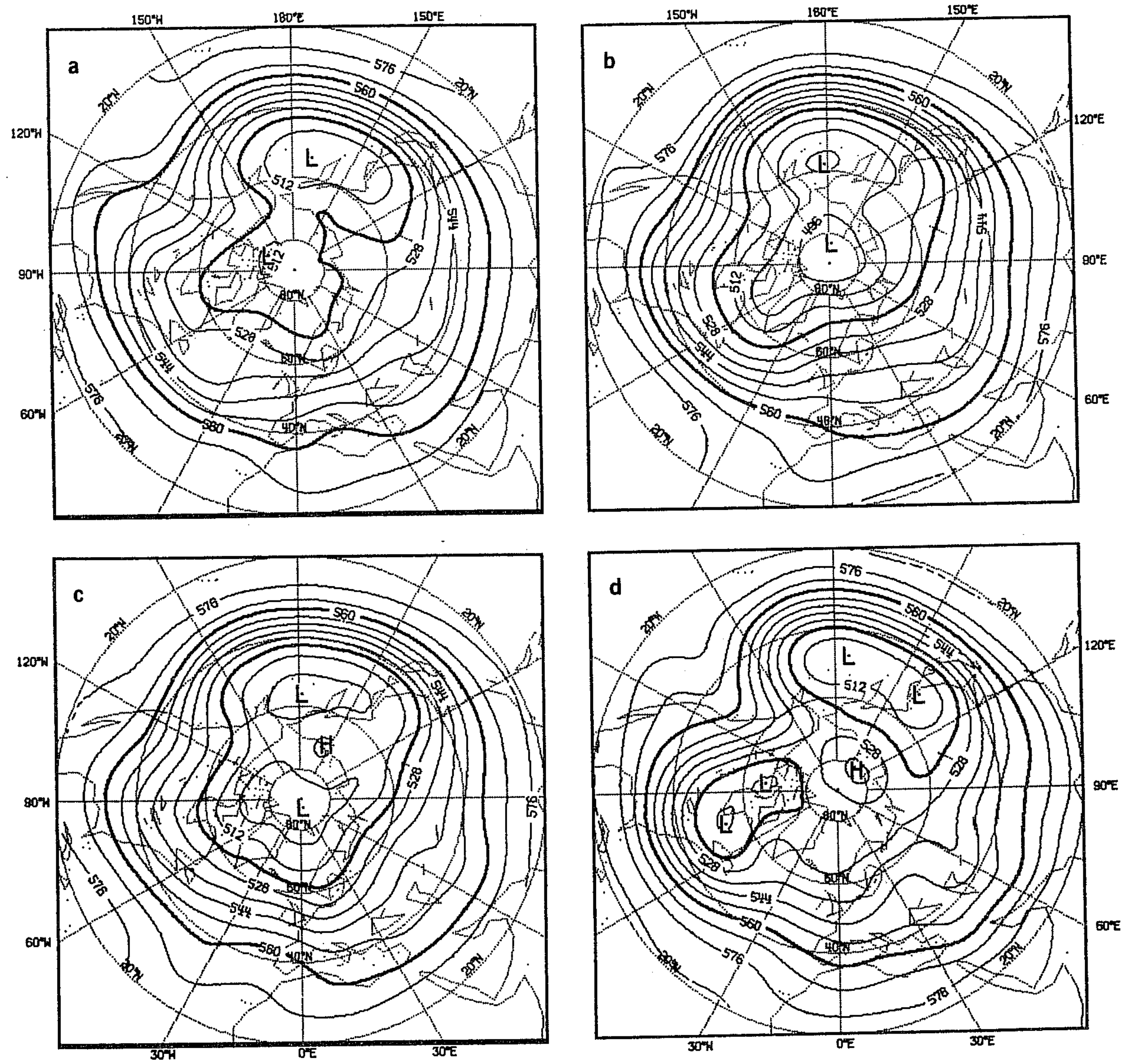


Fig. 10 The 30-day mean 500 mb flow for a) the T21 model, b) T40 model with T21 input data and orography, c) T40 model and d) DWD analysis.

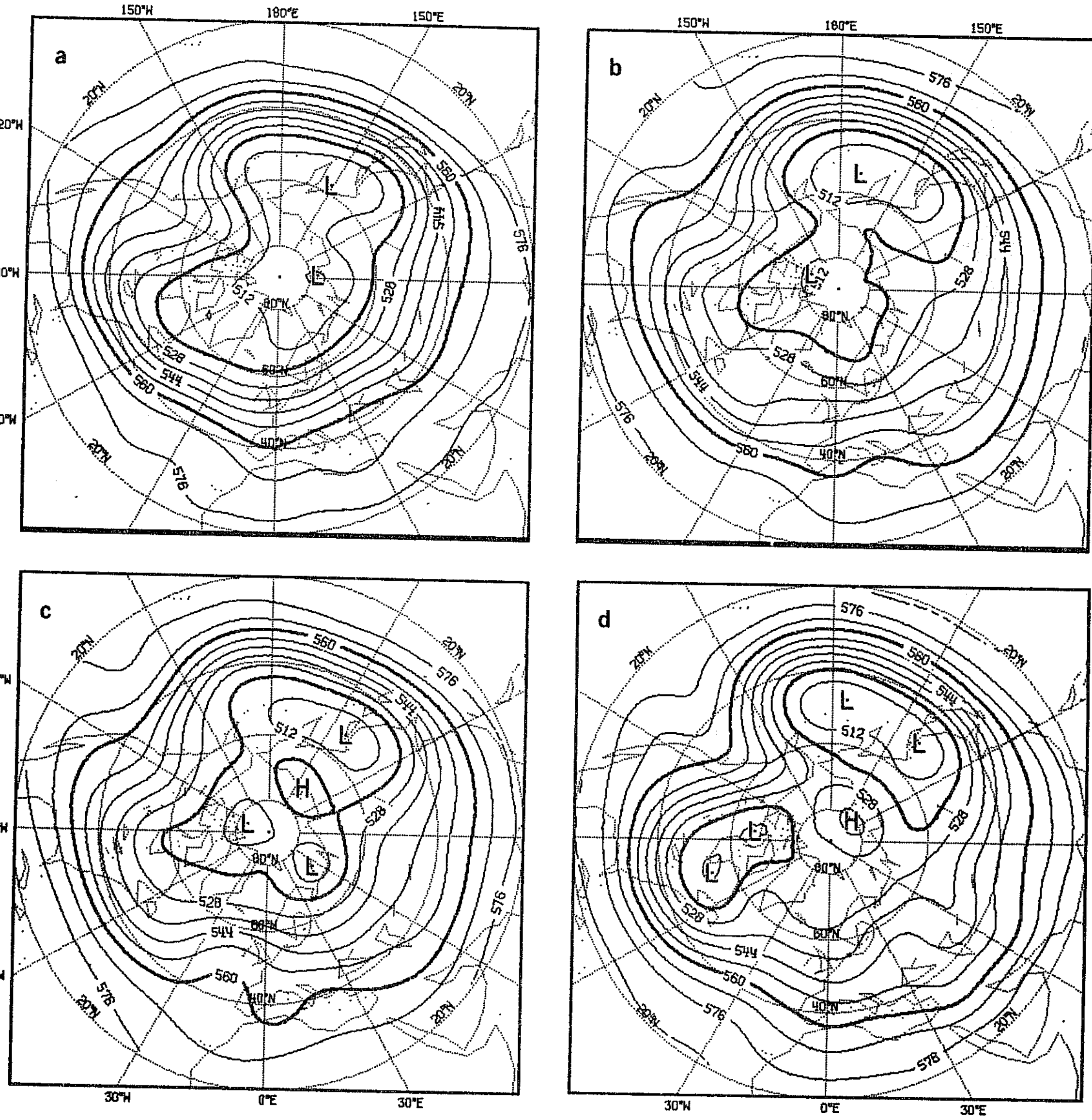


Fig. 11 The 30 day mean 500 mb flow simulated by the T21 model with a) surface friction only, b) ECMWF paramerisation and c) GFDL parameterisation. d) DWD analysis.

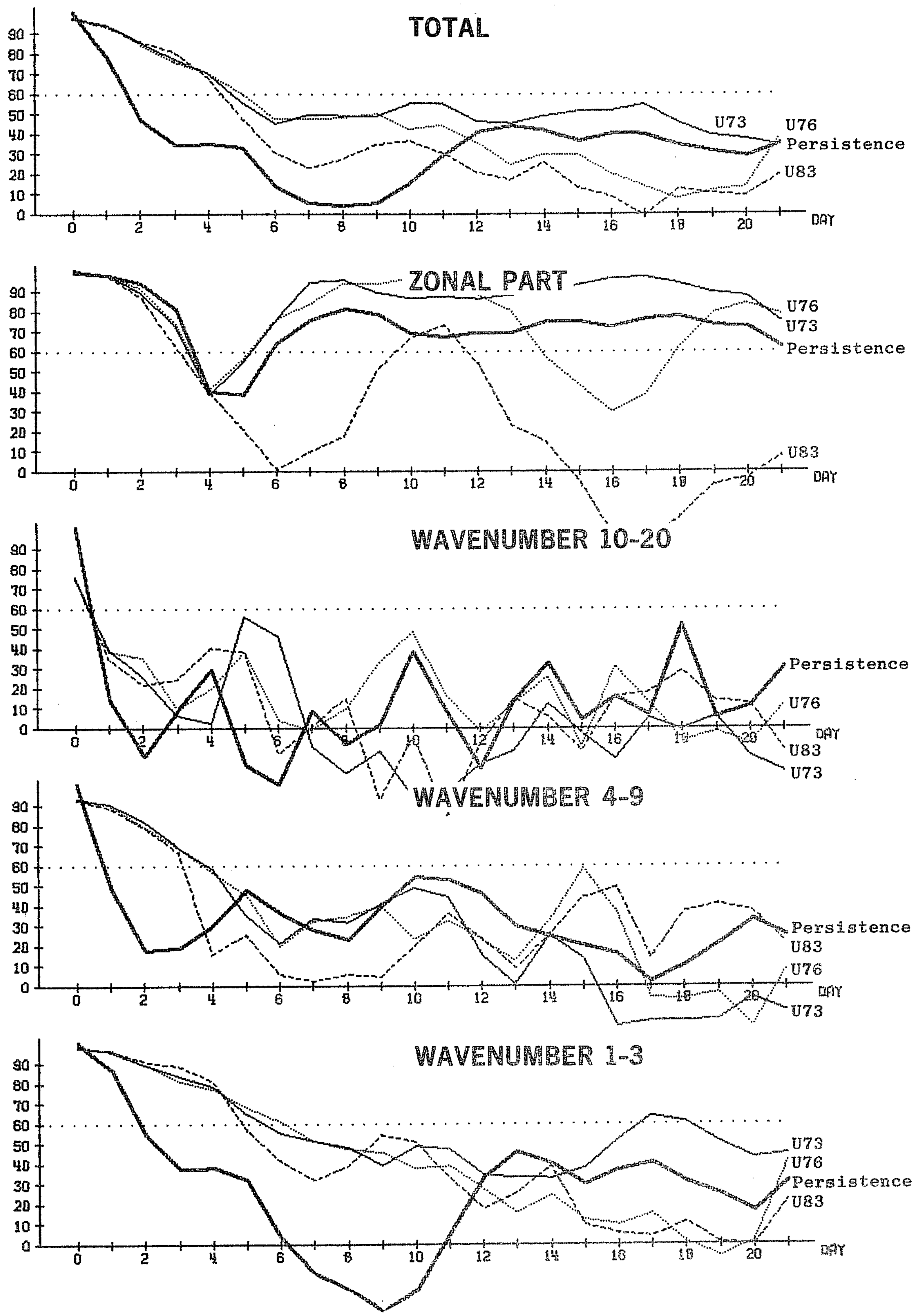


Fig. 12 The anomaly correlation for the 500 mb height field, latitude 20° to 82.5°N, for a T21 model integration using ECMWF physics (U73), GFDL physics (U76) and a simple surface friction (U83).