TECHNICAL MEMORANDUM

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The surface and sub surface scheme in the ECMWF forecasting model: revision and operational assessment

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Subject: The surface and sub-surface parametrisation scheme in the ECMWF forecasting system: revision and operational assessment of weather elements

INTRODUCTION

The wealth of surface and near surface parameters that are produced daily by the ECMWF operational forecasting system are an important source of information. Recent developments in the representation of physical processes in the ECMWF operational forecasting system have led to an increase in confidence in the forecast of such actual weather elements some of which are disseminated to Member States as experimental products. These include parameters which are a direct model products, such as precipitation, cloud amount and snowfall, and post-processed near-surface parameters, such as temperature and dewpoint at 2m above the model's surface and the wind at 10m.

The first three parameters are mainly related to the representation of the hydrological cycle in the model which was a subject of attention when developing the revision to the parametrisation implemented in 1985. The 1985 revisions included changes to the parametrisation of deep convection, the introduction of a shallow convection scheme and a new cloud formulation. The 2m temperature and dewpoint and the 10m wind are derived by interpolation of meteorological variables between the lowest model level and the model's surface and are particularly dependent on the parametrisation of surface processes. This aspect of the model has been the subject of recent research leading to a new surface scheme which was implemented operationally on 7 April 1987.

The verification of forecast weather elements has been undertaken systematically because they are valuable and sensitive indicators of the model in general and the parametrisation scheme in particular and there is an increasing interest in these parameters by Member States who wish to use them in order to obtain guidance for local weather forecasting.

The meteogram illustrated in Fig. 1 gives a model derived forecast for a single location, Washington DC, USA. The figure highlights the usefulness of the forecast products as they realistically display the synoptic evolution and the diurnal variation of weather parameters, but also the inadequacies inherent in the way the parameters are estimated in the model and problems related to their use. During the first five days of the forecast Washington remained under the influence of very humid and warm sub-tropical air ahead of a slowly eastward moving trough. The afternoon convection and shower/thunderstorm activity with temperatures well in excess of 25°C, which is reflected in the meteogram, appears realistic. One must however consider that the results apply to large areas (1.125° x 1.125°), are sensitive to unavoidable model errors at the smallest resolved scales, and therefore require further interpretation. Finally the validity of local products is obviously limited by the overall quality of the forecast.

The object of this paper is first to discuss recent changes in the forecasting system which affect the computation of weather parameters mentioned above and which are mainly related to a new representation of land-surface processes (Part I), and to present results concerning their operational evaluation, stressing where appropriate the impact of recent model changes (Part II).

PART 1 REPRESENTATION OF SURFACE PROCESSES AND COMPUTATION OF NEAR SURFACE PARAMETERS

1. GENERAL MOTIVATION

The quality of the forecast of actual weather parameters has benefited from the various improvements in the model physics and increases in resolution which have taken place in the last four years. Significant improvement was achieved following the operational implementation of the T106 model in May 1985 along with the parametrisation changes mentioned in the introduction.

Subsequently evaluation of operational products indicated too frequent and generally overestimated precipitation over temperate continental areas. This defect was traced back to the formulation of land surface evaporation, a modification for which was introduced in July 1985. This modification was a crude attempt to represent the resistance of vegetation to evaporation, leading to a decrease of moisture surface fluxes mostly in temperate regions.

As a result of this, a project to develop a revision to the parametrisation of surface processes was undertaken with the goal of including a realistic prescription of the properties of a vegetation cover.

Sensitivity studies have clearly shown the role played by surface parametrisation schemes in the simulation of climate (see Mintz, 1984 for a review). For medium range forecasting, surface parametrisation has a clear influence on surface variables, even in the short range, and through the assimilation process it has the main controlling influence on the initial state of the model's surface, because of the inadequacy of surface observations. The surface exchange processes that have to be parametrised are complex and difficult to describe accurately in a numerical model. The greatest difficulties are associated with the incorporation of evapotranspiration from vegetation and the best way to parametrise it.

In addition to problems mentioned above with precipitation, routine verification of operational forecasts since 1985 revealed a number of deficiencies in the prediction of surface parameters which could be related to the formulation of evaporation over land. The main systematic deficiencies, observed over continents were too low day time 2m temperatures and too warm night time 2m temperatures during clear nights, sometimes by more than 10°.

The day time cold bias was almost certainly an indication that too much of the sun's energy was being used to evaporate soil moisture. The night time warm bias was due mainly to the methods used to post-process the 2m temperatures and in winter there was some contribution to this bias from the specification of the thermal properties of snow.

Early results from the HAPEX-MOBILHY experiment carried out in May-June 1986 also served to underline the consistent erroneous behaviour of surface variables. These results showed clearly defects in both the analysis procedures and the parametrisation scheme, particularly the manner in which surface moisture fluxes were calculated.

The revised parametrisation and accompanying changes implemented on 7 April 1987 were aimed at alleviating some of these problems. The new surface scheme distinguishes between the properties of bare soil and of a vegetated area, taking into account both the aerodynamic and stomatal resistance of the surface. Only one vegetation type is considered with the properties of a tree-like canopy, which can retain a small amount of water on the leaves and pump underground water at various levels through the root system. A brief description of this scheme and of the associated revisions to the analysis procedure and the post-processing package are given in Section 2. Section 3 describes the results from pre-operational experiments.

2. GENERAL DESCRIPTION OF THE REVISION

2.1 Surface fluxes

The main objective of the revision was to provide a realistic description of the controlling influence of vegetation on surface processes. This is a key factor in the determination of surface moisture fluxes and their influence on the simulated/forecast diurnal temperature cycle. The old surface scheme was based on the computation of the surface moisture flux as a fraction (an efficiency coefficient) of the potential evapotranspiration, the efficiency coefficient depending on the surface wetness, and since July 1985, the surface temperature. A more realistic scheme should account for the basic physics involved in the interaction between a canopy layer and both the atmosphere and the underlying soil, and should be able to differentiate between the moisture flux regimes over vegetated and bare land areas.

The new scheme for the parametrisation of the turbulent moisture flux over land surfaces can be summarized in the following way:

- at each land grid point, a fractional vegetation coverage is prescribed (computed from Wilson and Henderson-Sellers, 1985) (Fig 2);
- the bare land fraction of the grid box evaporates according to a simple aerodynamical law in which the surface specific humidity depends on the surface wetness only;
- the vegetated fraction is split into wet and dry parts of the canopy; the wet canopy evaporates the water stored on the leaves due to the interception of precipitation or the collection of dew (at the potential rate); the transpiration of the dry part is controlled by the short wave radiation (connected to photosynthesis) and the moisture stress in the root zone (Fig 3), which define the stomatal resistance of the canopy; the aerodynamical resistance (the inverse of the drag) and the stomatal resistance together control the flux of moisture in the atmosphere.

Compared with the previous scheme, the new approach gives moisture fluxes which are less dependent on the static stability and the wind speed and are smaller for the same moisture stress.

The soil hydrology has been modified and now accounts for:

- surface run-off in hilly and mountainous regions due to the slope of the terrain (this is specified using the variance of the sub-grid scale orography);
- the surface run-off occurring when the precipitation and the melting rate exceed a maximum infiltration rate;
- gravitational drainage;
- the partitioning of the transpiration in terms of root extraction between the three soil reservoirs.

The thermal properties of the ground are now dependent upon snow cover. This is in contrast with the old scheme in which the influence of snow on conductivity and capacity was ignored. This dependence results in a more intense diurnal cycle with lower surface temperatures over persistent snow packs.

The new surface scheme presented here includes the basic physical processes which are felt to be important in the computation of thermal and water exchanges between land surfaces and the atmosphere. However due to the lack of available data at the global scale, some of the key parameters (such as thermal and hydraulic properties of the soil) which should in principle be geographically or possibly seasonally dependent, have been set to standard values. For the same reasons only one vegetation and one soil type are considered all over the globe. A precise evaluation of the present scheme in operations will indicate if further developments are necessary.

Although the main emphasis was put on land surface processes, some reassessment of the surface flux formulation over sea was carried out. This led to the use of a lower value of 0.018 for the Charnock constant in place of the value used previously, namely 0.032. The lower value is supported by results from field experiments published by Garratt (1977) and Wu (1982). However, this change had relatively little impact on surface fluxes and the estimate of the 10m wind over oceans.

2.2 Analysis of surface variables

The snow depth and the sea surface temperatures are the only surface variables which are analysed in the revised scheme. The analysis of soil moisture has been abandoned temporarily, and both the initial soil temperature and moisture content are taken from the first guess.

Prior to the implementation of the revised scheme, where there were observations of precipitation, a soil wetness analysis was carried out using a first guess (persistence), an estimate of evaporation rate (an initial value taken from the model) and observed precipitation. The representiveness of the observations as a grid square average and the accuracy of the initial evaporation rate are questionable. In addition, by neglecting the exchanges within the soil between the surface and the deeper reservoirs, this approach tended to assign extreme values (very dry or almost saturated soils) to the analysed surface wetness and to provide, as a consequence, erroneous surface moisture fluxes. Furthermore, there was no guarantee that the initial values of land surface temperatures as taken from the first guess were consistent with these analysed values for soil wetness. For the revised scheme, evaporation depends much more on the content of the intermediate reservoir which cannot be analysed. Finally, the use of first guess values for all reservoirs leads to a more stable partitioning between the sensible and the latent heat fluxes in the early stages of the forecast.

2.3 Post-processing

The derivation of surface weather elements such as the 10m wind and the 2m temperature and dew point temperature is of interest for two reasons. Firstly, these parameters are routinely observed over the continents and also over the sea where they are used to analyse the wind field in the lower part of the troposphere. Secondly, they are indirect indicators of the forecast quality and accuracy and their comparison with observations can help to detect model defects. To be consistent with the philosophy underlying the formulation of the ECMWF model, the calculation of parameters located between the surface and the first model level should be constrained by the following: the first model layer is assumed to be a Constant (turbulent) Flux Layer (CFL) in which the Monin-Obukhov similarity theory applies and is used to compute surface fluxes from surface and first level model values. Accordingly, the use of the Monin-Obukhov theory implicitly assumes particular structures in the vertical profiles of temperature and wind speed. The post-processing package used prior to April 1987 was inconsistent with those assumptions. The derivation of parameters within the CFL assumed a neutral profile in all cases and this assumption necessitated the use of modified roughness lengths so that the fluxes computed from the neutral profile matched those from the forecast model. Fig 4 illustrates the systematic positive bias of the computed 2m temperature and 10m wind, especially in very stable conditions, that was a feature of the old system.

The revised method (Geleyn, 1987) is based on the a priori specification of analytical profiles which are close to the theoretical profiles, the choice of analytic forms allowing exact vertical integration. This method corrects errors which occurred with the use of the old method when both the surface and the air temperatures are predicted correctly. Clearly the new scheme will not remove deficiencies arising from weaknesses in the upper air analysis, in particular its inability to resolve very shallow cold stable layers which often occur in winter over Europe, nor from weaknesses remaining in the surface parametrisation (melting snow conditions or snow-free frozen soil for example) and from errors in cloud cover estimates.

A large uncertainty remains in the validity of the Monin-Obukhov similarity theory for moisture profiles. The old method computed the 2m humidity using the same technique as employed for the 2m temperature which can lead to unrealistically sharp vertical moisture gradients. The revised method computes the 2m dew point depression assuming the relative humidity in the CFL is constant.

3. PRE-OPERATIONAL ASSESSMENT

3.1 The impact of the revision on the model climate

A considerable amount of the preliminary experimentation was focussed on the evaluation of the sensitivity of T42 90 day (winter and summer) integrations to various choices of parameters. These extended integrations were used to assess the sensitivity of the model to the parametrisation of the dependence of soil characteristics upon snow, parametrisation of the interception of precipitation and/or collection of dew by the canopy, parametrisation of the extension of a root zone outside the first soil layer, etc. In this first attempt to include new processes in the scheme, "standard" values of snow thermal properties, soil hydraulic characteristics and canopy constants have been used.

Results of winter (initial date 12Z 6/12/83) and summer (initial date 12Z 15/06/86) simulations (90 day forecasts) are available for both the revised and the old (control) schemes, the four integrations being labelled as follows:

DW1: winter control

EHE: winter revised scheme

DYH: summer control

EHF: summer revised scheme

The impact of the revised scheme was qualitatively similar in both seasons, the impact being larger in the summer integration, as should be expected, since the revision is concerned mainly with the surface heat fluxes over the continents. In what follows, the comparisons are made between DYH and EHF.

The revision leads to reduced moisture fluxes over continents. This is clearly illustrated in Fig 5 where a reduction at all latitudes, except between 20 N and 30N, may be discerned. As a result, the sensible heat flux is increased, though this is less than the decrease in the latent heat flux - less moisture and more heat is transported in the planetary boundary layer. The performance of the shallow convection scheme is insensitive to the change. In contrast, the deep convection scheme responds directly to the reduction in evaporative flux of moisture over land. The diagnostics plotted in Fig 6 show that:

- the convection penetrates to the same height in both experiments,

- the heating in the middle of the troposphere is reduced by approximately 20% with the revised physics,

- the evaporation of precipitation takes place at higher levels in EHF compared with DYH;

- the convective precipitation arriving at the surface is decreased by 30% in EHF.

However, convective precipitation is slightly more intense around 25N. The greater evaporation in this area in EHF indicates the effectiveness of the feedback between the interception of precipitation by the canopy and its direct evaporation at the potential rate. Large scale precipitation is marginally reduced. The overall impact is quite small over the sea. There is little change in the radiative fluxes due to the marginal changes in cloud cover.

The revisions have very little impact on the mean wind fields. For example, the 200 mb wind field in the tropical region, which has the largest errors compared with the analysis, is not significantly affected. From Fig 7, it is clear that the main defects (too strong easterlies north of the equator and too weak westerlies along 25°S) have not been corrected by the revision. The deficiencies of the simulation of the Hadley circulation (a too northward position of the ITCZ in both seasons, a too weak and diffuse outflow, cf Fig 8) are very similar with both versions of the surface scheme. This is not surprising, since the root cause of these errors is more directly related to the convection scheme itself, to the radiation because of inappropriate cloud optical properties and to deficiencies in the parametrisation of the turbulence in the free atmosphere. Only a small improvement can be detected in the zonal mean errors of the zonal wind in the winter simulation (Fig 9).

The impact on the temperature is clearer. Because of the decrease of heating due to deep convection, the positive bias of the temperature of the mid-troposphere is reduced, a positive bias being replaced by a smaller negative bias in the winter simulation (Fig 10).

The most satisfying result is the change which occurs in the model energy cycle due to the modifications of the surface fluxes. By averaging results of both integrations (winter and summer), a modelled estimate of the annual global energy may be calculated and compared with other estimates. Fig 11 shows a comparison between the model energy with both versions of the physics and the Verstraete and Dickinson (1986) estimates. Their comparison "continents versus oceans" is derived from Budyko (1982).

Significant improvements have been achieved in:

- the Bowen ratio over the continents, which was too small with the previous physics and is now much nearer to Budyko's estimate.

- the partitioning of the evaporation, and consequently the partitioning of precipitation between the continents and the oceans.

However, fluxes are still too weak, particularly over the ocean, and this basic problem clearly requires further study.

Another interesting feature of the revision of the physics is a modest increase of the kinetic energy in the model at all levels and wave lengths (Fig.12). This result was difficult to anticipate, on the grounds that a reduction in the evaporation should decrease the convective activity. Nevertheless, an increase in the variance due to the transient waves is obtained in the troposphere.

3.2 Results from the pre-operational parallel run

Prior to the operational implementation on 7 April 1987, two parallel assimilations were carried out (an operational control versus revised scheme) - an 8 day assimilation for the period 21 to 29 November 1986 and a 6 day assimilation for the period 1st to 6th April 1987.

The use of observations (rejections/acceptances) was similar in both the control and revised assimilations, with slightly less rejections in the revised assimilation. The analysed surface temperature and soil wetness do, however, differ significantly.

Fig 13 illustrates these differences for the African continent. The revised scheme produces more spatial variability; differences between the control and revised analysed surface temperature can be as large as 8°C. Generally, the control scheme produced analysed values of the soil wetness which were significantly lower than values typical of 10 day forecasts made with the control scheme. This inconsistency has been removed completely in the revised system and the evolution of the soil wetness during a forecast is now more steady.

The revision had a direct impact on the moisture analysis (Fig 14) a drier planetary boundary being consistent with the use of the first guess and the revised scheme. In contrast, there was little impact on forecasts of primary variables - wind, temperature and height - in the free atmosphere. However, the revision had a significant impact on both predicted and post-processed values of near-surface parameters and this is discussed in Part II. The impact on the model's energetics was consistent with that obtained with the long integrations.

PART II OPERATIONAL VERIFICATION AND EVALUATION OF FORECAST WEATHER ELEMENTS

The use of the direct model output (DMO) of near-surface weather parameters as local forecast guidance requires careful evaluation of these products by verification against observations. Daan (1985) proposed a standardised verification scheme for local weather forecasts. Many ECMWF Member States are in the process of implementing local verification schemes in line with Daan's proposals and this will provide a comparison of the results from different locations and an assessment of the progress of local forecasting based on the Centre's numerical products. ECMWF has also implemented its own local verification scheme in order to provide feedback to the Member States on the quality of the experimental products, and also to monitor the model performance near the surface. Some results are presented below. The impact of the revised surface scheme on the near surface weather parameters is highlighted as appropriate.

1. Grid systems and orography

Before presenting the verification results, it is necessary to discuss the effect of horizontal grid interpolation and the effect of the orography on the products.

All direct model output of near-surface weather parameters is computed on the model grid used for the calculations of the physical processes. This is a nearly regular grid of 1.125° resolution in latitude and longitude. The model's land/sea mask is also defined on this grid (Fig 15). In order to make use of the model information at full horizontal resolution, data should be provided on the model grid for any further processing, e.g. plotting, statistical adaptations, input for other models. The present ECMWF dissemination to Member States only allows the distribution of data on a 1.5° grid (or multiples thereof). Although endeavours are made to maintain the effects of land/sea characteristics on the temperature fields and the dry areas on the precipitation fields, horizontal interpolation will tend to smooth the fields and result in a loss of information. However, it should be noted that with the implementation of the Centre's new dissemination strategy during the second half of 1987, Member States will have access to all products on the original grid and on model levels. Support will be given for:

- Spectral data
- Data on model levels on defined sub-sets of the model grid
- Pressure level data on multiples of 1°, 1.5° and 2.5° grids
- Ad hoc requests, including sets of GKS metafiles produced as standard ECMWF operational plots.

Another factor which adversely effects the usefulness of local weather forecasts derived directly from the model are the local discrepancies between the model orography and the real orographic height. For each 1.125° grid square the model orography is based on the mean height derived from a high resolution orography to which one standard deviation of the subgrid scale variance is added (envelope orography). This grid point representation is then fitted with a spectral representation in terms of spherical harmonics truncated at total wavenumber 106 (Fig 16). As a consequence, steep gradients tend to be smoothed and spread into less elevated land, and negative heights occur, especially near high mountains.

In the past, ECMWF has, for dissemination purposes, applied a correction to 2m temperatures (Fig 17) to account for the difference between an envelope and a mean orography. The correction was meant to provide a better continuity for the near surface temperature products, when changes were made to the model orography. With the introduction of the T106 model, the magnitude of the correction became small (less than 1°) over most parts of Europe, apart from mountainous regions near the Alps, over Scandinavia, the Pyrenees and the Iberian peninsula, where surface temperature forecasts are inaccurate. In some areas the correction was found to introduce biases rather than to reduce them. Therefore with the introduction of the new surface scheme in April 1987, the correction applied to the disseminated 2m temperature and dewpoint was omitted.

2. Verification results

All parameters are verified against a fixed set of reliably reporting synoptic stations in Europe and North America. Verification results are accumulated monthly for each station and are presented in charts or statistical summaries.

2.1 Temperature at 2m

Bias and mean absolute error in Europe

Figs 18 and 19 show the proportional distribution of the 60 and 72 hour forecast bias (mean error) over all stations in Europe for each month since January 1986. There are distinct differences in the biases for the 00 and the 12 UTC forecast times. The fluctuation of the bias with the time of the year is also quite noticeable. Positive biases are dominant during the summer, occurring at a larger proportion of stations during the night than in day time. These biases arise from a number of sources, primarily inadequacies in the physical parametrisation and the mismatch between model and station orographies and the model's resolution. Following the introduction of the revised parametrisation of surface processes a shift towards a cold bias is noticeable for April and May 1987, which can only partly be explained by the omission of the temperature correction (see Fig 17). It will require another year before the overall impact on the near surface temperature bias can be fully assessed. Results which can be inferred from the direct comparison between the revised and old surface scheme are presented below.

Figs 20 and 21 give the corresponding distribution of the mean absolute error over all stations in Europe for the same period. Obviously, strong biases will also contaminate the mean absolute error for the same regions. It is, however, noteworthy that, on average, at 80% of the stations (which coincidentally corresponds to about 80% of the area), the 2 metre temperature forecast for the night and the day on Day 3 is within a mean absolute error of 3.5°.

Local results

Figs 22 to 23 show comparisons of forecasts produced with the old and the new, now operational, surface parametrisation scheme for four different locations - three in Europe and one in continental North Africa.

The revised post-processing improved the diurnal variability of the 2m temperature and helped capture low night time minima associated with strong radiation cooling. This is best demonstrated for In Salah (Fig 22) where the humidity is low and nocturnal radiation cooling is very effective. The new scheme gives better forecasts by a margin of 10°C and more. In mid-latitudes the radiation cooling can on occasions be exaggerated - see the meteogram for Hannover (Fig 23) where for the first three days of the forecast the temperature drops too rapidly during the early hours of the night. For this forecast, the model performed similarly for Wien (Fig 24), where otherwise the diurnal temperature variation is well predicted. The forecast, however, is biased by about 5°C which could be corrected by statistical adaptation. Such local bias corrections need to be monitored and updated on a regular basis as they change with the season and surface conditions.

Finally, the forecast for Jokioinen (Fig 25) in Finland highlights the problem of forecasting the near surface temperature over melting snow in spring. Neither the old or the revised parametrisation and post-processing schemes capture the above freezing conditions in late spring when the snow cover starts to break up, the albedo changes and the liquid water content of the snow mantle is changing rapidly. Such changes in snow properties are not represented at present. Consequently, the near surface temperature in regions where snow is melting, over Scandinavia for example, exhibits a strong negative bias in spring. As the snow cover is not limited to, but tends to follow, the elevated orography, resulting temperature biases are compounded by the two effects.

Inadequate temperature forecasts over snow in spring have also been noticed outside Europe. Figs 26 and 27 show the biases at 54 and 66 hours forecast time over North America. Biases are largest at daytime (forecast at 54 hours over the eastern regions), but much reduced at night time. In the east, south-east and mid-west of the USA the temperature forecasts are almost unbiased. It should be noted that further to the north of Canada, where the snow properties should be very close to the ones assumed by the parametrisation scheme, the biases return to a random distribution around zero.

2.2 Dewpoint at 2 metres

In the past the near surface layer in the model, especially over land, was found to be too moist with little diurnal variation. The modified parametrisation and the new post-processing improved the product, resulting in more realistic dewpoint spreads. Otherwise the systematic errors of the dewpoint at 2 metres are closely related to the errors in the 2m temperature.

2.3 Precipitation

The comparison of model predicted precipitation amounts with observed values will be adversely affected by localised precipitation events and orographic effects which cannot be resolved by the operational model. However, grouping the monthly averaged verification results from each station in Europe into categories of correct, under and over-prediction of precipitation is an effective method for studying the behaviour of the model for a representative data sample. Figs 28 and 29 indicate that the ECMWF precipitation forecasts for Europe have been unbiased for the last two autumn seasons, whilst winters are characterised by over-forecasting, which mainly occurs in the range of active frontal zones embedded in strong westerly flows. The model performs similarly in all seasons.

The parametrisation scheme also differentiates between rain and snow and convective and large-scale precipitation. Obviously this partitioning is particularly sensitive to model changes. Studies to evaluate the usefulness of such parameters are currently in progress

2.4 Wind at 10m

As with precipitation, the model derived wind at 10m above the surface should only be compared with observations for representative data samples. Figs 30 and 31 show the mean wind in December 1985 and the systematic error of the 48 hour forecast compared with observations averaged over 2° latitude.

longitude boxes. The biases are generally small, but become more apparent in the range of mountain barriers such as over Scandinavia, north of the Alps and over the northern part of the Iberian peninsula.

2.5 Total cloud amount

Although the model parametrisation scheme distinguishes between 3 layers of stratiform cloud and convective clouds, the current dissemination product is the total cloud cover only. As with the individual components of precipitation, the usefulness of the different cloud components is also under investigation.

The verification of model predicted cloud amount against synoptic surface observations is a somewhat more dubious exercise than it is for the other parameters. A forecast is an instantaneous value verified as a snapshot of cloud cover as observed from the ground. Random sampling errors will largely distort the results. However, it is possible to draw some conclusions from the mean error characteristics. Experimental studies using satellite cloud observations corroborated the verification against ground based observations to a large extent. Figs 32 and 33 show the 72 hour forecast bias for the total cloud amounts during July 1986 and January 1987. In summer a systematic under-representation of convective clouds determines the bias characteristics. The picture is somewhat more balanced in winter. However, low level stratiform clouds are typical for that time of the year but are only poorly represented in the model. It should be noted that the parametrisation changes to the surface processes had only little impact on the cloud forecasts during the 6 day parallel run in April 1987.

3. Summary and recommendations in the use of DMO (Direct Model Output)

3.1 General remarks

(i) Near-surface weather parameters (Direct Model Output) should ideally be used on the model grid only, in order to avoid horizontal interpolation. The nearest grid point (either land or sea, as appropriate) should be chosen to provide forecast guidance. The user must be aware of deficiencies in the products when the gridpoint is not representative of the forecast location or region, due to the coarseness of the model grid, the choice of the land-sea mask and misrepresentation arising from the specification of the orography.

(ii) Best use of products is made in homogeneous terrain away from coasts and mountain ranges. Forecast performance needs to be monitored carefully and continuously. Simple bias corrections will often improve the usefulness of the products.

(iii) Users are advised to exercise caution in their use of the DMO (experimental products) after model changes - modifications to the physical parametrisation, the orography or the horizontal resolution are particularly relevant in this regard. Model changes, whilst leading to an improvement in the overall performance of the forecast system, may, on occasions, have a detrimental effect on the near-surface weather parameters in places much influenced by the orography.

3.2 Temperature at 2 metres

(i) Unbiased in homogeneous terrain, selection of land or sea point is crucial for local guidance; mean absolute error in such favourable conditions is normally below 3.5° often below 2.0°;

(ii) large biases over Alpine, Scandinavian, and Iberian terrain;

(iii) large biases over snow, in particular over melting snow in spring, when daytime maxima near the model surface do not exceed 0°C.

(iv) The new parametrisation of surface processes and new post-processing improved the diurnal variability of the model, and helped to capture low night time minima, with some exaggeration of the radiation cooling during the night.

3.3 Dewpoint at 2 metres

(i) The modifications improved the product resulting in more realistic dewpoint spreads. Other systematic errors are closely related to the temperature at 2 metres itself.

3.4 Wind at 10 metres

(i) The forecast 10m wind can only be compared with 10 minute anemometer windspeed averages, it does not reflect any gustiness.

(ii) Biases in the wind are generally small, but can reach the magnitude of the mean observed wind near mountainous terrain or steep coastlines.

3.5 Precipitation

(i) Model predicted precipitation does not capture localised events (convective activity) but reflects the amounts averaged over the area represented by the gridpoint.

(ii) Absolute amount should not be used as direct forecast guidance; verification statistics indicate that the DMO of precipitation may, however, be used as indicator of dry and wet periods for regions.

(iii) The orography has a strong influence on the local and regional precipitation forecast and may lead to large biases, e.g. too dry over Austria and northern Yugoslavia during last winter for example.

(iv) There is evidence from some cases that the separation of snow from rain is handled successfully by the model.

3.6 Cloud amount

(i) The verification of cloud amount forecasts against synoptic observations is unsatisfactory, as an instantaneous forecast is compared with a snapshot of the atmospheric state. Nevertheless, there are indications that the cloud amount is systematically under-estimated, in particular convective clouds, the bias being of the order of 30%.

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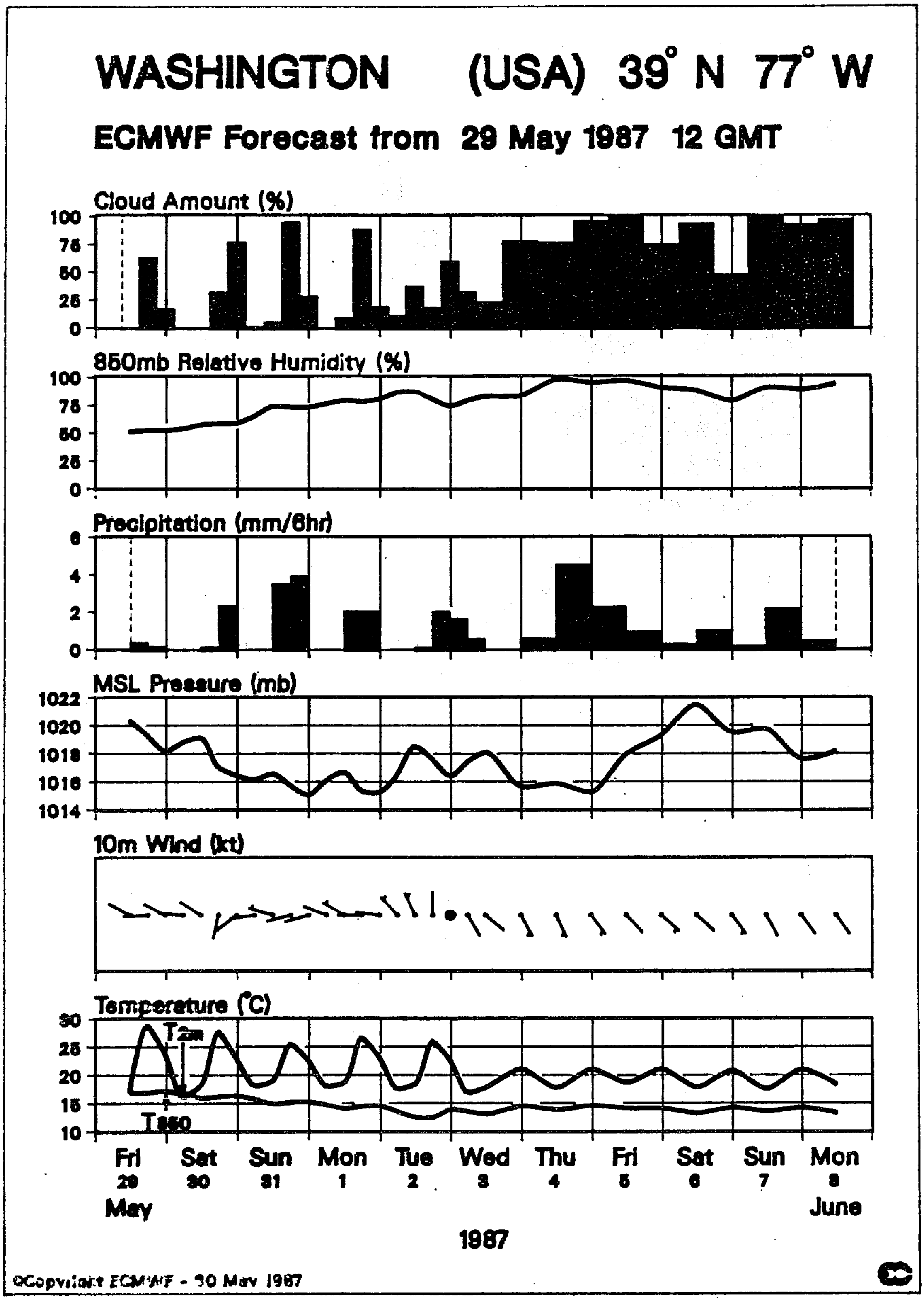


Fig 1 Direct model output of near surface weather parameters for Washington from the forecast run of 29 May 1987

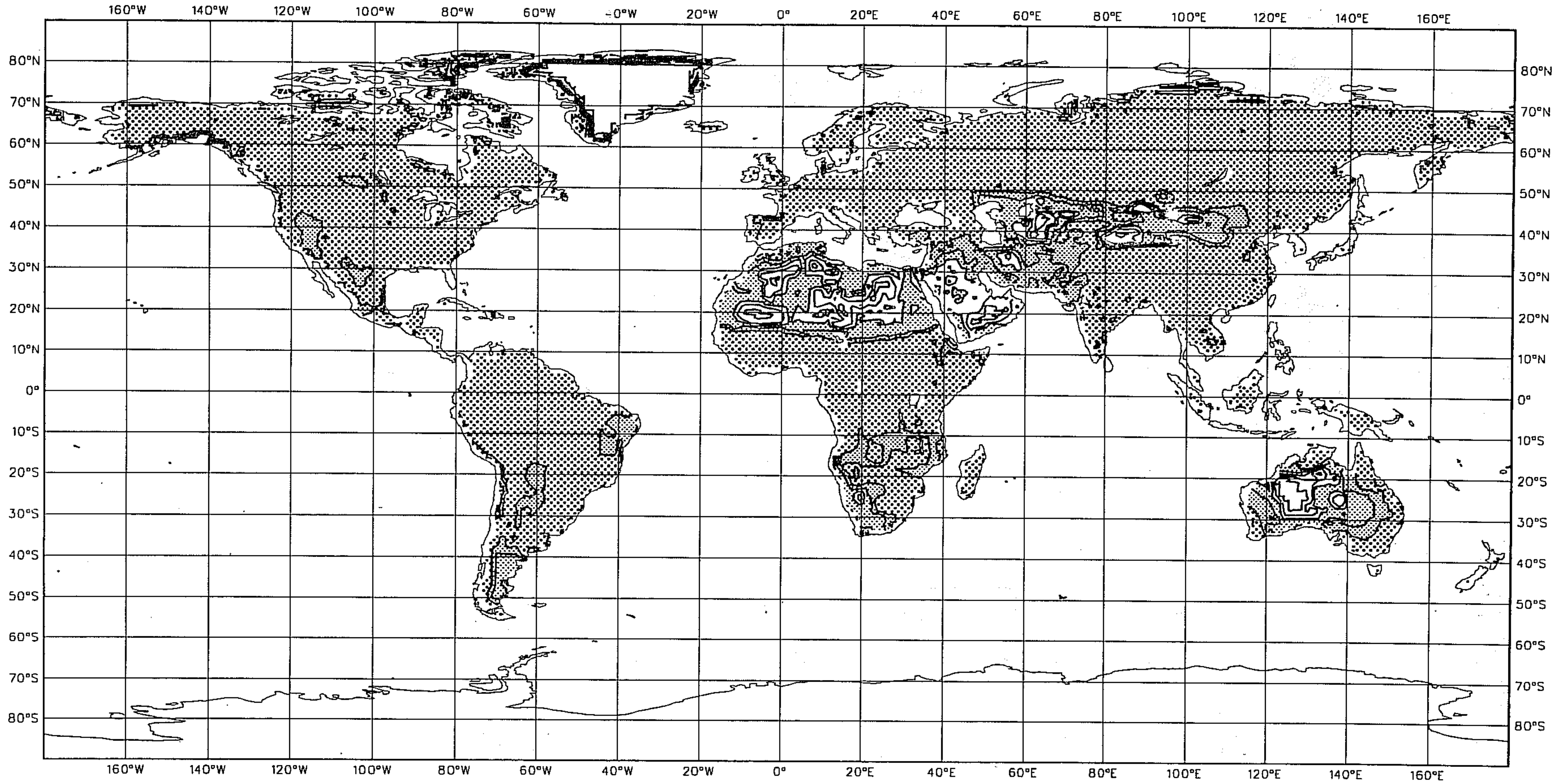


Fig 2 Vegetation ratio (T106 resolution) from Wilson/Henderson-Sellers (1985).
Dot shading over continents: heavy: 100%>80%, light: 80%>40%, empty: 40%>0%

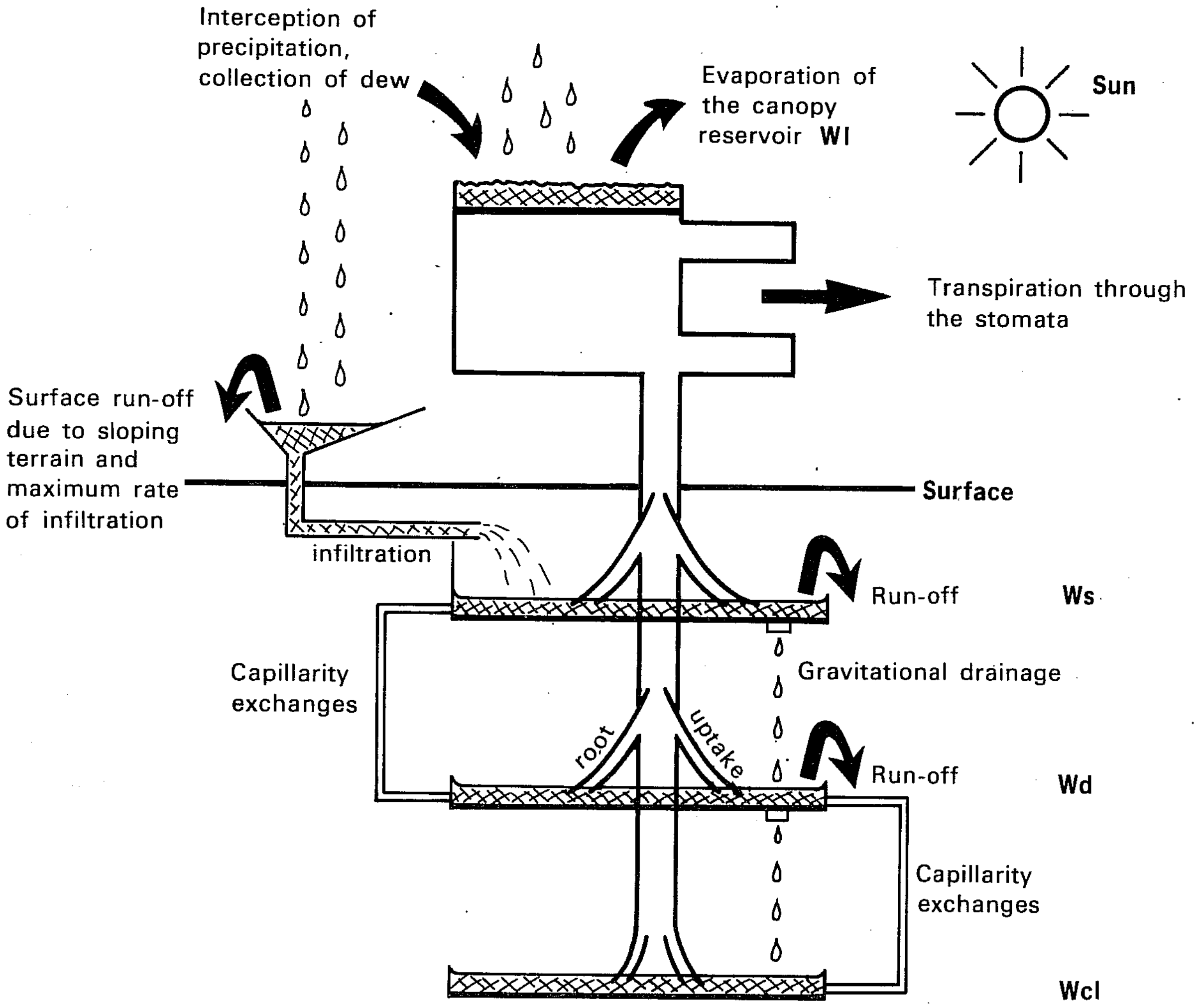


Fig 3 Schematic description of the evapotranspiration over vegetated areas and the soil hydrology

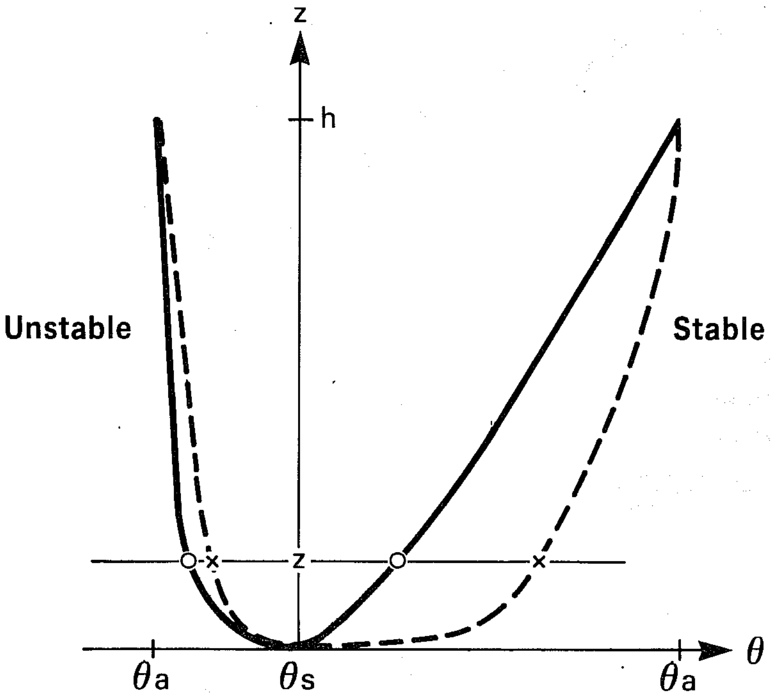


Fig 4 Different estimations of the 2m temperature. x represents values obtained assuming a pure logarithmic profile (---) (previous method); 0 represents values obtained using the revised method based on appropriate profiles (——)

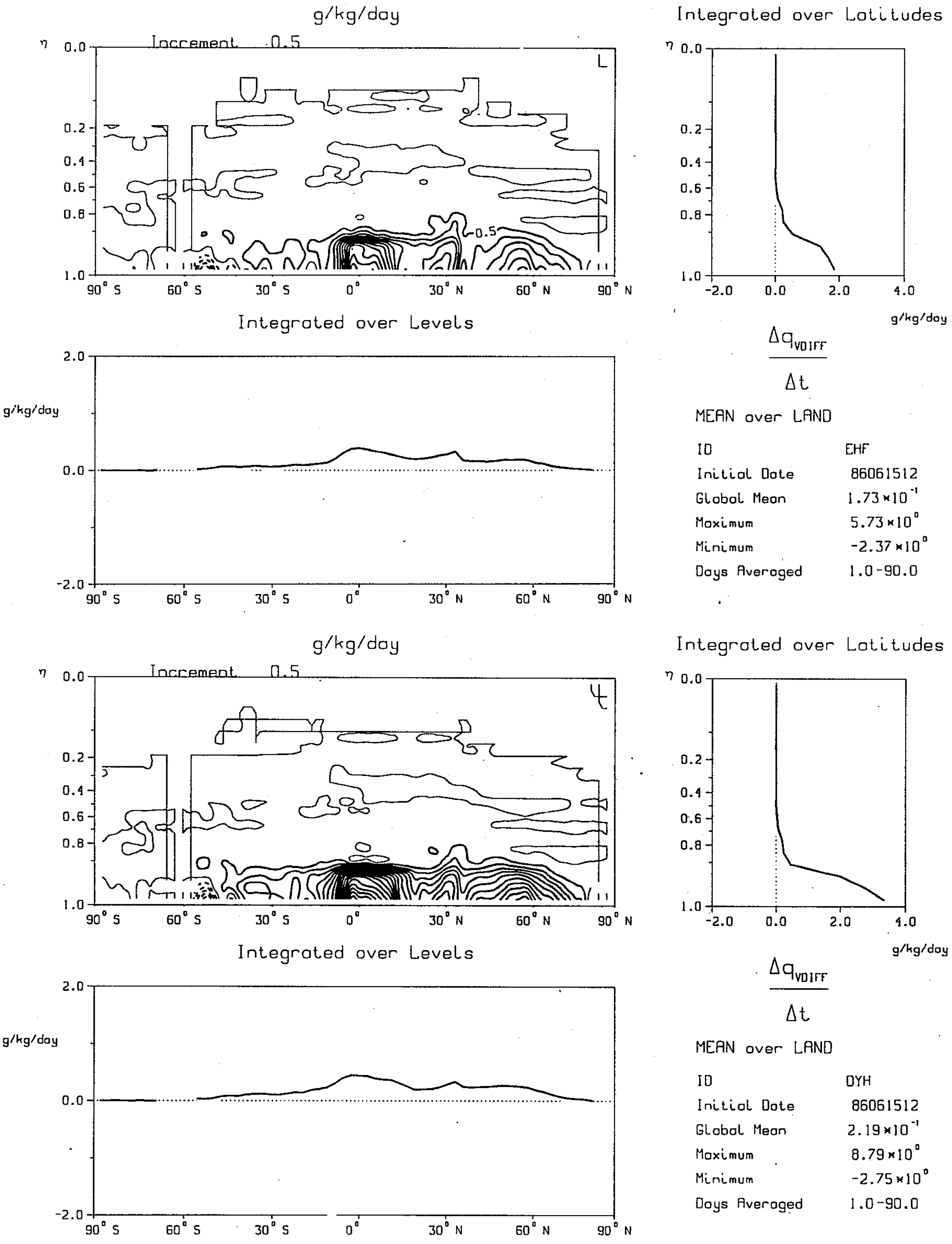


Fig 5 90 day average zonal mean tendency over land of the specific humidity q due to turbulent exchanges for the revised (top) and the previous (bottom) surface scheme

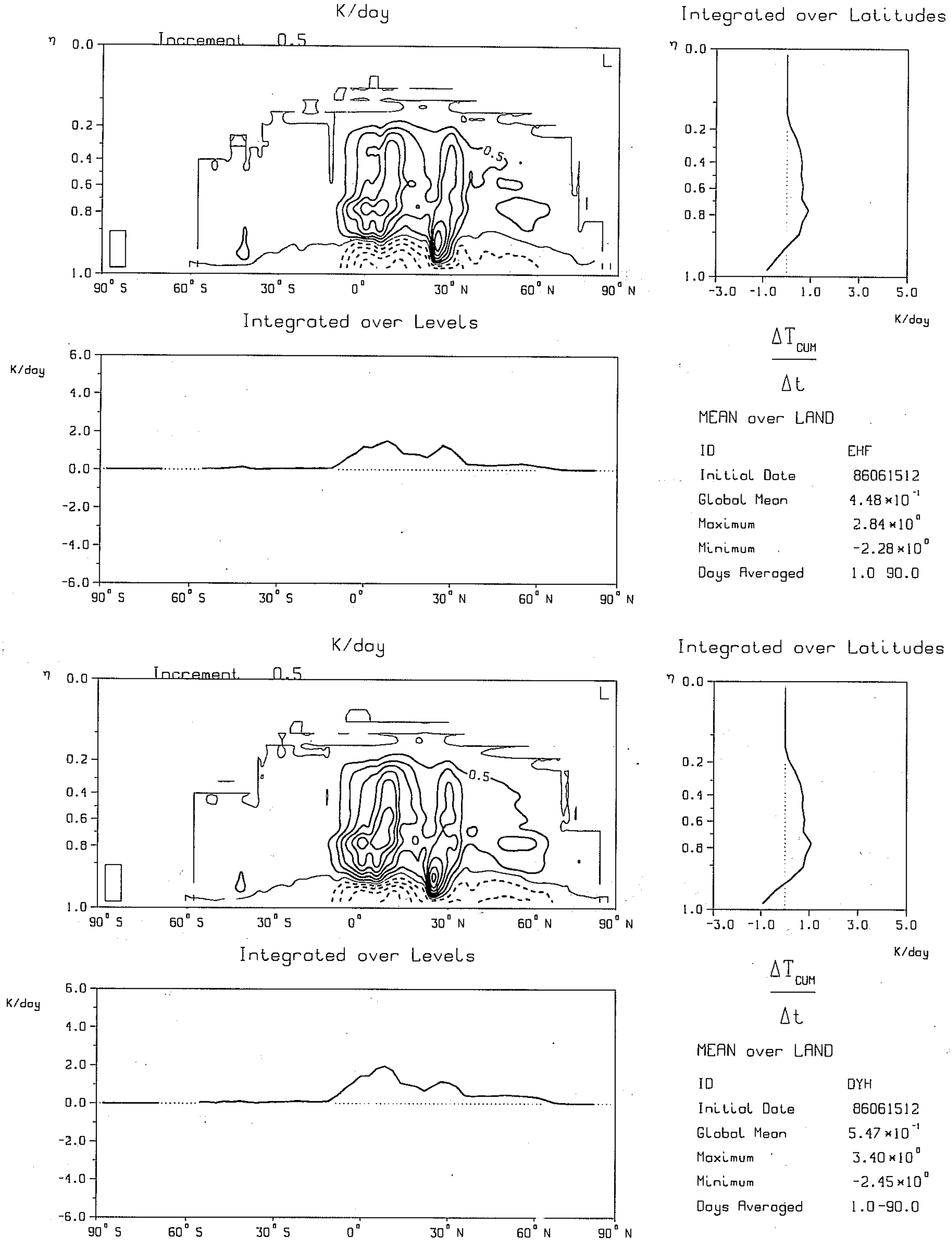


Fig 6 90 day averaged zonal mean tendency over land of the temperature T due to deep convection for the revised (top) and the previous (bottom) surface scheme

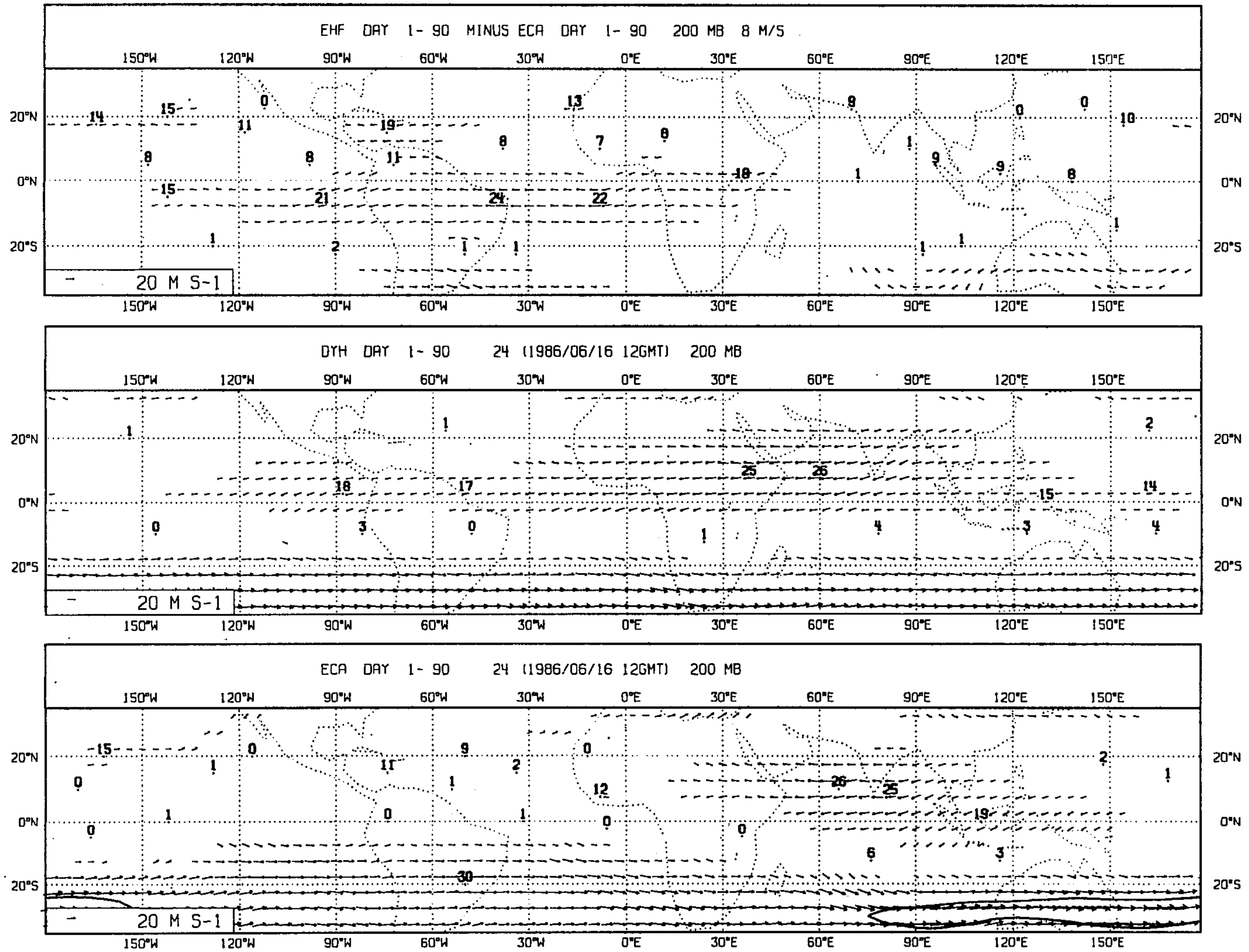


Fig 7 90 day mean of the differences of the wind field at 200 mb of (revised scheme - Analysed) (top) and (previous scheme - Analysed) (middle). Time mean of the analysis is shown in the bottom panel

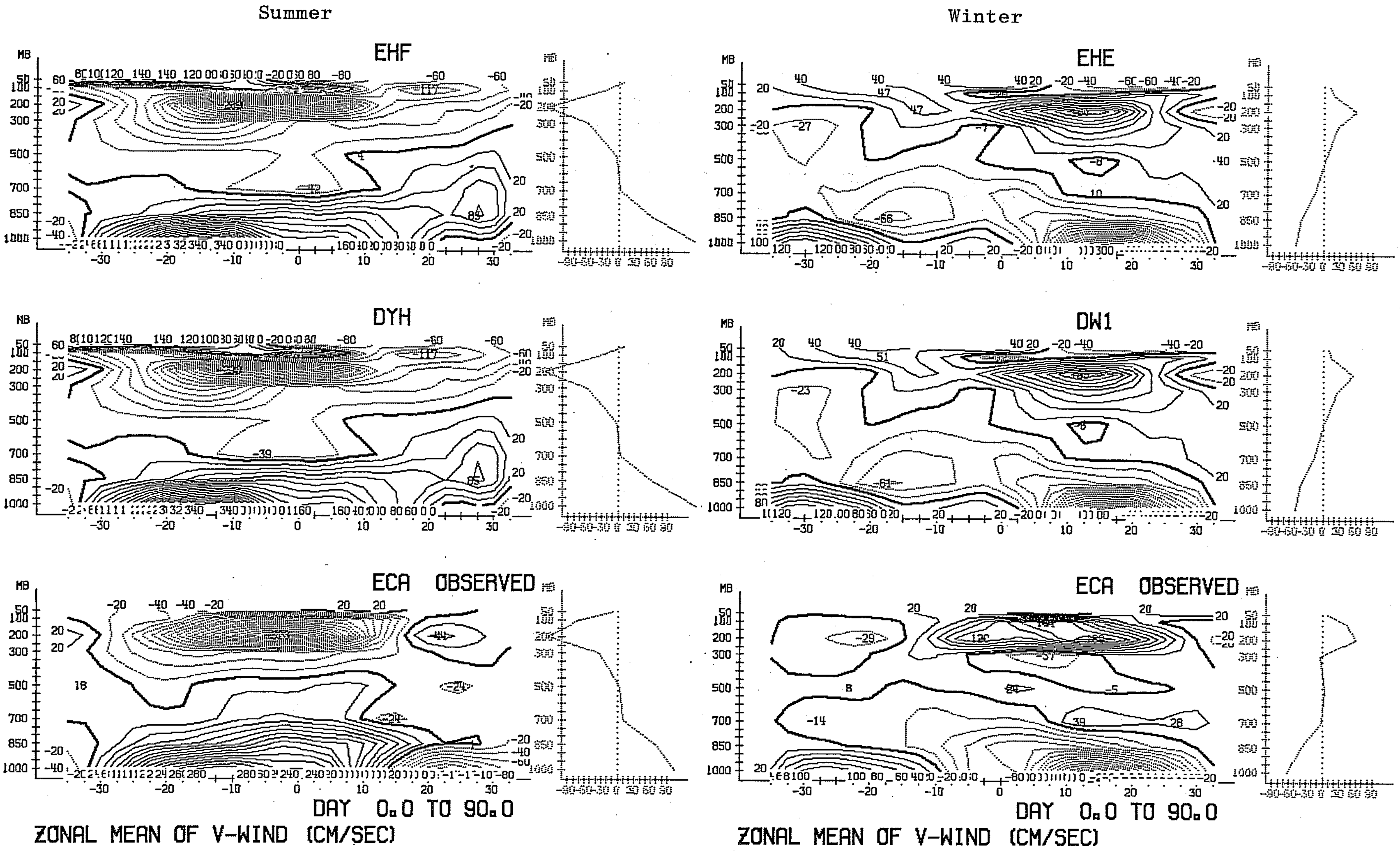


Fig 8 90 day mean of the zonal mean of the meridional wind component using the revised (top), the previous (middle) surface scheme as compared to the analysed field (bottom) for summertime (left) and wintertime (right)

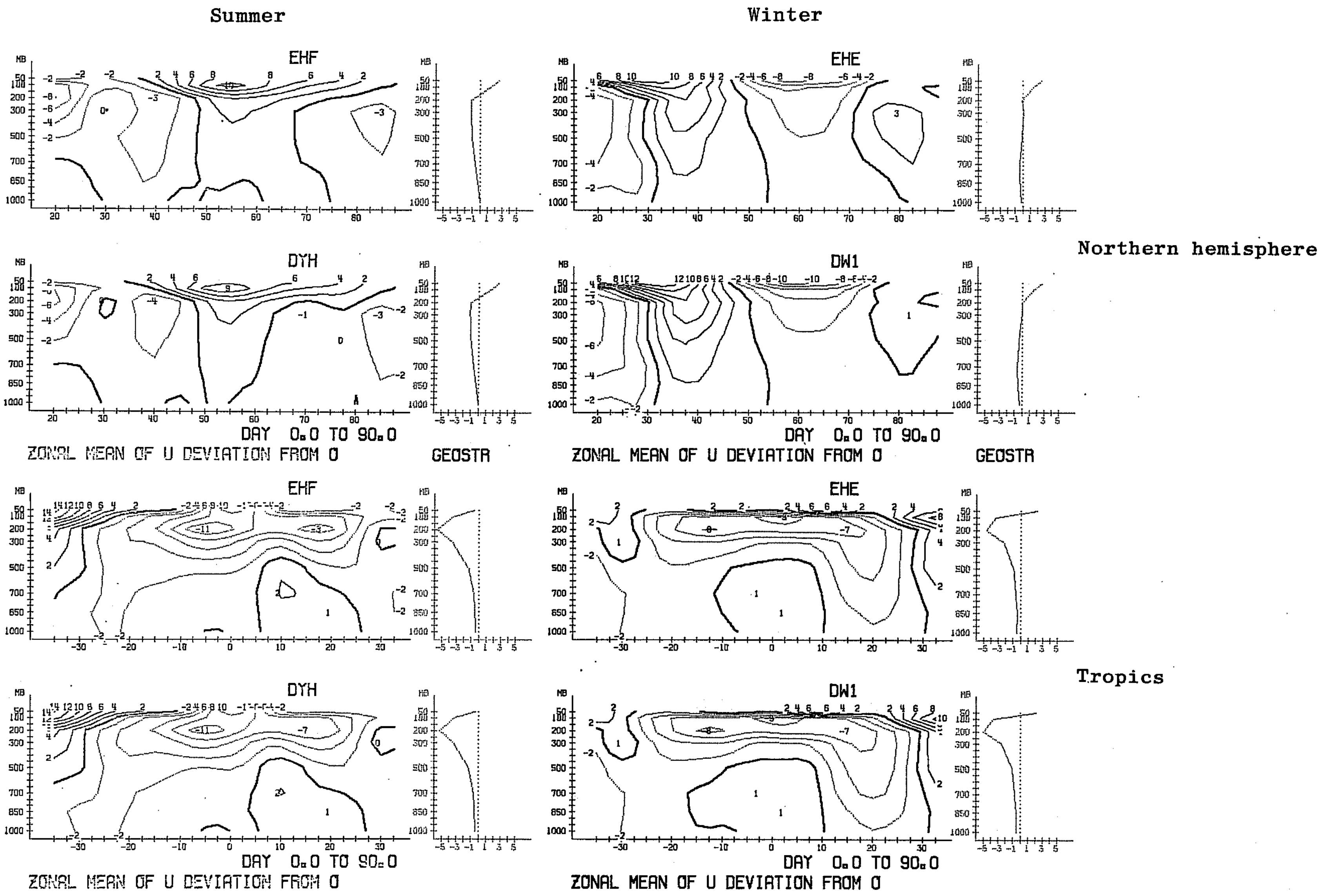


Fig 9 90 day mean of the zonal mean of the zonal wind deviations from analysis for (revised-analysed) (upper) and (previous-analysed) (lower) for the Northern Hemisphere (top part) and the tropics (bottom part) in summertime (left part) and wintertime (right part)

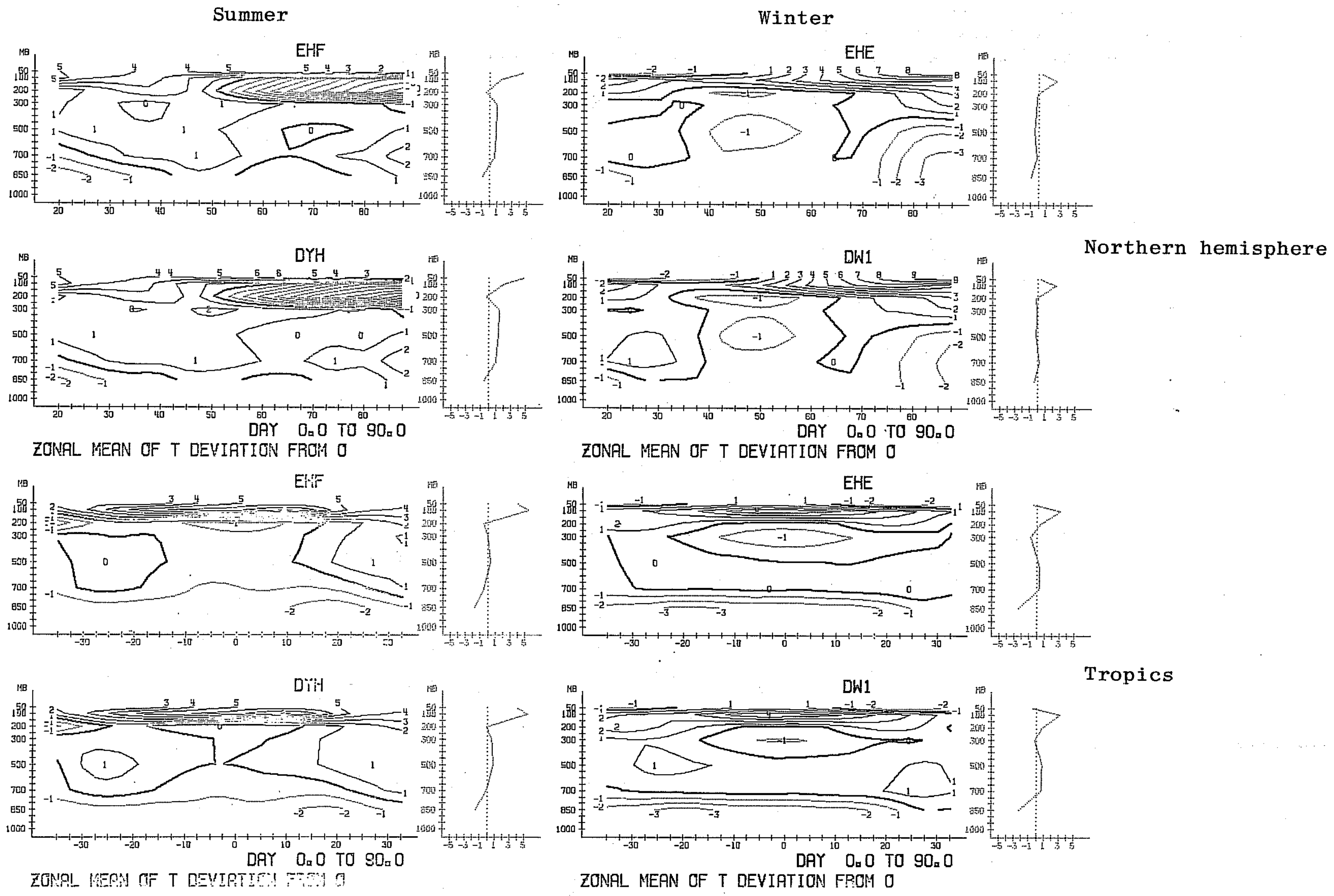


Fig 10 As in Fig 9 but for the zonal temperature deviations

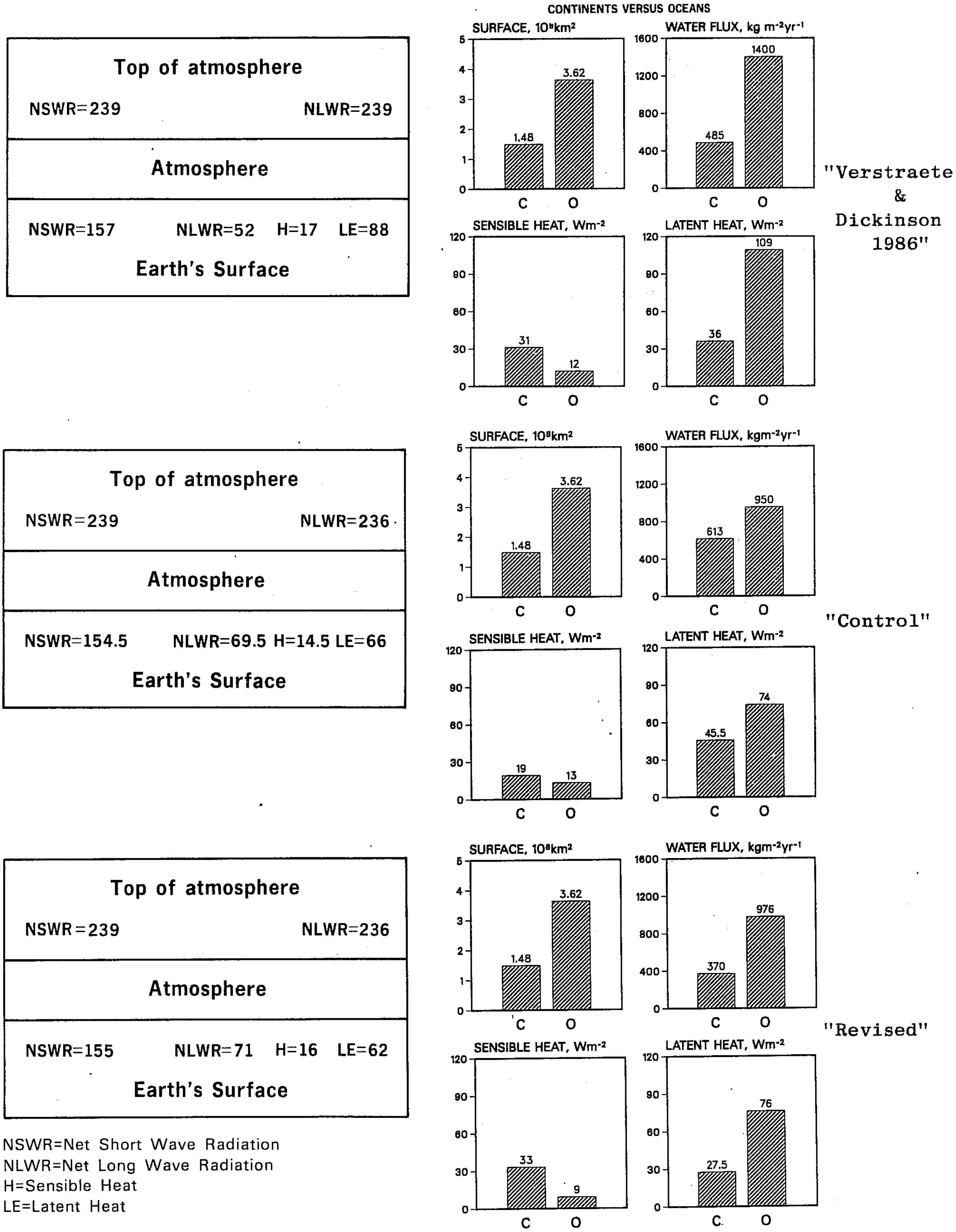
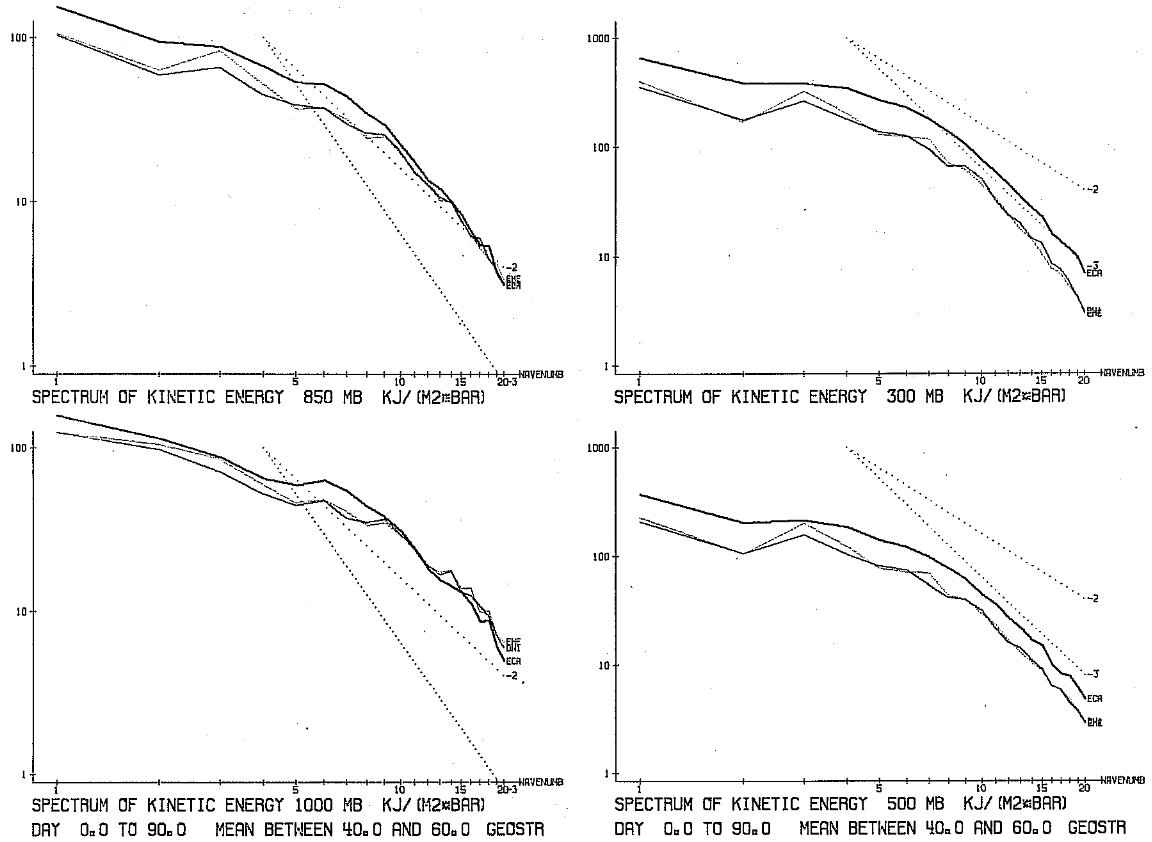


Fig 11 Left hand side: Global and annual average energy fluxes into and out of the atmosphere, in Wm^{-2}.
Right hand side: Comparison between oceans and continents, in terms of area, evaporation, sensible and latent heat annual mean fluxes

Winter



Summer

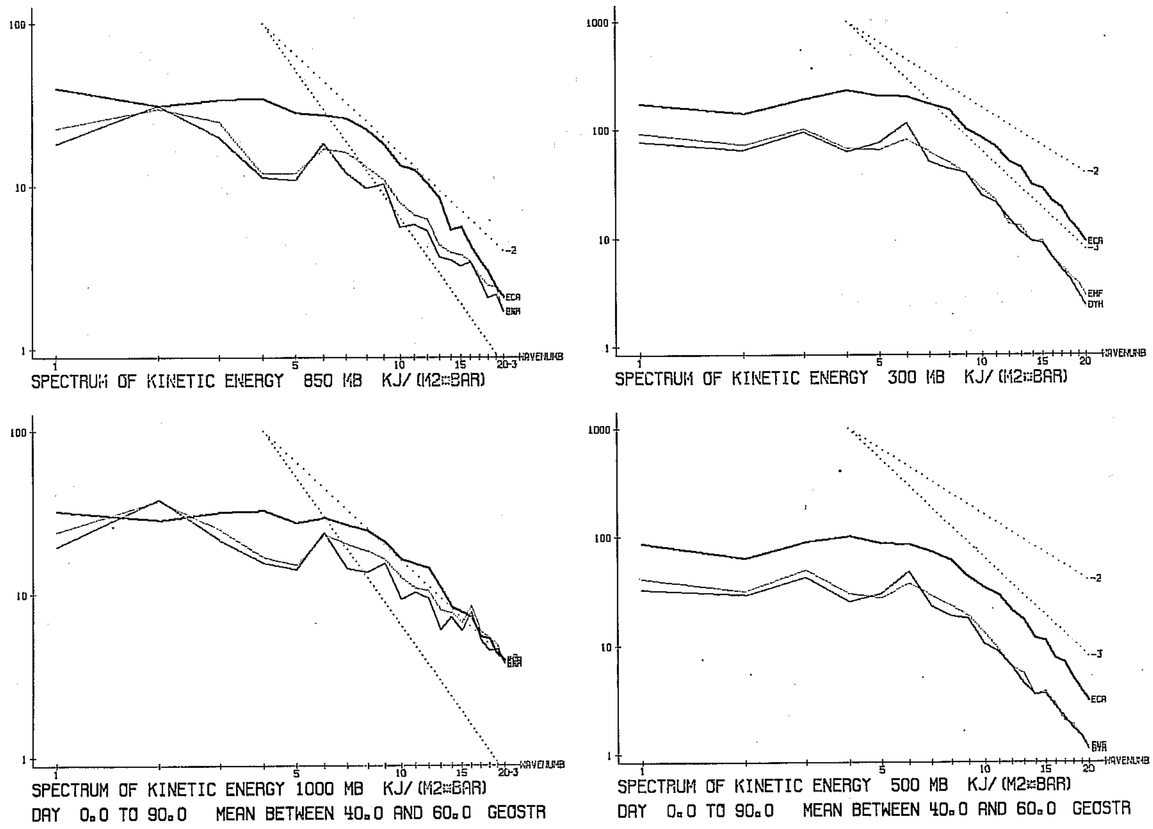


Fig 12 Comparison of 90 day averaged spectrums of kinetic energy at various pressure levels from analysed fields (thick solid line) and fields obtained using the revised (thin dotted line) and the previous (thin solid line) surface scheme

Operational **Revised**

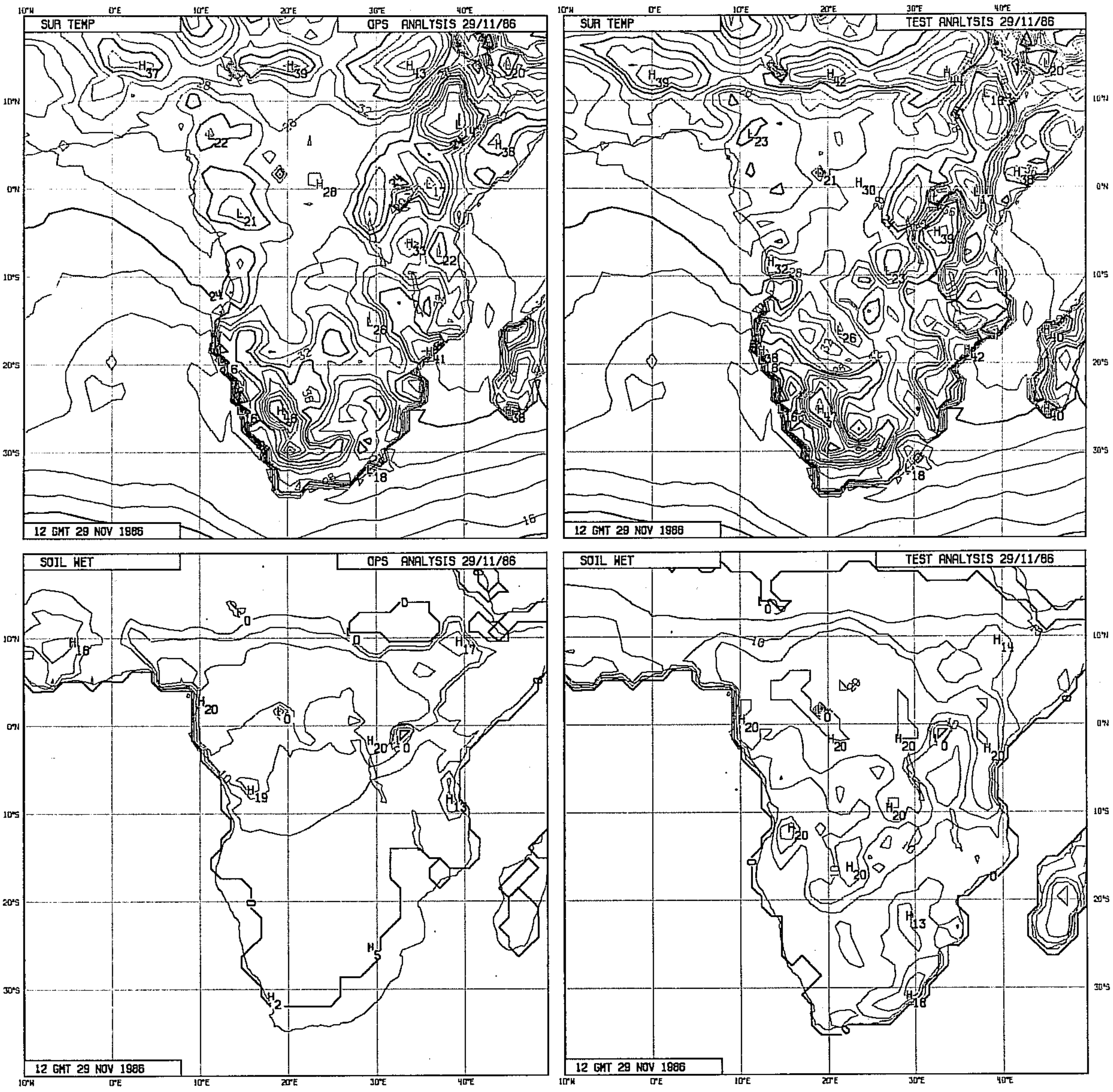


Fig 13 Maps of analysed surface temperature (top) and wetness (bottom) valid for the 29/11/86 as obtained in the operational runs (left) and after 8 days of assimilation (right) using the revised surface scheme

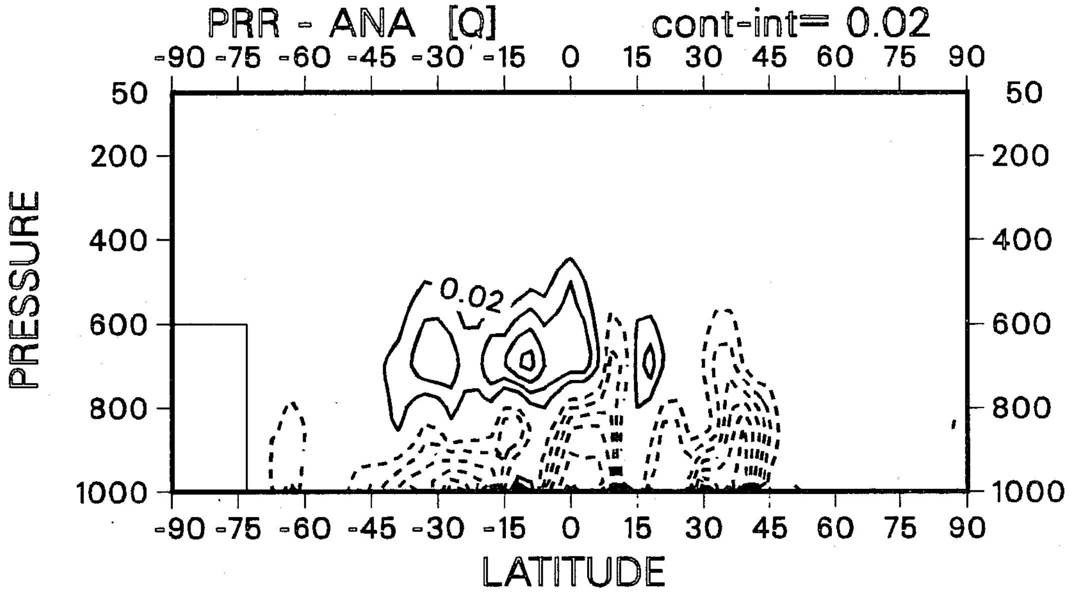


Fig 14 Cross-section of the differences of analysed specific humidity between the fields obtained after 8 days of assimilation using the revised surface scheme and the operational analysis of the 29/11/86. (Isoline interval: 0.02g/kg)

T106 LAND-SEA MASK

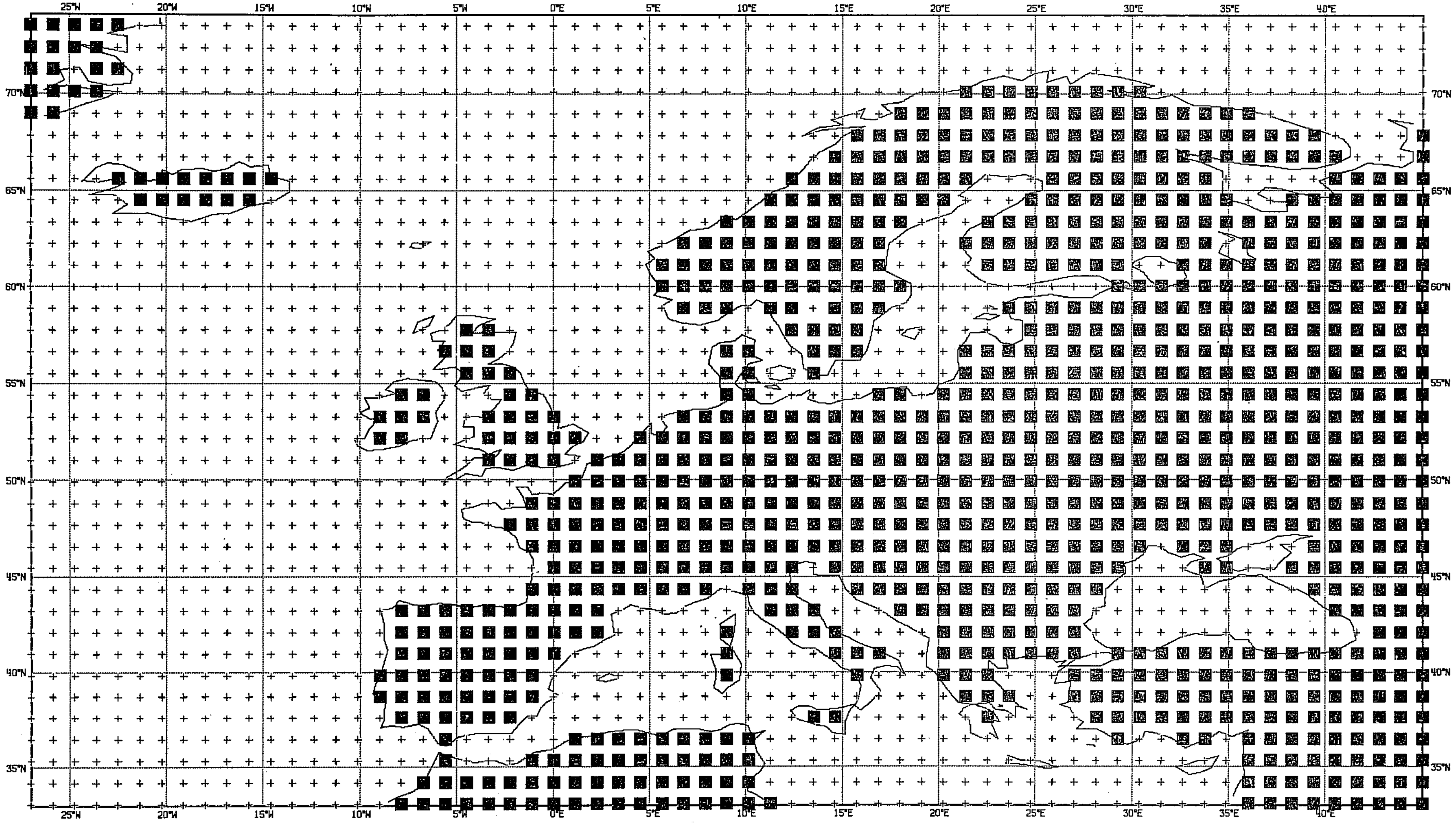


Fig 15 Model surface grid over Europe, full squares indicate land points

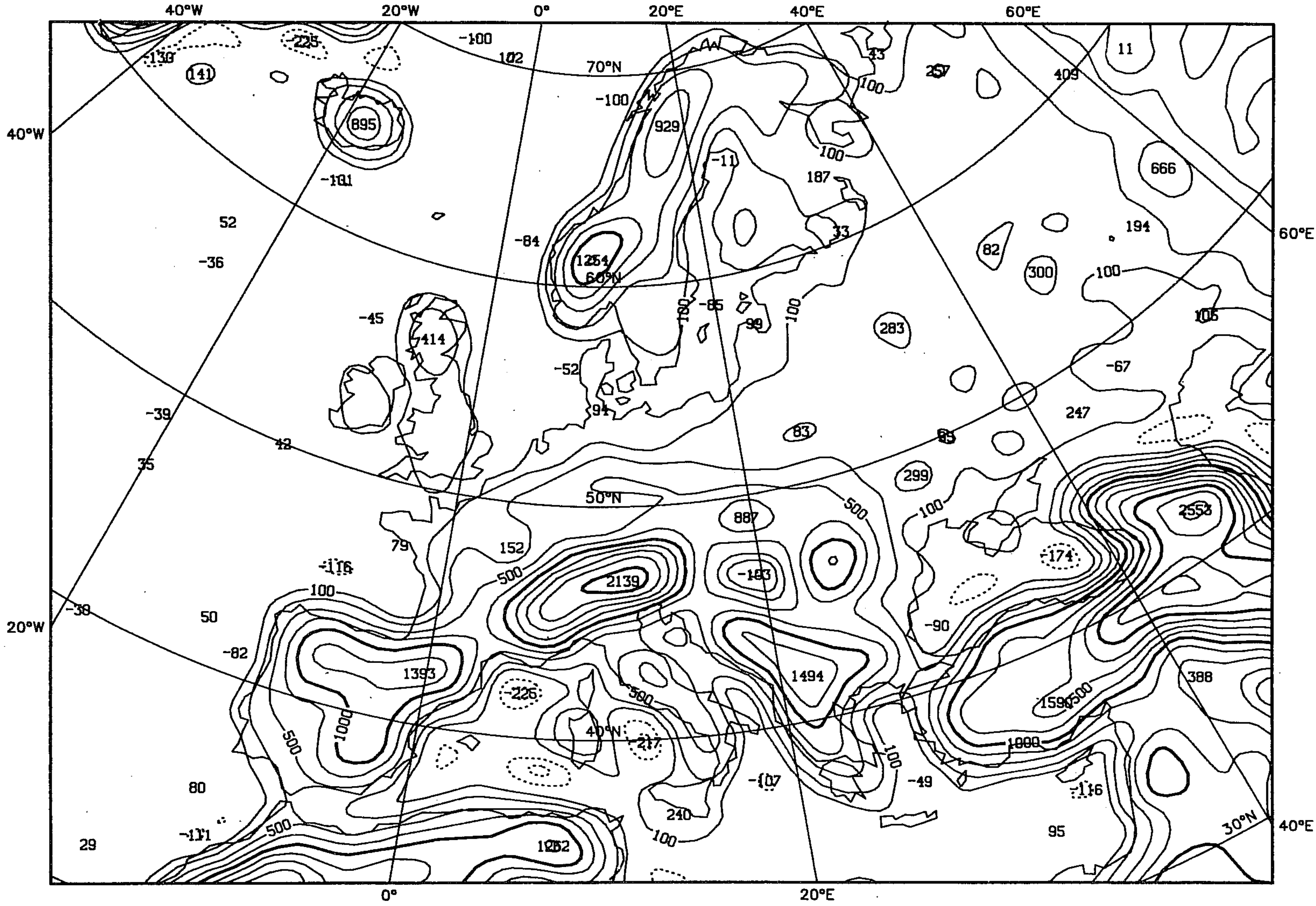


Fig 16 T106 orography, contour interval 250m, lowest contour line ±100m

T106 Orographic Temperature Correction (1/10 degree)

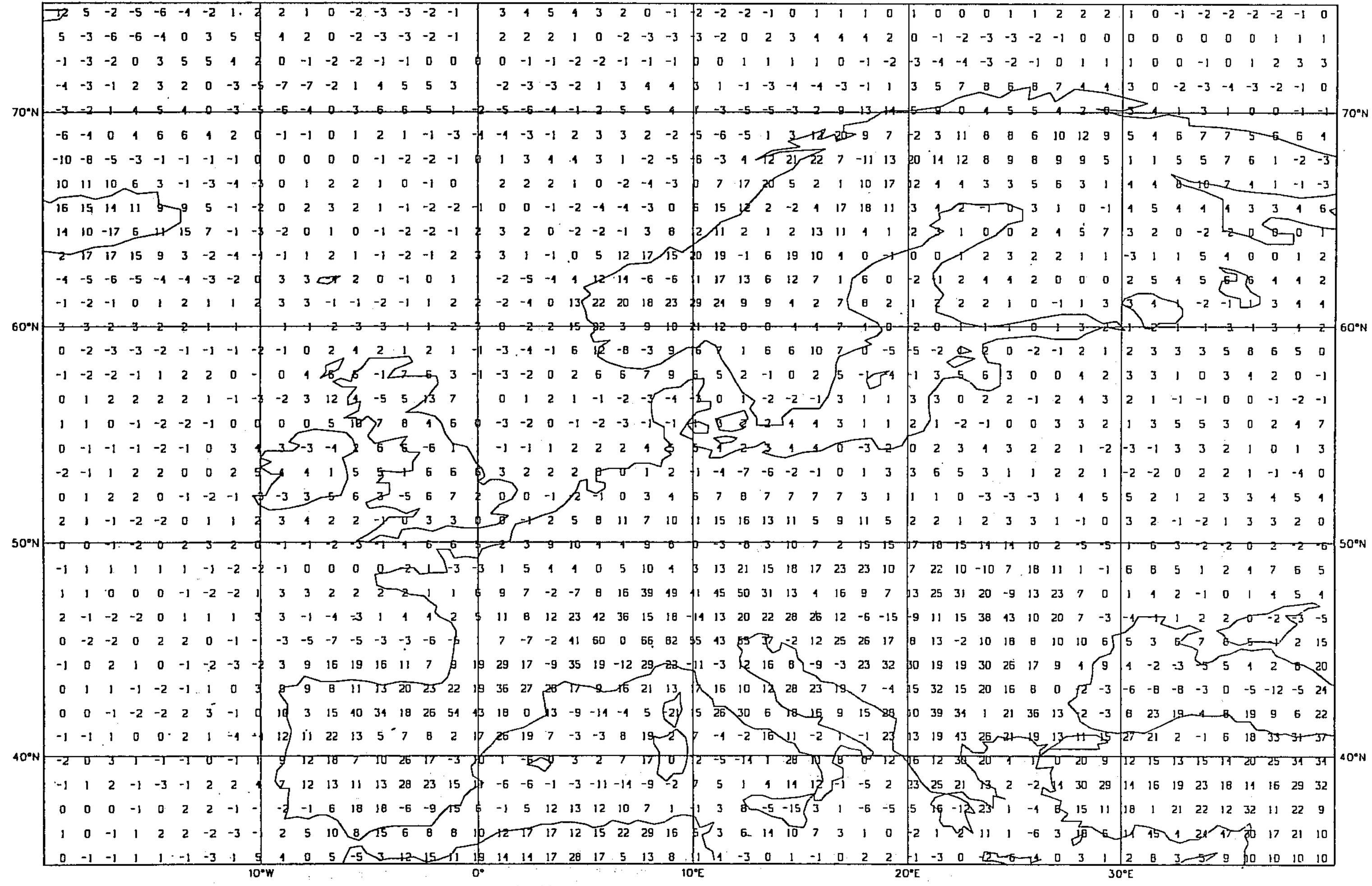


Fig 17 Temperature correction applied to the disseminated 2m temperature and 2m dewpoint (until April 1987) in order to account for the difference between envelope and mean orography

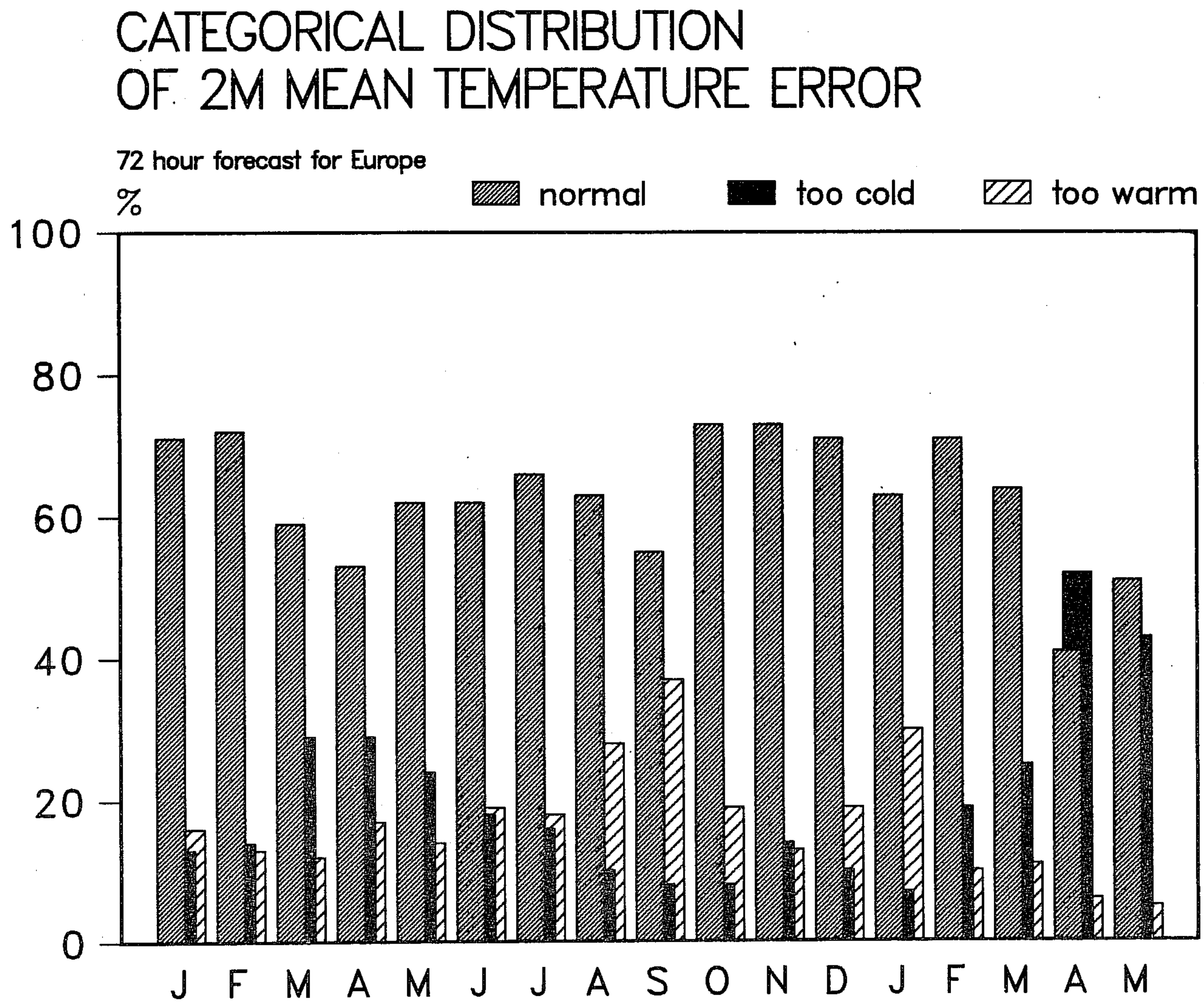


Fig 18 Categorical distribution of 2m mean temperature error for all available synoptic stations in Europe, 72 hour forecast. The bars indicate the number of stations (in percent) in each category

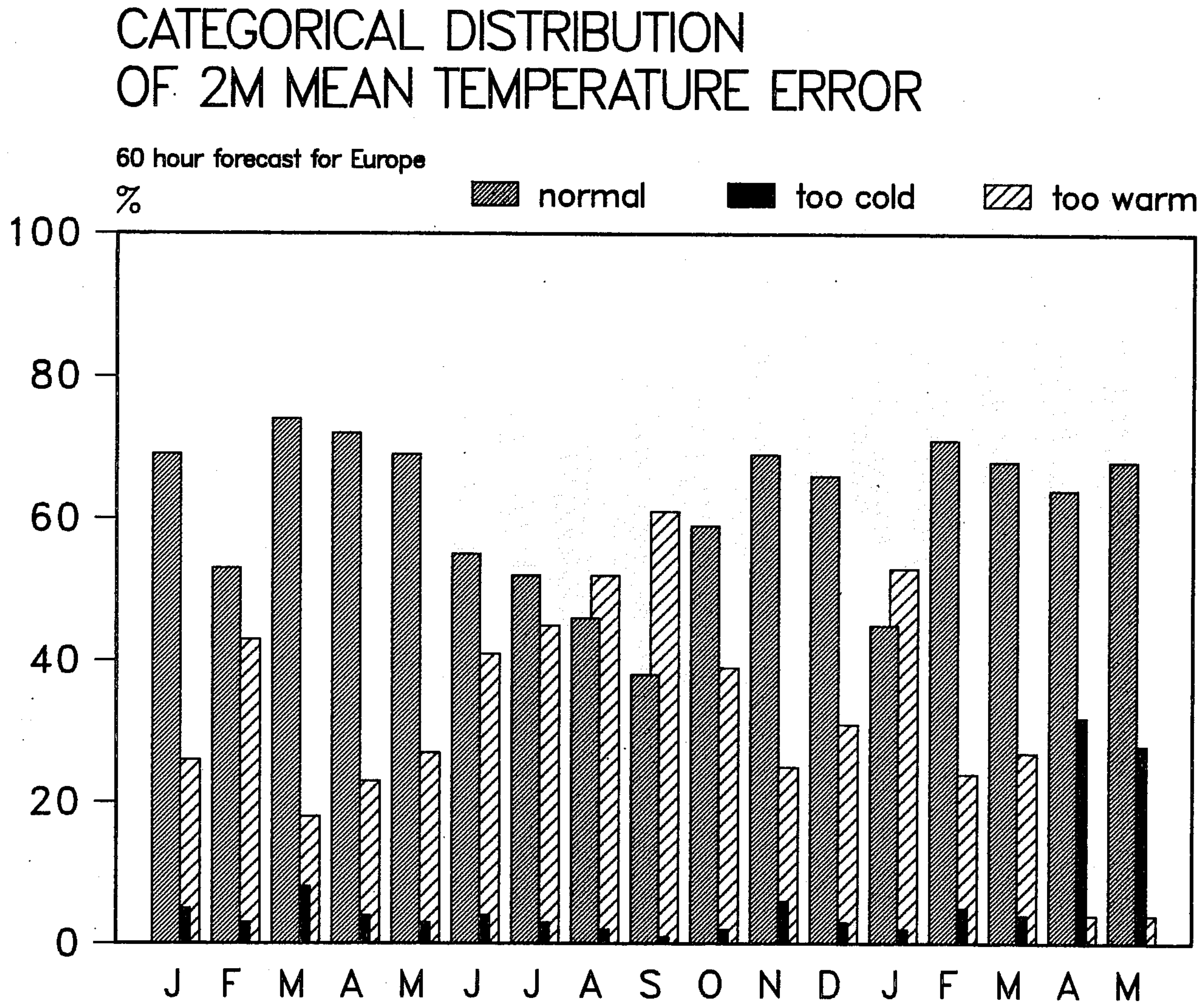


Fig 19 As Fig 18 but for 60 hour forecast

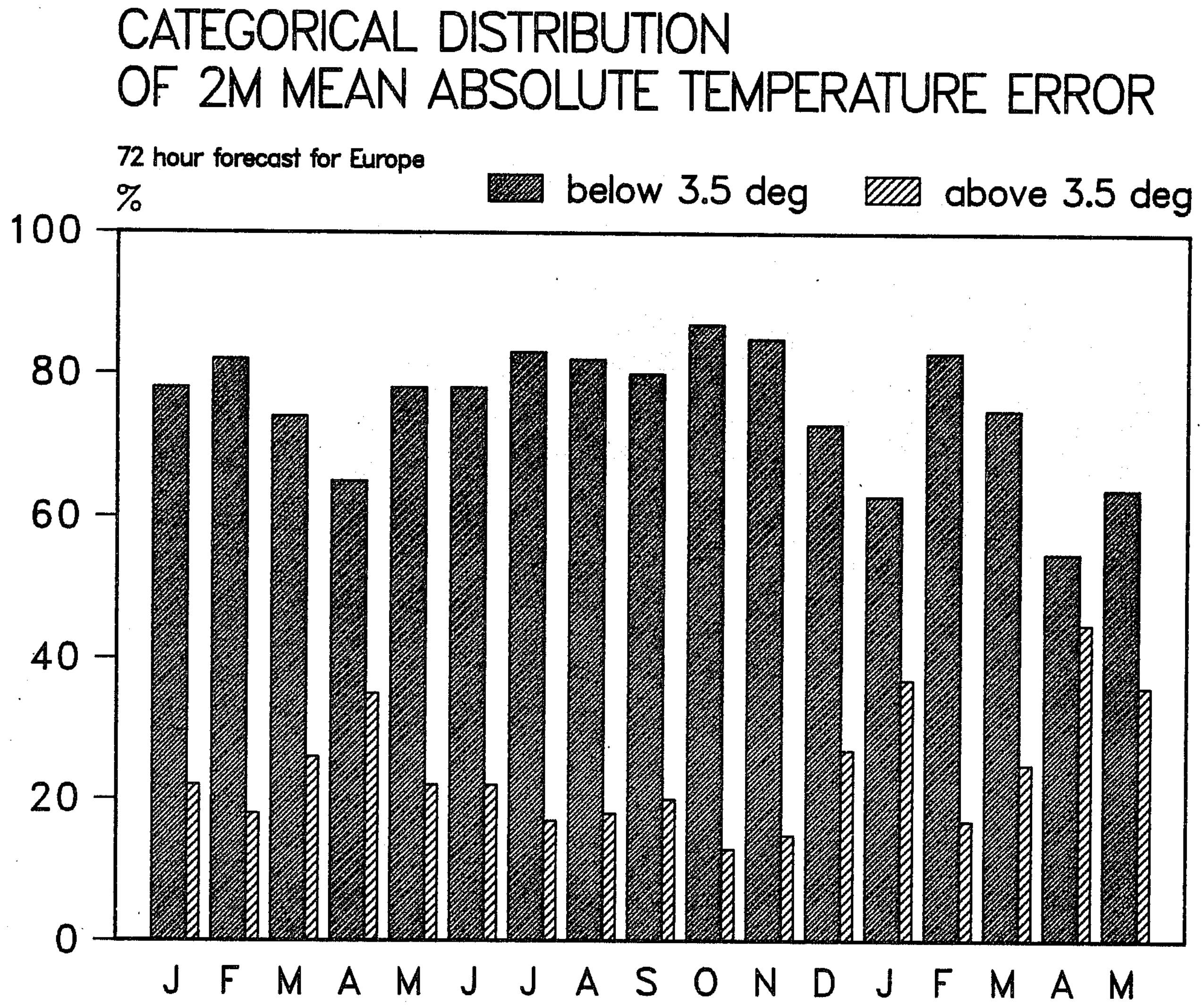


Fig 20 As Fig 18, but for the monthly mean absolute error, 72 hour forecast

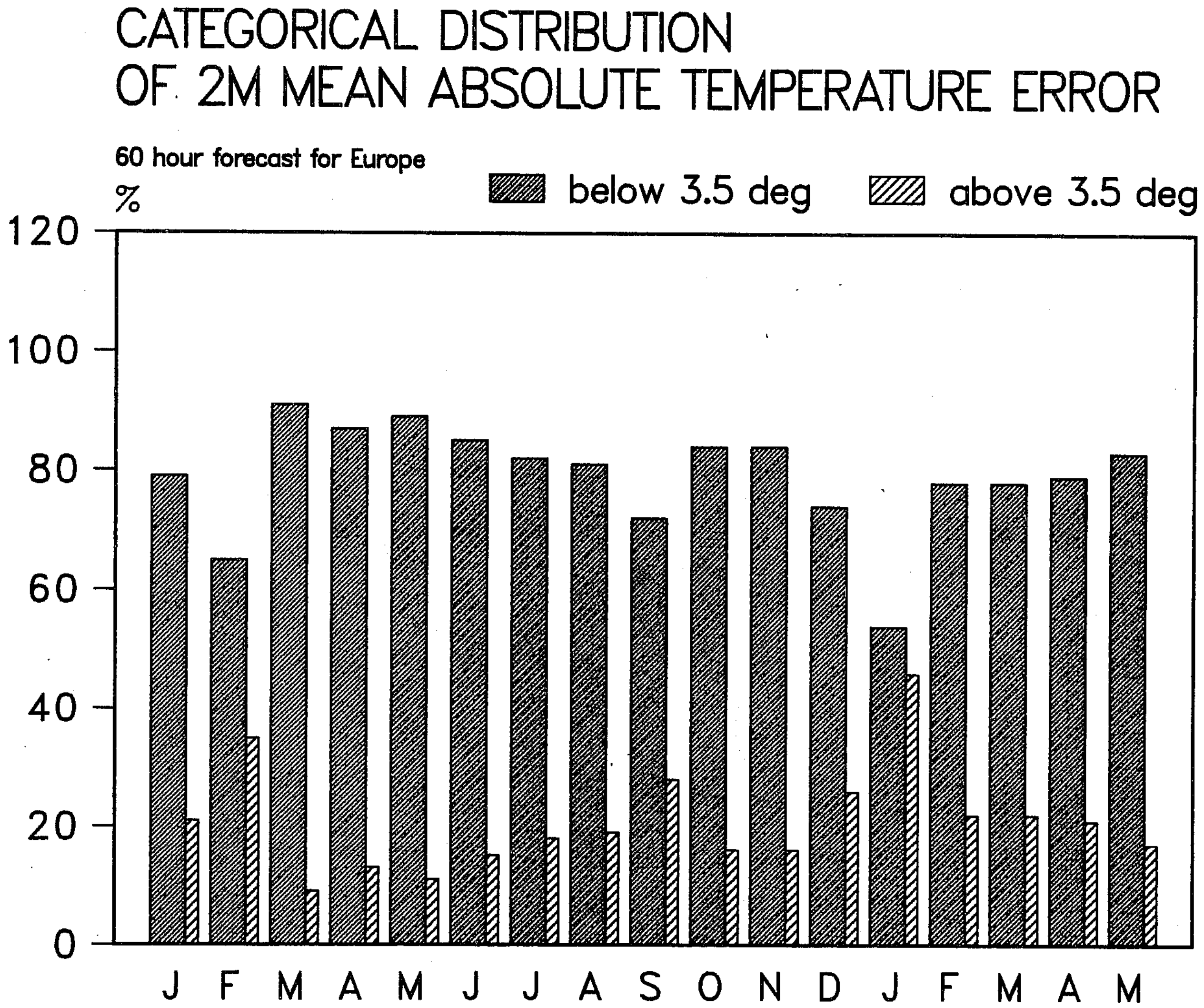


Fig 21 As Fig 20, but for 60 hour forecast

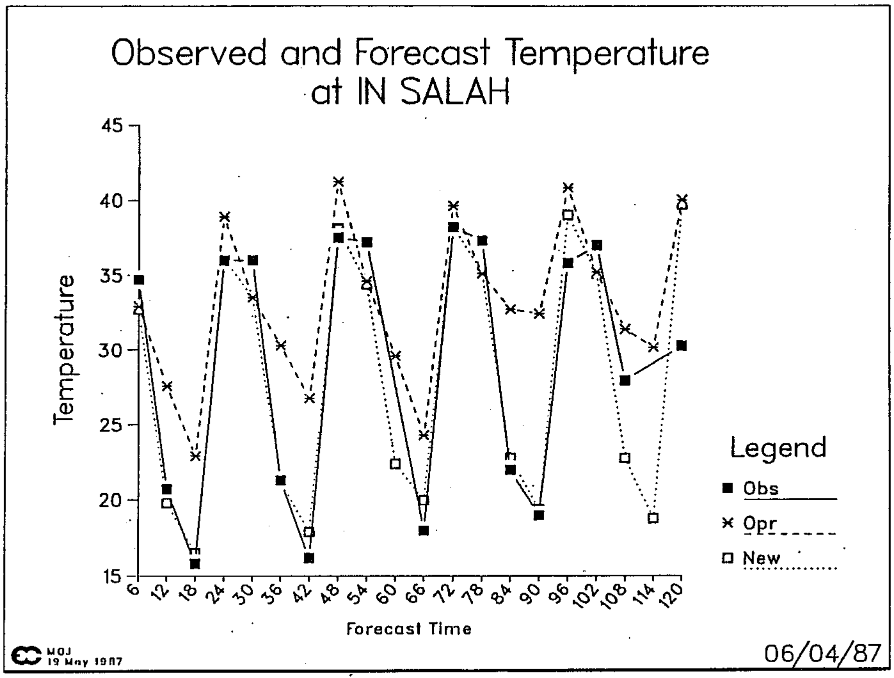


Fig 22 2m temperature forecast out to 120 hours for In Salah with the old operational surface scheme (Opr) and the new scheme implemented in April (new). The full squares give the actual observations (Obs).

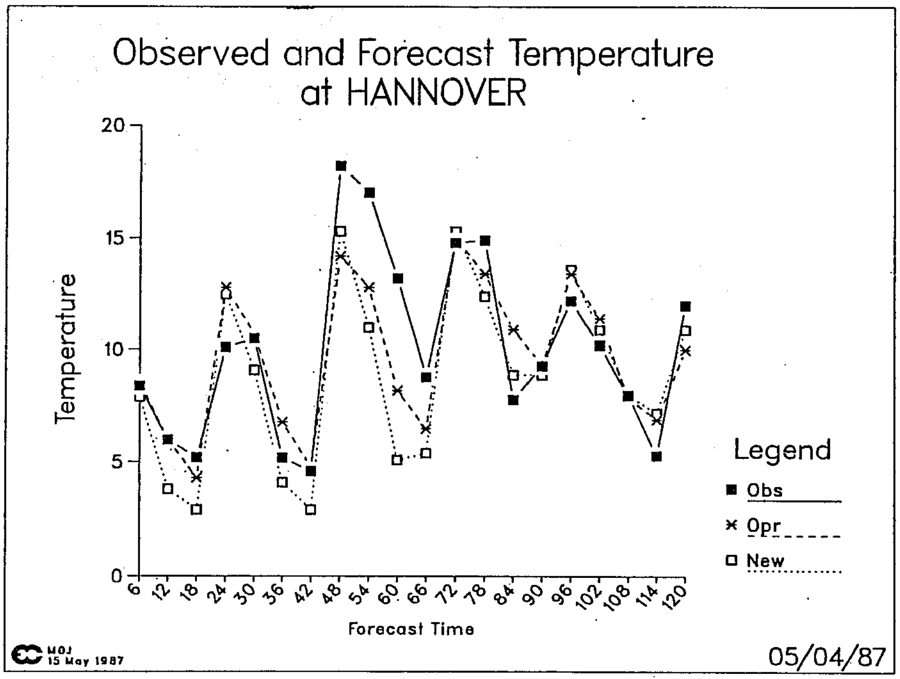


Fig 23 As Fig 22 for Hannover

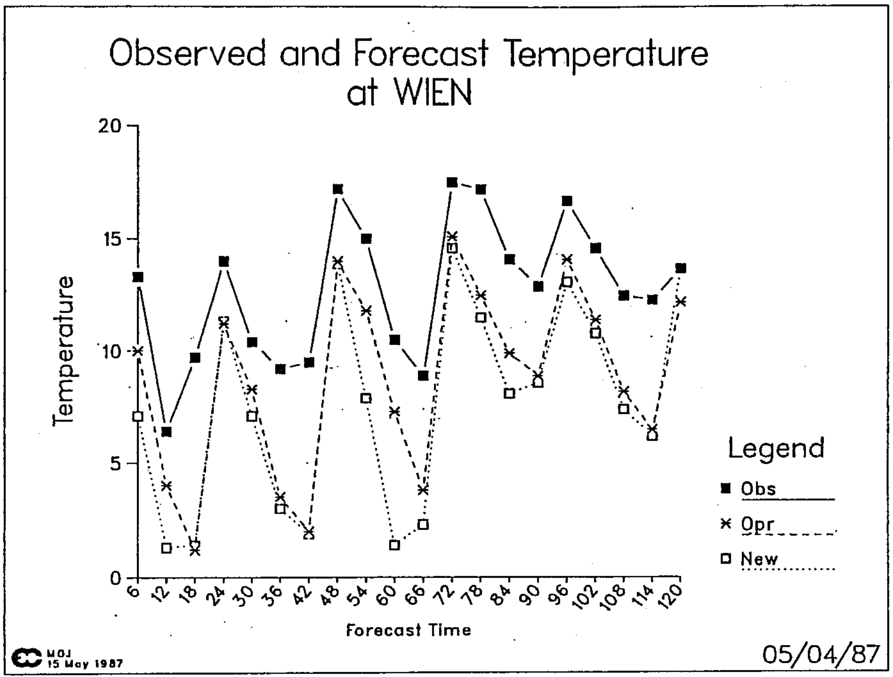


Fig 24 As Fig 22 for Wien

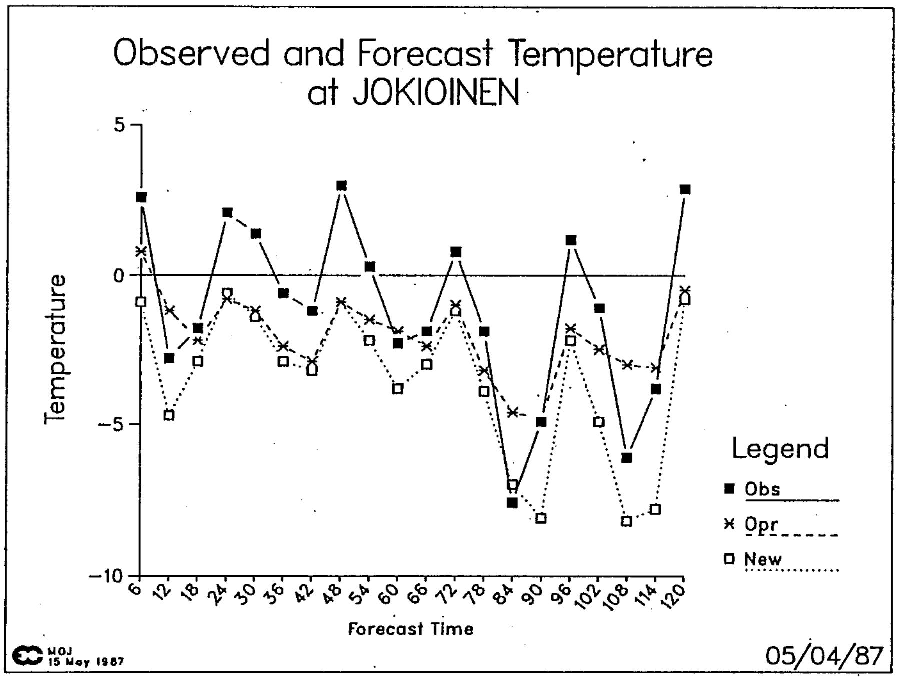


Fig 25 As Fig 22 for Jokioinen

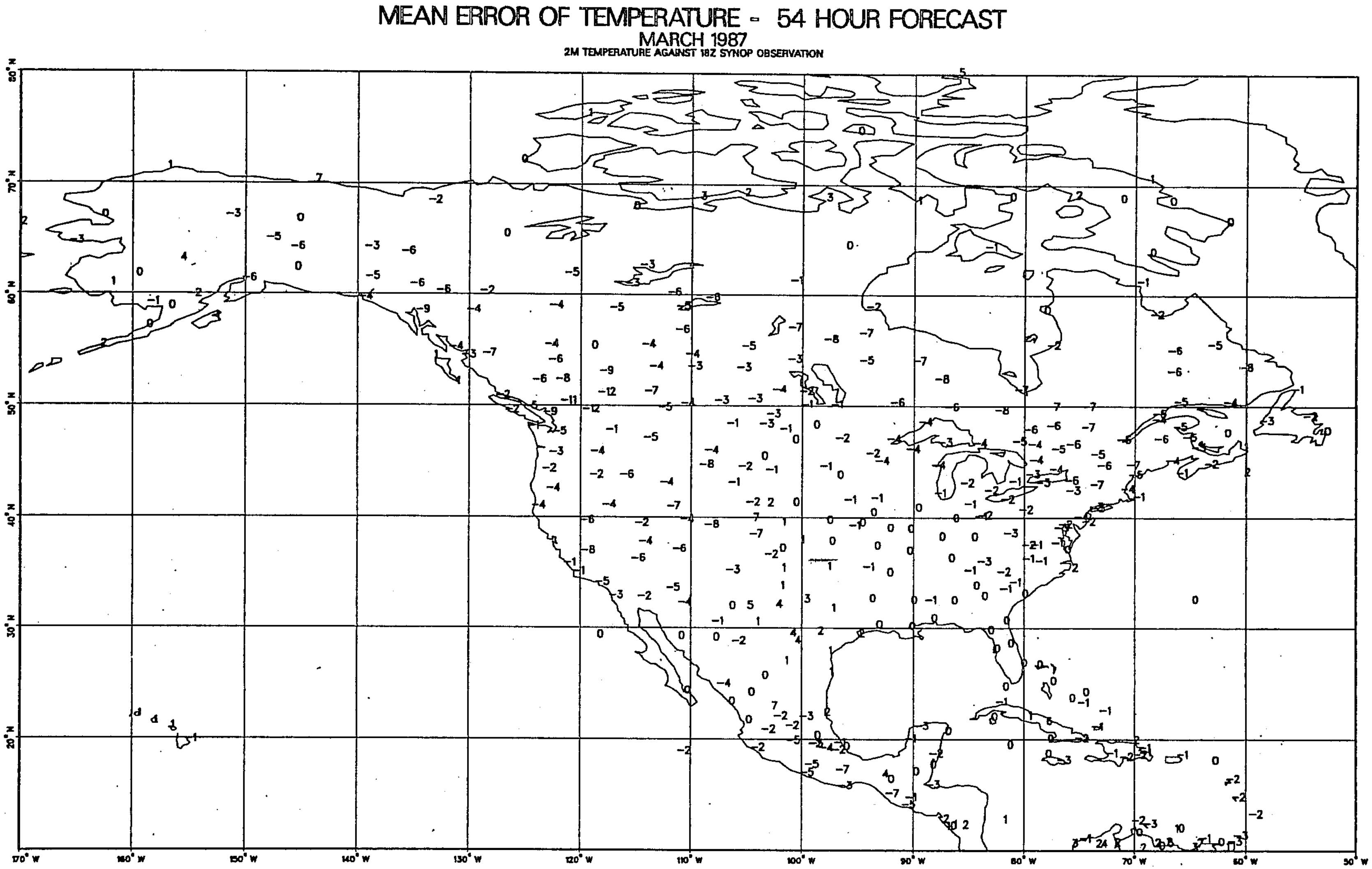


Fig 26 Mean error of 54 hour forecast of 2m temperature at all available synoptic stations in North America, March 1987. Unit is Kelvin

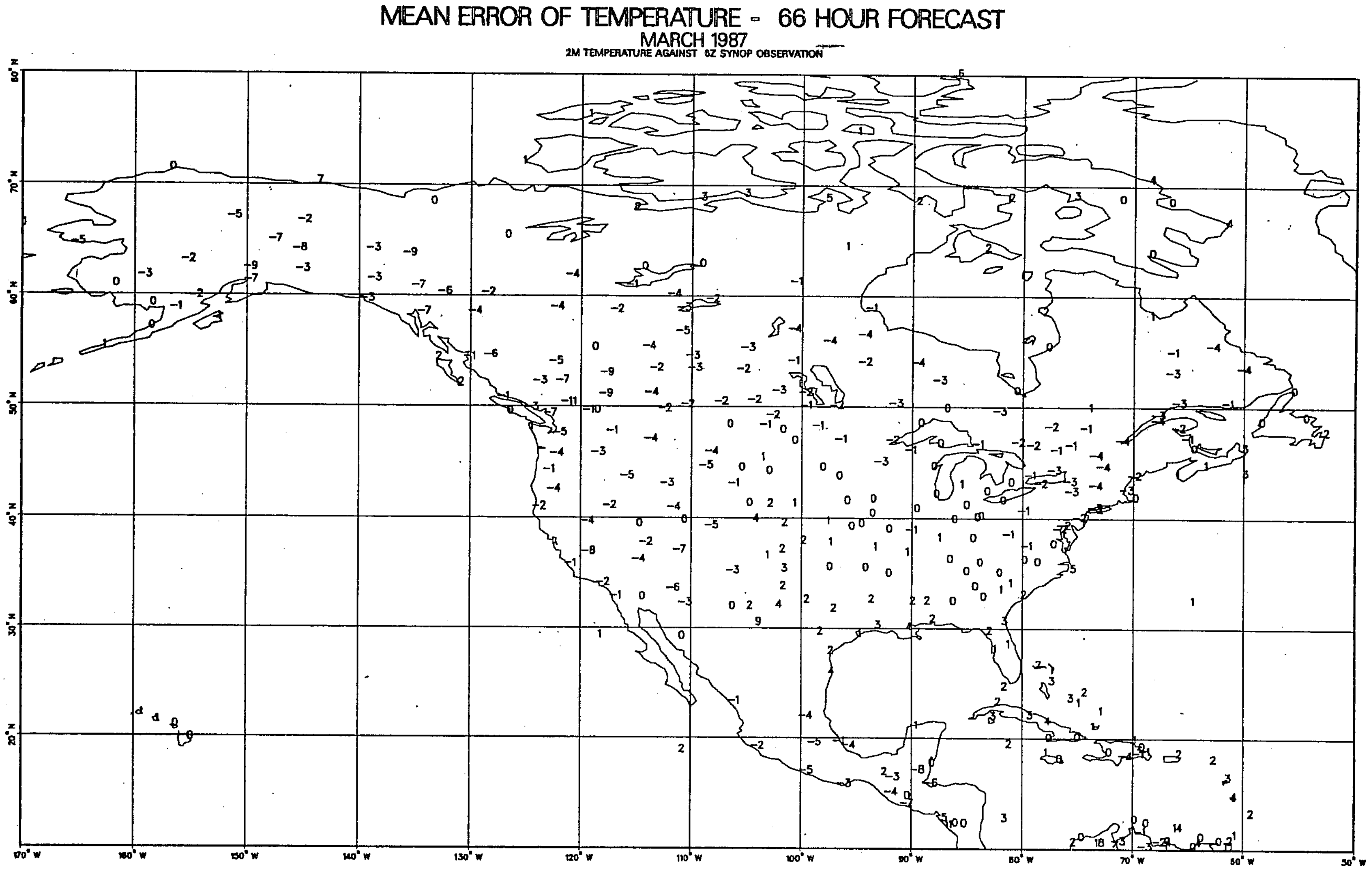


Fig 27 As Fig 26, but for 66 hour forecast

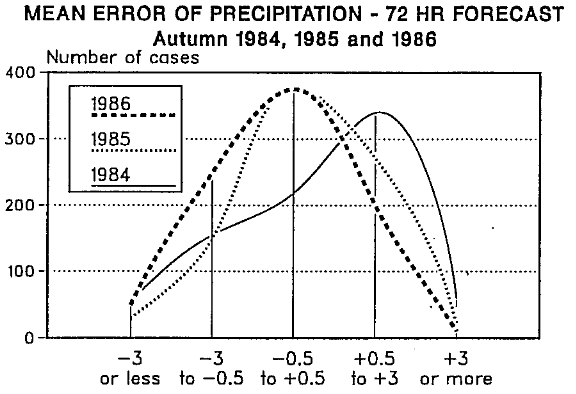


Fig 28 Mean error of 24 hour accumulated precipitation forecasts valid after 72 hours into the forecast for September to November 1984, 1985 and 1986. Unit of each category is mm/24 hours.

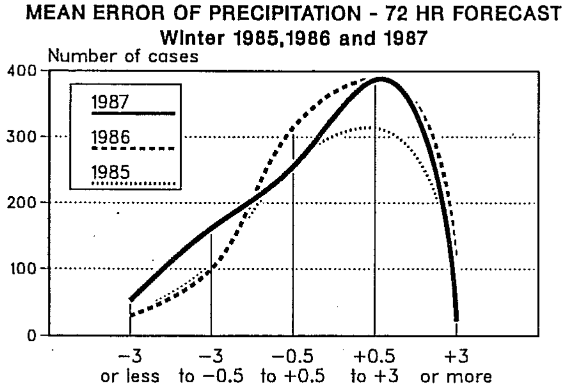


Fig 29 As Fig 28 for December to February of the winters 1984/85, 1985/86 and 1986/87.

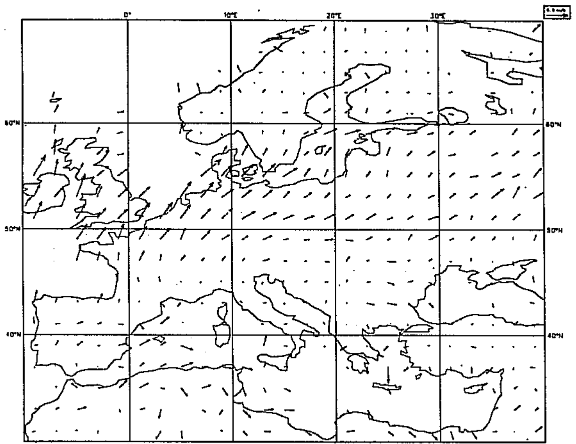


Fig 30 Analysed mean 10m wind field for December 1985

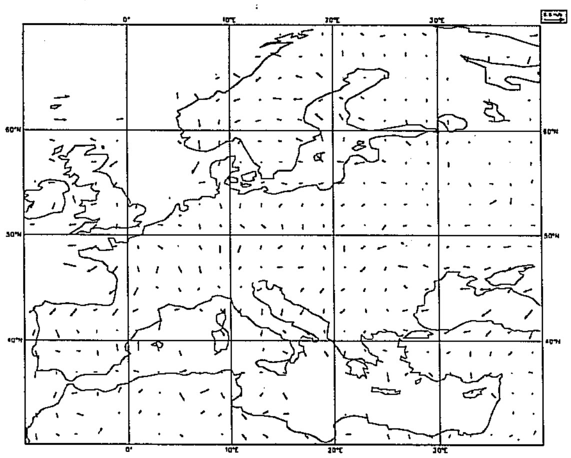


Fig 31 Mean error of the 48 hour 10m wind forecast for December 1985. Verification against SYNOP observations over land averaged in 2 degree boxes.

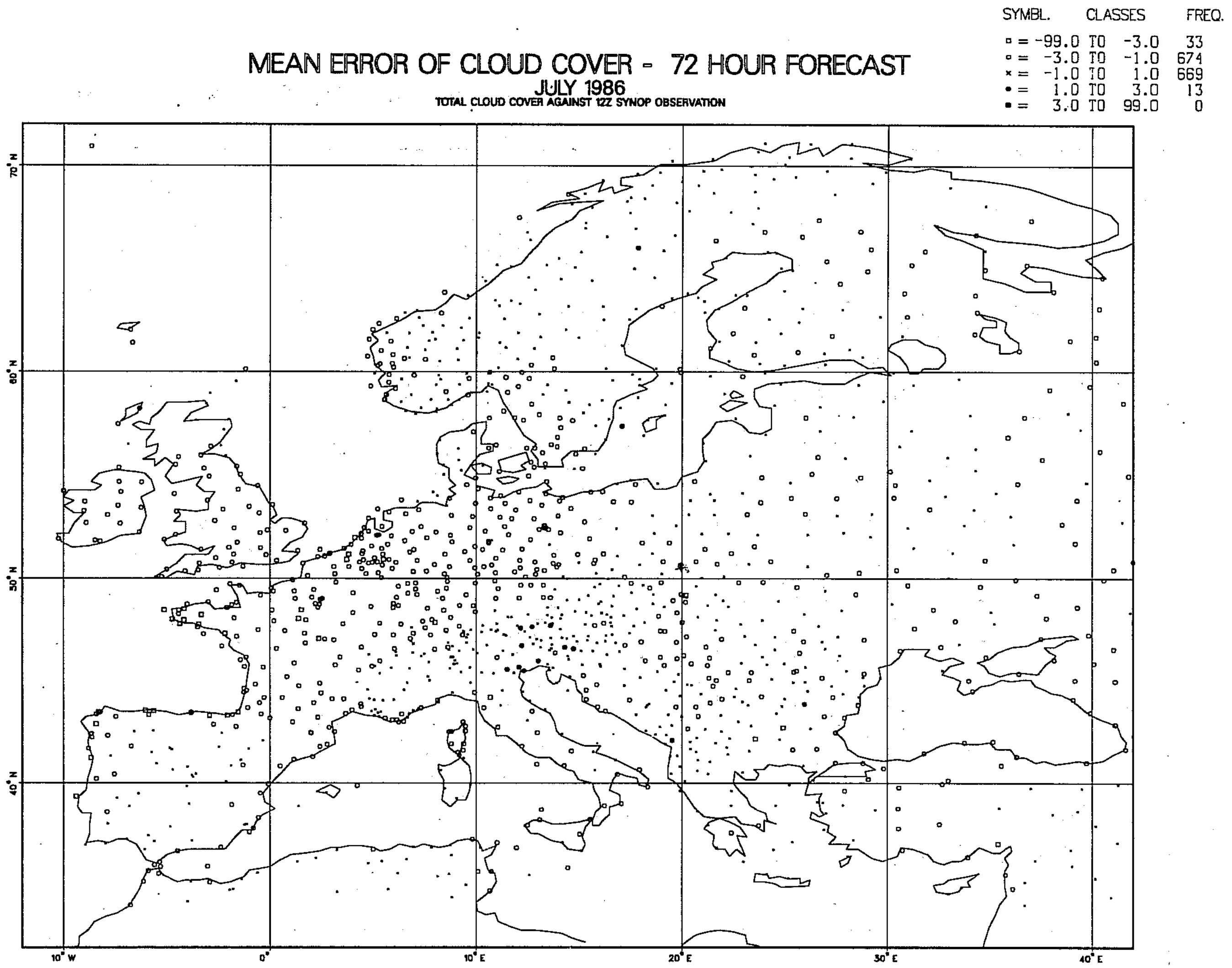


Fig 32 Mean error of 72 hour cloud forecast at all available synoptic stations in Europe in July 1986. The symbols, explained in the top right corner, give the error distribution in five categories

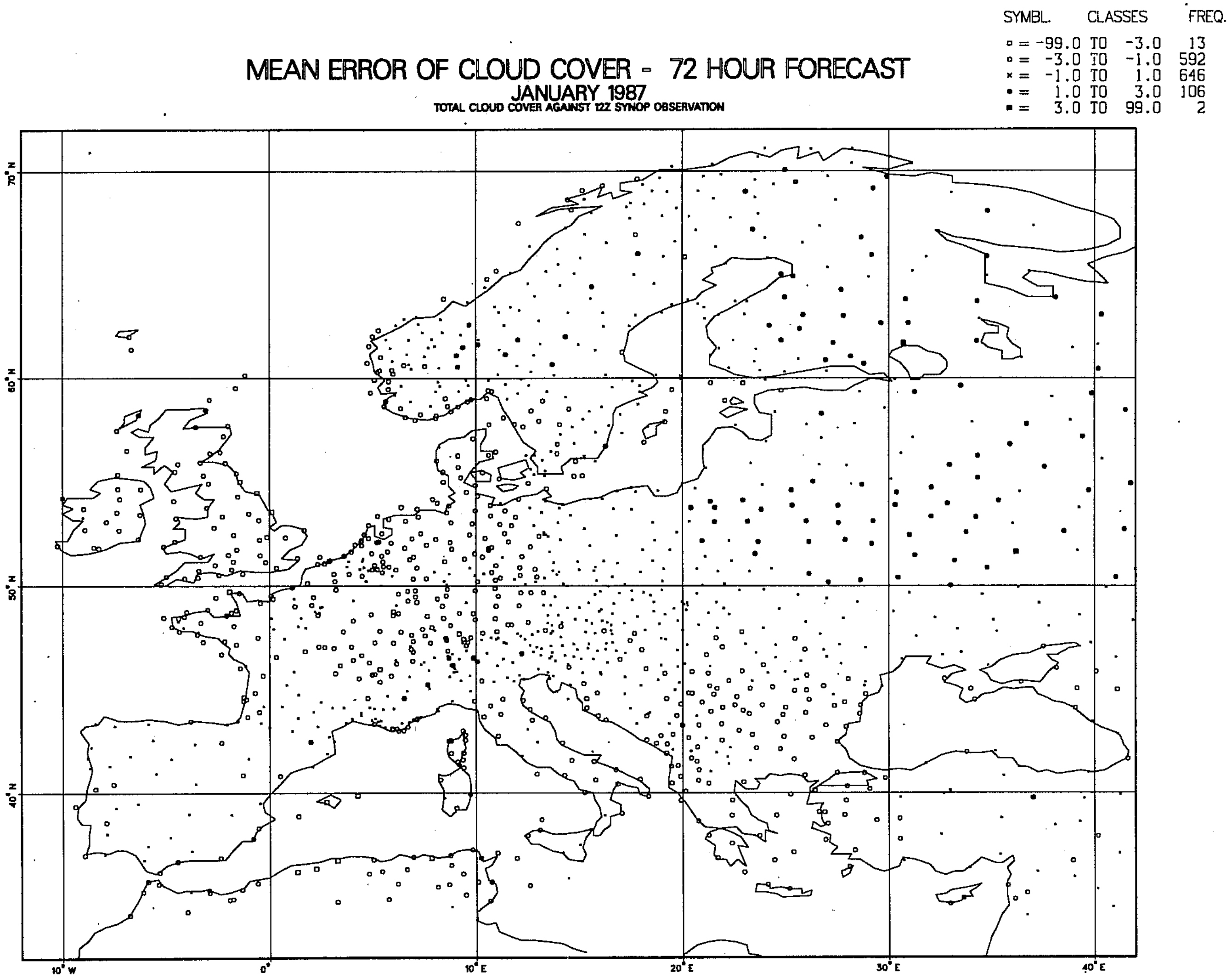


Fig 33 As Fig 32, but for January 1987