THE ECMWF ANALYSIS SYSTEM

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1. INTRODUCTION

The ECMWF data assimilation system has been designed to provide initial states for the Centre's operational forecast model and to produce analyses from observations made during the First GARP Global Experiment (FGGE). The analysis system produces global fields of horizontal wind, geopotential height and humidity at six hourly intervals. Observed information from a six hour time window centered at the analysis time is combined with the forecast from the preceding analysis. The sea surface temperatures (SST) are regularly updated by SST analyses from the National Meteorological Center (NMC) in Washington.

Most of the observations available on the global telecommunication system (GTS) are used in the ECMWF analysis system. A brief description of the preprocessing of the observed information is given in Section 2.

The mass and wind analysis is based on the statistical interpolation method developed by Gandin (1963). Rutherford (1973) and Schlatter (1975) extended the method to a multivariate analysis of height and wind in two dimensions. The ECMWF scheme (Lorenc, 1981) is a complete 3-dimensional multivariate system in height, wind and thickness. This system has a horizontal resolution of 1.875° by 1.875° and 15 levels in the vertical (See Fig. 1). The statistical interpolation assigns weights to the first-guess, i.e. the six hour forecast, and any available observations in a statistically optimal way. The scheme gives consistent analyses for a wide variety of observation types and distributions. Temporal and spatial variations of the magnitude of the forecast errors are calculated in the system. The statistical

ANALYSIS	PREDICTION
ϕ,u,v,q(for p≥300)	T,u,v,q
p(mb)	σ
10	0.025(σ_1)
20	0.077
30	0.132
50	0.193
70	0.260
100	0.334
150	0.415
200	0.500
250	0.589
300	0.678
400	0.765
500	0.845
700	0.914
850	0.967
1000	0.996(σ_{15})

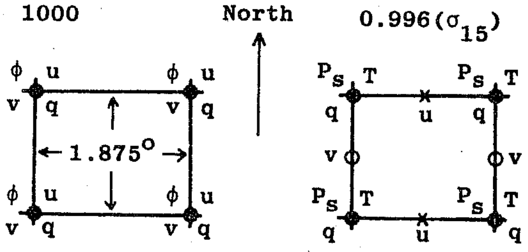

Fig. 1 The horizontal grid and the vertical levels of the ECMWF analysis and forecast systems.

interpolation method also offers an elegant technique of quality control of observations. The mass and wind analysis is discussed in detail in Section 3. A global balance between mass and wind fields is subsequently achieved by non-linear normal mode initialization (Wergen,1982).

Section 4 describes the humidity analysis which is based on a two-dimensional distance weighted correction method (Lorenc and Tibaldi, 1979). The analysis of the water vapour content of the five lowest layers (Fig. 1) is formed as a combination of the predicted humidity and estimates of moisture from observations. The SST analysis (Section 5) is basically a transformation of the NMC SST analysis to the ECMWF grid.

Prior to the analysis, the model fields must be transformed to the analysis coordinates. The corrections made by the analysis are transformed back to model coordinates and added to the six hour prediction. These interpolation methods are discussed in Section 6.

Some aspects of using the fields produced by the assimilation system for statistical interpretation of the weather are presented in the summary (Section 7).

2. OBSERVATIONS

All appropriate reports on the GTS are collected in the ECMWF Reports Data Base and ordered in groups covering a period within ± 3 hours of the analysis time. The observation types, which are presented to the analysis, are listed below with typical volumes per main synoptic hour :

Surface land and sea reports (SYNOPs/SHIPs ; 5000/800)

Radiosonde and pilot reports (TEMPs/PILOTs ; 600/200)

Satellite thickness reports (SATEMs ; 1000)

Satellite wind reports (SATOBs ; 800)

Aircraft reports (AIREPs and ASDARs ; 500)

Drifting buoy reports (DRIBUs ; 100)

Australian bogus reports (PAOBs ; 300)

The humidity analysis extracts information from TEMPs and SYNOPs only.

The observed information is checked at several stages. The ECMWF Reports Data Base checks code formats, the internal consistency between meteorological parameters within one observation, and compares the values against climatological extremes.

Each information item is presented to the analysis as a deviation from the first guess in nondimensional form, i.e. normalized by the expected forecast error for that variable and position. Four types of data are recognised by the statistical interpolation scheme, i.e. the east-west and the north-south wind components, the geopotential height at an analysis level, and the thickness between two neighbouring analysis levels. The analysis levels of the ECMWF scheme are shown in Fig. 1. Off-level observations are interpolated or extrapolated in the vertical to the nearest analysis level. Surface data are processed using the corresponding model surface fields. The sea surface pressure deviations are converted to height deviations using either the observed or the first-guess temperature and shifted to the closest analysis level. A similar procedure is applied to other pressure and height reports at non-analysis levels. The observed 10 m wind deviations are similarly assigned to the nearest analysis level. The frictional effects on the 10 m winds are assumed to be the same as in the first-guess. Winds from land stations above 500 m are not used unless the station is marked as important.

Orographic effects and the lack of detailed knowledge of land surface radiative properties degrades the quality of satellite wind and temperature measurements. Consequently, we exclude, over land, satellite thicknesses below 100 mb and all cloud winds.

An estimate of the observational error (as a function of pressure) is ascribed to each observing system and observed variable. The observation errors are assumed to be random, except for radiosonde heights and satellite temperatures. The radiosonde height errors are assumed to be vertically correlated. This enhances the accuracy of the reported gradient of height, i.e. temperature. The satellite thickness measurement errors are assumed to be both horizontally and vertically correlated.

Asynoptic surface pressure observations are corrected to the analysis time by the reported pressure tendency. For ships a correction is applied for its movement, using the forecasted pressure gradient field. The error assigned to an asynoptic observation is the sum of the measurement error and the persistence error:

$$E'_{obs} = (E_{obs}^2 + E_{pers}^2)^{1/2} \qquad (1)$$

The growth rate of the persistence error is a function of latitude and season.

Each observation is then compared against the first-guess. A reliability flag is assigned to it as a function of the magnitude of the departure compared to the expected standard deviation (std) of the difference. An observation is rejected if the departure exceeds eight stds and no close report can support it. For example, the limit for rejection is about 30 mb for a ship pressure report in the Mid-Atlantic.

Frequently, compatible and close observations with small departures from the guess field are found. This redundant information is averaged to "super-observations" and presented in the compressed form to the analysis.

3. DESCRIPTION OF THE ECMWF MASS AND WIND ANALYSIS

3.1 Basic method

Statistical interpolation is a powerful technique of combining a first-guess and observations with different error characteristics. Linear constraints such as geostrophy can be built into a multivariate statistical interpolation scheme to give consistent analyses for several meteorological quantities. An efficient data checking method can also be devised in a statistical interpolation scheme.

The equations of statistical interpolation have been derived in many papers, e.g Lorenc (1981), but for completeness I will repeat the derivation in this section.

The following notations are used for the departures from the "truth"

$$a = A - T \tag{2a}$$

$$o = O - T \tag{2b}$$

$$p = P - T \tag{2c}$$

where T is the "true" value and A, O and P are the analysed, observed and predicted values, respectively. The "true" value is assumed to represent scales we are interested in or capable of analysing.

The associated errors are defined by

$$E^a = \langle a^2 \rangle^{1/2} \tag{3a}$$

$$E^o = \langle o^2 \rangle^{1/2} \tag{3b}$$

$$E^p = \langle p^2 \rangle^{1/2} \tag{3c}$$

The angle brackets indicate ensemble means over several similar realizations. As a consequence of this definition of the "truth", the errors also include the atmospheric variability of the unresolvable scale. The resolution of the ECMWF analysis system is of the order of several hundred kilometers.

The six hour forecast generally approximates the actual atmospheric state quite well and a substantial reduction in the analysis error is achieved from using a prediction as a guess instead of climatology. The observed departures from the six hour forecast are the quantities analysed. The analysed departure from the background field is calculated by combining the observed deviations in a statistically optimal way and adding it to the guess. All departures are nondimensionalised by the assumed error of the guess field (3c) to simplify the derivation and application of the analysis equations. The analysis is formed as a linear combination of all influencing observations.

$$\frac{A_k - P_k}{E_k^p} = \sum_{i=1}^{N} w_{ki} \frac{O_i - P_i}{E_i^p} \qquad (4)$$

The subscript k denotes the analysis quantity, defined by level, horizontal position, and variable type. Similarly, subscript i defines the type and spatial position of observation i.

Define

$$\alpha^o = o/E^o$$

$$\alpha^p = p/E^p$$

$$\alpha^a = a/E^a \qquad (5)$$

$$\varepsilon^o = E^o/E^p$$

$$\varepsilon^a = E^a/E^p$$

and insert into (4)

$$\alpha_k^a \, \varepsilon_k^a = \alpha_k^p + \sum_{i=1}^{N} w_{ki} \, (\alpha_i^o \, \varepsilon_i^o - \alpha_i^p) \qquad (6)$$

Next, we want to determine the weights w_{ki} in such a way that the squared analysis error is minimized for an ensemble of similar situations, i.e. we take the ensemble mean of the square of (6). We also assume that the prediction and observation errors are uncorrelated:

$$\varepsilon_k^{a^2} = 1 - 2 \sum_{i=1}^{N} w_{ki} < \alpha_k^p \, \alpha_i^p >$$

$$+ \sum_{i=1}^{N} \sum_{j=1}^{N} w_{ki} \, (< \alpha_i^p \, \alpha_j^p > + \, \varepsilon_i^o < \alpha_i^o \, \alpha_j^o > \varepsilon_j^o \,) \, w_{kj} \qquad (7)$$

With vector (_) and matrix ($\underset{=}{\ }$) notations (7) can be written in the following form

$$\varepsilon_k^{a^2} = 1 - 2\,\underline{W}_k^T\,\underline{P}_k + \underline{W}_k^T\,\underline{\underline{M}}\,\underline{W}_k \tag{8}$$

where $\underline{W}_k$ is the column vector of weights w_{ki}, $\underline{\underline{P}}$ is the prediction error correlation matrix $[\langle\alpha_i^p\,\alpha_j^p\rangle]$, $\underline{\underline{O}}$ is the scaled observation error correlation matrix $[\varepsilon_i^o\langle\alpha_i^o\alpha_j^o\rangle\varepsilon_j^o]$ and $\underline{\underline{M}} = \underline{\underline{P}} + \underline{\underline{O}}$. $\underline{P}_k$ is the prediction error correlation vector between the gridpoint k and all observations; the components of the vector are $\langle\alpha_k^p\,\alpha_i^p\rangle$. We minimize (8) with respect to w_{ik}, i.e. we solve a set linear equations $\partial(\varepsilon_k^a)^2/\partial w_{ik} = 0$. The "optimal" weights are then

$$\underline{W}_k = \underline{\underline{M}}^{-1}\,\underline{P}_k \tag{9}$$

The analysis and the error associated with it are

$$\frac{A_k - P_k}{E_k^p} = \underline{P}_k^T\,\underline{\underline{M}}^{-1}\,\underline{B} \tag{10}$$

$$\varepsilon_k^{a^2} = 1 - \underline{W}_k^T\,\underline{P}_k \tag{11}$$

where $\underline{B}$ is the observation vector.

Formula (9) shows that the weights are independent of the observed values. The weights are determined by the geographical distribution of the selected observations and the assumed structures of the forecast and observation errors.

Formulae (9) and (10) show that the analysis depends on the horizontal grid and vertical coordinate system only through the prediction error correlations between the observation points and the gridpoint. Thus the analysis can be projected on any coordinates for which $\underline{P}_k$ is defined.

3.2 Forecast error statistics

The ECMWF system analyses simultaneously three fields (u, v and z) using four types of data (u, v, z and dz) in three dimensions. Consequently, prediction error correlations must be specified 3-dimensionally for all possible combinations of variables. The correlations are assumed to be separable in the horizontal and vertical, and are formed as products of a horizontal correlation function and a vertical correlation function. The horizontal correlation is modelled as a continuous function and the vertical correlation is given discretely, by a matrix, for all combinations of analysis levels.

Three constraints are modelled in the forecast errors. It follows from (10) that the analysis obeys the physical relationships built into the forecast error covariances in a given domain, only if a single observational data set is used for the analysis of all variables and points in that domain. If different variables (or gridpoints) are analysed with different sets of observations in a given domain, then the constraints will not be applied effectively. This means that all constraints are applied locally.

Currently, we ignore the error in the predicted divergent wind and determine the wind correlations (u-u, u-v, v-v) from an isotropic streamfunction correlation. This results in locally non-divergent wind changes.

The geopotential height and the wind are assumed to be in approximate geostrophic balance. By defining a correlation between the height and the streamfunction fields and assuming identical structures of these fields, we can determine the height-wind (z-u and z-v) correlations. A full coupling would make the height and wind increments geostrophic. In extratropical areas (poleward of 30° latitude) a height- streamfunction correlation of ± 0.95 is used. This gives in a situation of one height observation a wind analysis that is 95% of the geostrophic wind. For larger data amounts this allows for large departures from geostrophy if the data defines it. The geostrophic balance is relaxed to zero at the Equator.

An illustration of a multivariate analysis is given in Fig. 2, where only one height observation, at the centre of the area, is available. A circular height analysis results from the isotropic z-z correlation. The analysed winds are non-divergent and have the direction of the geostrophic wind. The wind speed depends on the specified correlation between geopotential and streamfunction.

The second idealized example demonstrates the sensitivity of the analysis to the specified geostrophic coupling. The "observed" winds are as shown in Fig. 3a and at the same positions zero heights are specified. The resulting analysis is shown for three different values of the height-streamfunction correlation. If strict geostrophy is imposed, the analysis (Fig. 3b) is a bad compromise of the geopotential and wind "observations". A relaxation of the coupling to 0.95 (Fig. 3c) gives an analysis that returns a substantial part of the original ageostrophic wind. By decreasing the height-streamfunction correlation to 0.5 (Fig. 3d), an analysis faithful to both geopotential and wind data is obtained. However,a weak coupling is undesirable in extratropical latitudes where the flow is approximately geostrophic.

The third constraint on the analysis relates the thicknesses hydrostatically to the heights.

The horizontal height and streamfunction correlations are modelled by an exponential function of distance r

$$\mu(r) = e^{-1/2 \left(\frac{r}{b}\right)^2} \tag{12}$$

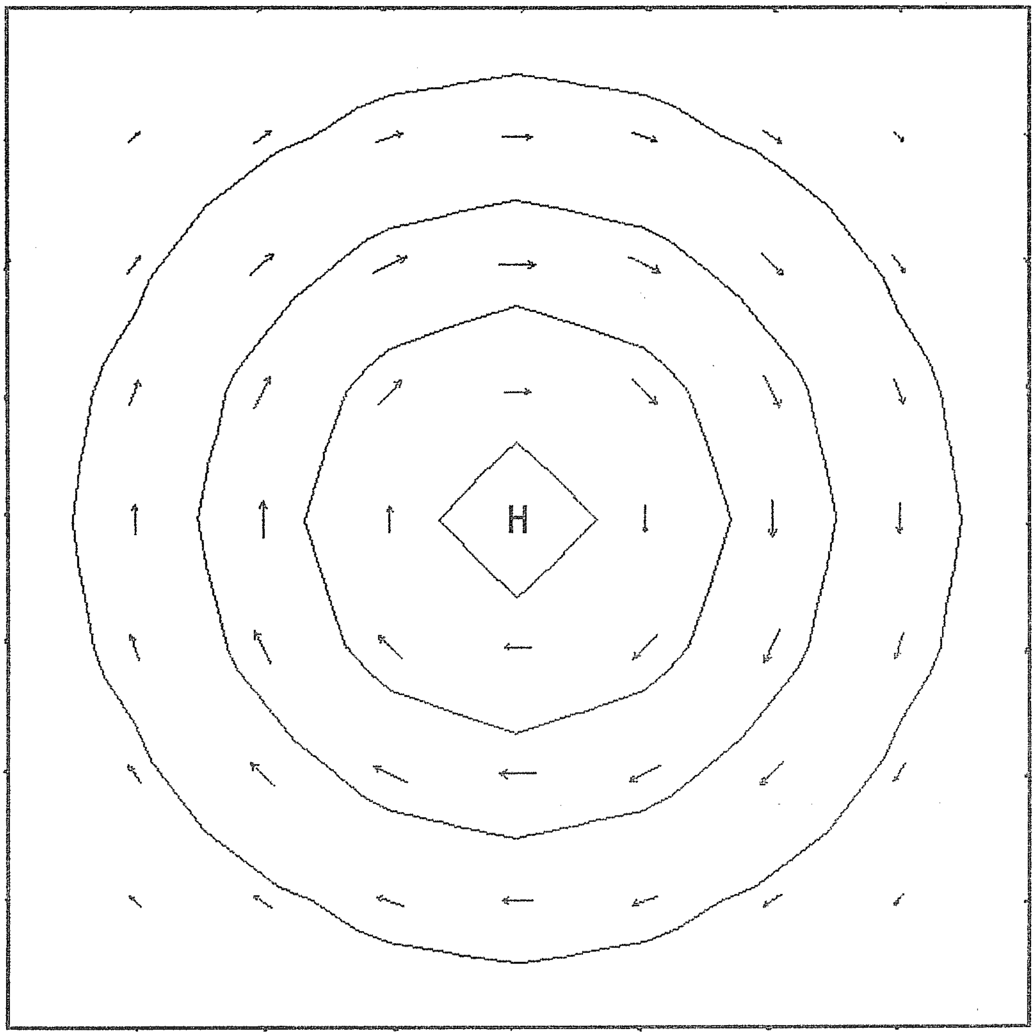

Fig. 2 A multivariate height and wind analysis using one height observation at the centre of the area.

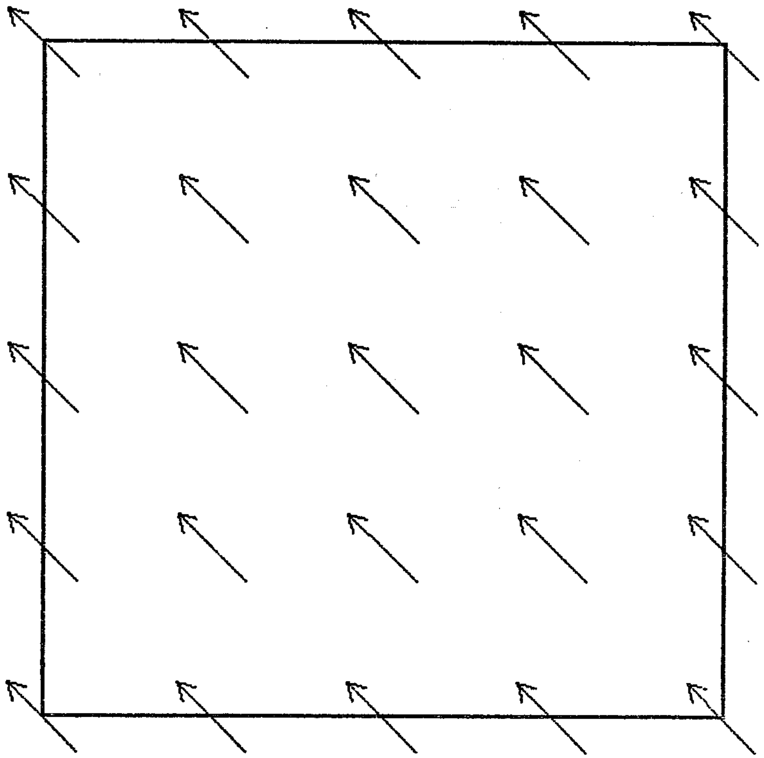

Fig. 3a The observed wind field in an idealized multivariate analysis with different height-streamfunction correlations. At each wind observation position a zero height datum is specified.

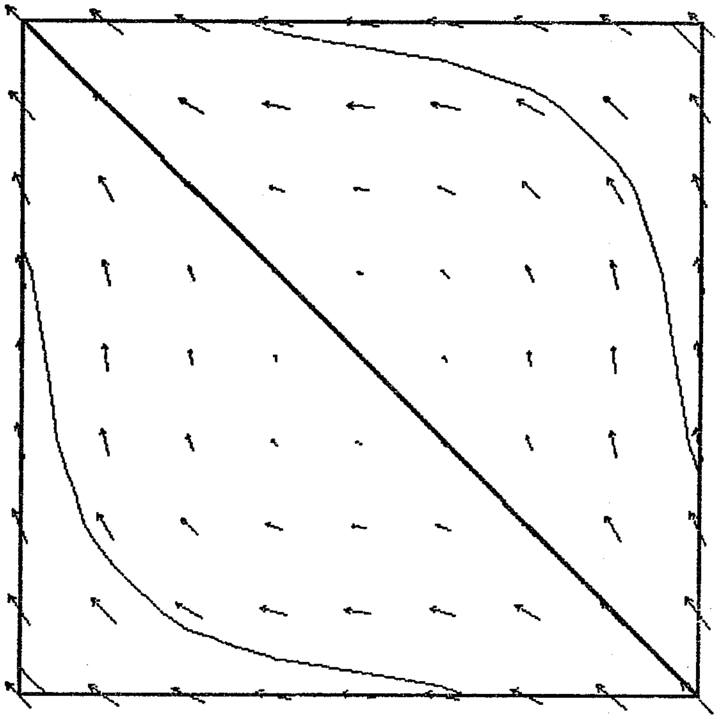

Fig. 3b The height and wind analysis from the observed fields of Fig. 3a with a height-streamfunction correlation $\gamma = 1.0$.

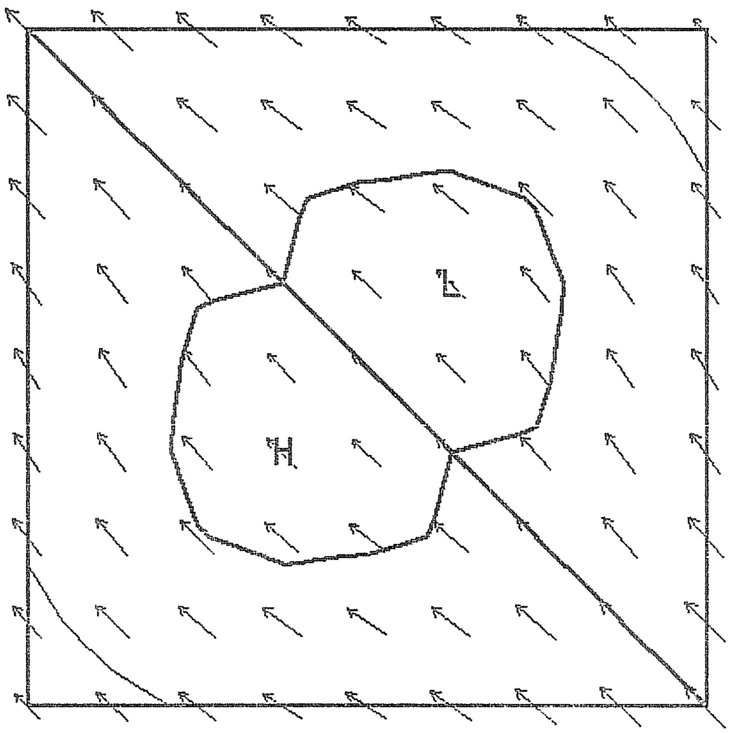

Fig. 3c Same as 3b but $\gamma = 0.95$.

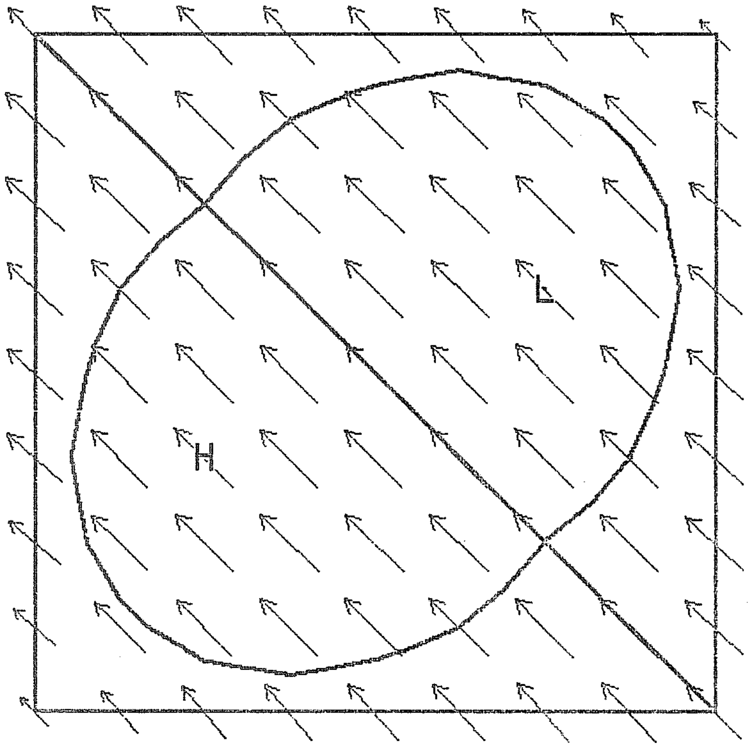

Fig. 3d Same as 3b but $\gamma = 0.5$.

where b defines the horizontal scale length of the forecast error. In the Northern Hemisphere b=600 km and in the Southern Hemisphere b=900 km.

The vertical correlations are based on several studies; the extratropical ones mainly on the thesis of Hollett (1975). Fig. 4 shows the impact in the vertical of one height observation at 1000 mb. The observation gives an almost constant (barotropic) increment up to 250 mb and above the tropopause its influence decreases rapidly. This is also reflected in the thickness as a weak change of the mean tropospheric temperature. A pressure fall (rise) at the surface causes a warming (cooling) at the tropopause and in the lower stratosphere.

The horizontal correlations are fixed in time, but the vertical correlations have an annual variation. The magnitude of the 6 hr. forecast error depends on the accuracy of the previous analysis. The analysis error is estimated according to (11) for all variables and levels on a coarse grid. This error is assumed to grow to the error of a random state in 36 hours, i.e. a sixth of the difference between the random and the analysis error is added to the analysis error. This apparently rapid error growth is caused not only by the pure forecast error but also from the fact that the analysis error is an underestimate of the "true" analysis error and that the initialisation moves the analysed state away from the "truth".

Fig. 5 shows the estimated forecast error of the 500 mb height on 1 November 1981 12 GMT. The North American and Asian continents as well as the Pacific have high forecast errors as a consequence of very few upper air observations in the previous analysis. The Equatorward decrease in the forecast error reflects the smaller climatological variability in the tropics.

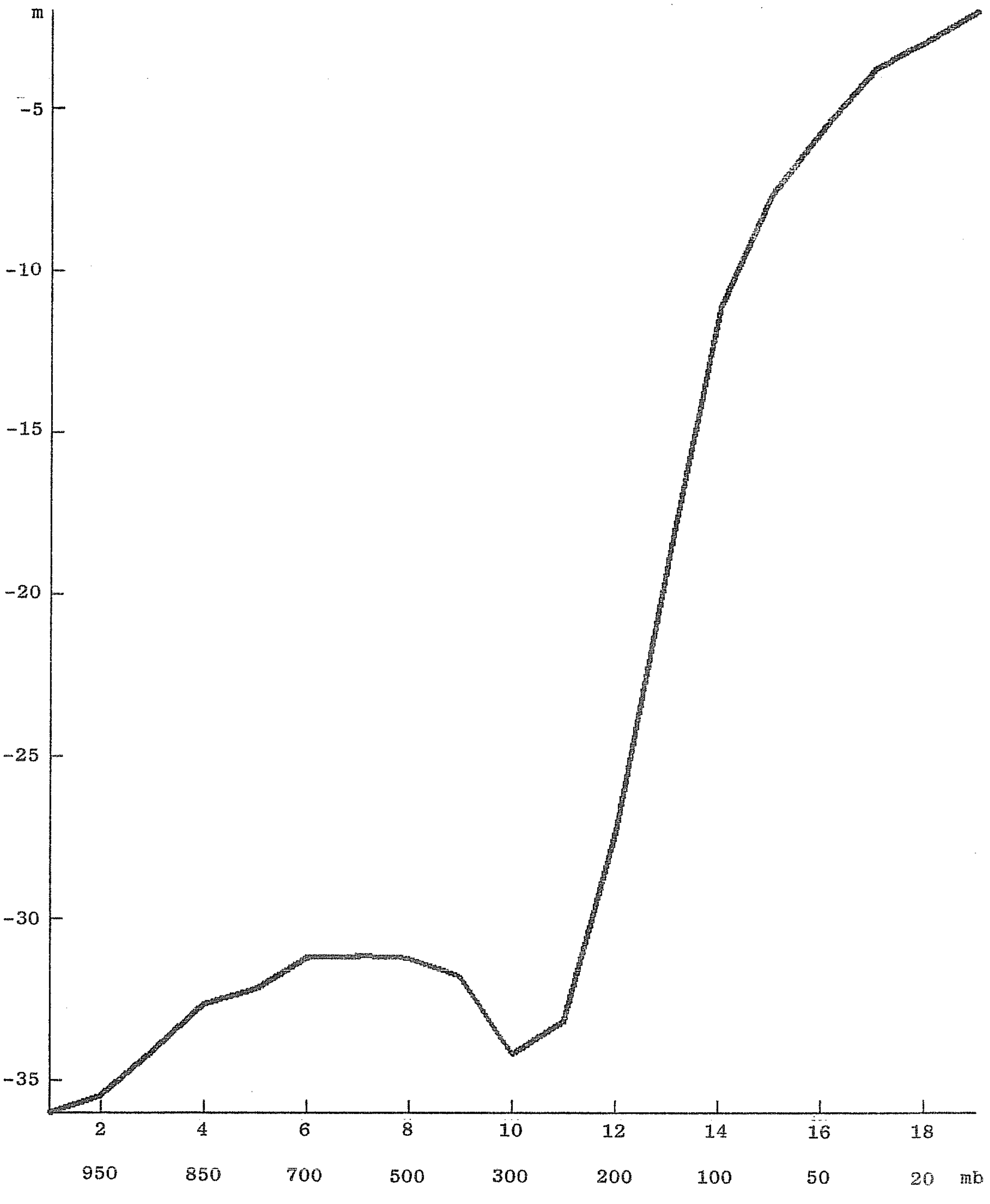

Fig. 4 The height analyses at different pressure levels from one height observation (-40 m) at 1000 mb. The assumed normalized observation error is 0.4.

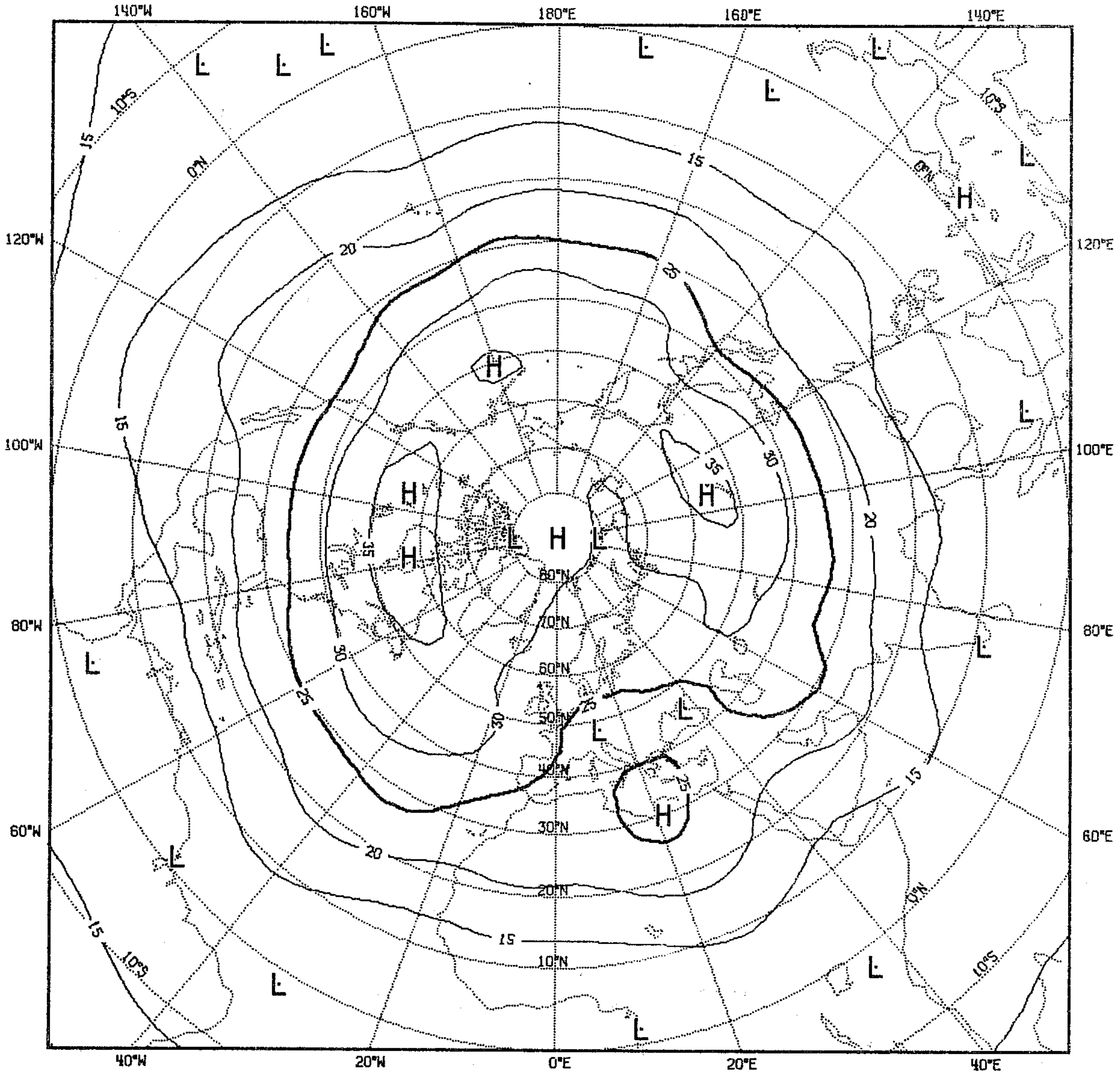

Fig. 5 An example of the estimated forecast error for 500 mb height at 12 GMT 1 November 1981. Unit: metre.

The estimated analysis error for the corresponding analysis, which has a normal data coverage, is shown in Fig. 6. The roughness of the field is caused by variations in the data coverage. Only a small reduction of the error of the first-guess is achieved over the oceans. Over the continents the error drops to a small fraction of the six hour forecast error.

3.3 Data selection and checking

After a coarse preliminary data check in the pre-analysis, each remaining item of information is checked by the statistical interpolation method. An analysis is calculated at each observation to be checked but without that observation. Averaged over a large ensemble, the mean of the squared difference between observations and independent analyses is the sum of the squares of the observation and analysis errors. An observation is most likely incorrect if its difference to the independent analysis exceeds the expected difference by a certain factor, say 4. Thus the observation is rejected if the following inequality is satisfied

$$(\alpha_k^o - \alpha_k^a) > c_1^2 (\varepsilon_k^{a^2} + \varepsilon_k^{o^2} + c_2) \qquad (13)$$

The constants c_1 and c_2 have been set to 4 and 0.1, respectively. The constant c_2 is added to the rejection limit to inflate the estimate of the analysis error which is based on the assumption that the statistics are perfect.

The discrete decision to reject or accept an observation can have enormous consequences for medium-range weather forecasting due to downstream propagation and amplification of the initial error (Cats, 1981).

The design of an efficient data selection algorithm is very difficult. Most analysis systems tend to chose no more than 10 observations for the analysis

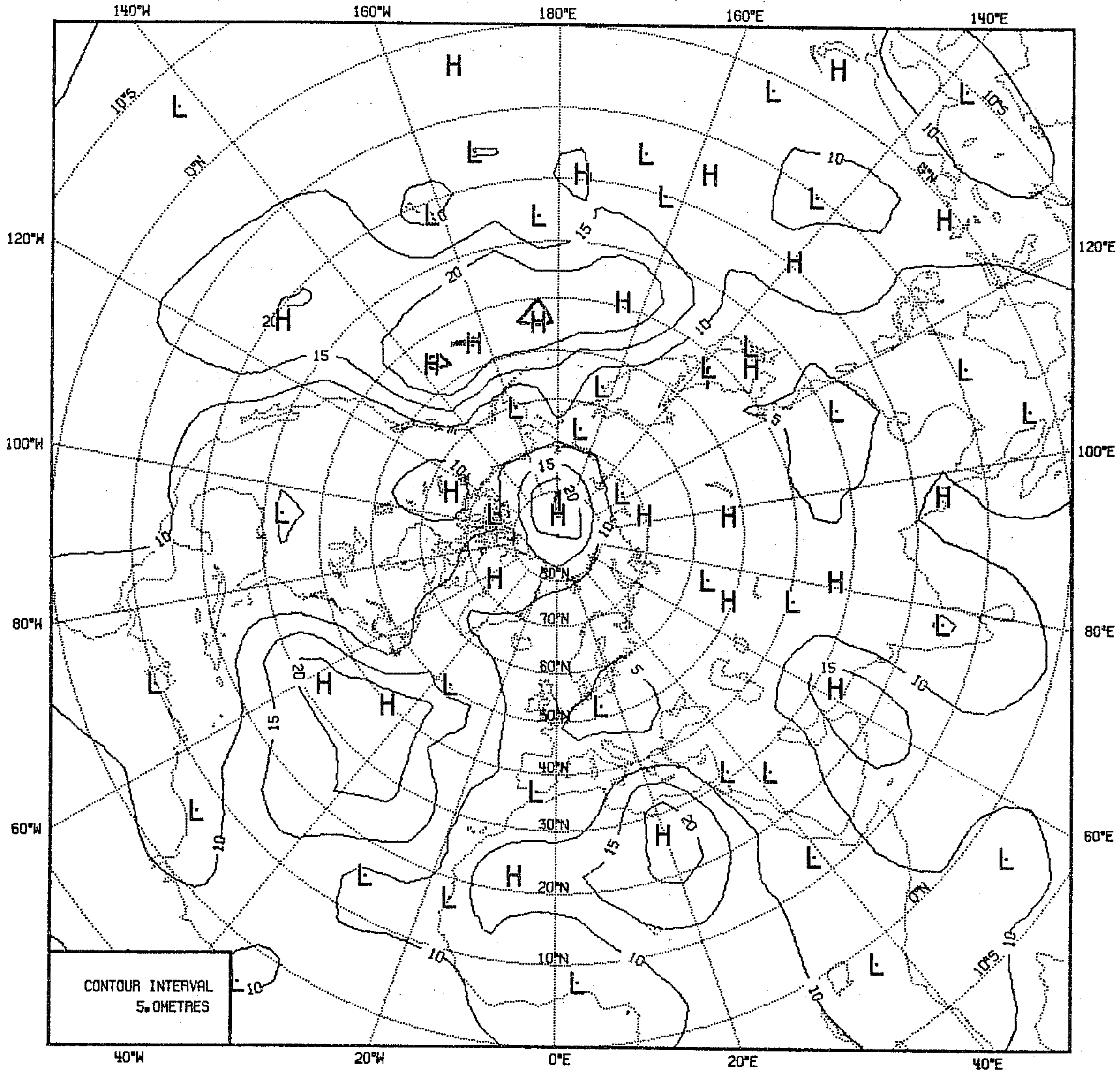

Fig. 6 The estimated analysis error for 500 mb height at 12 GMT 1 November 1981. Unit: metre.

of a particular point. On a fast vector computer it is practicable to invert matrices up to an order of 100-200. The ECMWF scheme selects all observations in an analysis volume and the selection proceeds outwards from the volume to a distance of 1 b-length (formula 12) until 5 data have been found for each analysis variable and level. An analysis volume is defined by the gridpoints and levels for which the analysis is calculated simultaneously using the same data set.

3.4 Organisation of the computation

The mass and wind analysis consists of three stages:-

- Preprocessing of observations as described in Section 2
- Data checking by the statistical interpolation method
- Calculation of the changes (increments) to the first-guess

As the matrix inversion is computationally expensive and the data selection for neighbouring gridpoints would in general be very similar, the analysed values for several gridpoints are calculated simultaneously.

The globe is divided into rectangular areas (boxes) of approximately equal size, 660 by 660 km (See Fig. 7). In data dense regions the atmosphere is divided into three layers in the vertical. For each such volume the appropriate data are selected and $\underline{\underline{M}}^{-1}\ \underline{B}$ (formula 10) is solved. The analysis can then be projected on any grid by multiplication with $\underline{P}_k$. In the data checking phase the analysis is only evaluated at the locations of the observations in the volume.

As the analysis might change dramatically between one box to its neighbour due to different data selection, analysis increments are also calculated to

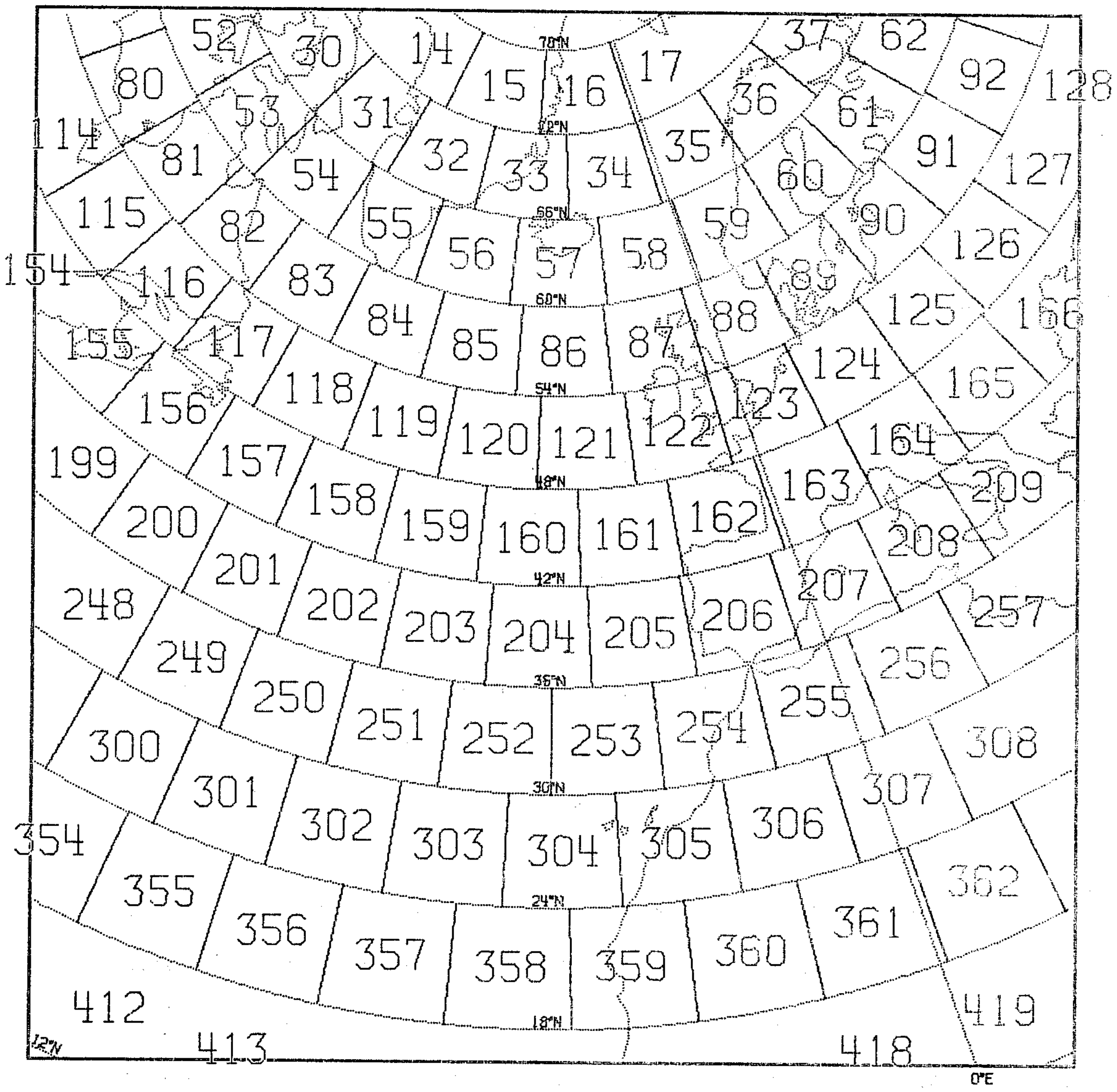

Fig. 7 The box structure of the ECMWF analysis system.

gridpoints in the neighbouring boxes. The final analysis increment is formed as a weighted mean of the different estimates of the analysis at that point.

3.5 Example of a mass and wind analysis

An example of height and wind increments fields produced by the statistical interpolation method is given in Fig. 8a. The corrections made by the analysis are generally less than 3-4 mb in the Northern Hemisphere and the winds and heights are in approximate geostrophic balance. The final height and wind analysis is shown in Fig. 8b. The corresponding changes to the divergence are presented in Fig. 9a. A good agreement can be found between the divergence and the pressure tendency fields. Although the horizontal correlations are locally non-divergent the magnitude of the changes in the large-scale divergence field represent an appreciable part of the total analysed divergence (cf Figs. 9a and b).

4. HUMIDITY ANALYSIS

For the analysis of humidity one can justify a less sophisticated scheme than statistical interpolation. Consequently a two-dimensional correction method is considered adequate for the humidity analysis. As for the mass and wind analysis, the six hour forecast from the previous analysis provides the guess field which is modified by available observations. In anticipation of good quality satellite water vapour measurements, the vapour content between two analysis levels was chosen as the analysis variable. At present, the scheme extracts information only from TEMPs and SYNOPs. The pressure levels that define the analysis layers are 1000, 850, 700, 500, 400 and 300 mb.

The structure of the error of the forecasted humidity is poorly known. The forecast is generally of good quality in extratropical areas, but in the tropics where the coupling between mass and wind field is weak, updating of the predicted humidity field is important.

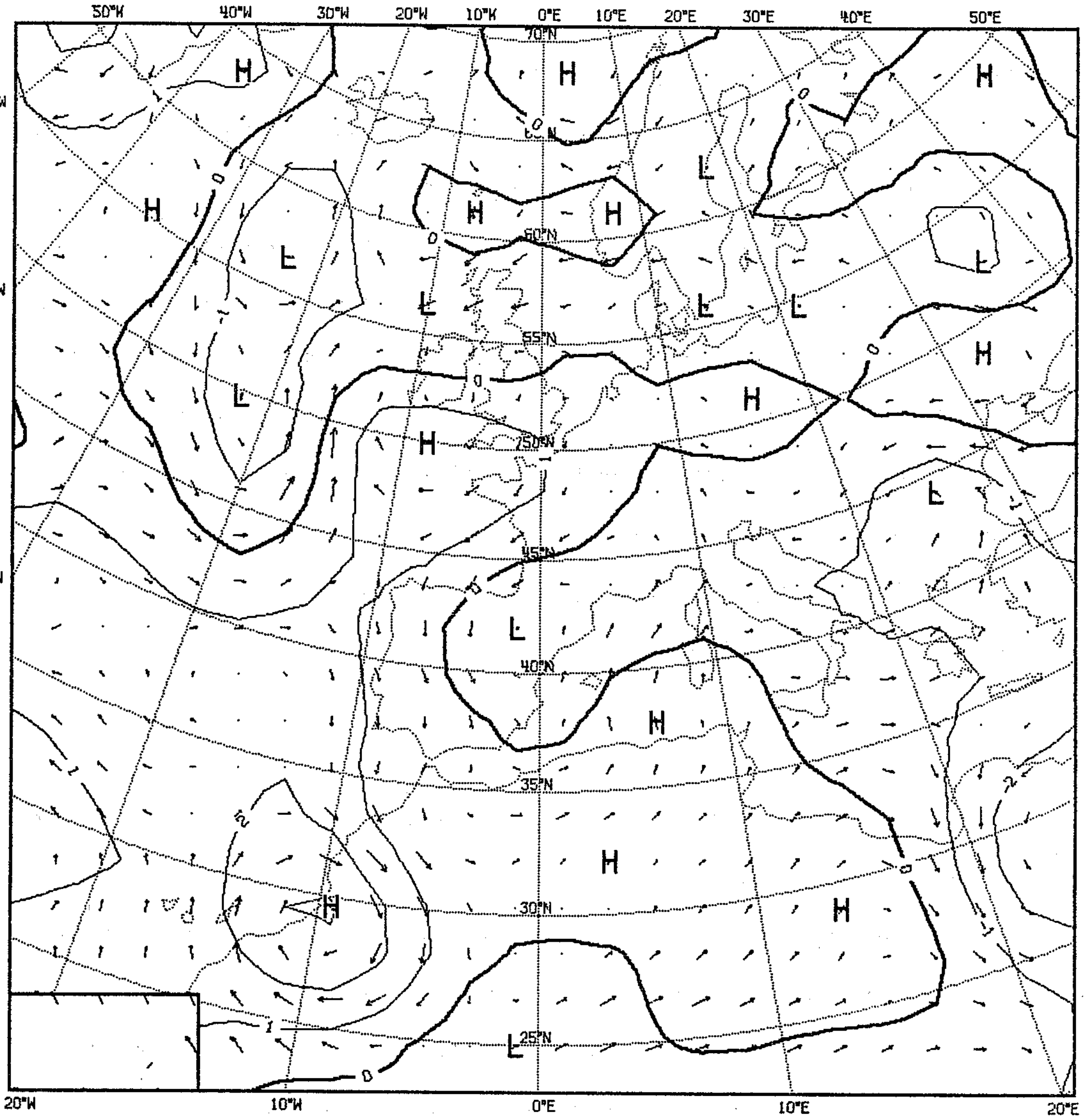

Fig. 8a The height and wind increments fields at 1000 mb at 12 GMT 1 November 1981. Unit for height is dm.

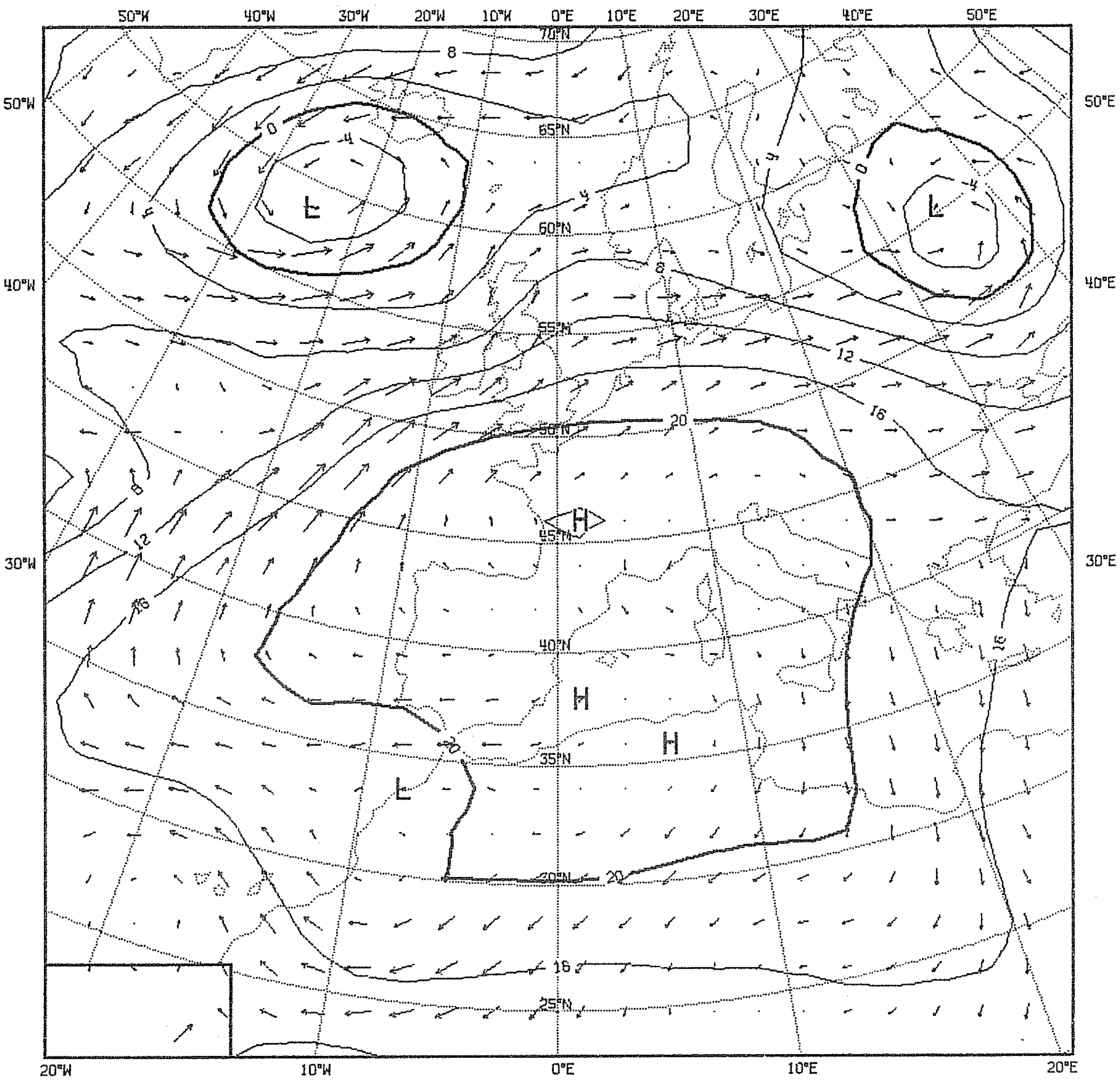

Fig. 8b Same as Fig. 8a but for height and wind analyses. The length of a wind vector is 0.4 of its magnitude in Fig. 8a.

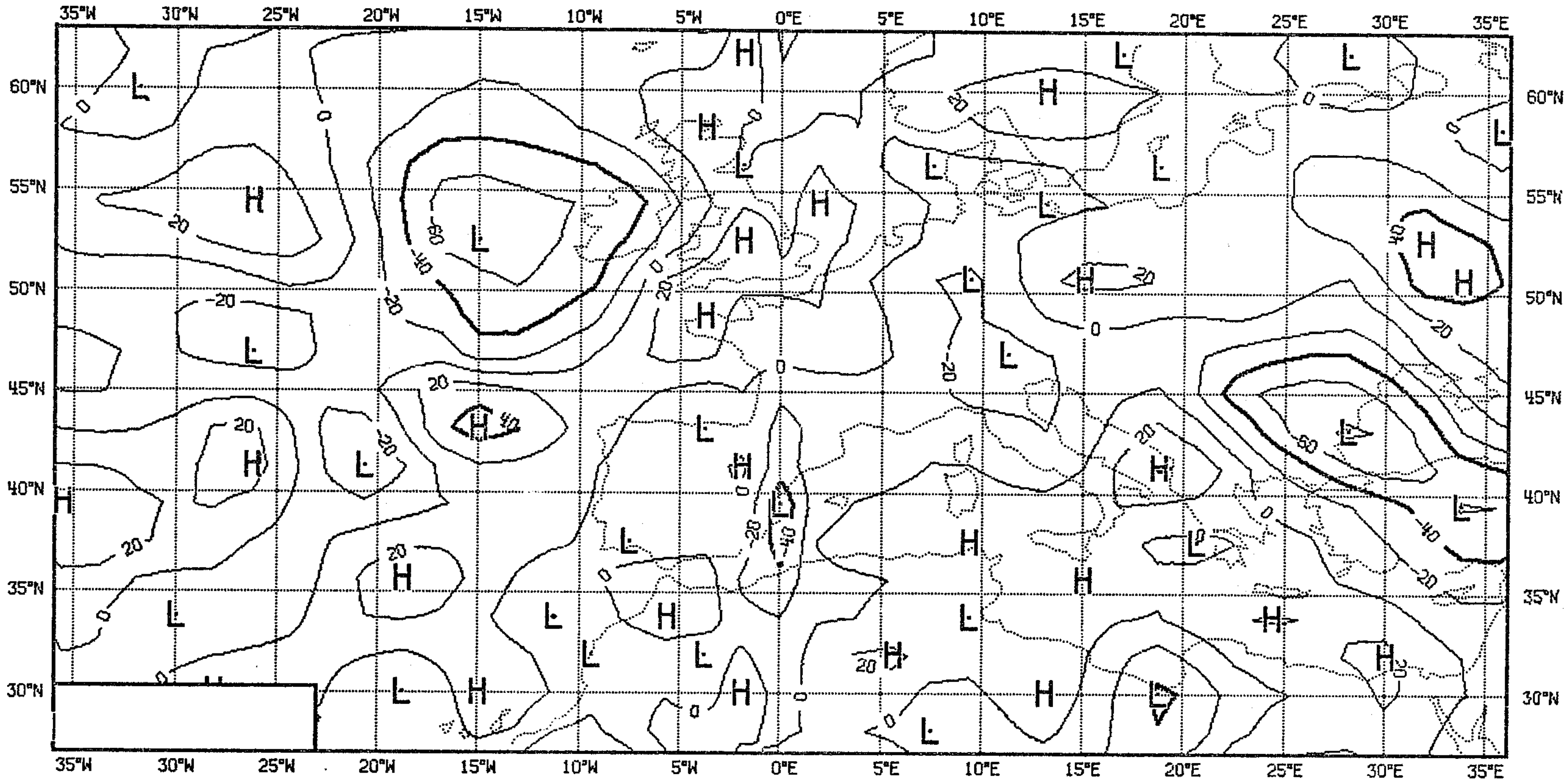

Fig. 9a The divergence of the wind increments in Fig. 8a. Units: 10^{-7} s^{-1}.

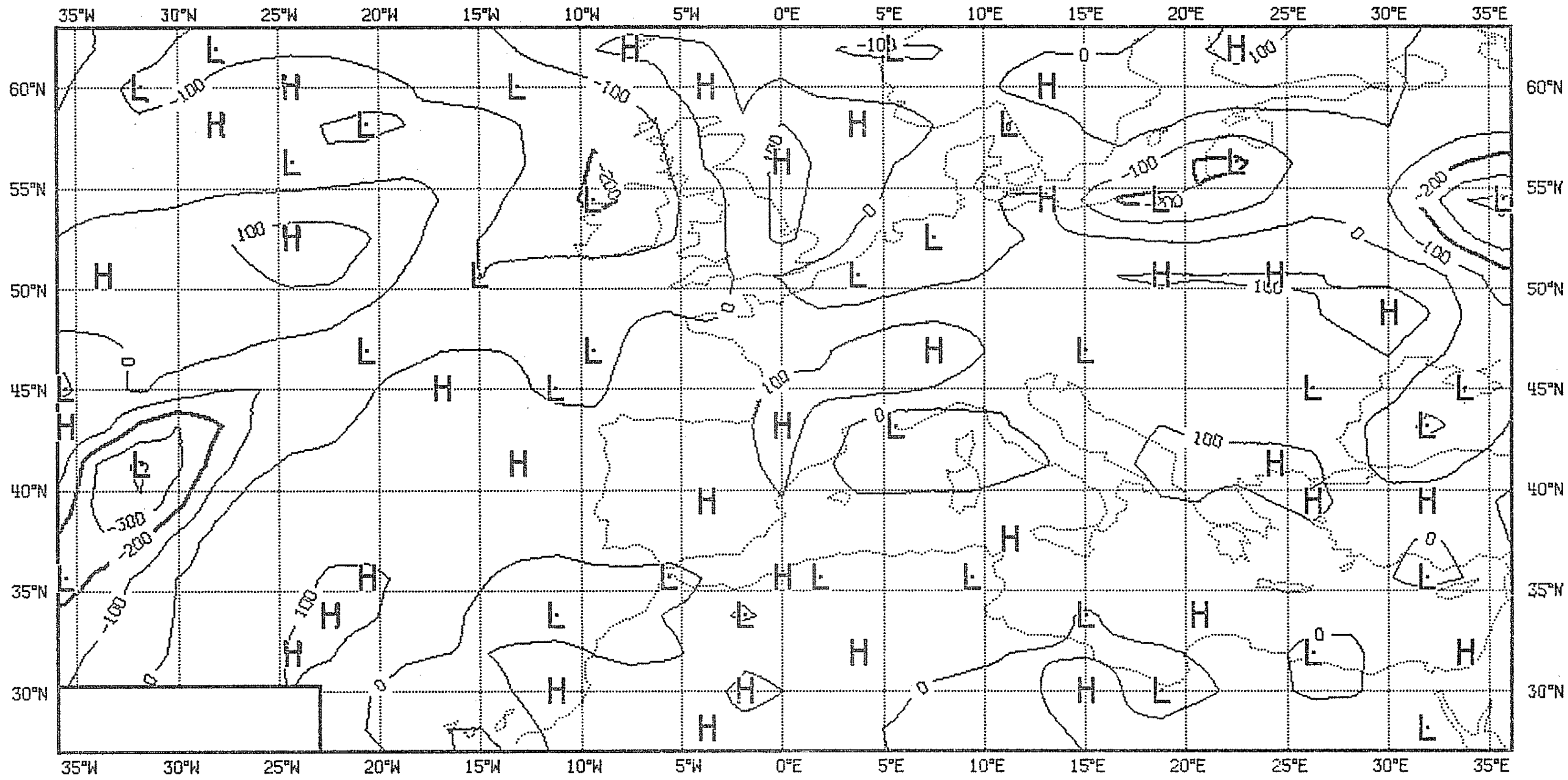

Fig. 9b The divergence of the final wind analysis in Fig. 9a. Units: 10^{-7} s^{-1}.

The two-dimensional scheme is a distance and error weighted mean of the observations. The weight given to an observation is

$$w_i = \mu(r_{ki})/[1 + \varepsilon_i^{o^2} - \mu^2 (r_{ki})] \qquad (14)$$

and the correction to the first-guess is given by

$$A_k - P_k = \sum_{i=1}^{N} w_i \,(O_i - P_i)/[1 + \sum_{i=1}^{N} w_i] \qquad (15)$$

where

$$\mu(r) = e^{-1/2 \left(\frac{r}{r_o}\right)^2} \qquad (16)$$

is the prediction error correlation for humidity as a function of distance r. r_0 = 250 km for the 1000-850 mb layer and increasing to 350 km for the 300-400 mb layer.

The temperatures and dew point temperatures are extracted from radiosonde reports and converted to mixing ratios, which are then integrated vertically to give the water vapour content in the analysis layers. In surface observations temperature and dewpoint, current weather and cloud amounts and types give estimates of the boundary layer and cloud level humidities. The weather and cloudiness information is converted to relative humidities according to a formulation based on Chu and Parrish (1977).

Above 300 mb the humidity is specified in the following way. A constant mixing ratio of $2.5*10^{-6}$ is assumed for the stratospheric humidity. Between 300 mb and the tropopause the relative humidity is assumed to decrease linearly with respect to pressure. The relative humidities and temperatures then define the mixing ratios at any level. The evaluation of the mixing ratios above 300 mb takes place in the vertical interpolation (Section 6), where the temperatures are available.

The impact of the humidity analysis is greatest over the tropical continents and has a marked effect on the initial rainfall in the forecast. In extratropical regions the first-guess is usually close to the measured values.

5. SEA SURFACE TEMPERATURE ANALYSIS

ECWMF receives the sea surface temperature analyses of NMC on a 5 by 5 degree grid. The climatological monthly mean temperatures are subtracted from the NMC analyses and the anomalies are interpolated to the ECMWF grid using bicubic splines. The horizontally interpolated values are then added to the climatology on the ECMWF grid. Over ice areas the climatological field is used and a smooth transition is applied from ice to open water.

6. VERTICAL INTERPOLATION

The aim of the vertical interpolation is twofold. Firstly, it provides the analysis with a model forecast in the analysis coordinates. Secondly, the corrections made by the analysis to the first-guess are interpolated back to the model coordinates.

The numerical technique of the vertical interpolation depends on the meteorological parameter. The wind is interpolated linearly in ln p and shifted horizontally to coincide with the non-staggered analysis grid (cf Fig. 1). The model temperatures are integrated hydrostatically in sigma coordinates to give geopotential heights. These are then interpolated to pressure levels through cubic spline interpolation with respect to ln p. The upper stratospheric (30, 20 and 10 mb) background heights are determined by adding a mix of persistence and climatological thicknesses to the 50 mb height. The stratospheric winds are determined through a similar procedure from the persistence and climatological wind shears and the 50 mb wind. The humidity first-guess is created through an interpolation of the model relative humidities to the pressure layers. The precipitable water content of the first-guess is then obtained from the first-guess relative humidity and layer mean temperature.

The changes or increments produced by the analysis are interpolated from pressure to sigma coordinates and added to the six hour forecast in model coordinates. This feature of the vertical interpolation preserves the model boundary layer structure. Surface pressure is not explicitly analysed, but calculated from the change of the geopotential at the first-guess surface pressure. The change in the geopotential at the surface is obtained from extrapolation or interpolation of the geopotential changes at the nearest analysis levels. Once the new surface pressure has been defined the pressure values of the sigma levels are determined.

The wind increments are staggered to the model's grid before the linear interpolation with respect to ln p. The height increments are first transformed into increments of mean virtual temperature. The temperature increments for the pressure layers are combined linearly to give the mean temperature change for each sigma layer. The weight given to each pressure layer temperature increment is proportional to its overlap with the sigma layer. A similar procedure is applied to the moisture interpolation. The vertically interpolated humidity variable is relative humidity increments calculated from the changes of layer water vapour content. This gives the sigma layer relative humidities which combined with the virtual temperatures is solved to give dry temperatures and mixing ratios.

7. SUMMARY

The ECMWF analysis system operates on 15 standard levels for mass and wind and 5 layers for humidity. Other parameters like the surface fields (land temperature,land soil moisture, surface pressure) either evolve during the data assimilation process or are a result of a purely numerical interpolation procedure applied to the analysed fields. Many important predictors used in statistical interpretation of weather depend strongly on the formulation in the forecast model of the influencing processes. Considerable errors occur in conjunction with high terrain, where the surface might be far from the closest analysis level.

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