Short Range Forecasting Division

Technical Report No. 22

Background Errors for the Quality Control and Assimilation of Atmospheric Observations in the Unified Model- the situation in July 1992

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1. Introduction

The background error (BGE) is an estimate of the standard deviation of the error present within a short-range forecast used as a background or first-guess for the quality control and assimilation of observations. Sometimes, BGEs are specified as climatological mean values, fixed in time, based on past model statistics. Most current data assimilation systems have a forecast/analysis cycle; the analysis reduces the model errors, which then grow again during the forecast step. The analysis error reduction is dependent on the density and quality of the observations available, whereas the forecast error growth depends on the current model state. Often, the former effects are taken into account by using optimum interpolation analysis error estimates, and the forecast error growth is taken to be linear (e.g. ECMWF). We consider that the variation in forecast error growth is a major factor and that it should be taken into account.

Our approach is to allow the BGEs to be dependent on the meteorological situation, making use of appropriate elements of the forecast such as pressure gradient or wind speed. Such synoptic-dependent BGEs have been used for the quality control of mean sea level pressure (P_{msl}) and 10m wind (V_{10m}) from surface marine observations since the introduction of the Bayesian ship quality control scheme in March 1988 (Barwell and Parrett, 1987 and Parrett, 1988). They were shown to produce better quality control decisions for P_{msl} and V_{10m} than using the fixed climatological BGEs. These surface synoptic-dependent BGEs were calculated at each observation position within the quality control program (using regression equations based on observation-minus-background (o-b) statistics) and were not used by the assimilation, which continued to use climatological BGEs.

With the introduction of the Unified Forecast/Climate Model (UM) on 12th June 1991, the calculation of BGEs was changed to be carried out within a separate program, in which fields of errors are produced (Parrett, 1989). These BGE fields are interpolated to the observation positions in the observation pre-processing step (Dumelow, 1991) and they are now used in both the quality control and assimilation stages. The impact of using synoptic-dependent

BGEs for surface variables in the assimilation is discussed in section 2.3. The current status of synoptic-dependent BGEs for surface reports is detailed in section 2.1; and the situation with climatological BGEs for upper air observations is given in 2.2. Recent work to extend the synoptic dependence to include upper level temperatures and winds is detailed in section 3, with some preliminary results in section 4. Section 5 deals with the modification of BGEs near to 'bogus' observations produced by forecasters in the Central Forecast Office (CFO) and observations given 'supported' flags by CFO forecasters.

2. The present operational BGE fields

2.1 Synoptic-dependent BGEs for surface variables

At present, the production of synoptic-dependent BGEs for P_{msl} and V_{10m} for the Unified Model is carried out largely as detailed in Parrett (1989). The errors are calculated on the global model grid, with P_{msl} errors being a function of horizontal pressure gradient and pressure tendency (plus a constant term) and wind errors being a function of the background wind speed (plus a constant term). The latitudinally-varying coefficients that are used were obtained from Observation Processing Database (OPD) statistics for a year's worth of data from the previous (Cyber) operational model. [Now that sufficient OPD data is available for the UM, these coefficients have been re-calculated (see section 3).] The fields of errors on the model grid are then smoothed to produce 5° latitude by 5° longitude fields. At present this is done by averaging the values within each 5°x5° box (after first limiting them to a maximum value for each field) and adding one standard deviation of the values within each box [a second order filter (1-4-6-4-1) is then applied along constant-latitude rows polewards of 65°N/S]. This is followed by a first order filter (1-2-1) of the global fields in both north-south and east-west directions. There are various other smoothing options available within the program (see Appendix A) and these were tested on several cases before deciding which produced the best final error fields.

The BGEs need to be reasonably smooth, because within the quality control (Ingleby and Parrett, 1991) the o-b values compared in the buddy check are always normalised by the total error variance. If the BGE for one observation is much larger than for a neighbouring observation, and the o-b values are equal, the normalised o-b values are not equal and similar observations may disagree with each other. This would be an advantage if the BGEs were known accurately - an 8mb error at the centre of a depression might be associated with a 4mb error 100km away, and observations 9mb and 3mb from the background at the two locations would be judged as having similar normalised o-b values. However, our current methods of estimating the BGEs cannot be relied upon to position gradients in BGE that accurately, so it is better that the BGE varies smoothly; then the total error variance for the two observations being compared will be similar. Also, the Analysis Correction scheme used at the Meteorological Office (Bell et al, 1991) implicitly assumes that the BGE variance is smooth, since the increments from observation 1 are normalised by BGE_1 at all grid-points that it influences.

There is only one global operational dataset of BGEs and the synoptic-dependent BGEs are presently updated four times a day, following the QU00, QG06, QU12 and QG18 runs. [N.B. QGhh are global model runs starting from the analysis at hour hh, QUhh are global 'update' runs that include data received up to 11.5 hours after the analysis time and are used to produce the best possible background fields for the following QG06 and QG18 analyses, and QLhh are limited area model runs.] The limited area (LA) model runs use the same dataset of errors, and consequently some runs (QL03, QL06, QL09, QL15, QL18 and QL21) use errors valid at an earlier time. With the relatively low resolution of the error fields and the amount of smooothing applied to them, the values of BGE vary only slowly during the 3 to 9 hours that the runs are ahead, so this should have little impact. It is planned to examine the benefits of a separate dataset of BGEs for the LA model, using coefficients calculated from regression statistics derived from that model.

2.2 Climatological BGEs for the upper air

The BGE fields on pressure levels are based on the climatological values used by the Cyber model (Bell 1985), which have been interpolated or extrapolated from the previous 6 levels to the new 16 levels (1000, 850, 700, 500, 300, 200, 100, 50, 20, 10, 5, 2, 1, 0.5, 0.2 and 0.1mb). Following an OPD study in June 1990 (C D Hall, pers comm) the observation errors for temperature and wind reports were revised, and to approximately preserve the error ratios, the climatological BGEs were modified by similar amounts (temperature reduced by 20% globally at all levels and wind reduced by 10% above 150mb). Also, values at and above 20mb were suggested and supplied by R Swinbank (pers comm), following experience with stratospheric analysis experiments.

An error was discovered in the operational BGEs in August 1991, which had been affecting the climatological fields (i.e. all upper air BGEs) since the UM became operational on 12th June 1991 - it was corrected on 10th September 1991. Its effect was to displace the BGE fields northeastwards by 3.75 rows, leaving the values over Antarctica (south of 75^{o}S) set at zero, thereby causing all upper air reports from this region to be flagged - fortunately there were only a few reports (usually only one radiosonde) at any one reporting time.

The effect of the geographical displacement of the BGEs on the quality control decisions and the assimilation cannot be assessed properly without re-running all of the operational model runs for the 3 months concerned, which is not feasible. There were probably some quality control decisions that would have been different with the correctly positioned BGEs, and the assimilation of observations would also have been affected by local changes in the ratio of BGE to observation error ("error ratio"), which affects the weight given to each observation (Bell et al, 1991). The overall effect on the statistics produced by the quality control can be seen in Table 1, which compares statistics obtained from the period with misplaced or zero BGEs against those obtained from a period after they had been corrected. Table 1 shows that there was little difference in either the percentage of observations flagged or the BGE (standard deviation) for those observations passed by the quality control. However, the correlation between

Table 1. Global QC stats obtained from the 3 weeks 10^{th} to 30^{th} Sep compared with stats from the 2 weeks 26^{th} Aug to 9^{th} Sep 1991 when the clim BGEs were misplaced (in brackets). [T in °C, V in ms^{-1}, and wind component (u and v) values have been averaged.]

Data type	No. of reports	% flagged	BGE	RMS o-b	Correlation: BGE vs |o-b|
R/S Temp	14732 (8017)	1.8 (2.1)	1.3 (1.3)	1.5 (1.5)	0.19 (0.15)
R/S Wind	14732 (8017)	0.8 (0.6)	4.3 (4.5)	3.5 (3.4)	0.18 (0.12)
AIREP T	20809 (12703)	1.0 (1.3)	1.5 (1.3)	1.9 (1.8)	0.14 (0.17)
AIREP V	20809 (12703)	1.0 (1.0)	5.2 (5.1)	5.7 (5.5)	0.00 (0.06)
SATOB V	26134 (15999)	3.6 (4.1)	4.4 (4.4)	3.6 (3.5)	0.31 (0.23)
SATEM T	5871 (5961)	19.6(14.5	1.5 (1.8)	1.4 (1.4)	0.23 (0.24)

the BGEs and the o-b values was generally higher with the correct BGEs (except for AIREPs!). Some differences would be expected anyway, due to the different periods used for each set of statistics and the natural variability from day-to-day and week-to-week. This comparison suggests that the overall impact on the assimilations and forecasts was probably small.

2.3 Impact of the synoptic-dependent BGEs for P_{msl} and V_{10m} on the assimilation of data

Prior to the introduction of synoptic-dependent BGEs for P_{msl} and V_{10m}, a detailed case study was carried out to assess the impact of using these error fields within the assimilation, as well as the quality control. The case, chosen at random, was 28th February 1991, for which BGE files were set up for 3 successive data times (18Z, 00Z and 06Z), so that a 2-cycle (test) assimilation could be run using these errors with the same observations as used by the control pseudo-operational Cray runs which used climatological BGEs in the assimilations. Looking at the globe as a whole, the P_{msl} errors from the test runs were similar to those climatological values used operationally by the assimilation, although naturally there were local differences and generally the test run's BGEs were lower over the southern oceans. All of the noticeable analysis differences (oper-test) were attributable to different quality control decisions (due to differences between the smoothed BGE field values and those spot values calculated operationally at the observation positions), with no noticeable differences arising from the treatment within the assimilation.

For winds, the synoptic-dependent BGEs were generally lower than the climatological values. OPD statistics lend support to the lowering of wind BGEs. This would lead to an increase in the observation/background error ratio, which in turn would reduce the weight given to the observations in the assimilation. To avoid a re-tuning of the assimilation, it was decided to reduce the observation error for surface wind reports by about 20% (generally from $2.5ms^{-1}$ to $2.0ms^{-1}$). Most of the analysis differences in the wind were again as a result of different quality control decisions, rather than different treatment in the assimilation. Changes in the globally averaged error ratio were quite small. The resultant fit of the analyses to the observations at 0600 GMT is summarised in Table 2(a), which shows that the RMS o-a values for the test run are smaller everywhere for P_{msl} and outside of the tropics for wind.

Table 2(a). RMS observation-analysis (o-a) increments at t+0 for the test assimilation using synoptic-dependent BGEs for P and V_{10m} at 06Z 28/2/91, compared with operational values (in brackets) for 3 latitude bands. (Units are mb and ms^{-1}.)

Variable	90°N - 22°N	22°N - 22°S	22 S° - 90 S°
P_{msl}	1.19 (1.25)	1.26 (1.38)	1.46 (1.64)
V_{10m}	3.86 (3.92)	3.00 (2.95)	2.49 (2.89)

Another case study was run to see the impact of using synoptic-dependent BGEs for P_{msl} and V_{10m} on a 12 hour forecast, after assimilating 24 hours worth of observations. Data from 18Z 17th April to 12Z 18th April 1991 was quality controlled and assimilated using synoptic-dependent BGEs, and a 12 hour forecast was run. The resultant fit of the t+12 forecast fields to the observations of P_{msl} and V_{10m} are shown in Table 2(b), and compared to the fit of the operational t+12 forecast to the same set of observations. Overall, there is little difference in the fit, although for P_{msl} north of 22°N the fit of the test run is slightly better, while south of 22°N the fit is slightly

Table 2(b). RMS observation-forecast increments at t+12 for the test assimilation/forecast using synoptic-dependent BGEs for P_{msl} and V_{10m}, VT 00Z 19/4/91, compared with operational values (in brackets) for 3 latitude bands. (Units are mb and ms^{-1}.)

Variable	90°N - 22°N	22°N - 22°S	22 S°- 90 S°
P_{msl}	2.68 (2.71)	1.64 (1.62)	2.27 (2.24)
V_{10m}	5.29 (5.29)	3.92 (3.91)	5.58 (5.60)

worse. There were also small differences in the fit of the forecasts to radiosonde wind and temperature observations (not shown), with a slightly better fit of the test run to radiosonde winds at model levels 2-11 north of 22°N, and little difference elsewhere; whereas the fit to radiosonde temperatures was very slightly worse at low levels north of 22°N, but better elsewhere.

Following the results of these test runs, it was decided to include the calculation of synoptic-dependent BGEs for P_{msl} and V_{10m} in the Cray suite of programs, and this was done on 23rd April 1991.

3. Calculating BGE regression coefficients

3.1 The BGE regression equations

The following regression equations have been used to calculate the synoptic-dependent BGE variances (BGEVs) for pressure (P), temperature (T) and wind (V):

$$BGEV(P) = P_{c0} + P_{c1}|\nabla P|^2 + P_{c2}(\partial P/\partial t)^2 \quad (1),$$

$$BGEV(T) = T_{c0} + T_{c1}|\nabla T|^2 + T_{c2}(\partial T/\partial t)^2 \quad (2),$$

$$BGEV(V) = V_{c0} + V_{c1}|\underline{V}|^2 \quad (3),$$

where P_{c0}, P_{c1}, P_{c2}, T_{c0}, T_{c1}, T_{c2}, V_{c0} and V_{c1}, are latitude-dependent coefficients obtained from o-b statistics. Equations (1) and (3), using pressure tendency^2 and gradient^2 and wind speed^2 as predictors, are used operationally for the surface pressure and wind field errors and seem a reasonable starting point for similar calculations for upper level temperature and wind errors. Equation (1) was originally derived assuming Gaussian timing and location errors in the forecast model; whereas equation (3) is a simpler, more empirical, formula which has been shown to fit the data reasonably well (Barwell and Parrett, 1987).

3.2 The accumulation of statistics

With the Cyber model, the values of pressure gradient and tendency at the observation positions were calculated within the Ship Quality Control program (e.g. Parrett, 1989) and were stored in a separate (SHIPQC) OPD to enable them to be used (together with the o-b values) to update the regression coefficients for P_{msl}. In order to calculate the new synoptic-dependent BGE regression coefficients (in equations (1)-(3)), background gradient and tendency values are now required for upper level temperatures (as well as P_{msl}). They are not available from the new UM OPD, so separate statistics have been (and continue to be) accumulated for the purpose of obtaining the regression coefficients - see Appendix C for details.

Most of the observation data types used in the assimilation are included, except for satellite temperatures (SATEM, SAT120, LASS), which are excluded because of their high correlation with the background (i.e. SATEMs are often the only data source over large areas of the oceans, and LASS data use a background forecast in their retrieval). Rather than exclude all flagged data, it was decided to set cut-off values for the o-b values (6°C for temperature, 40ms^{-1} for wind (25ms^{-1} for V_{10m}) and 9mb for P_{msl}), beyond which the data is excluded from the archive. This is to reduce the bias towards small o-b values and include observations with large o-b values that may be correct, but need to be flagged so as not to produce noise in the analysis. It will inevitably allow some bad data into the statistics, but this should be reasonably random and be swamped by the good data. Observations with CFO or permanent reject flags set are not used.

3.3 Analysis of statistics

BGE coefficients have been obtained for P_{msl} and V_{10m} and for upper level temperature and wind at 6 levels (1000, 850, 500, 250 100 and 30mb), in regression analyses of the form

$$MSE(P) = P_{c0}' + P_{c1}|\nabla P|^2 + P_{c2}(\partial P/\partial t)^2 \quad (4),$$

$$MSE(T) = T_{c0}' + T_{c1}|\nabla T|^2 + T_{c2}(\partial T/\partial t)^2 \quad (5),$$

and $$MSE(V) = V_{c0}' + V_{c1}|\underline{V}|^2 \quad (6),$$ where MSE is the mean square error $\left(\overline{(o-b)^2}\right)$ for all obs and includes the observation error, (hence the prime (′) on the constant terms). In order to obtain coefficients for BGE rather then MSE, it was assumed that the observation error was constant for all observations at any particular level and for each variable - they were taken from the latest operational values. In addition to equation 6, regressions for the wind errors were carried out for the root mean square error (RMSE) as a function of wind speed:

$$RMSE(V) = V_{c0}' + V_{c1}|\underline{V}| \quad (7).$$

This gives less weight in the regression to strong wind speeds than equation 6 does. Equation 7 was found to explain more of the variance in the o-b values and is consequently used in preference to equation 6. Figure 1 shows two examples of |o-b vector wind| plotted against background wind speed, for radiosonde and airep data between 30°N and 50°N for the period 19th February to 30th March 1992. The observations have been grouped into 2.0 m/s ranges of background wind speed, and the plots show the medians (joined by a full line), the quartiles (boxes) and the ranges (extent of the vertical bars). The straight lines are the regression lines obtained from equation 7; they tend to be above the median because of the unrestricted range of the higher o-b values. The amount of the variance of the o-b values explained by the wind speed term in equation 7 is 0.20 for the data shown in Figure 1(a) and 0.17 for Figure 1(b); these compare with values of 0.12 and 0.15 using equation 6. For all of the 250mb data for this period, the proportion of the variance explained using equation equation 7 (6) ranges between 0.11 (0.07) and 0.42 (0.35) for each 20° latitude band and is 0.23 (0.16) globally.

Two sets of programs have been used to calculate the regression coefficients in equations (4) to (6): programs using a NAG (Numerical Algorithm Group) routine, and programs using SAS (Statistical Analysis Software Co.) software. The programs using the NAG routine first divide the observations into boxes with different gradient and tendency values (for P_{msl} and temperature) or different speed values (for wind). The numbers of observations in each box and the average box values are input into NAG routine G02CJE (see volume 6 of NAG, 1988), which then calculates the best fit of the data to the regression equation and also outputs a residual term. The smaller the residual term, the better the fit of the data to the regression equation (with the coefficients obtained); so this was used to "tune" the size and number of boxes used. For results discussed here, the box details were as follows: for temperature - 30 gradient intervals of 1.0^0C/1000km by 30 tendency intervals of 0.025 ^{0}C/hour (i.e. 30x30 = 900 boxes), and for wind - 30 speed intervals of 1.25 ms^{-1} (2.0 ms^{-1} for the 250mb level). [For more program details, see Appendix D.]

The SAS programs use routine REG (SAS, 1991) to calculate the regression coefficients, using all of the archived data (unless specifically omitted - eg a certain data type or data with final PGE > 0.996), rather than only the data fitting into the boxes for the NAG routine. The SAS programs also give more information on the amount of the variance of the o-b values explained by each of the regression variables (predictors). Consequently, the results presented here are based mainly on the coefficients obtained using the SAS programs, while the NAG programs were used to calculate the coefficients used in the preliminary runs shown below in section 4.2 and also as a check on some of the SAS results.

Figures 2-5 show the BGE coefficients obtained for 20^0 latitude bands, for data from QU00 and QU12 runs, taken from 3 or 4 periods spanning one year (April 1991 to March 1992). For the 4 pressure levels 850, 500, 250 and 100mb, coefficients were calculated for wind and temperature data from 4 periods (of between 6 and 10 weeks) and these were then averaged to produce the values shown. For P_{msl}, V_{10m} and 1000mb and 30mb V and T only 3 periods of data were available, and these were similarly averaged. There were differences in the coefficients obtained from the different periods of data, but no consistent seasonal trends were seen; so the average values shown in Figures 2-5 should be valid for the whole year, with the seasonal variation in the BGEs being accounted for by the synoptic dependence. The figures also include some smoothing/extrapolation, particularly for latitude bands with little data (e.g. low level temperatures near the South Pole), and, before the different periods were averaged, a few 'rogue' values (very different to the others) were removed. For high level temperatures (100mb and 30mb), a large bias was present in the mean o-b values and this was removed before calculating the coefficients, since we are estimating the variance of the model errors (i.e. not including model biases).

The observation errors used to obtain the constant terms are shown in Table 3. They are based on the operational radiosonde errors for pressure level wind and temperature, with a few exceptions. The temperature errors have been increased slightly at 250mb to reflect the larger errors assumed for Aireps (although runs with and without Aireps were little different, so the Airep temperature errors may be too high). Also, the assumed wind errors have been decreased from radiosonde values at 1000mb, 250mb and

Table 3. Assumed observation errors used in calculating the BGE coefficients shown in Figures 2-5.

(a) Errors for radiosonde and airep data -

Pressure (mb)	Temperature error (°C)	Wind component error (m/s)
30	1.0	2.1
100	0.8	1.8 (1.4 N of 50N)
250	1.2	3.0 (2.2 N of 50N)
500	0.8	2.1
850	1.0	1.8
1000	1.2	1.5

(b) Errors for surface data -

P_{msl} : 1.0mb.   10m wind component (marine data only): 2.0 m/s.

100mb, because the operational values were higher than the BGE constant terms and nearly as large as the RMS o-b values. At 1000mb the wind component error has been reduced from 2.0 ms^{-1} to 1.5 ms^{-1} everywhere, while the 250mb/100mb errors have been reduced from 3.2/2.1 ms^{-1} to 3.0/1.8 ms^{-1} generally and to 2.2/1.4 ms^{-1} north of 50°N - to account for a step reduction in the RMS o-b values around 45°N. This step reduction in RMS o-b may be due to the more common use of primary radar or NAVAID systems by North European countries (containing the most dense network of sonde stations in these latitudes), because these systems are more accurate than radiotheodolite or secondary radars which are used more generally world-wide (Hall, 1990). The reductions in assumed observation (obs) error approximately restore the ratio of obs error to BGE to those calculated theoretically by Hollingsworth and Lonnberg (1986) - i.e. BGE 25% larger than obs error at 250mb and 100mb, and obs error largest at 1000mb. The step change in RMS o-b values may also be accentuated by some southern European sonde stations being of poor quality (Hall, 1990). The assumed observation error for V_{10m} of 2.0 ms^{-1} (component) is that used for surface marine data, which is the only data that was used to give the results shown in Figure 4 [the inclusion of lowland synops (<150m) gave a smaller constant term (smaller than the obs error) and a larger speed term]. For the P_{msl} results shown in Figure 5, surface marine data and land synops below 300m were used - using all high level synops gave less consistent coefficients, which also explained less of the variance of o-b.

Most of the coefficients in Figures 2-5 are somewhat higher in the Southern Hemisphere, where there is less data and the short-period forecasts are consequently worse. The constant terms for temperature are generally largest at 1000mb due to local boundary layer effects, near the tropopause (250mb near the poles and 100mb in the tropics), where large errors are to be expected, and in the stratosphere at 30mb; in the troposphere they are smallest in the tropics. The constant term for P_{msl} (Figure 5(a)) is also smallest in the tropics. The temperature and pressure gradient and tendency terms (Figures 2(b), 2(c), 5(b) and 5(c)) are generally largest in the tropics, although the gradients themselves are smallest here. As expected, the constant term for the wind errors is highest at jetstream levels, except south of about 50°S; while the speed term is largest at low levels (especially towards the poles) and in the stratosphere. Most of the coefficients for the stratospheric levels (100mb and 30mb) show somewhat different characteristics (almost opposite for the temperature constant term) to those for the troposphere.

Initially, coefficients were obtained for wind BGEs with an additional dependence on the gradient of the background wind speed, i.e. $BGEV(V) = V_{c0} + V_{c1}|\underline{V}|^2 + V_{c2}(\nabla|\underline{V}|)^2$ (8).
The inclusion of the gradient term slightly reduced the residual and also the constant term (implying that some of the error was explained by the gradient term). Consequently, the gradient term was included in the calculation of BGEs for the preliminary runs described below in section 4.2. But, subsequently it was decided that the gradient term should be removed, since it accounted for only a small amount of the total wind variance, and further investigations should be carried out to find better predictors (e.g. vorticity, vorticity tendency, divergence, etc.). For the preliminary results shown below in section 4.2, the BGE coefficients for wind and temperature were calculated from only 4 levels (850, 500, 250 and 100mb) of data, being extrapolated above and below, from a period of 2 months (April-June 1991). However, the coefficients were not greatly different to those shown in Figures 2 and 3; indeed the values used to obtain them have been included in the overall averages shown in Figures 2 and 3. Also, the coefficients for P_{msl} and V_{10m} were those calculated from the previous (Cyber) model statistics, and used operationally since June 1991. The P_{msl} tendency coefficient has actually been wrong by a factor of 1/36 since June 1991, as can be seen in the very low operational values in Figure 5(c), and this was still the case for the results in section 4.2.

4. Preliminary results

4.1 An example of some synoptic-dependent BGEs

Several cases were looked at to check (subjectively) that the synoptic-dependent BGE fields for temperature and wind were reasonably realistic. At this stage it was discovered that a few "bullseyes" were being produced in the temperature error fields, due to isolated model grid-points having very large gradients (particularly at points where the orography is very steep, e.g. the edge of Antarctica and the Andes). To counteract this, maximum values of BGE (BGE_{max}) are now set for each variable, so that any model grid-points with BGEs greater than BGE_{max} are set equal to

BGE_{max}. The present values of BGE_{max} are 3^oC for temperature, $8ms^{-1}$ for wind, and 5mb for P_{msl}.

Figures 6 to 8 show some examples of synoptic-dependent BGE fields (a), the background fields from which they were obtained (b), and the climatological fields used operationally (c), with a validity time of 12GMT 14th May 1992. [For P_{msl}, Figure 6(c) shows the old climatological BGEs and 6(d) shows the current operational synoptic-dependent BGEs.] As expected, the synoptic-dependent BGEs (a), calculated using equations (1) and (2) and the equivalent of equation (7), are seen to be largest in regions of synoptic activity (e.g. near depressions and jetstreams) and near mountains, where errors in the short-period forecasts are expected to be largest. Whereas, the climatological BGEs (c) are largest in the pre-defined areas where on average (but not necessarily on this occasion) the Cyber model forecast errors were largest. The latitudinal dependence of the pressure and temperature coefficients can be seen most easily with the larger BGEs in the Southern Hemisphere extra-tropics, although the dependence is much less marked than for the climatological BGEs. This is indicative of the improvement in the UM in the southern hemisphere, compared to the Cyber model of the mid-1980s upon which the climatological BGEs were based. The synoptic-dependent BGEs for the 300mb wind are generally smaller than the climatological BGEs, except near to jetstreams. Figure 6(d) shows that the operational synoptic-dependent BGEs for P_{msl} have much less spatial variation than those produced with the new coefficients (Figure 6(a)), largely due to the error in the tendency term mentioned at the end of section 3.3. The BGEs are also considerably higher south of 30°S due to the much larger constant term here (see the dashed line in Figure 5(a)), reflecting the poorer performance of the Cyber model in this region.

4.2 A preliminary comparison of synoptic-dependent BGEs with climatological BGEs for temperature and wind - impact on quality control

The preliminary version of the BGE program mentioned at the end of section 3.3 (i.e. with coefficients based on 2 month's data for 4 levels, and including the wind gradient term) was run regularly for about a month to calculate synoptic-dependent BGEs from the 6-hour forecasts valid at 00GMT. These BGEs were then used by runs of the quality control programs (Ingleby and Parrett, 1991) to produce statistics from the QG00 runs for comparison with the operational QG00 quality control statistics (obtained using climatological BGEs). These statistics are shown in Table 4 (a-f) for each data type, for the period from 10^{th} September to 4^{th} October 1991. Table 4(a) shows that for radiosonde temperatures there is little difference between the globally-averaged values of synoptic-dependent and climatological BGEs; whereas for radiosonde winds (Table 4(b)) the synoptic-dependent BGEs are substantially lower generally, except at jet-stream levels. The numbers of radiosonde temperature observations flagged with the two sets of BGEs are similar, except between 200mb and 50mb where the number is halved with the synoptic-dependent BGEs, which is probably an improvement. There are more radiosonde wind observations flagged below 700mb and above 100mb with the synoptic-dependent BGEs, due to the lower threshold values in the quality control.

Table 4. Quality control statistics from QG00 runs using synoptic-dependent BGEs and climatological BGEs (in brackets), for the period from 10^{th} September to 4^{th} October 1991. [N.B. For wind, the errors are for each wind component.]

(a) Radiosonde temperatures (°C)

Press band:mb	No. obs pass QC	Percent flagged	RMS o-b	RMS ob error	RMS BGE	Correl. of BGE & |o-b
10- 30	11958	3.6 (3.5)	2.2	1.1	1.1 (1.5)	.01 (.11)
50- 70	9827	2.6 (4.6)	1.6	0.9	1.1 (1.0)	.05 (.03)
70-100	10493	3.5 (7.3)	1.5	0.8	1.2 (1.0)	.30 (.18)
100-200	26498	1.2 (2.3)	1.5	1.1	1.4 (1.4)	.20 (.15)
200-300	24318	0.7 (0.8)	1.5	1.1	1.4 (1.4)	.22 (.19)
300-400	20032	0.9 (0.9)	1.3	0.8	1.3 (1.3)	.23 (.16)
400-500	18964	0.7 (0.8)	1.2	0.8	1.2 (1.2)	.19 (.17)
500-700	31888	0.8 (0.9)	1.2	0.8	1.1 (1.1)	.18 (.15)
700-800	24376	0.8 (1.4)	1.4	0.8	1.3 (1.1)	.30 (.19)
850-900	21783	0.6 (0.8)	1.6	0.9	1.4 (1.4)	.29 (.24)
>950	11556	0.8 (1.2)	1.9	1.1	1.5 (1.7)	.23 (.11)

(b) Radiosonde winds (ms^{-1})

Press. band:mb	No. obs pass QC	Percent flagged	RMS o-b u	RMS o-b v	RMS ob error	RMS BGE	Correl. of BGE & |o-b|: u & v
10- 30	9833	1.1 (0.8)	3.1	2.5	2.2	2.6 (4.9)	.38 .31(.30 .12)
50- 70	9395	1.3 (0.9)	2.9	2.1	2.3	2.7 (5.0)	.30 .22(.23 .09)
70-100	10295	1.3 (0.9)	3.3	2.8	2.6	3.1 (4.6)	.37 .32(.27 .24)
100-200	27409	1.2 (1.2)	3.9	3.8	3.1	4.4 (4.6)	.24 .25(.25 .22)
200-300	25544	1.0 (1.1)	4.4	4.5	3.8	4.8 (4.8)	.17 .20(.07 .05)
300-400	21293	0.9 (1.0)	3.9	4.0	3.4	4.3 (4.6)	.19 .20(.05 .04)
400-500	20336	0.8 (0.9)	3.5	3.4	2.8	3.6 (3.9)	.23 .23(.09 .07)
500-700	34585	0.7 (0.7)	2.9	2.1	2.1	3.0 (3.6)	.20 .20(.15 .12)
700-850	26661	0.8 (0.5)	2.9	2.8	1.8	2.8 (4.0)	.19 .18(.18 .16)
850-950	20608	1.0 (0.6)	3.0	2.9	2.0	2.6 (4.0)	.19 .19(.17 .16)
>950	10076	0.8 (0.5)	2.8	2.9	2.1	2.5 (3.9)	.21 .23(.12 .13)

(c) Airep temperatures (°C)

Press. band:mb	No. obs pass QC	Percent flagged	RMS o-b	RMS ob error	RMS BGE	Correl. of BGE & |o-b
100-200	2210	0.9 (1.0)	1.8	1.7	1.5 (1.6)	.18 (.08)
200-300	19090	0.7 (0.8)	1.8	1.7	1.4 (1.5)	.23 (.18)
300-400	1616	0.9 (1.3)	2.2	1.7	1.3 (1.3)	.25 (.13)

(d) Airep winds (ms^{-1})

Press. band:mb	No. obs pass QC	Percent flagged	RMS o-b u	RMS o-b v	RMS ob error	RMS BGE	Correl. of BGE & |o-b|: u & v
100-200	2161	0.6 (0.6)	5.4	5.4	4.0	5.1 (5.2)	.08 .15(.04 .05)
200-300	18367	1.0 (1.0)	5.6	5.9	4.0	5.0 (5.3)	.15 .21(-.01 -.05)
300-400	1613	0.6 (1.3)	5.7	5.9	4.0	4.8 (5.1)	.21 .20(.00 -.04)

(e) Satob winds (ms^{-1})

Press. band:mb	No. obs pass QC	Percent flagged	RMS o-b u v	RMS ob error	RMS BGE	Correl. of BGE & |o-b|: u & v
100-200	2742	9.7 (8.0)	5.1 5.5	5.0	4.2 (5.4)	.02 .11(.07 .03)
200-300	3362	9.8 (8.9)	5.4 5.4	4.9	5.0 (5.3)	.18 .14(.06 .02)
300-400	1772	5.3 (4.4)	4.8 5.0	4.3	5.2 (5.0)	.11 .19(.06 .10)
400-500	1418	3.8 (3.1)	4.1 3.7	3.0	4.0 (4.1)	.21 .19(.11 .10)
500-700	1115	3.1 (2.5)	3.5 3.3	2.0	3.5 (4.0)	.29 .12(.10 .05)
700-850	11221	1.0 (0.5)	2.4 2.5	1.8	2.7 (4.2)	.18 .18(.03 .05)
850-950	7861	5.0 (3.6)	2.4 2.4	1.8	2.3 (3.9)	.16 .17(.16 .13)

(f) Satem temperatures (°C)

Press. band:mb	No. obs pass QC	Percent flagged	RMS o-b	RMS ob error	RMS BGE	Correl. of BGE & |o-b
7- 10	3432	36.1(39.9)	1.9	1.5	1.6 (2.5)	.21 (-.26)
10- 30	7011	4.6 (4.4)	1.4	1.5	1.3 (1.6)	.32 (.07)
30- 50	7265	1.6 (1.5)	1.2	1.5	1.3 (1.2)	.20 (.20)
50- 70	7304	0.7 (0.7)	1.2	1.5	1.3 (1.2)	.16 (.09)
70-100	7287	0.9 (1.2)	1.3	1.5	1.3 (1.1)	.18 (.02)
100-200	5175	29.6(27.7)	1.2	1.7	1.4 (1.4)	.26 (.22)
200-300	5181	29.5(27.7)	1.4	1.6	1.5 (1.7)	.29 (.24)
300-400	5178	29.6(27.7)	1.3	1.4	1.5 (1.6)	.28 (.26)
400-500	5176	29.6(27.7)	1.4	1.3	1.4 (1.6)	.31 (.28)
500-700	5169	29.7(27.8)	1.3	1.3	1.3 (1.5)	.36 (.32)
700-850	5096	30.7(29.0)	1.5	1.4	1.4 (1.5)	.28 (.28)
850-1000	1783	27.8(20.5)	1.7	1.8	1.8 (2.7)	.22 (.19)

Tables 4(c) and 4(d) show that for the majority of both AIREP temperatures and winds the synoptic-dependent BGEs (globally) are very slightly smaller and the percentages flagged are slightly lower. The synoptic-dependent BGEs for SATOB winds (Table 4(e)) are substantially lower at low levels, resulting in a doubling of the percentage flagged (although still only 1%, which seems reasonable). For SATEMs (Table 4(f)), the synoptic-dependent BGEs are generally slightly lower in the troposphere, resulting in more observations being flagged; and the converse is true for most of the stratosphere. [N.B. The high percentage flagged below 100mb is due to the vertical stability check in the quality control (Ingleby and Parrett, 1991), and above 10mb there were problems with the model background.]

An important result from these parallel runs is that the correlation between the BGEs and the modulus of the o-b values (the final column in Table 4) is higher for the synoptic-dependent BGEs for all data types at nearly all levels. This indicates that, overall, the synoptic-dependent BGEs have a better (more realistic) pattern than the climatological BGEs, because the former tend to be large where the background is furthest from the observations and vice versa. The correlation varies between levels, with the highest correlation between |o-b| T and BGE(T) generally being in the lower troposphere and little correlation in the higher stratosphere for radiosondes. The BGE coefficients used in the stratosphere for these runs were based on data for 100mb only - the coefficients calculated from data for the 30mb level should help to improve matters in the higher stratosphere. For winds, the improvement in the correlation for the synoptic-dependent BGEs is most marked for AIREPs (-0.03 => 0.18 for the bulk of obs between 200 and 300mb) and for radiosondes between 200 and 500mb (0.06 => 0.20); it is also substantially improved for SATOBs at most levels.

5. The effect of intervention on BGE fields

Where a background forecast is very poor, the BGEs will tend to be too small, which can lead to good observations being flagged by the quality control. To combat this, forecasters doing intervention in the CFO can set a 'supported' flag on good observations that seem likely to be rejected. This flag is used within the quality control step to decrease the initial Probability of Gross Error (PGE) for that observation (multiplying it by 0.2) and increase (double) the BGE. (Similar action is taken for 'bogus' observations inserted by the forecasters.) At the moment, the BGEs are only increased for individual observations and only for the background check - buddy checking observations with significantly different BGEs can cause problems (see section 2.1). In the future it is planned to modify the fields of BGEs (see below) by increasing the values around such observations in a smooth way. The increased BGEs will then be used in the background check, buddy check and assimilation (giving more weight to all observations in these areas).

A program has recently been written to increase the BGEs in the region of both CFO bogus observations and supportive flags (see Appendix E for details). This program will access the intervention files on the front-end computer, after CFO have finished their intervention for each run, and then modify the BGEs before the observations are extracted for processing for the next run. The BGEs will be increased at the observation position by a factor (up to 2.0 for each observation), and this increase will be spread to the surrounding 4 grid-points by bi-linear interpolation. Where there are many bogus or supported observations the BGEs may be increased by a larger amount (up to a maximum value - presently 3.0). These increases to the BGEs (in a 'factor' array) will then be smoothed in the horizontal by a simple first or second order filter applied in both E-W and N-S directions, and then spread in the vertical (for the pressure level variables) by adding a fraction of the increase to the level above and the level below (presently the fractions are 1/2 for T and 1/4 for wind and RH).

Figure 9 shows an example where the BGE modification program has been used to modify the synoptic-dependent BGEs for the case discussed in section 4.1. Comparing Figure 9(a) with Figure 6(a), the P_{msl} BGE has been increased to the west of the UK (from about 1.8mb to 3.3mb) where there were 5 groups of 3-5 bogus observations inserted by CFO around and ahead of a depression; it has also been increased in the southern oceans, where 7 bogus obs were inserted south of Madagascar, 5 near Antarctica (about 10^{o}E) and 3 south of Tasmania, and also in the western North Pacific (only 3 supported obs here). The BGE for the 300mb wind has also been increased just west of the UK in a strong southerly jet, from about 4.3 m/s to about 6.0 m/s (comparing Figure 9(b) with Figure 7(a)), where 13 upper air bogus winds were inserted by CFO between 500 and 200mb, and one airep was supported; a total of 28 other aireps were supported in the jetstreams across the N Pacific and N Atlantic, but the next largest increase in BGE is in the jetstream over S America as a result of CFO inserting 9 bogus observations and supporting 7 aireps. The only (small) increase in the 850mb temperature errors (Figure 9(c) cf Figure 8(a)) is associated with one bogus temperature observation, inserted in the Bay of Biscay on the forward edge of a cold trough.

6. Conclusions and future work

This study shows that the use of synoptic-dependent background errors (BGEs) for the quality control and assimilation of observations leads to improvements when compared with the use of climatological BGEs. There was an improvement in the fit of an analysis to the observations for P_{msl} and V_{10m} after two cycles of assimilation; and an improvement in the fit of a 12-hour forecast (following 3 cycles of assimilation using synoptic-dependent BGEs) to P_{msl} observations in the northern hemisphere extra-tropics. Consequently, synoptic-dependence for P_{msl} and V_{10m} was included in the assimilation for the UM in April 1991. Synoptic-dependence for upper level temperatures and winds leads to a higher correlation between the estimated BGEs and the absolute values of the o-b differences, for all observation types. This implies that in areas of synoptic activity, where the BGEs are large, observations with large differences from the background are less likely to be flagged and will be given greater weight in the analysis, which should produce a better analysis and consequently a better forecast. Although we also need to get the average BGE values correct. The upper level synoptic-dependent BGEs, using the latest coefficients calculated using data from the first year of operational use of the Unified Model, are now undergoing tests in an assimilation/forecast experiment. As a result of these tests, the BGE coefficients may require some 'tuning'; also, the values of some observation errors may need revising, and the assimilation may require some tuning. Once this has been done, the synoptic-dependent BGEs will be ready to be included in an operational trial.

Where an individual background forecast is very poor, the BGEs will be too small, which can lead to good observations being flagged by the quality control. To overcome this, intervention forecasters in the CFO can set a 'supported' flag on good observations that seem likely to be rejected. The quality control then reduces the initial PGE for these observations and increases the BGE. (CFO 'bogus' observations are treated the same.) Currently, the increase in BGE is only for these observations and only for the background check. In future it is planned to increase the BGE field values around such observations and use these BGEs in the background check, buddy check and assimilation. This will lead to fewer observations being flagged in these areas and more weight being given to the observations. The program to increase the BGEs is also ready to be included in an operational trial and it seems reasonable to include it in a trial of the upper level synoptic-dependent BGEs.

Looking beyond the trial and operational implementation, future work includes investigating the dependence of the BGEs on the local data density of previous analyses. The error in the background forecast in a certain area is naturally related to the amount (and quality) of data from the surrounding area that has gone into previous analyses (upon which the forecast was based). The data density (or weight) in the analysis is related to the BGE variance. An extra data density term in the equations for the BGEs will allow more geographical variation in the BGEs and may account for much of the latitudinal change in the present coefficients. But, before it can be included, statistics on data density now being accumulated need to be analysed, to confirm the relationship between the data density and the o-b values, and to produce new regression coefficients for all variables. Any dependence of the wind errors on the time tendency of vorticity or wind speed will also be investigated.

Acknowledgements

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References

Barwell, B R and Parrett, C A, 1987: Modifications to the automatic quality control of ship data and an assessment using case studies. *Met O 11 Technical Note No. 261.*

Bell, R S (Editor), 1985: The data assimilation scheme. *Operational Numerical Weather Prediction System Documentation Paper No. 3.*

Bell, R S, Lorenc, A C, Macpherson, B and Swinbank, R 1991: The Analysis Correction Data Assimilation Scheme. *Unified Model Documentation Paper No. 30 (vn 1).*

Dumelow, R K, 1991: Observation Processing for the Atmospheric Model. *Unified Model Documentation Paper No. 31 (vn 1)*

Hall, C D, 1990: The use of an operational data assimilation system to infer the quality of wind observations from radiosondes. *Forecasting Products Monitoring Note 4.*

Hollingsworth, A and Lonnberg, P, 1986: The statistical structure of short-range forecast errors as determined from radiosonde data. Part I: The wind field. *Tellus 38A (1986), 2.*

Ingleby, N B and Parrett, C A, 1991: Quality Control of Atmospheric Data. *Unified Model Documentation Paper No. 32 (vn 1).*

NAG, 1988: *The NAG (Numerical Algorithms Group Ltd) Fortran Library Manual - Mark 13.*

Parrett, C A, 1988: The automatic quality control of surface observations from ships: the final trial, latest statistics, operational implementation and future work. *Met O 11 Technical Note No. 10.*

Parrett, C A, 1989: New Background Error Fields. *Met O 11 Working Paper No. 117.*

SAS Institute Inc., 1990: *SAS/STAT Users Guide (vn 6).*

Appendix A - The BGERR program

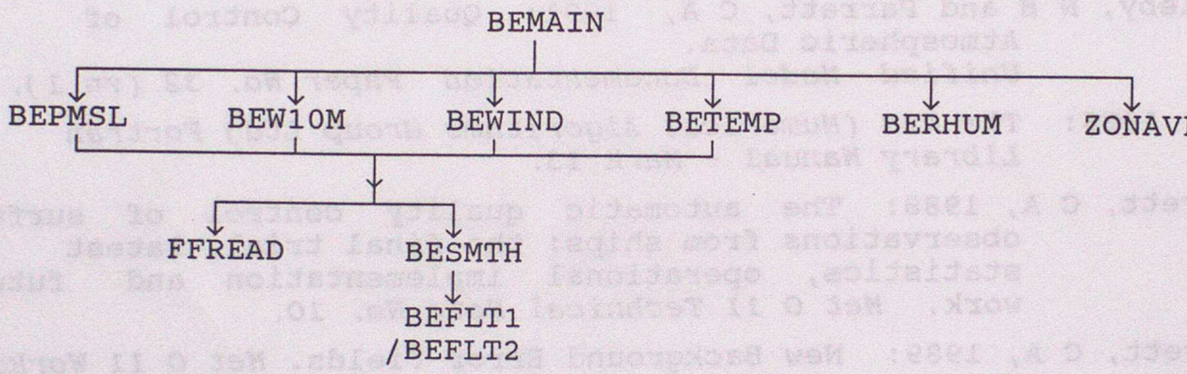
This appendix contains details about the program that calculates synoptic-dependent BGEs (called "BGERR").

A.1 Program design and structure

Program BGERR is written in standard Fortran, conforming to UM standards for meteorological routines (Unified Model Documentation Paper (UMDP) 4). At present it runs only on the Cray, using BUFFER IN and BUFFER OUT for IO, although it could be adapted to run on the front-end computer. A front-end pre-processing step (job in member PREBE of library MS12.EEBGE.FORT) includes the necessary modules (including some from the UM Fortran library).

There are separate subroutines that calculate the BGEs for each of the variables P_{msl}, V_{10m} and V, T and RH on pressure levels; and these routines (except the one for RH) call a smoothing routine, which can apply various (different) smoothing options (see Figure A1). The program modules are stored in the front-end library MS12.EEBGE.FORT, with member names being the same as the subroutine names.

Figure A1. BGERR program structure.



A.1.1 BEMAIN (main calling program)

Initialise control variables.
Read namelist input (from unit 50).
Open background fields-file (unit 10) and BGE files (unit 20 for input and unit 30 for output).
Read in and write out BGE file header and field headers (lookup table).
Read in fields-file header and lookup table, and extract information about fields.
Loop over surface variables (S) and then pressure-level variables (L), and either

(a) if L_UPDAT?=T (where ? = L or S), call the subroutine for each variable to calculate the field of synoptic-dependent BGEs (see 1.2 below);
or (b) if L_UPDAT?=F, read in existing ("old") BGE field.

Write out the BGE fields to the output BGE file.
Write out the updated BGE lookup table.
End.

A.1.2 BEPMSL, BEW10M, BEWIND, BETEMP (routines to calculate BGEs)
Set up BGE field header (modify default as necessary).
Read in required background fields (extract validity time for BGE field) and data density fields (when included).
Convert units where necessary.
Calculate fields of gradient/tendency squared and wind speed.
Calculate fields of synoptic-dependent BGE variance on the global model grid, using equation (1), (2) or (3). Constrained to be less than BGE_?_MAX, where ? is either PS, VS, V or T.
Call subroutine BESMTH.
Return to BEMAIN.

A.1.3 BERHUM
Assign a constant value of BGE to whole relative humidity field, dependent on pressure level.

A.1.4 BESMTH (smoothing routine)
Smooth (or filter) the synoptic-dependent BGE variance fields on the model grid (see below for options), and put them onto a reduced resolution grid (only set up for $5^o x 5^o$ latitude-longitude grid at present).
Convert BGE variances to standard deviations.
Return.
The type of smoothing is defined by the value of namelist variable ISMUTH_?? (where ?? = PS, VS, V or T) :

0	- None, take the nearest model grid-point value.
2,3,4,5,6	- Grid-box mean + 0, .5, 1, 1.5 or 2, respectively, standard deviations of values within grid-box.
8	- Grid-box maximum.
10	- 2nd order filter (BEFLT2) on input grid + take nearest grid-point.
12	- 2nd order filter on input grid + take grid-box mean.
22,23,24,25,26	- As 2,3,4,5,6 + 1st order filter on output grid.
32,33,34,35,36	- As 2,3,4,5,6 + 2nd order filter on output grid.

(The default value of ISMUTH_?? is 24.)

A.1.5 BEFLT1 and BEFLT2
Apply either a first order filter (1-2-1 : BEFLT1) or a second order filter (1-4-6-4-1 : BEFLT2) to a row (or column) of values.

A.1.6 FFREAD
UM subroutine to read in a field from a fields-file set up with the format specified in UMDP F3.

A.1.7 ZONAVE
Calculate and print out zonal (row) mean values of BGE and an area-weighted global mean value (only called if L_ZON_AVE = T).

A.2 Specification of constants (operational defaults in brackets)

A.2.1 Set in PARAMETER and DATA statements

NVARS (4)	Number of surface variables catered for.
NVARL (3)	Number of pressure-level variables.
NLEV (16)	Number of pressure levels.
MAX_NLEV (40)	Maximum number of pressure levels.

MAX_NPTS_FF (99840)	Maximum size of background fields.	
MAX_NPTS_BE (9728)	Maximum size of BGE fields.	
IUNIT_PRT (6)	Unit number for printed messages.	
IUNIT_FF (10)	Unit number for background fields-file.	
IUNIT_BE_IN (20)	Unit number for input BGE file.	
IUNIT_BE_OUT (30)	Unit number for output BGE file.	
IPLEV(MAX_NLEV)	Pressure levels (in mb)	For FFREAD, specified in DATA statements:
IVARL(NVARL)	Pressure-level variable type	
IVARS(2,NVARS)	Sfc variable type + level code	

IPLEV (1000, 850, 700, 500, 300, 200, 100, 50, 20, 10, 5, 2, 1, -5, -2, -1, 24*0)

[-5, -2 and -1 correspond to 0.5mb, 0.2mb and 0.1mb.]

IVARL (5, 3, 8)	Wind (u-component), temperature and relative humidity.
IVARS (12, 8888,	Pmsl
75, 9999,	10m wind (u-component)
58, 9999,	1.5m temperature
8, 9999)	1.5m RH

A.2.2 Namelist options (NAMLBE)

L_GLOB (T)	Global model resolution (LA model not catered for yet).
L_UPDATS(NVARS) (T,T,F,F)	Calculate surface synoptic-dependent BGEs (=T) or copy existing BGEs (=F).
L_UPDATL(NVARS) (F,F,T)	As above for pressure-level V and T, but for RH just set constant values.
L_DIAG (F)	Print detailed diagnostics.
L_ZON_AVE (T)	Print zonal average BGEs for each row.
IFCTIM (6)	Length (hours) of background forecast to be used.
IPROJ_FF (800)	Projection number of fields-file (for FFREAD).
IPROJ_BE (804)	Projection number of BGE file (for FFREAD).
ISMUTH_PS (24)	Smoothing to be applied to BGE fields (see 1.4 above).
ISMUTH_VS (24)	
ISMUTH_V(MAX_NLEV) (24)	
ISMUTH_T(MAX_NLEV) (24)	
BGE_PS_MAX (25.0(mb)^2)	Maximum values of BGE variance for P_{msl}, V_{10m}, V and T.
BGE_VS_MAX (49.0(m/s)^2)	
BGE_V_MAX(MAX_NLEV) (64.0(m/s)^2)	
BGE_T_MAX(MAX_NLEV) (9.0(^{0}C)^2)	

Appendix B - Format of the BGE file

The BGE file format is basically the same as the format of atmospheric fields-files described in Unified Model Documentation Paper (UMDP) F3, and this allows the use of the fields-file access routines (FFREAD, FIELDCOS, etc.). The BGE file header consists of the fixed-length header, integer constants, real constants and level-dependent constants arrays, followed by the lookup table.

B.1 Fixed-length header (256)

[Words not specified are set to missing data indicator (-32768).]

1 File format version (=13)
2 Atmospheric file (=1)
3 Vertical coordinate - pressure (=3)
4 Horizontal grid type - global (=0)
5 Indicator for BGE file (=13)
8 Type of calender - Gregorian (=1)
9 Grid staggering - none (=1)
11 Projection number (=804)
21-27 Validity time of BGE fields (yr/mon/day/hr/min/sec/day no)
28-41 Other date/times (=0)
100 Start of integer constants (=257)
101 Length of integer constants (=15)
105 Start of real constants (=272)
106 Length of real constants (=6)
110 Start of level-dependent constants (=278)
111 Length of first dimension of level-dep constants array (=40)
112 Length of second dimension of level-dep constants array (=1)
150 Start of lookup table (=513)
151 Length of first dimension of lookup table (=64)
152 Length of second dimension of lookup table (=4096)
160 Start of data (=262657)
161 Length of data (=132096)

B.2 Integer constants (15)

3 Number of validity times of BGEs (=1)
6 Number of E-W grid-points (=72)
7 Number of N-S grid-points (=37)
8 Number of pressure levels (=16)
15 Number of different field types (=7: 4 sfc + 3 P-level)

B.3 Real constants (6)

1 E-W grid-spacing (=5.0°)
2 N-S grid-spacing (=5.0°)
3 Latitude of first row (=90.0°)
4 Longitude of first point in row (=0.0°)
5 Latitude of pseudo N Pole (=90.0°)
6 Longitude of pseudo N Pole (=0.0°)

B.4 Level-dependent constants (40,1) [the 16 pressure levels (mb)]

1	1000.0
2	850.0
3	700.0
4	500.0
5	300.0
6	200.0
7	100.0
8	50.0
9	20.0
10	10.0
11	5.0
12	2.0
13	1.0
14	0.5
15	0.2
16	0.1
17-40	-32768.0

B.5 Lookup table or PP headers (64,4096)

The lookup table is the same as for atmospheric fields-files and is not duplicated here, except for the following words:

1-6	Validity time - taken from T+IFCTIM background fields used
7-12	Data time - taken from T+0 fields used
13	Time indicator (LBTIM = 11)
14	Forecast period (LBFT = IFCTIM (=6))
15	Length of data record (LBLREC = 2664)
16	Grid type code (LBCODE = 1)
17	Hemisphere indicator (LBHEM = 0)
18	Number of rows (LBROW = 37)
19	Number of points per row (LBNPT = 72)
20	Length of extra data (LBEXT = 0)
21	Packing method (LBPACK = 0 : not packed)
22	Header release number (LBREL = 2)
25	Processing code (LBPROC = 49 for P_{msl} - see below)
31	CF projection number (LBPROJ = 804)
45	Smoothing applied to BGE field (= 24 : see Appendix A)

LBPROC: synoptic dependence used to calculate the BGEs (numbers added together) -

0	no synoptic dependence
1	latitudinal coefficients used
2	longitudinal coeffs used
4	absolute value of the variable defined by LBFC
8	$(\text{variable})^2$
16	$(\text{gradient of variable})^2$
32	$(\text{tendency of variable})^2$
64	wind speed
128	divergence of wind
256	vorticity of wind
512	data-density
1024	...

Appendix C - The BGE statistics archive

This appendix contains details of the programs used to collect statistical data for use in calculating the regression coefficients used in program BGERR. It also contains the format of the archived data.

Three jobs were set up to extract the required information (gradient, tendency, etc.) from operational fields-files on a regular basis (in real time) and add it to the OPD information. The first job runs on the front-end computer and extracts all the necessary information for each observation (i.e. position, o-b, etc) from the operational OPD. It writes this information to a separate dataset for each of 6 pressure levels (1000, 850, 500, 250, 100 and 30mb) and the surface. The upper air obs are also grouped into 6 pressure bands, centred on the 6 pressure levels, to increase data volumes at each level. A Cray job then takes these front-end datasets across to the Cray and adds the information extracted from the operational fields-file; the gradients, etc for each pressure level being assigned to all obs grouped within that pressure band. The data is then written back to front-end datasets. Finally, other front-end jobs archive the data, firstly to disk and then (when these datasets are full) to cartridge.

The above jobs have been (and are currently being) run semi-automatically to extract data daily from the QU00 and QU12 runs. The archived data, when sufficient has been collected, is then used by other front-end jobs to calculate the regression coefficients for each variable and level (using the programs detailed in Appendix D).

C.1 Front-end job [Fortran code in MS12.EECRAY.FORT(BESTA1)]

C.1.1 Sort step

Sort out airep, model level radiosonde, satob and surface observation records from the operational OPD (COP.OPD.QU00/12), using SYNCSORT software.

C.1.2 Program BESTA1 (to construct reduced OPD records)

```
Initialise variables.
Open (temporary) output files and write headers.
Open OPD file.
Loop over OPD records:
   Set each data record to RMDI (= -32768.0)
   Read in each OPD record
   Loop over levels in OPD record:
      If obs P within one of the 6 P-bands, extract required
      information and construct reduced data record.
Write reduced data records to a separate file for each P-level.
End.
```

C.2 Cray program [Fortran code in MS12.EECRAY.FORT(BESTA2)]

C.2.1 Program BESTA2 (to add fields-file info to data records)

Initialisations.
Open fields-file.
Loop over P-level datasets of reduced data records (on front-end):
  Open dataset
  Read in header and convert to Cray numbers
  Loop over variables present (P and V , or V and T):
    Read in background field(s) and data density fields (using FFREAD)
    Read in data records and convert to Cray numbers (and check date/time of 1st record vs field-file's)
    Loop over data records:
      Call subroutine BEINTP: obtain field values at the observation position (including data-density)
      Call subr BEGRAD: calculate gradient of field at obs postn
      Calculate tendency of field at obs position
      Call subr BEDIVO: calculate divergence and vorticity of field at obs position
      Add above information to data record.
  Convert Cray numbers to IBM numbers + write out obs records.
  Close dataset.
End.

C.2.2 Subroutine BEINTP

Interpolate field values on a grid to an observation position within the grid-box formed by the 4 surrounding grid-points, using bi-linear interpolation.

C.2.3 Subroutine BEGRAD

Calculate the gradient of a field for an observation within a grid-box:
  Find the 4 surrounding grid-points.
  Calculate latitude and longitude intervals in terms of distance.
  Calculate the absolute value of the gradient within the grid-box.
  Return to BESTA2.

C.2.4 Subroutine BEDIVO

Calculate the divergence and vorticity from U and V fields within a grid-box:
  Find the 4 surrounding grid-points.
  Calculate lat/long intervals in terms of distance.
  Calculate divergence and vorticity.
  Return to BESTA2.

C.3 Location of jobs, etc.

The two jobs are run semi-automatically and are kept on library MS12.EECRAY.JOBS: members BEST100 and BEST112 (front-end, for QU00 and QU12 runs), and members BEST200 and BEST212 (Cray, for QU00 and QU12).

If both the front-end program and the Cray program complete successfully, the Cray job (BEST200/12) also adds the statistics in the temporary output files to disk archive datasets (and once these are full (about every 10 days) they are archived to cartridge, using job BEARCST on MS12.EE.CNTL).

C.4 Format of the BGE statistics archive

The reduced OPD data records, with the fields-file information added, are stored as real numbers to avoid the complexity of having to do conversions anywhere. The pressure-level data records are 18 words long and contain information on temperature and wind. The surface data records are 24 words long and contain information on P_{msl}, V_{10m} and $T_{1.5m}$. There is a 4-word integer header at the beginning of each file.

C.4.1 Integer header

Word	Contents
1	Length of this header [=4]
2	Length of each data record [=18 for P-level, =24 for sfc]
3	Type of archive [=1 for T and V on P-levels, and =2 for surface P, V and T]
4	Pressure level (mb) [=0 for surface dataset]

C.4.2 Data records

Word		Contents
1		Latitude (whole degrees)
2		Longitude " "
3		Pressure (mb) [station height for surface file (m)]
4		Date/time in the form MMddhhmm i.e. month*10^6 + day*10^4 + hour*10^2 + minute
5		Model observation type (+ 100*(ob no) when set in OPD)
	Pressure-level files:	
6	T data:	observed value (°C)
7		o-b value (°C)
8		PGE2*10^4 + PGE3 (%)
9		∇T (°C/km)
10		$\partial T/\partial t$ (°C/hour)
11		D(T) (data-density)
12	V data:	observed wind speed (m/s)
13		o-b $\underline{V}$ (m/s)
14		background wind speed (m/s)
15		PGE2*10^4 + PGE3 (%)
16		divergence: $\partial u/\partial x + \partial v/\partial y$ (1000 s^{-1})
17		vorticity: $\partial v/\partial x - \partial u/\partial y$ (1000 s^{-1})
18		D(V) (data-density)

Surface file:

6	P data:	observed value (mb)
7		o-b value (mb)
8		$PGE2*10^4$ + PGE3 (%)
9		∇P (mb/km)
10		$\partial P/\partial t$ (mb/hour)
11		D(P) (data-density)
12	V data:	observed wind speed (m/s)
13		o-b $\underline{V}$ (m/s)
14		background wind speed (m/s)
15		$PGE2*10^4$ + PGE3 (%)
16		divergence: $\partial u/\partial x + \partial v/\partial y$ ($1000\ s^{-1}$)
17		vorticity: $\partial v/\partial x - \partial u/\partial y$ ($1000\ s^{-1}$)
18		D(V) (data-density)
19	T data:	observed value (°C)
20		o-b value (°C)
21		$PGE2*10^4$ + PGE3 (%)
22		∇T (°C/km)
23		$\partial T/\partial t$ (°C/hour)
24		D(T) (data-density)

Appendix D - Calculation of BGE regression coefficients

The data contained in the statistics archive, detailed above in Appendix C, has been analysed to produce coefficients for regression equations using two different sets of programs. The programs described in sub-section D.1 below were used to produce the coefficients used in the preliminary runs of section 4.2; while the SAS programs (sub-section 2 below) have been used to produce the final coefficients shown in Figures 2-5. The SAS programs can also be more easily modified to include extra terms.

D.1 Programs BECOEFP, BECOEFUS, BECOEFU and BECOEFT (on MS12.EECRAY.FORT)

```
Initialisations, including setting box sizes (for grouping obs)
Loop over archive datasets for one pressure level (or for the
surface):
  Read header
  Loop over each observation record:
    Assign observation to a box and store obs information
    Find latitude band.
Loop over latitude bands:
  Loop over observations and accumulate sums-of-squares, etc.
  Loop over boxes:
    Loop over all observations in each box:
      Set up input data for regression routine.
  Call G02CJE (NAG routine to calculate regression coeffs).
Print details of regression analysis.
End.
```

D.2 Programs SASBEP, SASBEVS, SASBEV and SASBET (on MS12.EE.CNTL)

```
Read in data for 1 pressure level (or surface) and 1 variable.
Sort into latitude bands.
Call SAS routine REG to calculate and print regression
coefficients and 'standardised estimates' (the amount of the
variance of o-b values explained by each regressor).
End.
```

Appendix E - The BGEMOD program

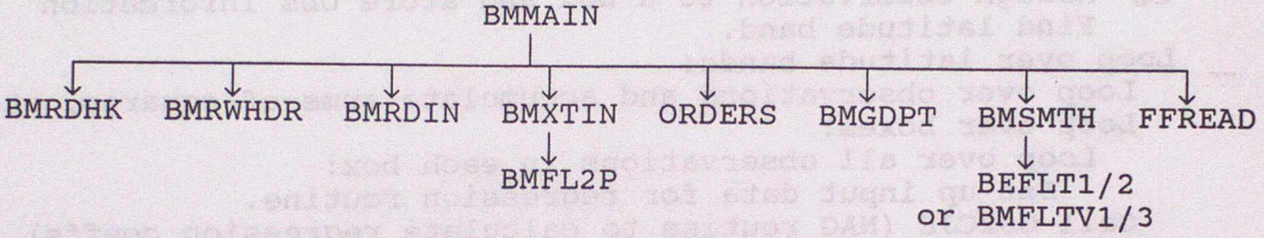
This appendix contains details about the program that increases the synoptic-dependent BGEs near to CFO Bogus and supported observations (called "BGEMOD").

A.1 Program design and structure

Program BGEMOD is written in standard Fortran, conforming to UM standards for meteorological routines (UMDP 4). As with the BGERR program, at present it runs only on the Cray, using BUFFER IN and BUFFER OUT for IO, although it could be adapted to run on the front-end computer. A front-end pre-processing job (member PREBM of library MS12.EEBGE.FORT) includes the necessary modules (including some from the UM Fortran library).

The program modules are stored in the front-end library MS12.EEBGE.FORT, with member names being the same as the subroutine names.

Figure E1. BGEMOD program structure.



E.1.1 BMMAIN (main calling program)

Initialisations.
Read namelist input (from unit 50).
Open BGE files: unit 20 (input) and unit 30 (output).
Call BMRDHK: read housekeeping file (unit 15).
Call BMRWHDR: read in and write out BGE file header and field headers (lookup table).
Call BMRDIN: read in intervention files (from units 41-46).
Call BMXTIN: extract required information from each bogus and supported observation.
Loop over surface variables:
- Initialise modification array.
- Set up position arrays.
- Loop over bogus and supported obs:
  - Call BMGDPT: find 4 nearest grid-points and factors to multiply BGE.
  - Increment modification array (limit to a maximum value).
- Call BMSMTH: smooth BGE modification array.
- Call FFREAD: read in each BGE field.
- Modify each BGE field (limiting the BGEs to a maximum value for each variable) and write it out.

Loop over pressure-level variables:
- Initialise modification array.
- Set up position and level arrays.
- Call ORDERS: sort bogus and supported obs into negative pressure order.

Loop over bogus and supported obs:
    Check for corrupt pressure level.
    Call BMGDPT: Find 4 nearest grid-points and factors to multiply BGE.
    Increment modification array (limit to a maximum value).
  Call BMSMTH: smooth BGE modification array.
  Loop over pressure levels:
    Call FFREAD: read in each BGE field.
    Modify each BGE field (limiting the BGEs to a maximum value for each variable and level) and write it out.
End.

E.1.2 BMRDHK

Read in the house-keeping file (for date/time checking).

E.1.3 BMRWHDR

Read in and write out the BGE file header (fixed length header, integer constants, real constants and level-dependent constants) and field headers (lookup table).

E.1.4 BMRDIN

Read in an intervention file from the front-end computer.

E.1.5 BMXTIN

Loop over intervention records:
  Read in each record.
  For each bogus/supported observation, extract its latitude, longitude and level (if an Airep, call BMFL2P: convert flight level to pressure).

E.1.6 BMFL2P

Convert an airep flight level to a pressure, using the standard ICAO atmosphere.

E.1.7 ORDERS

Cray sorting routine, used to sort intervention records into negative pressure order (i.e. beginning at the surface).

E.1.8 BMGDPT

Find the 4 grid-points nearest to an observation position, and use bi-linear interpolation to calculate the fraction of the incease in BGE to apply at each point (i.e. a maximum of 1.0 at one grid-point if that corresponds to the observation position, or 0.25 at all 4 grid-points if the observation is in the centre of the grid-box, etc.).

E.1.9 BMSMTH

Smooth BGE modification array - dependent on the values in ISMUTH_?? : 0 - no smoothing
1 - call BEFLT1
2 - call BEFLT2
3 - call BMFLTV1
4 - call BMFLTV2
5 - call BMFLTV3
6 - call BMFLTV4

Call either BEFLT1/2 or BMFLTV1/3: to either filter or spread the increases to the BGEs (the modification array) in the vertical.
Call BEFLT1/2: filter the modification array in the east-west direction (including an additional second order filter polewards of 62° north/south).
Call BEFLT1/2: filter the modification array in the north-south direction.
Set Polar rows to mean row values.

E.1.10 BEFLT1 and BEFLT2

Apply either a first order filter (1-2-1 : BEFLT1) or a second order filter (1-4-6-4-1 : BEFLT2) to a one-dimensional array of values (e.g. a row of the BGE modification array).

E.1.11 BMFLTV1/BMFLTV3

Smooth a vertical column of the BGE modification array, by adding a fraction of the increase (i.e. array value - 1.0) to the level above and the level below - the fraction is 1/2 in BMFLTV1 and 1/4 in BMFLTV3.

E.1.12 FFREAD

Routine to read in a field from a fields-file set up with the format specified in UMDP F3.

E.2 Specification of constants (default values in brackets)

Many of the constants are the same as for the BGERR program (Appendix A), although some have different names.

E.2.1 Set in PARAMETER and DATA statements

NVARS (4)	Number of surface variables catered for.
NVARL (3)	Number of pressure-level variables.
NLEV (16)	Number of pressure levels.
NLEV_MAX (40)	Maximum number of pressure levels.
NPTS_BE_MAX (9728)	Maximum size of BGE fields.
IUNIT_PRT (6)	Unit number for printed messages.
IUNIT_HK (15)	Unit number for housekeeping file.
IUNIT_BE_IN (20)	Unit number for input BGE file.
IUNIT_BE_OUT (30)	Unit number for output BGE file.
RPLEV(NLEV_MAX)	Pressure levels (in mb)

IPLEV(NLEV_MAX)	Pressure levels (in mb)	For FFREAD,
IVARL(NVARL)	Pressure-level variable type	specified in
IVARS(2,NVARS)	Sfc variable type + level code	DATA statements:

IPLEV (1000, 850, 700, 500, 300, 200, 100, 50, 20, 10, 5, 2, 1, -5, -2, -1, 24*0)
[-5, -2 and -1 correspond to 0.5, 0.2 and 0.1 in RPLEV.]

IVARL (5, 3, 8)	Wind (u-component), temperature and relative humidity.
IVARS (12, 8888,	P_{msl}
75, 9999,	10m wind (u-component)
58, 9999,	$T_{1.5m}$
8, 9999)	$RH_{1.5m}$

E.2.2 Namelist options (NAMLBM)

L_GLOB (T) Global model resolution (LA model not catered for yet).
L_WRAP (T) Wrap-around rows.
L_UPDATS(NVARS) (T,T,F,F) Modify surface BGEs (=T).
L_UPDATL(NVARS) (T,T,T) Modify pressure-level BGEs (=T).
L_RS_INT (T) Include radiosonde intervention (supported obs).
L_AR_INT (T) Include airep intervention (supported obs).
L_SF_INT (T) Include surface intervention (supported obs).
L_UA_BOG (T) Include upper air bogus obs.
L_TH_BOG (T) Include thickness bogus obs.
L_SF_BOG (T) Include surface bogus obs.
L_DIAG (F) Print detailed diagnostics.
IFCTIM (6) Length (hours) of background forecast used.
IPROJ_BE (804) Projection number of BGE file (for FFREAD).

ISMUTH_PS(2) (2,0) ISMUTH_VS(2) (2,0) ISMUTH_V(2) (2,3) ISMUTH_T(2) (2,5) ISMUTH_RH(2) (2,3)	Smoothing (horiz,vert) to be applied to BGE modification array (see E.1.9 above).

RMOD_MAX (3.0) Maximum value of BGE modification factor

BGE_PS_MAX (5.0 mb) BGE_VS_MAX (7.0 m/s) BGE_TS_MAX (4.0 °C) BGE_RHS_MAX (50 %) BGE_V_MAX(NLEV) (8.0 m/s) BGE_T_MAX(NLEV) (4.0 °C) BGE_RH_MAX(NLEV) (50 %)	Maximum final values of BGE

Figure 1.

O-B VECTOR WIND AS A FUNCTION OF WIND SPEED (UNITS: M/S) - Airep + Radiosonde da

30-50 deg N. 19th Feb - 30th Mar 1992.

(See text for details)

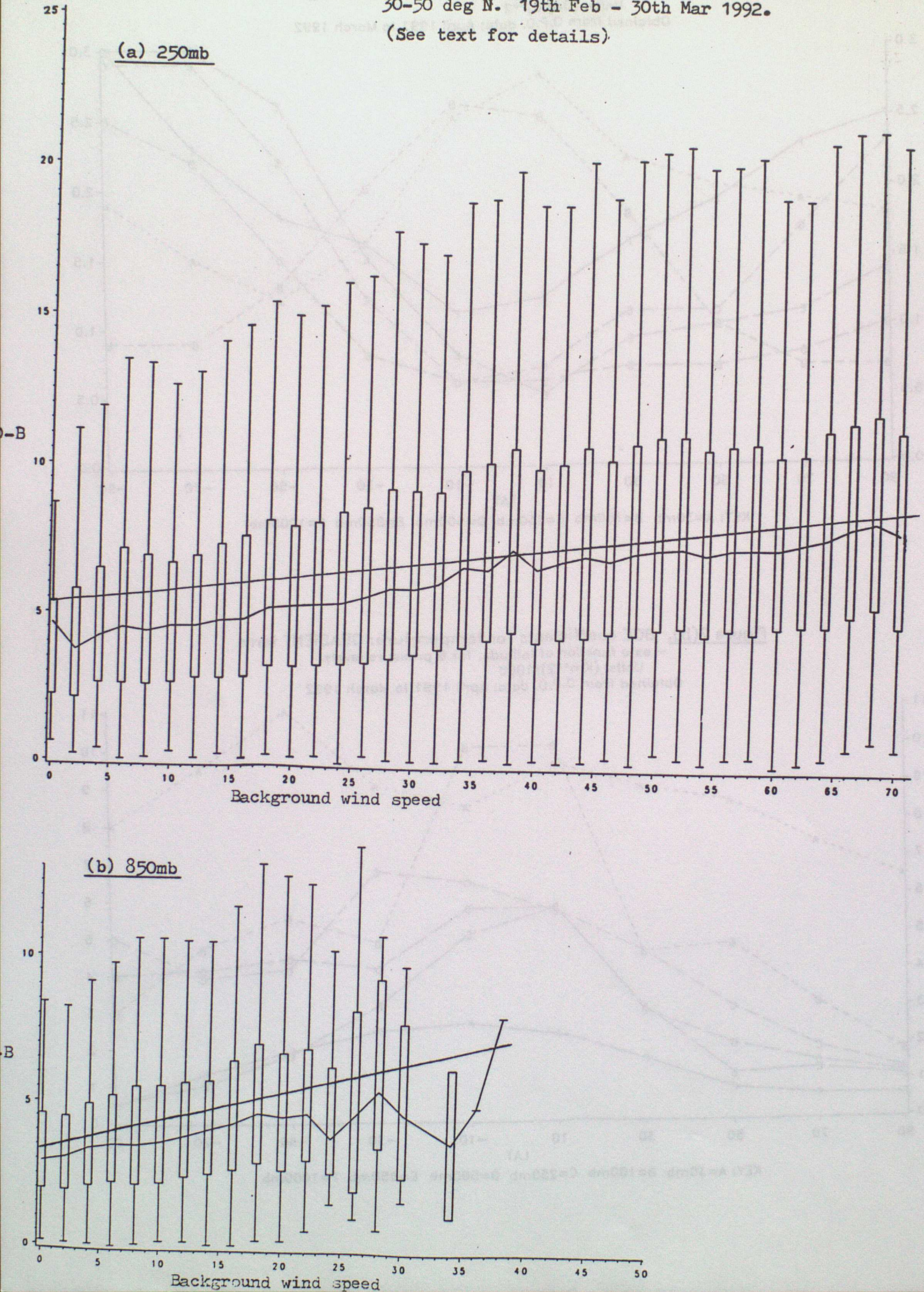
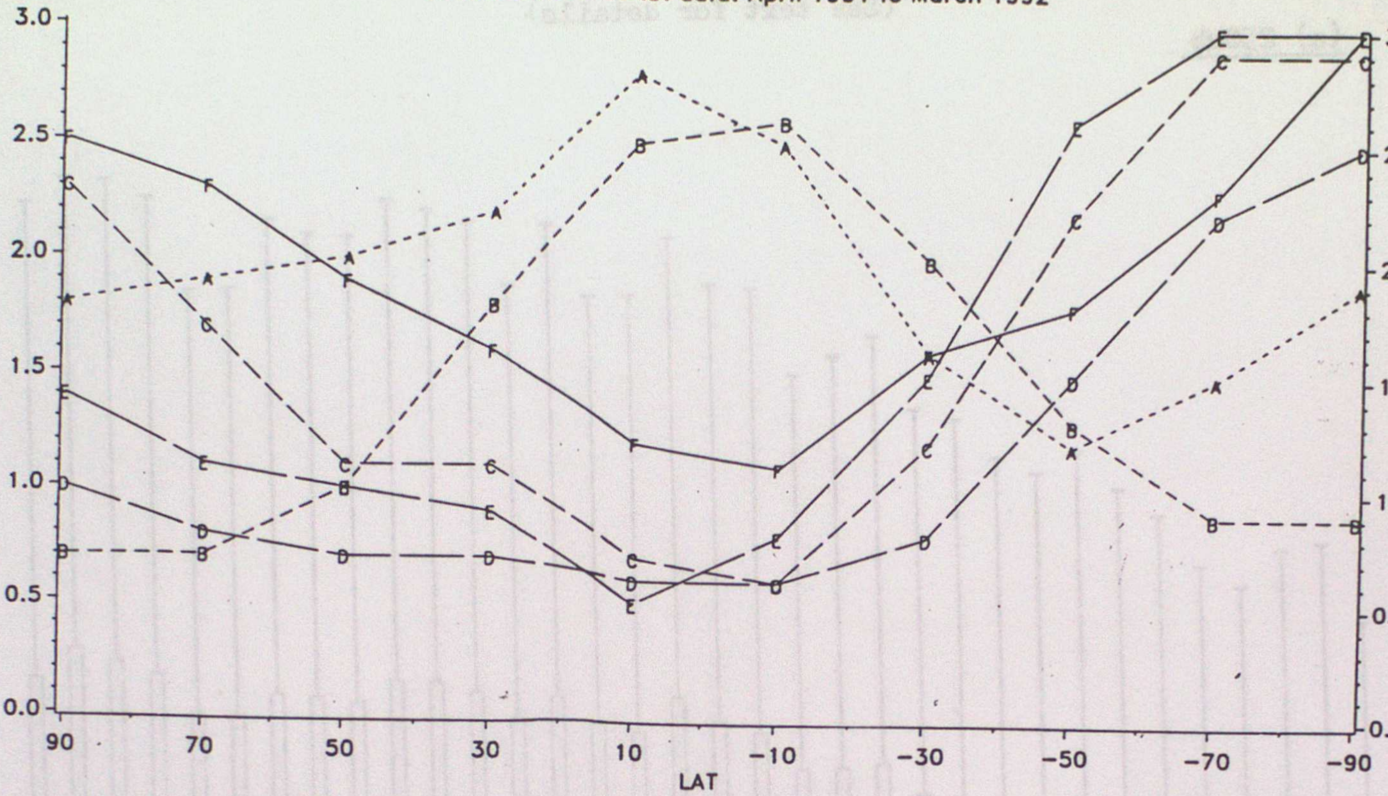
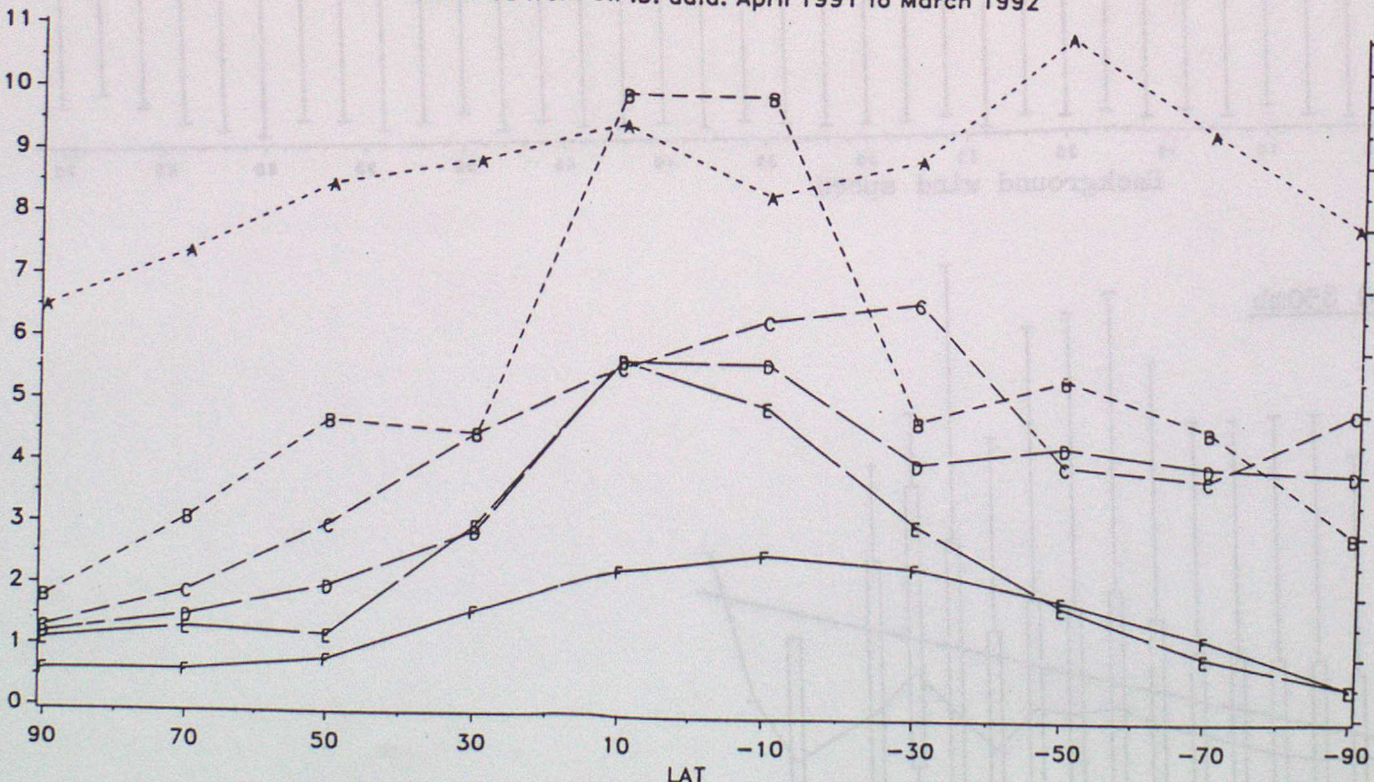


Figure 2(a). BGE coefficients for temperature: CONSTANT term
– as a function of latitude, for 6 pressure levels.
Units: (Deg C)**2
Obtained from O.P.D. data: April 1991 to March 1992



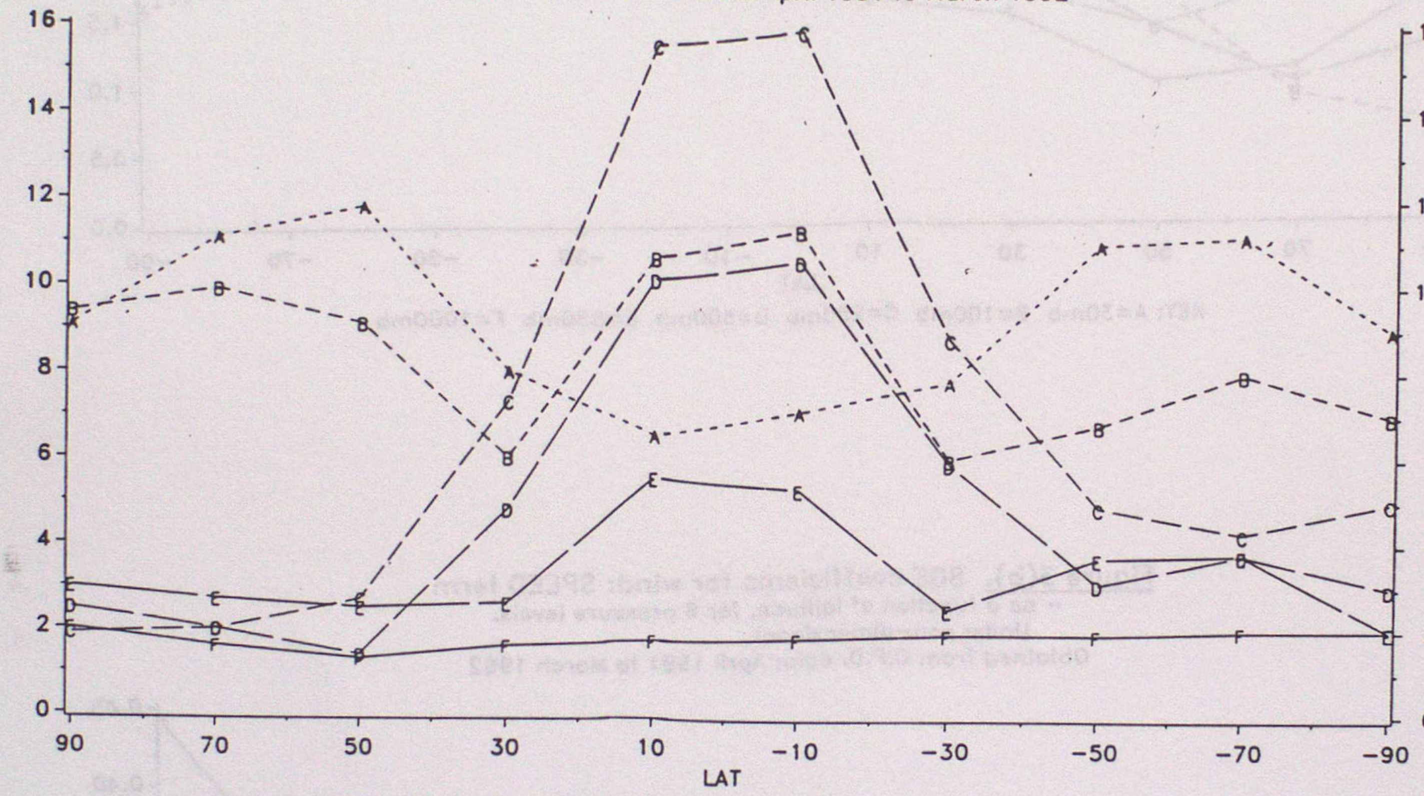
KEY: A=30mb B=100mb C=250mb D=500mb E=850mb F=1000mb

Figure 2(b). BGE coefficients for temperature: GRADIENT term
– as a function of latitude, for 6 pressure levels.
Units: (Km**2)*1000
Obtained from O.P.D. data: April 1991 to March 1992



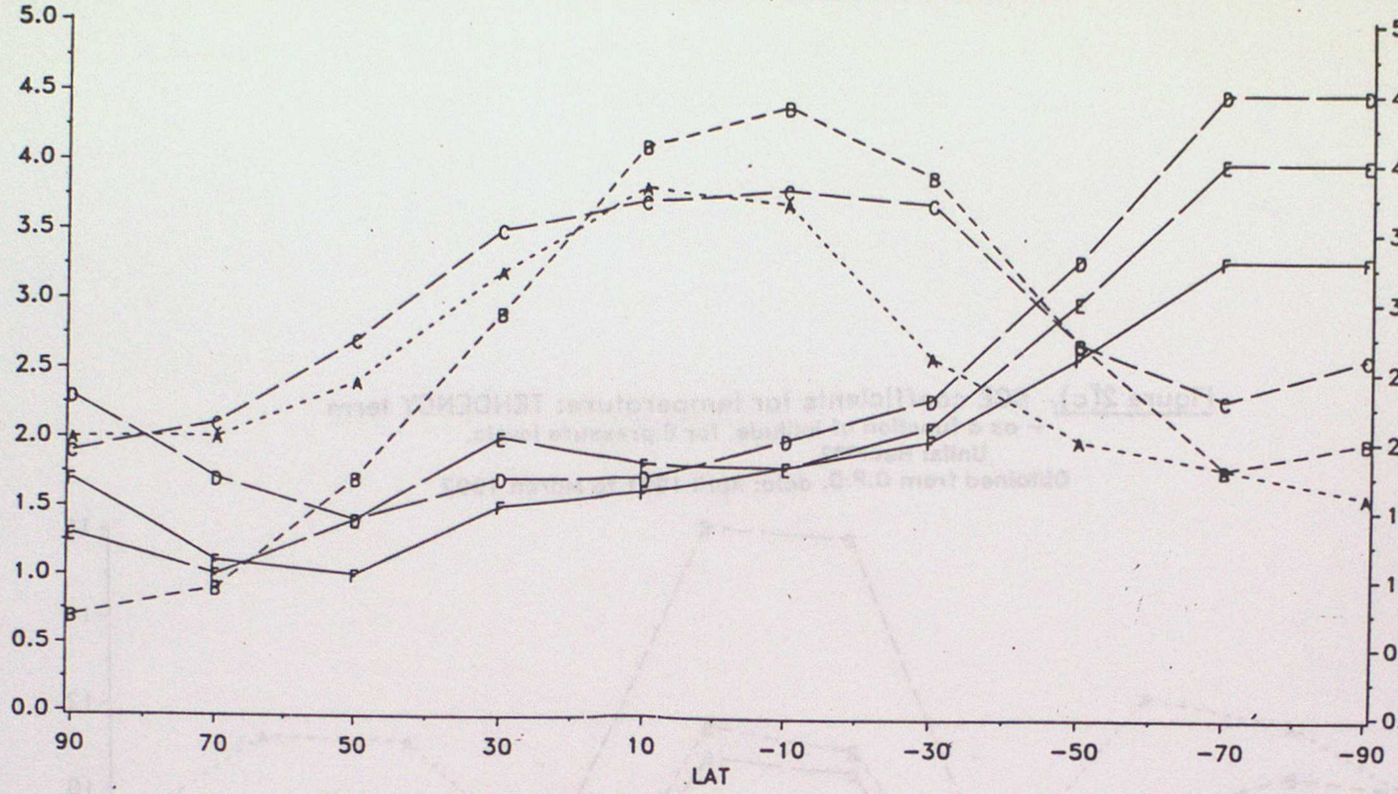
KEY: A=30mb B=100mb C=250mb D=500mb E=850mb F=1000mb

Figure 2(c). BGE coefficients for temperature: TENDENCY term
– as a function of latitude, for 6 pressure levels.
Units: Hour**2
Obtained from O.P.D. data: April 1991 to March 1992



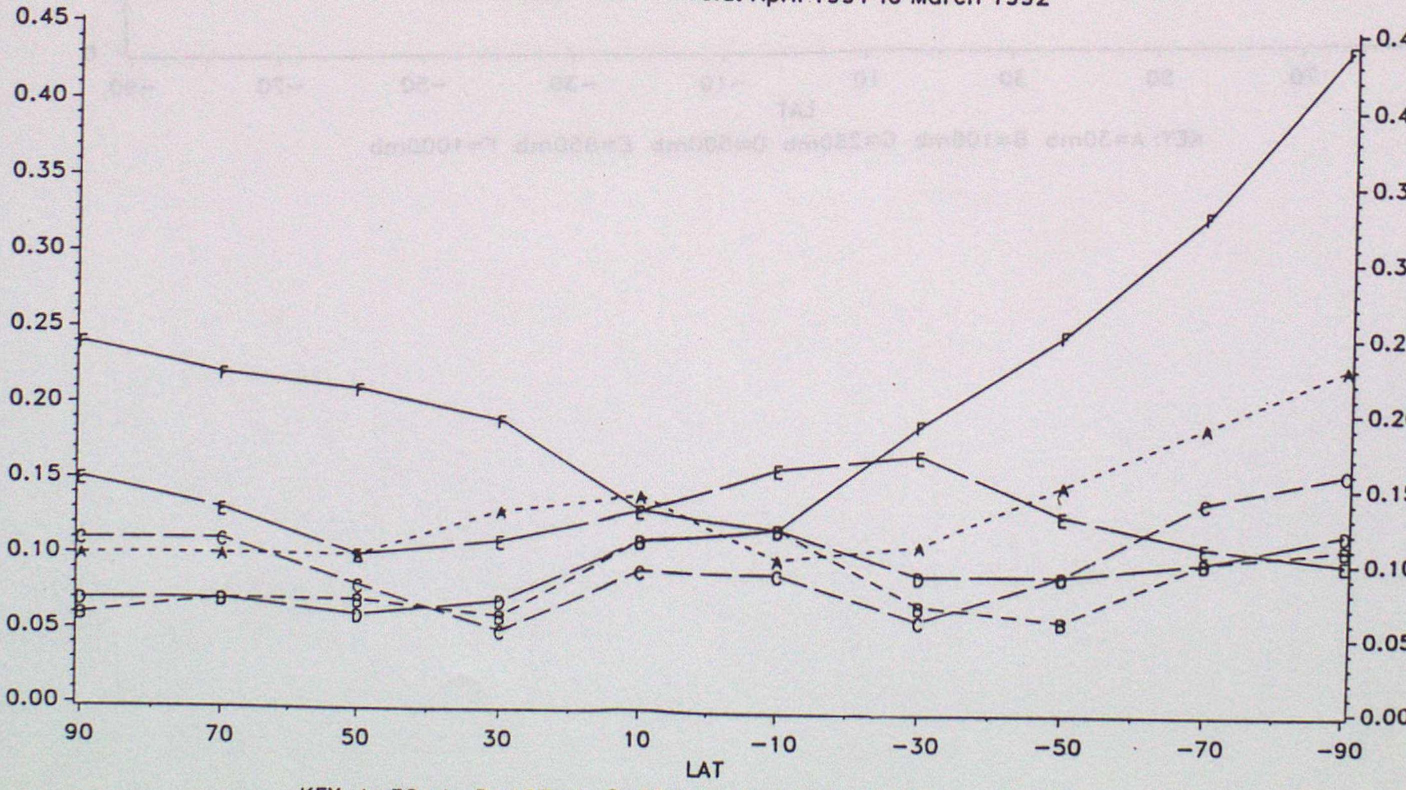
KEY: A=30mb B=100mb C=250mb D=500mb E=850mb F=1000mb

Figure 3(a). BGE coefficients for wind: CONSTANT term
– as a function of latitude, for 6 pressure levels.
Units: m/s
Obtained from O.P.D. data: April 1991 to March 1992



KEY: A=30mb B=100mb C=250mb D=500mb E=850mb F=1000mb

Figure 3(b). BGE coefficients for wind: SPEED term
– as a function of latitude, for 6 pressure levels.
Units: non-dimensional
Obtained from O.P.D. data: April 1991 to March 1992



KEY: A=30mb B=100mb C=250mb D=500mb E=850mb F=1000mb

Figure 4(a). BGE coefficients for 10m Wind: CONSTANT term
New values (std: m/s) from UM stats Sep91–Mar92 (full line)
& oper values (var: (m/s)**2) from Cyber stats (dashed line)

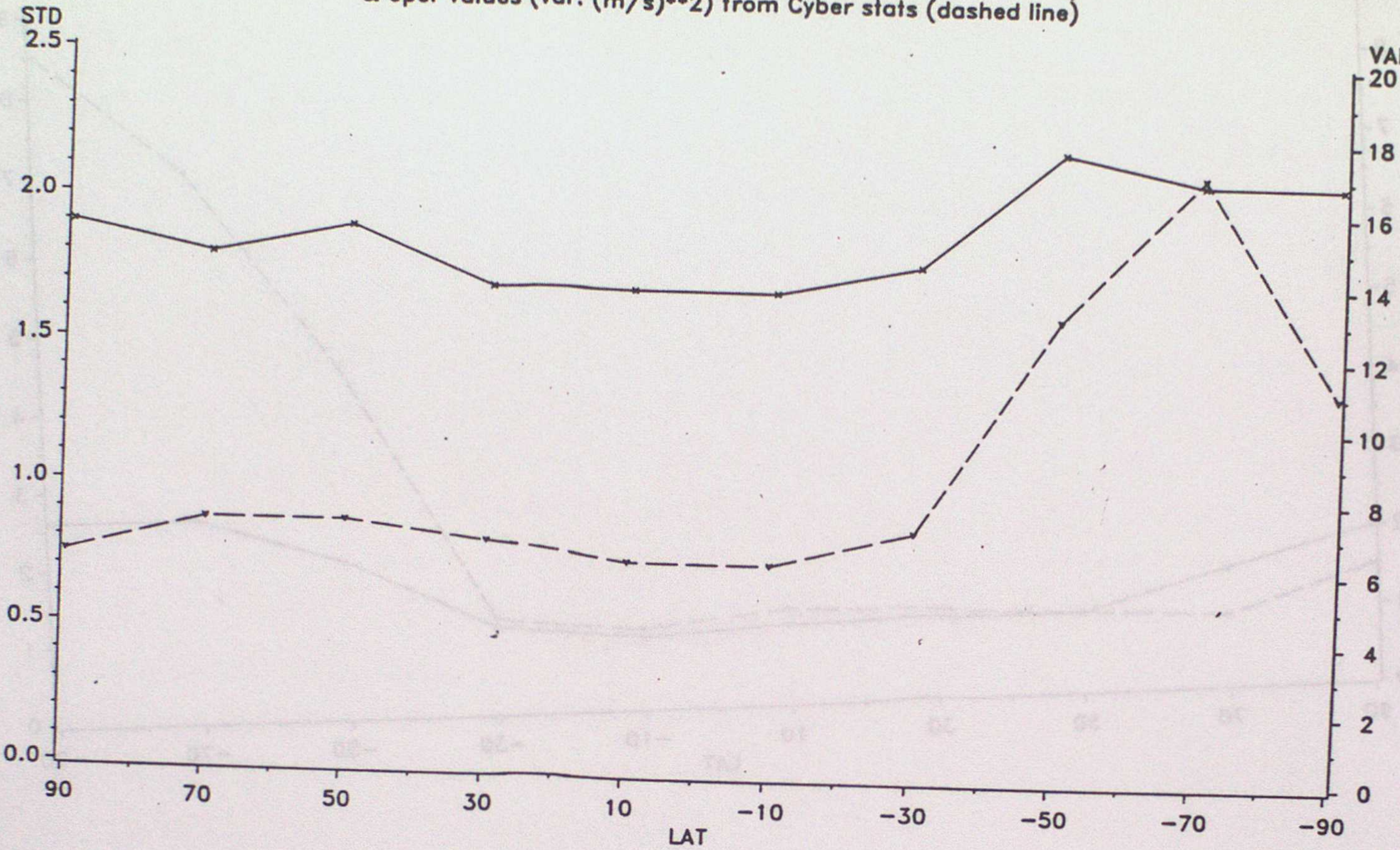


Figure 4(b). BGE coefficients for 10m Wind: SPEED term
New values, obtained from UM stats Sep91–Mar92 (full line)
& present oper values obtained from Cyber stats (dashed line)
Units: non-dimensional

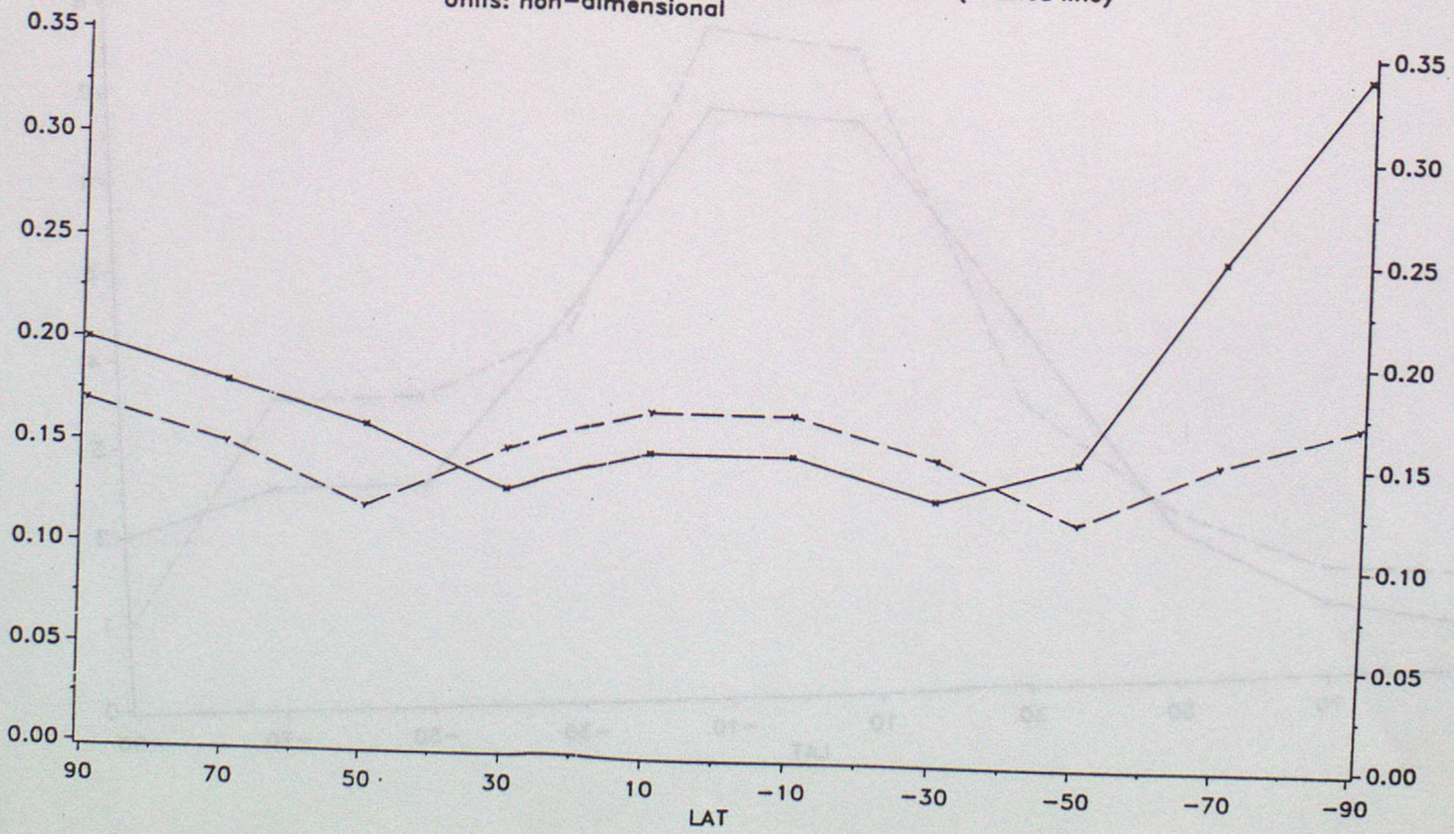


Figure 5(a). BGE coefficients for Pmsl: CONSTANT term
New values (full line) based on UM stats Sep 91 – Mar 92
& present oper values (dashed line) based on Cyber stats
Units: mb**2

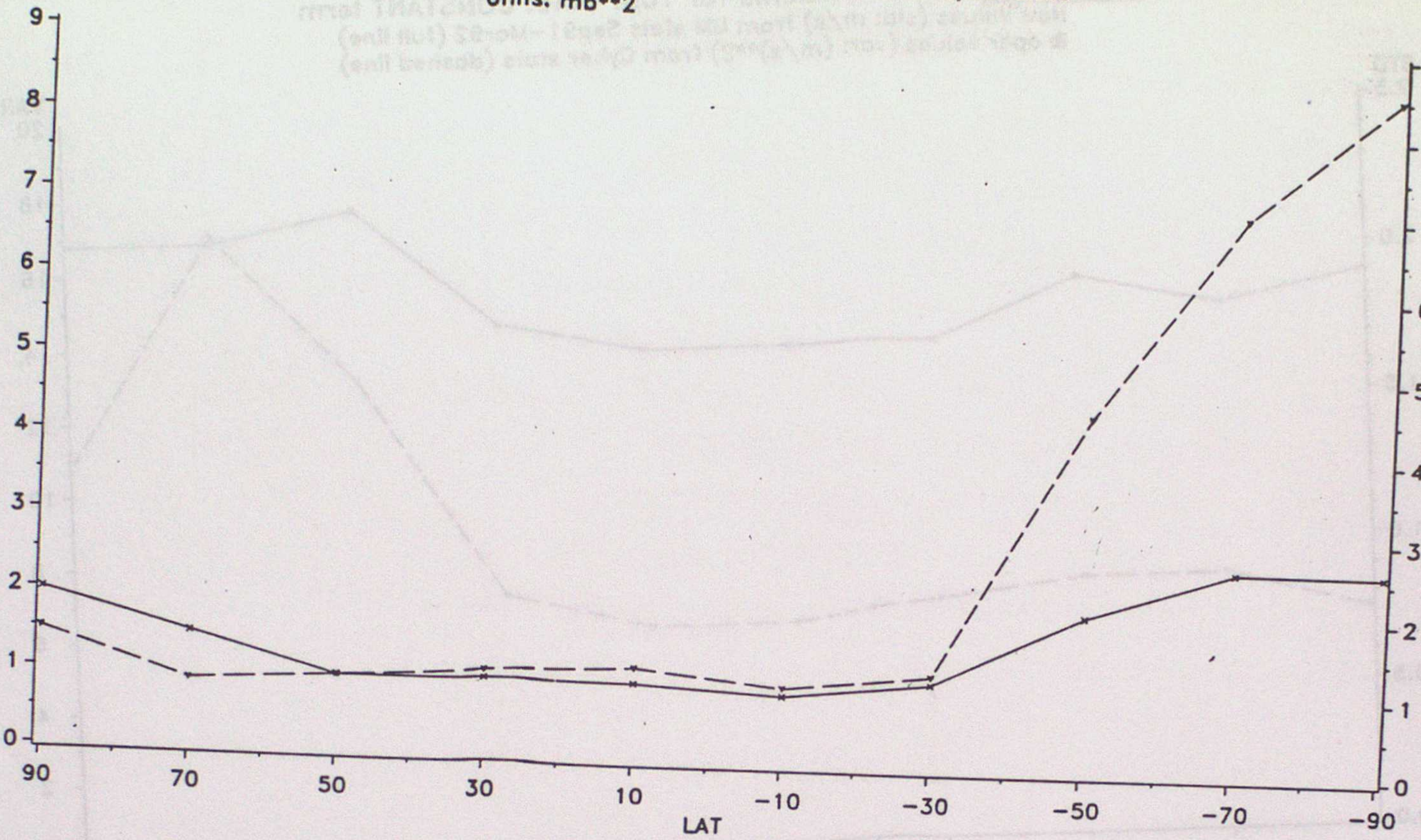


Figure 5(b). BGE coefficients for Pmsl: GRADIENT term
New values (full line) based on UM stats Sep 91 – Mar 92
& present oper values (dashed line) based on Cyber stats
Units: (Km**2)*1000

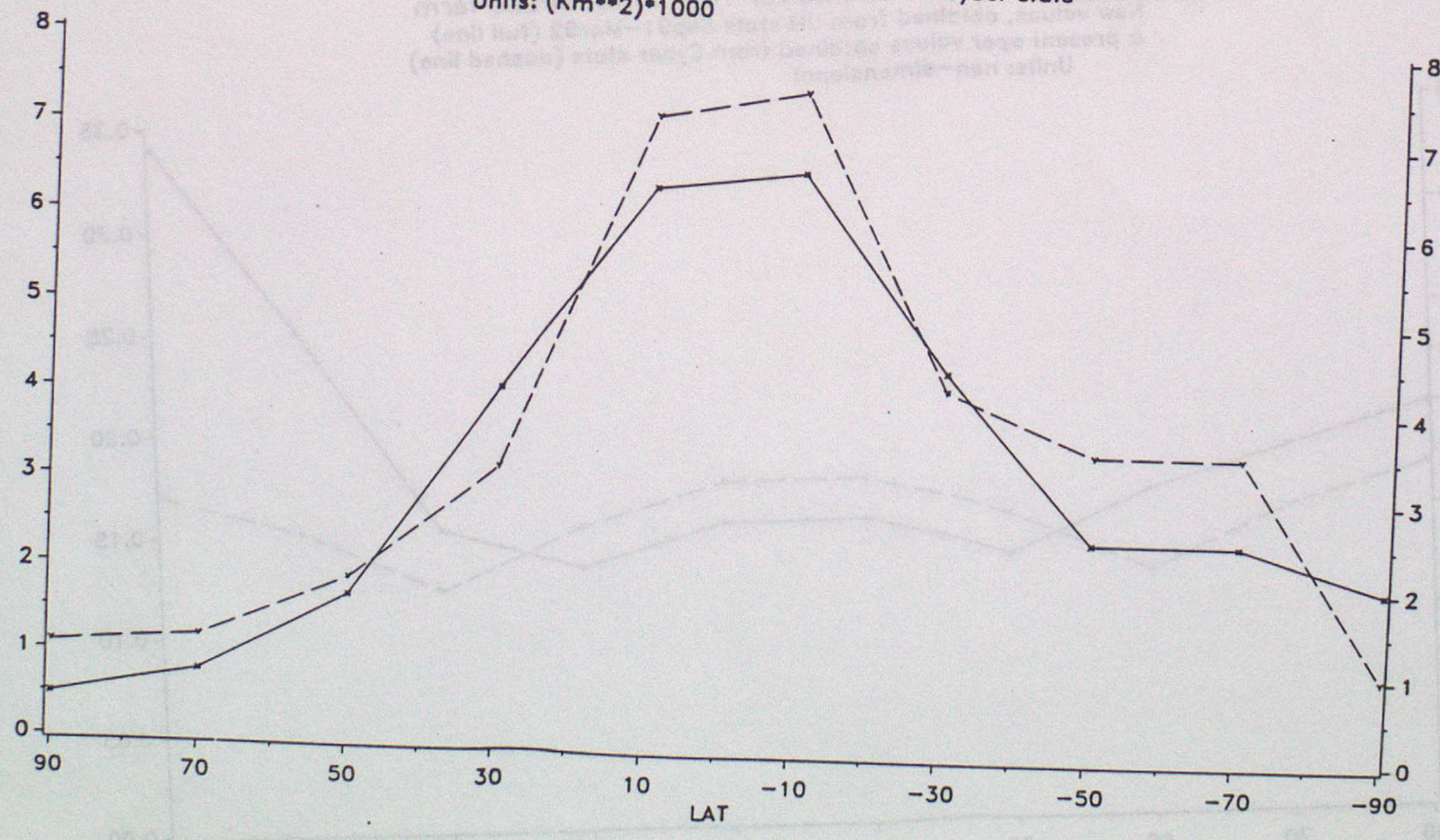


Figure 5(c). BGE coefficients for Pmsl: TENDENCY term
New values (full line) based on UM stats Sep 91 – Mar 92
& present oper values (dashed line) based on Cyber stats
Units: Hour**2

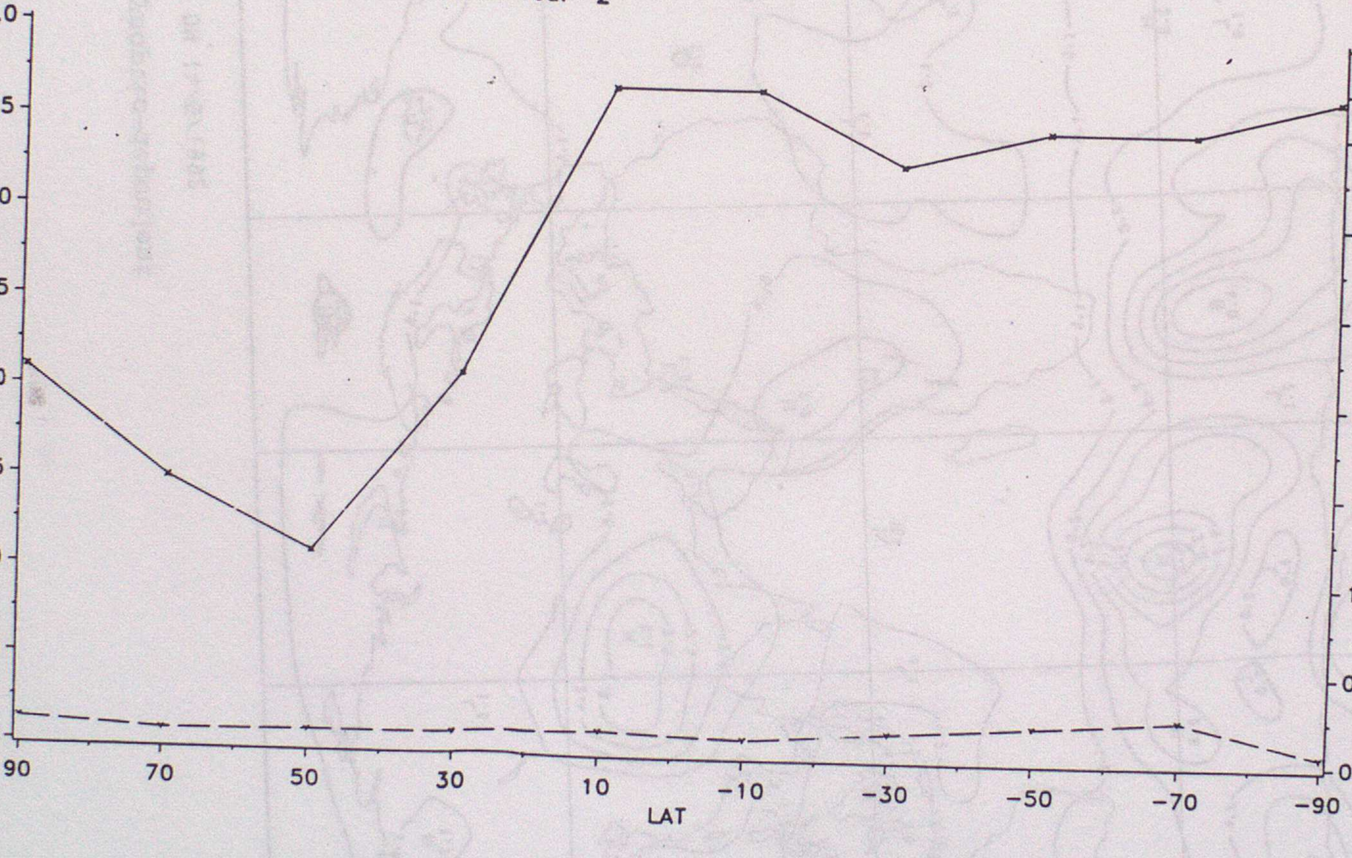


Figure 6(a).

BACKGROUND ERROR FIELD (STANDARD DEVIATION) - Synoptic-dependent
FOR MEAN SEA LEVEL PRESSURE (MB)
VALID AT 12Z ON 14/5/1992 DATA TIME 6Z ON 14/5/1992

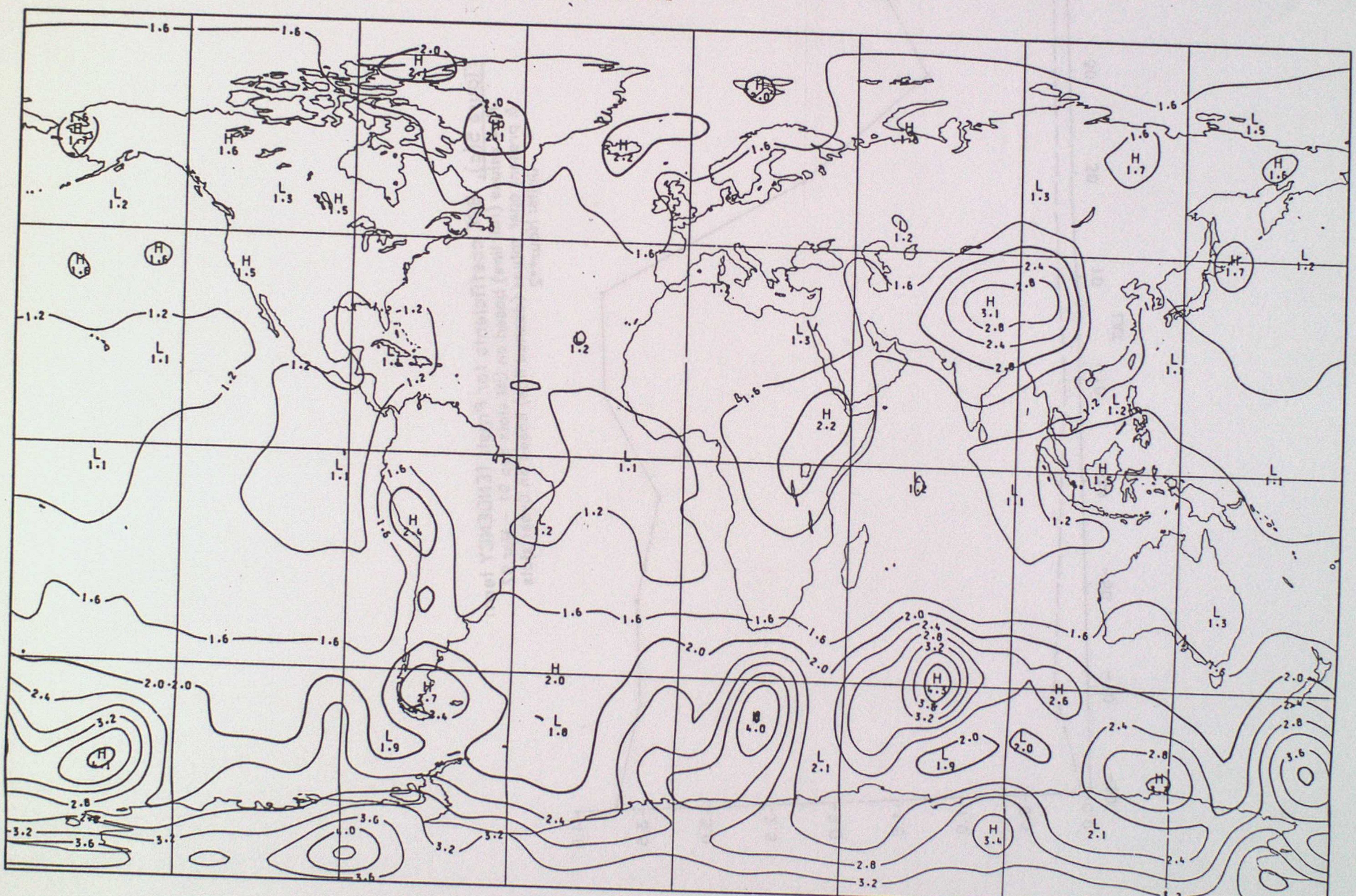


Figure 6(b).

BACKGROUND T+6 PMSL
VALID AT 12Z ON 14/5/1992 DATA TIME 6Z ON 14/5/1992

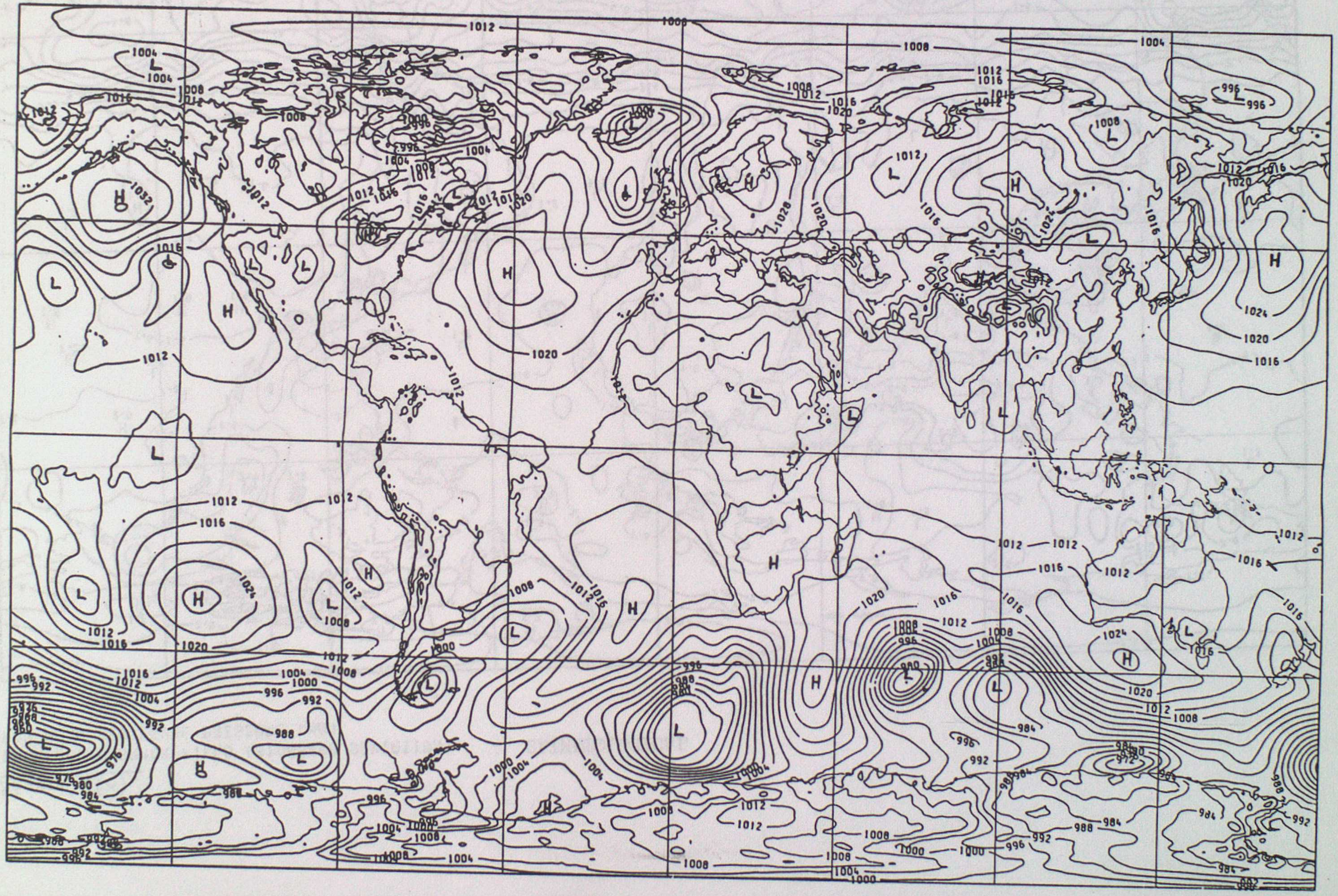


Figure 6(c).

BACKGROUND ERROR FIELD (STANDARD DEVIATION) - CLIMATOLOGICAL
FOR MEAN SEA LEVEL PRESSURE (MB)

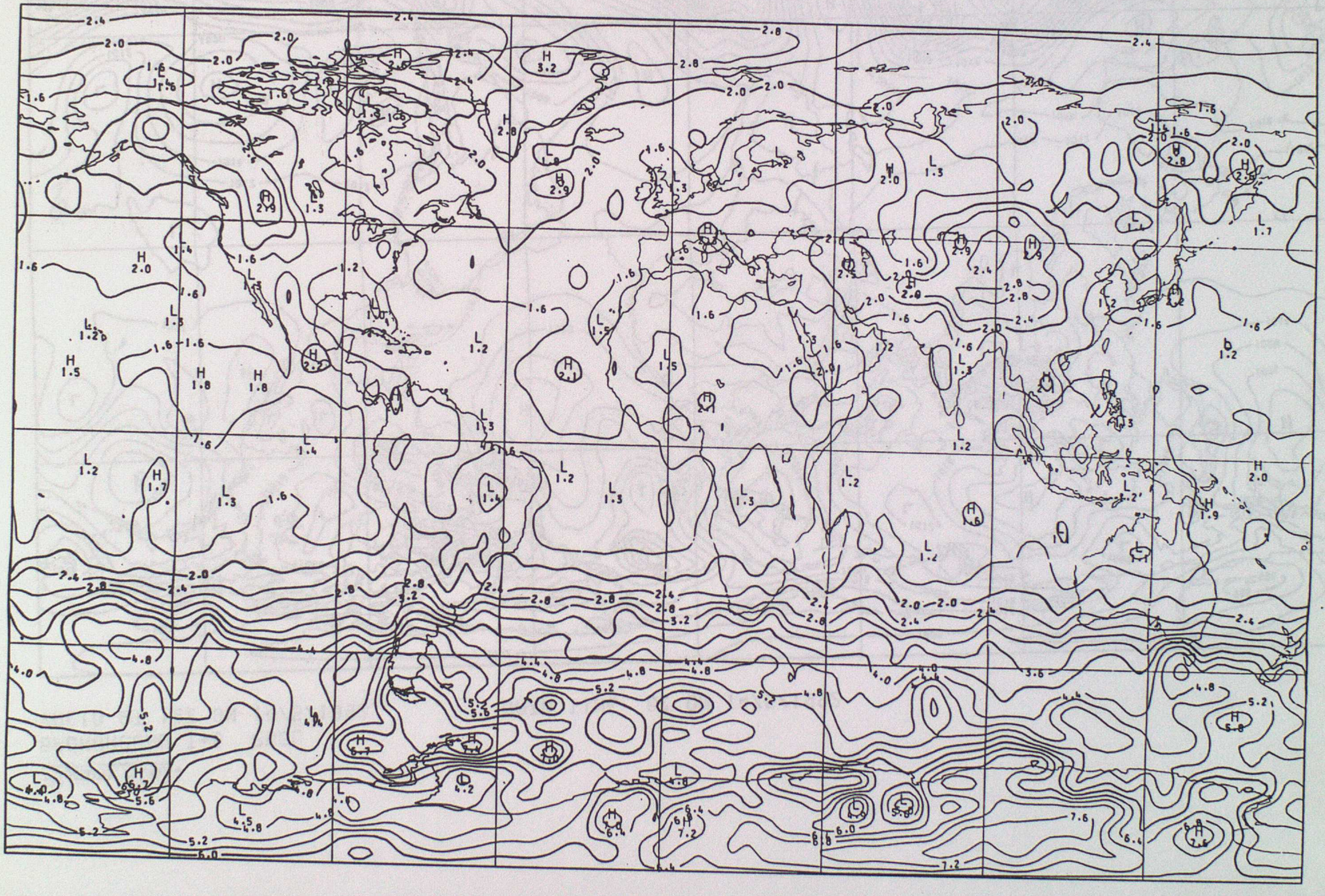


Figure 6(d).

BACKGROUND ERROR FIELD (STANDARD DEVIATION) - Operational Synoptic-dependent
FOR MEAN SEA LEVEL PRESSURE (MB)
VALID AT 12Z ON 14/5/1992

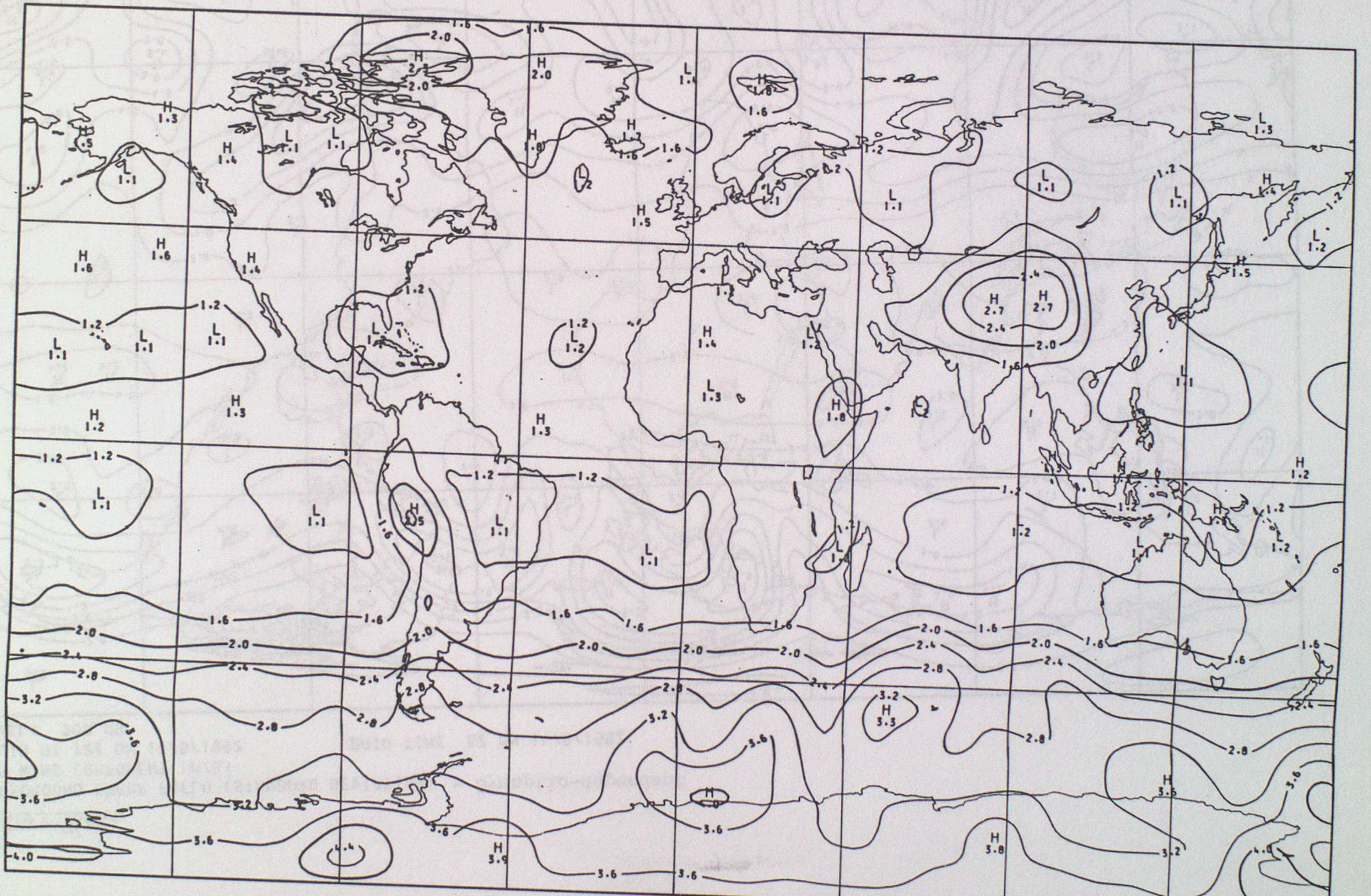


Figure 7(a).

BACKGROUND ERROR FIELD (STANDARD DEVIATION) - Synoptic-dependent
FOR WIND COMPONENT (M/S)
VALID AT 12Z ON 14/5/1992 DATA TIME 6Z ON 14/5/1992
LEVEL: 300 MB

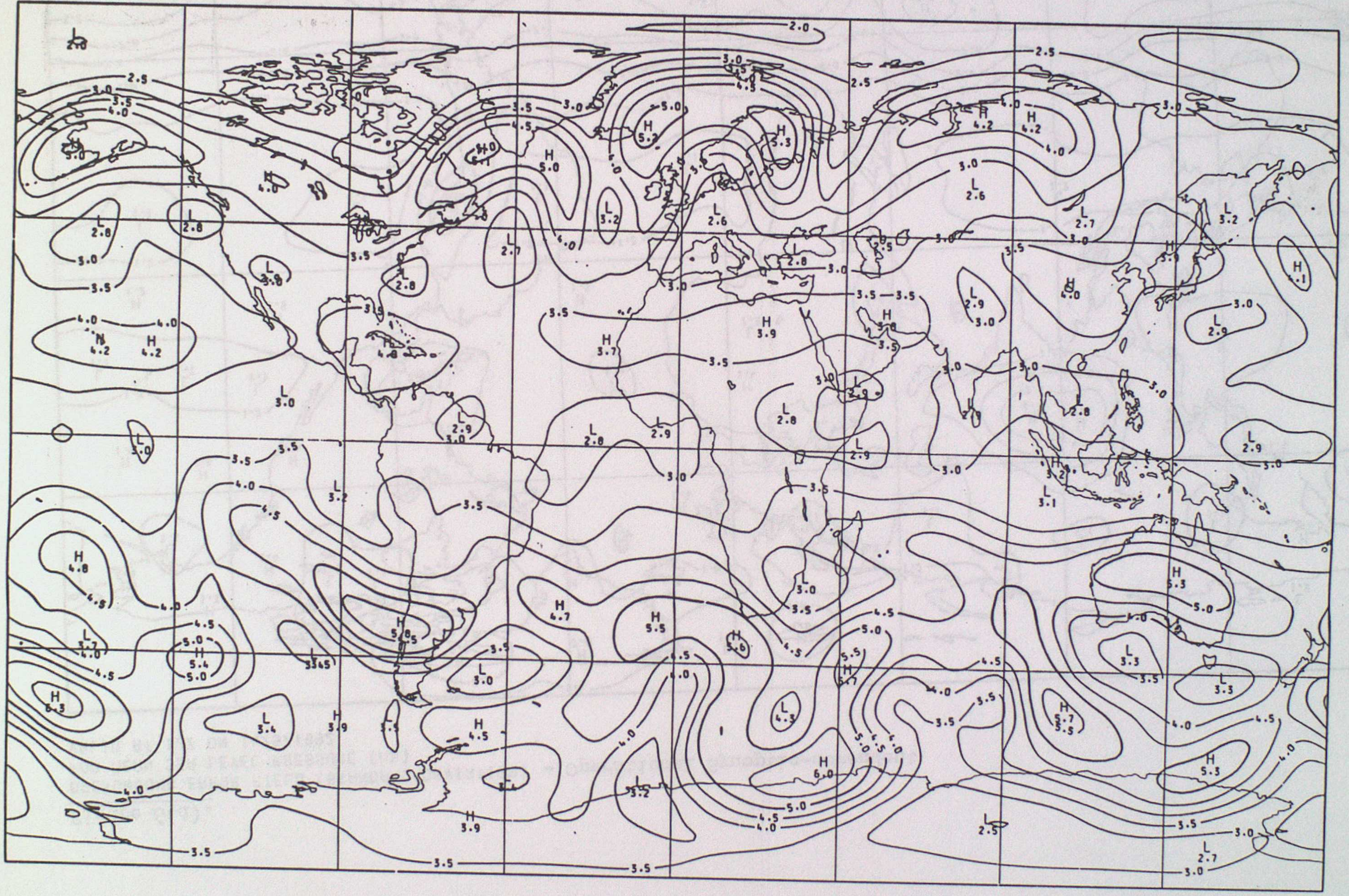


Figure 7(b).
BACKGROUND T+6 WIND SPEED AT 300MB
VALID AT 12Z ON 14/5/1992 DATA TIME 6Z ON 14/5/1992
CI: 10 M/S

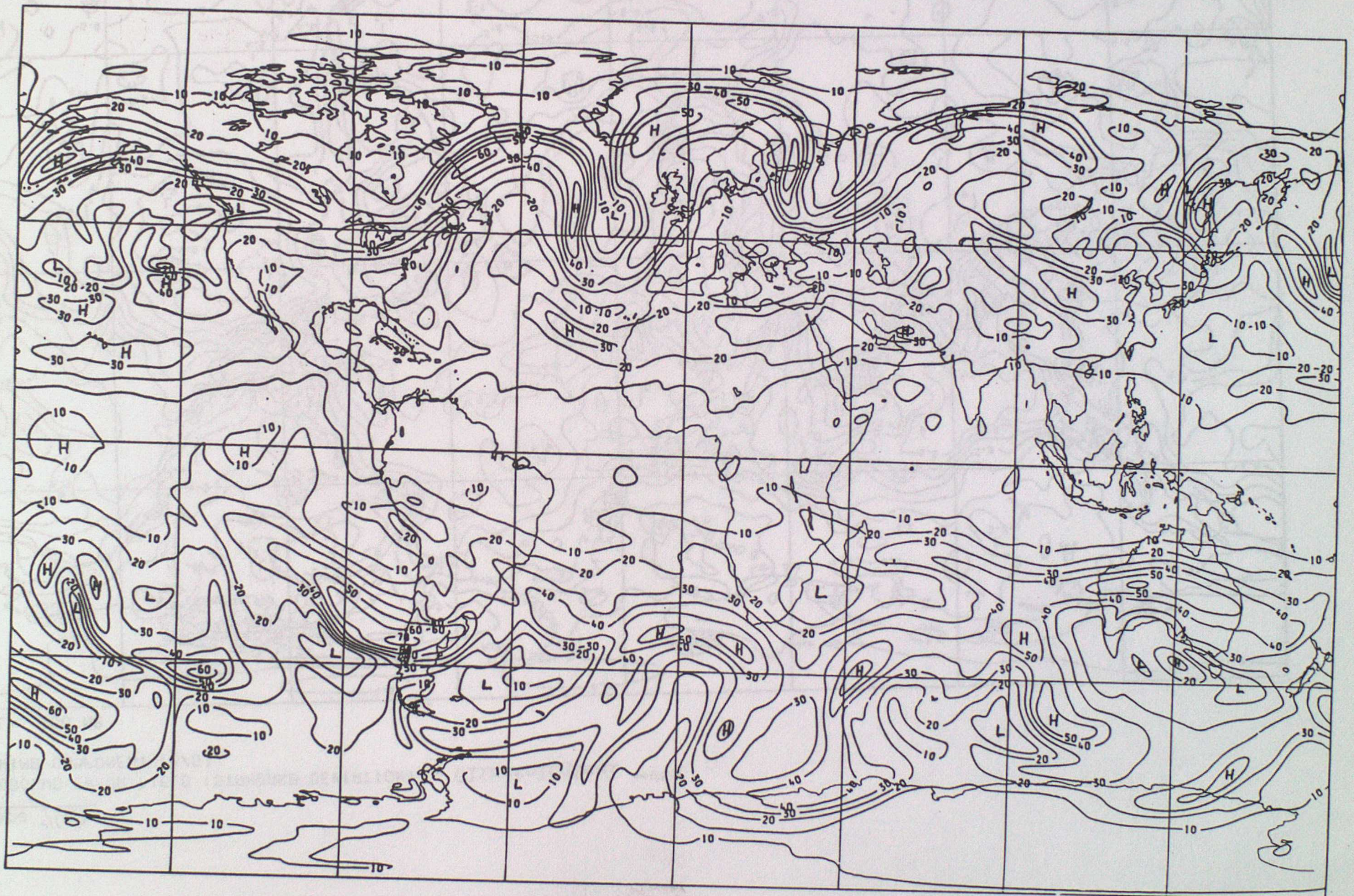


Figure 7(c).

BACKGROUND ERROR FIELD (STANDARD DEVIATION) - Climatological
FOR WIND COMPONENT (M/S)

LEVEL: 300 MB

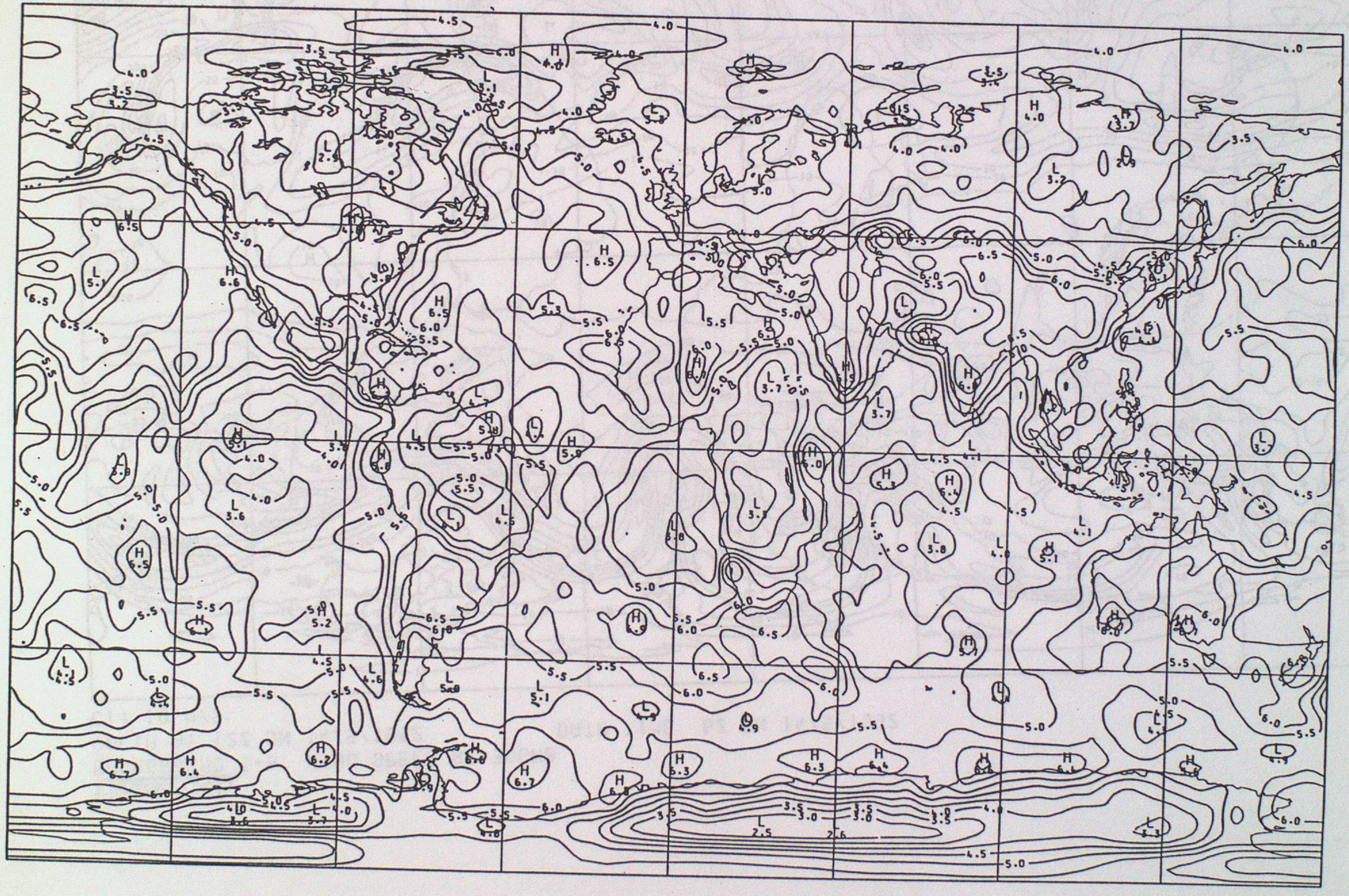


Figure 8(a).

BACKGROUND ERROR FIELD (STANDARD DEVIATION) - Synoptic-dependent
FOR TEMPERATURE (DEG C)
VALID AT 12Z ON 14/5/1992
LEVEL: 850 MB
DATA TIME 6Z ON 14/5/1992

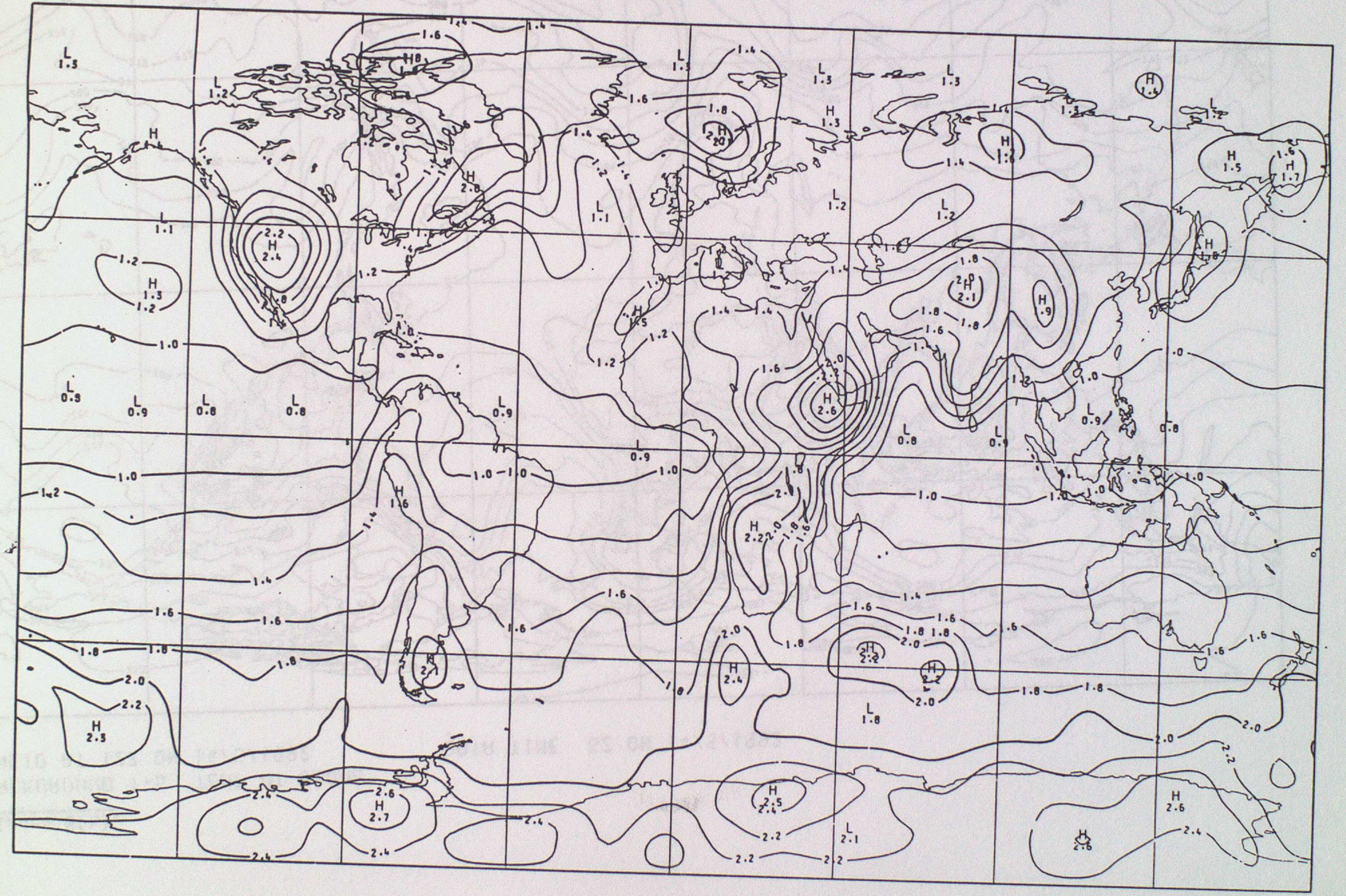


Figure 8(b).

BACKGROUND T+6 TEMP AT 850MB
VALID AT 12Z ON 14/5/1992 DATA TIME 6Z ON 14/5/1992

Figure 8(c).

BACKGROUND ERROR FIELD (STANDARD DEVIATION) - Climatological FOR TEMPERATURE (DEG C)

LEVEL: 850 MB

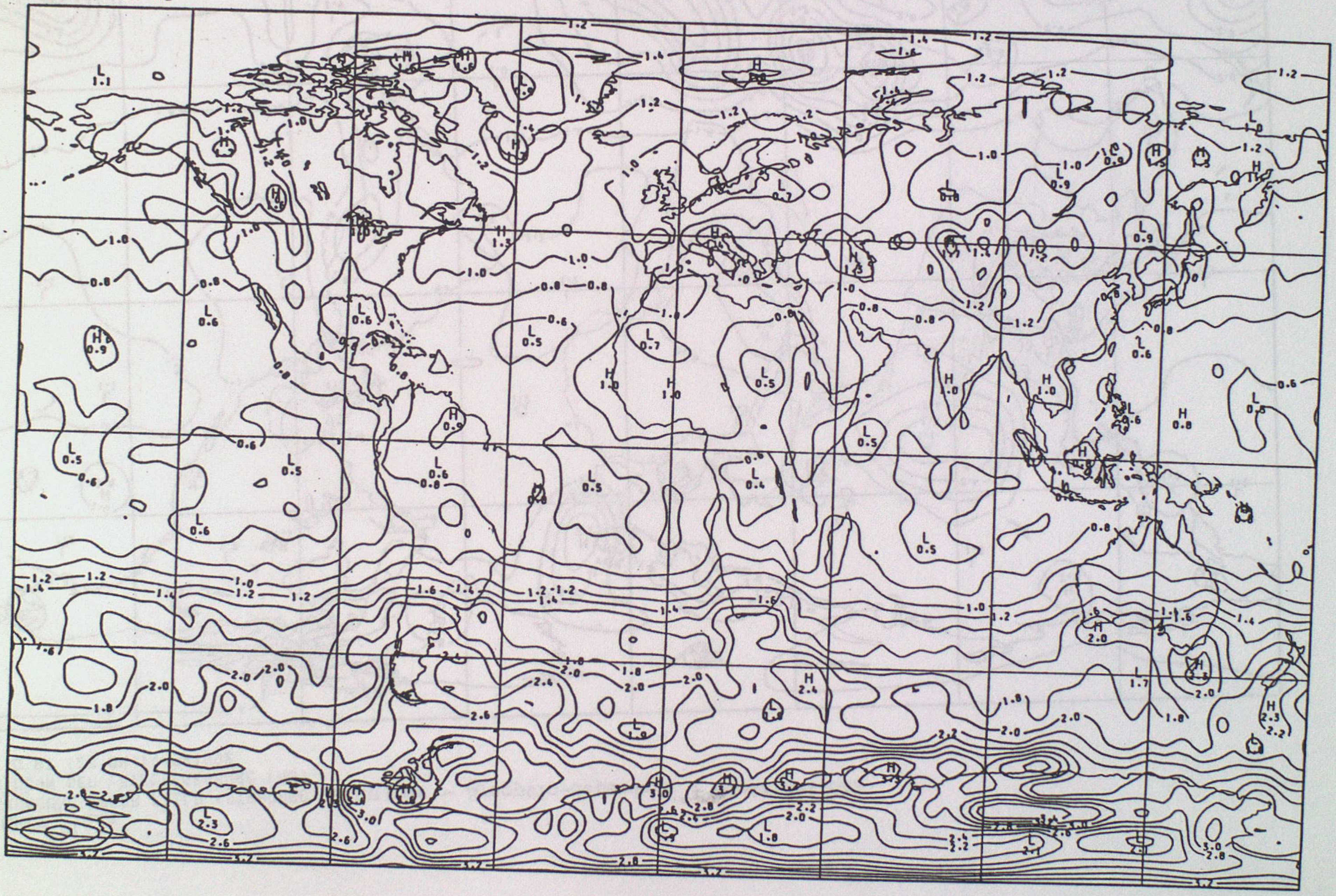


Figure 9(a).

BACKGROUND ERROR FIELD (STANDARD DEVIATION) - Synoptic-dependent + Modifications
FOR MEAN SEA LEVEL PRESSURE (MB)
VALID AT 12Z ON 14/5/1992

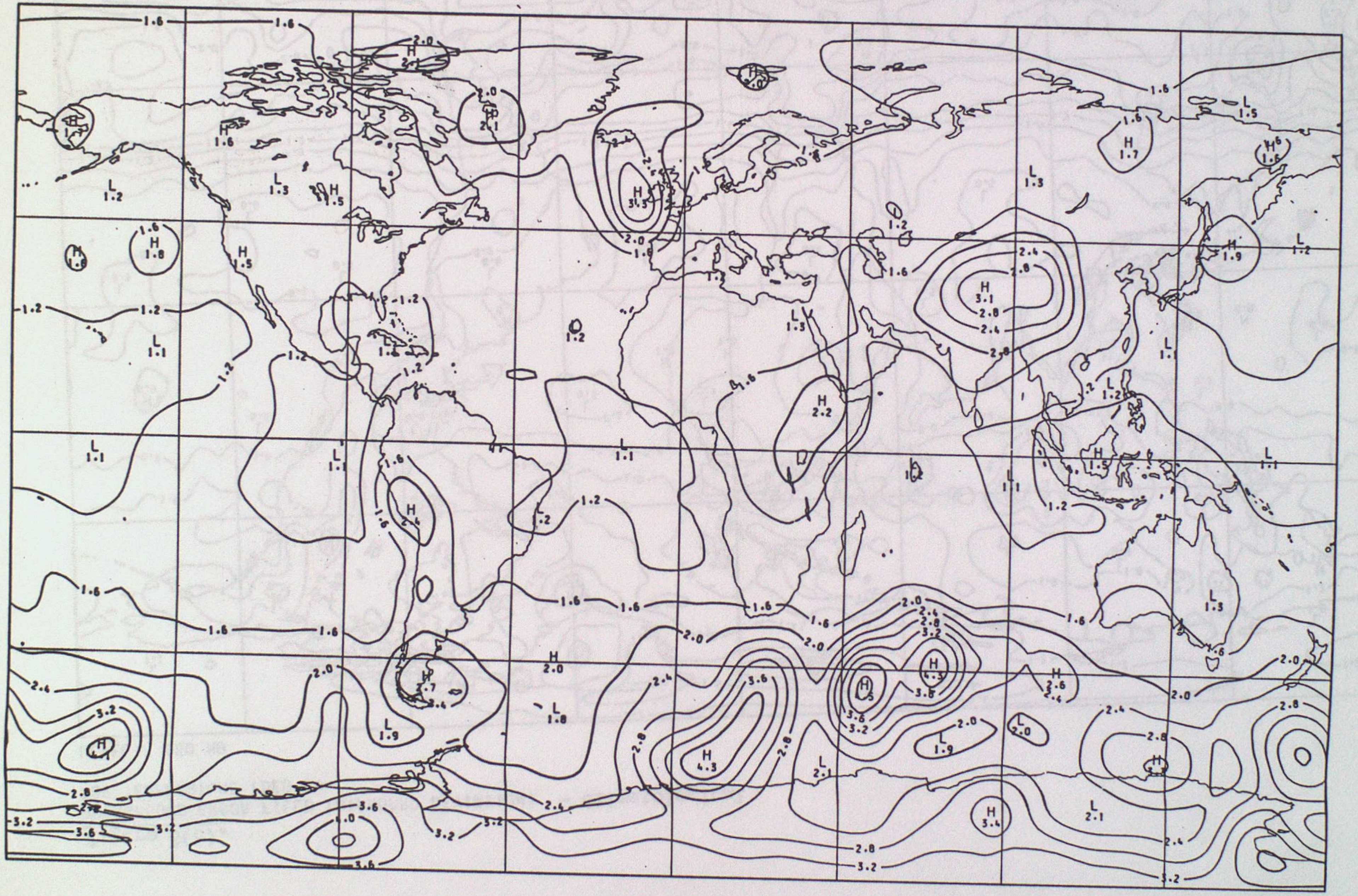


Figure 9(b).

BACKGROUND ERROR FIELD (STANDARD DEVIATION) - Synoptic-dependent + Modifications
FOR WIND COMPONENT (M/S)
VALID AT 12Z ON 14/5/1992
LEVEL: 300 MB

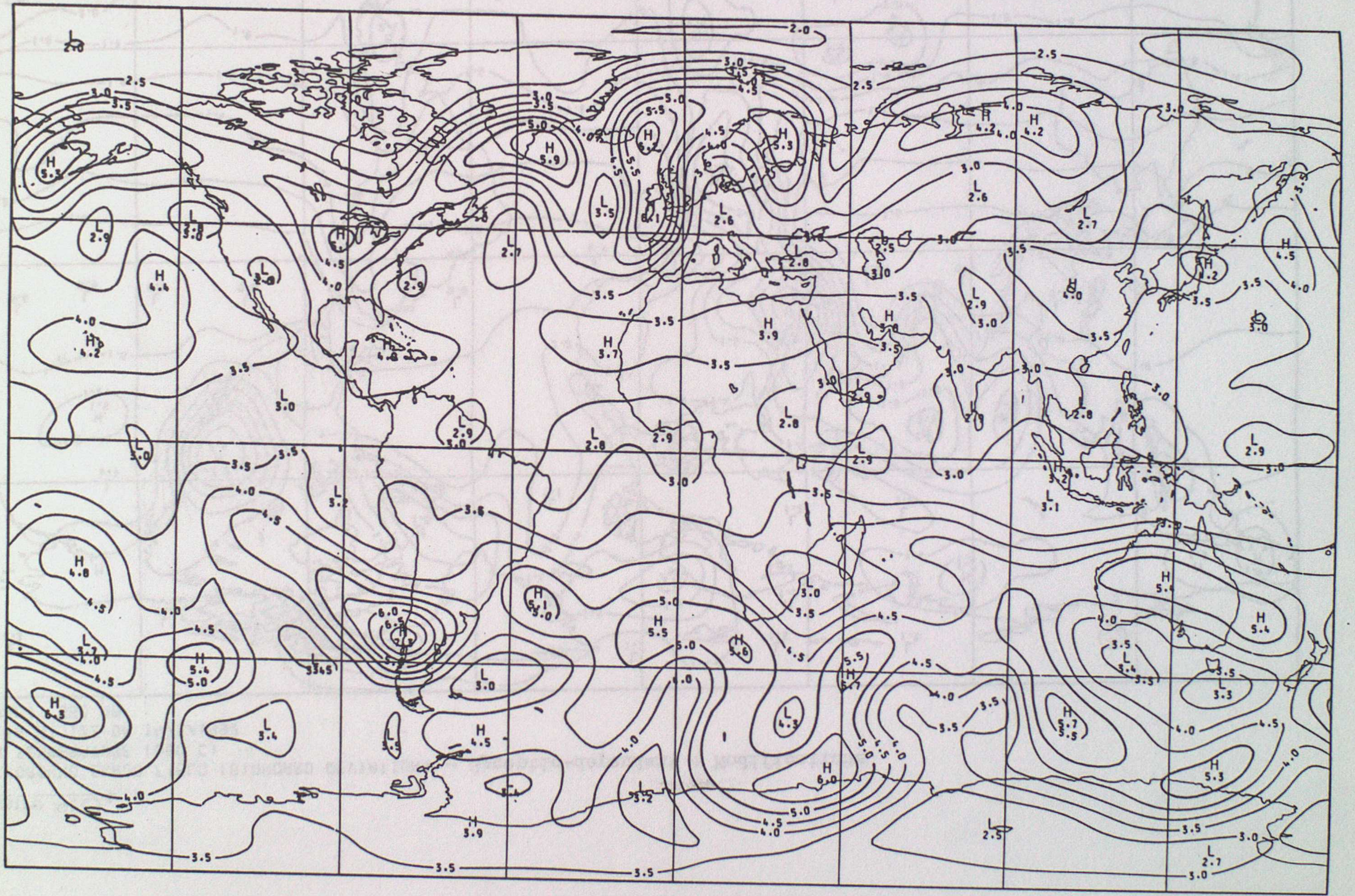


Figure 9(c).

BACKGROUND ERROR FIELD (STANDARD DEVIATION) - Synoptic-dependent + Modifications
FOR TEMPERATURE (DEG C)
VALID AT 12Z ON 14/5/1992
LEVEL: 850 MB