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A trial of modified diffusion in the coarse-mesh model

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1. Introduction

Maximum wind forecasts from the coarse-mesh version of the 15-level model have been criticised because of the frequency with which jet maxima are underestimated. Detailed subjective and objective verification in the Central Forecasting Branch has revealed that mean errors in model forecast maximum winds exceeds 20 knots during summer if only the strong wind cases are considered (Hardman, 1985). The fact that statistics for summer jets are substantially worse than the winter jets and also that even the objective analysis has a significant bias compared with radiosondes both are suggestive of a resolution problem. The inadequate resolution of the coarse-mesh model with regard to jets, has also been noted by McKenna (Met O 15, private communication) who compared data from the MRF Hercules with both fine-mesh and coarse-mesh upper wind fields. Clearly the resolution of the coarse-mesh model is inadequate to define the detail of the jet core with the accuracy required by forecasters, nevertheless we might hope that the forecast should at least retain much of the information included in the analysis and that forecasts of maximum wind are unbiased when compared with verifying objective analyses. This is not the case at the moment and recent work by Carter (1986) has suggested that if we were more selective in applying the diffusion which is needed to maintain stability then jet forecasts might be improved.

The technique tested by Carter involved a reduction in the amount of conventional diffusion together with the addition of a rather more selective diffusion along streamlines. He noted marginal improvements in jet forecasts but a slight worsening in other model variables (based on rms difference from verifying observations). An alternative approach is considered here whereby the increased noise generated by running with a reduced coefficient for the conventional non-linear diffusion is combatted by including a small amount of divergence diffusion which has proved very successful in controlling the noise in data assimilation (Dumelow 1983) and also more recently in fine-mesh forecasts.

A brief account of the experiments undertaken to identify appropriate diffusion coefficients is included in Section 2. The impact on jet forecasts, based on a subjective assessment of eight cases (four winter and four summer) is discussed in Section 3. The medium range msl pressure forecasts for the same eight cases are compared against control forecasts in Section 4 and the results of an objective verification is included in Section 5.

2. Determination of diffusion coefficients

The horizontal non-linear diffusion for variable X takes the form $K|\nabla^2 X|\nabla^2 X$, whilst the divergence diffusion entails the addition of a term $K_D \nabla D$ to the momentum equations where D is the horizontal divergence. At present $K = 2*10^{14}\ m^4 s^{-1}$ and K_D is zero in the coarse-mesh forecast model, although a non-zero value ($K_D = 5*10^6\ m^2 s^{-1}$) is used during the coarse-mesh assimilation.

The first step taken was to run a series of sensitivity forecasts to assess the impact of smaller values of K and larger values of K_D. Values in the range $K = 2*10^{13} - 2*10^{14}$ and $K_D = 0 - 5*10^6$ were considered. The forecasts were assessed subjectively with regard to increased jet speeds and increased roughness in the surface pressure field, and also the degree of smoothing was assessed objectively by considering the rms global pressure tendency, the mean rainfall rate and the rms global divergence. A summary of these results is contained in Table 1.

RUN	1	2	3	4	5	6	7	8	9
K	2E14	2E14	2E14	2E14	2E14	1E14	5E13	2E13	4E13
K_D	5E6	2E6	1E6	5E5	0	0	0	0	1E6
T+24 rms pressure tendency (mb/hr)	.61	.70	.76	.81	.92	.97	1.03	1.12	.80
T+24 rms total divergence	.6E-5	.7E-5	.8E-5	.9E-5	1.2E-5	1.4E-5	1.6E-5	1.8E-5	.9E-5
T+24 mean dynamic rain rate (mm/hr)	.019	.021	.023	.025	.028	.033	.036	.037	.029
T+24 mean speed of 10 jets in chart 15 area (knots)	104	105	106	107	109	111	113	115	111

Diagnostics from tuning experiments

Table 1

Column 5 indicates the results for the present operational case. Progressively smoother results are obtained by increasing the value of K_D as can be seen from columns 4 to 1. Columns 6-8 show increasingly noisier results as the diffusion coefficient K is reduced. Clearly the value of K must be reduced below a quarter of its operational value before we see a significant impact on jet wind forecasts. It is equally clear that some additional smoothing is then required since the forecast becomes unacceptably noisy. Several further runs which consisted of a reduced value of K in the range $2*10^{13}$ to $4*10^{13}$ and a non-zero value of K_D in the range $5*10^5$ to $2*10^6$ enabled the values of $K = 4*10^{13}$ and $K_D = 1*10^6$ to be arrived at for additional testing. These values are one fifth of those used in the operational assimilation. The diagnostic results using these values are given in column 9 of Table 1. Compared with the operational case, the rms pressure tendency and rms total divergence are slightly less whilst there is about the same amount of rainfall. Jet speeds are increased by a modest 2 knots on average. The mean increase in jet speeds is a little misleading since it hides the fact that broad jets are relatively unaffected by the changes, whereas some of the smaller jets are increased by much bigger margins.

Figures 1 and 2 show the extreme cases of maximum wind forecasts at T+24. They are based on runs 1 and 8, that is "1/10 diffusion" with no divergence diffusion compared with a run with the diffusion coefficients set to the values used in the operational assimilation. In places the jet wind speeds differ by well over 10 knots. The unrealistic feature over the Sahara in Figure 1 is in fact removed by a very small amount of divergence diffusion. The numbers attached to each jet maximum (under the wind speed value) represent changes compared with the operational case. The smoothing introduced by divergence diffusion is slightly more selective than the normal diffusion but is still capable of reducing jet cores by up to 10 knots. This poses an interesting question regarding the retention of strong jets in the data assimilation cycle in data sparse regions and it might be worth considering whether less damping in the assimilation model is feasible.

3. Subjective assessment of impact on upper wind forecasts

The main trial consisted of four winter forecasts and four summer forecasts which were run to 5 days. As upper wind forecasts are only used in the short range, we only assessed the T+24 fields subjectively. Upper wind forecasts for both hemispheres were studied and comparisons were made between test and control as well as with verifying objective analyses and for the Atlantic sector with verifying subjective analyses. 156 jets in excess of 100 knots were identified in the eight forecasts (79 in the Northern Hemisphere and 77 in the Southern Hemisphere). The trial jets were stronger than those in the control runs by an average 2.7 knots. There was some indication that the strongest were increased by rather more than the average (see Table 2).

	100-119 knots	120-139 knots	140-159 knots	160+ knots
Northern Hemisphere				
number of cases	36	29	10	4
mean (trial-control) (knots)	2.4	3.9	3.2	3.7
Southern Hemisphere				
number of cases	35	30	9	3
mean (trial-control) (knots)	1.9	2.5	2.8	3.7

Mean change in jet speed as a function of strength of jet

Table 2

Although the mean speed is increased by only a modest amount, a significant number of jets are increased by around 10 knots, whereas very few jets show any decrease. Figure 3 contains a histogram of the number of jets as a function of the increase.

The above results show a useful increase in jet speeds from the trial over the control. To see if this increase represented an improvement, we examined those jets in the North American, North Atlantic and European sectors and compared them with a subjective analysis by CFO forecasters. The results for 54 jets are summarised in Table 3.

	trial	control
mean difference (f/c-verif) (knots)	-10.9	-14.7
rms difference	20.0	21.6

Comparison with subjective verifying analyses of the jets

Table 3

Clearly the increased jet speeds in the trial forecasts are in the right direction with the negative bias reduced from an average 15 knots to 11 knots and rms errors reduced by 2 knots.

In addition to the 8 trial cases already discussed, we ran two other cases, one to compare results directly with Carter's streamline diffusion runs and one to examine the impact on a recent poor forecast.

Case I - 12Z 10 June 1986

In this case there was a strong flow across the Atlantic with jet speeds of near 150 knots to the west of an upper trough over Ireland. During the 24 hour period the trough sharpened as it moved East across the

UK. By 12Z 11 June CFO were still analysing a NW jet of 150 knots over the country, although by this time reports from UK radiosondes did not exceed 135 knots. At the surface a small warm front wave depression developed at 25W and moved towards Brittany. The disappointing aspect about the operational forecast was the way in which the jet speed declined from 165 knots at T+6 to only 108 knots at T+24. The wave depression was little more than a weakness in the High pressure system which was developing. The trial forecast improved on the operational forecast by 9 knots with a jet core of 117 knots at T+24. The maximum wind forecasts at T+24 for the operational and trial forecasts are given in Figures 4 and 5. Further forecasts were run using the fine-mesh model starting from both an interpolation of the same coarse-mesh analysis and from the fine-mesh analysis. Further increases in the jet speeds were obtained as can be seen from Figure 6. Clearly the jet core is a subgrid scale feature as far as the coarse-mesh model is concerned and by far the most useful improvements in forecast skill are obtained by running a higher resolution model which is capable of resolving the detail of the jet core. The fine-mesh forecast which resulted in the maximum wind chart depicted in Figure 6 started from a fine-mesh analysis and used the same values of diffusion coefficients as the coarse-mesh trial (with an appropriate adjustment to cater for the increased resolution). This gave stronger jets than the equivalent run with the operational fine-mesh forecast which incorporates additional diffusion designed to give smoother rainfall forecasts. Both runs using the fine-mesh analysis were more successful than comparable runs from an interpolated coarse-mesh analysis. The T+24 maximum wind from the best run is, coincidentally, the same as was reported by the radiosonde network.A summary of the jet speeds from the six forecasts is given in Table 4.

	T+0	T+6	T+12	T+18	T+24
operational coarse-mesh	135	165	140	136	108
coarse-mesh with modified diffusion	135	167	141	142	117
operational fine-mesh (interpolated coarse-mesh analysis)	135	178	143	143	118
fine-mesh with modified diffusion (interpolated coarse-mesh analysis)	135	183	150	148	125
operational fine-mesh (fine-mesh analysis)	140	175	163	138	128
fine-mesh with modified difussion (fine-mesh analysis)	140	179	172	143	135

Forecast jet speed over UK 10 June 1986

Table 4

Case II 00Z 14 January 1986

The 24 hour forecast from this data time is given in Figure 7 and compares directly with Figures 1-3 of Carter (1986). Much the same modest increases in speed are obtained as Carter noted in this case. The six jets in Figure 7 have a mean speed of 141.3 knots, compared with 141.5 knots from a forecast with streamline diffusion and 137.8 knots for the operational forecast.

4. Subject assessment of impact on surface pressure forecasts

The trial forecasts evolved in a similar manner to the control forecasts for the first three days and it was only in the latter stages of the forecasts that we observed the forecasts diverging. The most significant feature of the trial forecasts was the slight deepening of the low pressure systems in response to the stronger jets. We assessed the central pressures of 50 depressions in the eight T+96 forecasts by comparing them against verifying subjective analyses produced for the Northern Hemisphere by CFO. The results of this assessment are summarised in Table 5. No allowance was made for positional errors in this assessment.

	trial	control
mean error	-2.4 mb	0.5 mb
rms error	8.1	7.7
standard deviation	7.7	7.7

Results of a subjective assessment of depths of depressions

Table 5

In these forecasts the slight deepening was not beneficial. Although the standard deviation of the difference was unchanged, the average 3 mb deepening represents a slight worsening in the mean errors. One example of a four day surface pressure forecast is shown in Figures 8 and 9. In this case the two Pacific systems are incorrectly deepened whereas the major Atlantic system is correctly 6 mb deeper. The most noticeable feature of this case is the small system in the Atlantic at 50W 30N. The difference here is the largest both in this forecast and the other seven examined. The low verified well as regards position but the trial forecast was much too deep compared with the 1010 mb analysed objectively. Although the control forecast at 1016 mb was more correct than the trial forecast's 997 mb, it is debatable whether it was more useful in terms of the information presented to the forecasters since only a weak trough was predicted where in reality there was a substantial low latitude disturbance.

Apart from examining the synoptic evolution we also look for any signs of increased noise in the trial forecasts. Nothing was noted in the smoothed polar stereographic output (300 km projection) but a closer examination of the results output at the model resolution showed some interesting differences in the tropics. Figures 10 and 11 compare 5 day forecasts of surface pressure for one of the summer cases. The characteristic feature of an operational forecast at this projection is a large number of Lows and Highs in the low pressure belt near the equator. In the trial forecast there are many fewer lows and highs marked but the tropical forecast is characterised by roughness in the contours particularly equatorward of the subtropical highs.

5. Objective verification

A summary of the objective verification is contained within the two Tables 6 and 7. Table 6 indicates, for each of the eight cases, whether the trial forecasts were better or worse than the comparable controls. Surface pressure verification is based on a comparison with ships and synops, whilst 250 mb wind verification is performed against the radiosonde network. Details are presented for three forecasts periods (T+24, T+72, T+120) and three latitude zones, the tropics and the northern and southern extra-tropics.

	T+24			T+72			T+120		
	NH	TR	SH	NH	TR	SH	NH	TR	SH
PMSL									
CASE 1	X	O	X	X	X	O	X	X	O
CASE 2	O	O	X	X	O	X	O	X	O
CASE 3	O	O	X	X	X	O	X	X	O
CASE 4	X	O	O	O	O	X	O	X	O
CASE 5	O	O	X	X	O	O	X	O	X
CASE 6	X	O	O	X	X	X	X	X	X
CASE 7	O	O	O	X	O	X	X	X	O
CASE 8	-	-	-	X	X	O	X	X	X
250 MB WIND									
CASE 1	X	X	O	X	X	X	X	X	X
CASE 2	X	X	O	O	X	X	O	X	O
CASE 3	O	X	O	O	X	O	O	X	O
CASE 4	X	O	O	O	X	X	X	X	O
CASE 5	O	O	X	X	X	X	X	X	O
CASE 6	X	O	X	X	O	X	X	O	O
CASE 7	X	O	X	X	O	X	X	X	X
CASE 8	-	-	-	X	X	X	X	X	O

Scores for the individual case for three forecast periods
(1 day, 3 day, 5 day) and three latitude zones
(NH = north, TR = tropics, SH = south)

X = TRIAL WORSE, O = TRIAL EQUAL OR BETTER

Table 6

At T+24, the two sets of runs are comparable with as many of the trial forecasts scoring equal or better as were scoring worse. However, even at T+24, the rms error for 250 mb wind in the Northern hemisphere was increased more often than it was reduced. This apparent contradiction with the results presented for the jets is probably because slight positional errors in jets which have been correctly strengthened will lead to greater rms errors. As the forecasts progressed there was a marked tendency for the majority of trial forecasts to be worse than the control. Northern Hemisphere summer trial forecasts, in particular, were giving consistently higher rms errors at 5 days.

The rms difference from verifying observations were obtained for the combined eight cases and the changes in rms error (control-trial) are given in Table 7.

	T+24			T+72			T+120		
variable	NH	TR	SH	NH	TR	SH	NH	TR	SH
pmsl	-0.1	0	-0.1	-0.2	0	-0.1	-0.3	-0.2	-0.1
850 ht	-0.1	-0.1	-0.2	-0.2	-0.2	-0.1	-0.4	-0.2	-0.2
500 ht	0	-0.1	0.1	-0.2	0	-0.1	-0.4	-0.1	-0.1
250 ht	0.1	0	0	-0.1	0	-0.2	-0.4	0.1	-0.1
100 ht	0.1	0	-0.1	0.2	0.1	0	0.4	0.3	-0.4
850 temp	-0.1	0	-0.2	0	0	-0.2	-0.1	-0.1	-0.2
500 temp	-0.1	0	0	-0.1	0.1	0	-0.1	0.1	0
250 temp	0	0	0	-0.1	0	-0.3	-0.2	-0.1	-0.3
100 temp	-0.1	0	0.1	-0.1	0.1	0.1	-0.1	0.1	0.1
850 wind	-0.3	0.1	-0.1	-0.6	-0.1	-0.6	-0.8	-0.3	-0.8
500 wind	-0.2	0	-0.1	-0.6	0	0.1	-0.9	-0.2	-0.9
250 wind	-0.1	0.2	-0.2	-0.7	-0.2	-1.2	-0.6	-0.2	-0.4
100 wind	-0.1	0.1	0	-0.2	-0.1	-0.2	-0.5	0	-0.2

Change in rms error
(control-test)

Table 7

At T+24, the change in the rms error was at the limit of detectability for all but a few variables. There was a positive impact in the tropics and at higher levels generally, but in total the impact was very slightly negative.

For the longer range forecasts the negative impact of the trial is more clear, although of course the rms errors are greater and the difference in rms error does not necessarily indicate a larger change in percentage terms.

6. Conclusions

The trial of a coarse-mesh forecast with modified diffusion has been successful in its aim of increasing forecast jet speeds. The increase is generally modest but a significant proportion of jets are increased by up to 10 knots. We have demonstrated that this increase represents an improvement by comparing the forecasts against verifying subjective analyses. In the medium range forecasts we noted a general deepening of low pressure systems which did not verify better than the control when we considered the mean errors for all eight cases. However, operationally the model does seem to produce rather weak small scale systems in the longer period forecasts, particularly during the summer, and in these situations the change is likely to be marginally beneficial. The objective verification indicated a broadly neutral impact at T+24 but a consistent negative impact for longer forecasts. If the increase in rms errors for forecasts beyond 2 days is unacceptably large, it would be a straightforward matter to revert back to the present operational values of diffusion coefficients for the last four days of an operational six day forecast whilst retaining the benefits to aviation forecasts of the trial version in the first two days.

There are two further points arising from this study which are worth reiterating. Firstly, there is a significant weakening of jet cores when the assimilation value of the divergence diffusion coefficient is used and this implies that analysed jets will not be fully retained during the data assimilation cycle unless further observations are available. Stronger analysed jets in data sparse areas would result from less damping in the assimilation, which might be a feasible proposition when the smoother analyses produced by the analysis correction scheme are available. Secondly, in the one case where we examined fine-mesh forecast jets, the detail of the jet core was resolved substantially better than by the coarse-mesh model as one might expect. There is clearly a case for using the fine-mesh model for aviation forecasts.

References

Carter M J 1986 An investigation of streamline diffusion Met O 2b TN109.

Dumelow R K 1983 Some experiments in the use of divergence damping in the operational assimilation model Met O 11 TN17.

Hardman M E 1985 The use of 15-level model products in the Central Forecast Office for forecasts for civil aviation. Meteorol Mag 114 pp 273-281.

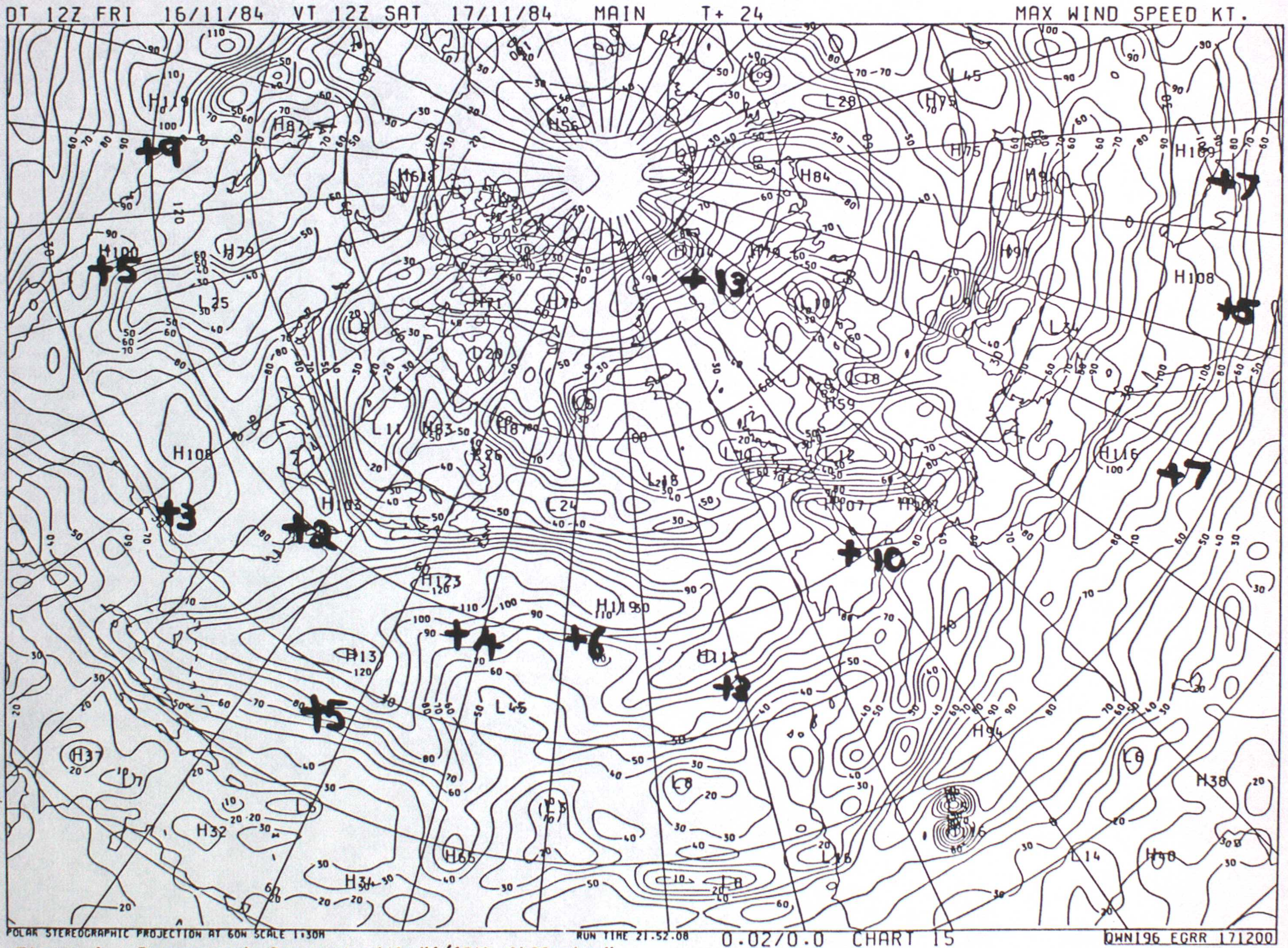

Figure 1...Coarse-mesh forecast with "1/10th diffusion"

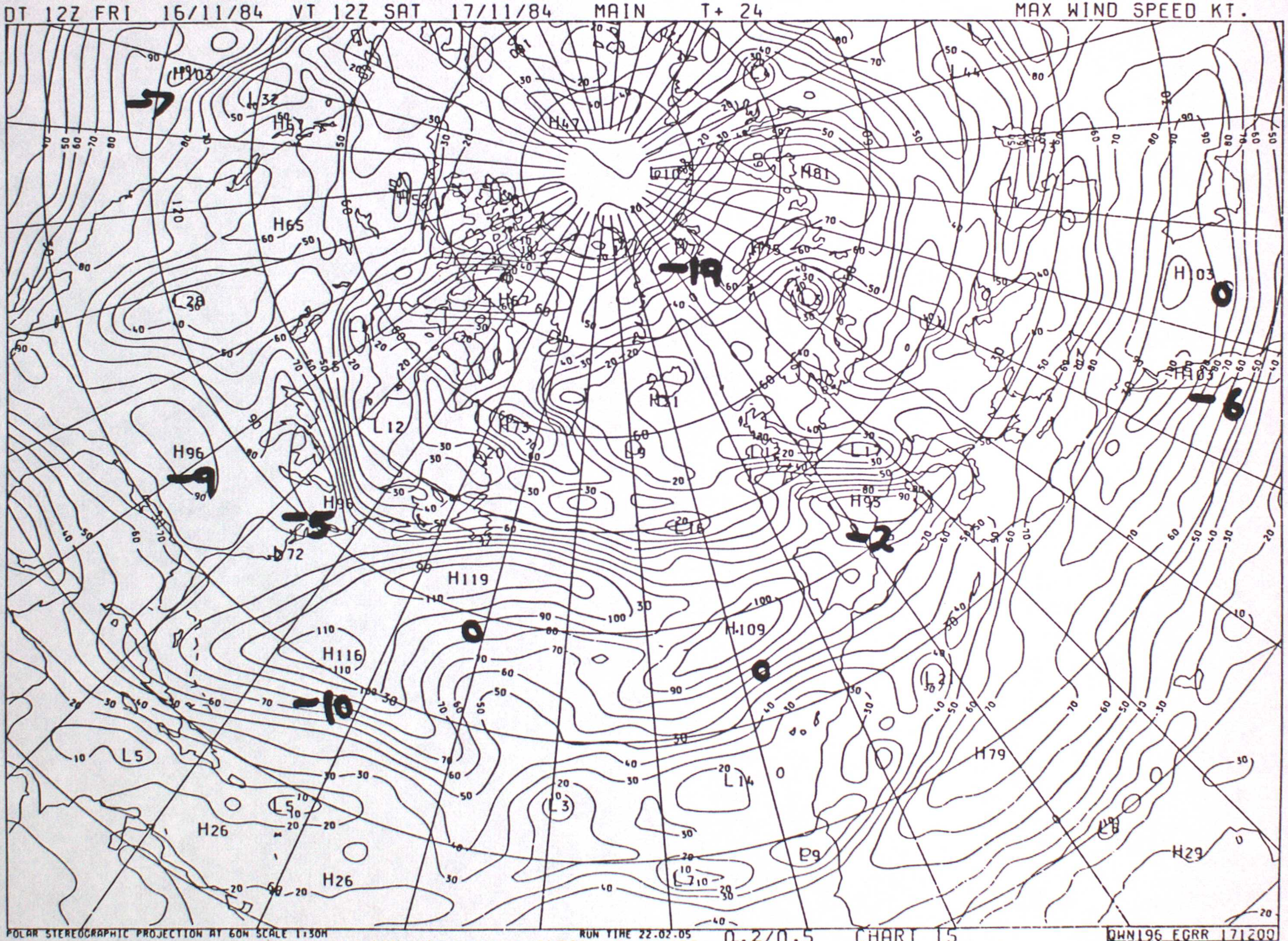

Figure 2...Coarse-mesh forecast with divergence diffusion coeff.=.5e7 (as for assimilation)

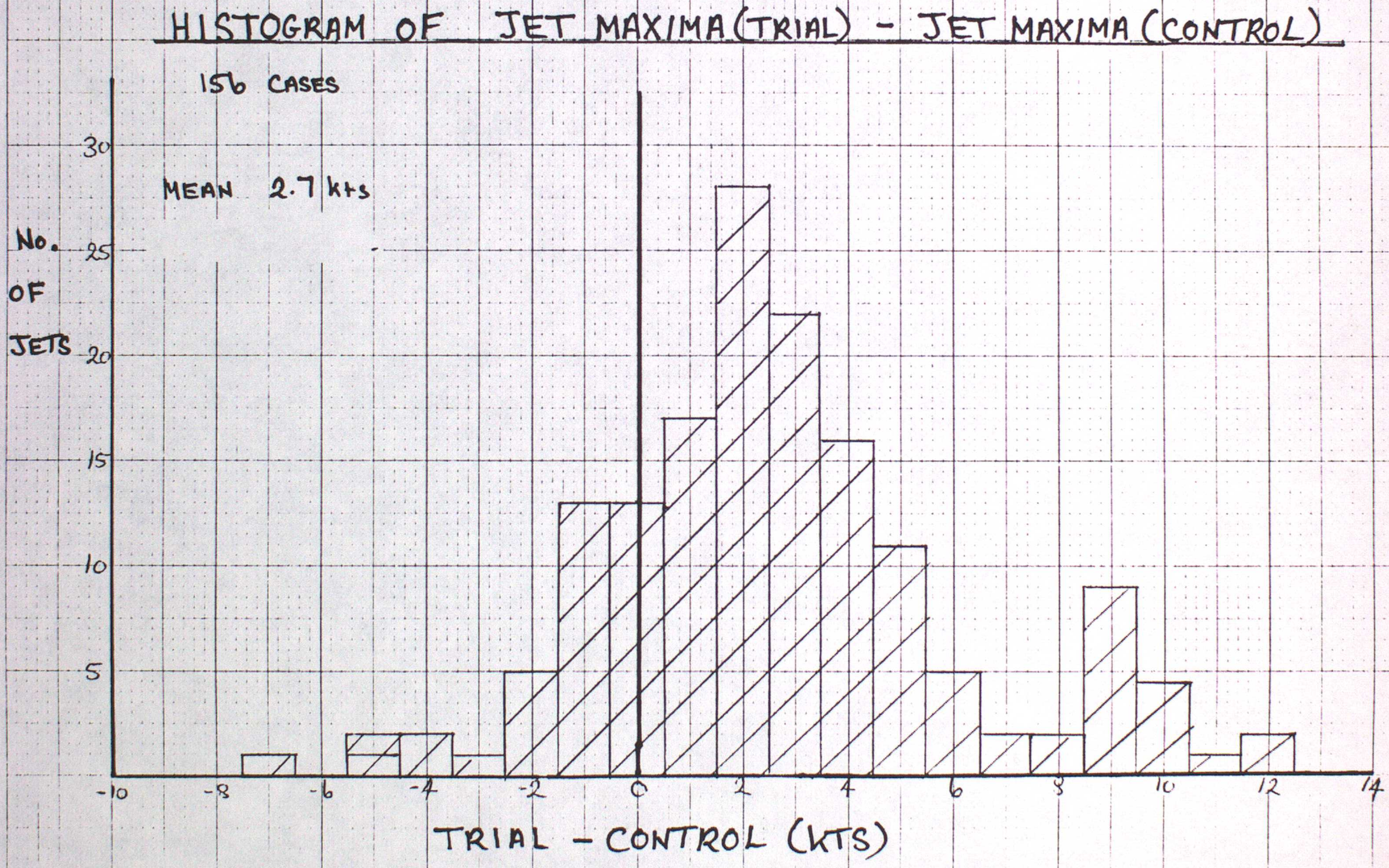
HISTOGRAM OF JET MAXIMA (TRIAL) - JET MAXIMA (CONTROL)
156 CASES
MEAN 2.7 kts
No. OF JETS
30
25
20
15
10
5
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
TRIAL - CONTROL (KTS)

Figure 3....

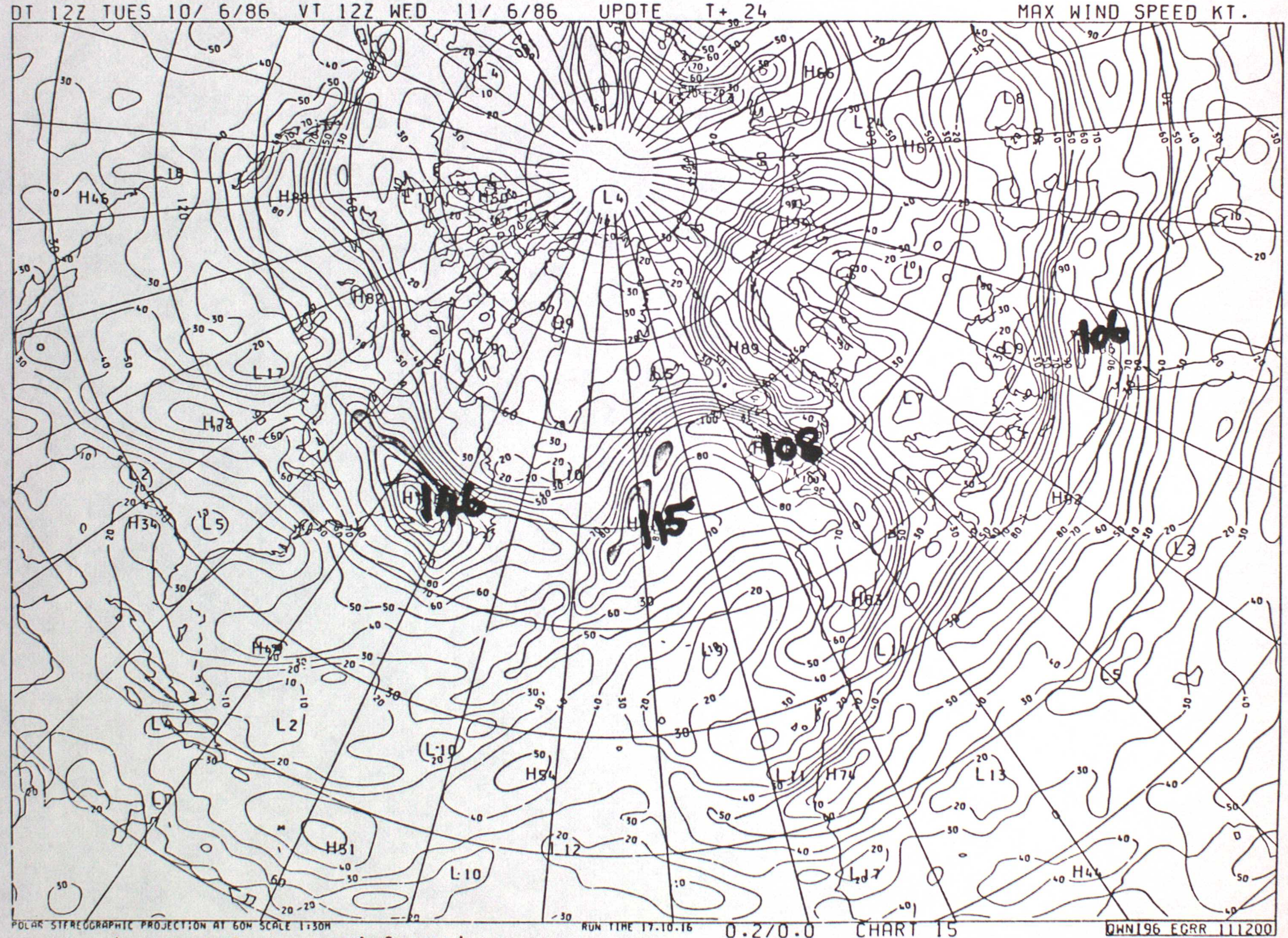

Figure 4... Control coarse-mesh forecast

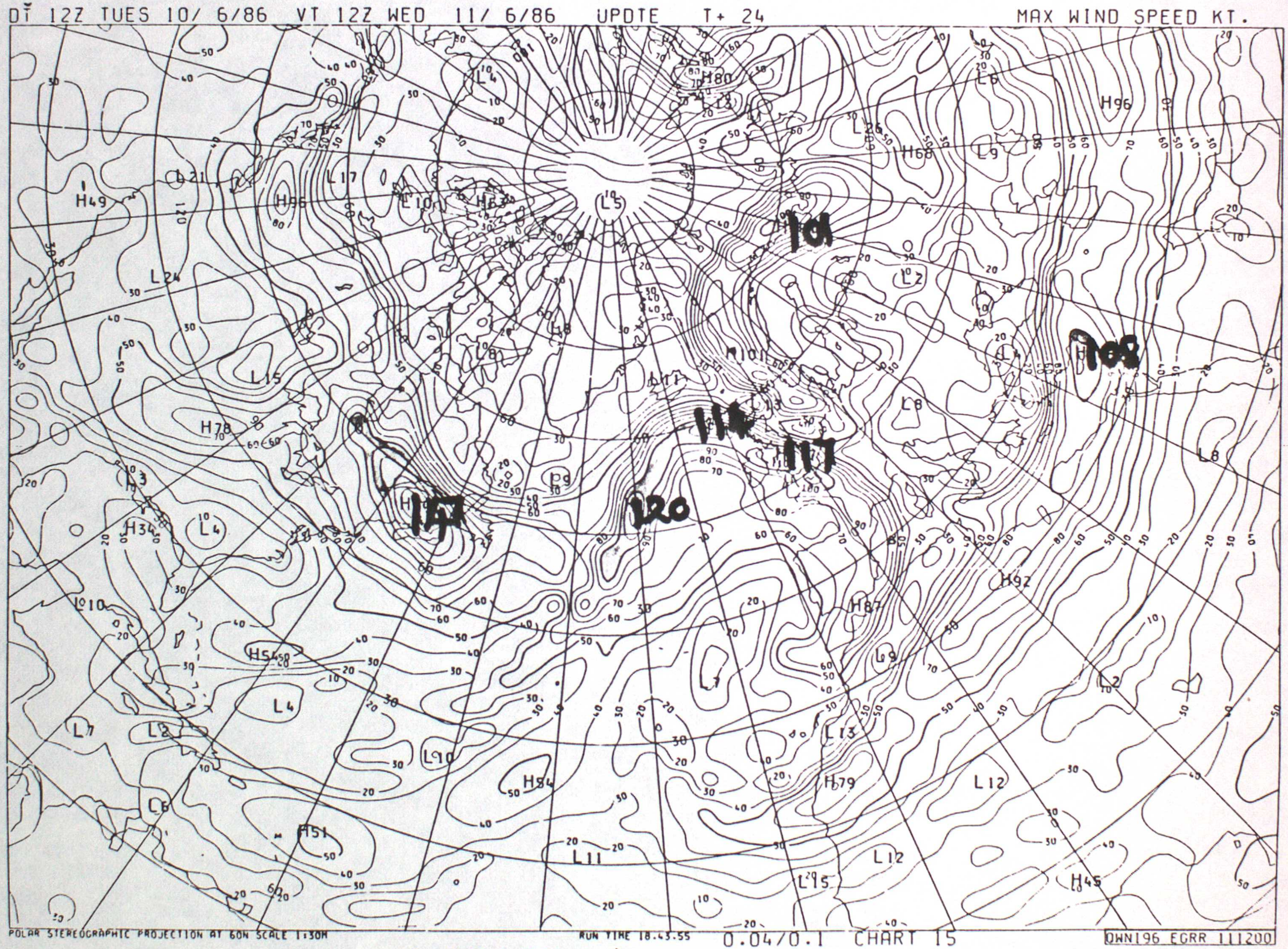

Figure 5... Trial coarse-mesh forecast(modified diffusion)

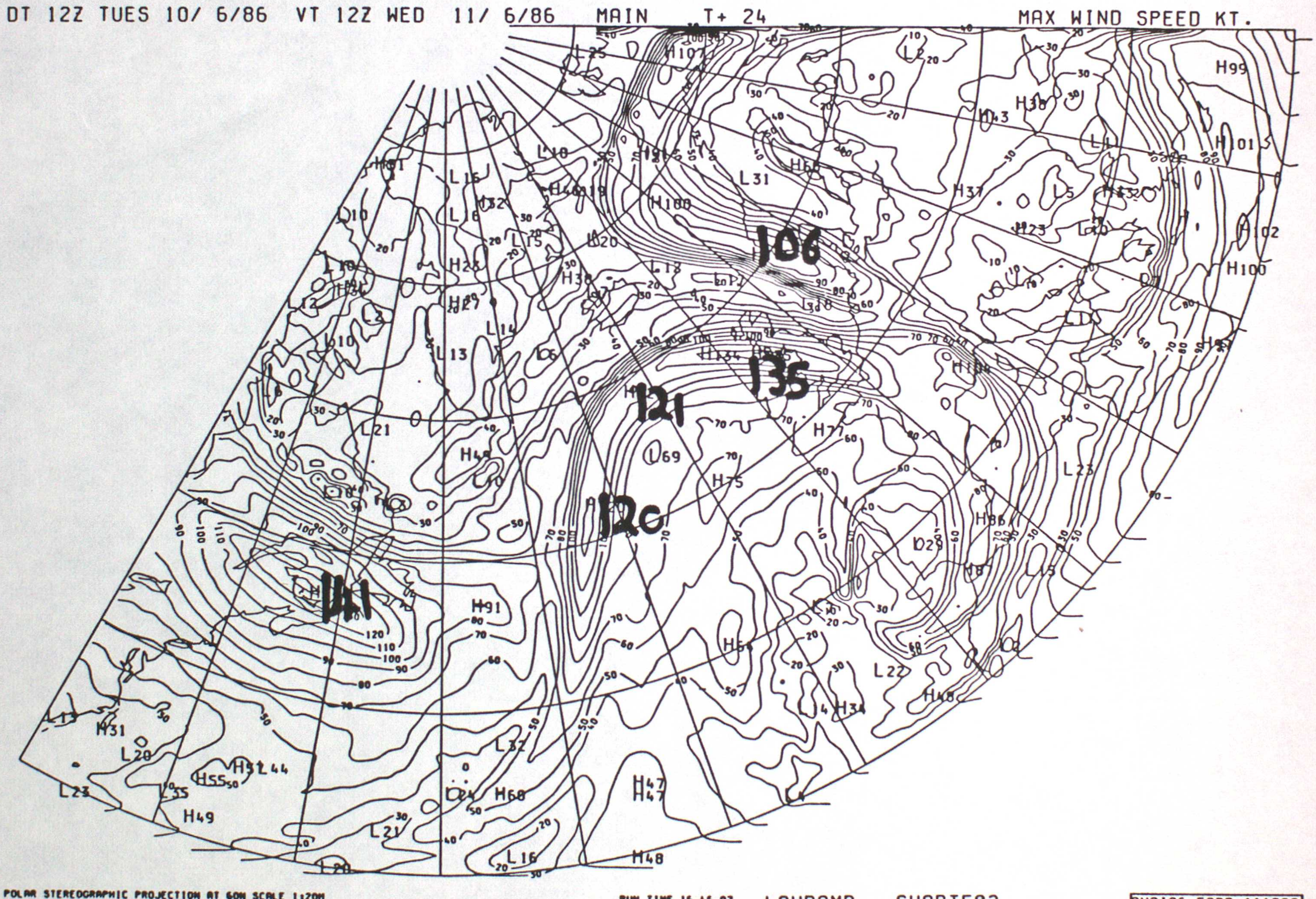

Figure 6... Trial fine-mesh forecast(modified diffusion) starting from fine-mesh analysis

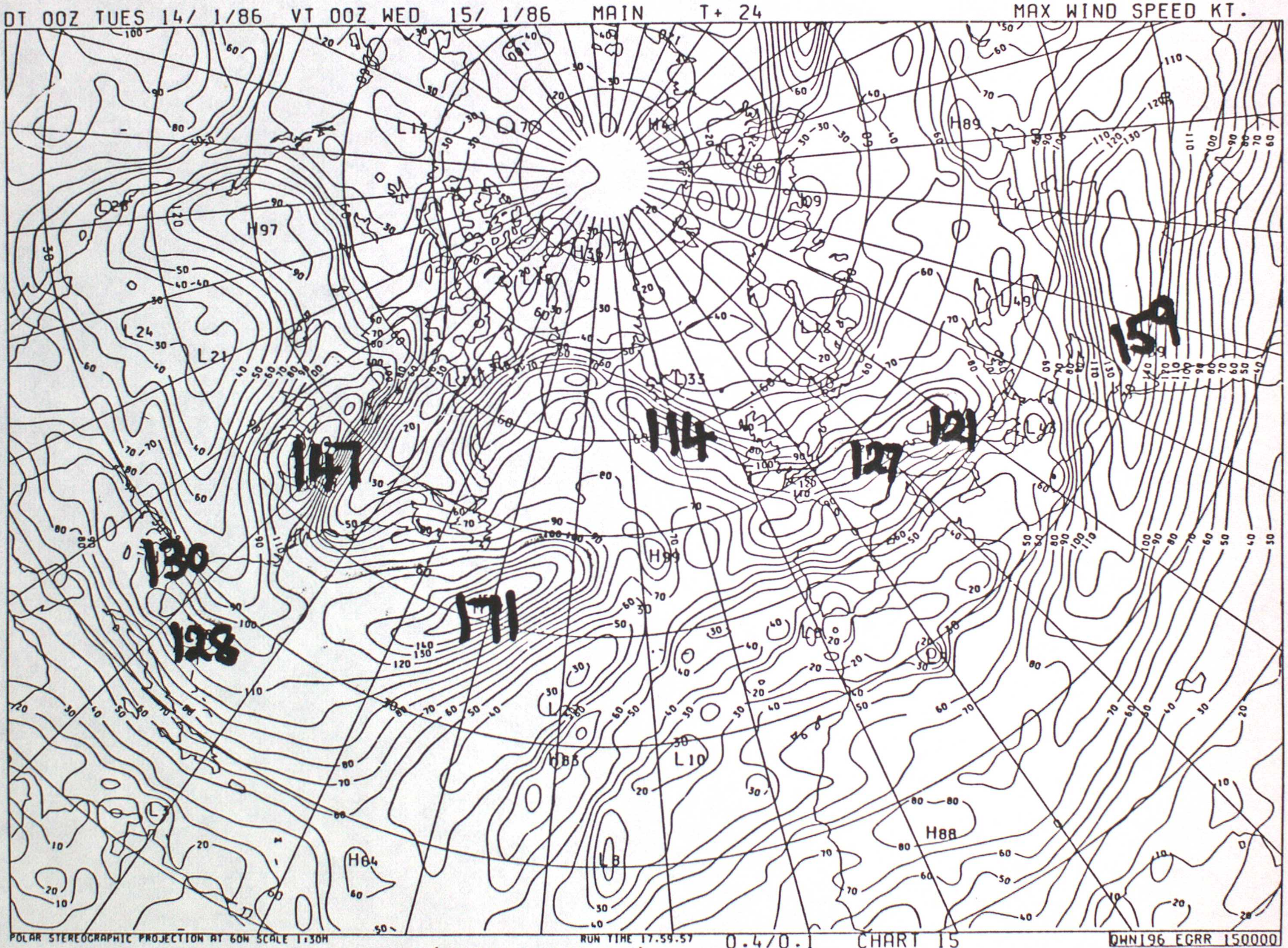

Figure 7... Trial coarse-mesh forecast (modified diffusion)

CONTROL
MEAN SEA LEVEL PRESSURE
VALID AT 12Z ON 27/11/1984 DAY 332 DATA TIME 12Z ON 23/11/1984 DAY 328
LEVEL: SEA LEVEL

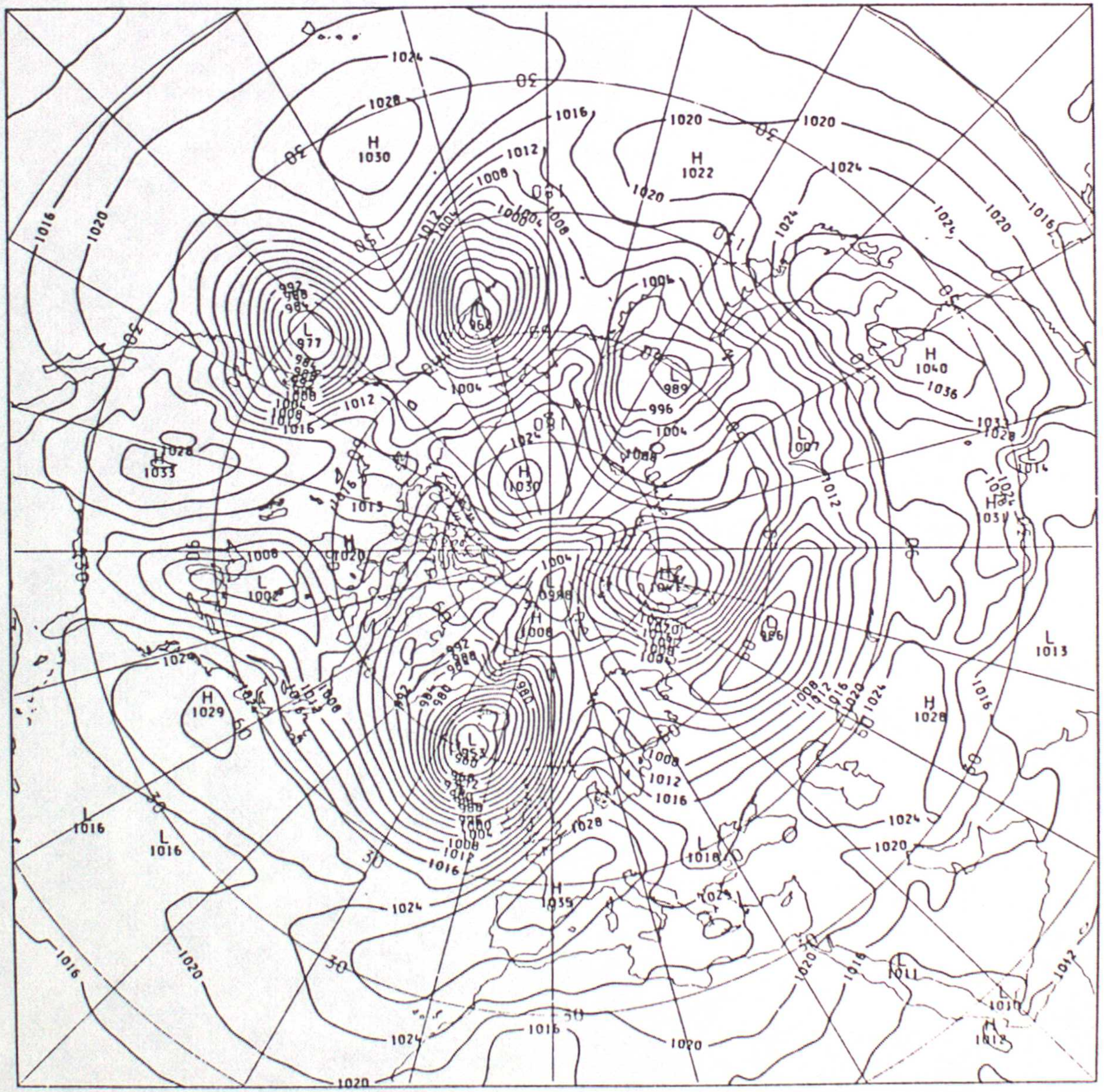

Figure 8 Control coarse-mesh forecast (t+96 pmsl)

TEST (MOD DIFFUSION)
MEAN SEA LEVEL PRESSURE
VALID AT 12Z ON 27/11/1984 DAY 332 DATA TIME 12Z ON 23/11/1984 DAY 328
LEVEL: SEA LEVEL

Figure 9.. Trial coarse-mesh forecast(modified diffusion) (t+96 pmsl)

OPERATIONAL
MEAN SEA LEVEL PRESSURE
VALID AT 12Z ON 4/6/1985 DAY 155 DATA TIME 12Z ON 30/5/1985 DAY 150
LEVEL: SEA LEVEL

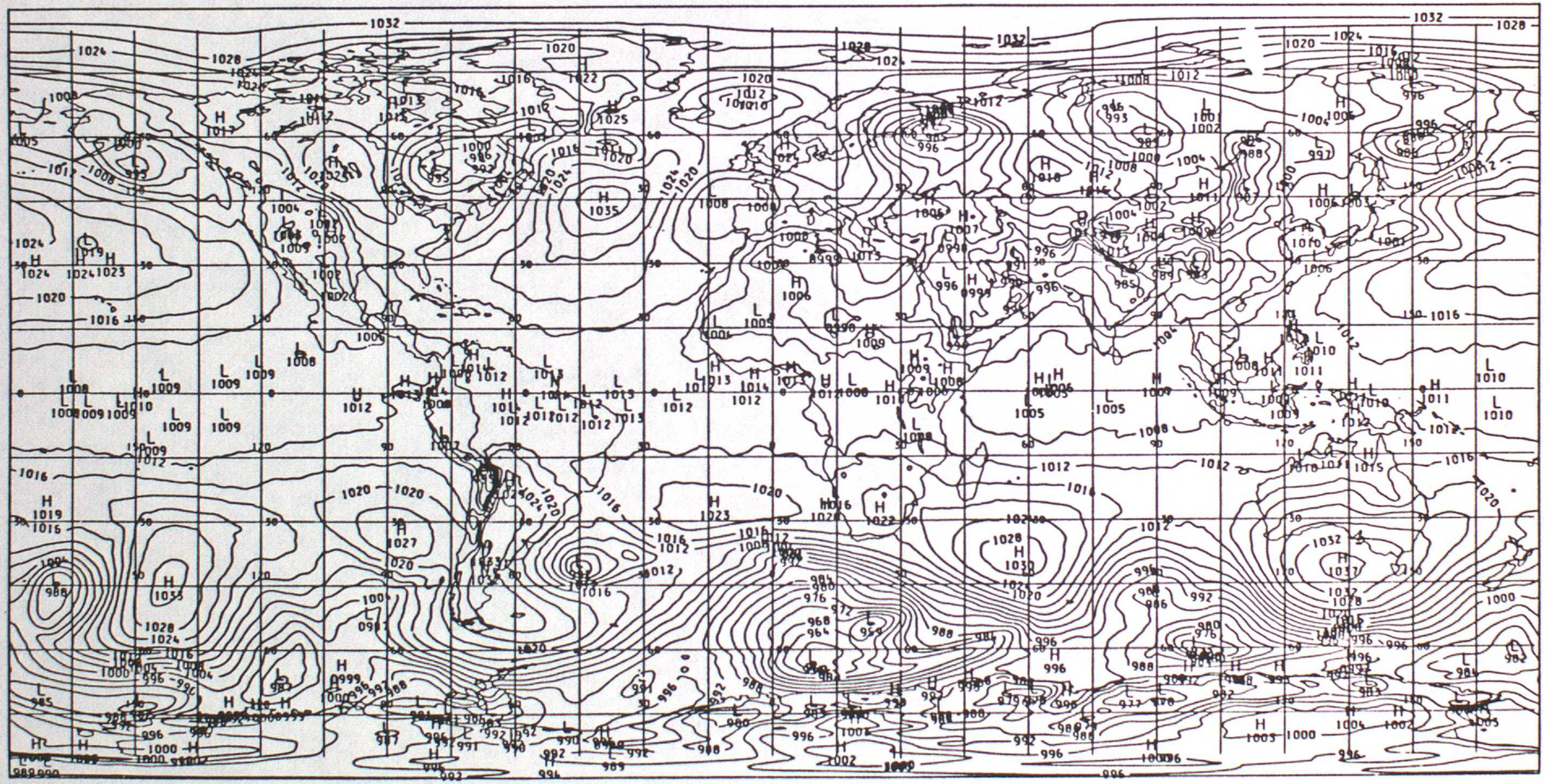

Figure 10... Control coarse-mesh forecast displayed at model resolution (t+120 pmsl)

TRIAL
MEAN SEA LEVEL PRESSURE
VALID AT 12Z ON 4/6/1985 DAY 155 DATA TIME 12Z ON 30/5/1985 DAY 150
LEVEL: SEA LEVEL

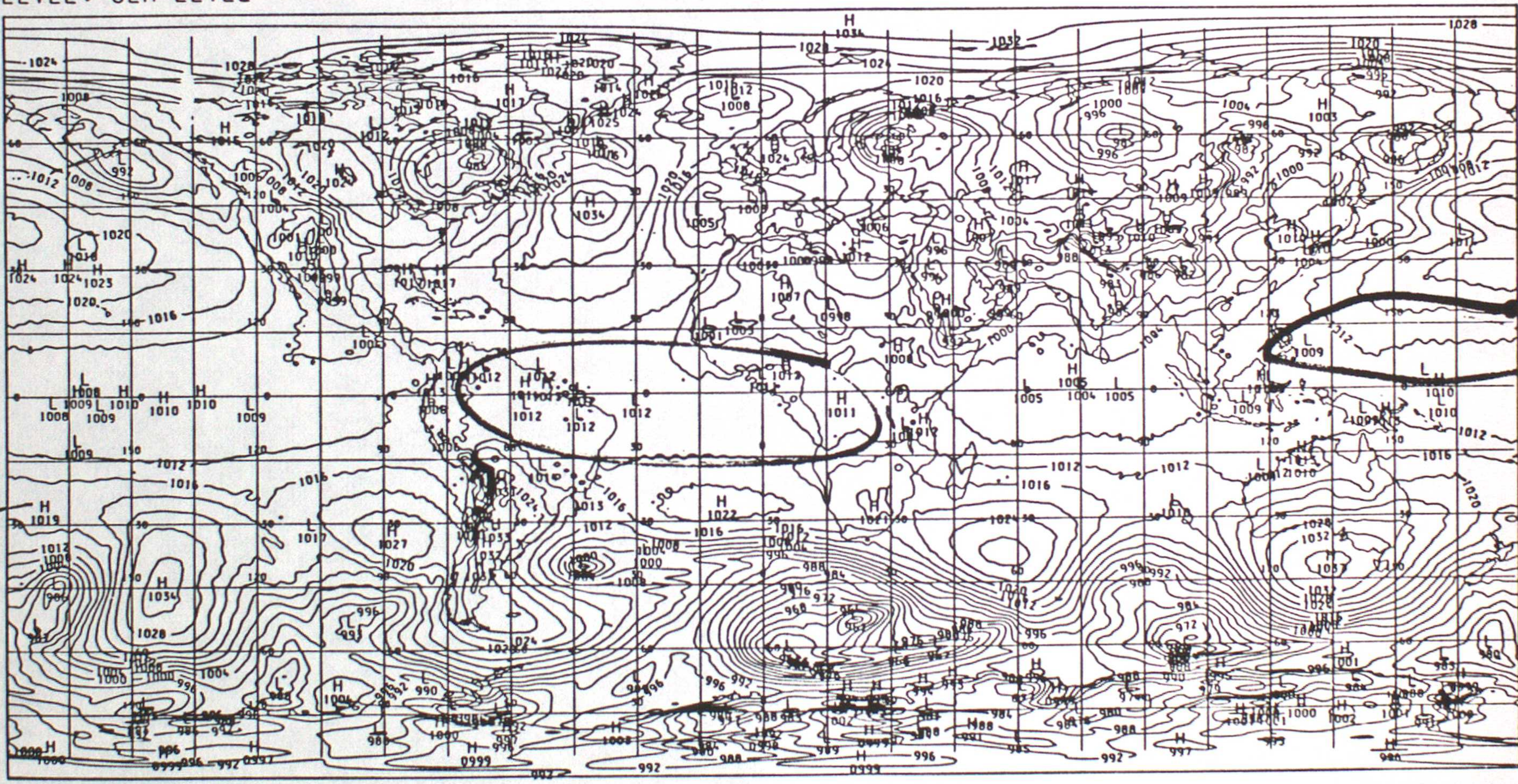

Figure 11 .. Trial coarse-mesh forecast with modified diffusion displayed at model resolution (T+120 pmsl)