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An assessment of the results of trials of a new analysis scheme for the operational global model

by

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1. Introduction

This paper seeks to measure the improvements obtained in global analyses and forecasts due to a new approach to data assimilation. The new scheme (known as the *analysis correction method*) performs a successive correction type analysis at each model timestep using an algorithm which is simpler and more flexible than the optimum interpolation scheme used as part of the present operational repeated insertion assimilation (*Bell and Dickinson, 1987*). It eliminates the need for data selection ,allows a larger observational radius of influence and enables asynoptic data to be inserted in a window around their validity time rather than suffer translation to the nearest synoptic hour.

The analysis increments (I) are calculated from the observation increments (i) by

$$I=QRWi$$

where (W) is the weight assigned to the observation at the gridpoint and (R) is a time factor equal to unity at the observation time and less than unity before and after that time. (Q) is a normalisation factor controlling the rate of convergence towards the observations ,equal to the inverse of an approximate four dimensional data density. Full details of the scheme are given in *Lorenc and Dumelow (1985)*.

The scheme has undergone substantial modification since an unsuccessful preliminary trial during June 1986. These developments include a higher weight for data which falls in the time window T+0→T+3, a new observational weight formula and revised forcing rate towards observations, including a latitudinally varying correlation scale and relaxation coefficient to suit the different dynamical and data characteristics of the three latitude zones. Latitudinal variation of the geostrophic coupling constraint was also improved. In the vertical correlation function for single level data a cut off equivalent to insertion over one scale height rather than the whole atmosphere was also found to be beneficial. *Macpherson (1987)* discusses these in more detail .

A two-week trial was completed in April 1987 and encouraging results were obtained as we shall demonstrate in the subsequent sections. A further short trial was run during August 1987 and results for this period will also be discussed.The version run in August was slightly different from that run in April. As well as being more efficient , several coding bugs were found and removed which had the effect of improving results from single level upper air data and also removing undesirable oscillations in the surface pressure.

The format of the trials and the verification procedures adopted are discussed in the next section . The objective verification using verifying observations is given in section three .A comparison against objective analyses is given in section four.A subjective assessment including examples of particularly interesting cases will be given in section five.

2. The trials

The April trial of the analysis correction (AC) scheme was run from Tuesday 14th to Sunday 26th .The trial consisted of a complete global data-assimilation cycle using exactly the same set of quality controlled observations as were used operationally . A fifth cycle was also run to duplicate the 12z main forecast run , the trial forecast from this cycle extended to 3 days.This procedure does not entirely mimic what would happen if the new scheme were operational since we are not quality controlling the observations using first guess fields derived from the trial assimilations. However the use of identical observation sets makes the evaluation task much easier since differences are restricted to the assimilation method. The trial suite ran successfully until the 25th when incomplete recovery from a planned power outage in COSMOS meant that results could not be compare precisely with the operational results. 10 forecasts were available for verification from the 15th to the 24th , however the sample was reduced slightly due to problems with the verifying observations.

The August trial commenced on the 26th and ran for one week. The format of this trial was identical to the April trial except that the assimilation for the fifth cycle which duplicated the main forecast run was continued on to T+4, thus allowing for the full assimilation of data whose time of report was after T+0. The trial ran successfully for the full week except for a problem with the observations for the 06GMT run on the 29th.

For both trials ,a detailed subjective assessment was done by forecasters in the Central Forecast Office. They examined analyses and forecasts (for days 1-3) of pmsl and 500mb height for the Atlantic, Pacific and Southern Hemisphere and also analyses and day 1 forecasts of maximum wind in the N. American-Atlantic-European sector.The main aim being to identify cases where one system performed significantly different from the other.

The objective assessment consisted mainly of a comparison of model analyses (at 00z and 12z) and forecasts against verifying surface and radiosonde reports.Results were meaned for three latitude bands (north of 30°N, 30°N-30°S and south of 30°S) . The forecast verification was for T+24,48 and 72 from the 12z forecast run and also T+6 forecast first guess fields from the intermediate 6z and 18z analyses.

3.Objective assessment

a) Verification of the data assimilation cycle for the April trial

The objective verification of analyses for the trial was lost because of software problems, and has not yet been repeated. T+6 verification is available and this is a better measure of the quality of the assimilation , since a close fit of the analysis to data does not necessarily imply a good analysis. Table 1 below gives the rms differences of the first guess fields from verifying synops and radiosondes during a 10 day period this April for both the test data assimilation cycle and the comparable operational cycle. .The new scheme has outperformed the operational scheme for all variables at almost every level in each of the three latitude bands. Improvements in fit are about 0.5knots in the wind errors,1 metre in the height errors , 0.1°C in the temperature errors and nearly 0.2mb in the surface pressure errors.

These changes represent a substantial reduction in the first guess error. This appears to be a consistent improvement; we have noted that for the 20 first guess fields verified, the new scheme betters or equals the operational scheme on every occasion for both surface pressure and 250mb winds in the northern hemisphere.

	Northern Hemisphere (90°N-30°N)	Tropics (30°N-30°S)	Southern Hemisphere (30°S-90°S)
pmsl (mb)	**2.21** (2.37)	**2.13** (2.27)	**2.58** (2.64)
850mb height(dm)	**1.42** (1.55)	**1.43** (1.54)	**1.64** (1.68)
500mb height(dm)	**2.00** (2.08)	**2.31** (2.35)	**2.63** (2.65)
250mb height(dm)	**3.36** (3.44)	**3.95** (4.03)	3.55 (**3.53**)
850mb temp(degC)	**2.07** (2.13)	**2.14** (2.17)	**2.63** (2.70)
500mb temp(degC)	**1.46** (1.53)	**1.67** (1.70)	**1.79** (1.83)
250mb temp(degC)	**2.13** (2.20)	1.91 (**1.90**)	**2.47** (2.54)
850mb vec.wind(kts)	**9.6** (10.0)	**10.1** (10.4)	**11.5** (12.0)
500mb vec.wind(kts)	**10.8** (11.2)	**10.9** (10.9)	**13.5** (13.9)
250mb vec.wind(kts)	**14.8** (15.5)	**16.1** (16.5)	**19.1** (20.5)

Table 1

Verification of first guess(T+6) against synops and radiosondes
VT 00GMT and 12GMT 16th-25th April 1987

RMS errors for the trial with comparable operational figures bracketed

b) Forecast verification for the April trial

The following tables (2a,2b and 2c) summarise the forecast verification results of the April trial. They show the rms errors for both trial and control forecasts from the 12GMT analyses (forecast periods T+24,48,72) for areas 200,300 and 400 (that is north of 30°N, 30°N to 30°S and south of 30°S respectively). Results are shown for three levels for height, temperature and wind together with surface pressure and one level for relative humidity.

The results are rather mixed. It appears that the improvements obtained using the analysis correction scheme, which are clearly seen in the T+6 verification are not present to the same extent in the forecast verification beyond T+6. In the northern hemisphere (Table 2a) we see that , at T+48 for example , the height fields verify marginally worse from the trial yet the wind fields are slightly better. In general the results are very close and with such a small sample, the differences are probably not very significant. The same conclusion can be drawn from the tropical verification (Table 2b). More promising results are obtained in the southern hemisphere (Table 2c) where at T+72 for example lower rms errors are obtained for almost every field.

	T+24	T+48	T+72
pmsl	3.0 (3.0)	4.3 **(4.1)**	5.7 **(5.4)**
850ht	1.9 (1.9)	2.8 **(2.7)**	3.8 **(3.7)**
500ht	2.6 **(2.5)**	3.8 **(3.7)**	5.4 **(5.2)**
250ht	4.0 **(3.9)**	5.3 **(5.1)**	7.3 **(7.0)**
850temp	2.5 (2.5)	3.1 (3.1)	3.7 (3.7)
500temp	1.7 (1.7)	2.2 **(2.1)**	2.7 (2.7)
250temp	2.4 (2.4)	2.8 (2.8)	**3.1** (3.2)
850wind	11.2 **(11.1)**	**13.4** (13.5)	15.7 **(15.6)**
500wind	13.1 **(12.8)**	16.7 **(16.6)**	20.4 **(19.9)**
250wind	17.5 **(17.3)**	**22.4** (22.6)	27.3 **(26.8)**
700rh	**23.4** (23.7)	**27.1** (27.4)	30.2 (30.2)

Table 2a Forecast verif Area 200 (N H)

	T+24	T+48	T+72
pmsl	2.6 **(2.5)**	2.8 **(2.7)**	3.1 **(3.0)**
850ht	1.7 (1.7)	2.0 **(1.8)**	2.2 **(2.1)**
500ht	2.4 (2.4)	2.6 **(2.5)**	2.8 (2.8)
250ht	**4.0** (4.1)	**4.3** (4.4)	**4.6** (4.8)
850temp	2.4 (2.4)	2.8 (2.8)	3.1 **(3.0)**
500temp	**1.7** (1.8)	**1.9** (2.0)	**2.0** (2.1)
250temp	2.1 (2.1)	2.2 **(2.1)**	2.3 **(2.2)**
850wind	**10.6** (11.2)	12.3 (12.3)	13.2 **(13.0)**
500wind	**12.2** (12.3)	13.5 **(13.4)**	14.4 **(14.3)**
250wind	**20.4** (20.5)	**22.1** (22.7)	**23.7** (24.1)
700rh	**20.4** (20.7)	23.4 **(23.2)**	26.0 **(25.6)**

Table 2b Forecast verif Area 300 (Tropics)

	T+24	T+48	T+72
pmsl	**4.1** (4.2)	**5.5** (5.7)	**6.3** (6.5)
850ht	2.4 (2.4)	3.5 (3.5)	4.3 **(4.2)**
500ht	3.5 **(3.3)**	**4.8** (4.9)	6.1 (6.1)
250ht	4.7 (4.7)	**6.3** (6.7)	**8.9** (9.6)
850temp	**2.7** (2.8)	**3.1** (3.2)	**3.7** (3.8)
500temp	2.2 **(2.1)**	**2.6** (2.7)	**3.2** (3.4)
250temp	2.7 **(2.6)**	3.0 **(2.9)**	**3.2** (3.4)
850wind	**13.6** (13.9)	16.4 **(15.8)**	**17.6** (17.8)
500wind	**16.3** (16.4)	20.8 (20.8)	**23.7** (25.0)
250wind	**21.9** (23.3)	30.2 **(29.7)**	**35.1** (36.3)
700rh	**29.2** (30.7)	32.3 **(31.2)**	**30.7** (32.6)

Table 2c Forecast verif Area 400 (S H)

Table 2 Comparison rms differences of forecast fromverifying synop/ship and radiosondes for trial and (operational)---April period

c) <u>Verification of the data assimilation cycle for the August trial</u>

Verification of the data assimilation cycle for the August trial is given in Table 3 below. The layout is similar to Table 1. Differences of analyses from observations (both 00GMT and 12GMT) are given in Table3a whilst differences of first guess fields (T+6) from observations for the same verifying times are given in Table 3b.

	Northern Hemisphere (90°N-30°N)	Tropics (30°N-30°S)	Southern Hemisphere (30°S-90°S)
pmsl (mb)	**1.65** (1.67)	**2.00** (2.04)	**1.75** (1.84)
850mb height(dm)	**1.13** (1.14)	**1.28** (1.32)	**1.23** (1.39)
500mb height(dm)	1.70 (1.70)	**2.16** (2.17)	3.66 (**3.56**)
250mb height(dm)	3.03 (**2.95**)	3.66 (**3.56**)	**2.63** (2.66)
850mb temp(degC)	1.29 (**1.20**)	1.61 (**1.45**)	1.91 (**1.60**)
500mb temp(degC)	1.07 (**1.03**)	1.42 (**1.34**)	1.10 (**0.89**)
250mb temp(degC)	1.65 (**1.56**)	1.48 (**1.40**)	1.71 (**1.41**)
850mb vec.wind(kts)	6.9 (**6.8**)	7.8 (**7.0**)	9.6 (**9.0**)
500mb vec.wind(kts)	7.2 (**7.0**)	7.9 (**7.0**)	11.2 (**10.5**)
250mb vec.wind(kts)	11.5 (**10.9**)	11.2 (**9.9**)	17.9 (**17.0**)
700mb rel hum	14.6 (**13.9**)	13.2 (**12.1**)	18.9 (**17.2**)

<u>Table 3a (T+0)</u>

	Northern Hemisphere (90°N-30°N)	Tropics (30°N-30°S)	Southern Hemisphere (30°S-90°S)
pmsl (mb)	**1.98** (2.14)	**2.16** (2.29)	**2.56** (2.57)
850mb height(dm)	**1.32** (1.49)	**1.34** (1.49)	**1.84** (1.86)
500mb height(dm)	**2.05** (2.08)	2.28 (**2.27**)	3.37 (**3.35**)
250mb height(dm)	**3.58** (3.60)	3.95 (**3.92**)	4.25 (**4.11**)
850mb temp(degC)	**1.79** (1.82)	2.01 (**1.98**)	**2.77** (2.84)
500mb temp(degC)	**1.42** (1.46)	1.68 (**1.65**)	**1.89** (1.94)
250mb temp(degC)	**2.08** (2.11)	**1.72** (1.74)	**2.65** (2.67)
850mb vec.wind(kts)	**8.7** (9.0)	**10.3** (10.8)	**12.7** (13.3)
500mb vec.wind(kts)	9.5 (9.5)	**10.9** (11.0)	**16.0** (16.7)
250mb vec.wind(kts)	**14.7** (14.9)	**16.0** (16.2)	**23.8** (24.8)
700mb rel hum	**19.6** (20.5)	**17.3** (18.0)	**27.3** (28.1)

<u>Table 3b (T+6)</u>

<u>Table 3 Verification of analyses and first guess fields against synops and radiosondes at 00GMT and 12GMT 26th Aug -1st Sept 1987</u>

RMS errors for the trial assimilations with operational bracketed

The trial analyses only give a better fit to data for surface pressure and low level height fields (see Table 3a) , although differences are generally small in the northern hemisphere for other variables. In the data sparse tropics and southern hemisphere the operational analyses fit data very much closer. There is no benefit to be gained from fitting data too closely as can be seen from the first guess verification in Table 3b. As was seen from the April trial (compare with Table 1) the trial assimilations are providing much more accurate first guess forecasts for almost every variable.

d) Forecast verification for the August trial

The following tables (4a,4b and 4c) summarise the forecast verification results of the August trial. They show the rms errors for both trial and control forecasts from the 12GMT analyses (forecast periods T+12,24,48,72) for areas 200,300 and 400 (that is north of 30°N,30°N to 30°S and south of 30°S respectively).

	T+12	T+24	T+48	T+72
pmsl	**2.2** (2.4)	**2.5** (2.6)	3.6 **(3.5)**	4.9 **(4.8)**
850ht	**1.5** (1.6)	1.7 (1.7)	2.6 (2.6)	3.6 **(3.5)**
500ht	2.1 **(2.0)**	2.4 (2.4)	3.7 **(3.6)**	4.9 **(4.8)**
250ht	3.7 (3.7)	4.1 **(4.0)**	5.6 **(5.4)**	7.1 **(6.9)**
850temp	1.8 (1.8)	2.1 (2.1)	2.6 (2.6)	3.1 (3.1)
500temp	1.4 (1.4)	1.7 **(1.6)**	2.0 (2.0)	2.5 **(2.4)**
250temp	2.2 (2.2)	2.4 **(2.3)**	2.7 (2.7)	**3.1** (3.2)
850wind	**9.1** (9.2)	10.0 **(9.9)**	11.6 **(11.5)**	13.5 **(13.3)**
500wind	9.8 **(9.6)**	11.3 **(10.9)**	14.3 **(14.0)**	17.4 **(17.0)**
250wind	14.9 **(14.7)**	17.1 **(16.6)**	22.6 **(22.0)**	**27.2** (27.3)
700rh	**19.8** (20.5)	**21.6** (21.8)	**24.7** (24.9)	**27.2** (26.6)

Table 4a forecast verif for Area 200 (N H)

	T+12	T+24	T+48	T+72
pmsl	**2.2** (2.3)	**2.5** (2.6)	2.7 (2.7)	3.1 **(3.0)**
850ht	**1.4** (1.5)	1.8 (1.8)	2.2 (2.2)	2.6 **(2.4)**
500ht	2.3 **(2.2)**	2.6 (2.6)	2.9 **(2.8)**	3.2 **(3.0)**
250ht	4.0 **(3.9)**	4.1 **(4.0)**	**4.2** (4.3)	4.7 **(4.6)**
850temp	1.9 (1.9)	2.2 (2.2)	2.4 (2.4)	2.5 **(2.4)**
500temp	1.5 (1.5)	1.9 **(1.8)**	2.0 (2.0)	2.1 (2.1)
250temp	**1.7** (1.8)	1.8 (1.8)	1.8 (1.8)	1.9 (1.9)
850wind	**10.8** (11.3)	**11.0** (11.2)	11.5 (11.5)	12.4 **(12.2)**
500wind	**10.7** (10.8)	12.3 (12.3)	13.5 **(13.3)**	14.8 **(14.1)**
250wind	**15.3** (15.5)	19.2 **(18.8)**	20.4 **(19.8)**	21.3 (21.3)
700rh	**17.3** (18.3)	**18.5** (19.3)	**20.9** (21.1)	21.7 (21.7)

Table 4b forecast verif for Area 300 (Tropics)

	T+12	T+24	T+48	T+72
pmsl	3.2 (3.2)	4.0 **(3.8)**	5.1 (5.1)	6.8 **(6.5)**
850ht	2.4 (2.4)	3.1 **(3.0)**	4.6 **(4.3)**	6.3 **(5.9)**
500ht	3.8 **(3.7)**	4.6 (4.6)	5.8 (5.8)	8.0 **(7.7)**
250ht	4.6 **(4.4)**	**5.2** (5.4)	**7.2** (7.6)	**9.6** (9.7)
850temp	2.8 (2.8)	3.0 **(2.9)**	2.9 (2.9)	**3.3 (3.3)**
500temp	**1.9** (2.0)	**2.3** (2.4)	2.9 **(2.8)**	3.2 **(3.1)**
250temp	2.7 (2.7)	**3.2** (3.3)	**3.4** (3.5)	**3.8** (3.9)
850wind	**13.2** (13.9)	**14.3** (15.0)	**16.8** (17.5)	**18.8** (18.9)
500wind	**17.2** (17.7)	**18.8** (18.9)	**22.7** (23.3)	**26.5** (26.9)
250wind	**24.5** (24.6)	**27.2** (28.0)	**32.0** (33.2)	38.8 **(38.3)**
700rh	**29.0** (30.2)	28.4 **(26.5)**	29.0 **(28.7)**	32.1 (32.1)

Table 4c forecast verif for Area 400 (S H)

Table 4 Comparison of rms differences of forecast from verifying synop/ship and radiosondes for trial (operational) for August period

As with the April trial it is disappointing to see that the superiority of the trial assimilations, as measured by the fit of the first guess fields to verifying observations, does not yield substantially improved forecasts. Generally the rms errors differ by only a very small amount . In the northern hemisphere the trial provides better early period forecasts, but deteriorates slightly in the medium range. In the tropics the trial is better at T+12, comparable at T+24 and T+48 and perhaps marginally worse at T+72. In the southern hemisphere more verification figures favour the trial than the operational forecasts.

Further insight can be obtained by looking at the results from each days runs. The following table gives a summary of the number of times that the trial performed better/same/worse than the comparable operational product during the August period. Only area 200 has been considered for a limited number of fields. The trial is performing well for surface pressure at T+12 and T+24, whereas the operational model is performing better for upper winds at T+48 and for 500mb heights. The remaining variables/forecast periods give comparable results.

	TRIAL	better	same	worse
pmsl	T+12	6	1	0
	T+24	4	2	1
	T+48	2	2	3
	T+72	3	1	3
850temp	T+12	2	2	3
	T+24	1	5	1
	T+48	1	5	1
	T+72	2	2	3
500ht	T+12	1	3	3
	T+24	0	2	5
	T+48	2	0	5
	T+72	2	1	4
250wind	T+12	2	2	3
	T+24	1	4	2
	T+48	0	2	5
	T+72	2	4	1

Table 5 trial better/worse in N Hem during August period e)Additional verification of the upper wind fields

One important user of global forecasts is civil aviation, and it is of interest to consider the upper wind forecasts in some considerable detail. The above verification against radiosondes shows the trial to have marginally higher errors than the operational forecasts during the August period (by 0.6knots,0.2knots and 0.5knots at T+0 ,T+12 and T+24 respectively in the northern hemisphere at 250mb). This seems to be worse than the April period when the T+24 results were within 0.2knots. These results have considerable geographical bias in favour of the land areas and also do not focus on the important jetstreams.

Comparison over oceanic areas can be obtained using aircraft reports. These results are given Table 6 below and seem to agree with those for radiosonde data. It should be noted that the relatively poor result for the trial at T+0 is to be expected because many of the verifying AIREPs report after data time and would not be fully assimilated at T+0 by the new scheme.

	T+0	T+12	T+24
250 wind	14.7 (14.0)	19.1 (18.0)	22.6 (22.3)

Table6 Comparison rms difference of analyses and forecast for Area 200 (N H) during August period from verifying AIREPs for the trial with operational figure in brackets

The jets were assessed by examining the charts and noting all jet cores with maxima in excess of 90kt at 250mb. For the seven 12GMT runs there were about 60 jets identified in the Northern Hemisphere. Table 7 summarises the comparison of trial and operational jets. The first six T+24 forecasts were then verified against the objectively analysed jets which were taken to be the mean of the trial and operational to avoid any bias,with small positional errors ignored.

	T+0	T+12	T+24
Number of jets	61	62	59
Mean speed(trial)	104.3	103.7	99.9
Mean speed(oper)	106.8	103.5	101.8
No. trial-oper<-5kt	16	11	10
No. trial-oper>5kt	1	10	5

	trial	oper
No. of T+24 jets verified	45	45
mean error	-6.0	-4.3
standard dev.	8.4	8.0
rms error	10.3	9.1
Number of better forecasts	19	26

Table7 Comparison of trial and operational jets in the N Hemisphere for the August period

Table 7 suggests that the operational assimilations are still superior with respect to jets . The 2.5kt trial deficit at T+0 is relatively unimportant since it is almost certainly due to the smaller weight given to AIREPs reporting after the analysis time. The new scheme caters for this by assimilating beyond T+0 and the benefit of this can be seen from the T+12 results which show stronger jets relative to the operational scheme. It is interesting to note a bimodal distribution in the T+0 histogram of trial - operational speeds with one peak at zero and the other at -8kt. This second peak is presumed to relate to jets which are only identified by late AIREPs. The distribution at T+12 has only one peak at the origin and the same is true at T+24 except that the peak is shifted to minus 1½ kts. This weakening reflects in the marginally poorer verification of the T+24 trial jets.

4. Verification of forecasts using objective analyses

a) Global statistics

The forecasts were verified against objective analyses to give some detail about the geographical distribution of the errors for both the trial and operational forecasts. Since trial analyses are unavailable for the entire verification period (which extends beyond the trial period), the verification is done against operational analyses. This biasses the results slightly in favour of the operational scheme since, especially for short period forecasts in data sparse areas, the forecast and verifying analyses will be correlated. For this reason T+12 forecasts have not been assessed in this way and T+24 comparisons are suspect in the southern hemisphere. The area mean rms differences of forecasts from analyses for three latitude bands during the August period have been obtained for three fields and are given below in Table 8. These results can be compared with the observation verification in Table 4.

	T+24	T=48	T+72
Northern Hemisphere			
pmsl (mb)	2.20 (**2.23**)	3.23 (3.23)	4.20 (**4.11**)
500mb heights (dm)	1.73 (**1.64**)	2.77 (**2.66**)	3.88 (**3.71**)
250mb heights (dm)	2.47 (**2.23**)	3.94 (**3.71**)	5.49 (**5.34**)
Tropics			
pmsl (mb)	**1.54** (1.55)	1.71 (**1.56**)	1.72 (**1.70**)
500mb heights (dm)	**1.02** (1.07	1.19 (**1.13**)	**1.85** (1.87)
250mb heights (dm)	1.38 (**1.30**)	**1.56** (1.64)	**1.85** (1.87)
Southern Hemisphere			
pmsl (mb)	3.20 (**3.14**)	**4.34** (4.52)	**5.67**(5.70)
500mb heights (dm)	2.56 (**2.38**)	**2.80** (3.82)	5.25 (**5.06**)
250mb heights (dm)	3.42 (**3.18**)	5.47 (**5.41**)	7.25 (**7.15**)

Table 8 Verification of trial and operational forecasts against operational analyses during the August period

The results above compare reasonably closely with those from the verification against observations in Table 4 for the northern hemisphere, showing a slightly poorer performance for the trials runs of the order of .1mb or .1dm increased rms error in the later forecast stages which amounts to a loss of about 2 hours predictive skill. Table 4 and Table 8 show similar results for the Tropics with little to choose between trial and operational. Conflicting results are obtained in a similar comparison for the southern hemisphere, reflecting the difficulty of obtaining a 'truth' in this data sparse region. Against analyses (leaving aside T+24) the trial is better at the surface, similar at 500mb and very marginally worse at 250mb compared with operational in the southern hemisphere.

b)Error maps

The mean T+72 500mb height field from the seven operational forecasts is given in Fig 1a with the corresponding mean field for the trial forecasts at Fig 1b. As one might expect, the two mean fields are very similar,however there seems to be an indication that the mean upper troughs are slightly deeper from the trial, for instance over Scandinavia and the East Pacific.The rms difference of these forecasts from verifying operational analyses are given in Fig 2a for the operational runs and Fig 2b for the trial runs. Focussing on the areas of largest rms error we see that the trial is better in the Atlantic by 2dm but worse over the Pacific and Northern Canada. The error patterns are similar over the southern hemisphere with the trial better in some places and worse in others. Figures 2a and 2b can be compared more easily in Fig 3a which shows the difference in rms errors, with negative shading implying trial worse. The improved results in the Atlantic standout and the trial is also better over western USA and the west Pacific, but overall the shaded area exceeds the unshaded area.

T+24 differences in rms errors at 500mb are given in Fig 3b. In the Northern hemisphere the trial is better in the eastern USA ,mid Atlantic and parts of the Eurasian land mass. The areas where the trial is worse (bold contour) seem to be around the periphery of the main data dense area, the Pacific and Atlantic coasts of North America, Northern Canada and the Atlantic coast of Europe . We have seen that the new scheme performs well over data dense regions becasuse the first guess over such regions is of higher quality. We have also seen that the scheme performs well in the data sparse area (eg Southern hemisphere). The apparent problems at the periphery of the data dense areas at T+24 may be due to some difficulty in the trial analyses at the edge of the data dense region .

Figures 4-6 follow the same format as fig 1-3, but illustrate the results for the mean pmsl fields.A comparison of the mean T+72 pmsl fields in Fig 4 shows that the most significant difference is that the trial tends to give deeper lows by a few millibars in the mean. The differences in the mean pressures in the Norwegian sea and in the Canadian Arctic demonstrate this point.The comparison of pmsl rms differences in Fig 5 shows a similar signal to that given by the 500mb heights. This is again more clearly seen by examining the difference between the rms error fields in Fig 6a. The trial is producing substantially lower errors in the east Atlantic, and also western USA, but as with the 500mb heights there is probably a larger shaded area indicating where the trial is worse. Fig 6b shows the same difference field as fig 6a but for T+24 when it is not clear whether trial or operational is better.

Further evidence of differing performance over land and sea in the northern hemisphere can be seen from the partitioning of verification results against observations. We have seen that one of the few fields which verified better at T+0 from the trial was pmsl (**1.65mb** for trial (1.67 for oper)). This improvement was entirely due to better results over land (**1.48mb** (1.52mb)) whereas over the sea ,including some coastal synops we see a deterioration (1.92 (**1.90**)) .At **T+6** the only field which was not better in the trial was 500mb winds, where we again see a better result over land (**9.41kt** (9.43)) and a worse result over the sea (9.84 (**9.78**)). Even at T+24, the same effect is seen for some fields, for instance the 500mb temperature verify similarly over land (both 1.61°C) but the trial is is worse over the sea (1.81 (**1.74**)).

4. Subjective assessment

a) Forecasters assessment

The subjective score is based on an A,B,C,D,E scoring system with A,B meaning trial better, C meaning trial and control comparable and D,E meaning trial worse. A and E are reserved for substantial differences whilst marginal differences are scored B or D. As well as a score, the forecasters were encourage to make any comments they felt were relevant.

The main subjective assessment of surface and 500mb charts was partioned into 3 sectors, The Atlantic ,The Pacific and the Southern Hemisphere for which charts were examined at T+0,T+24,T+48 and T+72. In addition to this ,an assessment was made of the maximum wind charts in the Atlantic sector at T+0 and T+24.

		April results					August results				
		A	B	C	D	E	A	B	C	D	E
pmsl	T+0	0	3	4	3	0	0	1	3	3	0
	T+24	0	2	5	3	0	1	2	3	1	0
	T+48	0	3	4	3	0	0	1	4	1	1
	T+72	1	2	4	2	1	0	1	4	1	1
850wbpt	T+0						0	4	2	1	0
	T+24						1	1	4	1	0
500mb	T+0	1	3	6	0	0	0	3	3	1	0
	T+24	1	0	6	3	0	1	3	1	2	0
	T+48	0	2	7	1	0	0	1	5	1	0
	T+72	0	1	8	1	0	0	1	5	1	0
maxwind	T+0	0	1	13	8	0	0	2	0	11	0
	T+24	0	3	4	4	0	0	1	0	4	0

Table 9a Subjective marks-Atlantic sector

During the April period the trial and operational schemes seem to be evenly matched as regard surface pressure both for analyses and forecasts. The trial analyses are definitely superior at 500mb ,forecast verification at 500mb shows the results are comparable. The forecasters comments imply that the trial jets were marginally lighter (5-10 knots) on those occasions which were scored D, but this deficiency of the trial analyses does not carry forward to the forecasts.

The same comments could be made for the August period. T+4 charts of maximum wind were also made available foe assessment during the August period. The few comments regarding the T+4 charts indicated that the extra period of assimilation to accommodate late data with full weight was generally of benefit for the max wind analysis.

		April results					August results				
		A	B	C	D	E	A	B	C	D	E
pmsl	T+0	0	2	6	2	0	0	1	6	1	0
	T+24	0	0	6	4	0	0	1	3	2	0
	T+48	0	3	2	5	0	1	2	2	0	0
	T+72	0	1	6	2	0	0	0	2	2	0
500mb	T+0	0	1	8	1	0	0	1	6	0	0
	T+24	0	2	8	0	0	0	1	3	2	0
	T+48	1	0	7	2	0	0	2	3	0	0
	T+72	0	5	3	2	0	0	0	3	1	0

Table 9b Subjective marks-Pacific sector

During April the reults are comparable at T+0 in the Pacific sector, but conflicting results are obtained from the forecast verification with the trial scoring better at 500mb but worse at the surface. For the August period, given the small sample size , it would be unwise to suggest that the results were anything other than comparable.

		April results					August results				
		A	B	C	D	E	A	B	C	D	E
pmsl	T+0	1	9	9	1	0	0	3	9	2	0
	T+24	1	5	14	0	0	0	5	7	2	0
	T+48	0	4	15	3	0	0	3	10	1	0
	T+72	0	4	11	4	0	0	5	6	3	0
500mb	T+0	0	9	10	1	0	0	3	9	2	0
	T+24	0	7	13	0	0	0	1	12	1	0
	T+48	0	5	13	4	0	0	3	11	0	0
	T+72	0	7	11	2	0	0	3	9	1	0

Table 9c Subjective marks-southern hemisphere

During the April period the was a positive benefit from the new analysis in the Southern Hemisphere in terms of better analyses and better short period forecasts. The results are perhaps rather closer in the August period than they were during April, but the test runs have a few more successes than failures at all periods for both pmsl and 500mb heights

b)Comparison of selected forecast charts

The T+72 operational pmsl forecast from the first day of the trial (verif time 12GMT 29/8/87) is given in Figure 7a. The pecked lines on this figure are the differences (operational-trial) from the trial forecasts which are given in Figure 7b. An objective verification is given in Figure 7c . Figures 8-13 are identical in format to Figure 7 and give comparison T+72 pmsl forecasts from the rest of the week long August trial (verif times 12GMT 30/8/87-4/9/87 respectively) . A few brief points on each comparison will help clarify the above subjective assessment.

(i)DT 26/8/87 VT 29/8/87 (Fig 7)

Of all the seven cases, differences were smallest for this case, perhaps because only a few assimilation cycles with the trial scheme had been performed prior to the data time. Nowhere did differences exceed 5mb. The trial forecast was closer with the intensity of the high pressure south of Ireland. Both forecasts produced an erroneous low south of Newfoundland which was marginally deeper in the trial.

(ii)DT 27/8/87 VT 30/8/87 (Fig 8)

This can be counted as a success for the trial . Pressure near the low south of Iceland is incorrectly 11mb deeper in the operational forecast as the low moved faster and displaced the ridge. The low near Newfoundland has the depth correctly forecast by the trial run whilst the operational low is too shallow, however because both forecasts are too fast the absolute errors are probably larger in the trial run. Note also the 10mb difference near Hudson Bay, with a deeper centre in the trial forecast. This characteristic of the trial forecast to give deeper lows has already been seen in the mean fields.

(iii)DT 28/8/87 VT 31/8/87 (Fig 9)

This was one instance when a low was incorrectly forecast less deep by the trial. Although the operational forecast (at 1007mb) could hardly be considered a success, it was much better than the trial. This was probably the worst trial forecast. The differences between the forecasts were examined in the earlier stages to try and trace the problem back to analysis differences. Thsi proved to be extremely difficult as the differences at T+0 were extremely small. 1dm differences were noted at 500mb near the base of the short wave upper troughs over NE Canada and off Newfoundland, the most easterly of which became a 4dm difference at T+12 and was trackable throughout the forecast. The 250mb jet exiting N America differed by less than 5knots

(iv)DT 29/8/87 VT 1/9/87 (Fig 10)

This day was appallingly forecast by both runs, although the operational run scores slightly by having better positions for the two major lows despite being in excess of 20mb shallow for both.

(v)DT 30/8/87 VT 2/9/87 (Fig 11)

The only substantial difference on this day was in the Norwegian Sea, where the trial gave a very good forecast of the low ,with a correct position and only 2mb different from verification in depth. The operational run had the low too far forward and much too shallow, giving a 16mb difference in pressure at a point to the west of the low.

(vi)DT 31/8/87 VT 3/9/87 (Fig 12)

Very large pmsl differences are evident in the Atlantic on this day, with the trial being 9mb and 12mb deeper at positions near the two lows. With the eastern low, the trial was correctly deeper and more rounded. With the western low the trial was too deep but the shape was better in that it correctly troughed to the NW and SW, rather than having a double centre.

(vii)DT 1/9/87 VT 4/9/87 (Fig 13)

Both forecasts were slightly too fast with the low near Iceland, but this error was worse for the operational run and was compounded by the low being too shallow to give a 16mb difference south of Iceland over the actual verifying position of the low. The trial got the depth correct to 1mb and correctly did not bring the northwesterlies into western parts of the UK.

One feature of interest in the Pacific sector was a low latitude depression at 20°N 130°E which was consistently forecast to be deeper by the trial forecasts . The central pressure of this system for T+72 forecasts verifying 1st-4th September are given in the Table below.

	TRIAL T+72	OPER T+72	OBJECTIVE ANALYSIS
1st Sept	997	1004	1007
2nd Sept	996	1001	1007
3rd Sept	994	995	1003
4th Sept	991	996	1002

Table 10 Central pressure of Low at 20°N to south of Japan

There is a clear tendency for these low latitude systems to be deeper in the operational forecast than in the analysis. The fact that this particular system is deeper in the trial forecasts suggests that perhaps the data in tropical areas is being assimilated by the new scheme in a more consistent manner. There are substantial differences in the total rms divergence in the tropical analyses. This particular system was apparently captured by the model rather early but it was a severe event , being classified as Tropical Storm *Gerald* on the 5th and reaching typhoon status several days later.

6. Summary

The results of this trial have been extremely valuable in terms of identifying the good points of the new analysis scheme and helping to pinpoint several remaining problem areas whcih require further attention. We have seen that the trial first guess fields are substantially better than the equivalent operational fields . We have also seen that the medium range pmsl fields for the Atlantic were better forecast by the trial. Also the southern hemisphere is marginally better forecast, although not perhaps by as great a margin as in the April trial. The slight deterioration overall between April and August could simply be a sampling difference as only a relatively small number of forecasts are being considered, however there is some indication that changes to the algorithm for spreading information in the horizontal from observation to model gridpoint ,which were introduced as a time saving measure, may have contributed to the deterioration. Other differences between the two trials which may have been relevant are the extra 4 hour assimilation in August (in the period T+0→T+4) which might have resulted in the insertion of asynoptic increments over the continental areas from oceanic data,and the lack of satem in August which would have increased the data density contrast between land and sea. Further investigation is needed here. The difference in performance at jet levels is only marginally worse and probably not very significant but nevertheless not entirely satisfactory. The main problem is ,that inspite of better verification of the first guess, the improved signal is not retained in the overall verification figures for the medium range. We have suggested that the problem may lie in the treatment of the area around the periphery of the data dense areas and this point requires further study.

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Lorenc A.C, Dumelow R.K.	1985	Four dimensional Analysis by repeated insertion of observations in the Meteorological Office NWP model *Met O 11 TN224*
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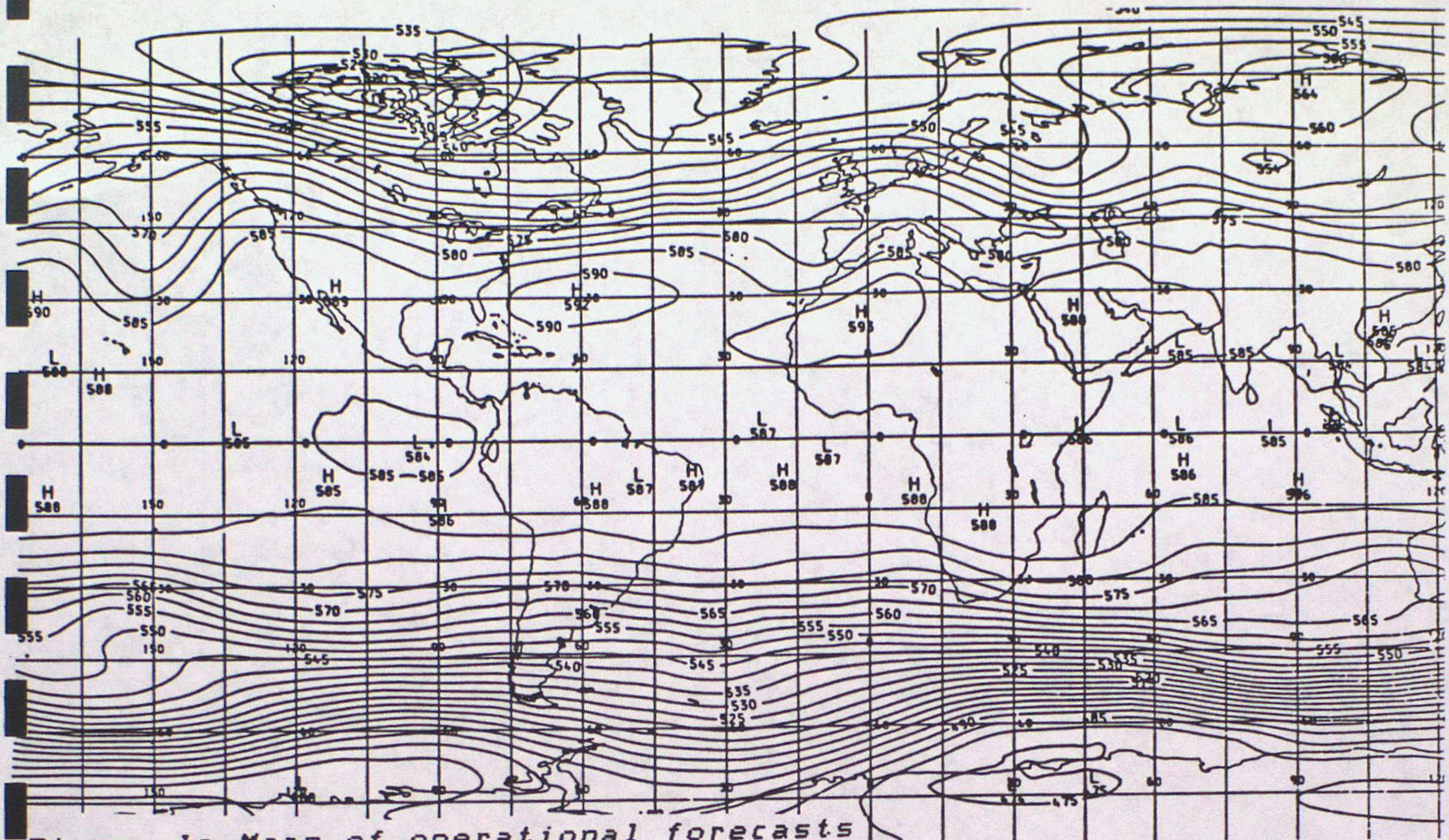

Figure 1a Mean of operational forecasts

Figure 1b Mean of trial forecasts

Figure 1 Mean of 7 T+72 500mb height forecasts

VT 29/8/87-4/7/87

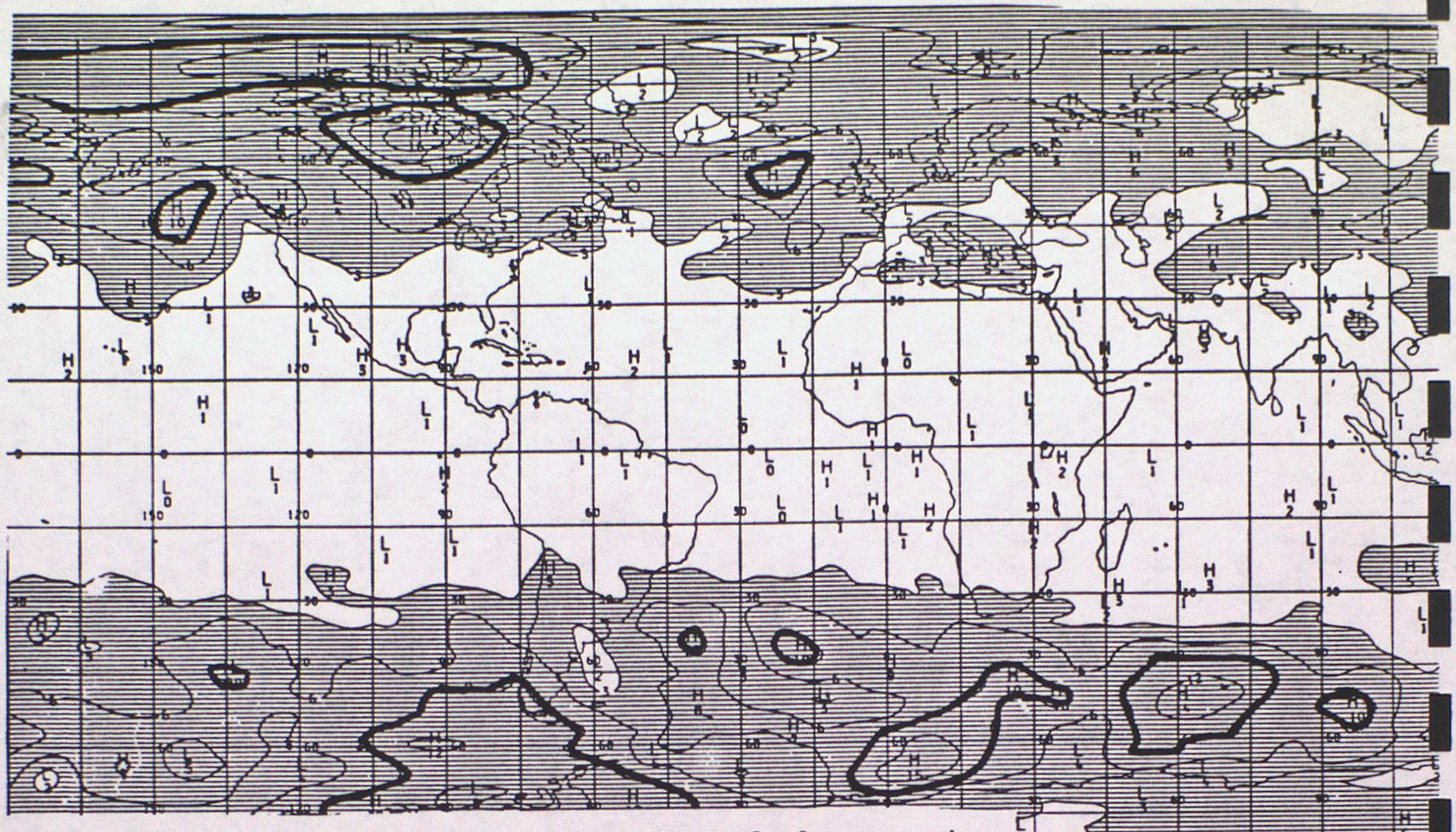

Figure 2a RMS error for operational forecasts

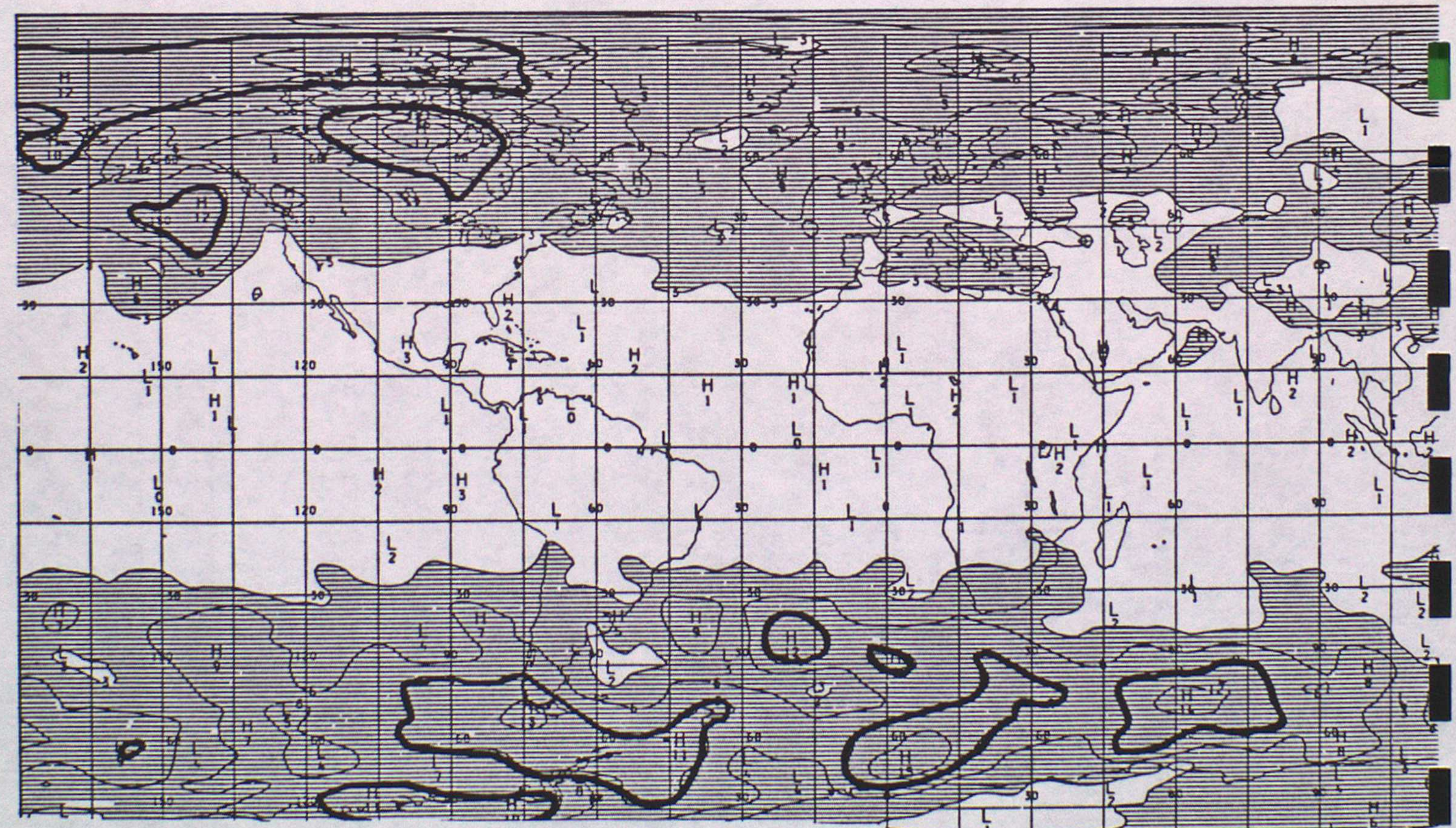

Figure 2b RMS error for trial forecasts

Figure 2 RMS Difference from verifying analyses of 7 T+72 500mb height forecasts VT 29/8/87-4/7/87

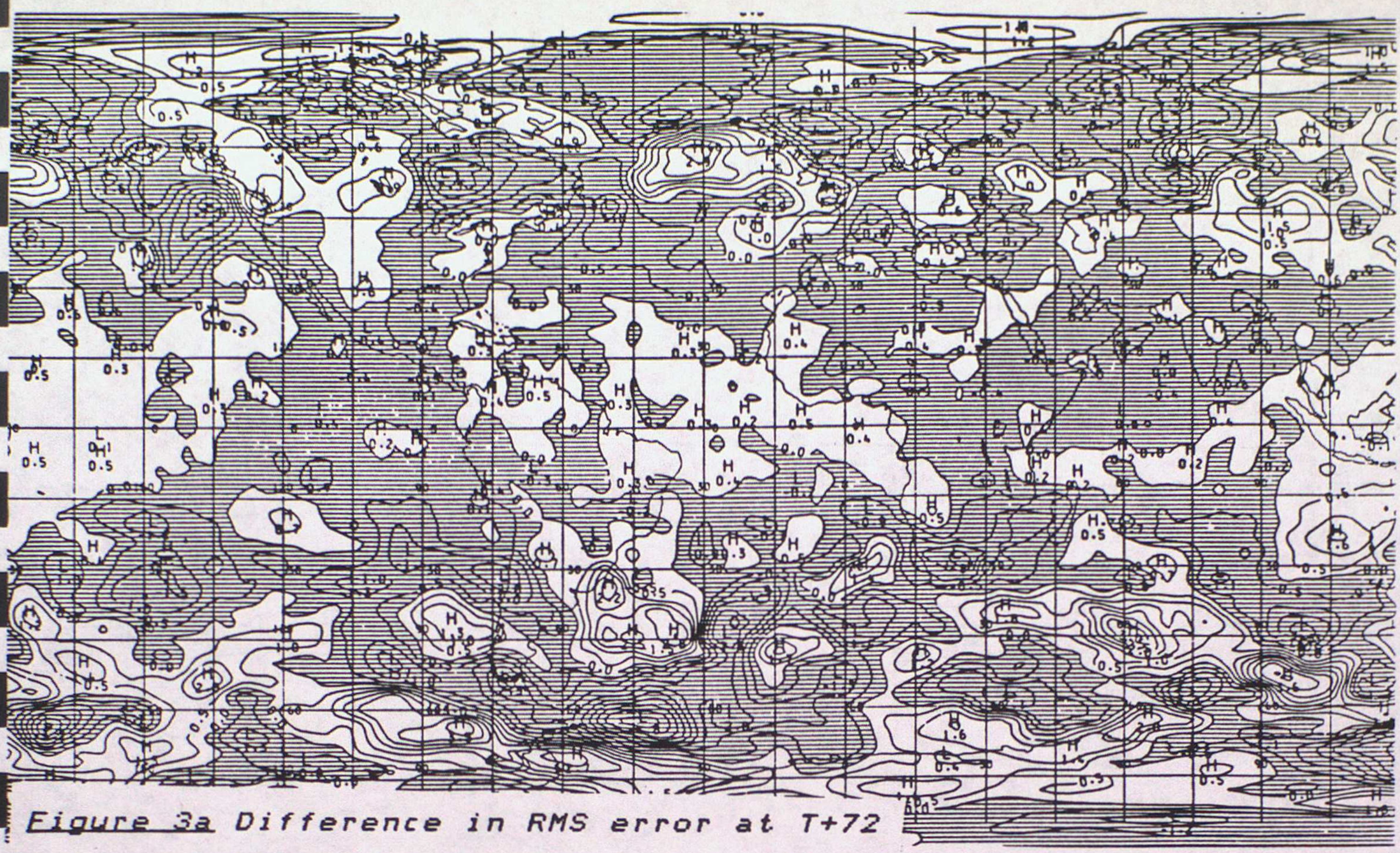

Figure 3a Difference in RMS error at T+72

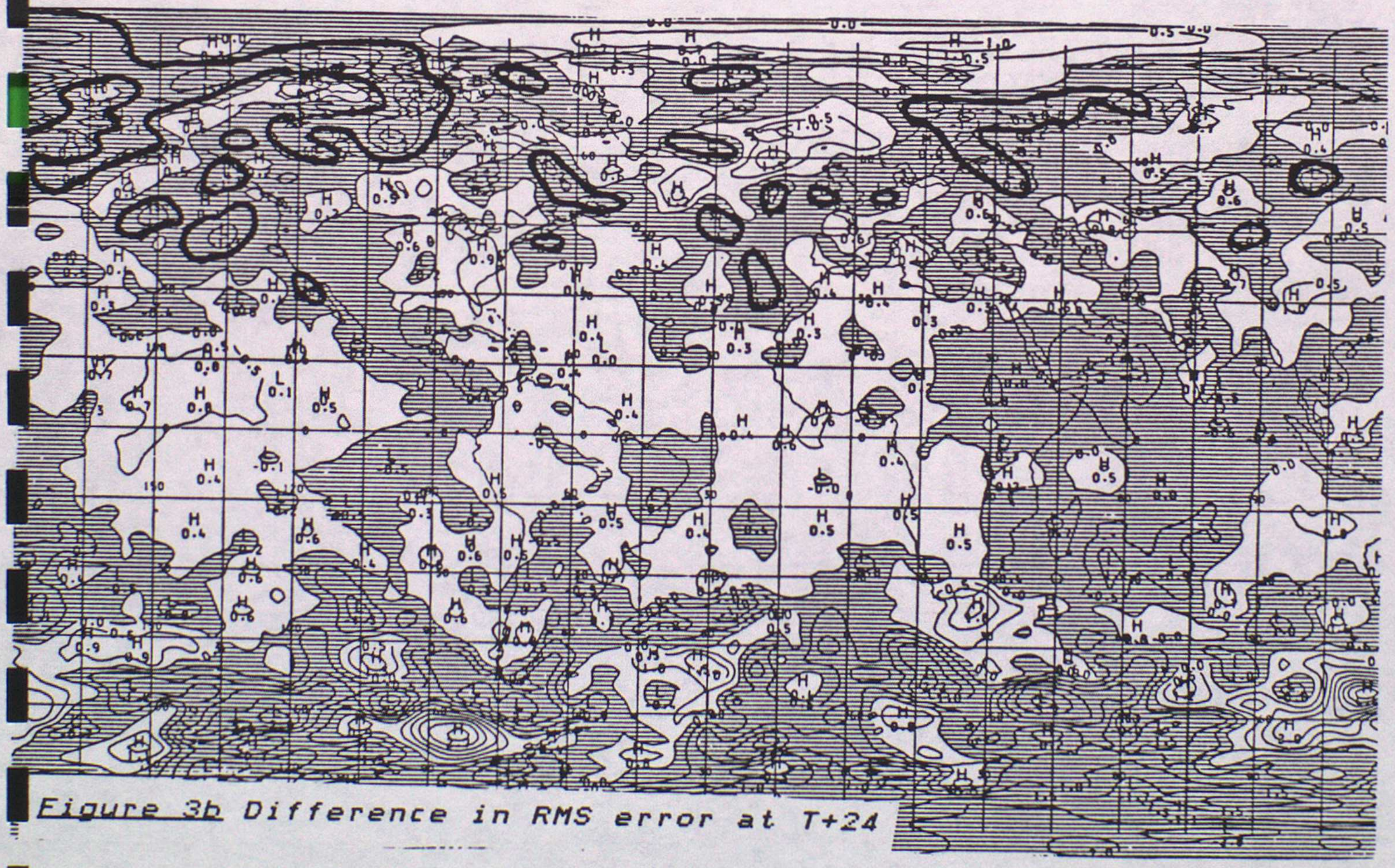

Figure 3b Difference in RMS error at T+24

Figure 3 Difference in RMS error of 7 500mb height forecasts VT 29/8/87-4/7/87 (shading=trial worse)

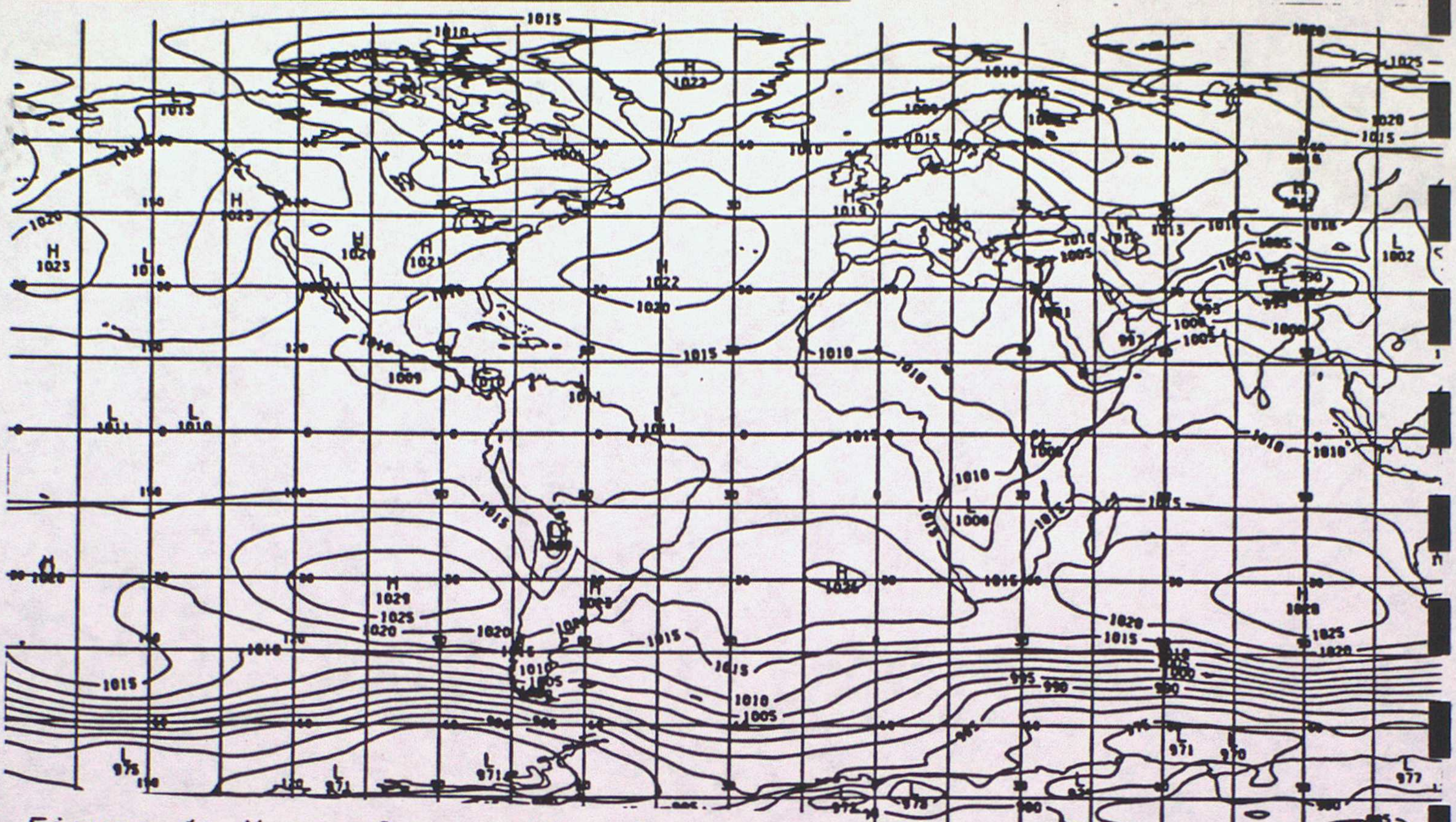

Figure 4a Mean of operational forecasts

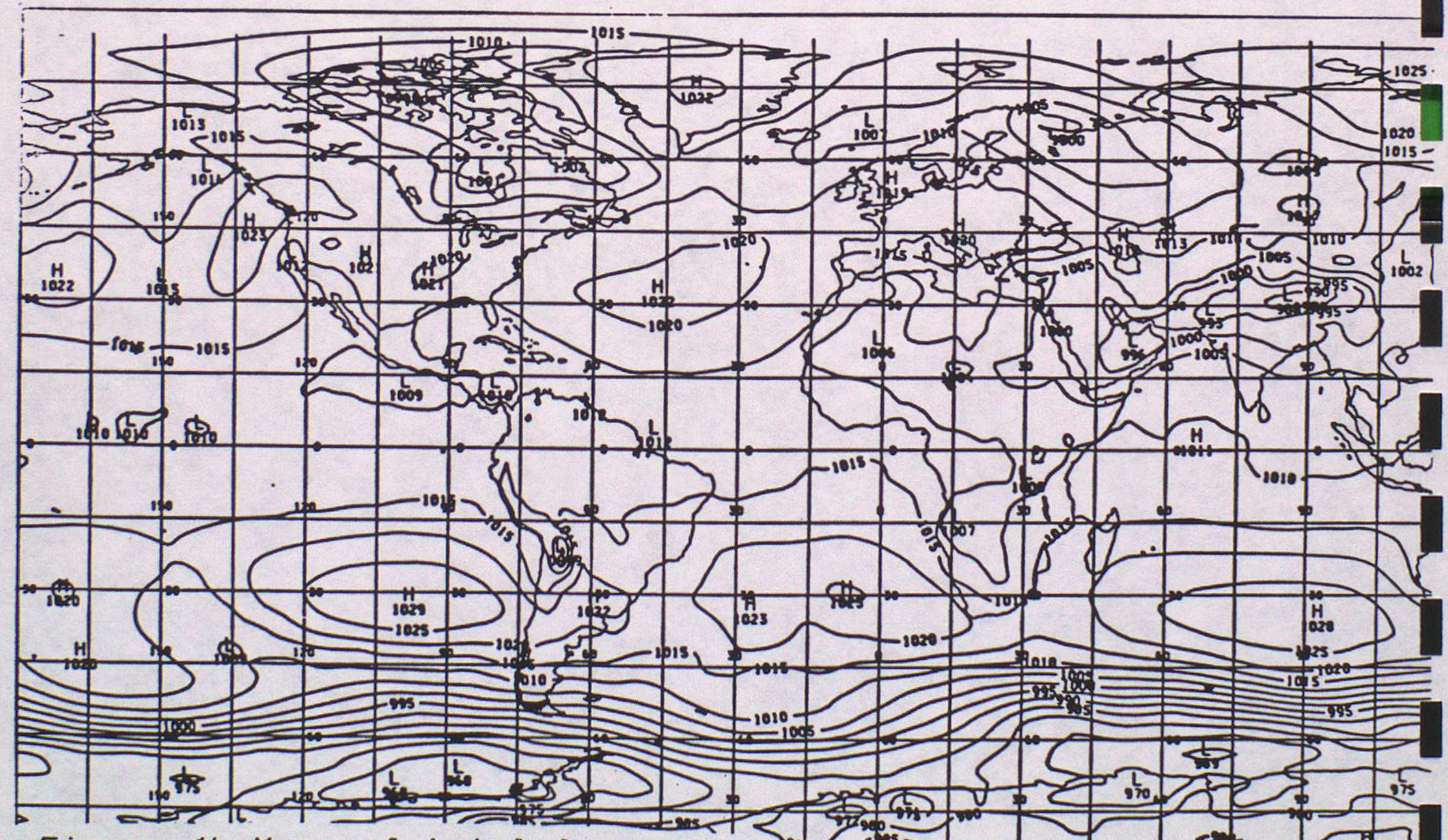

Figure 4b Mean of trial forecasts

Figure 4 Mean of 7 T+72 pmsl forecasts

VT 29/8/87-4/7/87

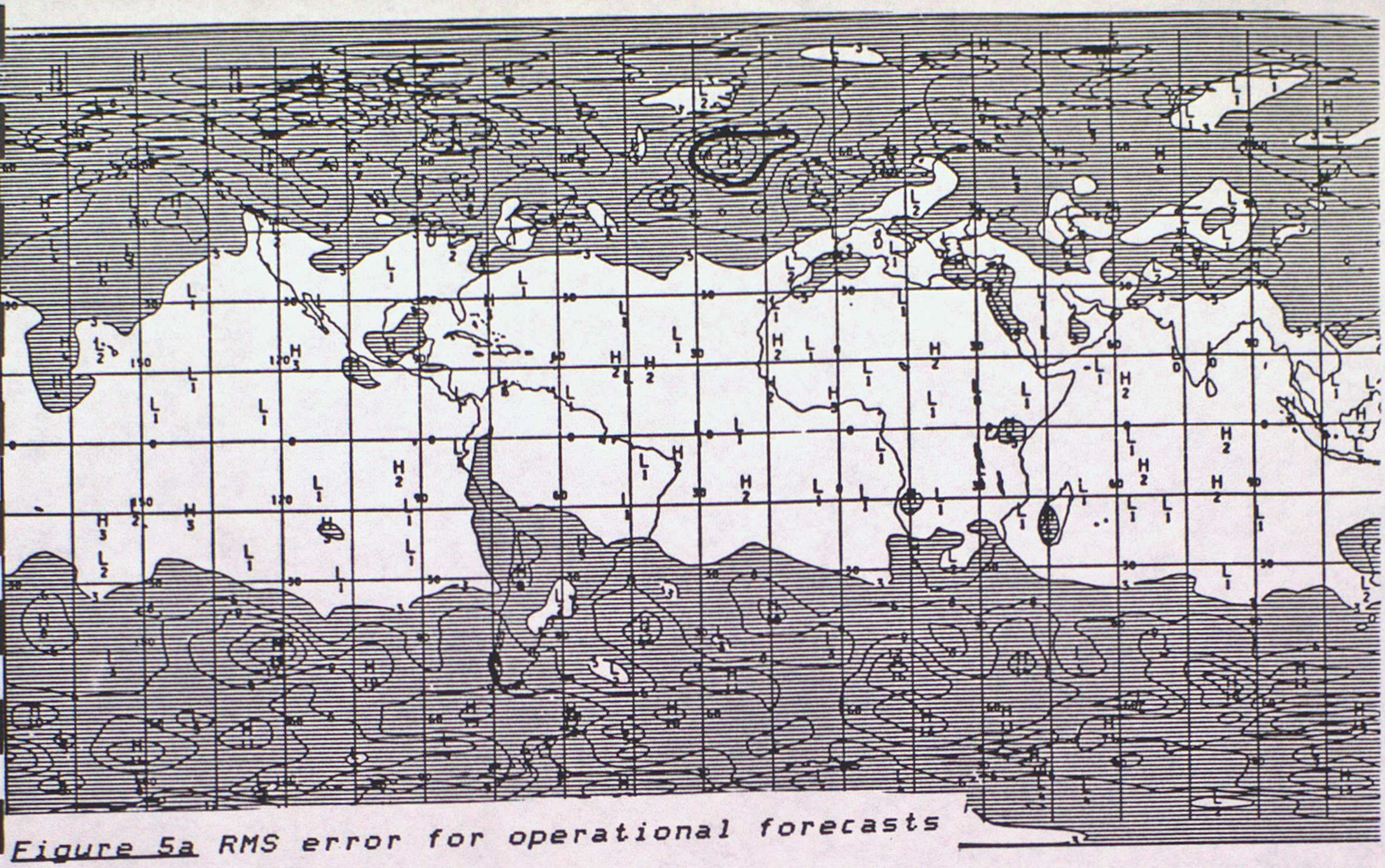

Figure 5a RMS error for operational forecasts

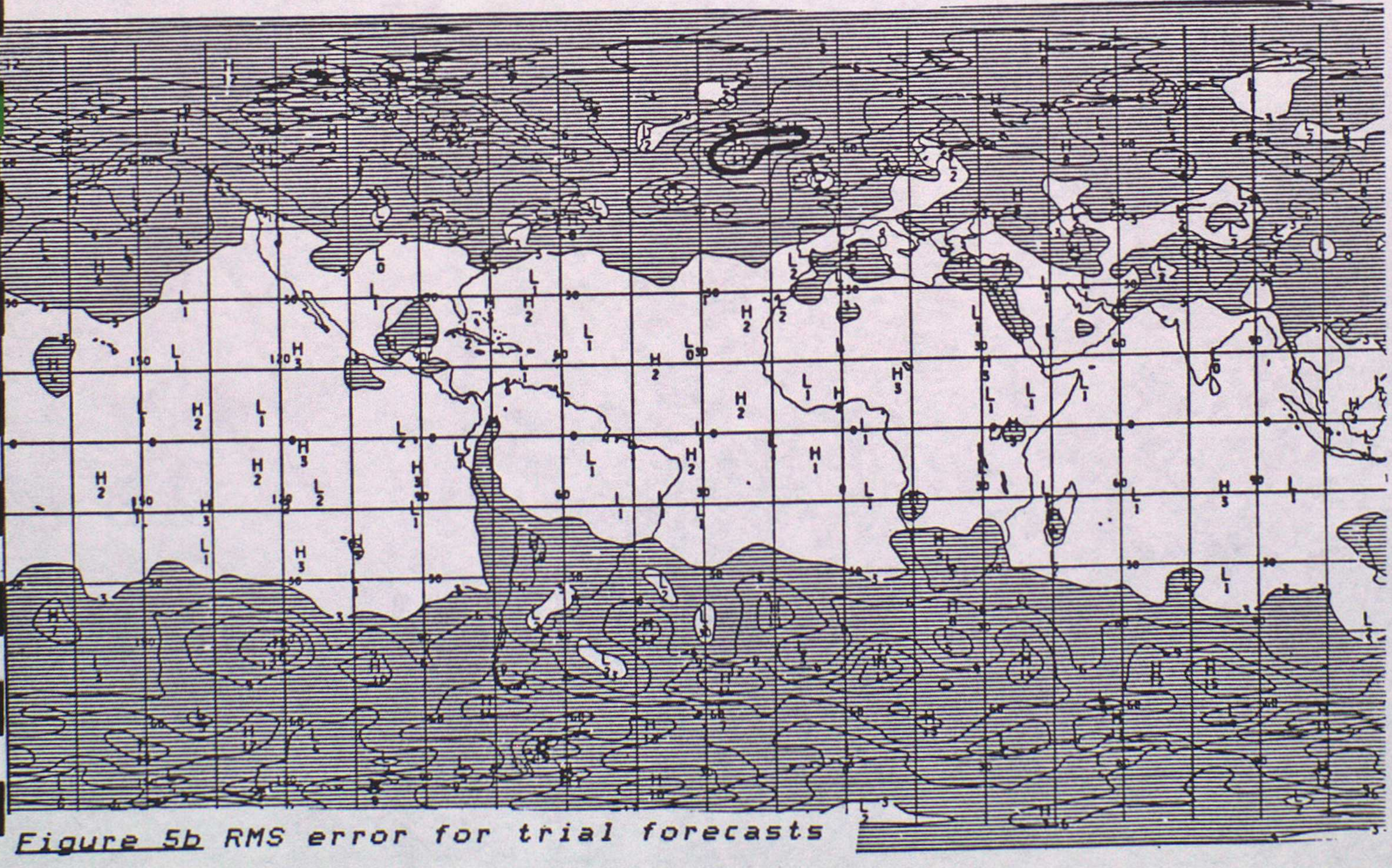

Figure 5b RMS error for trial forecasts

Figure 5 RMS Difference from verifying analyses of

7 T+72 pmsl forecasts VT 29/8/87-4/7/87

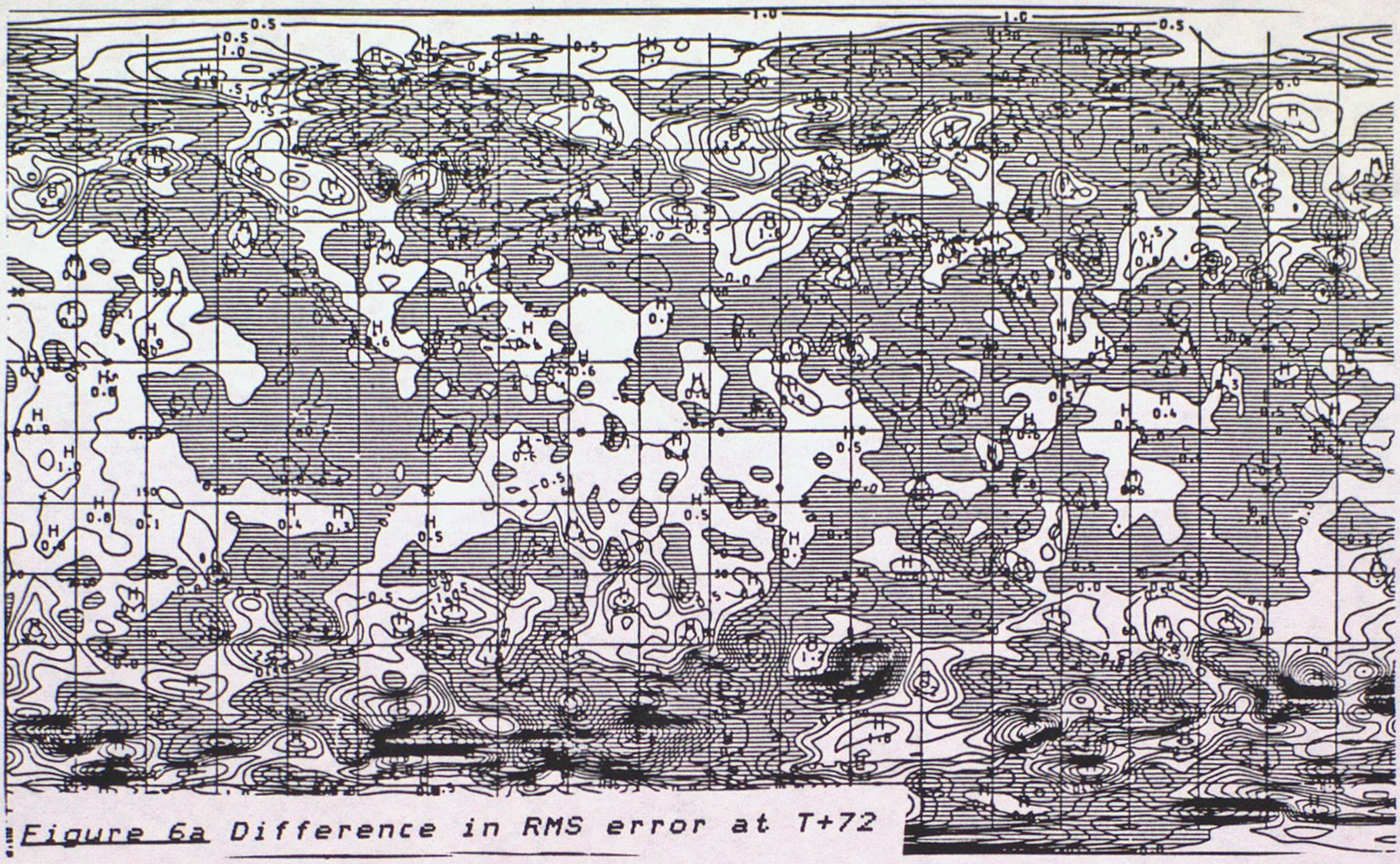

Figure 6a Difference in RMS error at T+72

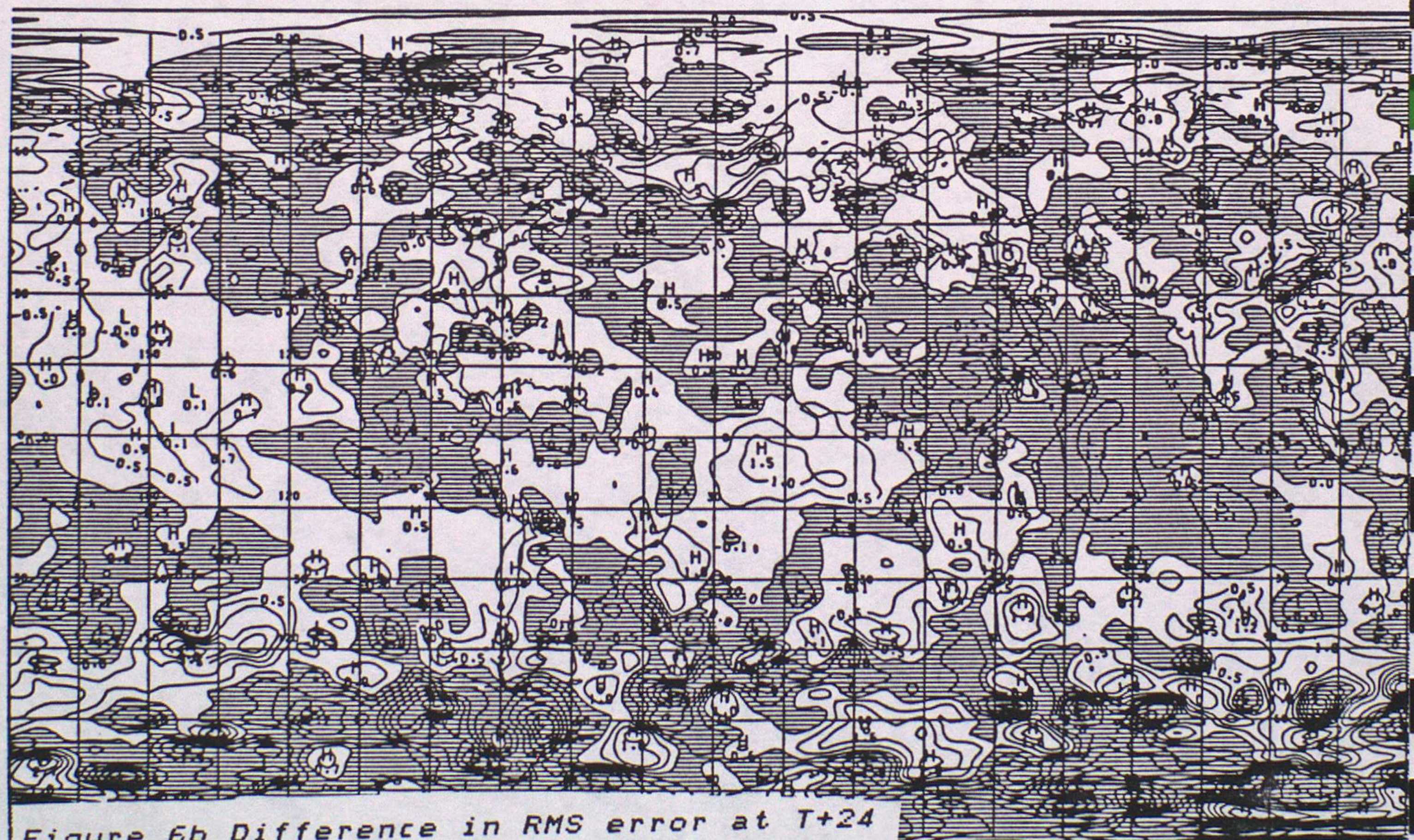

Figure 6b Difference in RMS error at T+24

Figure 6 Difference in RMS error of 7 pmsl forecasts VT 29/8/87-4/7/87 (shading=trial worse)

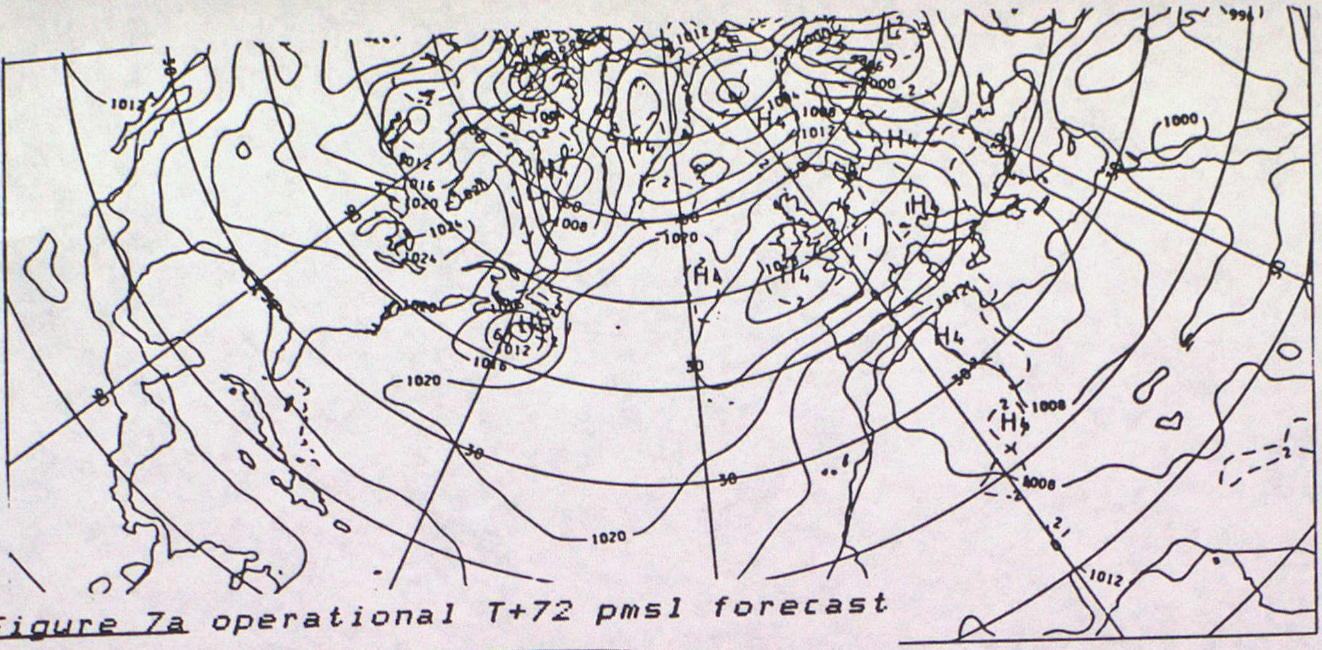

Figure 7a operational T+72 pmsl forecast

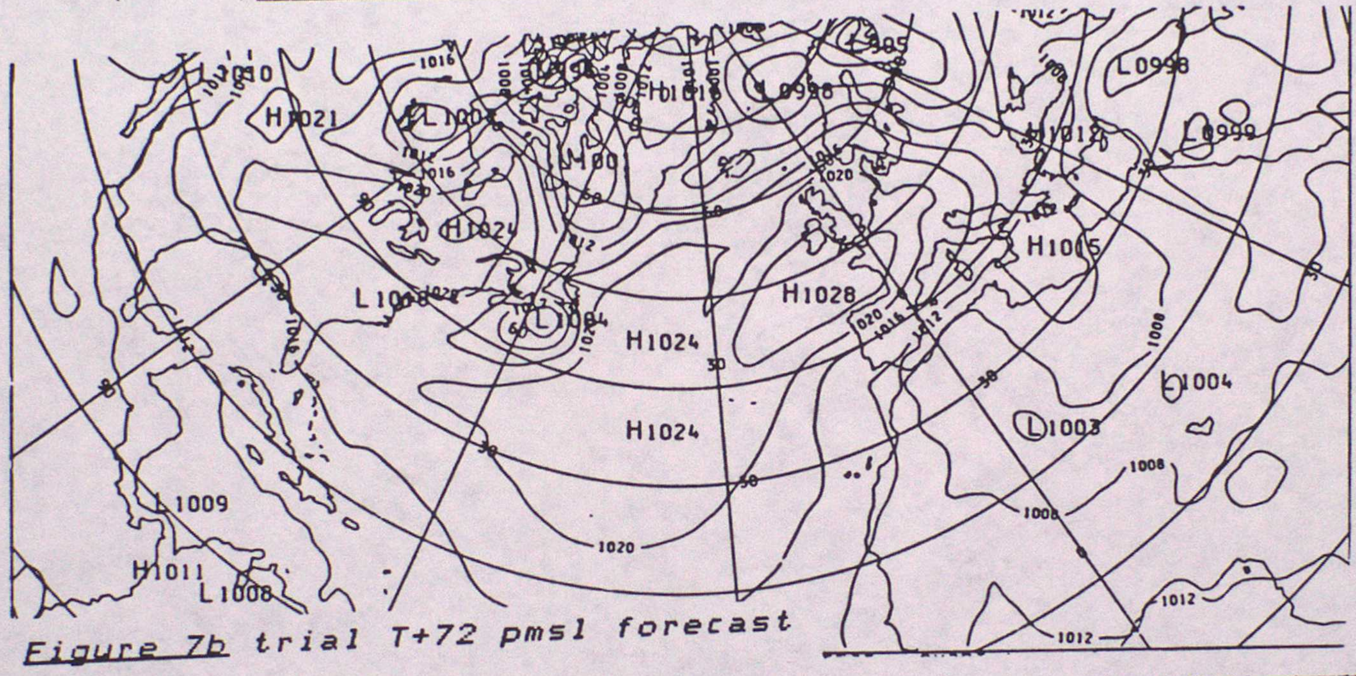

Figure 7b trial T+72 pmsl forecast

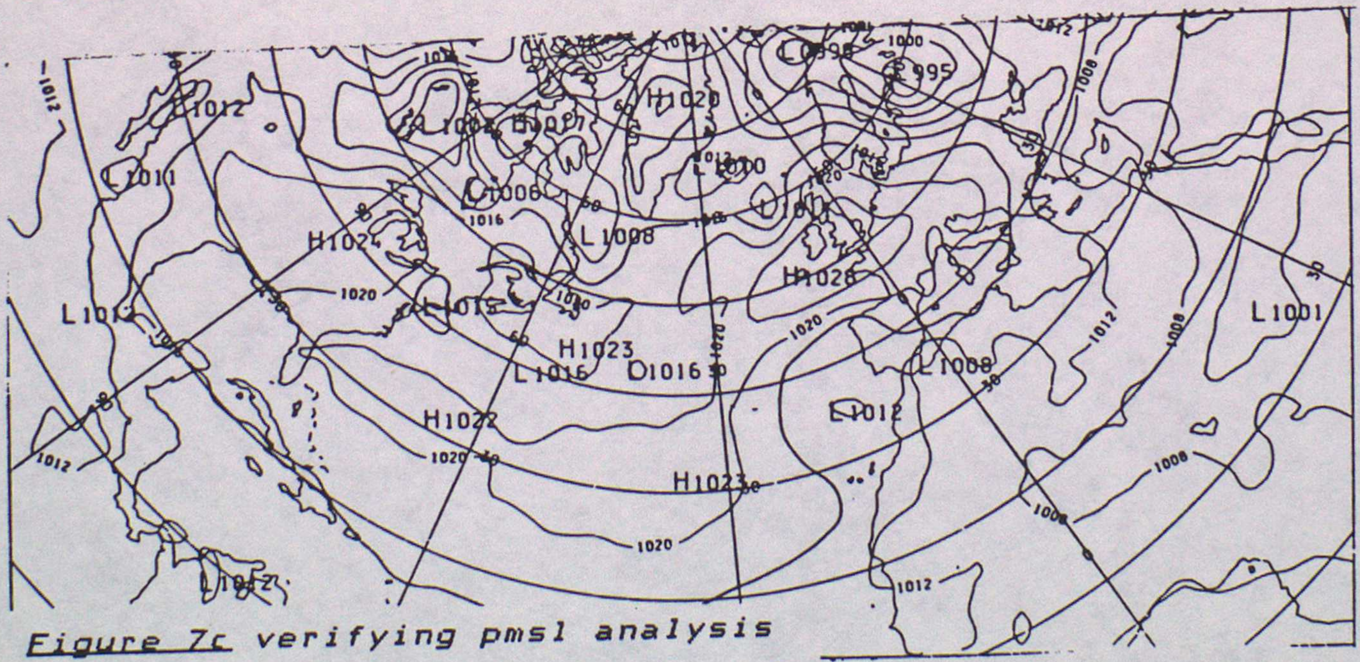

Figure 7c verifying pmsl analysis

Figure 7 Comparison pmsl fields verifying 29/8/87

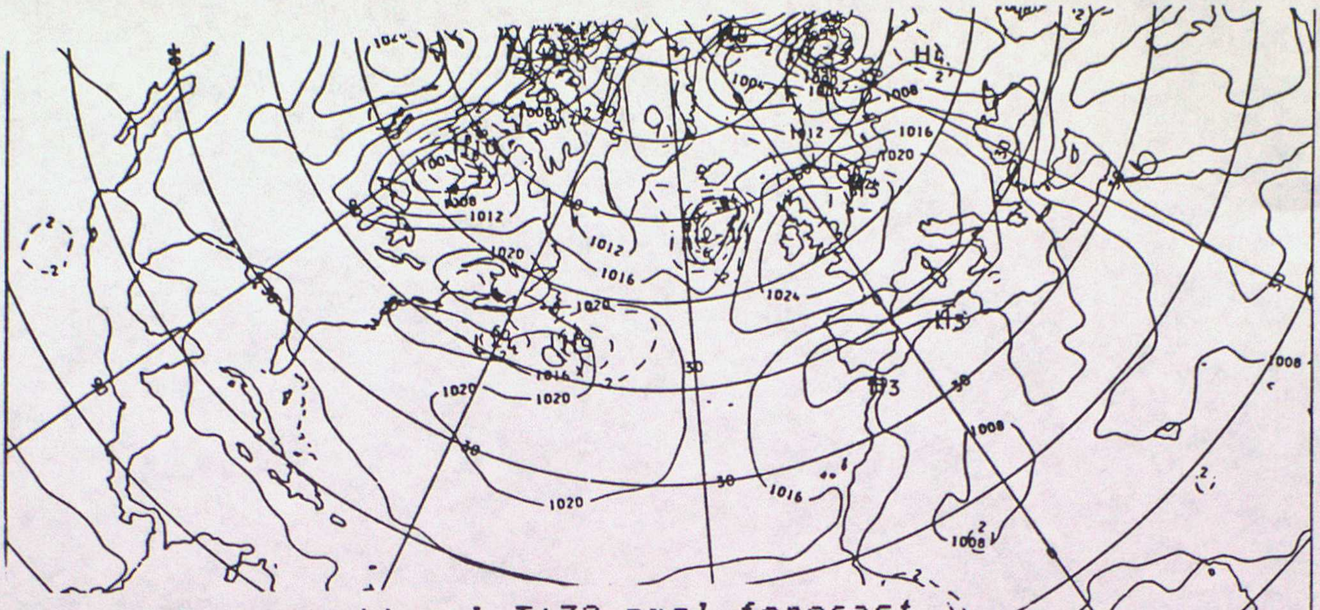

Figure 8a operational T+72 pmsl forecast

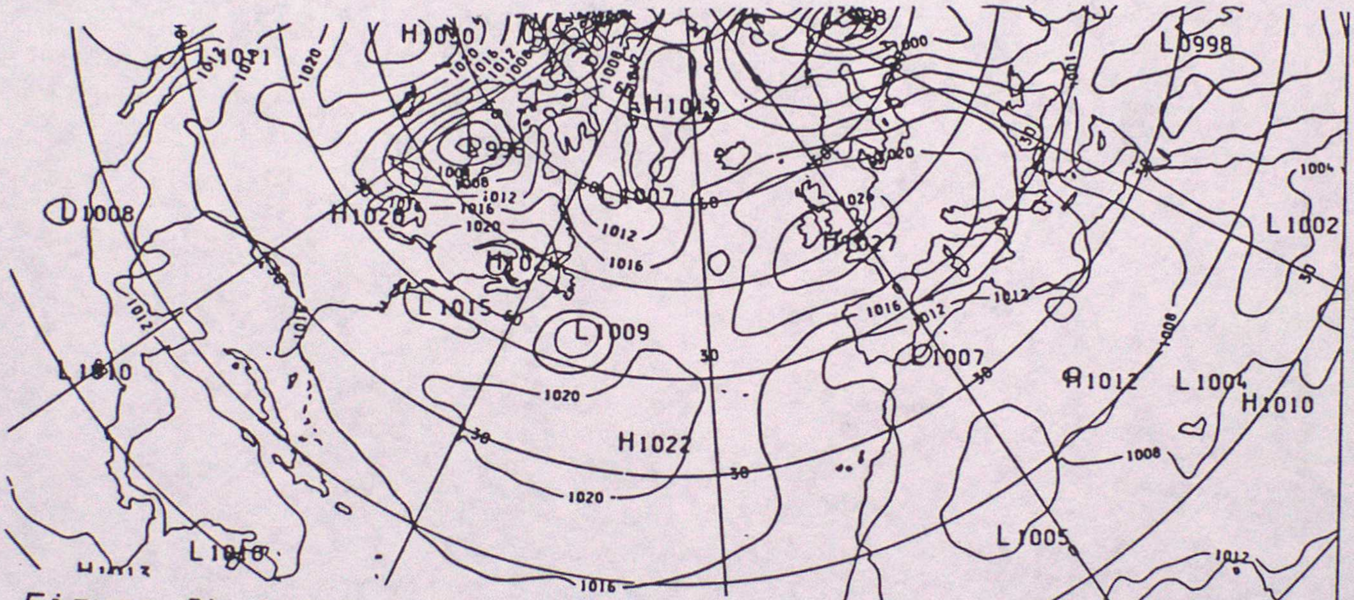

Figure 8b trial T+72 pmsl forecast

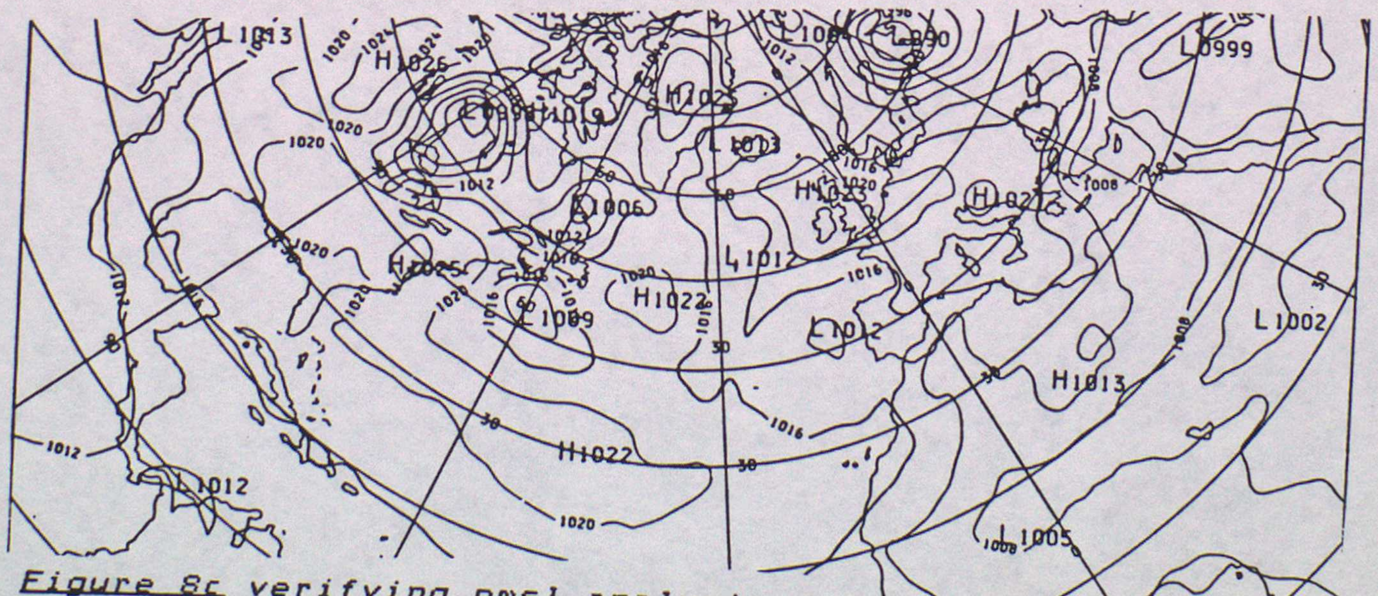

Figure 8c verifying pmsl analysis

Figure 8 Comparison pmsl fields verifying 30/8/87

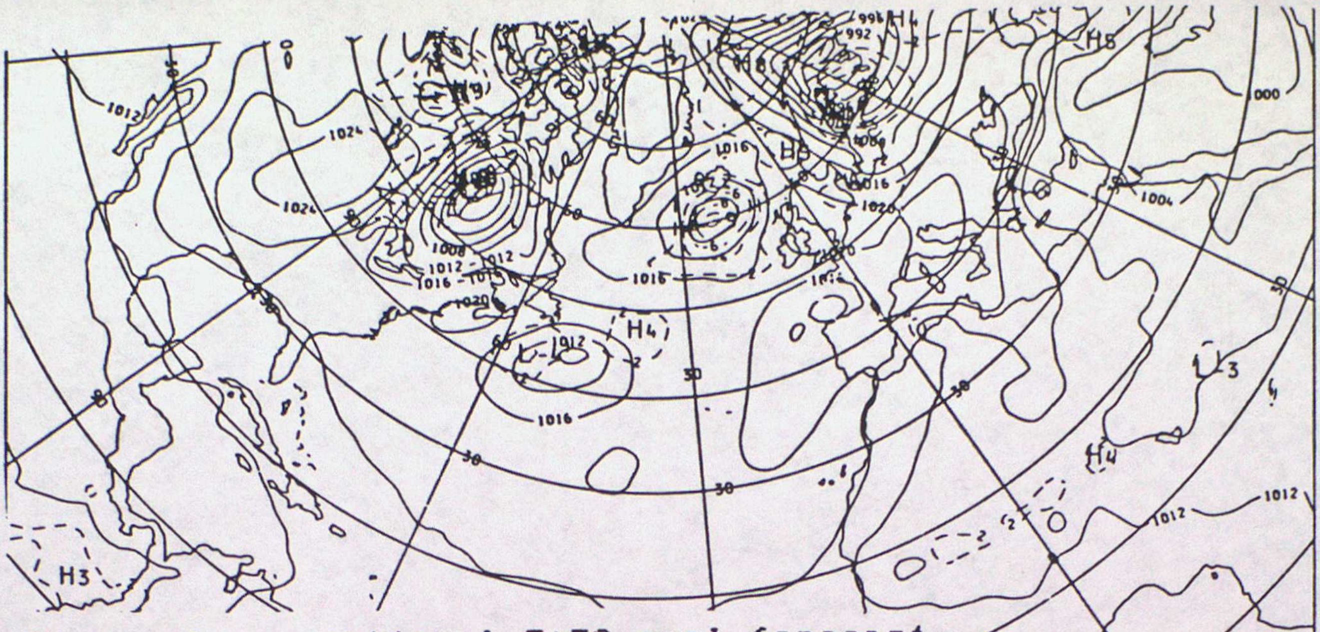

Figure 9a operational T+72 pmsl forecast

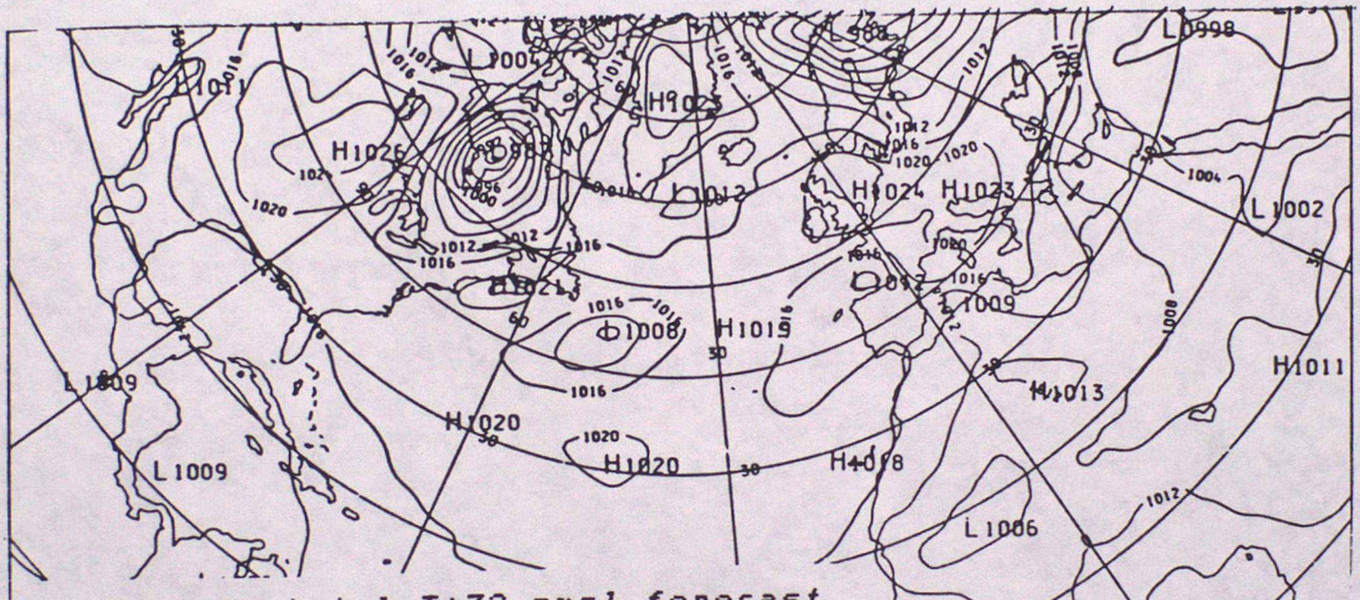

Figure 9b trial T+72 pmsl forecast

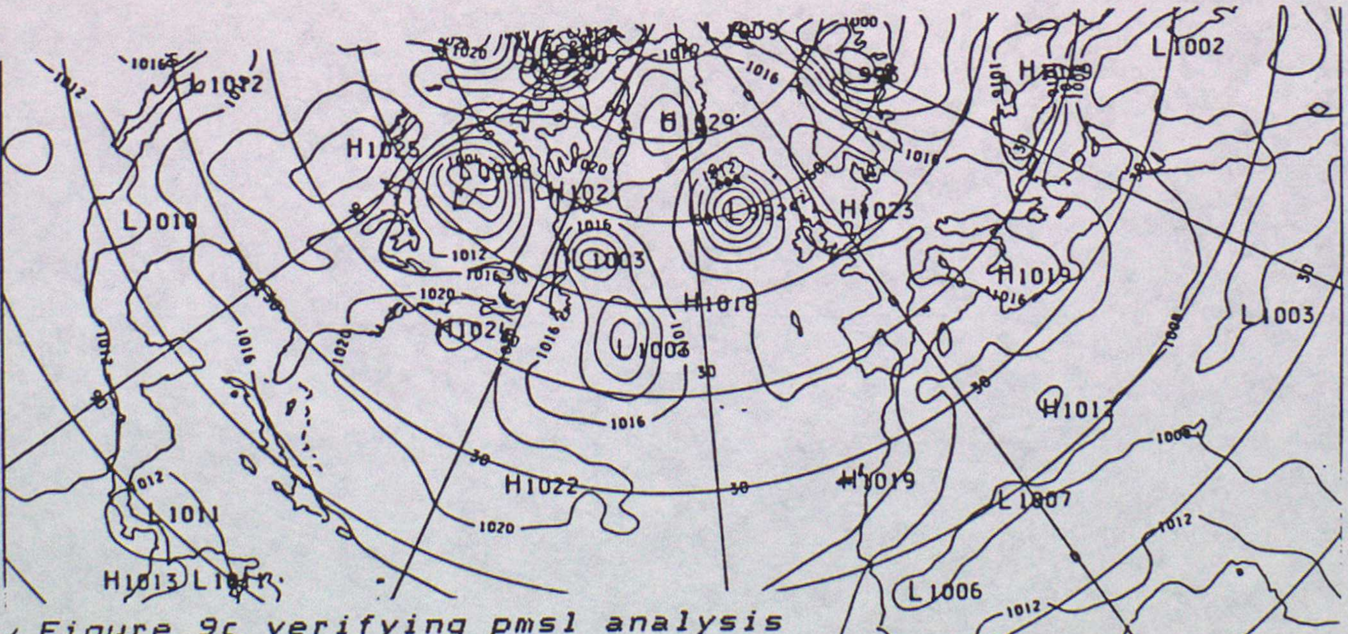

Figure 9c verifying pmsl analysis

Figure 9 Comparison pmsl fields verifying 31/8/87

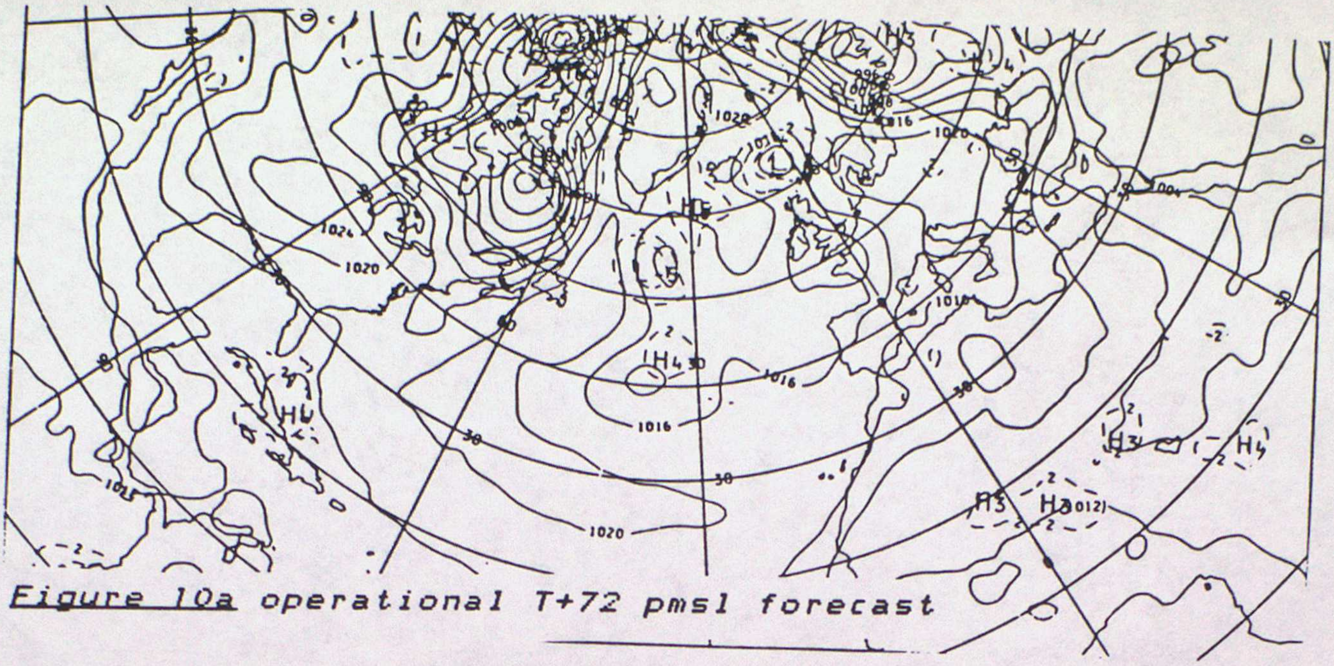

Figure 10a operational T+72 pmsl forecast

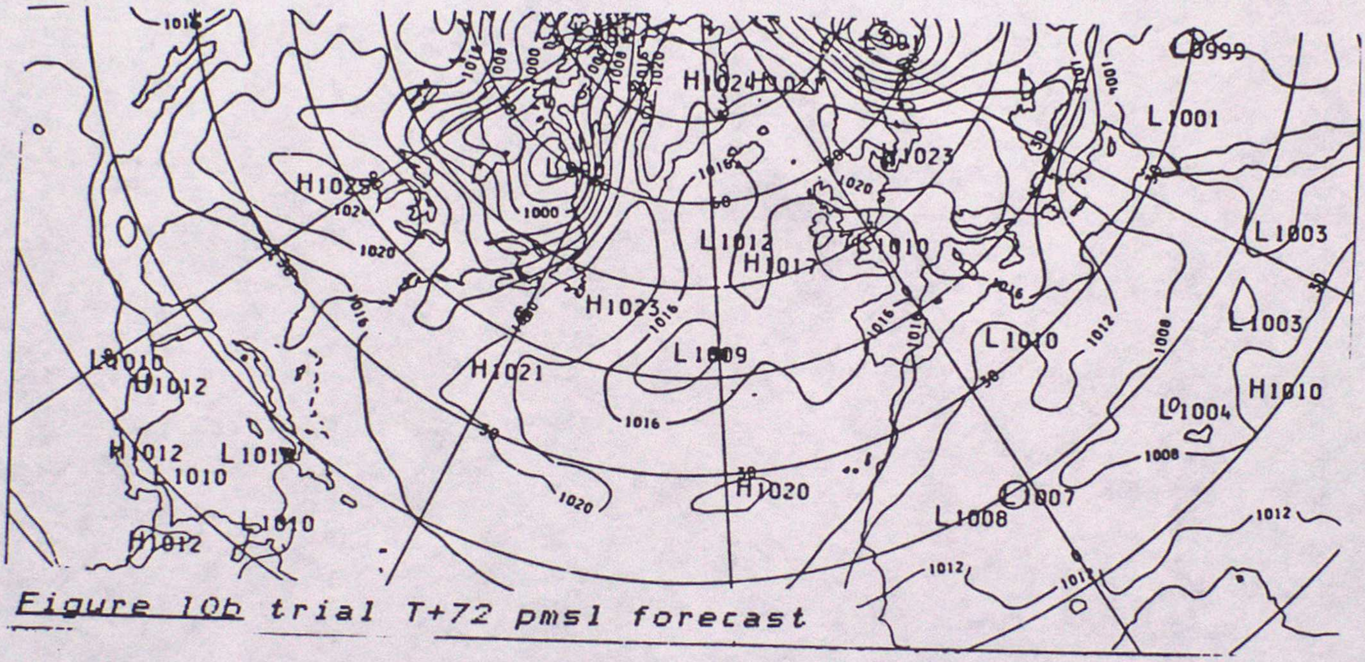

Figure 10b trial T+72 pmsl forecast

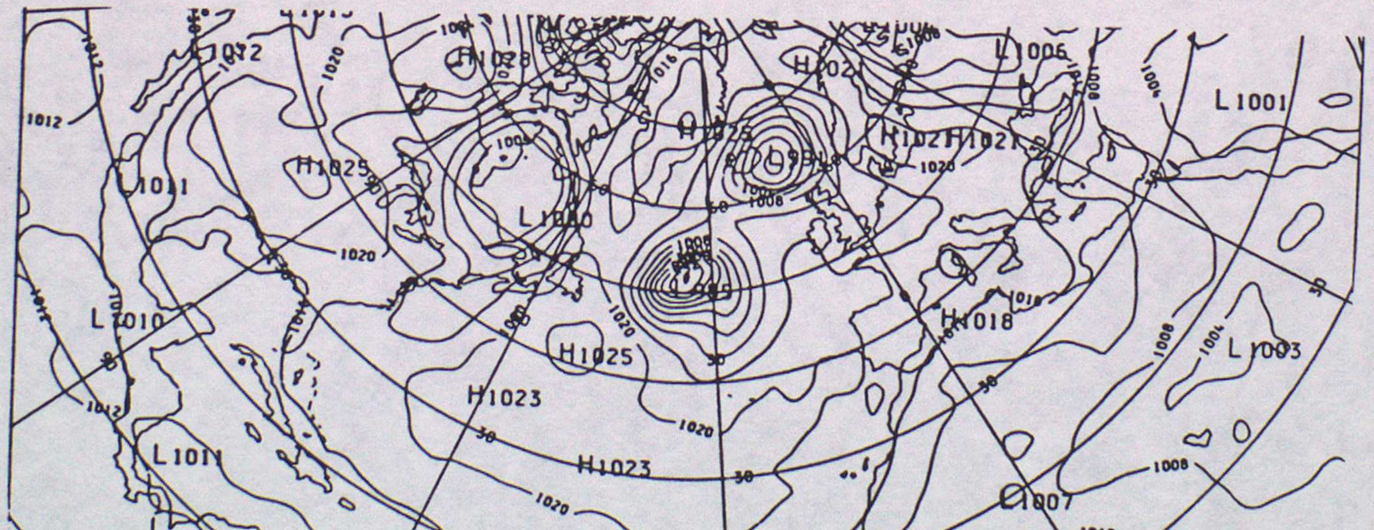

Figure 10c verifying pmsl analysis

Figure 10 Comparison pmsl fields verifying 1/9/87

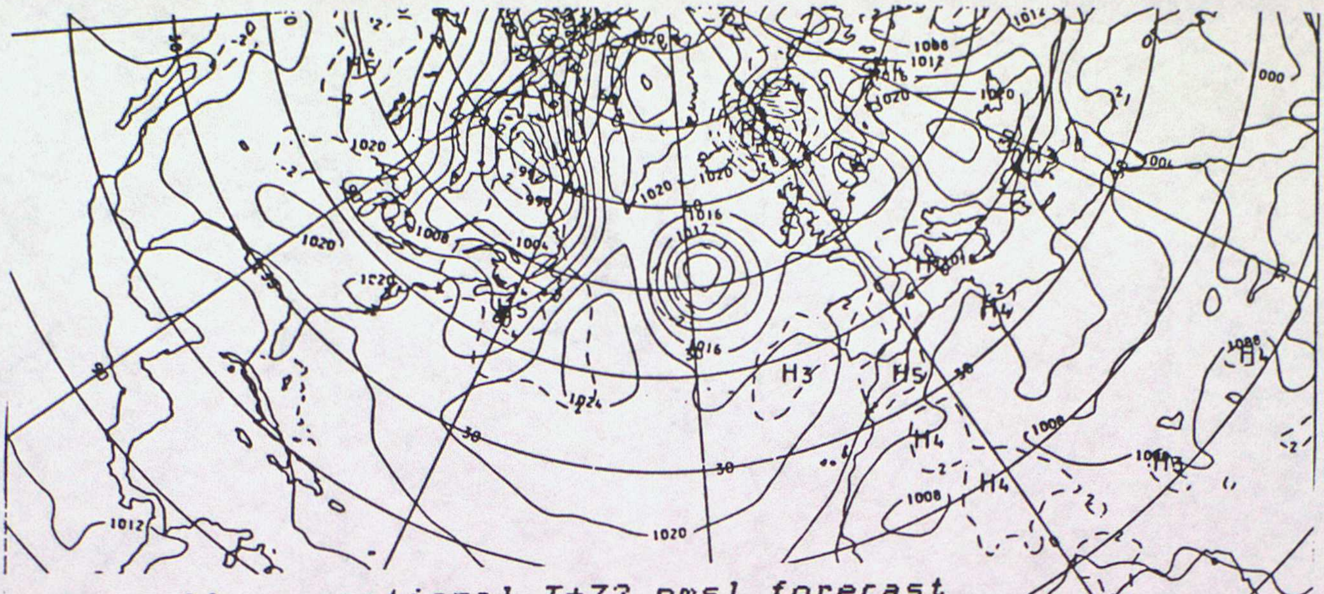

Figure 11a operational T+72 pmsl forecast

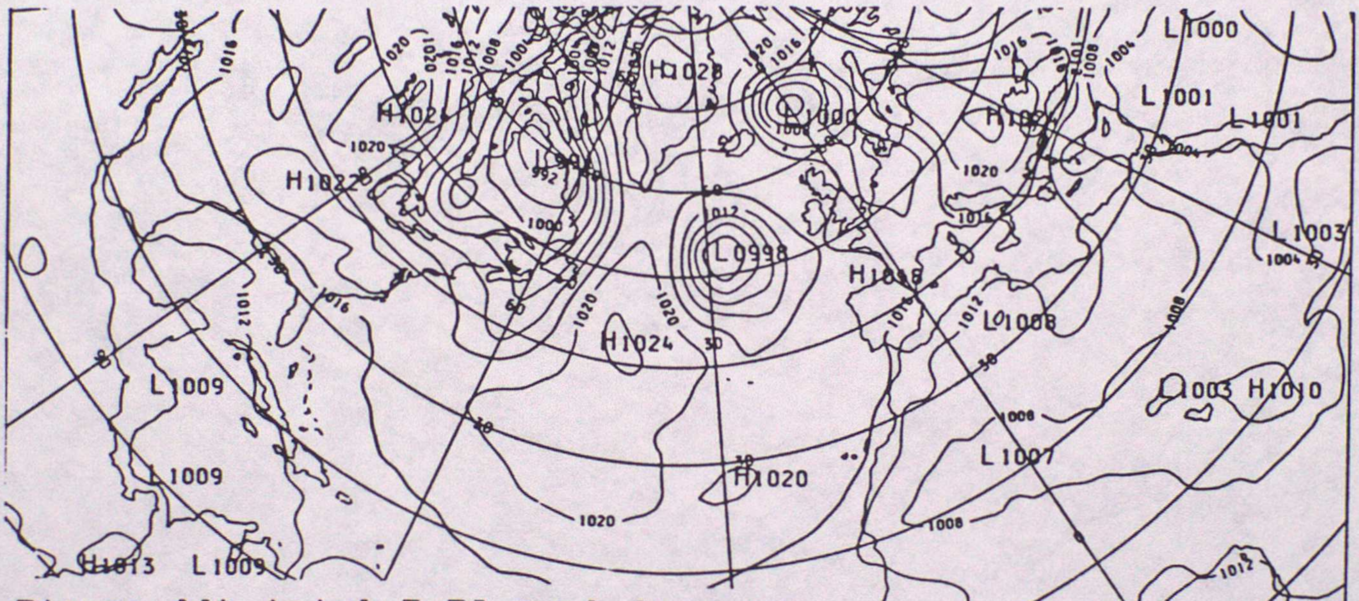

Figure 11b trial T+72 pmsl forecast

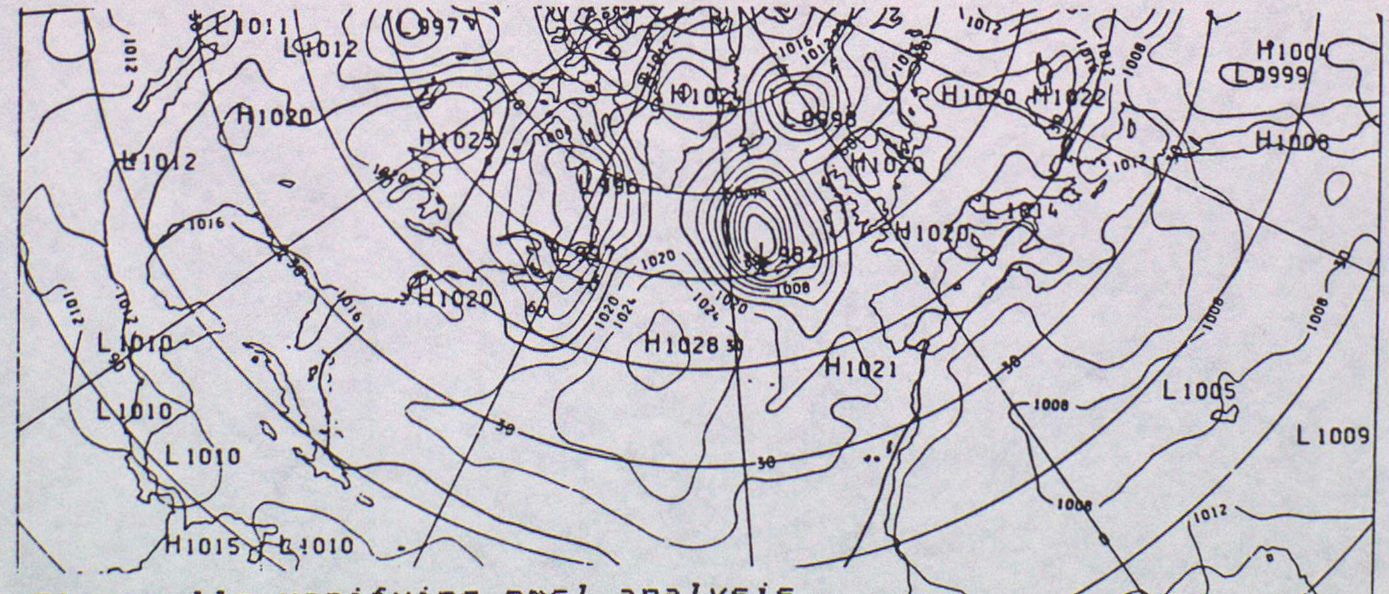

Figure 11c verifying pmsl analysis

Figure 11 Comparison pmsl fields verifying 2/9/87

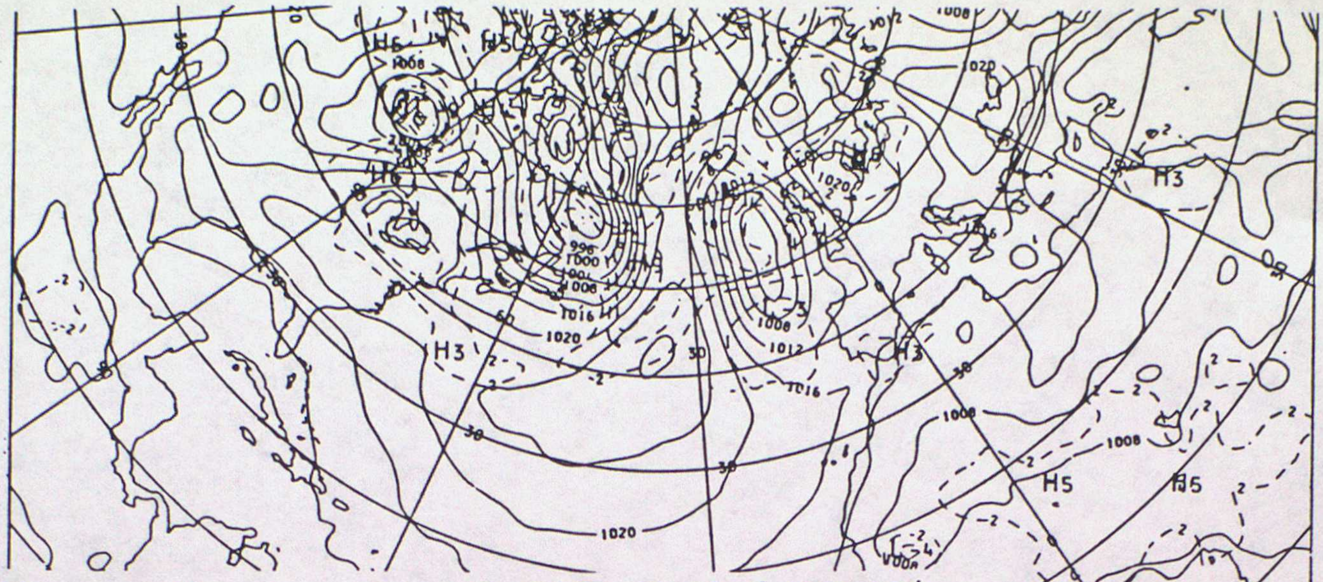

Figure 12a operational T+72 pmsl forecast

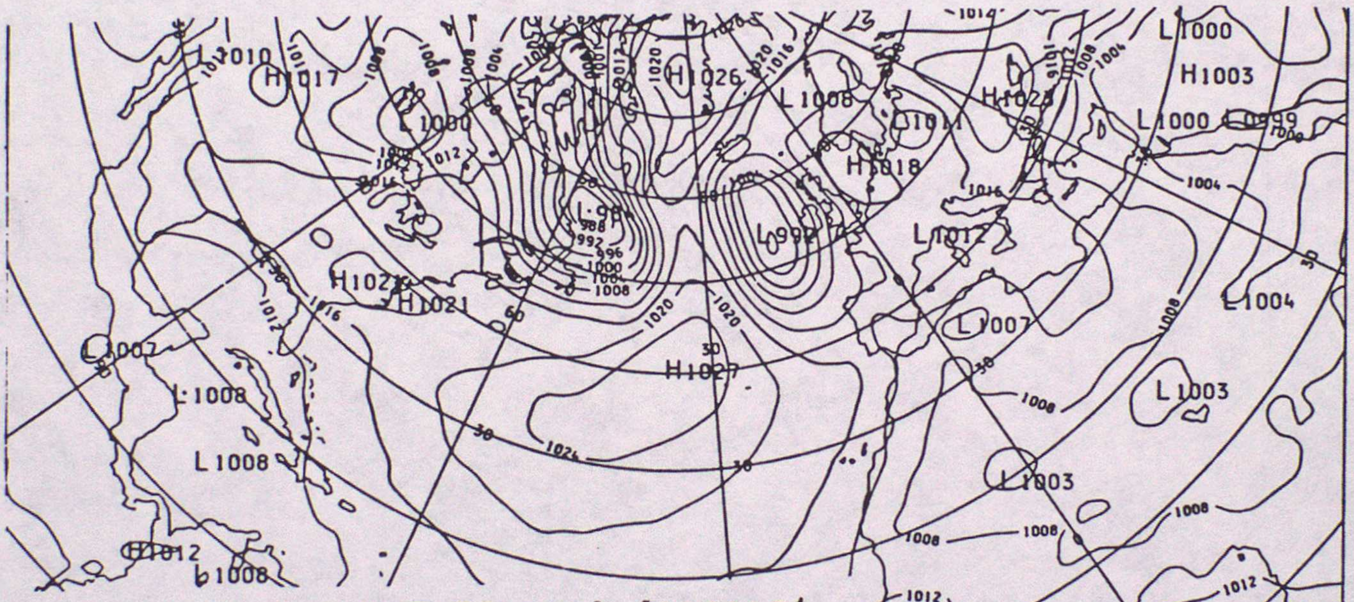

Figure 12b trial T+72 pmsl forecast

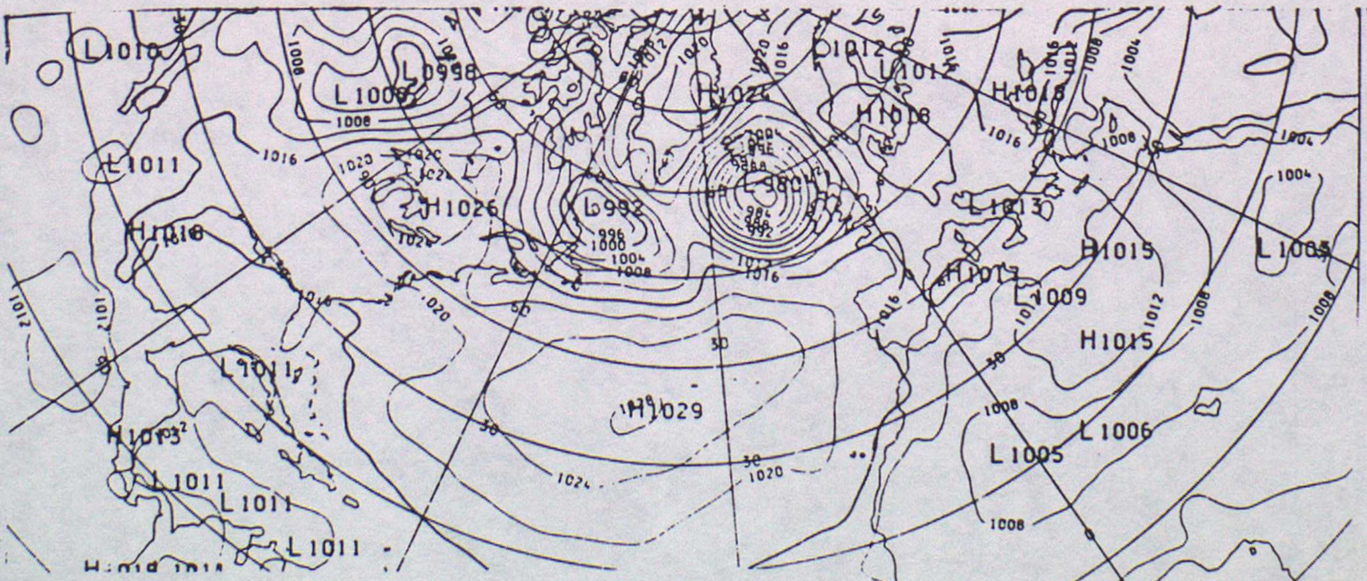

Figure 12c verifying pmsl analysis

Figure 12 Comparison pmsl fields verifying 3/9/87

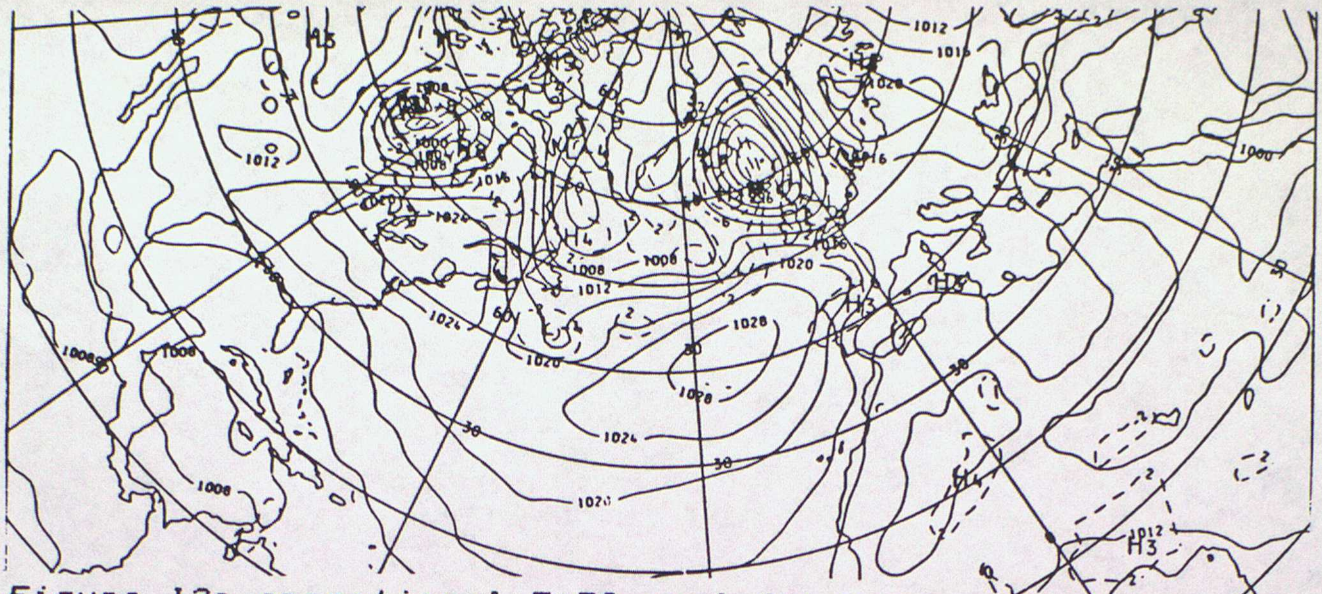

Figure 13a operational T+72 pmsl forecast

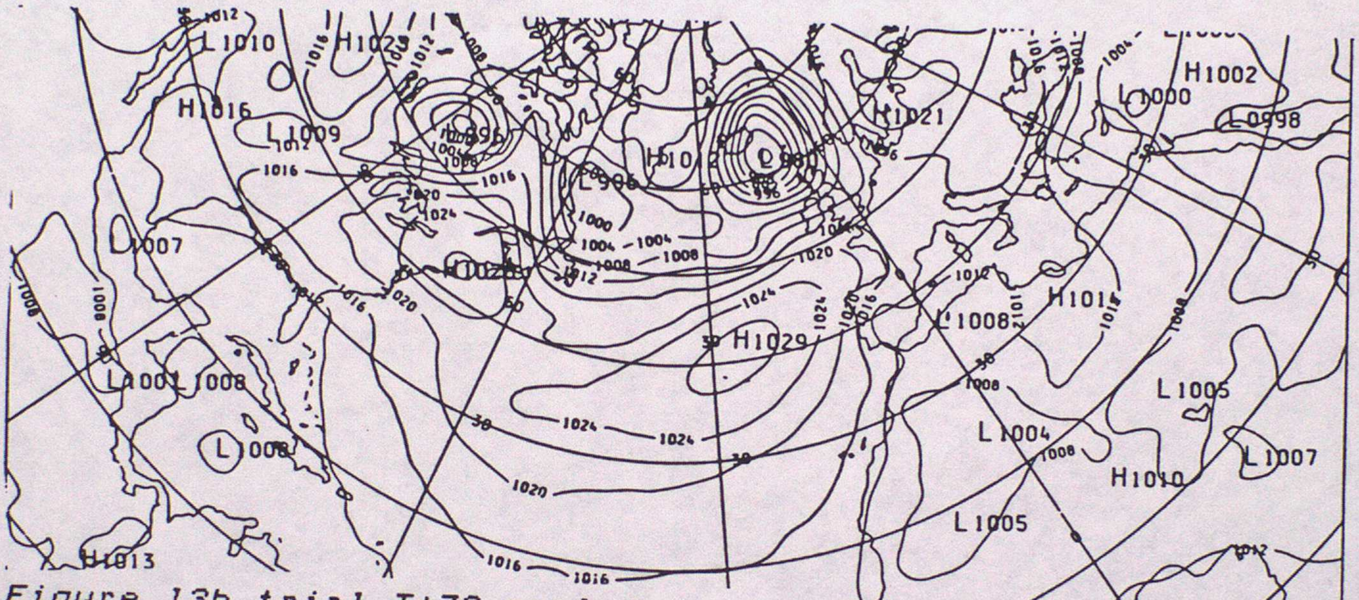

Figure 13b trial T+72 pmsl forecast

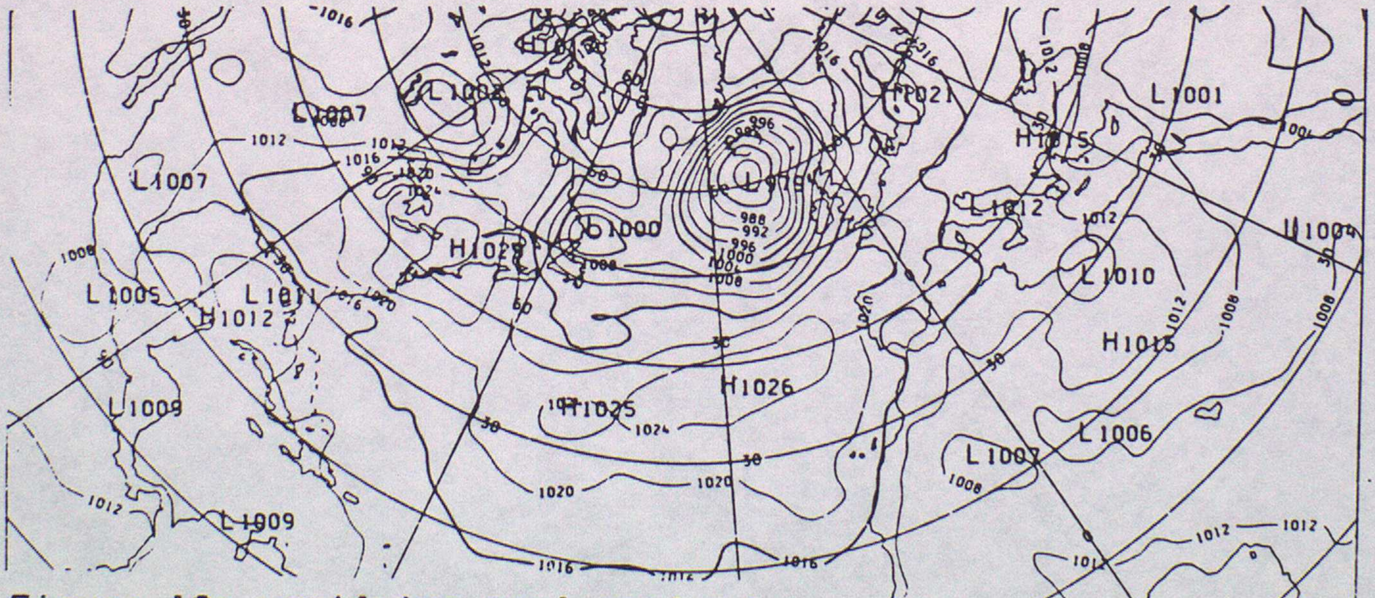

Figure 13c verifying pmsl analysis

Figure 13 Comparison pmsl fields verifying 4/9/87