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Verification of mesoscale model forecasts during the period May-July 1986.

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VERIFICATION OF MESOSCALE MODEL FORECASTS DURING THE PERIOD MAY-JULY 1986

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1. INTRODUCTION

The aim of this report is to assess the progress made by the mesoscale model during the quasi-operational trial. It will describe in detail results of the subjective and objective verification for the three month period May to July 1986. A brief description of model performance and changes during the period is given in section 2. The results from the objective verification of wind, temperature, rain, cloud and surface humidity forecasts are described in Section 3. Essentially the format will be the same as described in the previous two reports (1,2). However, one important change has been made. During early May, the mesoscale model morning forecast, DT06GMT, and the fine mesh comparison forecasts were extended to eighteen hours, and for the first time in this series, we can compare the accuracy of the two models at T+15 and T+18. Another important way of assessing the model is to see how well it performs in comparison with a subjective forecast. Two methods of subjective assessment will be described in Section 4. First, a detailed assessment of temperature forecasts for a few stations has been made in comparison with those prepared at Weather Centres for issue to various Gas Boards. Secondly, a detailed comparison is made between forecasts for Bracknell from the mesoscale model and from the British Isles Forecaster in CFO. Both forecasts are marked according to how accurately wind, temperature, cloud and weather are predicted.

2. MODEL PERFORMANCE AND CHANGES

During the period February to April, the mesoscale model forecast ran successfully on 95.5% of occasions. The success rate of the model was not as high during the period May to July; nevertheless 87.5% of forecasts (161 out of 184) ran successfully. Out of the twenty-three failures, 17 were model failures associated with the over-development of convective systems, whilst the rest were due to hardware problems. The main model problem occurred during hot, thundery weather in June when 12 of the model failures occurred.

Many small changes have been made to the model during this period. Objective verification results have indicated that in cloudy (i.e. 5-7 octas of cloud) weather, the mesoscale model temperature rises less than the observed temperature. To help alleviate this problem, the transmission of short-wave radiation through thin cloud was increased for high elevations of the sun. A major change was made to the modelling of cloud during early April, with the introduction of the stratiform cloud precipitation scheme, which included a more accurate treatment of the ice phase. Although this change improved the model's ability to maintain a stratiform layer of cloud in the forecast, April verification results indicated that the model still over-predicted the number of occasions of clear skies at night. (30% forecast, only 8% observed.) To help this problem, changes were made to the cloud top radiation budget during May. This change had a marked impact on the forecasting of cloud amount by the model, and this effect will be described in Section 3. Multi-level cloud analysis was also introduced in stages during May.

A number of changes have been made to help solve problems with the model's convection scheme. During April, verification results indicated that the mesoscale model was forecasting excessive amounts of convective rain. During May, the rain-out efficiency of convective clouds was decreased from 50% to 20%. This change reduced the number of showers forecast by the model significantly but led to large amounts of cloud water accumulating in the top model levels. The change did not help to prevent model failures in hot thundery weather. In July this scheme was abandoned, and the efficiency of convective precipitation was made dependent upon the mean humidity in the whole depth of the convective layer. In particular, if the mean humidity > 100%, all water condensed in the updraught rains out and none becomes detrained into the environment. Two other corrections were made to the convection scheme during June. First the downdraught from convection was prevented from becoming warmer than the ambient air. Finally, the convective parametrization was prevented from taking the cloud tops above level 14 to help maintain stability in warm thundery situations with a high tropopause. These last three changes will help to prevent model failures through the over-development of convective systems.

The method of analysing the rainfall rate was altered in June to help the analysis scheme remove spurious rain from the first guess in data-sparse areas. Time smoothing of the cloud water variable was also re-introduced to control oscillations, in order to reduce small amounts of spurious rain in the forecast. Of all the changes described in this section, the one which has had the most obvious impact on model forecasts during this period was the change to the cloud top radiation budget. The changes to the convection scheme made in July have also been tried with success on previous cases where the model had failed. However,we await the next hot thundery situation to test these changes thoroughly.

Only one change affected the fine-mesh model during the period. During May, the resistance to surface evaporation was gradually increased from 0 to 60 s/m. This change had a marked impact on the accuracy of fine-mesh temperature forecasts. Morecs data on the ratio of actual to potential evaporation is also being used to correct soil moisture content.

3. OBJECTIVE VERIFICATION RESULTS

In this section, fine-mesh and mesoscale model forecasts of rain, temperature, wind, cloud and relative humidity are compared for both forecast periods, 06-24 and 18-12. In this report, we will be able to compare the models at T+18 for the first time. Because of the many changes made to the model during the summer, we will place most emphasis on the July results, since these represent the latest status of the model. The greatest impact on the model has been caused by the changes in the modelling of cloud, so more attention will be given to this aspect than in previous reports.

a. RAINFALL FORECASTS

Due to a mixture of model, Cyber and verification problems, we do not have a complete month for rainfall verification. The best month was July, during which 49 forecasts out of a possible 62 were verified successfully.

The main difference between the two models during the summer months has been the excess rain predicted by the mesoscale model compared to the deficit of rain forecast by the fine-mesh model. The difference may be attributed to the models' convection schemes. Table 1 shows the mean forecast accumulations for both models expressed as a percentage of the observed accumulations over the three month period. The over prediction of rain by the mesoscale model is slightly greater during the 06-18 period, which suggests a problem connected with the convection scheme. The June figures refer to the first fifteen days only.

		MESOSCALE MODEL		FINE MESH MODEL	
MONTH		06-18	18-06	06-18	18-06
MAY	F/C/OBS x 100%	124	122	91	72
JUNE	F/C/OBS x 100%	135	121	59	49
JULY	F/C/OBS x 100%	192	145	85	66

TABLE 1. TOTAL MEAN FORECAST RAINFALL OVER A 12-HOUR PERIOD EXPRESSED AS A PERCENTAGE OF OBSERVED TOTALS

Figure 1 shows the observed accumulations for the whole of July for selected stations within the UK. The predominance of a westerly airstream during July resulted in the highest totals being recorded over high ground in the west. Nantmor in North Wales measured 169 mm of rain during July. In the absence of a complete set of results, an exact comparison of model forecast accumulations with those in Figure 1 is not possible. However, a brief comparison between Figure 2 (mesoscale model forecast accumulation for July for the 49 forecasts verified) and Figure 1 gives an indication of the excess rainfall forecast by the mesoscale model. Figure 3 shows the observed accumulations of selected stations covering the same period as the 49 forecasts verified. In many cases, the mesoscale model has forecast twice the amount observed. In contrast, the fine mesh model accumulations (shown in Figure 4) are too low especially in the east.

The observed rainfall accumulations for Eskdalemuir and Birmingham, corresponding to the forecasts run successfully during August, were 97 mm and 34 mm respectively. (Figures taken from Figure 3.) The corresponding mesoscale model accumulations were 130 and 84 mm respectively compared to the fine-mesh figures 67 mm and 13 mm.

One of the main reasons for over-prediction is that the mesoscale model forecasts too many wet periods, whilst the fine mesh model does not. This fact is shown in Table 2. These contingency tables compare the skill of the two models in predicting the occurrence of rain in a 12-hour period.

		MESOSCALE MODEL			FINE MESH MODEL			
MAY		OBS → NO	YES		OBS →	NO	YES	
F/C	NO	30%	7%	37%	NO	34%	11%	45%
	YES	21%	42%	63%	YES	16%	39%	55%
		51%	49%	100%		50%	50%	100%
JUNE*		OBS → NO	YES		OBS →	NO	YES	
F/C	NO	48%	7%	55%	NO	61%	13%	74%
	YES	21%	24%	45%	YES	9%	17%	26%
		69%	31%	100%		70%	30%	100%
JULY		OBS → NO	YES		OBS →	NO	YES	
F/C	NO	32%	8%	40%	NO	46%	15%	61%
	YES	28%	32%	60%	YES	14%	25%	39%
		60%	40%	100%		60%	40%	100%

TABLE 2. CONTINGENCY TABLES FOR FORECASTING THE OCCURRENCE OF RAIN IN A TWELVE HOUR PERIOD (18-06 AND 06-18 AVERAGED).

*Due to vertification problems, accumulations for the models were only available during the first fifteen days in June.

The fine mesh model is slightly more successful in predicting the occurrence of rain during the period May to July with 74% forecasts correct compared to 69% for the mesoscale model. These figures are obtained by taking the average of the percentages given on the main diagonals in Table 2. Errors in mesoscale model forecasts are three times more likely to be rain forecast/nil observed than the reverse, with the greater number of incorrect forecasts coming from the 18-06 forecast. In contrast, errors in the fine mesh model balance out. Errors in the mesoscale model forecasts are shown in more detail in Table 3 which shows an analysis of the July 12 hour rainfall accumulation (periods 06-18 and 18-06 averaged) for the mesoscale model.

FC 12-HR RAINFALL ACCUMULATIONS	OBSERVED 12-HR RAINFALL ACCUMULATIONS <0.1 mm	.1-1 mm	1-5 mm	5-10 mm	>10 mm	FC TOTALS
<0.1 mm	31.6%	5.8%	1.8%	0.1%	0.1%	30.4%
.1-1 mm	16.7%	6.8%	4.3%	0.7%	0.1%	28.6%
1-5 mm	9.4%	5.5%	1.7%	0.6%	0.6%	22.7%
5-10 mm	1.3%	1.1%	1.6%	0.9%	0.7%	5.6%
>10 mm	0.9%	0.5%	1.0%	0.5%	0.8%	3.7%
OBS TOTALS→	59.9%	19.7%	14.2%	3.9%	2.3%	100.0%

TABLE 3. JULY ACCUMULATION ANALYSIS FOR 12-HOUR PERIOD FOR MESOSCALE MODEL

The majority of the incorrect rain forecasts fall into the category 0.1 mm to 5 mm rain forecast/nil observed. Significant rainfall amounts (12-hour accumulation ≥ 5 mm) were better forecast by the mesoscale model with 47% correct forecasts compared with 39% for the fine mesh model.

The reasons for the over-prediction of rain by the mesoscale model are easily understood and are listed below:-

(i) Excessive rain in the first 1-3 hours. If we analyse the forecast and observed rainfall of selected stations, an average 28% of the mesoscale model forecast rainfall fell in the first hour compared with 10% of the observed, and 49% of the forecast rain fell in the first three hours compared with 28% of observed. In addition two-thirds of the rain forecast during the first hour was convective. This reason re-emphasizes the fact that the first three hours of the mesoscale model forecast should not be used for rain forecasts and verification.

(ii) On occasions when instability was present, the model forecast too much rain, too soon. Several cases of over-prediction were associated with weak frontal systems in July, when the model forecast too much convective rain from potential instability. There also is a continuing problem with mesoscale model forecasts in hot thundery weather with a high tropopause. Twelve model failures occurred in June due to the over-development of convective systems and the changes made in July have not been fully tested operationally.

In contrast, the fine mesh problem is one of too little rain rather than too much. The deficit over Eastern England (Figure 4) is probably associated with the lack of showers.

b. TEMPERATURE VERIFICATION

Following the excellent results described in the previous report, the mesoscale model temperature forecasts during this summer have been less accurate and a little disappointing. Part of the increased error will be due to greater temperature fluctuations in summer, but more significant has been the effect of recent model changes on cloud and temperature forecasts. In contrast, the fine mesh model's forecast temperatures have been more accurate following the increased resistance to evaporation implemented during May. The amount of cloud forecast by the mesoscale model has increased significantly and as a consequence, daytime temperatures have been forecast on the cool side, whilst the systematic warm bias overnight has continued. In Table 4, we show the percentage of model forecasts of maximum and minimum temperatures divided into categories of errors.

RANGE OF TEMP / ERROR IN °C (FC-OB)		<-4	-4 TO -3	-3 TO -2	-2 TO -1	-1 TO 0	0 TO 1	1 TO 2	2 TO 3	3 TO 4	>4
MAXIMUM TEMP	MAY	8	11	17	21	19	12	7	3	1	2
	JUNE	7	8	14	17	17	13	11	6	2	4
	JULY	9	11	18	20	18	13	7	3	1	1
MINIMUM TEMP	MAY	0	0	0.1	1	9	27	28	18	10	7
	JUNE	0.1	0.3	0.5	3	8	19	26	18	12	14
	JULY	0	0	0.2	1	8	25	28	17	9	10

TABLE 4. FREQUENCY OF OCCURRENCE OF ERRORS IN MESOSCALE MODEL MAXIMUM AND MINIMUM TEMPERATURE FORECASTS, EXPRESSED AS % OF TOTAL

NB: The June figures are for the first half (the cold half!) of the month only.

On average, over the three-month period 58% of model forecasts of maximum temperature were correct within 2°C. This compares poorly with the average figure of 78% for the period February to April, but the range of observed temperatures has been much greater during the summer. The cool bias is shown in Table 4; an average 34% of maximum temperature forecasts are too cold by more than 2 degrees celsius. However, on a hot sunny day, with no cloud problems, the mesoscale model proved that it was capable of predicting high temperatures. In Table 5, we show the observed and forecast maximum temperatures for six stations over Eastern England for July 16th.

STATION	OBSERVED MAX TEMP IN °C	MESOSCALE MODEL F/C MAX TEMP
MARHAM	29.1	29.1
FINNINGLEY	29.9	27.7
BINBROOK	28.4	28.4
HONNINGTON	28.1	28.1
HEATHROW	28.0	27.3
STANSTED	27.7	27.6

TABLE 5. OBSERVED AND FORECAST MAXIMUM TEMPERATURES ON JULY 16th

Figure 5 shows how the model fared on a day to day basis for one station, Marham in East Anglia. This shows the systematic warm overnight bias in the mesoscale model. On every night, the forecast minimum temperature was higher than that observed and errors of 3°C or more were not uncommon.

No direct comparison of extreme temperatures can be made with the fine mesh model, but we can compare errors at three-hourly intervals. In Figure 6, we have plotted the mean and rms temperature errors for both models at three-hourly intervals during both forecast periods in July, 06-24 and 18-12. This shows that in general, the fine mesh model was more accurate in July. The mesoscale model is only better at 21 GMT (T+15) in the daytime forecast; (this time coinciding with the switch from cool day bias to warm night bias) and at 21 GMT (T+3) in the night time forecast. In Table 6 we have chosen to compare the models at 15 GMT and 03 GMT for the three month period. This is the closest comparison we can make for maximum and minimum temperatures.

MODEL	MONTH	DT 06 GMT VT 15 GMT MEAN ERROR (°C)	RMS ERROR (°C)	% CORRECT WITHIN 2°C	DT 18 GMT VT 03 GMT MEAN ERROR (°C)	RMS ERROR (°C)	% CORRECT WITHIN 2°C
	MAY	-1.0	2.3	60	1.0	1.8	77
MES	JUNE	-0.7	3.0	51	1.3	2.3	65
	JULY	-1.2	2.4	61	1.3	2.0	72
	MAY	-1.3	2.3	61	0.1	1.5	83
FM	JUNE	-0.6	2.5	62	0.6	1.8	74
	JULY	-0.6	2.0	71	0.8	1.7	79

TABLE 6. COMPARISON OF TEMPERATURE ERRORS BETWEEN MESOSCALE MODEL AND FINE MESH MODEL AT 15 GMT AND 03 GMT, MAY TO JULY 1986

The results in Table 6 show that the fine mesh model was more successful in forecasting an accurate temperature for 15 GMT. The fine mesh advantage at 15 GMT over the mesoscale model is 10% in terms of accuracy within 2°C (Averages taken from column 3) and 0.5°C on average. However, using just one value to judge the accuracy of temperature forecasts over the UK can be misleading, since geographical location of errors is more important. Figure 7 shows the distribution of mean errors for the mesoscale model for VT 15 GMT during July. The shaded areas enclose regions where the negative bias is greater than 2°C. These largest errors occur over high ground, particularly over Scotland and Wales, whilst errors over low ground, especially over Eastern England are small. The large errors over Scotland are partly due to unrepresentativeness (model orography is higher than most observing stations in Scotland) and partly to the model forecasting too much low cloud in this region (see comment later in cloud section). In Figures 8 and 9, we can compare rms errors from the mesoscale model forecast, VT 15 GMT during July, with those from the fine mesh model. The shaded areas enclose regions where the rms errors are greater than 3°C. This figure shows that the fine mesh rms errors were lower in the majority of places.

The overnight temperature forecast is straightforward, in that the mesoscale model has a definite warm bias for nearly all stations. Figure 10 shows the distribution of mean errors for the mesoscale model for VT 03 GMT during July. The shaded area encloses regions where the warm bias exceeds 2°C. This region encompasses an area over Eastern England and the Midlands down to Somerset and Dorset. The reason is probably due to over-prediction of low cloud. Figures 11 and 12 compare the rms temperature errors for the mesoscale and fine mesh models for VT 03 GMT during July. The shaded areas enclose regions where the rms error exceeds 2.5°C. The fine mesh model has an advantage of 8% in terms of accuracy within 2°C during the period May-July, and 0.6°C in rms error. This

1°C over Eastern England and the Midlands in July. This difference can be attributed to cloud; the mesoscale model had an average surplus of 1-2 octas overnight whilst the fine mesh model had a deficit of 1-2 octas.

c. WIND VERIFICATION

Table 7 shows the wind speed errors for both the mesoscale and fine mesh models for the period May to July 1986. The fine mesh wind speed forecasts for level 1 (25 m) have been multiplied by a factor of 0.85 so that they can be compared fairly with the mesoscale model winds at 10 m and also wind observations.

DATE TIME 06 GMT		VERIFICATION TIME					
MODEL	MONTH	9	12	15	18	21	24
MES	MAY	5.3	5.3	5.4	5.3	5.6	5.5
MES	JUNE	4.9	4.9	5.1	4.9	5.1	5.3
MES	JULY	4.5	4.5	4.8	4.6	5.0	5.0
FM	MAY	5.2	5.2	5.4	5.7	6.1	5.5
FM	JUNE	4.8	4.6	4.9	5.0	5.5	5.2
FM	JULY	4.5	4.4	4.6	4.6	5.3	4.7

TABLE 7(a). RMS WIND SPEED ERRORS IN KNOTS AT 3-HOURLY INTERVALS DURING THE 06-24 FORECAST

DATE TIME 18 GMT		VERIFICATION TIME					
MODEL	MONTH	21	00	03	06	09	12
MES	MAY	5.2	5.3	5.3	5.1	5.3	5.4
MES	JUNE	4.5	4.9	4.9	5.2	5.2	5.2
MES	JULY	4.8	4.7	4.8	5.0	4.9	4.9
FM	MAY	5.3	5.2	5.4	5.5	5.5	5.4
FM	JUNE	4.8	4.7	4.8	5.0	4.8	4.8
FM	JULY	4.8	4.5	4.8	4.6	4.7	4.7

TABLE 7(b). RMS WIND SPEED ERRORS IN KNOTS AT 3-HOURLY INTERVALS DURING THE 18-12 FORECAST

Tables 8(a) and (b) show how close the models are in terms of accuracy. Figure 13 shows the geographical distribution of mesoscale model wind speed rms errors for T+9, VT 15 GMT during July. The shaded areas represent rms errors ≥ 5 kt, which is the average value taken from Table 8a. The largest errors are mainly over the coast or high ground, whilst many inland stations have rms errors less than 4 kt. Figure 14 shows the number of occasions when the forecast wind speed error exceeded two beaufort force during July. Most frequent errors occurred at hill and coastal stations; eg errors of two or more beaufort force occurred at Southampton on 17 occasions, with the model wind speed being too strong. This is probably due to the situation of Southampton Weather Centre in the centre of the city rather than on the coast.

Table 8 shows the frequency of occurrence of particular wind speed errors at 03 GMT and 15 GMT during July. Both observations and forecasts have been converted to Beaufort forces and the forecast errors have been partitioned in terms of the number of Beaufort force in error.

ERROR IN BEAUFORT FORCE [FC-OB]	<-3	-3	-2	-1	0	1	2	3	>3
VT 03 GMT MESOSCALE	0.1%	0.2%	2%	8%	29%	40%	18%	2%	0.1%
VT 03 GMT FINE MESH	0	0.3%	4%	15%	32%	34%	11%	2%	0.3%
VT 15 GMT MESOSCALE	0.1%	0.8%	4%	17%	40%	27%	9%	2%	0.2%
VT 15 GMT FINE MESH	0	0.4%	4%	18%	40%	28%	9%	2%	0.1%

TABLE 8. FREQUENCY OF OCCURRENCE OF WIND SPEED ERRORS AT 3 GMT AND 15 GMT DURING JULY

Table 9 shows that 77% of mesoscale wind speed forecasts verifying at 03 GMT were correct to one Beaufort force, compared to 81% for the fine mesh model. There was a definite tendency for the mesoscale winds to be too strong. The ratio of strong forecasts to weak forecasts at 03 GMT was 6:1 for the mesoscale model but only 2.5:1 for the fine mesh model. At 15 GMT, the models compared very closely with approximately 85% of forecasts correct to one Beaufort force. Wind speed forecasts were generally more accurate, with the ratio of strong forecasts to weak being 1.7:1 for both models.

Table 9 shows the observed and forecast wind speed climatology for 03 GMT and 12 GMT during July.

VT	BEAUFORT FORCE	1	2	3	4	5	6	7	8
03Z	OBS FREQUENCY %	31	27	24	14	3	1	0.3	0.1
03Z	MES F/C FREQUENCY %	6	23	37	27	5	1	0.1	0
03Z	FM F/C FREQUENCY %	5	43	30	16	4	2	0.3	0.1
15Z	OBS FREQUENCY %	9	17	31	33	8	2	0.5	0.1
15Z	MES F/C FREQUENCY %	4	14	33	36	11	2	0.2	0
15Z	FM F/C FREQUENCY %	5	10	32	42	10	2	0.1	1

TABLE 9. OBSERVED AND FORECAST WIND SPEED CLIMATOLOGY VT 03 GMT AND VT 15 GMT FOR JULY

Table 9 confirms that light winds (Beaufort force 1 and 2) are underestimated, particularly by the mesoscale model, at 03 GMT. 58% of observed winds were Beaufort force 1/2 at 03 GMT during July compared to 29% forecast by the mesoscale model. Figure 15 shows the number of occasions of mesoscale model wind forecasts in error by two or more Beaufort forces at 03 GMT. The shaded area indicates five or more occasions of wind speed errors of two Beaufort force or more. A significant number of inland stations, particularly over Southern England, East Anglia and the Midlands had errors exceeding two Beaufort force on more than five occasions.

There was little to choose between the models during the daytime with both having rms errors of approximately five knots and an accuracy (+/- 1 Beaufort force) of approximately 85%. However, the mesoscale model has a slight systematic strong bias overnight.

d. Surface Relative Humidity Verification

Fog has been omitted from this sub-section since it was not a significant feature of the summer, except possibly over the sea and coasts where it cannot be easily verified. Table 10 shows the percentage of surface relative humidity forecasts as a function of their differences from the observed values at 15 GMT, for both models. The figures are expressed as a percentage of the total forecasts verified during the month.

% RH ERROR [FC-OB]		<-30	-30 TO -20	-20 TO -10	-10 TO 0	0 TO 10	10 TO 20	20 TO 30	>30
MODEL	MONTH								
MES	MAY	0.3	2	6	19	26	23	16	8
MES	JUNE	0.4	2	8	22	29	22	13	4
MES	JULY	0.3	1	5	18	28	26	15	7
FM	MAY	0.4	1	7	21	30	24	12	5
FM	JUNE	1.0	5	16	28	28	15	5	2
FM	JULY	0.6	4	13	31	31	16	4	1

TABLE 10. FREQUENCY OF OCCURRENCE OF SURFACE RELATIVE HUMIDITY ERRORS DT 06 GMT VT 15 GMT

Both models tend to be too moist rather than too dry but the moist bias is larger in the mesoscale model. This is in contrast to the previous three-month period, February to April, in which the fine mesh model was too wet. Table 10 shows the improvement in the fine mesh model after May, following the implementation of the increased resistance to surface evaporation. The average percentage of forecasts accurate to within 10% has increased by 10%. The percentage of relative humidity forecasts too moist by more than 20% decreased from 26% in April to 17% in May and to 5% in July. The mesoscale model, on the other hand has become wetter. Only 6% of surface humidity forecasts were more than 20% too moist in April compared with 22% in July. The reason is thought to be due to the increased cloudiness in the model and excessive low cloud. Figure 14 shows the distribution of the mean surface relative humidity errors of the forecast verifying at 12 GMT, an 18-hour forecast from the initial time 18 GMT. The shaded area encloses stations where the positive bias exceeds 15%. Again, the highest errors are over high ground in the north, but the over-moist bias also affects the Midlands.

e. Cloud Verification

We verify two cloud parameters from the models; base and amount. During the winter months, the mesoscale model was unable to maintain thin layers of stratiform cloud and hence frequently under-predicted cloud amounts, especially at night. Important changes were made to the mesoscale model during April and May to improve the modelling of cloud. The main changes were:

i. the stratiform cloud precipitation scheme and

ii. introduction of the cloud top radiation budget.

These changes have made a pronounced impact on the forecasting of cloud amounts by the model, particularly during the night. As we will show, the problem during the summer months has been too much cloud forecast rather than too little. Table 11 shows the mean grid point cloud amount errors for both models at T+12, (VT 18 GMT and VT 06 GMT) during the period May to July. This table shows the tendency for the mesoscale model to forecast too much cloud and also the deficit of cloud in the fine mesh

MODEL	MONTH	DT 06 GMT VT 18 GMT	DT 18 GMT VT 06 GMT
MES	MAY	0.6	0.7
MES	JUNE	0.2	0.2
MES	JULY	1.6	1.0
FM	MAY	-0.7	-0.8
FM	JUNE	-1.4	-1.8
FM	JULY	-1.2	-1.3

TABLE 11. MEAN CLOUD AMOUNT ERROR IN OCTAS AT T+12

forecast. The cloud amount bias for July is shown in more detail at three-hourly intervals in Figure 16. For the mesoscale model forecast, the bias is small during the daytime, amounting to only 0.5 octa. The fine mesh forecast has a marked deficit of cloud of 1 to 1.5 octas throughout. In Table 12, we compare forecasts of cloud amount from the two models more closely. This table shows the correct and incorrect cloudy and clear forecasts at T+12, VT 18 GMT for both models.

		% CORRECT			% INCORRECT		
MODEL	MONTH	CLEAR	PARTIAL	CLOUDY	CLEAR	PARTIAL	CLOUDY
MES	MAY	8	13	17	12	10	41
MES	JUNE	17	10	13	15	10	35
MES	JULY	4	15	18	10	10	43
FM	MAY	16	13	16	23	10	23
FM	JUNE	24	12	7	31	10	17
FM	JULY	10	17	12	33	11	16

TABLE 12. CLOUD AMOUNT FORECASTS AT T+12, VT 18 GMT FOR PERIOD MAY TO JULY

Clear periods are defined as 4 octas of cloud or less, partial cloudiness as 5 to 7 octas, and cloudy periods as more than 7 octas. For the fine mesh model, the highest correct and incorrect forecasts both appear in the clear column, confirming the tendency of the model to forecast too little cloud rather than too much. For the mesoscale model, the greatest number of incorrect cloud forecasts occur in the cloudy column, showing that this model tended to over-predict cloud amount. This tendency was increased during the overnight period. Table 13 shows the mesoscale model's forecast cloud amount at VT 03 GMT during July in terms of a contingency table with cloud amount categories 0-1 octa, 2-4 octas, 5-7 octas and 8 octas. The results are expressed as percentages of all forecasts verifying at 03 GMT.

OBSERVED CLOUD AMOUNT IN OCTAS	0-1	2-4	5-7	8	
FORECAST CLOUD AMOUNT IN OCTAS					% FORECAST
0-1	2	1	1	1	5
2-4	1	1	3	1	6
5-7	2	2	7	3	14
8	6	9	33	27	75
% OBS →	11	13	44	32	100

TABLE 13. CONTINGENCY TABLE FOR OBSERVED AND MESOSCALE FORECAST CLOUD AMOUNTS VT 03 GMT DURING JULY

Approximately 37% of forecasts were correct, (as shown by the main diagonal) and 53% over-predicted amounts. The major error, 33% of forecasts, falls into the category 5-7 octas observed/8octas forecast. This accounts for the mean overnight bias of 1.5 octas. The above results give full credit for the cloud forecast even if the base is completely wrong. The skill of the models in predicting cloud base in the correct category is more important. Table 14 compares the model climatology of cloud base with the observed climatology during the summer. The six cloud base categories given in Table 14 include four categories for low cloud, based on mesoscale model levels 2-5, then two categories for medium and high cloud. The fine mesh cloud base forecasts are based on an interpolation of relative humidity on to the mesoscale model grid, with values of 85% or more interpreted as cloud. All forecasts for all stations verifying at 18 GMT are included in Table 14 and at 06 GMT in Table 14.

CLOUD BASE (Feet)		0-600	600-1500	1500-2600	2600-4100	4100-1800	>18000
MAY	OBS	4%	11%	29%	18%	23%	15%
	MES	20%	31%	27%	13%	4%	5%
	FM	50%	12%	12%	9%	7%	10%
JUNE	OBS	5%	9%	21%	16%	29%	20%
	MES	19%	23%	24%	10%	8%	17%
	FM	31%	14%	15%	11%	9%	20%
JULY	OBS	11%	22%	40%	20%	7%	0%
	MES	27%	29%	24%	12%	4%	5%
	FM	40%	13%	15%	17%	7%	8%

TABLE 14a. CLIMATOLOGY OF FORECAST AND OBSERVED CLOUD BASES MAY-JULY FOR VERIFYING TIME 18 GMT

CLOUD BASE (Feet)		0-600	600-1500	1500-2600	2600-4100	4100-1800	>18000
MAY	OBS	9%	18%	23%	14%	22%	14%
	MES	43%	30%	10%	4%	4%	9%
	FM	86%	2%	2%	2%	3%	6%
JUNE	OBS	9%	18%	23%	14%	22%	14%
	MES	43%	30%	10%	4%	4%	9%
	FM	86%	2%	2%	2%	3%	6%
JULY	OBS	26%	29%	22%	12%	12%	0%
	MES	51%	29%	11%	3%	3%	3%
	FM	89%	1%	2%	2%	2%	5%

TABLE 14b. CLIMATOLOGY OF FORECAST AND OBSERVED CLOUD BASES, MAY-JULY FOR VERIFYING TIME 06 GMT

It is important to emphasize the limitations of the figures in Tables 14(a) and (b). It gives the climatology of the lowest cloud base of any amount, so that if the model forecasts excessive low cloud then it will automatically appear to have a deficit of upper cloud. Table 14 shows the tendency of both models to forecast excessive low cloud in the lowest model cloud level, level 2. The fine mesh model is much worse, especially for verifying time 06 GMT, when the fine mesh forecasts fog or very low stratus on an average 87% of occasions. The mesoscale model low cloud is better distributed between model levels 2-4 than the fine mesh model.

In order to counteract the limitations of Table 14, a more detailed analysis of mesoscale model cloud was tried during July. In Table 15 we have considered significant cloud amounts (≥ 5 octas) from a subset of stations, all of which possess a cloud base recorder to help with cloud height. The fine mesh model is not included in this analysis. During July the fine mesh model was diagnosed as having 5 octas or more on only 30% of occasions on average compared with the observed figure of 55% and the mesoscale model figure of 77%, so a fair comparison could not be made. The times chosen for the analysis were 06 GMT and 15 GMT.

SIGNIFICANT CLOUD BASE OF 5 OCTAS OR MORE (FEET)		0-600	600-1500	1500-2600	2600-4100	4100-6000
6 GMT	OBS	7%	10%	12%	9%	18%
6 GMT	MES F/C	23%	38%	18%	4%	2%
15 GMT	OBS	2%	4%	9%	11%	27%
15 GMT	MES F/C	5%	21%	30%	18%	5%

TABLE 15. SIGNIFICANT CLOUD BASE ANALYSIS (≥ 5 OCTAS) FOR JULY FOR VERIFYING TIMES 06 GMT AND 15 GMT

Again, this table shows that even if we only consider cloud observed and forecast of 5 octas or more, the model cloud base is too low. Figure 17 shows the distribution of excess low cloud errors for verifying time 21 GMT. The figures plotted have been calculated by subtracting the number of observed occasions of low cloud below base 1500 feet from the number forecast. The shaded area indicates values ≥15 occasions. The largest number of errors are found over Scotland and this may be partly due to the difference between model orography and the height of the observing stations. Negative values are confined to coasts.

4. SUBJECTIVE VERIFICATION

Objective verification is useful in identifying systematic model errors, but it gives no idea of the relative difficulty of a forecast or of how useful the model is in a particular situation. It is important to see how well the model performs in a particular situation in comparison with a subjective forecast. Two ways in which this comparison has been made are described in this section.

a. Bracknell Local Area Forecast

A special Bracknell Local Area Forecast for the period 09-18 GMT was prepared, based entirely on the mesoscale model forecast run from 06 GMT initial data. This forecast was compared with a similar

forecast issued by CFO prior to receiving the mesoscale model output. The period was divided into three sections, 09-12, 12-15 and 15-18 GMT and forecasts of weather cloud, wind and temperature for the three periods were assessed. During July the forecast period assessed was extended from 09-18 GMT to 09-24 GMT, and two extra periods, 18 to 21 GMT and 21 to 24 GMT were added to the assessment. Also during July, the method of assessing cloud was altered. The total cloud forecast was assigned one of three letters;

B = 0-4 octas to represent clear/sunny periods
P = 5-6 octas to represent partial cloudiness
C = 7-8 octas to represent cloudy skies.

This change was made to make cloud assessment easier and more accurate. The main problem during May and June was in trying to interpret model output in terms of sunny periods or sunny intervals. The subjective verification results for temperature, wind, cloud and weather are described separately below in sections (i)-(iv).

i. Temperature Forecasts

The comparative accuracy of the CFO and mesoscale model temperature forecasts are shown in Table 16a, which gives the percentage of forecasts correct within 2°C.

MONTH	VT 12 GMT		VT 15 GMT		VT 18 GMT		VT 21 GMT		VT 00 GMT	
	MES	CFO	MES	CFO	MES	CFO	MES	CFO	MES	CFO
MAY	69%	83%	72%	76%	68%	86%	-	-	-	-
JUNE	63%	70%	63%	74%	73%	81%	-	-	-	-
JULY	61%	90%	55%	84%	55%	81%	84%	93%	81%	74%

TABLE 16a. PERCENTAGE OF BRACKNELL TEMPERATURE FORECASTS CORRECT TO WITHIN 2°C

At this level of accuracy, CFO were clearly better. The decrease in accuracy between May and July is noticeable in the results for the mesoscale model. The model had a cold bias which reached -1.6°C at 15 and 18 GMT in July, whereas the CFO temperature bias was very small. The cold bias in the mesoscale model temperature forecast switched to a small warm bias by 00 GMT, hence the good results at 00 GMT. The gap in accuracy between the mesoscale model and CFO narrows if we examine the percentage accuracy to within 3°C. (see table 16b). Table 17 compares the accuracy of the C.F.O. and mesoscale model temperature forecasts for Bracknell on a day to day basis.

MONTH	VT 12 GMT		VT 15 GMT		VT 18 GMT		VT 21 GMT		VT 00 GMT	
	MES	CFO	MES	CFO	MES	CFO	MES	CFO	MES	CFO
MAY	93%	93%	83%	86%	68%	89%	96%	-	-	-
JUNE	81%	81%	74%	93%	92%	88%	-	-	-	-
JULY	90%	93%	77%	90%	74%	90%	97%	97%	93%	87%

TABLE 16b. PERCENTAGE OF BRACKNELL TEMPERATURE FORECASTS CORRECT WITHIN 3°C

The subjective assessment figures are given in Table 17.

VERIFICATION TIME	12 GMT	15 GMT	18 GMT	21 GMT	00 GMT
CFO better by ≥2°C	29%	34%	25%	10%	10%
Forecasts within 2°C	57%	49%	65%	77%	71%
MES Better by ≥2°C	14%	16%	11%	13%	19%

TABLE 17. SUBJECTIVE ASSESSMENT OF THE ACCURACY OF CFO AND MESOSCALE MODEL TEMPERATURE FORECASTS FOR BRACKNELL DURING THE PERIOD MAY-JULY

NB. Only July figures could be assessed at verifying times 21 and 00 GMT.

ii. Wind Forecasts

The comparison between the CFO and the mesoscale model wind forecasts for Bracknell is shown in Table 18.

VERIFICATION PERIOD	09-12	12-15	15-18	18-21	21-24
CFO MORE ACCURATE WIND FORECASTS	22%	20%	22%	29%	17%
SIMILAR	47%	54%	60%	52%	67%
MES MORE ACCURATE	31%	26%	17%	19%	17%

TABLE 18. SUBJECTIVE ASSESSMENT OF THE ACCURACY OF CFO AND MESOSCALE MODEL WIND FORECASTS FOR BRACKNELL, MAY-JULY 1986

NB: Only July figures were available for the periods 18-21 GMT, 21-24 GMT. The wind forecasts were generally good with only isolated large errors, so this assessment was not easy. The criteria used to judge which wind forecast was more accurate was; CFO better if the magnitude of the mesoscale wind vector error ≥5 kt larger than the magnitude of the CFO wind vector error; MES better if reverse applies. Table 18 shows that the mesoscale model was slightly better in the early stages of the forecast but CFO were better during the later stages.

iii. Forecasts of Cloud Amount

The comparison between the CFO and the mesoscale model cloud amount forecast for Bracknell is shown in Table 19.

VERIFICATION PERIOD	09-12	12-15	15-18	18-21	21-24
CFO MORE ACCURATE CLOUD FORECASTS	30%	36%	30%	32%	32%
SIMILAR	51%	47%	55%	26%	32%
MES F/C BETTER	19%	17%	15%	42%	35%

TABLE 19. SUBJECTIVE ASSESSMENT OF THE ACCURACY OF CFO AND MESOSCALE MODEL CLOUDINESS FORECASTS FOR BRACKNELL, PERIOD MAY-JULY

NB. Only July figures were available for periods 18-21 GMT and 21-24 GMT. The criteria used for assessing the cloud forecast is as follows:

The forecast and observed cloudiness over the given three hour period was given a value of 0, 1 or 2 according to the following rules;

B = 0 = 0-4 octas/clear or sunny periods
P = 1 = 5-6 octas/partly cloudy or sunny intervals
C = 2 = 7-8 octas/cloudy or overcast.

The final assessment score is calculated by subtracting the modulus of (MES score - OBS score) from the modulus of (CFO score - OBS score).

ie final assessment score = $|CFO-OBS|-|MES-OBS|$
Negative scores mean that the CFO forecast was better, positive scores mean that the mesoscale model forecast was better. The CFO forecast was more accurate during the day time due to the tendency of the mesoscale model to predict too much cloud. Out of a total of 103 negative scores, 75 were due to the model over-predicting cloud amounts. During the evening, the mesoscale model was slightly better than CFO, due to CFO forecasting breaks in the cloud sheet too early. In Table 20 we compare the accuracy of the cloud amount forecasts for Bracknell during July. All periods are included.

	B = 0-4 octas	P = 5-6 octas	C = 7-8 octas
OBS	20%	31%	49%
MES F/C	19%	23%	58%
CFO F/C	23%	45%	32%

TABLE 20. A COMPARISON OF THE CLIMATOLOGY OF CLOUDINESS FORECASTS FOR BRACKNELL DURING JULY

The forecasts were close in terms of accuracy; 49.5% mesoscale cloud forecasts were correct compared with 51.2% for CFO. The main error categories were as follows:

CFO : C observed/P forecast
MES : P observed/C forecast during period 9-15 GMT
B observed/C forecast during period 18-24 GMT

iv. Weather Forecast

The mesoscale model forecast of rain, the CFO forecast and the observed weather are assigned values of 0, 1, or 2 according to the following rules:

0 = dry
1 = light showers or rain
2 = moderate or heavy showers or rain.

The assessment score is calculated from the equation;

$$|CFO-OBS| - |MES-OBS|$$

Negative scores imply CFO was better whilst positive scores imply the mesoscale model was better. Table 21 compares the accuracy of the CFO and mesoscale model forecasts of precipitation for the period May to July.

SCORE	RESULT	VT 09-12	VT 12-15	VT 15-18	VT 18-21	VT 21-24
-2,-1	CFO BETTER	20%	25%	14%	13%	13%
0	FORECASTS EQUAL	70%	59%	69%	74%	68%
1,2	MES BETTER	10%	16%	17%	13%	19%

TABLE 21. A COMPARISON OF THE ACCURACY OF PRECIPITATION FORECASTS FOR BRACKNELL DURING PERIOD MAY TO JULY 1986

The results for the periods 18-21 and 21-24 were based on July only; nevertheless the results were encouraging for the mesoscale model. Most forecaster errors consist of incorrect forecasts of isolated showers.

b) Temperature Forecasts for Gas Boards

A useful way of assessing the quality of model temperature forecasts is to see how well they compare with temperature forecasts issued by Weather Centres for a 12-18 hour period. Temperatures taken from the fine-mesh and mesoscale model forecasts for Glasgow Airport, Watnall, Southampton and Rhoose were compared with those issued by forecasters at the respective Weather Centres to the Gas Board industry. Two verification times were chosen, 12 and 18 GMT. Model temperature forecasts for 12 GMT were taken from the forecasts starting from 18 GMT and compared with forecasts issued from the Weather Centres at 24 GMT. In this case, the forecasters had the advantage, with a 12 hour subjective forecast being compared with an 18 hour model forecast. Model temperature forecasts for 18 GMT were taken from the forecasts starting at 06 GMT, and compared with forecasts issued by the Weather Centres at 08 GMT. This was a fair comparison, with all forecasts based upon 06 GMT data. The results are summarised in table 22. The figures in the table refer to the percentage accuracy of the forecasts withing 2°C.

LOCATION		GLASGOW			SOUTHAMPTON			RHOOSE			WATNALL		
VERIFYING TIME	MONTH	MES	W.C	F.M	MES	W.C	F.M	MES	W.C	F.M	MES	W.C	F.M
18 GMT [MODEL DT 06 GMT]	MAY	48	61	44	70	89	67	93	77	85	48	92	67
	JUNE	48	63	63	63	77	67	52	67	67	41	74	70
	JULY	54	77	76	50	77	72	85	89	92	50	88	76
	OVERALL	50	67	61	61	81	69	77	78	81	46	85	71
12 GMT [MODEL DT 18 GMT]	MAY	89	68	60	89	88	84	85	96	84	69	76	88
	JUNE	48	52	30	52	62	80	57	76	65	62	67	60
	JULY	50	78	71	58	79	71	29	83	42	54	63	63
	OVERALL	62	66	54	66	76	78	57	85	64	62	69	70

TABLE 22. COMPARISON BETWEEN MODEL TEMPERATURE FORECASTS [DT 06Z V.T 18Z AND DT 18Z V.T 12Z] AND SUBJECTIVE TEMPERATURE FORECASTS ISSUED BY WEATHER CENTRES TO THE GAS INDUSTRY.

In this intercomparison, temperatures were verified only on those days when forecasts were available from the Weather Centres as well as from the models. The most reliable forecasts were those issued by the Weather Centres, with an average accuracy within 2°C of 76% for those four stations, compared to 69% for the fine-mesh model and 61% for the mesoscale model. The mesoscale model temperature forecasts were disappointing, with errors reflecting the problems of cloudiness and cloud base, and the fine-mesh model temperatures were more accurate, on most occasions. However, if we compare accuracy within 3°C, then both models compare better with the forecasters and all three sets of forecasts are accurate within 3°C on over 80% of occasions. [W.C and Fine-mesh model 88%, Mesoscale model 82%].

5. Conclusion

The mesoscale model produced forecasts on 87.5% of occasions during the period May to July. Seventeen forecast failures, mainly in late June, were caused by the overdevelopment of convective systems. Model changes to the convection scheme during the summer have improved the reliability of the model but there is still a risk of forecast failure in hot thundery weather with a high tropopause.

Although orographic intensification of rain is well predicted, the mesoscale model has over-predicted amounts of rain substantially. There are two main reasons. They are:

a. Excessive rain in the first one to three hours of the forecast.

b. When the airmass was unstable, the model forecasts too much precipitation.

The overnight forecast suffered from three small systematic problems. They were:

i. A warm bias of 1-2°C in most places. This could be easily corrected by a forecaster aware of the bias, but objective verification results were less accurate than those for the fine mesh model.

ii. Light winds are under-predicted.

iii. Too much cloud (bias 1-2 octas).

The daytime forecast was generally better than the overnight forecast. There was an overall cool bias, but the worst errors were over high ground and could be attributed partly to the discrepancy between model orography and true orography. Cloud amount was fairly accurately predicted during the daytime inland, except over high ground, where the model forecast too much low cloud.

This period was noticeable for the improved accuracy of the fine-mesh model temperature forecasts, which were almost equal in accuracy to those issued by forecasters at the Weather Centres during June and July.

References

1. O. Hammon — Results from mesoscale Model Trial from February-April 1986.

2. S. Bell and O. Hammon — Results from mesoscale Model Trial from November 1985 to January 1986.

List of Figures

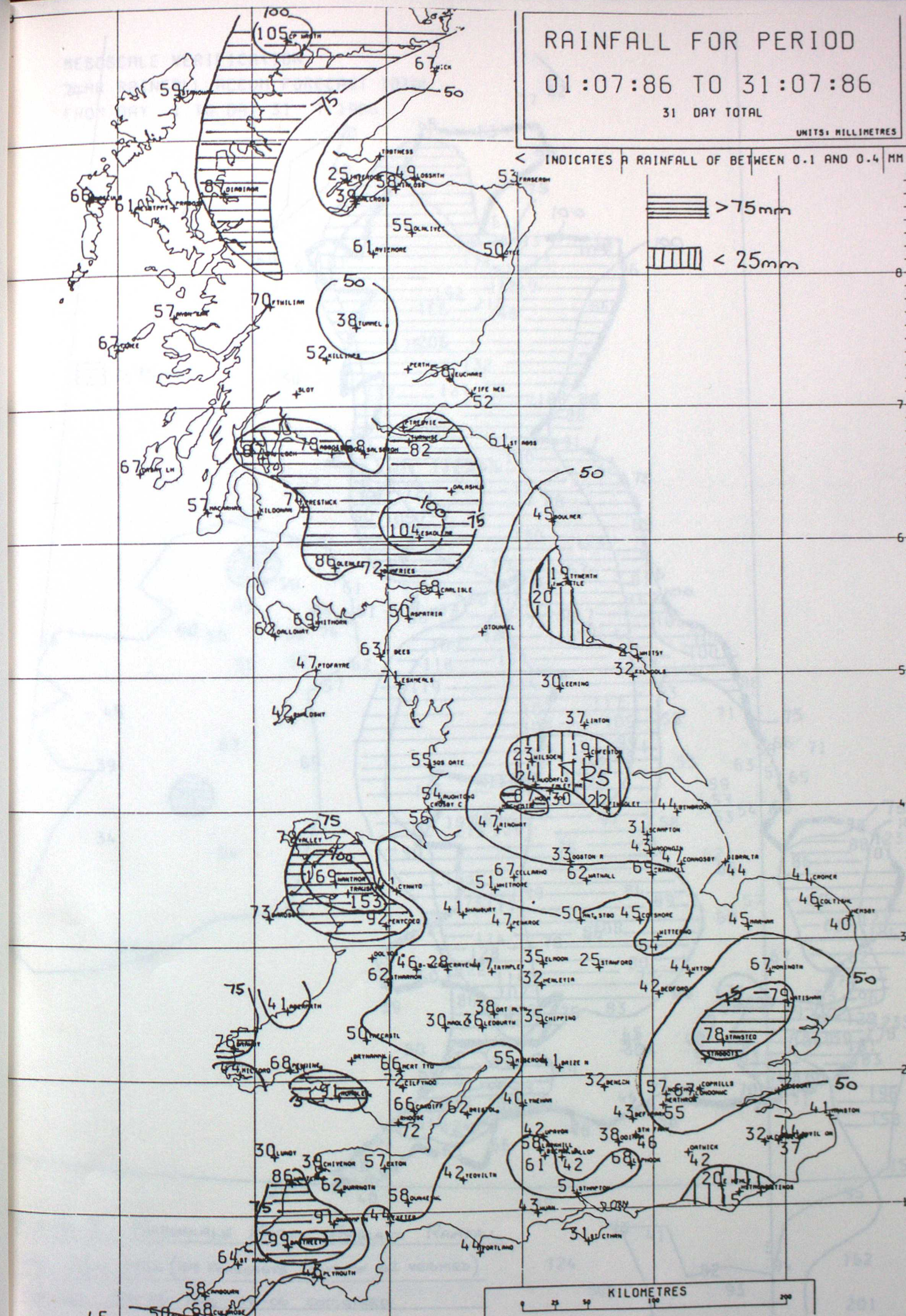
RAINFALL FOR PERIOD
01:07:86 TO 31:07:86
31 DAY TOTAL
UNITS: MILLIMETRES
< INDICATES A RAINFALL OF BETWEEN 0.1 AND 0.4 MM
>75mm
< 25mm
KILOMETRES
0 25 50 100 200

FIGURE 1.

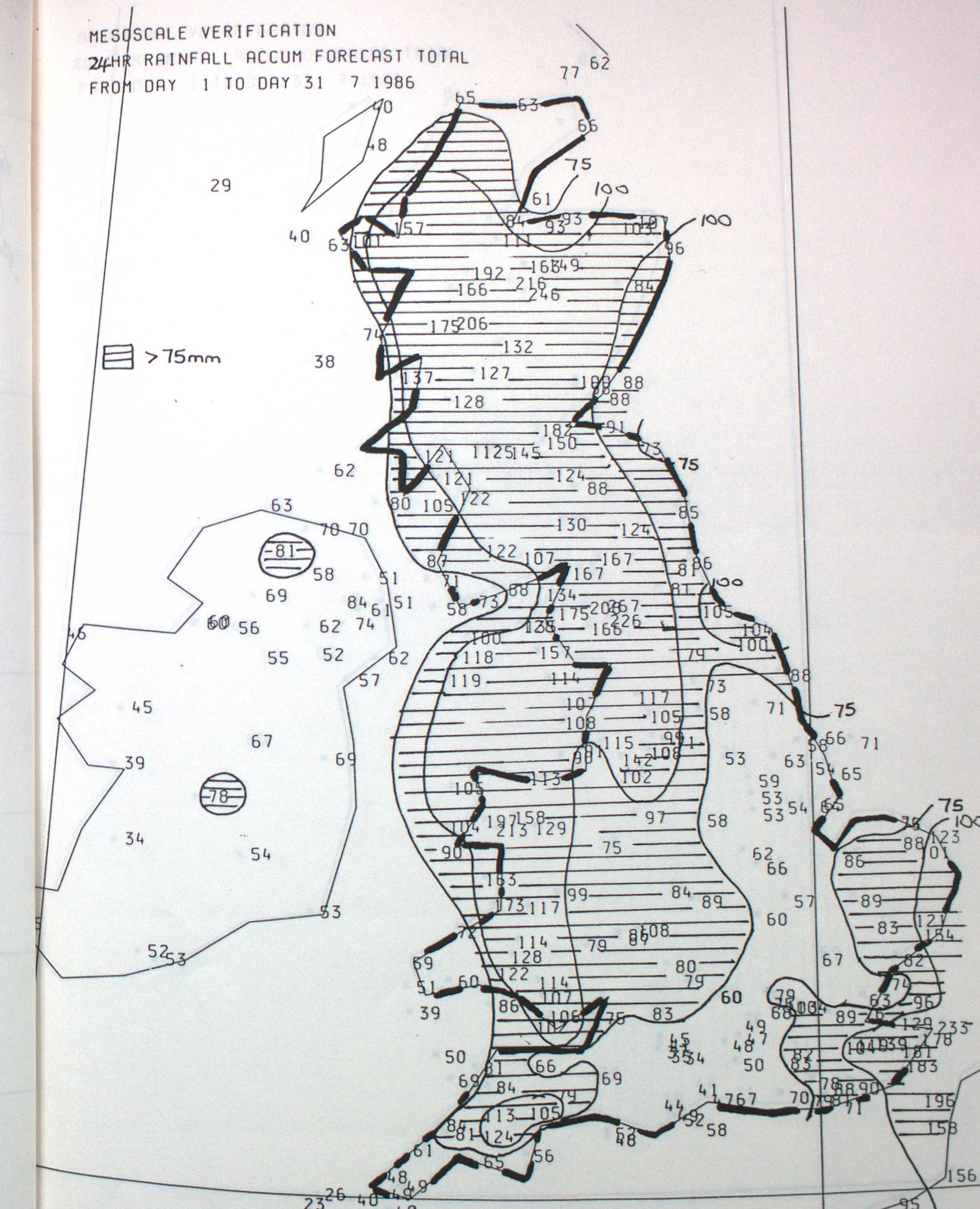

FIGURE 2. MESOSCALE MODEL FORECAST RAINFALL FOR JULY 1986 (49 FORECASTS OUT OF 62 VERIFIED)

PERIODS 06-18 AND 18-06 COMBINED

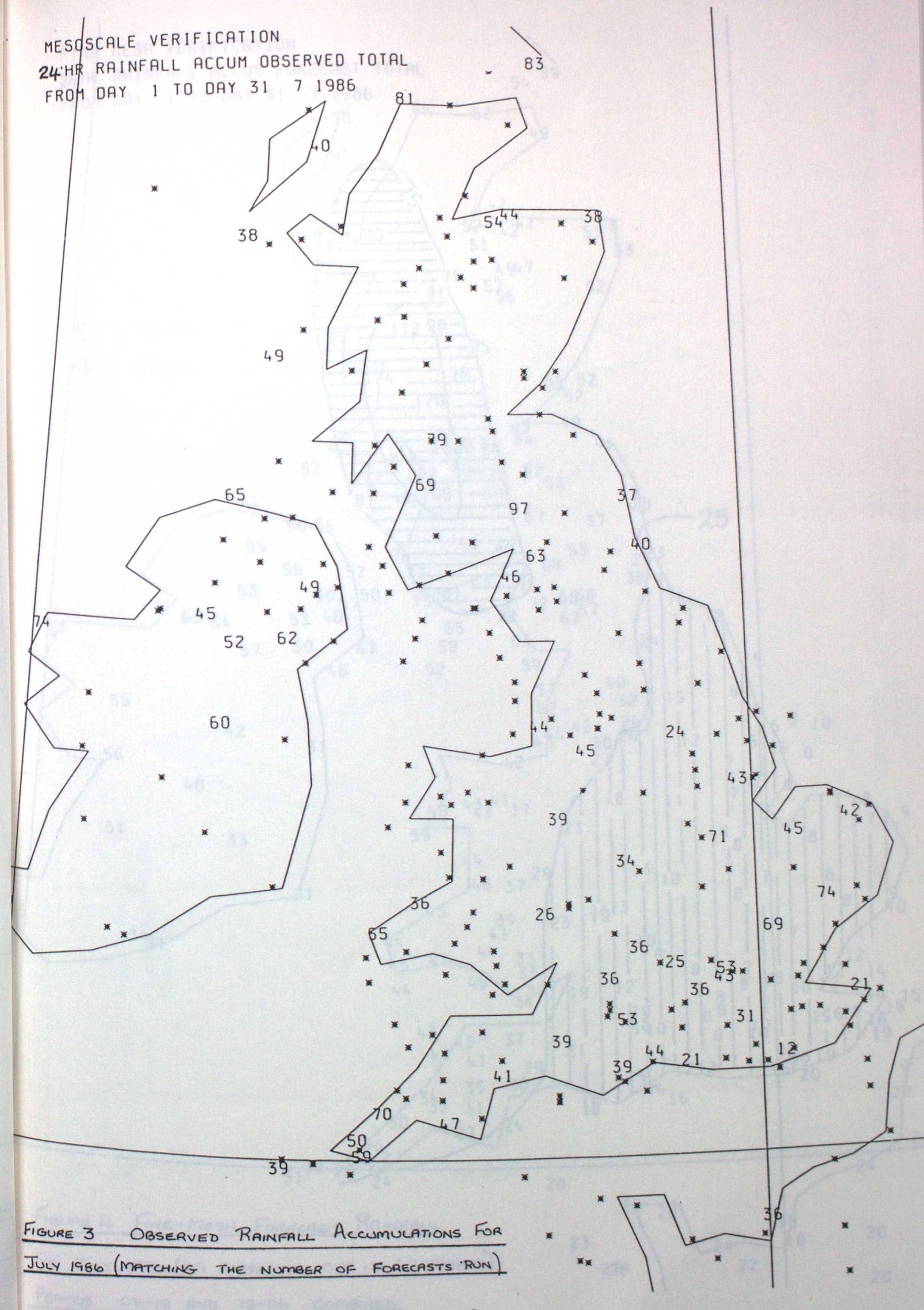

FIGURE 3 OBSERVED RAINFALL ACCUMULATIONS FOR JULY 1986 (MATCHING THE NUMBER OF FORECASTS RUN)

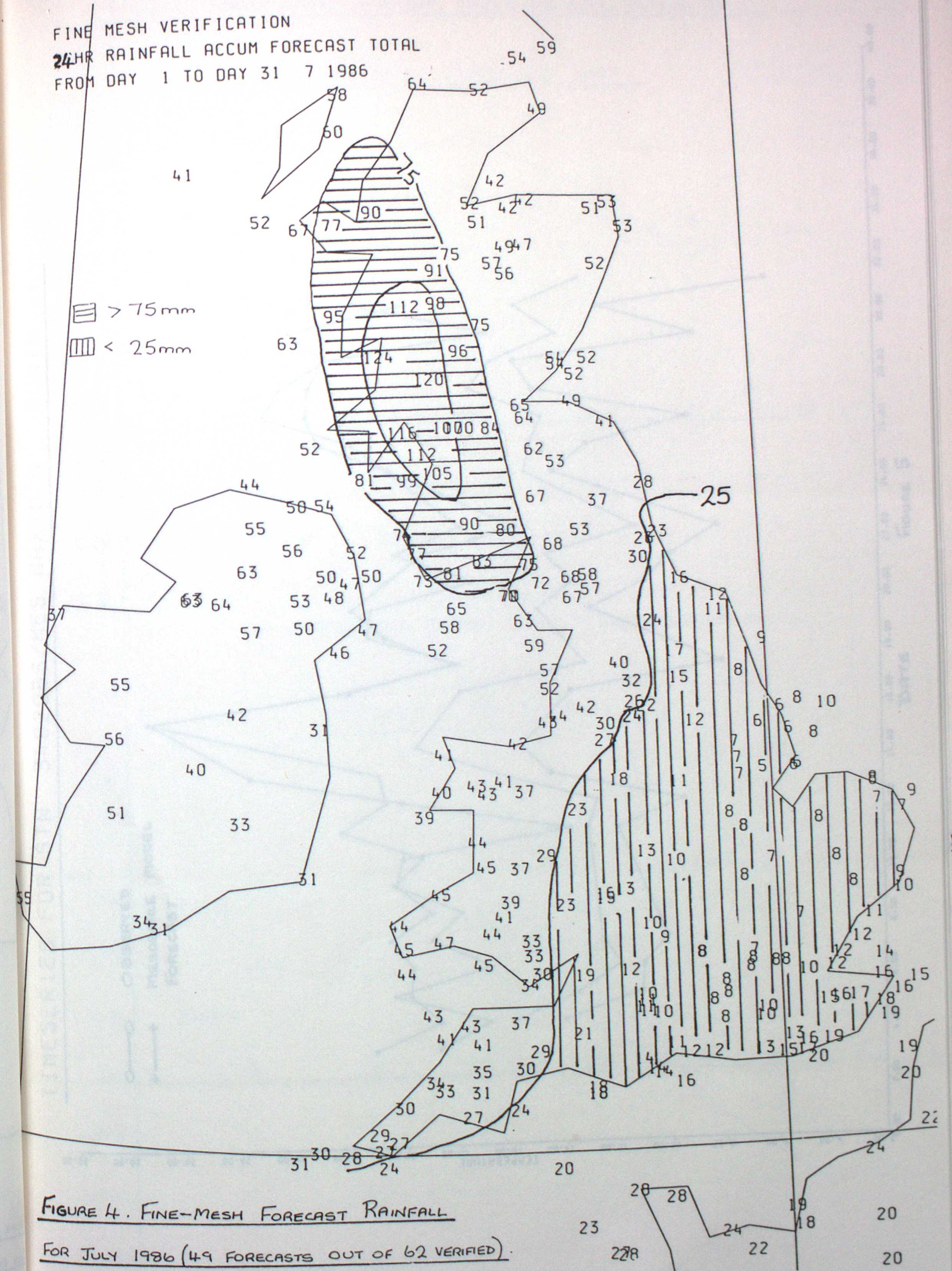

Figure 4. Fine-Mesh Forecast Rainfall

For July 1986 (49 forecasts out of 62 verified).

Periods 06-18 and 18-06 combined

TIMESERIES FOR STN 34820BS/MES MAX/MIN MONTH 7

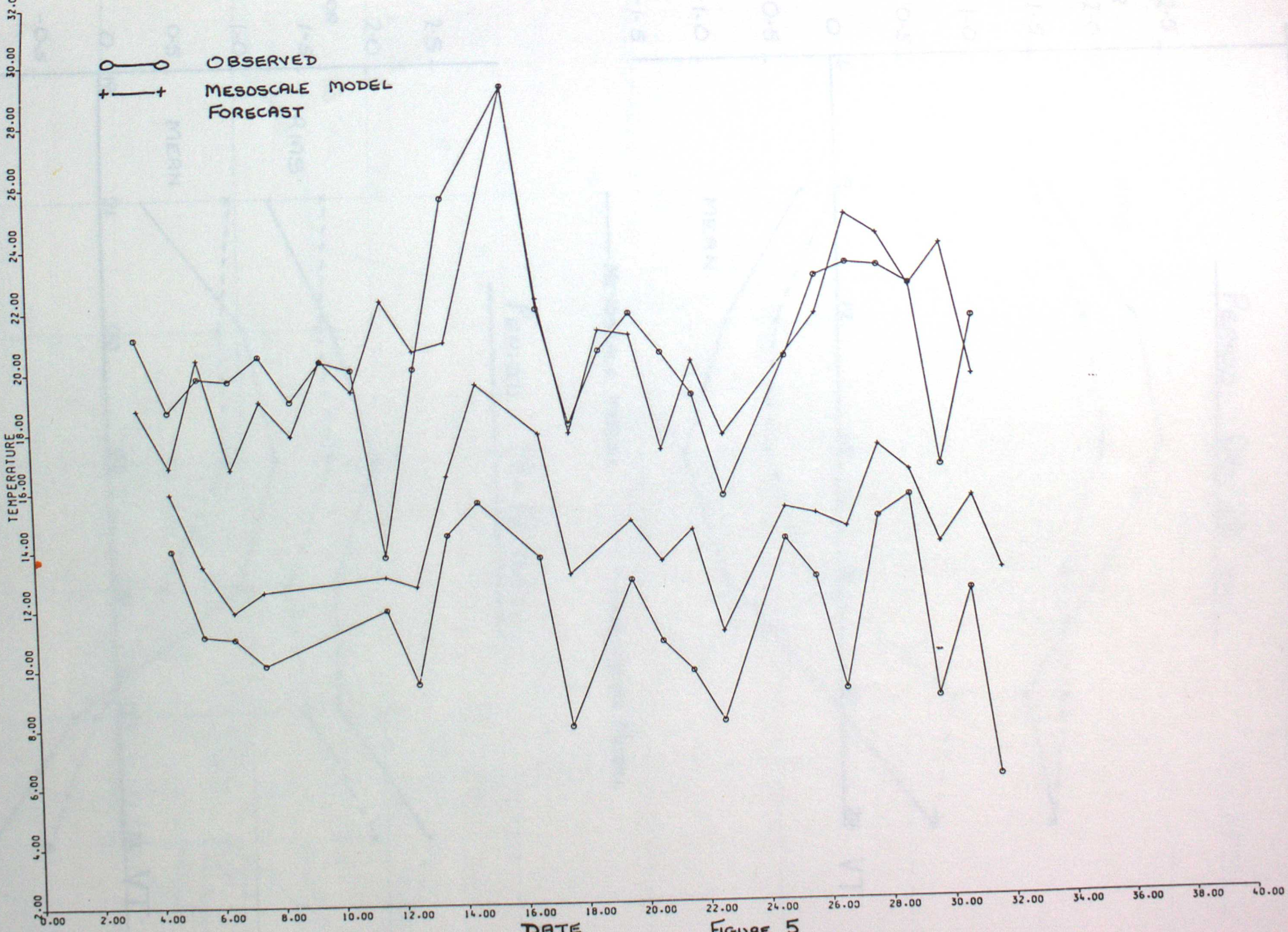

FIGURE 5

Model Temperature Errors (Mean and RMS) during July

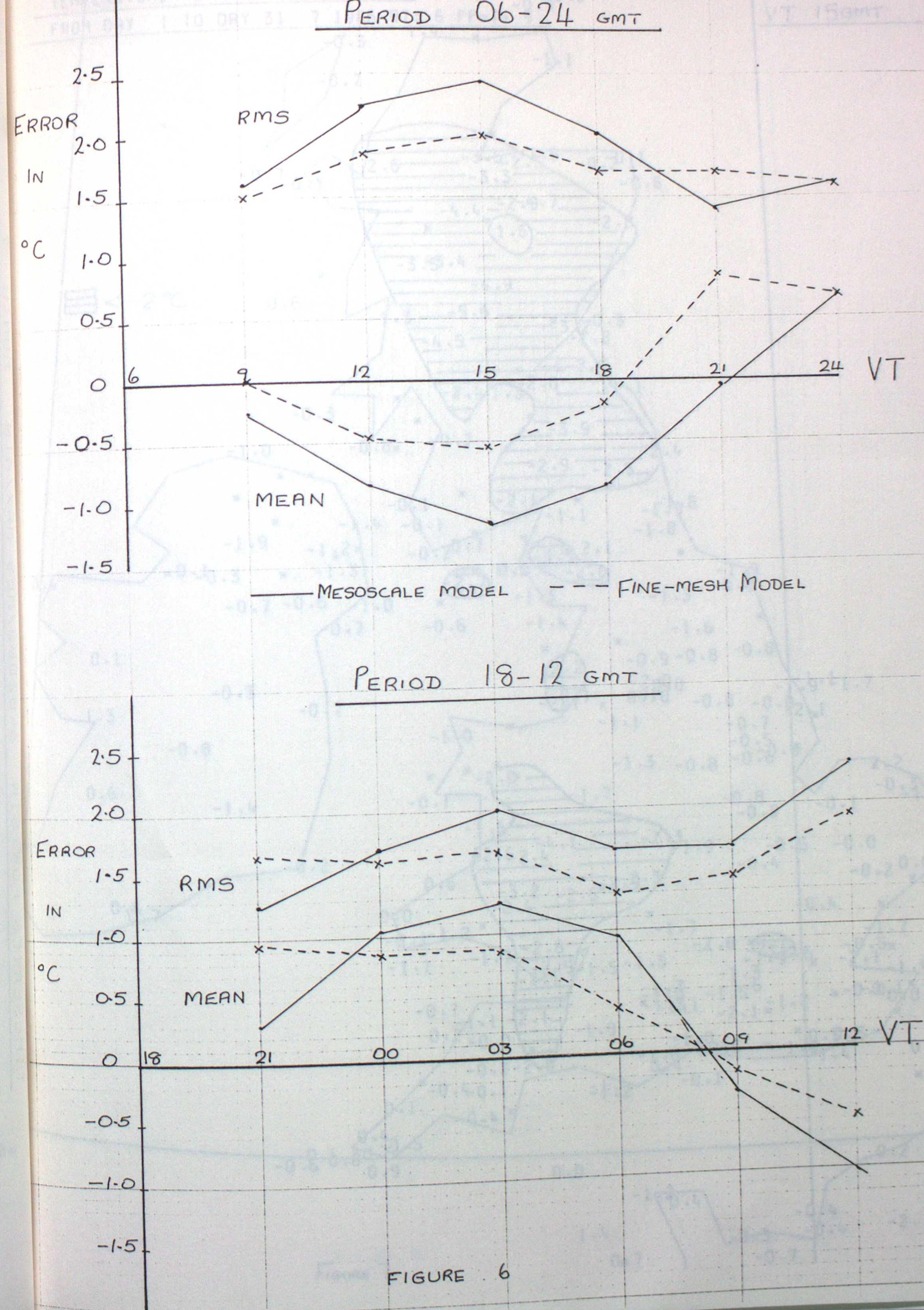

Figure 6

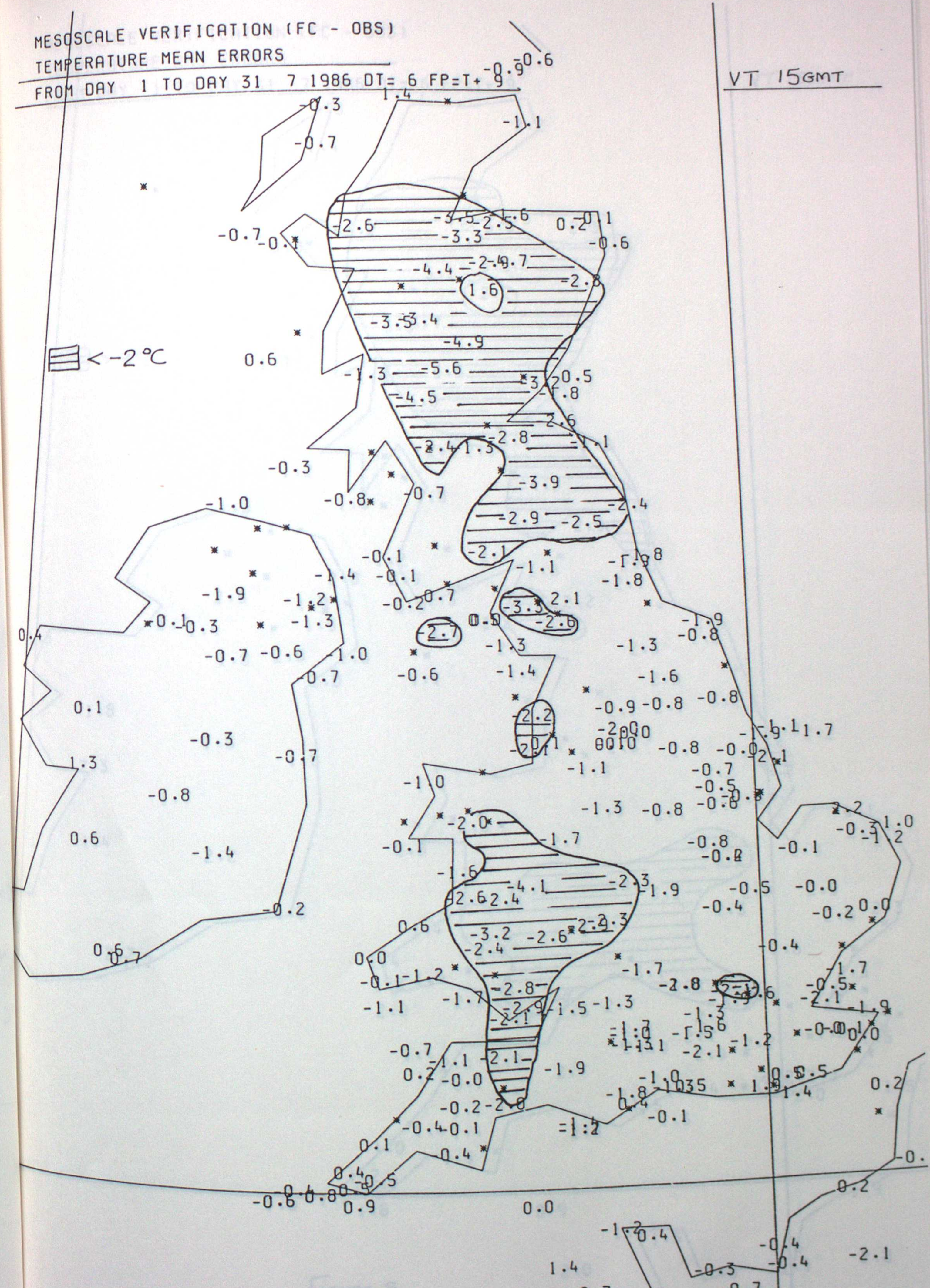
MESOSCALE VERIFICATION (FC - OBS)
TEMPERATURE MEAN ERRORS
FROM DAY 1 TO DAY 31 7 1986 DT= 6 FP=T+ 9
VT 15GMT
< -2°C

Figure 7


MESOSCALE VERIFICATION (FC - OBS)
TEMPERATURE RMS ERRORS
FROM DAY 1 TO DAY 31 7 1986 DT= 6 FP=T+ 9
VT 15GMT
> 3°C

FIGURE 8

FINE MESH VERIFICATION (FC - OBS)
TEMPERATURE RMS ERRORS
FROM DAY 1 TO DAY 31 7 1986 DT= 6 FP=T+ 9

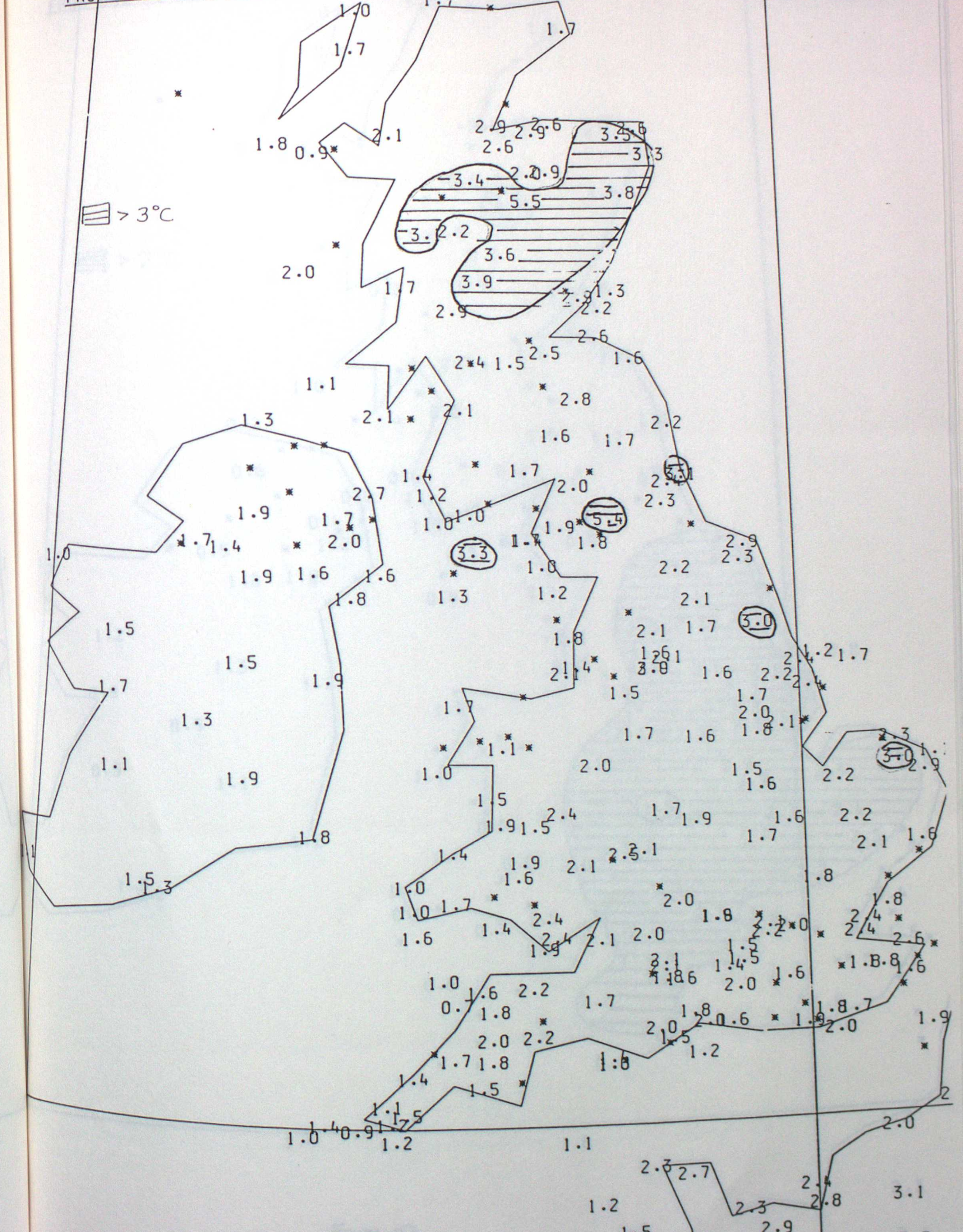

FIGURE 9

MESOSCALE VERIFICATION (FC - OBS)

TEMPERATURE MEAN ERRORS

FROM DAY 1 TO DAY 31 7 1986 DT=18 FP=T+ 9

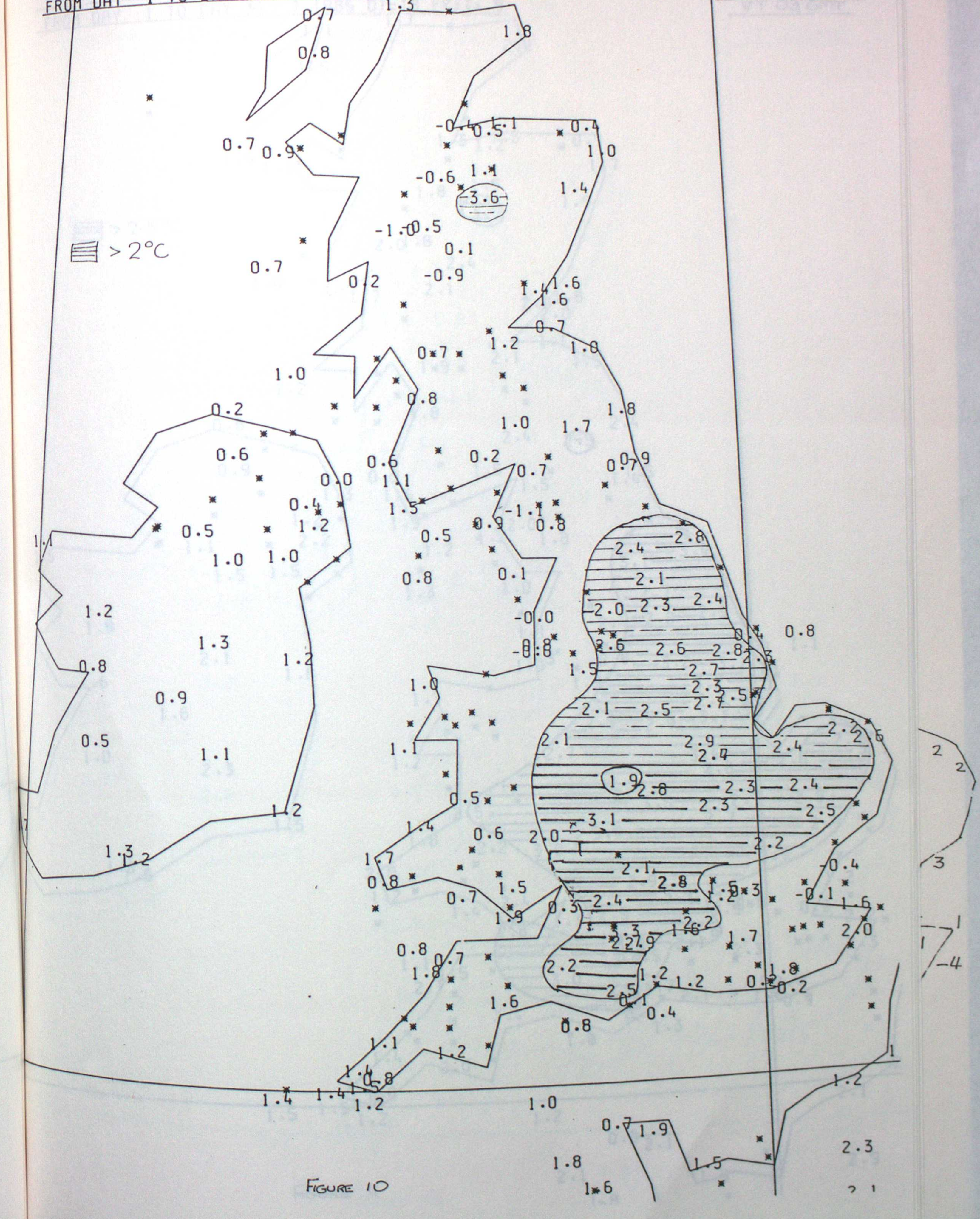

FIGURE 10

MESOSCALE VERIFICATION (FC - OBS)
TEMPERATURE RMS ERRORS
FROM DAY 1 TO DAY 31 7 1986 DT=18 FP=T+ 9

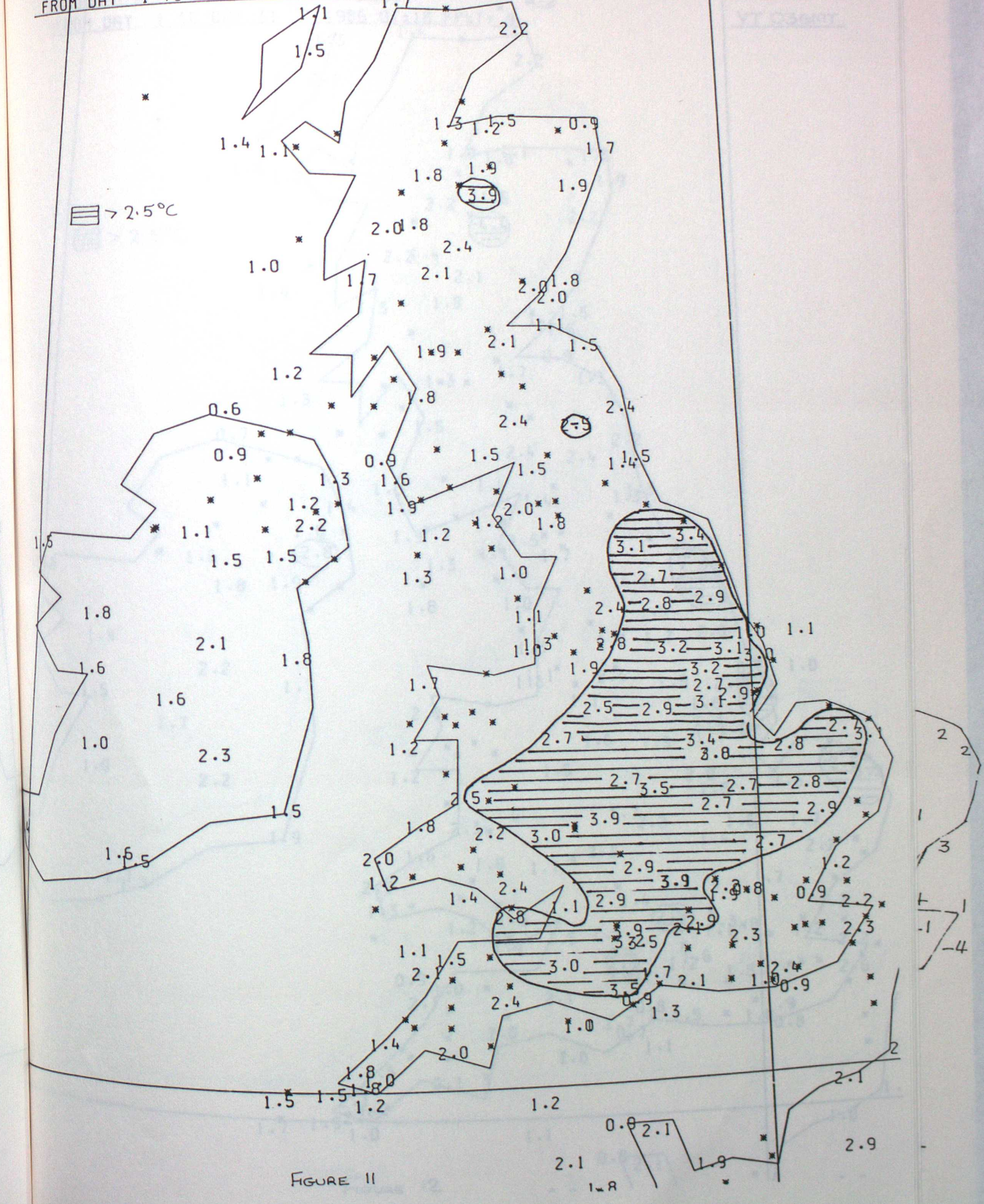

FIGURE 11

FINE MESH VERIFICATION (FC - OBS)
TEMPERATURE RMS ERRORS
FROM DAY 1 TO DAY 31 7 1986 DT=18 FP=T+ 9

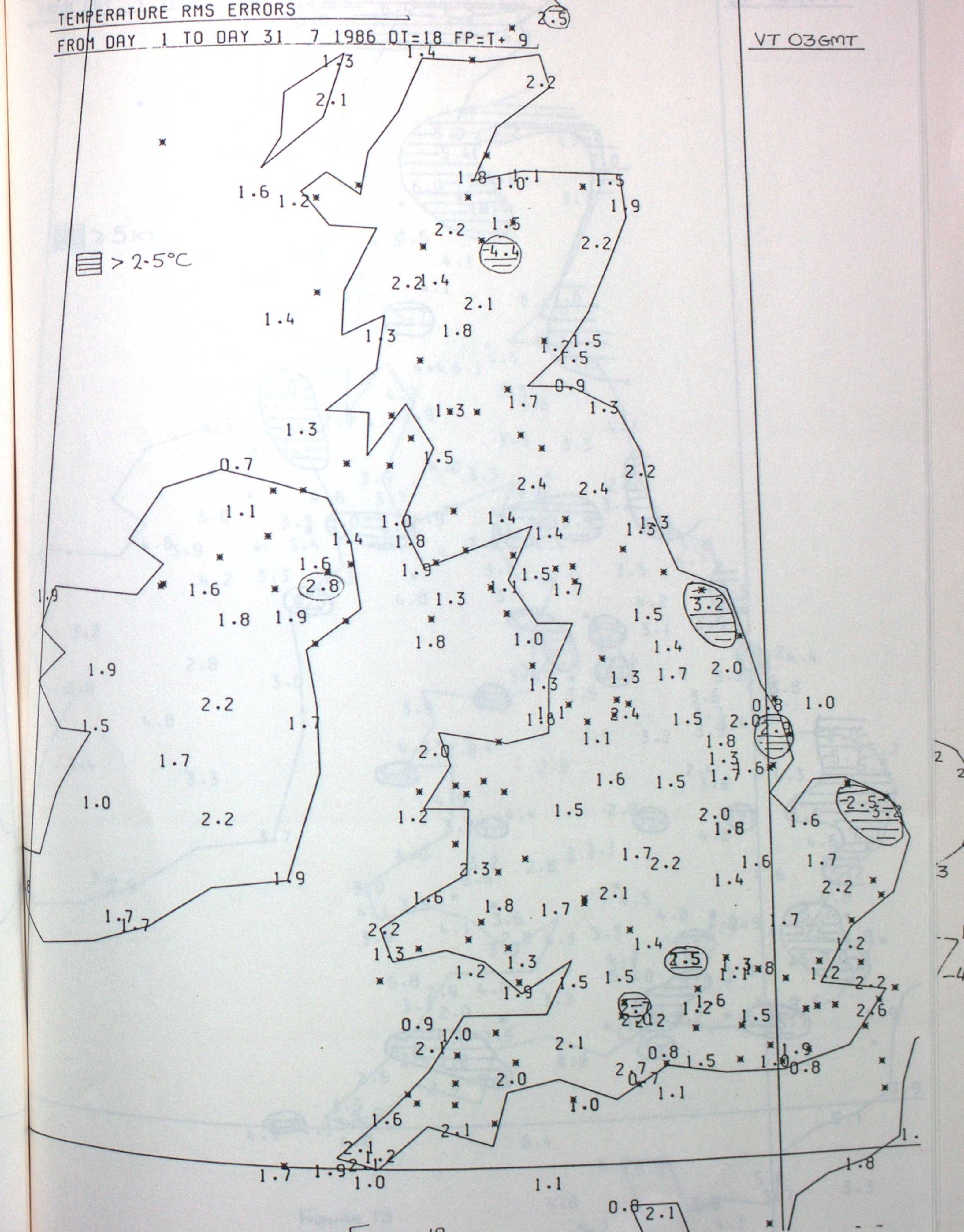

Figure 12

MESOSCALE VERIFICATION (FC - OBS)
WIND SPEED RMS ERRORS
FROM DAY 1 TO DAY 31 7 1986 DT= 6 FP=T+ 9

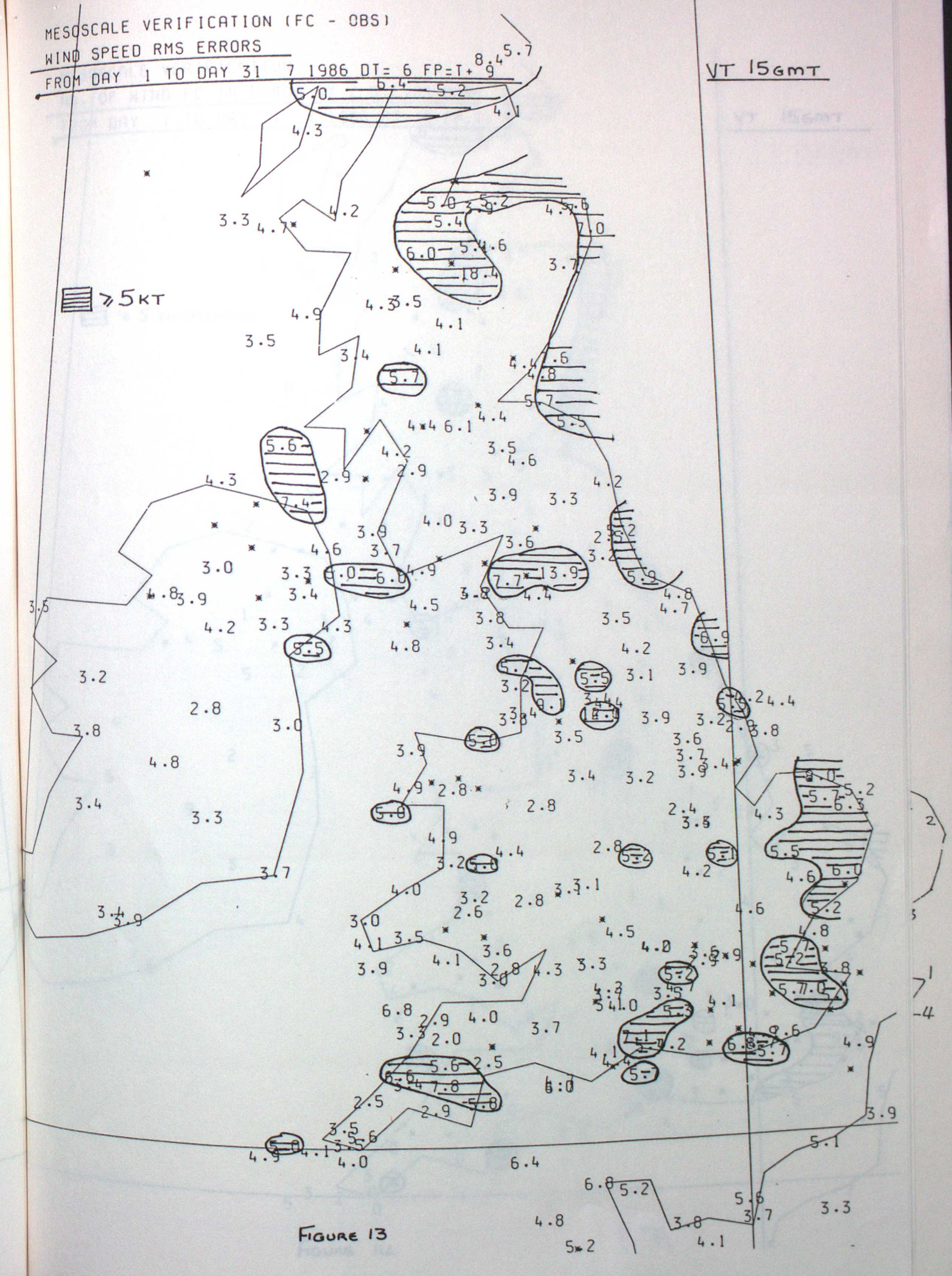

FIGURE 13

MESOSCALE VERIFICATION

NO. OF WIND FC IN ERROR BY 2 B.F.OR MORE

FROM DAY 1 TO DAY 31 7 1986 DT= 6 FP=T+ 9

VT 15GMT

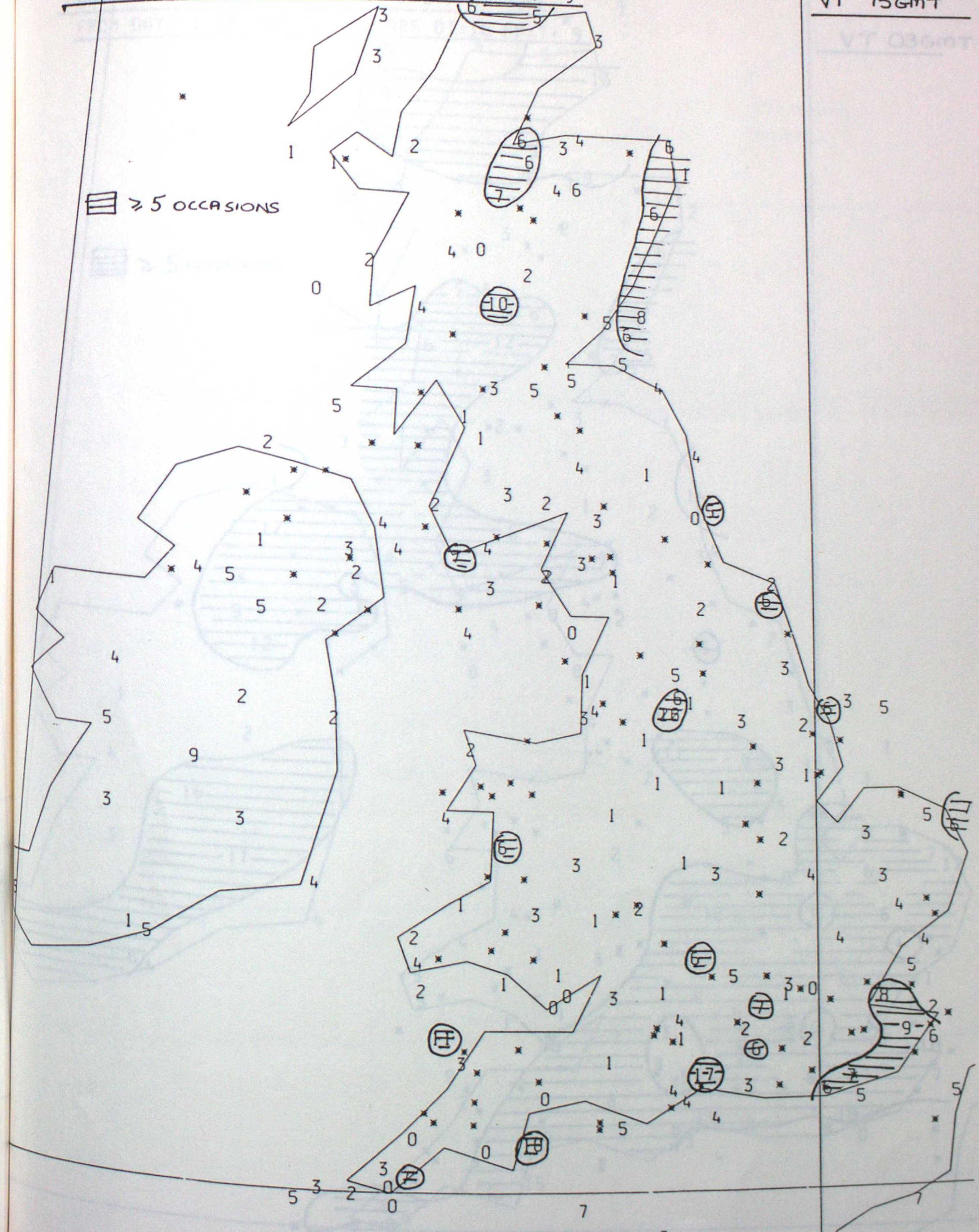

FIGURE 14

MESOSCALE VERIFICATION
NO. OF WIND FC IN ERROR BY 2 B.F.OR MORE
FROM DAY 1 TO DAY 31 7 1986 DT=18 FP=T+ 9

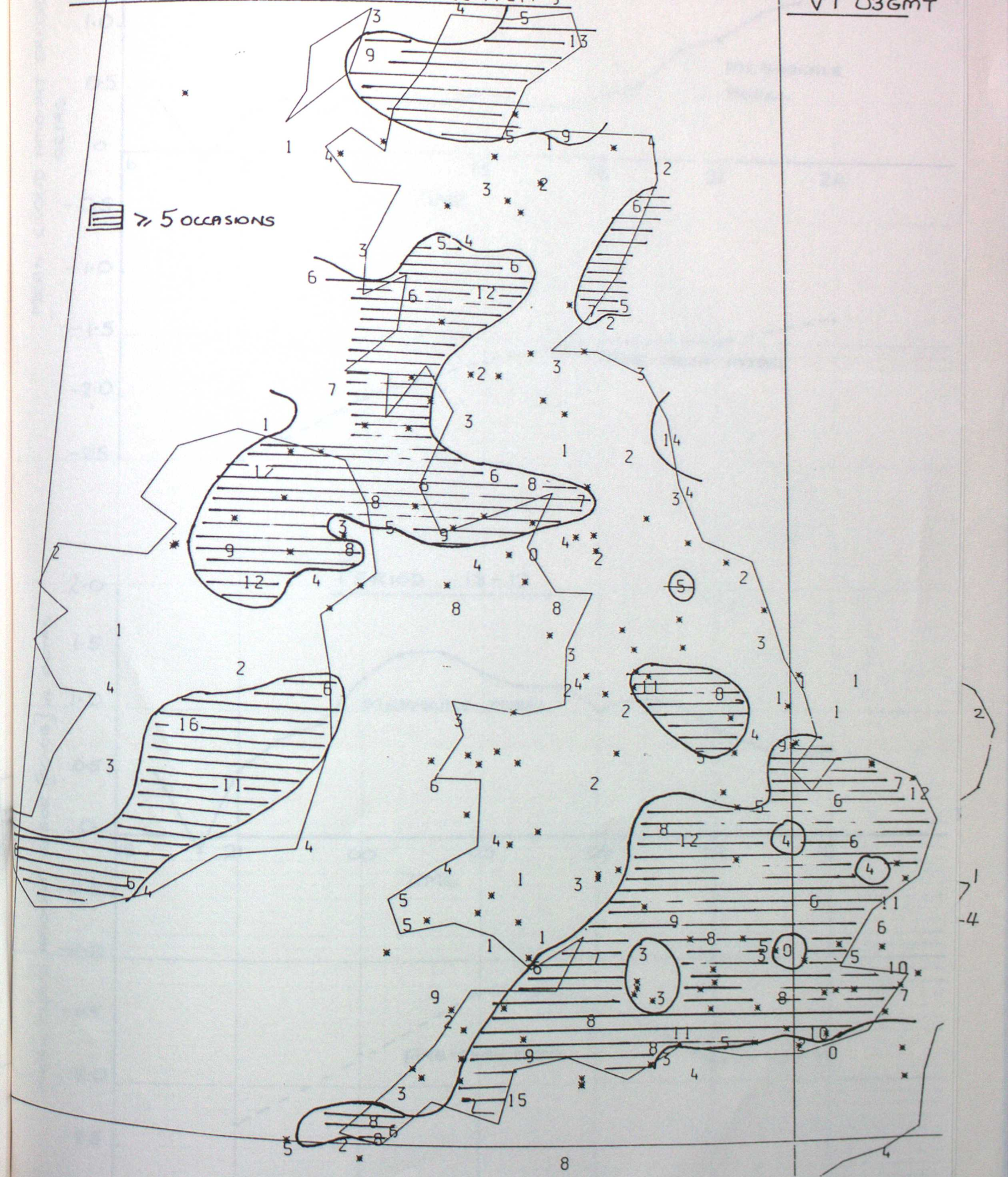

FIGURE 15

MODEL CLOUD AMOUNT BIAS DURING JULY

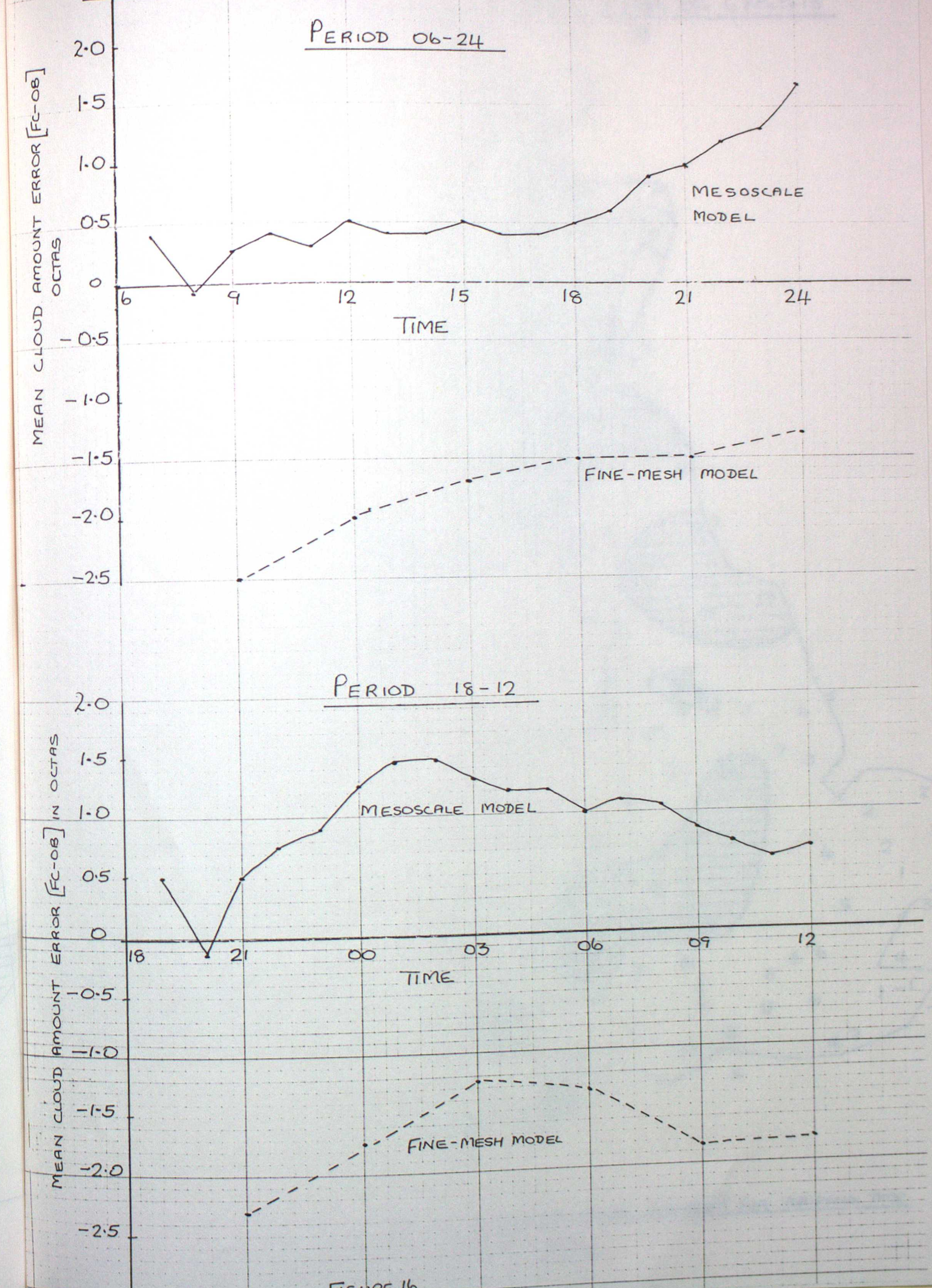

FIGURE 16

MESOSCALE VERIFICATION FROM DAY 1 TO DAY 31 7 1986 DT= 6 FP=T+15

NUMBER OF CLOUD BASE FC BELOW 1500FT

[FC-OBS]

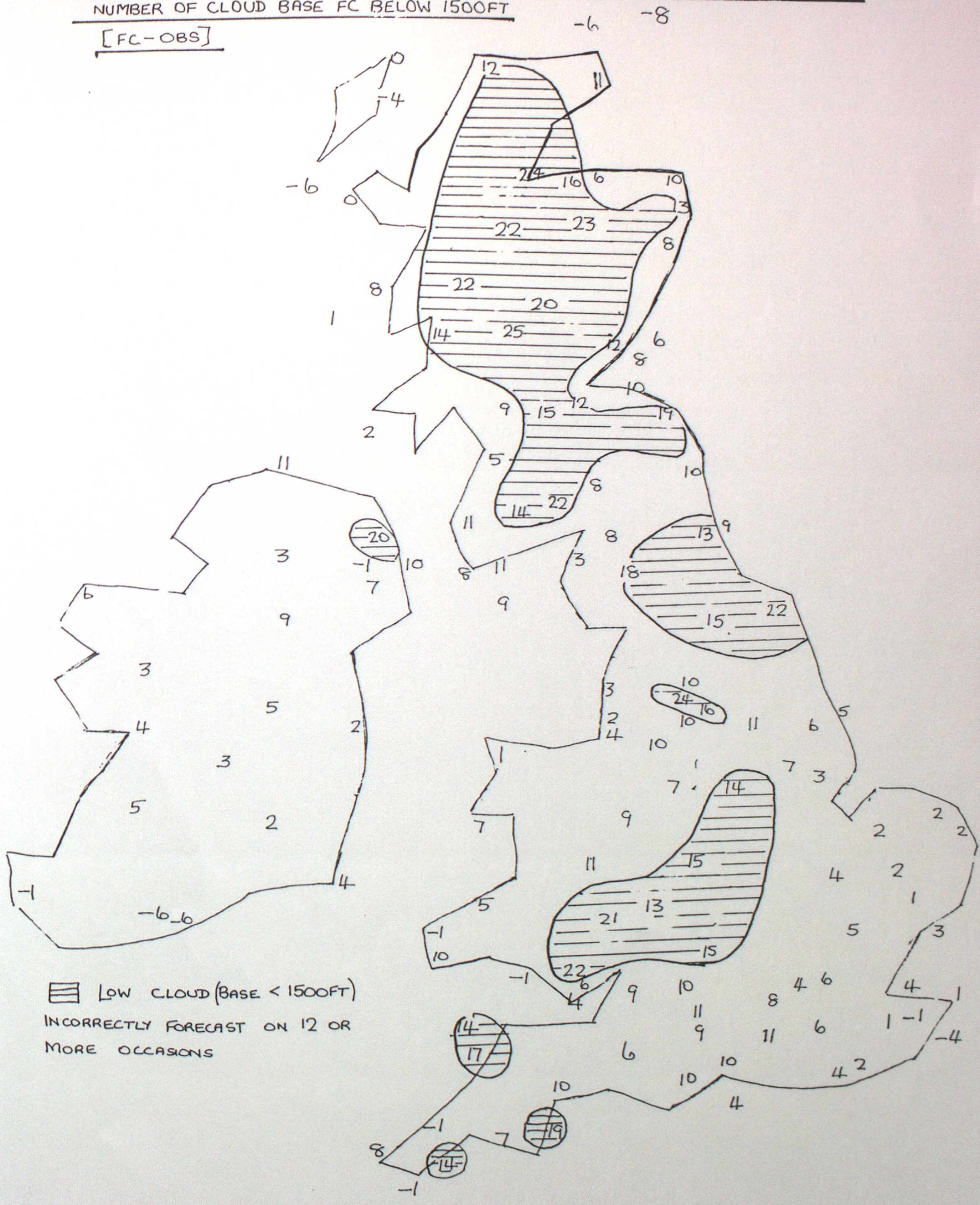

FIGURE 17 DISTRIBUTION OF CLOUD ERRORS [BASE BELOW 1500 FEET] FOR VERIFYING TIME 21 GMT (T+15HR FORECAST) FOR THE MESOSCALE MODEL