LF/MO11

MET O 11 TECHNICAL NOTE NO. 234

RESULTS FROM MESOSCALE MODEL TRIAL FROM FEBRUARY 1986 TO APRIL 1986

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June 1986

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1. INTRODUCTION

This report is the fourth in a series which describes the progress of the mesoscale model trial. It will describe the results of the objective and subjective verification for the three month period February to April 1986. The format of the objective verification results in section 2 will be similar to that in the previous report (Bell and Hammon, April 1986). However, the type of subjective assessment made by the British Isles forecaster in CFO has changed. The assessment of the forecast over the UK ceased at the beginning of March. Instead, a detailed comparison is made between forecasts for Bracknell from the mesoscale model and also from British Isles forecaster in CFO. Both forecasts are marked according to how accurately wind, temperature and weather are predicted. The results are described in section 3.

There were few model failures during the period. Out of a possible total of 178, 170 model forecasts were run successfully. Five of the missed forecasts were due to systems and hardware problems. Three model failures occurred during strong wind situations in March. The problems were associated with a low tropopause, upper front and a strong jetstream (core ~ 80 ms^{-1}).

Three important changes to the model were made during March and April. The code for calculating the solar elevation was changed on March 3rd so that all grid points could be calculated separately, instead of just one single value being used, based on the centre of the grid. On the 9th April, a new higher resolution orography was added to the model, together with compatible changes to the land type and surface roughness specifications. The new stratiform cloud precipitation scheme was implemented on April 10th. This change consisted of a more accurate treatment of the ice phase (Golding, May 1986). Prior to the change, cloud below 0°C was considered to be composed entirely of ice crystals which tended to fall out too readily in the form of light rain/snow. The new scheme defined a critical region between 0°C and -15°C. If the cloud is warmer than -15°C, it will consist of supercooled water droplets only. However, if a deep, continuous cloud layer extends into regions colder than -15°C, seeding of the cloud occurs and as in the old scheme, the cloud will be composed of ice crystals only above the 0°C isotherm. The maximum difference between the two schemes will occur when the cloud temperature is between 0 and -15°C. This change is designed to reduce the areas of light spurious precipitation forecast by the model and improve the ability of the model to retain a stable stratocumulus layer. Any noticeable impact on the model forecast due to the changes described above will be discussed in section 2.

2. OBJECTIVE VERIFICATION RESULTS

Model forecasts of wind, temperature, precipitation, relative humidity, and cloud will be described separately in the following sub-sections for both forecast periods, 06-18 GMT and 18-06 GMT. The last six hours of the overnight forecast, covering the period 06-12 GMT, has not been assessed objectively. As in the previous reports, we will place most emphasis on the third month of the period, April, because this reflects the current status of the model. In view of the marked contrasts in weather between the three months, special attention will be given to important aspects, such as the abnormally low temperatures during February, the gales of March and the heavy showers of April.

(a) TEMPERATURE FORECASTS

The skill of the model in predicting maximum temperatures reflects problems in the initialisation of cloud. February 1986 was the second coldest of the century, with temperatures well below average. The mesoscale model had a warm temperature bias during this month with a maximum value at 13 GMT, caused by a marked deficit of cloud. In the cold easterly airstreams, the model was unable to maintain a layer of stratocumulus in its forecast. During March and April, the model's warm bias was confined to the morning, with a maximum value at 10 GMT. Due to the cloud loss during the first two hours, the model temperature rose too fast. However, with the more unstable airstreams of March and April, the model developed cloud towards midday and the warm bias decreased steadily during the afternoon. In Table 1, we show the percentage of model forecasts of maximum and minimum temperature divided into categories of errors. The model performance improved steadily during the period. During February, 74.0% of model forecasts of maximum temperature were correct to within 2°C, compared with 79.5% in March and 81.5% in April. Figure 1 shows the geographical distribution of maximum temperature forecast rms errors for April 1986. The largest errors (rms errors ≥ 2.0°C) are located around the coast and over high ground, whereas inland, rms errors are mainly ≤ 1.6°C. Figure 2 shows the number of maximum temperature forecasts with errors exceeding 2°C. Again, most frequent errors occur over coasts and high ground.

RANGE OF TEMPERATURE 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 TEMPERATURE	FEBRUARY	0.4	0.4	1.2	5.5	13.6	24.0	30.9	16.5	4.8	2.7
	MARCH	0.4	1.3	5.4	13.3	25.7	25.5	15.0	7.5	3.3	2.6
	APRIL	0.5	1.9	5.4	14.6	24.2	26.4	16.3	6.9	2.7	1.2
MINIMUM TEMPERATURE	FEBRUARY	4.7	5.0	10.5	14.6	18.0	15.4	10.5	8.6	5.8	7.0
	MARCH	0.3	0.4	1.7	4.9	12.1	26.1	27.1	14.6	7.7	5.0
	APRIL	0.7	0.7	3.0	6.2	15.0	24.2	23.2	13.1	7.3	6.4

TABLE 1. FREQUENCY OF OCCURRENCE OF ERRORS IN MESOSCALE MODEL MAXIMUM AND MINIMUM TEMPERATURE FORECASTS, EXPRESSED AS % OF TOTAL

Overall, the model was less successful in forecasting the night minimum temperature. The precentage of forecasts correct to within 2°C is substantially less than for day maximum temperature forecasts. February was the worst month, as Table 1 shows, with only 58.5% of forecasts correct to within 2°C. Again, the model cloud deficit was the cause, and this resulted in a cold bias inland. However, results were much better during March and April, with the percentage of forecasts correct to within 2°C rising to 70.2% and 68.6% respectively. In contrast to February, the forecast night minimum temperatures in March and April were slightly too warm in most places, with largest errors over coasts and high ground. As Figure 3 shows, the values of rms errors in April for the night minimum temperature are larger than those for the day maximum temperature. Figure 4 gives the number of times minimum temperature forecasts were in error by ≥ 2°C for specific stations. The number of occasions when the errors exceeded 2°C is also larger, notably in Southern England for Gatwick, Hurn and LWC. During March and April, there was a definite tendency for the forecast minimum temperatures to be too warm rather than too cold (approx 52% were more than 1°C too warm compared with 9% which were more than 1°C too cold).

No direct comparison of extreme temperatures can be made with the fine mesh model; but we can compare errors at specific times. In Table 2, we have chosen to compare the models at 15 GMT and 06 GMT. This is the closest comparison we can make for maximum and minimum temperatures.

MODEL	MONTH	DT 06 GMT VT 15 GMT MEAN ERROR IN °C	DT 06 GMT VT 15 GMT RMS ERROR IN °C	DT 06 GMT VT 15 GMT % CORRECT WITHIN 2°C	DT 18 GMT VT 06 GMT MEAN ERROR IN °C	DT 18 GMT VT 06 GMT RMS ERROR IN °C	DT 18 GMT VT 06 GMT % CORRECT WITHIN 2°C
MES	February	1.4	2.2	63.7	-0.1	2.8	52.5
	March	0.7	1.9	74.2	1.0	1.9	70.5
	April	0.5	1.8	74.8	0.8	2.0	71.8
FM	February	0.6	2.2	64.3	1.5	3.1	48.1
	March	-1.0	2.2	62.8	0.4	1.9	71.3
	April	-1.4	2.3	61.7	-0.6	1.9	72.9

TABLE 2. COMPARISON OF TEMPERATURE ERRORS BETWEEN MESOSCALE MODEL AND FINE MESH MODEL AT 15 GMT AND 06 GMT

The results in Table 2 for March and April show clearly that the mesoscale model was more successful in forecasting the temperature for 15 GMT. The fine mesh model was too cold. This cold bias is probably caused by excessive evaporation of surface moisture. The mesoscale model improved during the period, but the fine mesh model deteriorated. However, the fine mesh model was slightly more successful in forecasting the temperature for 06 GMT.

Frost is an important forecast for the models to get right during the winter and spring. If frost was observed at a particular station at 06 GMT, then the mesoscale model was more successful in predicting it, with 77% of correct forecasts compared to 61% for the fine mesh model. Just as important, however, is the persistence of frost during the daytime in winter. This was an important feature of the weather in February. The fine mesh model was more successful in predicting daytime frost at 12 GMT, with 76.5% of correct forecasts compared with 70.8% for the mesoscale model. Table 3a compares a combined contingency table for the occurrence of frost at 06 GMT for the mesoscale model for the three month period, with a similar one for the fine mesh model. Table 3b shows the contingency tables for the occurrence of frost at 12 GMT for February only.

MES	OBSERVED TEMP IN °C <0	>0	
<0	20.6	5.2	25.8
>0	6.0	68.2	74.2
	26.6	73.4	100.0

FM	OBSERVED TEMP IN °C <0	>0	
<0	16.2	4.2	20.4
>0	10.2	69.4	79.6
	26.4	73.6	100.0

TABLE 3a. CONTINGENCY TABLES FOR THE OCCURRENCE OF FROST AT 06 GMT FOR THE THREE MONTH PERIOD, FEBRUARY TO APRIL 1986

MES	OBSERVED TEMP IN °C <0	>0	
<0	12.3	1.7	14.0
>0	18.5	67.5	86.0
	30.8	69.2	100.0

FM	OBSERVED TEMP IN °C <0	>0	
<0	19.3	12.0	31.3
>0	11.5	57.2	68.7
	30.8	69.2	100.0

TABLE 3b. CONTINGENCY TABLES FOR THE OCCURRENCE OF FROST AT 12 GMT FOR FEBRUARY 1986

Overall, if we compare the two models at three hourly intervals during April, then the mesoscale model was better at all times except at 09 GMT (T+3) and 06 GMT (T+12).

The reliability of the model's forecast temperatures is shown by Figure 5, which gives a time series of the observed and forecast maximum and minimum temperatures for Marham during April. Large errors (3-4°C) occurred only twice during the month (maximum on 26th, minimum on the 25th).

(b) WIND FORECASTS

Table 4 gives the rms wind speed errors for both the mesoscale and fine mesh models for the period February to April 1986. The fine mesh wind speed forecasts at 25 m have been scaled down by a factor of 0.85 so that they can be compared more fairly with the mesoscale model winds at 10 m and also observed winds.

		DATA TIME	6	6	6	6	18	18	18	18
		VERIF TIME	9	12	15	18	21	00	03	06
MODEL	MONTH									
MES	FEB		5.2	5.3	5.1	4.9	4.5	4.6	4.7	4.8
MES	MARCH		5.3	5.4	5.4	5.5	5.3	5.3	5.3	5.5
MES	APRIL		4.6	4.7	4.9	4.7	4.5	4.5	4.6	4.8
FM	FEB		6.3	5.7	5.6	6.1	6.0	6.1	6.1	6.1
FM	MARCH		6.4	5.9	6.0	6.2	6.1	6.0	6.3	6.2
FM	APRIL		5.0	4.8	5.1	5.1	5.1	5.1	5.3	5.4

TABLE 4. RMS WIND SPEED ERRORS (KNOTS)

These values are generally about 1 knot less than the values given in the report for the period November to January. The mesoscale model has an overall advantage of 0.75 knot over the fine mesh model. Figure 6 shows the geographical distribution of the wind speed rms errors for 12 GMT (T+6 forecast) during March. We have chosen to look at March forecast wind speeds in more detail, because twice as many strong winds and gales were observed in March than in April. For most inland stations, rms wind speed errors are less than the 5 knot average given in Table 4, which is based on the full observing network. Table 4 shows the frequency of occurrence of particular wind speed errors at 6 GMT and 18 GMT during March. 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 06	MESOSCALE	0.5%	0.5%	3%	14%	33%	34%	12%	3%	0.2%
VT 06	FINE MESH	0.3%	1%	6%	19%	33%	26%	10%	4%	0.8%
VT 12	MESOSCALE	0.5%	1%	4%	16%	38%	30%	9%	1%	0
VT 12	FINE MESH	0.3%	1%	6%	21%	36%	24%	8%	2%	0.4%

TABLE 5. FREQUENCY OF OCCURRENCE OF WIND SPEED ERROR AT 6 GMT AND 12 GMT DURING MARCH

Table 5 shows that 81% of mesoscale wind speed forecasts verifying at 6 GMT and 84% of those verifying at 12 GMT were correct to within one Beaufort force. The corresponding fine mesh figures are 78% and 81% respectively. Forecast wind speeds tend to be too strong rather than too weak. The ratio of strong forecasts to weak forecasts is 2.2 for the mesoscale model and 1.4 for the fine mesh. Table 6 shows the observed and forecast wind speed climatology for 06 GMT and 12 GMT during March.

VT	BEAUFORT FORCE	1	2	3	4	5	6	7	8	9
06Z	OBS FREQUENCY %	18	16	20	24	12	7	2	0.8	0.5
06Z	MES F/C FREQUENCY %	3	17	23	29	16	8	3	0.5	0.1
06Z	FM F/C FREQUENCY %	6	22	22	28	11	8	2	1.0	0.4
12Z	OBS FREQUENCY %	9	13	19	30	17	8	3	1.2	0.6
12Z	MES F/C FREQUENCY %	3	9	24	33	18	11	3	0.5	0
12Z	FM F/C FREQUENCY %	5	11	21	34	16	10	3	0.5	0.3

TABLE 6. OBSERVED AND FORECAST WIND SPEED CLIMATOLOGY VT 06Z AND VT 12Z FOR MARCH

Light winds, (Beaufort Force 1 and 2) are underestimated by both models, but the mesoscale model is worse. It is not easy to prove a bias one way or the other when it comes to the forecasting of strong winds by the models. Table 7 gives an analysis of the wind speed forecasts when observed winds were ≥ 22 knots at 12Z (T+6 forecast).

VERIFYING TIME	MODEL	% OBSERVED WIND SPEEDS ≥ 22 KT	WIND SPEED % OBSERVED AND FCST ≥ 22 KT	WIND SPEED % OBSERVED ≥ 22 KT FCST < 22 KT	WIND SPEED % OBSERVED < 22 KT FCST ≥ 22 KT
12 GMT	MESOSCALE	13	7	6	7
12 GMT	FINE MESH	13	6	7	8

TABLE 7. FORECASTS OF STRONG WINDS AND GALES VT 12 GMT MARCH 1986

There is little sign of any bias in the figures shown in Table 7. Both model over-predict strong winds and underpredict strong winds on an almost equal number of occasions. Most errors in strong wind situations appear to be caused by evolution error rather than model bias. Figure 7 shows the number of occasions when the forecast wind speed error exceeded one Beaufort force at 12 GMT during March. The expected number of occasions per month per station is 5 (15.5% forecasts are in error by 1 beaufort force or more). Many inland stations, notably over Eastern England, had correct forecasts nearly all the time, whereas more frequent errors occurred at hill and coastal stations.

(c) PRECIPITATION FORECASTS

The most significant feature of this three month period has been the substantial over-prediction of precipitation amounts by the mesoscale model. Although the model has forecast peak amounts over high ground well, it has consistently forecast too much precipitation over low ground, especially in the south. Table 8 shows the mean forecast totals for both models expressed as a percentage of observed mean totals for the three months.

MONTH		MESOSCALE MODEL		FINE MESH MODEL	
		PERIOD 06-18	PERIOD 18-06	PERIOD 06-18	PERIOD 18-06
FEBRUARY	FC/OBS	229 %	218 %	167 %	137 %
MARCH	FC/OBS	147 %	117 %	80 %	89 %
APRIL	FC/OBS	168 %	119 %	87 %	85 %

TABLE 8. TOTAL MEAN FORECAST PRECIPITATION EXPRESSED AS PERCENTAGE OF OBSERVED

Two significant reasons for the over-prediction of amounts have been highlighted during the period. During the coldest month, February, most precipitation was observed near the east coast, with the west remaining predominantly dry. The mesoscale model predicted twice as precipitation as was observed. In the February verification figures, 27.5% of forecasts fell into the error 'precipitation forecast/nil observed'. 78% of this spurious rainfall was very light, producing only 0.1 to 1 mm in a twelve hour period. It was caused by the ice cloud in the model precipitating out as light snow. The stratiform cloud precipitation scheme was designed to deal with this problem by a more accurate treatment of the ice phase. Two February cases were rerun using the new precipitation scheme. Both showed a substantial reduction in the area of very light precipitation forecast by the model and increased cloud amounts.

During the period, both models showed a tendency to forecast too many wet periods, as the contingency tables show in Table 9. These contingency tables compare the skill of the models in predicting the occurrence of rain or snow in a twelve hour period.

MONTH		MESOSCALE MODEL				FINE MESH MODEL		
	FCST	NO	YES		FCST	NO	YES	
	OBS				OBS			
FEB	NO	49%	5%	54%	NO	60%	4%	64%
	YES	30%	16%	46%		24%	12%	36%
		79%	21%	100		84%	16%	100

MONTH		MESOSCALE MODEL				FINE MESH MODEL		
	FCST	NO	YES		FCST	NO	YES	
	OBS				OBS			
MARCH	NO	33%	5%	38%	NO	36%	8%	44%
	YES	19%	43%	62%	YES	17%	39%	56%
		52%	48%	100		53%	47%	100

MONTH		MESOSCALE MODEL				FINE MESH MODEL		
	FCST	NO	YES		FCST	NO	YES	
	OBS				OBS			
APRIL	NO	30%	7%	37%	NO	32%	10%	42%
	YES	22%	41%	63%	YES	19%	39%	58%
		52%	48%	100		51%	49%	100

TABLE 9. CONTINGENCY TABLES FOR FORECASTING THE OCCURRENCE OF SNOW/RAIN IN A TWELVE HOUR PERIOD

There is little to choose between the models during March and April; with both being correct on an average 73% of occasions. However, errors are more likely to be precipitation forecast/nil observed than the reverse. The ratio of incorrect wet forecasts to incorrect dry forecasts during March and April was 3.4:1 for the mesoscale model and 2.0:1 for the fine mesh model.

As Table 8 shows, the over-prediction of rain during March and April was greater in the 06-18 GMT period for the mesoscale model, and this suggests that the model is forecasting too many heavy showers. Observed rainfall totals for April are shown in Figure 8. Greatest amounts were observed over Northern England, Wales and south-west England with amounts in the range 100 to 150 mm. The forecast rainfall totals for April for the mesoscale and fine mesh models are shown in Figures 9 and 10 respectively. All model forecasts during April were run successfully. These charts show very clearly the differences between the two models, with the mesoscale model over-predicting amounts of rain substantially. Comparing Figures 8 and 9, the mesoscale model has predicted the highest peaks of rainfall over the Pennines, Wales and SW England quite well, but has substantially over predicted amounts elsewhere, particularly over low ground. In contrast (compare Figures 8 and 10), the fine mesh model has under-predicted rainfall amounts over high ground but is more accurate than the mesoscale model over low ground. Table 10 compares monthly accumulations, observed and forecast, for 6 stations in England.

STATION	OBSERVED	MES F/C	FM F/C
HEATHROW	61 mm	118 mm	69 mm
GATWICK	63 mm	117 mm	68 mm
BRIZE NORTON	62 mm	108 mm	68 mm
LYNEHAM	53 mm	112 mm	65 mm
HURN	64 mm	109 mm	61 mm
SHAWBURY	65 mm	136 mm	68 mm

TABLE 10. FORECAST AND OBSERVED RAIN ACCUMULATIONS FOR APRIL 1986

These figures show that the fine-mesh model was much more accurate in predicting rainfall amounts, whereas the mesoscale model over-predicted amounts by a factor of 1.7 to 2.1. To find the reason, we subdivided observed and mesoscale forecast accumulations into dynamic and convective sub-totals. The observed accumulations were partitioned into dynamic and convective sub-totals by careful scrutiny of the hourly present weather codes. The results will not give an exact comparison. In overcast conditions, observers will tend to report dynamic rain, although it may be falling from unstable medium cloud. The mesoscale model, on the other hand, tends to forecast convective rain readily, even in frontal situations. The results are shown in Table 11.

From Table 11, the average ratio of convective to dynamic rain is approximately 0.5:1 for observations compared to 1.7:1 for the mesoscale model, which suggests that the mesoscale model is predicting 3-4 times too much convective rain.

STATION	CONVECTIVE TOTAL		DYNAMIC TOTAL	
	OBS	MES FCST	OBS	MES FCST
HEATHROW	18	78	43	39
GATWICK	22	65	41	36
BRIZE NORTON	22	64	40	44
LYNEHAM	24	75	29	36
HURN	20	66	44	43
SHAWBURY	15	83	50	52

TABLE 11. DYNAMIC AND CONVECTIVE ACCUMULATIONS OBSERVED AND FORECAST FOR APRIL 1986

Figure 11 shows that the over-predicting of convective rain by the mesoscale model is fairly general. In many cases (compare Figures 8, 11) the forecast convective accumulation exceeds the monthly observed accumulation.

Snow was an important feature of the weather during this period. The contingency tables shown below show how well the mesoscale model forecast the type of weather (ie snow/dry/rain) at T+12 for verification times 06 GMT and 18 GMT during the three month period.

DT 06Z VT 18Z FEB	FCST / OBS	SNOW	DRY	RAIN	
	SNOW	2.7	12.9	0.8	16.4
	DRY	2.1	67.7	1.4	71.2
	RAIN	1.1	8.7	2.5	12.3
		5.9	89.3	4.7	

DT 18Z VT 06Z FEB	FCST / OBS	SNOW	DRY	RAIN	
	SNOW	3.1	17.1	0.6	20.8
	DRY	3.7	62.9	1.2	67.8
	RAIN	0.8	8.9	1.7	11.4
		7.6	88.9	3.5	

DT 06Z VT 18Z MARCH	FCST / OBS	SNOW	DRY	RAIN	
	SNOW	0.1	1.3	0.1	1.5
	DRY	0.1	75.2	5.3	80.6
	RAIN	0.1	11.5	6.4	18.0
		0.3	88.0	11.8	

DT 18Z VT 06Z MARCH	FCST / OBS	SNOW	DRY	RAIN	
	SNOW	0.3	1.1	0.1	1.5
	DRY	0.3	68.1	7.5	75.9
	RAIN	0.3	11.5	10.8	22.6
		0.9	80.7	18.4	100.0

DT 06Z VT 18Z APRIL	FCST / OBS	SNOW	DRY	RAIN	
	SNOW	0.2	1.0	0.3	1.5
	DRY	0.2	73.6	5.0	78.8
	RAIN	0.3	13.2	6.3	19.8
		0.7	87.8	11.6	

DT 18Z VT 06Z APRIL	FCST / OBS	SNOW	DRY	RAIN	
	SNOW	0.2	1.2	0.1	1.5
	DRY	0.4	69.4	6.7	76.5
	RAIN	0.4	11.8	9.8	22.0
		1.0	82.4	16.6	

TABLE 12. CONTINGENCY TABLES FOR THE FORECASTING OF SNOW AT T+12

February was the most significant month for snow. Although the mesoscale model forecast the weather type correctly on 70% of occasions at T+12, it predicted about three times as much snow as was observed. This was due to the model ice cloud settling out. During March and April, occurrences of sleet and snow were more borderline, but the mesoscale model was correct on an average 80% of occasions. Sleet and snow were observed on only 1% of occasions during March and April, so it is difficult to make any firm conclusions. However, errors at VT 06Z were more likely to be snow observed-rain forecast than the reverse, due to the warm bias in the model overnight forecast.

d. CLOUD AND HUMIDITY FORECASTS

Forecasts of cloud and surface relative humidity will be considered together in this section. Fog has been omitted since it was not a significant feature of the period February to April. Table 13 gives the percentage of forecasts of surface relative humidity as a function of their difference from observations for both models over the three month period. The verification time is 12 GMT and the figures are expressed as a percentage of the total number of forecasts made in 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	FEB	1	4	10	26	30	20	7	2
MES	MARCH	1	4	10	28	35	16	5	1
MES	APRIL	1	3	12	29	33	16	5	1
FM	FEB	1	3	9	21	26	23	11	6
FM	MARCH	0	0	5	18	28	24	16	9
FM	APRIL	0	1	3	18	28	24	17	9

TABLE 13. FREQUENCY OF OCCURRENCE OF RELATIVE HUMIDITY ERRORS DT 06Z VT 12Z

The mean observed surface relative humidity for February, March and April was 77%, 78% and 73% respectively. The mesoscale model was very close to these figures with corresponding values of 79%, 79% and 74%, but the fine mesh model was too moist with verifying values of 83%, 88% and 84% respectively. The mesoscale forecasts show a greater degree of skill; over the three month period an average of 78% of mesoscale forecasts of surface relative humidity are within 10% of the observations, compared with 70% for the fine mesh model. Both models tend to be too moist rather than too dry, but the wet bias in the fine mesh is much bigger. An average 45% of fine mesh forecasts of surface relative humidity are more than 10% too moist. This excessive evaporation of water from the surface probably accounts for much of the cold bias in the fine mesh daytime temperature forecasts. Figures 12 and 13 compare the mean surface relative humidity errors for each station for forecasts verifying at 12Z in April, for the mesoscale model and the fine mesh model. The positive bias inland shows clearly on Figure 13 for the fine mesh model.

It is difficult to compare forecasts of cloud amount from the two models closely, because the fine mesh model has little representation of partial cloudiness; a grid point either has cloud or not. For this reason, a simpler comparison has been shown in Table 14, which gives the correct and incorrect, cloudy and clear forecasts at T+12 for both models. Clear skies are defined as 4 octas or less, cloudy skies as 5 octas or more.

MODEL	MONTH	VT	CORRECT FORECAST CLEAR	CORRECT FORECAST CLOUDY	INCORRECT FORECAST CLEAR	INCORRECT FORECAST CLOUDY
MES	) FEB	06Z	27	24	46	3
FM	)		18	44	24	14
MES	) MAR	06Z	20	50	20	9
FM	)		17	52	17	14
MES	) APR	06Z	19	48	27	6
FM	)		14	57	18	11
MES	) FEB	18Z	26	24	47	3
FM	)		16	51	20	13
MES	) MAR	18Z	17	52	25	6
FM	)		13	60	16	11
MES	) APR	18Z	18	50	24	8
FM	)		14	57	17	12

TABLE 14. CLOUD AMOUNT FORECASTS AT T+12 FOR PERIOD FEB-APR

February was a unique month and these forecasts should be considered separately. It was a very cold month, dominated by an easterly airstream, and when the airmass was stable, a layer of stratocumulus cloud often persisted in reality which was not predicted by the mesoscale model. With temperatures generally below zero, all cloud in the model was designated as ice cloud. The ice particles settled out very readily and the model was unable to retain the cloud layer. This explains the large number of incorrect clear forecasts for February. This problem has been largely corrected by the introduction in April of the stratiform cloud precipitation scheme. Two February cases were rerun to test the impact of the new scheme. Both cases showed an increase in the amount of cloud forecast and a reduction in the area of spurious light snow predicted. During March and April, the model's forecast of cloudiness improved substantially, as the weather became more unsettled and less cold, although there was still a tendency for the model to under-predict amounts of layer cloud (compare columns 3 and 4). This bias is counteracted in April during the daytime by convective cloud, which is not included in Table 14. Overall, during March and April, the two models were close, with 69% correct cloud amount forecasts for the mesoscale model compared with 71% for the fine mesh model. The bias towards clear forecasts is much less in the case of the fine mesh model.

The mesoscale model's climatology of partial cloudiness is quite well represented. Table 15 shows the April T+12 forecast of cloud amount, in terms of a contingency table with cloud amount categories 0-1 octa, 2-4 octa, 5-7 octa and 8 octa. The results are expressed as percentages of all forecasts verifying at 6Z and 18Z.

OBSERVED CLOUD AMOUNT IN OCTAS	0-1	2-4	5-7	8	TOTAL FCST
FORECAST CLOUD AMOUNT IN OKTAS					
0-1	5	9	11	2	27
2-4	1	4	19	3	17
5-7	1	3	10	6	20
8	1	3	15	17	36
TOTAL OBS	8	19	45	28	

TABLE 15. CONTINGENCY TABLE FOR OBSERVED AND FORECAST CLOUD AMOUNTS - APRIL T+12. (MESOSCALE MODEL)

The main fault is the overprediction of clear skies by the model, and this problem is worse in the night-time forecast, when 30% of all forecasts are for clear skies compared with only 8% observed.

Even more important than cloud amount, is the ability of the models to predict cloud base in the correct category. The most significant feature of the previous three months (November to January) was the excessive amount of cloud forecast in the lowest category (0-600 feet). This tendency continued during February but lessened during March and April by day with the arrival of more unstable air masses. Table 16 shows details of the observed and forecast cloud base climatologies for 18Z during the past three months. The six cloud base categories listed include four categories for low cloud which compare to mesoscale model levels 2-5, then two categories for medium level cloud. The fine-mesh cloud base forecasts are based on an interpolation of relative humidity on to the mesoscale grid, with high values being interpreted as cloud.

CLOUD BASE IN FEET		0-600	600-1500	1500-2600	2600-4000	4000-6000	6000-18000
MONTH	OBS/FCST						
FEB	OBS	6	18	35	23	6	8
	MES FC	28	13	6	2	1	2
	FM FC	25	13	6	12	3	4
MARCH	OBS	8	14	26	12	5	17
	MES FC	17	22	17	5	1	9
	FM FC	26	8	6	6	1	23
APRIL	OBS	5	13	31	17	7	14
	MES FC	15	21	21	13	4	6
	FM FC	18	9	4	10	4	26

TABLE 16. CLIMATOLOGY OF FORECAST AND OBSERVED CLOUD BASES FEB-APRIL, VT 18Z

If we consider the February results in isolation, then Table 16 demonstrates the problems of cloud prediction during that month. Both models have over predicted cloud amounts in the lowest category substantially and under predicted in all other categories. The fine mesh model has predicted about half of the cloud observed in the layer corresponding to model layer 5. The problems of ice cloud in the mesoscale model forecast have already been discussed.

The forecasting of the cloud base by the mesoscale model has shown a clear improvement during the 06-18 GMT period in March and April, with the model predicting a diurnal rise in the base and the development of shallow CuSc. However the night run, period 18-06, remained disappointing with the model being too moist near the surface. Figures 14 and 15 show the percentage of low cloud, observed and forecast, in the categories 0 to 700 feet and 2600 to 4000 feet, corresponding to model levels 2 and 5. Figure 14 shows that the amount of cloud predicted in the lowest category (< 700 feet) increases sharply during the first hour of the 06-18Z forecast. However this is followed by a steady decrease as the temperature rises. In the middle of the afternoon, the forecast amount, 7%, compares favourably with the 3.5% observed. During the 18-06 forecast, the mesoscale model follows the trend of the fine mesh model in predicting excessive low cloud. In the category corresponding to model level 5, amounts of cloud predicted shows a sharp decrease during the first hour as the initialized cloud 'rains out'. During the (06-18)Z forecast, amounts predicted increase during the late morning and afternoon as the model develops a shallow CuSc layer. During the (18-06)Z forecast, however, the model maintains a marked deficit of cloud.

3. SUBJECTIVE ASSESSMENT

Although objective verification identifies model strengths and weaknesses clearly, it gives no idea of the relative difficulty of a forecast or of how useful the model is in a particular situation. An important way of assessing the model is to see how well it performs in comparison with a subjective forecast. Two particular ways in which this comparison has been attempted during the past three months are described in this section.

a. Temperature forecasts for the Gas Industry

A useful way of assessing the reliability of the mesoscale model temperature forecasts is to see how well they compare with the temperature forecasts issued by selected Weather Centres over a 12 to 18 hour period. Forecast temperatures from the mesoscale model forecast for Glasgow Airport, Watnall and Southampton were compared to those issued by the Weather Centres to the Gas Board industry. Three verification times were chosen; 15 GMT, 17 GMT and 09 GMT. The model temperatures for 15 GMT and 17 GMT were taken from the forecast run starting from 06 GMT data and compared to those forecasts issued by the Weather Centres at 0800 GMT. This is a fair comparison, since all forecasts will be based on the 0600 GMT analysis. The fine mesh forecast temperatures were included in the comparison at 15 GMT. The mesoscale model temperature forecasts for 0900 GMT are taken from the forecast run starting from 1800 GMT and compared with the forecast issued by the Weather centres at 0000 GMT. In this case, the forecasters have a few hours advantage. To ensure a fair comparison, the model forecast temperatures and observed temperatures are rounded to the nearest degree (.5 rounded to the odd). Temperatures were verified only on those days when forecasts were available from both the Weather Centres and the models. The results are summarised in Table 17.

% TEMPERATURE FORECASTS			CORRECT WITHIN 2°C			CORRECT WITHIN 3°C		
VERIF TIME	STATION	NR FCST	MES	FM	FCR	MES	FM	FCR
15 GMT	GLASGOW	84	93	49	92	99	72	97
(T+9 F/C)	WATNALL	78	81	74	88	93	90	99
FROM	SOUTHAMPTON	79	82	66	81	93	86	87
(MODEL)	AVERAGE	-	86	63	87	95	82	94
17 GMT	GLASGOW	79	95	-	91	100	-	99
(T+11 F/C)	WATNALL	78	90	-	91	96	-	98
FROM	SOUTHAMPTON	78	86	-	87	99	-	95
(MODEL)	AVERAGE	-	90	-	90	98	-	97
09 GMT	GLASGOW	78	81	-	82	90	-	93
(T+15 F/C)	WATNALL	77	69	-	83	83	-	90
FROM	SOUTHAMPTON	82	68	-	86	90	-	94
(MODEL)	AVERAGE	-	73	-	84	88	-	92

MES - MESOSCALE MODEL TEMPERATURE FORECAST, FCR - WEATHER CENTRE TEMPERATURE FORECAST, FM - FINE MESH MODEL TEMPERATURE FORECAST

TABLE 17. FORECAST TEMPERATURES FOR GAS BOARDS

The mesoscale model temperature forecasts were equal in accuracy to those issued by the Weather Centres for 15 GMT and 17 GMT and much better than those from the fine mesh model, which had a definite cold bias. The Weather Centre forecasts were better at 09 GMT. This is partly due to the small warm bias in the mesoscale overnight temperature forecasts and partly due to the fact that the Weather Centres issue these forecasts at 00 GMT, six hours later than the data time of the mesoscale model forecast.

b. Subjective Assessment of the British Isles Weather

During February 1986 the British Isles forecaster in CFO carried out a detailed subjective assessment of the mesoscale model's three hourly forecast charts of precipitation, cloud, fog and frost. The main results are summarised in Table 18 for verification times T+12 and T+18.

FORECAST	VERIFICATION TIMES	DT 06 GMT VT 18 GMT	DT 18 GMT VT 06 GMT	DT 18 GMT VT 12 GMT
AREA OF PRECIPITATION WELL FORECAST		54 %	62 %	60 %
INTENSITY CORRECT		90 %	92 %	92 %
PRECIPITATION TYPE WELL FORECAST		79 %	85 %	88 %
ERRORS - PRECIPITATION FORECAST/NIL OBS		38 %	54 %	43 %
AREA OF CLOUD FORECAST WELL		52 %	32 %	52 %
% CLOUD BASE FORECAST TOO LOW		58 %	71 %	56 %
FROST FORECAST ACCURATELY		92 %	97 %	77 %

TABLE 18. MAIN RESULTS FROM CFO ASSESSMENT FOR FEBRUARY MESOSCALE MODEL FORECASTS

Although this type of assessment ended at the beginning of March, it provided very useful information during February. Continuous assessment of both forecasts helped to focus the attention on the main problems; spurious areas of light snow forecast and deficit of cloud.

c. Bracknell Local Area Forecast

At the beginning of March, a more detailed comparison of the local area forecasts for Bracknell produced by CFO and the mesoscale model was started. The period 09-18 GMT is divided into three sections, 09-12, 12-15 and 15-18 GMT. Forecasts of weather, wind and temperature for the three sections are assessed. Wind and temperature forecasts cover the three hour period. The forecasts are assessed on a five point scale to make it esier to identify particularly good or bad mesoscale model forecasts.

i. Temperature Forecasts

The comparative accuracy of the CFO and mesoscale model temperatures are shown in Table 19; which gives the percentage of forecasts correct within 2°C.

	VT 12 GMT		VT 15 GMT		VT 18 GMT	
MONTH	MES	CFO	MES	CFO	MES	CFO
MARCH	79	83	96	87	88	92
APRIL	93	87	87	87	90	87

TABLE 19. PERCENTAGE OF BRACKNELL TEMPERATURE FORECASTS CORRECT WITHIN 2°C

The two sets of forecasts are very close in terms of accuracy, with the mesoscale model having a slight advantage during April. CFO generally were slightly better at 12 GMT, when the mesoscale model had a small warm bias. The mesoscale model was generally more successful at 18 GMT. The comparison and scoring for both sets of forecasts is shown in Table 20.

ASSESSMENT SCORE	SCORE CRITERIA	VT 12Z	VT 15	VT 18Z	TOTAL
-2	CFO BETTER BY ≥2°C	8	3	3	14
-1	CFO BETTER BY 1°C	17	13	10	40
0	TEMPS IDENTICAL	12	23	17	52
1	MES BETTER BY 1°C	11	7	20	38
2	MES BETTER BY ≥2°C	6	8	4	18

TABLE 20. NUMBER OF BRACKNELL TEMPERATURE FORECASTS DURING MARCH AND APRIL WHICH SATISFIED SCORE CRITERIA

ii. Wind Forecasts

The comparison between the CFO and mesoscale model wind forecasts for Bracknell is shown in Table 21.

ASSESSMENT SCORE	SCORE CRITERIA	VT 12Z	VT 15	VT 18Z	TOTAL
-2	CFO MORE ACCURATE BY ≥10 KT/≥45°DIRN	1	0	1	2
-1	CFO MORE ACCURATE BY 5-10 KT/30°DIRN	11	11	10	32
0	WIND FORECASTS IDENTICAL	30	22	27	79
1	MES MORE ACCURATE BY 5-10 KT/30°DIRN	11	19	15	45
2	MES MORE ACCURATE BY ≥10 KT/45°DIRN	1	2	1	4

TABLE 21. NUMBER OF WIND FORECASTS FOR BRACKNELL DURING MARCH AND APRIL SATISFYING SCORE CRITERIA

The two sets of forecasts were close and errors small, but the mesoscale model was slightly better at forecasting the wind direction during April.

ii. Forecast of Cloudiness

Cloudiness is difficult to score accurately, since it is hard to estimate amounts of sunshine from model output. The mesoscale model forecast cloudiness over the three hour period is given a value of 0, 1 or 2 according to the following criteria;

0 = clear, sunny periods (0-4 octas)

1 = partly cloudy, sunny intervals (5-6 octas)

2 = cloudy (7-8 octas).

The CFO forecast and the observed cloudiness are assigned values similarly. Using these values, the final assessment score is calculated by subtracting the modulus of (MES-OBS) from the modulus of (CFO-OBS)
ie final assessment score = $|CFO-OBS| - |MES-OBS|$.
Negative scores mean that CFO is better, positive scores mean that the mesoscale model is better.

SCORE	PERIOD 09-12 GMT	PERIOD 12-15 GMT	PERIOD 15-18 GMT	OVERALL
-2	2	5	1	8
-1	8	16	13	37
0	31	25	28	84
1	13	8	11	32
2	0	0	1	1

TABLE 22. COMPARISON BETWEEN CFO AND THE MESOSCALE MODEL CLOUD FORECASTS FOR BRACKNELL DURING MARCH AND APRIL

The forecast cloudiness from the mesoscale model was better in April than in March and considerably better than in February. Although the model still loses much of its initial cloud during the first two hours, it generates more by 12 GMT. In fact, more negative scores were caused by the model having too much cloud during the afternoon than too little.

iv. Precipitation Forecasts

The mesoscale model forecast of precipitation, the CFO forecast and the observed weather are assigned values of 0, 1 or 2 according to the following criteria;

0 = dry

1 = light showers or rain

2 = moderate or heavy showers of rain, or snow.

The assessment score is calculated from the equation;

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

SCORE	VT 09-12	VT 12-15	VT 15-18	TOTAL
-2	2	1	2	5
-1	11	13	11	35
0	38	34	33	105
1	3	6	7	16
2	0	0	1	1

TABLE 23. COMPARISON SCORES BETWEEN CFO AND MESOSCALE MODEL FORECASTS OF PRECIPITATION FOR BRACKNELL DURING MARCH AND APRIL

Negative scores mean that the CFO forecast was better on the given number of occasions (-2 means that CFO forecast was much closer to the observed weather, -1 slightly closer). Although CFO are clearly better in forecasting the weather for Bracknell, the model forecasts were much better in April than in March or February.

4. SUMMARY

The mesoscale model produced forecasts on 95% of possible occasions during the period February to April. Only three models failures could be attributed to model instability in strong wind situations in March. Temperature forecasts during the daytime in March and April were of a high standard, and comparable to those subjective forecasts issued by CFO and the Weather Centres, and better than forecasts from the fine mesh model. Minimum temperature forecasts were less accurate due to a small warm bias.

Although orographic intensification of rain is forecast well, the mesoscale model has over-predicted amounts of precipitation substantially elsewhere, and the fine mesh has been more accurate. Two reasons for the over-prediction of precipitation have been identified. They are:-

i. Excessive precipitation during February was caused by ice cloud in the model settling out to give large areas of light snow, which were incorrect. This problem has been corrected by a more accurate treatment of the ice phase in the stratiform cloud precipitation scheme.

ii. Convective rain amounts were excessive during April due to the model forecasting too many heavy showers.

In the comparison with subjective forecasts for the Bracknell area, the model was equal in accuracy to CFO in forecasting wind and temperature but less accurate in forecasting cloud and weather. Cloud bases were much better forecast in unstable conditions during the day time in April but still poor overnight with excessive low cloud.

5. References

Bell, R S and O Hammon — Results from the Mesoscale Model Trial from November 1985 to January 1986. Met O 11 TN 227.

B W Golding — Stratiform cloud precipitation. Version 1 May 1986. Met O 11 Mesoscale Documentation Paper No. 8.

List of Figures

Figure 15.   As Figure 14 but for model level 5.

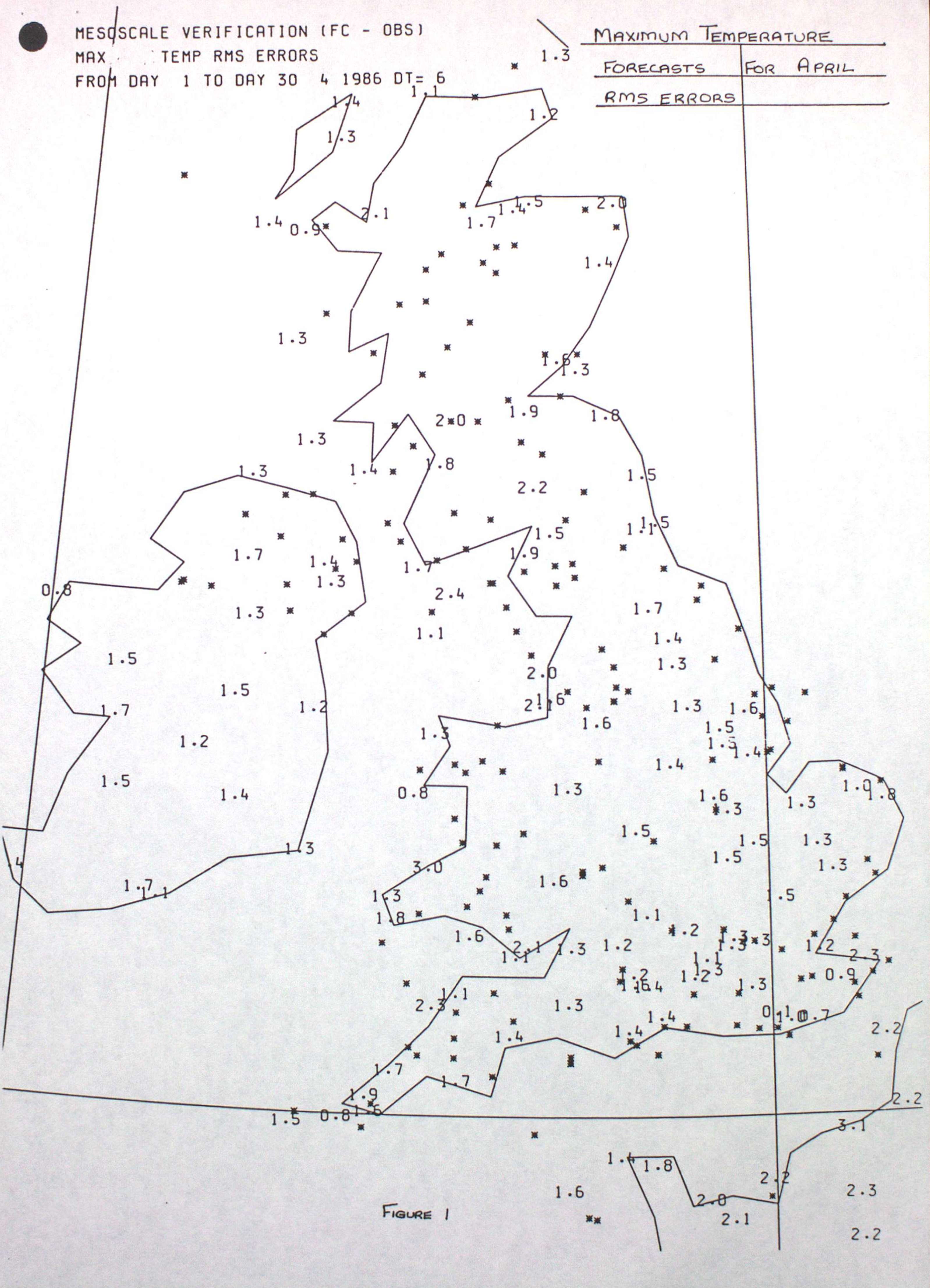

MESOSCALE VERIFICATION (FC - OBS)
MAX TEMP RMS ERRORS
FROM DAY 1 TO DAY 30 4 1986 DT= 6
MAXIMUM TEMPERATURE
FORECASTS FOR APRIL
RMS ERRORS

FIGURE 1

FIGURE 2

NUMBER OF OCCASIONS THE MAXIMUM TEMPERATURE ERROR EXCEEDED 2°C DURING APRIL 1986

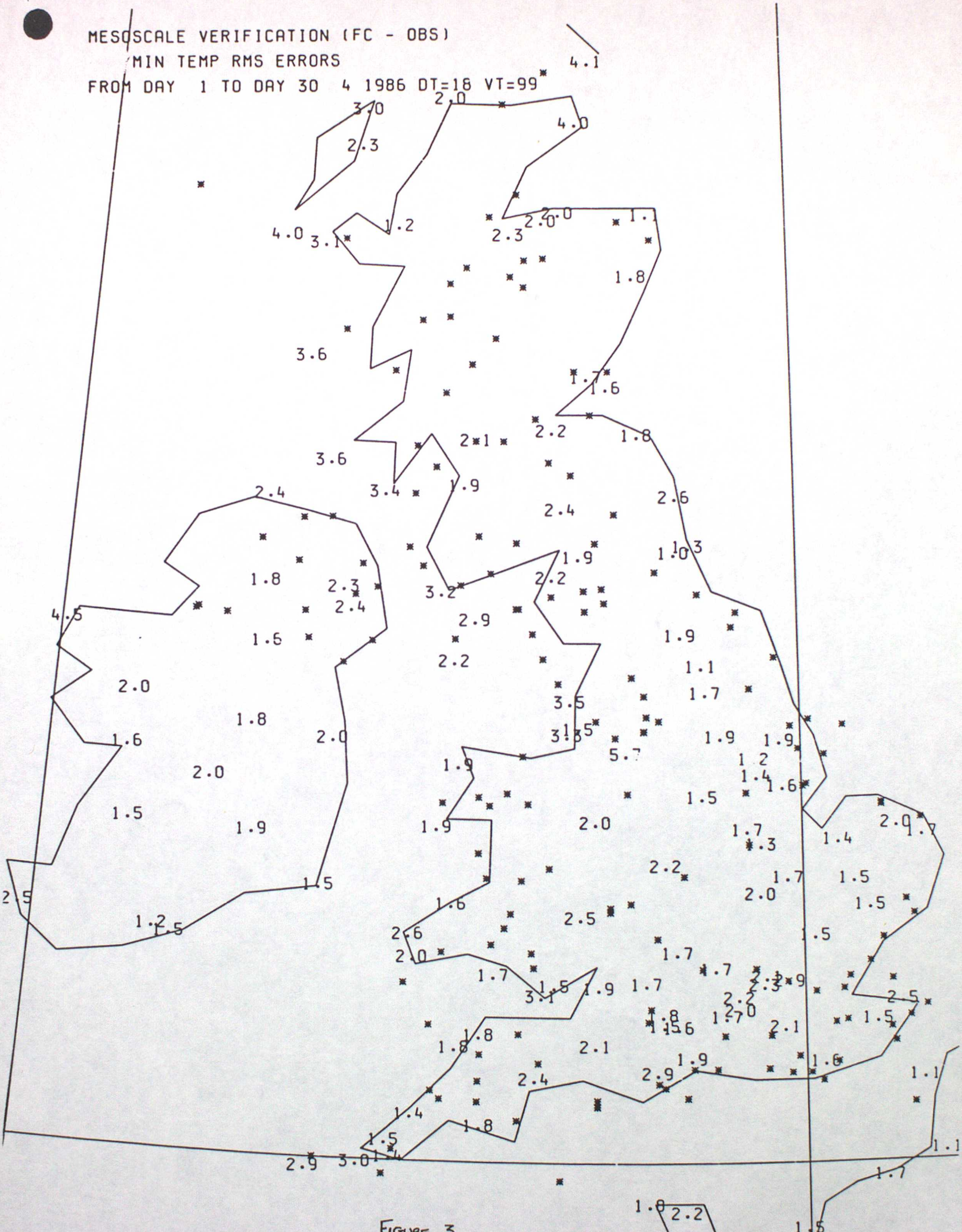


FIGURE 3

MINIMUM TEMPERATURE FORECAST RMS ERRORS FOR THE MESOSCALE MODEL DURING APRIL 1986

Figure 4

Number of times the forecast minimum temperature error exceeded 2°C during April

Time Series showing Maximum and Minimum Temperates, Forecast and observed, for Marham [STN 03482] during April 1986.

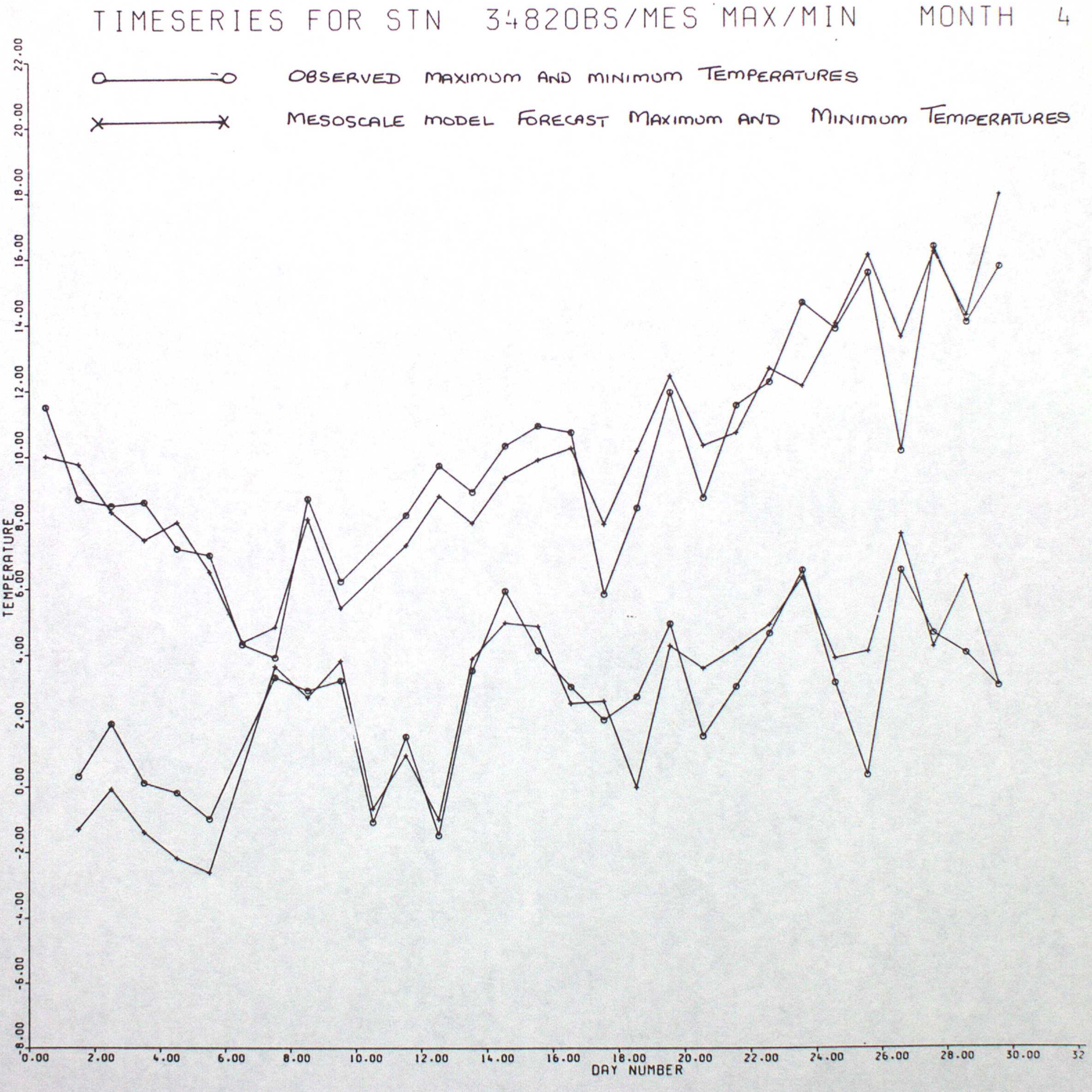


Figure 5

WIND SPEED RMS ERRORS AT T+12, VT 12GMT

FROM MESOSCALE MODEL FORECASTS IN MARCH 1986

[WIND SPEED IS IN KT]

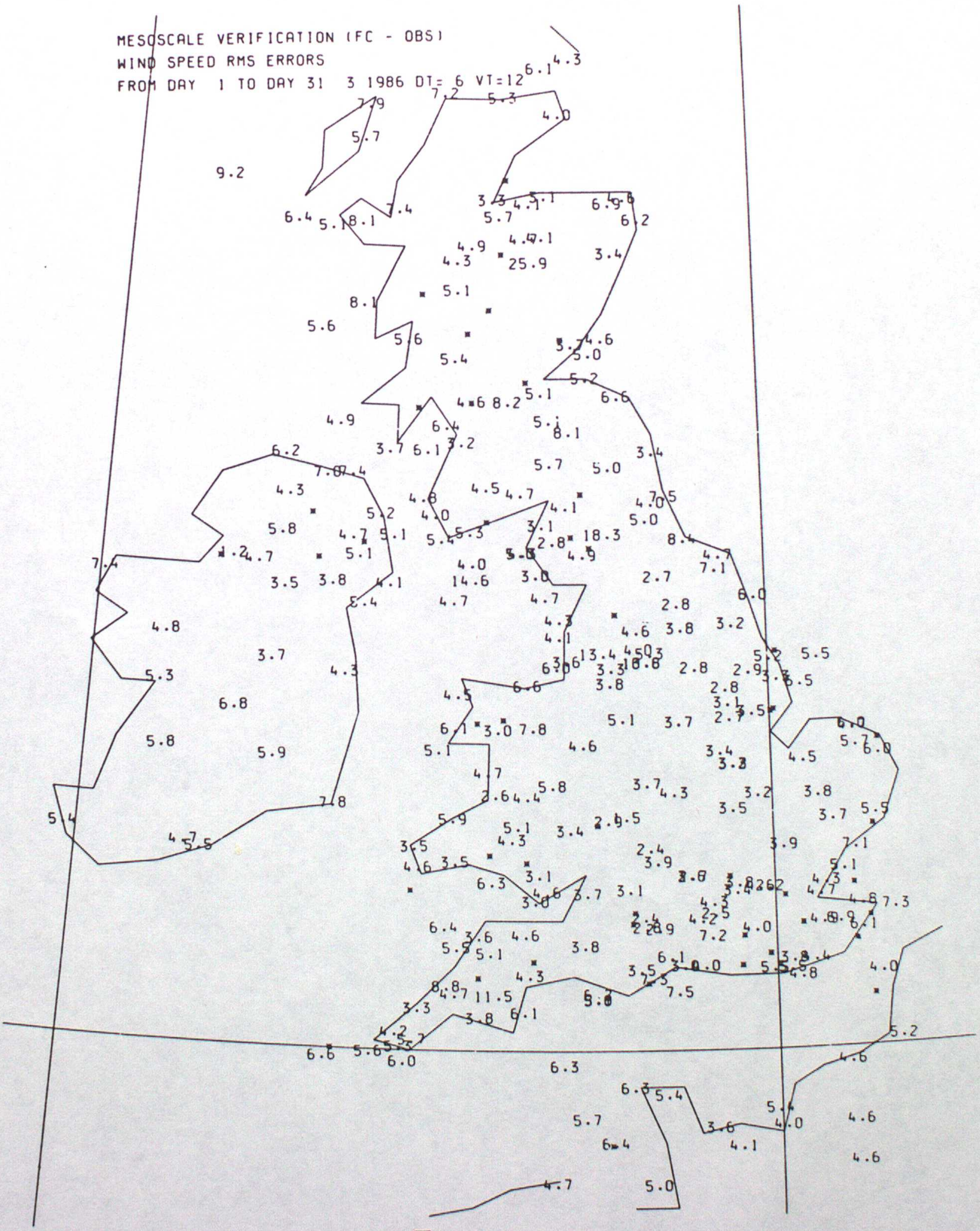


FIGURE 6

Number of occasions during March 1986 when the Forecast Wind Speed for 12 GMT was in error by more than 2 Beaufort Force

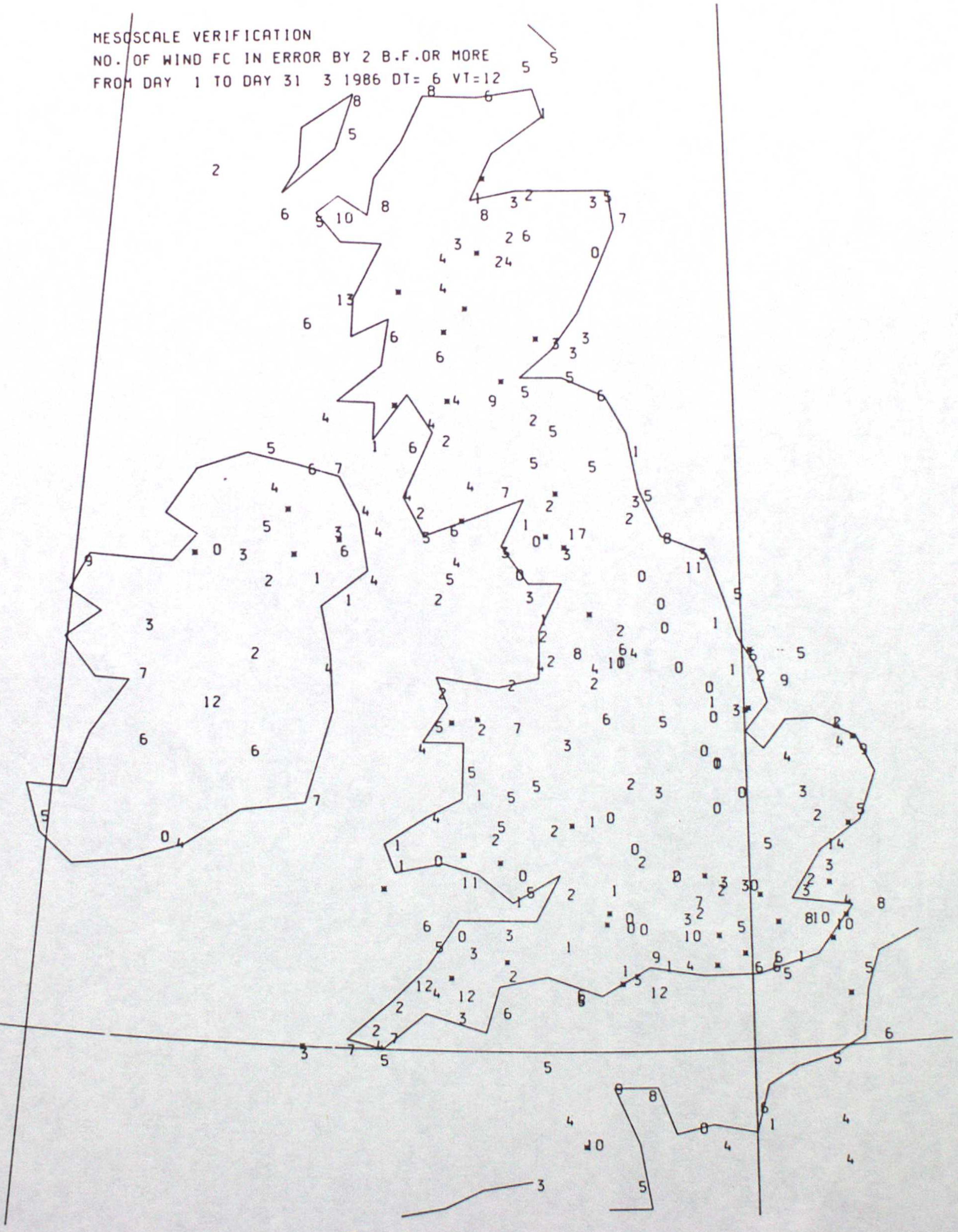


Figure 7

Observed Rainfall Accumulations for April 1986

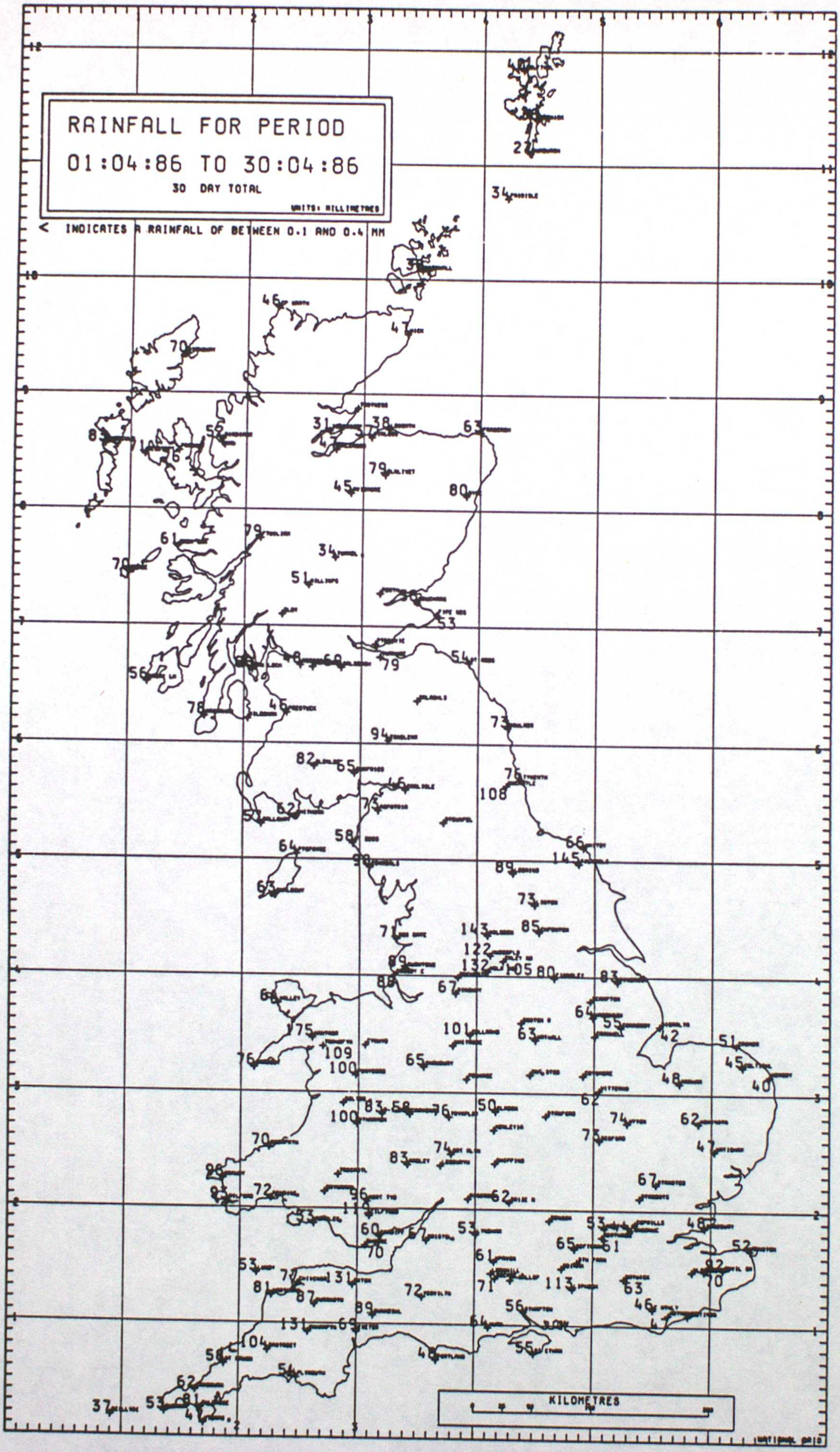


Figure 8

APRIL RAINFALL TOTAL FROM THE MESOSCALE MODEL (BASED ON A SUMMATION OF 12-HOUR TOTALS FROM EACH FORECAST).

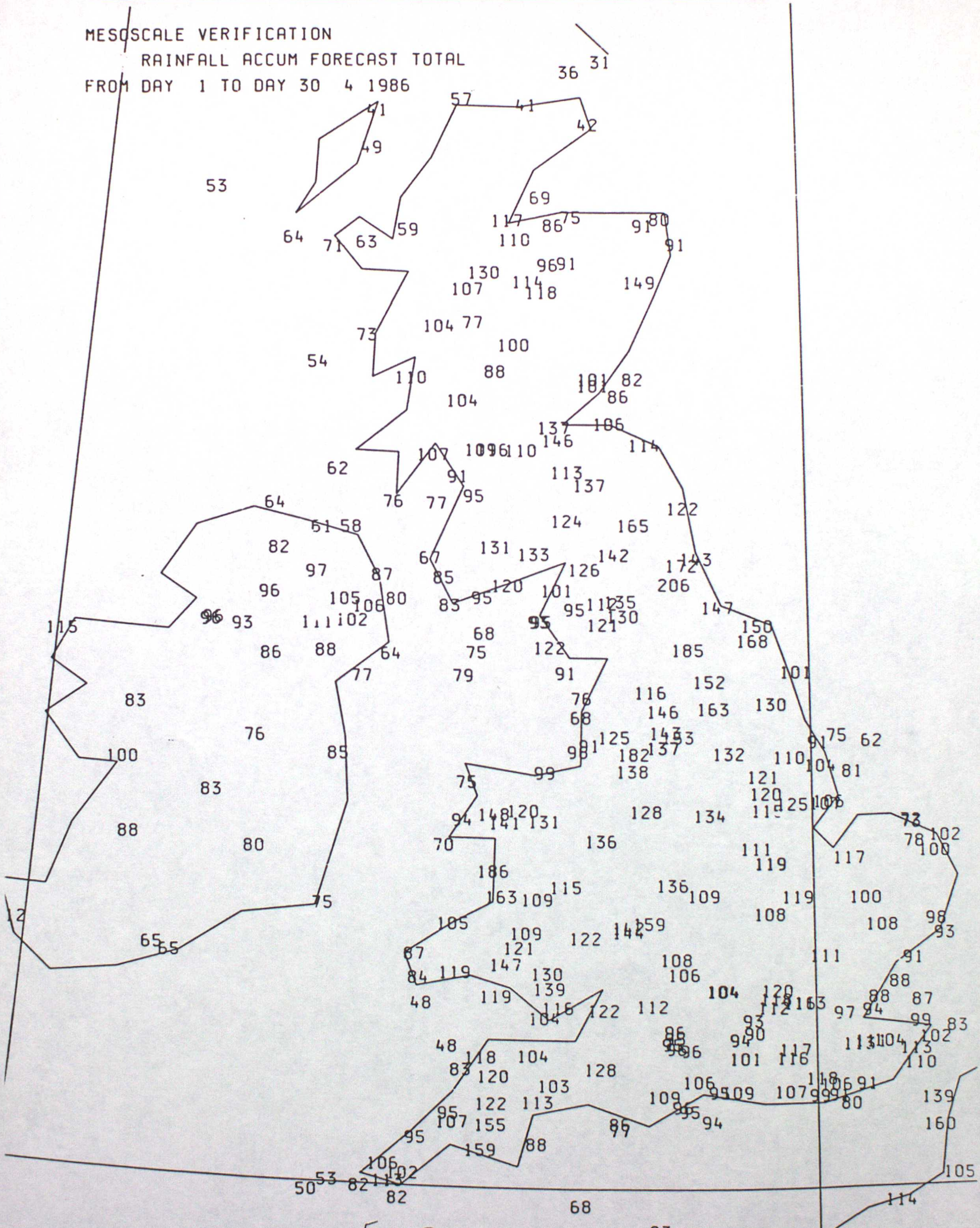


FIGURE 9

APRIL RAINFALL TOTAL FROM THE FINE MESH MODEL

(BASED ON A SUMMATION OF 12-HOUR TOTALS FROM EACH MODEL)

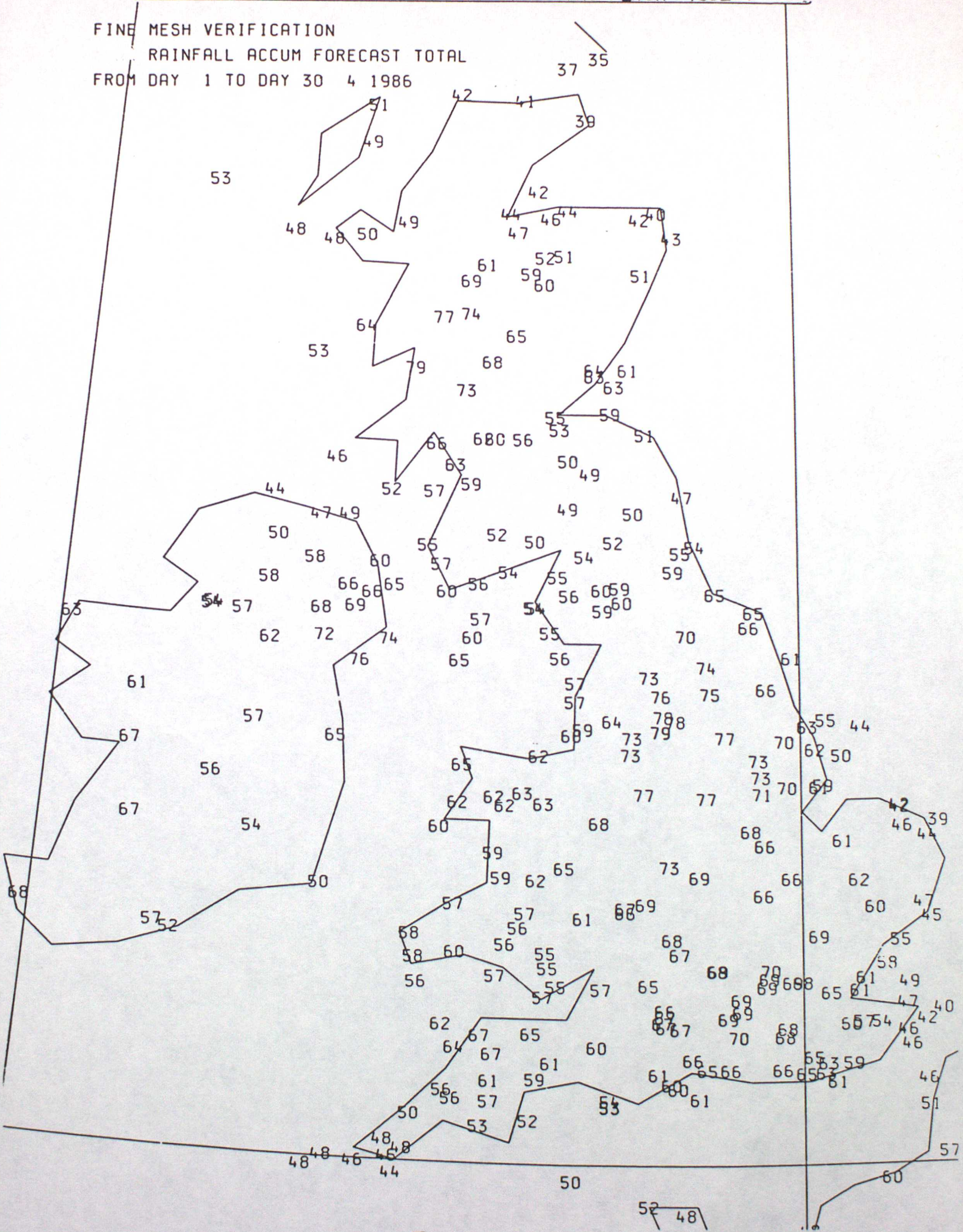


FIGURE 10

APRIL CONVECTIVE RAINFALL TOTAL FROM THE MESOSCALE MODEL

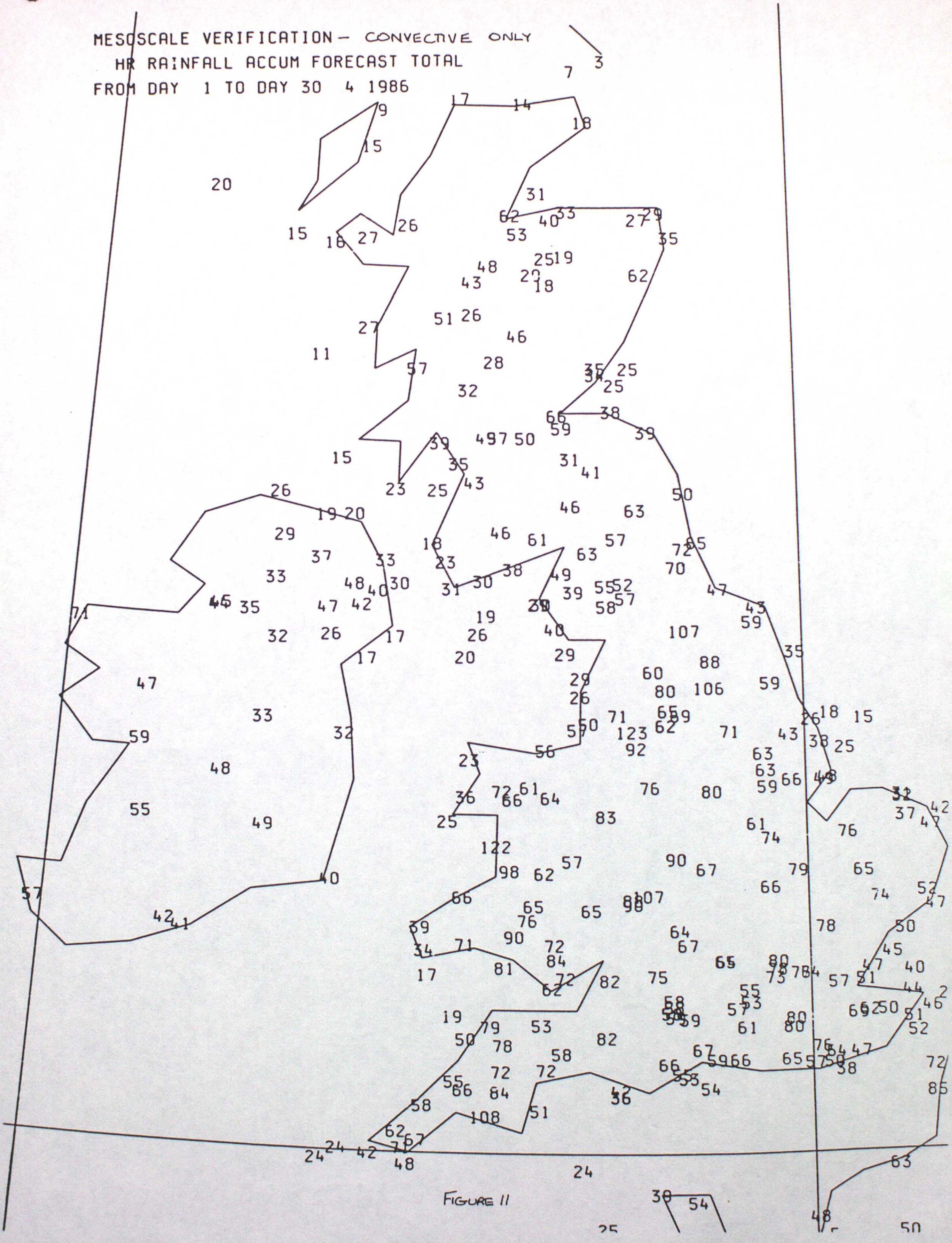


FIGURE 11

Bias in Mesoscale Model Surface Relative Humidity Forecasts for April 1986, VT 12GMT

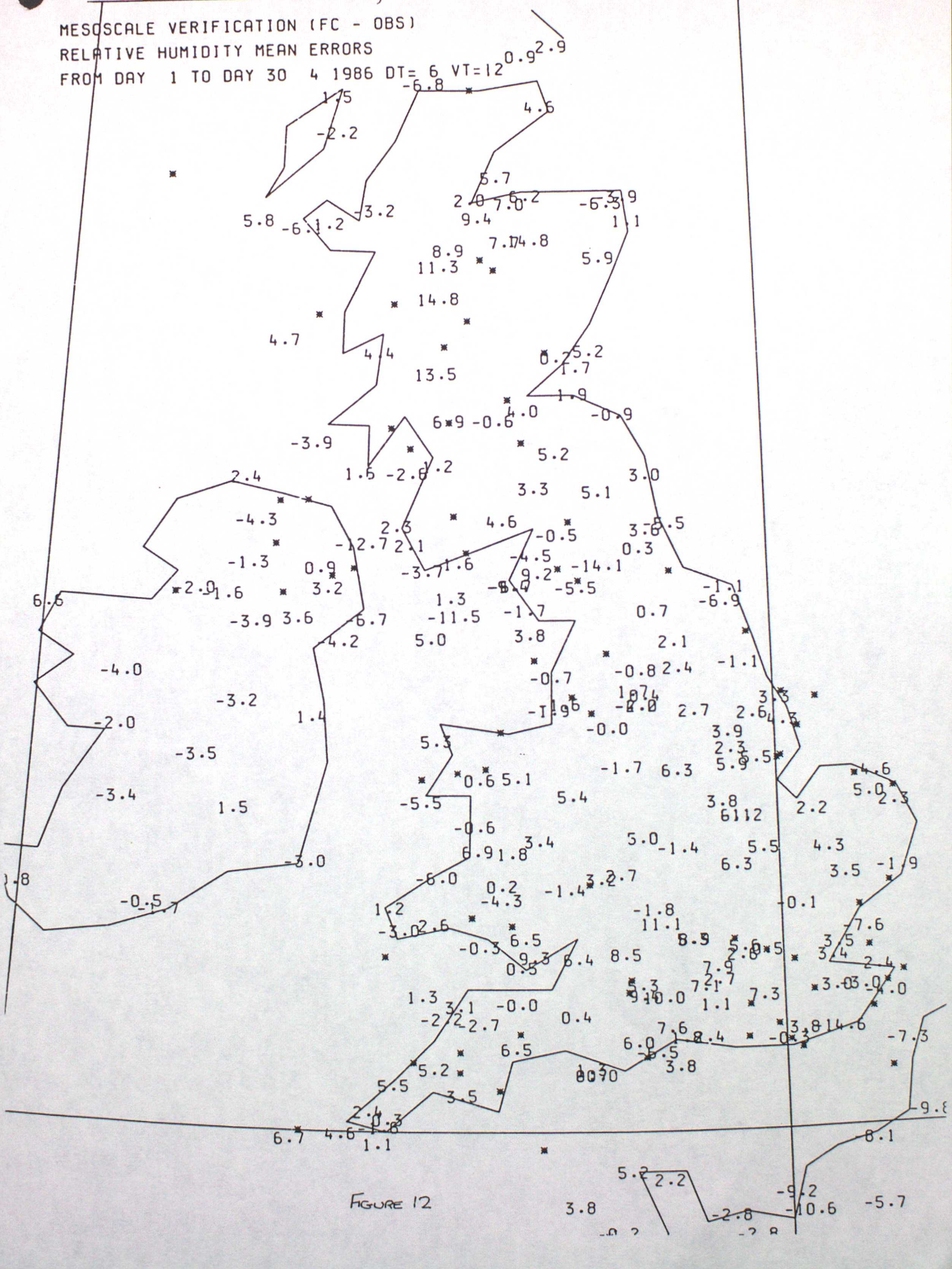


Figure 12

FINE MESH VERIFICATION (FC - OBS)
RELATIVE HUMIDITY MEAN ERRORS
FROM DAY 1 TO DAY 30 4 1986 DT= 6 VT=12

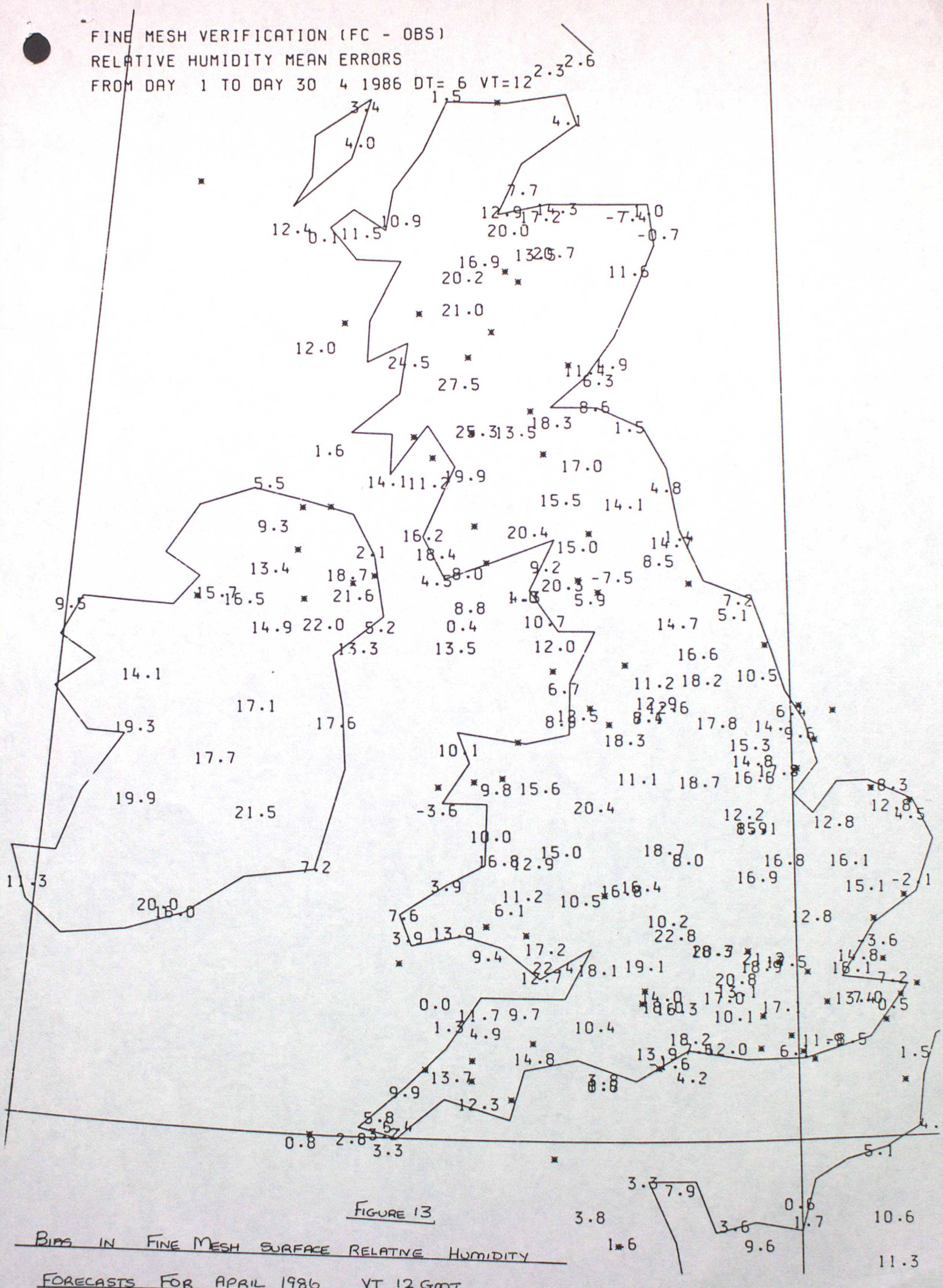
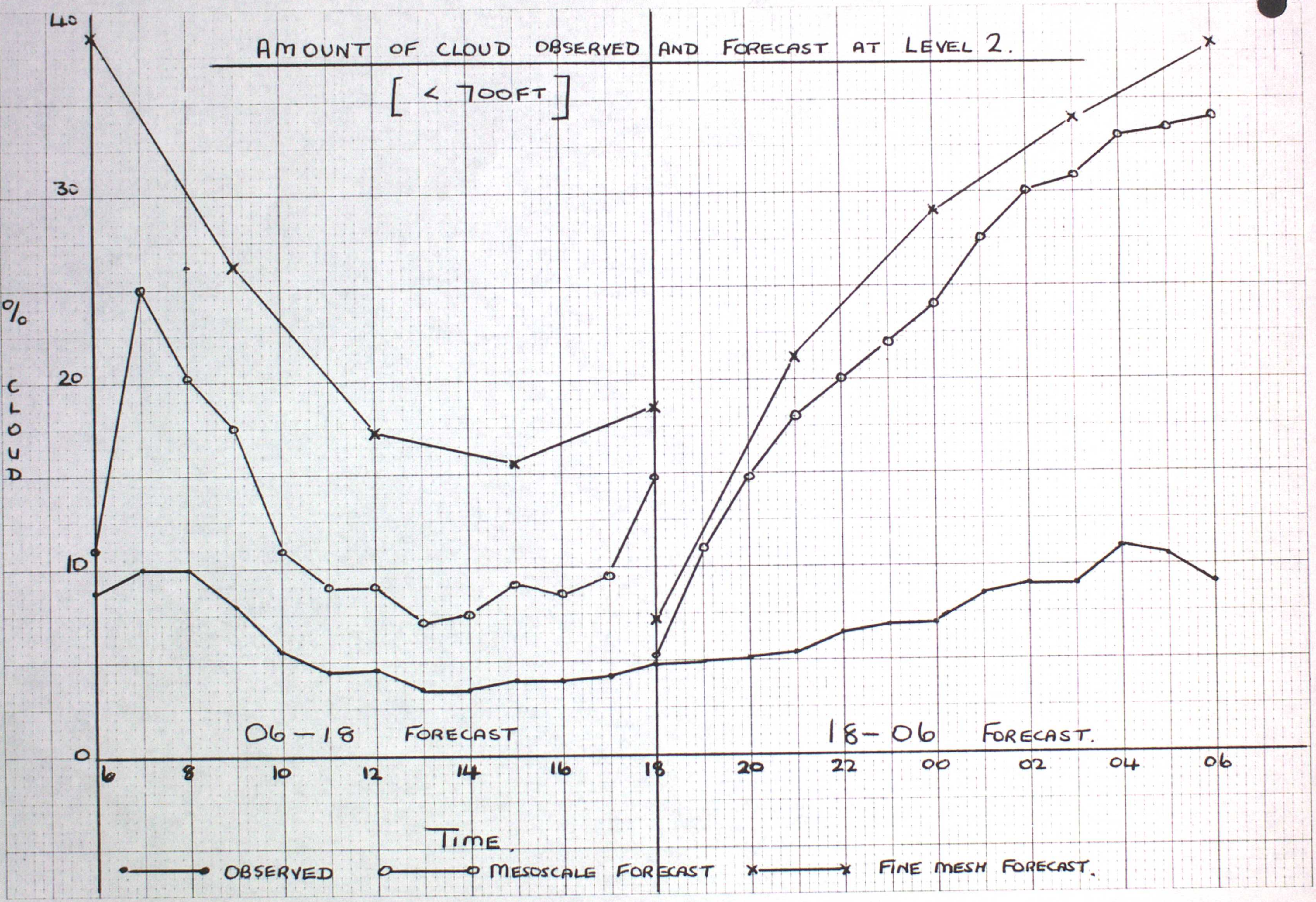


FIGURE 13

BIAS IN FINE MESH SURFACE RELATIVE HUMIDITY FORECASTS FOR APRIL 1986, VT 12 GMT



AMOUNT OF CLOUD OBSERVED AND FORECAST AT LEVEL 2.
[< 700FT]
% CLOUD
0
10
20
30
40
06-18 FORECAST
18-06 FORECAST.
6
8
10
12
14
16
18
20
22
00
02
04
06
TIME.
OBSERVED
MESOSCALE FORECAST
FINE MESH FORECAST.

FIGURE 14

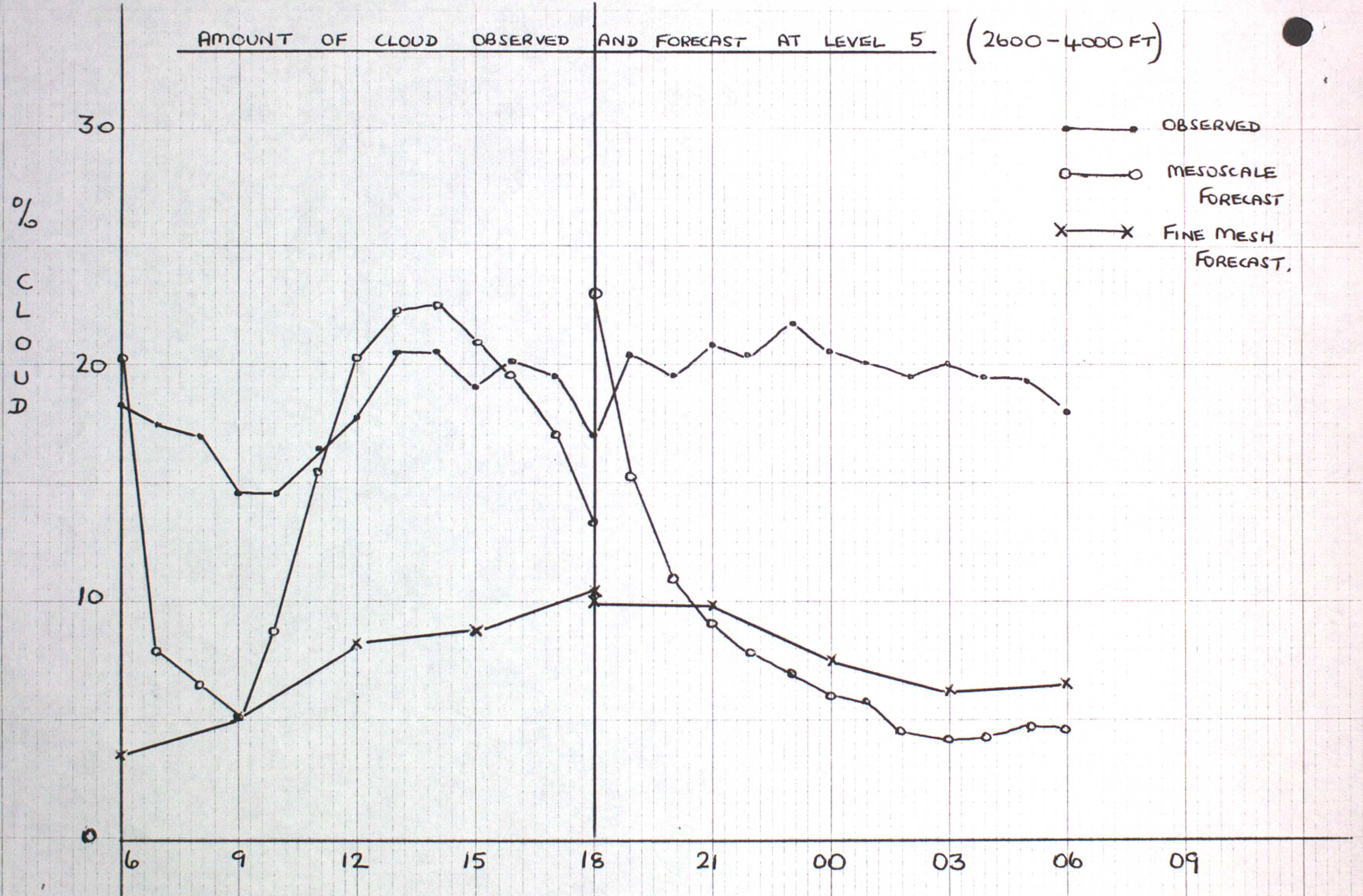

AMOUNT OF CLOUD OBSERVED AND FORECAST AT LEVEL 5 (2600-4000 FT)
OBSERVED
MESOSCALE FORECAST
FINE MESH FORECAST.
% CLOUD
30
20
10
0
6
9
12
15
18
21
00
03
06
09

FIGURE 15