287

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Verification of the mesoscale model forecasts during the winter November 1986 to February 1987.

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VERIFICATION OF MESOSCALE MODEL FORECASTS DURING THE WINTER, NOVEMBER 1986-FEBRUARY 1987

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VERIFICATION OF THE MESOSCALE MODEL FORECASTS DURING THE WINTER NOVEMBER 1986 TO FEBRUARY 1987

1. INTRODUCTION

This is the eighth report in a series describing the progress of the mesoscale model trial. Unusually, we have included four months in this report in order to include February with the other main winter months, December and January. The report will assess the quality of the mesoscale model forecasts in comparison with those from the fine-mesh model and also from forecasters at Weather Centres and from CFO.

In section 2, we will describe briefly model performance and changes. In addition to several changes introduced into the mesoscale model during December, a trial version of the fine-mesh model was being tested during the winter.

In section 3, results from the objective verification of wind speed, temperature, weather, cloud and surface relative humidity will be described. For the months November-January, the format will be similar to that described in previous reports. However, a major change was made on February 4, with the starting times of the mesoscale model forecasts switching from 06 GMT and 18 GMT to 00 GMT and 12 GMT.

An equally important way of assessing the model is to compare its forecasts with those issued by human forecasters at Weather Centres and in CFO. Two methods of subjective assessment will be described in section 4.

Section 5 summarises the main conclusions from the winter verification results.

2. MODEL PERFORMANCE AND CHANGES

i) THE MESOSCALE MODEL

During the four month period, the mesoscale model ran successfully on 232 occasions out of a possible 240, ie on 97% of occasions. Three of the missed forecasts were due to model failures, and the rest were due to problems with the Cyber computer.

Boundary problems affected the first two weeks following the switch to initial data times 00 and 12 GMT in February. The 12 GMT hybrid was made using a T+12 forecast from the DT 00 GMT fine-mesh but boundary conditions were provided by the DT 12 GMT fine-mesh forecast. A similar error occurred at 00 GMT. This error was corrected on February 17. The verification for the first half of February may have been affected by this error.

Changes introduced on December 8

a) Fine-mesh relative humidity only to be specified at the boundaries and not cloud water;

b) The implicit scheme for sound waves was changed to forward weighting;

c) A new snow scheme was introduced which takes into account the melting of snow as it falls and on the ground;

d) The cloud cover was smoothed to correspond to a hemispheric view from the ground;

e) An allowance was to be made for dissipated moisture in calculating convective precipitation;

f) The effect of surface fluxes on first level values would be calculated implicitly instead of explicitly.

Changes introduced on December 23

g) The efficiency coefficient in the stratiform precipitation scheme was reduced from 1g/kg to 0.8g/kg;

h) In the calculation of the surface resistance to evaporation, the solar altitude would be calculated at each model grid-point instead of one average value being used.

Changes introduced during January

i) All precipitation at sub-freezing levels would be output as snow.

j) The output modelling of minimum temperature was changed to a linear interpolation.

The most important of these changes was the introduction of a new scheme for predicting snow at the surface (change (c)). In the old scheme, snow was assumed to melt instantaneously below the freezing level and snow was predicted only if the 310 m temperature was less than zero. In the new scheme, falling snow is said to melt at a certain rate (given by a Met O 15 formula), so that if the snow is heavy enough it will reach the surface where it will accumulate if the temperature is less than zero. There was a deficiency in the new scheme in that precipitation from supercooled water droplets in stratocumulus cloud was not covered by the Met O 15 formula. The extra change (change (i)) during January was intended to correct this deficiency.

Changes (e) and (f) were designed to reduce the amount of convective rainfall forecast by the model, and change (j) to improve minimum temperature forecasts slightly.

ii) THE FINE-MESH MODEL

Two trial versions of the fine-mesh model were used during the period November to January. The details are given below.

a) November 1-December 15

This version included the implicit boundary layer scheme, the shallow convection scheme, increased resistance to surface evaporation, changes to the interactive radiation scheme, including the treatment of ozone.

b) December 15-February 3

This version included most of the above changes, but the shallow convection scheme was replaced by a new version of the split final detrainment scheme which included some boundary layer changes.

c) February 4-28

With the change to the initial data time, it was decided to use the current version of the fine-mesh model in the verification scheme. Prior to February 11th, this was the old operational version. An operational change was made at 12 GMT February 11. The new operational version of the fine-mesh was similar to the version described in paragraph b) above, except that an extra cloud change was added. The marine stratocumulus scheme was dropped and shallow convective cloud was added to the low cloud output.

3. OBJECTIVE VERIFICATION RESULTS

In this section, we will compare and assess forecasts for temperature, weather, wind speed, cloud and humidity from the mesoscale and fine-mesh models. February results will be considered separately due to the altered starting times 00 GMT and 12 GMT.

The weather during this four month period was very varied, providing a good test of the accuracy of model forecasts. In the following sub-sections, we will describe the important features of each month. The weather during November and December was mild and unsettled, with periods of heavy rain especially over high ground in the west. Two particularly interesting cases of heavy rain occurred during these months. They are described briefly below.

i) November 20. A depression crossed Southern England bringing heavy rainfall accompanied by thunderstorms and tornadoes.

ii) December 29-30. Orographic intensification of rain in a westerly airstream over Wales resulted in more than 100 mm of rain falling over parts of Wales during the twenty-four hour period from 09 GMT December 29 to 09 GMT December 30. This case will be featured in the sub-section on rainfall.

November also produced a short period of persistent fog from 28-30th. January was a cold, dry month which will be remembered for the extremely cold week from the 10th to the 17th, and also for the long period of dull weather which occurred immediately afterwards and broke records in some places for the longest dull spell without sunshine. A joint Met O 11 and Met O 15 case study of a very good mesoscale model forecast of snowfall over Kent during the period 11-13 January is being prepared. Finally February was a mixed month, mild at the beginning and end, but colder in the middle with widespread night frosts.

3. a) TEMPERATURE VERIFICATION RESULTS

i) Maximum and Minimum temperature forecasts from the mesoscale model

Maximum temperatures were very well predicted by the mesoscale model during the winter months, with an average 87% of forecasts being accurate to within 2°C. The results for the individual months are given in table 1. The model was slightly better in the cloudy, mild months, when the diurnal variation of temperature was smaller. The overall bias in the model is very small. Figure 1 shows the geographical distribution of maximum temperature rms errors for January. The largest errors occur over the coast and hills and rms errors inland are generally less than 1.5°C.

MONTH	PERIOD	MAXIMUM TEMP		MINIMUM TEMPERATURES	
		CORRECT WITHIN 2C	BIAS	CORRECT WITHIN 2C	BIAS
NOV	06-24	90%	-0.2	52%	2.08
DEC	06-24	92%	0.1	59%	1.70
JAN	06-24	83%	0.1	63%	1.13
FEB	00-18	82%	-0.2	65%	1.11

TABLE 1. ACCURACY OF MESOSCALE MODEL MAXIMUM AND MINIMUM TEMPERATURE FORECASTS DURING THE WINTER 1986-87

Accurate forecasts of minimum temperature are very important during the winter, especially to public utilities. Unfortunately, the mesoscale model is less accurate in predicting the minimum temperature. The main cause is a warm bias in the model, probably due to excessive low cloud. Provided that it predicts clear skies correctly, then the mesoscale minimum temperature forecast is quite accurate. e.g. on the coldest night of the winter, January 11/12, the model forecast temperatures -10C to -14C over Southern England at 06 GMT. These temperatures compared well with observed values -9C to -13C. Table 1 shows that an average of 60% of minimum temperature forecasts were correct within 2°C and the overall warm bias was 1.5°C. This warm bias affects inland stations, as well as coastal and could be allowed for by forecasters using the model output. Figure 2 shows the geographical distribution of minimum temperature errors for January.

Figure 3 shows how well the model predicted maximum and minimum temperatures for one station, Birmingham, during January.

ii) Comparison of 3-hourly temperature forecasts with the fine-mesh model.

The nearest we can get to assessing maximum/minimum temperature forecasts from the fine-mesh model is to compare forecasts verifying at 15 GMT and 06 GMT with the equivalent from the mesoscale model. Table 2 compares the percentage of forecasts correct within 2C for both models.

MONTH	F/C PERIOD	V.T 15 GMT		F/C PERIOD	V.T 06 GMT	
		% WITHIN 2C			% WITHIN 2C	
		MES	F.M		MES	F.M
NOV	06-24	71	73	18-12	66	70
DEC	"	87	81	"	68	71
JAN	"	70	59	"	66	59
FEB	00-18	80	71	12-06	69	66

TABLE 2. PERCENTAGE OF FORECASTS CORRECT WITHIN 2C AT 15 GMT AND 06 GMT FROM THE MESOSCALE AND FINE-MESH MODELS DURING THE WINTER 1986/87

During the mild, wet months, November and December, the two models were close overall in terms of accuracy, with the mesoscale model slightly better at 15 GMT (fine-mesh model too cold) and the fine-mesh model slightly better at 06 GMT (mesoscale model too warm). However, during January, the mesoscale model was clearly better at all times. The fine-mesh model had a very marked warm bias (errors often exceeding 5°C) along the coast, caused by the large land-sea temperature contrast. Inland, the fine-mesh model tended to be too cold. Mesoscale model temperature errors were smaller, both inland and along the coast.

Table 3 compares the overall r.m.s. errors for both models at 3-hourly intervals for the period November to January. Overall mean temperature errors, especially for the fine-mesh model (warm coastal bias, cold inland bias) are considered to be misleading, so they are not included.

V.T	NOVEMBER		DECEMBER		JANUARY	
DT 06	MES	F.M	MES	F.M	MES	F.M
VT 09	1.3	2.1	1.3	2.1	1.6	3.0
VT 12	1.4	1.8	1.4	1.9	1.7	2.4
VT 15	1.4	1.7	1.4	1.6	1.8	2.2
VT 18	1.6	1.8	1.7	1.7	1.9	2.4
VT 21	1.9	1.9	2.0	1.9	2.1	2.5
VT 00	2.1	2.0	2.1	2.0	2.2	2.6
DT 18	MES	F.M	MES	F.M	MES	F.M
VT 21	1.4	1.8	1.4	1.9	1.6	2.5
VT 00	1.7	1.9	1.6	1.9	1.9	2.6
VT 03	2.0	2.0	1.8	2.0	2.1	2.8
VT 06	2.1	2.0	2.0	2.0	2.3	2.6
VT 09	2.0	1.9	2.0	1.9	2.3	2.6
VT 12	1.5	1.7	1.7	1.7	2.0	2.2

TABLE 3. R.M.S TEMPERATURE ERRORS IN DEG. C AT 3-HOURLY INTERVALS, NOVEMBER TO JANUARY FOR THE MESOSCALE MODEL AND FINE-MESH MODEL

If we consider the (06-24) GMT forecast first, then the mesoscale model errors increase with time. The errors are slightly less than those of the fine-mesh model except during the late evening in November and December. These larger errors may be attributed to a warm bias developing in the model due to excessive low cloud.

In the (18-12) GMT forecast, the largest errors for the mesoscale model occur around minimum temperature time (06-09) GMT. These largest errors are due to the model forecasting too much cloud and too strong a wind. The fine-mesh model was slightly better at these times in November and December.

The mesoscale model was better than the fine-mesh model for all times during January. However, for both models, the largest errors occurred during January, especially along the coast, where there was a strong contrast between land and sea temperatures. This was more marked in the fine-mesh model, which had frequent errors of 5 to 8 degrees C along the coast. Table 4 compares the mean and r.m.s. errors for a group of 40-50 inland stations in England for January.

40/50 INLAND STNS	MEAN ERRORS		R.M.S ERRORS	
DT 06	MES	F.M	MES	F.M
VT 09	0.0	-1.7	-	-
VT 12	0.3	-1.4	-	-
VT 15	-0.1	-0.1	1.2	1.6
VT 18	-0.1	0.2	1.6	1.7
VT 21	0.3	-0.8	1.6	2.3
VT 00	0.4	-0.7	1.8	2.3
DT 18	MES	F.M	MES	F.M
VT 21	-0.1	-0.5	1.1	2.0
VT 00	0.0	-0.4	1.5	2.1
VT 03	0.1	-0.2	1.7	2.1
VT 06	0.3	-0.3	1.8	1.9
VT 09	0.3	-0.4	1.8	2.1
VT 12	0.2	-0.6	1.6	1.8

TABLE 4. MEAN AND R.M.S TEMPERATURE ERRORS FOR A GROUP OF INLAND STATIONS (40 DURING NIGHT, 50 DURING DAY IN ENGLAND DURING JANUARY.

For both models, the inland temperature errors are smaller than the overall errors, confirming the poor results for coastal and hill stations during January. The fine-mesh model had a cold inland temperature bias, except at 15 GMT; and these results may be explained by the marked deficit of cloud in the model. The warm bias at night in the mesoscale model during January was, in fact, smaller than the bias in November and December. In the cold dry month of January, the model did not forecast so much spurious low cloud, hence the warm bias was lessened.

The temperature results for February have been tabulated separately in Table 5 due to the change in forecast periods.

	OVERALL R.M.S ERRORS		INLAND R.M.S ERRORS	
DT 00Z	MES	F.M	MES	F.M
VT 03	1.4	2.3	1.0 (0.1)	2.0 (-0.8)
VT 06	1.6	2.3	1.3 (0.3)	1.9 (-0.7)
VT 09	1.7	2.1	1.3 (0.5)	1.9 (-0.8)
VT 12	1.8	2.0	1.5 (0.1)	1.8 (-0.6)
VT 15	1.7	2.0	1.3 (-0.2)	1.9 (-0.4)
VT 18	1.6	1.9	1.2 (0.0)	1.6 (0.3)
DT 12	MES	F.M	MES	F.M
VT 15	1.5	1.8	1.1 (-0.5)	1.5 (-0.1)
VT 18	1.5	1.8	1.4 (-0.3)	1.4 (0.2)
VT 21	1.6	2.0	1.4 (0.1)	1.7 (-0.9)
VT 00	1.8	2.1	1.7 (0.5)	1.8 (-0.7)
VT 03	2.0	2.2	1.8 (0.7)	1.9 (-0.7)
VT 06	2.1	2.2	2.0 (0.8)	1.9 (-0.6)

TABLE 5. OVERALL AND INLAND R.M.S TEMPERATURE ERRORS FOR THE MESOSCALE AND FINE-MESH MODELS DURING FEBRUARY. THE FIGURES IN BRACKETS IN COLUMNS 4 AND 5 ARE MEAN ERRORS FOR THE SUBSET OF INLAND STATIONS.

If we consider the (00-18) GMT forecast for February, then the mesoscale model was better at all verifying times, both overall and inland. The mesoscale model tended to be slightly warm, except at 15 GMT, whilst the fine-mesh model was too cold, except at 18 GMT. In the (12-06) GMT forecast, the fine-mesh model achieved its only success; a smaller error than the mesoscale model for inland stations at 06 GMT. The warming in the mesoscale model forecast is shown clearly by the mean errors (in brackets) in column 5 in table 5. The warm bias is substantial at 06 GMT. The fine-mesh model, in contrast, was too cold throughout this forecast.

(iii) FROST VERIFICATION RESULTS FOR 06 GMT

The skill of the models in predicting the occurrence of frost at 06 GMT is summarised in table 6.

V.T 06 GMT	NOV		DEC		JAN		FEB	
	MES	F.M	MES	F.M	MES	F.M	MES	F.M
% OBS FROST	2.6	2.6	4.4	4.4	38	36	25.5	25.5
% F/C FROST	0.8	0.9	2.4	3.6	32	33	23.1	23.3
% FROST CORRECTLY F/C	0.5	0.7	1.0	1.2	28	26	18.8	16.2

TABLE 6. PERCENTAGES OF FROST, OBSERVED AND FORECAST BY THE MESOSCALE AND FINE-MESH MODELS DURING THE WINTER 1986/87

At 06 GMT during November and December, when frost occurred, temperatures were only one or two degrees below zero. The mesoscale model, with a warm bias of 0.5-1.5°C at 06 GMT, was less successful in predicting the slight frost than the fine-mesh model. However, during January and February, temperatures were often well below zero. Thus the small warm bias in the mesoscale model was not so important and a more crucial factor was the occurrence of frost at coastal stations which tended to be missed more often by the fine-mesh model.

During January, temperatures were frequently well below zero so that table 6 does not indicate any particular skill of the models. A harder test is provided by the results shown in table 7. This table shows the severity of frost (observed and forecast) for 06 GMT for 12 inland low-level stations in England during January.

DEGREE OF FROST	% OBS	% F/C BY MES	% F/C BY F.M
NIL	50	48	41
SLIGHT	16	13	12
MODERATE	13	18	18
SEVERE	12	8	19
VERY SEVERE	9	13	8

TABLE 7. DEGREE OF FROST, OBSERVED AND FORECAST AT 06 GMT DURING JANUARY FOR 12 INLAND LOW-LEVEL STATIONS IN ENGLAND

In determining the degree of frost, wind speed is a crucial factor. In this comparison, the fine-mesh model winds were multiplied by 0.85, to give a rough conversion of the 25 m wind speed to 10 m values. Also, all observed calm winds were reset to 2 kt. Both models did well in forecasting the severity of frost, with both tending to predict too severe a frost rather than the reverse. For the mesoscale model, 67% of frost forecasts were predicted correctly, and on 21% of occasions, the degree of frost was over-predicted. The comparable figures for the fine-mesh model were 62% and 28% respectively. For both models, the major error was in predicting too strong a wind speed at 06 GMT.

3. b) PRECIPITATION FORECASTS

The most interesting months for rainfall case studies were November and December, the two mild, mainly westerly months. During these two months, the mean monthly accumulations per observation point were 97 mm and 133 mm respectively. In both these months, the mesoscale model over predicted accumulations by a mean factor of 1.3. Peak totals over high ground in the west were often predicted accurately, but accumulations over lower ground in the east were too large. However, this mean factor of 1.3 was substantially lower than the corresponding figures (1.7,1.7) for August and October respectively. A major reason was the smaller percentage of convective rain forecast during the winter. No over-prediction of rainfall occurred in the fine-mesh model forecasts for November and December. Amounts were well forecast over Western Scotland and in the east, but under-predicted over Wales and South-West England due to over-smooth orography.

January was a much drier month and the mean monthly accumulation per observation point was only 16.5. The mesoscale model over-predicted rainfall by an average factor of 1.4, mainly because the model forecast too much convective precipitation from the North Sea over Eastern England and Scotland.

During February, over-prediction of rainfall by the mesoscale model was less of a problem. Amounts predicted over low ground in the east were still slightly too high, but over high ground in the west, accumulations were, if anything, slightly under-predicted. In fact, the fine-mesh model actually forecast more rainfall in many places. There were two reasons for the mesoscale model forecasting less rainfall in February:-

a) One of the major causes of over-prediction of rainfall was the excessive amounts of convective rainfall forecast by the mesoscale model. During February, however, 90% of the forecast rainfall was dynamic.

b) Due to the change in starting times in February, we had to switch to verifying the periods 06-18 and 18-06. (Forecast period T+6 to T+18.) Much of the over-prediction of rainfall in the mesoscale model occurs during the first six hours of the forecast period.

The above results are summarised in Table 8, which gives the values of forecast accumulations in a twelve-hour period expressed as a percentage of the observed accumulations.

MODEL RAINFALL BIAS	MESOSCALE MODEL		FINE-MESH MODEL	
FORECAST PERIOD T+3-T+15	09-21	21-09	09-21	21-09
NOVEMBER	148	118	92	93
DECEMBER	132	137	107	118
JANUARY	140	143	87	113
FORECAST PERIOD T+6-T+18	06-18	18-06	06-18	18-06
FEBRUARY	104	125	110	129

TABLE 8. TOTAL MEAN FORECAST RAINFALL OVER A 12-HOUR PERIOD EXPRESSED AS A PERCENTAGE OF OBSERVED VALUES [(FCST/OBS)X100]

Figure 4 shows the observed accumulations for December for selected stations in the UK. December was a mild wet month and the highest totals were reported in the west, e.g., 414 mm at Fort William, 433 mm over North Wales, 363 mm over South-west Scotland and 312 mm over Baastreet. The driest spots were on the eastern side of the UK (Manston 52 mm). Figure 5 shows the forecast accumulations from the mesoscale model for December. Peak totals in the west have been well predicted, but the model has forecast too much rain in the drier east. Figure 6 shows the fine-mesh forecast accumulations for December for comparison. Totals in the east are more accurate but the fine-mesh model has under-predicted totals substantially over Wales and South-west England.

The wettest 24-hour period occurred between 09 GMT 29th to 09 GMT 30th December, during which over 100 mm of rain fell in parts of Wales (e.g. 109 mm at Nantmoor). Figure 7 shows the forecast rainfall from the relevant mesoscale model forecasts for the period 29/12 GMT to 30/12 GMT. The model has forecast a maximum of 78 mm in central Wales, a good attempt at forecasting the orographic enhancement of precipitation.

In Tables 9, a-d, we compare the skill of the models in predicting the occurrence of rain (or snow) in a twelve hour period. The twelve-hour periods considered are 09-21 and 21-09 during November, December and January, switching to 06-18 and 18-06 during February.

Table 9a. NOVEMBER (09-21/21-09)

MESOSCALE MODEL

		OBS YES	OBS NO	
F/C	YES	58	10	68
	NO	12	20	32
		70	30	100

FINE-MESH MODEL

		OBS YES	OBS NO	
F/C	YES	57	10	67
	NO	12	21	33
		69	31	100

Table 9b. DECEMBER (09-21/21-09)

		OBS YES	OBS NO	
F/C	YES	52	17	69
	NO	7	24	31
		59	41	100

		OBS YES	OBS NO	
F/C	YES	50	17	67
	NO	10	23	33
		60	40	100

Table 9c. JANUARY (09-21/21-09)

		OBS YES	OBS NO	
F/C	YES	22	17	39
	NO	8	53	61
		30	70	100

		OBS YES	OBS NO	
F/C	YES	21	21	42
	NO	9	49	58
		30	70	100

Table 9d. FEBRUARY (06-18/18-06)

		OBS YES	OBS NO	
F/C	YES	29	18	47
	NO	12	41	53
		41	59	100

		OBS YES	OBS NO	
F/C	YES	34	18	52
	NO	7	41	48
		41	59	100

TABLES 9 a-d. CONTINGENCY TABLES FOR THE OCCURRENCE OF RAIN IN A 12-HOUR PERIOD

In the simple tests applied in the contingency tables, there was very little to choose between the two models, and both were correct on 74-75% of occasions. The tables show that the main error of both models was to forecast the occurrence of rain incorrectly. This tendency was most marked in the fine-mesh model forecasts during January and February and may be due to small amounts of rain falling from fine-mesh level 2 cloud in the new version of the fine-mesh model. A more detailed examination of rainfall is shown in Tables 10 (a) and (b). These are contingency tables for rainfall accumulations in a twelve-hour period based upon the four winter months, November to February.

TABLE 10a. MESOSCALE MODEL 12-HOUR RAINFALL ACCUMULATIONS FOR PERIOD NOVEMBER TO FEBRUARY

		Observed accumulations in mm <0.05	0.05-1	1-5	5-10	>10	
F/C	<0.05	34.4	7.2	2.1	0.2	0.1	44.0
	0.05-1	10.6	7.7	4.1	0.8	0.2	23.4
	1-5	4.2	6.0	7.2	2.3	0.7	20.4
	5-10	0.5	1.4	2.8	1.8	0.7	7.2
	>10	0.2	0.5	1.3	1.3	1.5	4.8
		49.9	22.8	17.5	6.4	3.2	99.8

TABLE 10b. FINE-MESH MODEL 12-HOUR RAINFALL ACCUMULATIONS FOR PERIOD NOVEMBER TO FEBRUARY

		Observed accumulations in mm <0.05	0.05-1	1-5	5-10	>10	
F/C	<0.05	33.1	7.5	2.2	0.2	0.1	43.1
	0.05-1	12.4	8.0	4.9	0.7	0.1	26.1
	1-5	4.0	5.8	7.7	2.6	1.1	21.2
	5-10	0.4	1.3	2.0	1.9	1.2	6.8
	>10	0.1	0.2	1.7	0.9	1.0	2.9
		50.0	22.8	17.5	6.3	3.5	100.1

Overall, these tables show that there was not much difference between the models in overall accuracy. From the main diagonal, we find the overall accuracy of the mesoscale model to be 53% compared with 52% for the fine-mesh. The main error is to be found in column 2 row 2, which corresponds to the models forecasting between 0.05 mm and 1 mm of rain on occasions when no rain was observed. The fine-mesh was slightly worse (12.4% against 10.6%) and this surplus rain may be attributed to spots of rain falling from cloud in the lowest model layers. Both models have predicted too much rain on a similar percentage of occasions (Mes 29%, F.M 28%). The main difference between the models is that the mesoscale model predicts significant amounts of rain more often than the fine-mesh model. Occurrences of 5 mm or more in 12 hours occurred on an average 9.7% of occasions. The mesoscale model forecast 5 mm or more on 12% of occasions, of which 5.3% were correct. The corresponding figures for the fine-mesh model were 9.7% and 5.0%.

b) SNOW VERIFICATION

Table 11a. JANUARY

Mesoscale Model DT 06 GMT VT 15 GMT

		OBSERVED SNOW	DRY	RAIN	
F/C	SNOW	1.3	4.5	0.4	6.2
	DRY	1.8	77.9	4.6	84.3
	RAIN	0.3	6.5	2.7	9.5
		3.4	88.9	7.7	100.0

Table 11b. JANUARY

Fine-Mesh Model DT 06 GMT VT 15 GMT

	OBSERVED SNOW	DRY	RAIN	
SNOW	0.6	2.9	0.3	3.9
DRY	2.6	81.2	4.1	88.0
RAIN	0.3	5.2	2.7	8.2
	3.5	89.3	7.2	100.0

Table 11c. FEBRUARY

Mesoscale Model DT 00 GMT VT 15 GMT

		OBSERVED			
		SNOW	DRY	RAIN	
F/C	SNOW	0.1	0.8	0.3	1.2
	DRY	0.5	75.5	5.8	81.8
	RAIN	0.2	9.3	7.5	17.0
		0.8	85.5	7.5	100.0

Fine-mesh model DT 00 GMT VT 15 GMT
NOT AVAILABLE

TABLES 11 a-c. CONTINGENCY TABLES FOR THE TYPE OF PRECIPITATION OBSERVED AND FORECAST DURING JANUARY AND FEBRUARY FOR 15 GMT

Neither model is particularly impressive judging on the results in Tables 11, a-c. During January, the mesoscale model forecast almost twice as much snow as was observed, but only $^1/_5$ of this was in the correct place. However, it was better than the fine-mesh model which only succeeded in forecasting $^1/_6$ of the observed snow.

3. c) WIND SPEED VERIFICATION

Table 12 shows the forecast wind speed errors for both models for the period November to February. 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 10 m wind speeds and with surface wind observations.

MODEL	PERIOD	VERIFICATION TIME					
DT 06		09	12	15	18	21	00
MES	NOV-JAN	5.7	5.9	6.1	6.5	6.7	6.5
F.M	NOV-JAN	6.5	6.2	6.3	6.6	6.8	6.7
D.T 18		21	00	03	06	09	12
MES	NOV-JAN	5.9	5.9	6.2	6.4	6.5	6.7
F.M	NOV-JAN	6.2	6.1	6.3	6.3	6.9	6.6
DT 00		03	06	09	12	15	18
MES	FEB	4.8	4.9	4.9	5.1	5.1	5.2
F.M	FEB	5.0	5.1	5.5	5.2	5.2	5.7
DT 12		15	18	21	00	03	06
MES	FEB	4.9	5.0	5.1	5.2	5.3	5.3
F.M	FEB	4.8	5.3	5.2	5.2	5.2	5.3

TABLE 12. R.M.S WIND SPEED ERRORS IN KNOTS AT 3-HOURLY INTERVALS FOR PERIOD NOVEMBER TO FEBRUARY

For both models, the largest errors occurred during November and December and were probably due to evolution errors. Errors during January were smaller by 1-2 kt and were similar to those during February. The February errors have been tabled separately because of the different initial data times. Table 12 shows how close the models are in terms of accuracy. The mesoscale model's errors are generally smaller but only by an average 0.2

kt. Figure 8 shows the geographical distribution of rms errors for mesoscale model wind speed errors for T+9, VT 15 GMT for December. The largest errors occur mainly over high ground and along the coast. Figure 9 shows the number of occasions during December when the forecast wind speed error for 15 GMT exceeded two Beaufort Forces.

Table 13 shows the frequency of occurrence of wind speed errors for verification times 6 GMT and 15 GMT during the four month period. Observed and forecast wind speeds have been converted into Beaufort Forces and the errors partitioned in terms of the number of Beaufort Force incorrect. Again, figures for the period November to January have been averaged, whilst the February figures have been kept separate, due to the different initial data time.

VT	PERIOD	MODEL	<-3	-2	-1	0	1	2	≥3
VT 06Z	T+12	MES-NOV-JAN	1.0	3.2	11.0	28.7	33.7	17.0	5.1
VT 06Z	T+12	F.M-NOV-JAN	1.3	4.8	15.6	30.2	29.4	13.4	5.3
VT 06Z	T+18	MES-FEB	0.8	2.9	10.9	30.6	35.4	15.2	4.0
VT 06Z	T+18	F.M-FEB	0.7	4.2	15.0	32.0	31.0	13.1	3.6
VT 15Z	T+9	MES-NOV-JAN	1.0	3.2	11.0	31.8	32.9	13.9	3.6
VT 15Z	T+9	F.M-NOV-JAN	1.3	4.8	15.6	31.9	28.1	13.0	5.9
VT 15Z	T+15	MES-FEB	1.5	4.8	17.0	36.8	28.0	9.8	1.9
VT 15Z	T+15	F.M-FEB	1.5	5.0	16.8	36.0	27.5	10.3	2.9

TABLE 13. FREQUENCY OF OCCURRENCE OF WIND SPEED ERRORS (IN BEAUFORT FORCE) FOR VERIFICATION 06 GMT AND 15 GMT DURING WINTER, NOVEMBER TO FEBRUARY

For verification time 06 GMT, an average 74% of mesoscale model forecasts during the winter were correct within one Beaufort Force, compared with 75% for the fine-mesh model. There is a tendency for forecast wind speeds to be too strong. The ratio of too strong forecasts to too weak forecasts at 06 GMT was 3.7 : 1 for the mesoscale model compared to 2.3 : 1 for the fine-mesh model.

Similarly at 14 GMT, the models were close in overall accuracy with approximately 79% of forecasts correct to the Beaufort Force.

In Table 14 below, we show the observed and forecast wind speed climatology for 06 GMT and 15 GMT for the winter period.

BEAUFORT FORCE	1	2	3	4	5	6	7	8	9
15Z OBS FREQUENCY %	13.8	14.4	20.2	26.7	13.0	7.8	2.8	1.0	0.5
15Z MES FREQUENCY %	5.2	12.2	19.7	28.2	17.9	11.4	4.2	1.1	0.3
15Z F.M FREQUENCY %	5.1	10.7	18.3	32.5	17.8	10.3	3.8	0.9	0.3
06Z OBS FREQUENCY %	18.7	14.6	19.2	24.1	12.3	7.1	2.6	1.0	0.4
06Z MES FREQUENCY %	5.2	14.3	18.6	25.8	17.9	12.2	4.7	1.1	0.1
06Z F.M FREQUENCY %	4.4	15.6	22.7	29.8	14.8	8.3	3.1	1.1	0.2

TABLE 14a. OBSERVED AND FORECAST WIND SPEED CLIMATOLOGY VT 06Z AND 15Z, FOR PERIOD NOVEMBER TO JANUARY

BEAUFORT FORCE	1	2	3	4	5	6	7	8	9
15Z OBS FREQUENCY %	15.6	19.8	27.4	24.6	8.5	2.9	0.9	0.2	0.2
15Z MES FREQUENCY %	9.7	18.1	26.3	32.2	10.2	3.2	0.3	0.0	0.0
15Z F.M FREQUENCY %	9.8	14.4	27.8	35.6	9.0	2.7	0.7	0.1	0.0
06Z OBS FREQUENCY %	29.1	20.3	22.1	17.4	6.9	3.1	0.7	0.3	0.1
06Z OBS FREQUENCY %	7.6	23.0	26.7	26.9	10.7	4.4	0.6	0.1	0.0
06Z F.M FREQUENCY %	6.9	28.2	29.8	23.2	8.5	2.9	0.5	0.1	0.0

TABLE 14b. OBSERVED AND FORECAST WIND SPEED CLIMATOLOGY VT 06Z AND 15Z FOR FEBRUARY.

3. d) RELATIVE HUMIDITY AND FOG FORECASTS

Surface relative humidity and fog are discussed together in this section since they are closely related. Taking the winter period as a whole, both models had a similar degree of accuracy, with 61% of mesoscale model forecasts of relative humidity for 15 GMT being correct within 10% compared to 63% for the fine-mesh model. However, a moist bias is much more apparent in the mesoscale model forecasts. The results for 15 GMT are given in Table 15 below.

	% FORECASTS CORRECT WITHIN 10%		% FORECASTS MOIST BY > 10%		% FORECASTS MOIST BY > 20%	
MONTH	MES	FM	MES	FM	MES	FM
NOV (T+9 F/C)	55	65	39	23	11	4
DEC (" ")	69	69	24	21	4	4
JAN (" ")	63	61	26	21	7	6
FEB (T+15 F/C)	55	56	38	15	33	12

TABLE 15. ACCURACY OF MODEL SURFACE RELATIVE HUMIDITY FORECASTS FOR 15 GMT NOVEMBER TO FEBRUARY

The worst months for the mesoscale model were November and February when nearly 40% of forecasts were too moist by over 10%. February results were particularly bad, with 1/3 of forecasts being more than 20% too moist. On average during the winter, 32% of mesoscale model forecasts were too moist by more than 10% compared with only 7% being too dry by more than 10%. The fine-mesh model was better balanced; an average 20% of forecasts being too moist by more than 10% compared to 17% being too dry. The two models matched closely during December (wettest month) and January (coldest driest

month) as Table 15 shows. The reason for the excessive moisture in February is not clear, except that we are comparing a 15-hour forecast with 9-hour forecasts. This may indicate an accumulation of excess moisture during the forecast.

The verification results for fog show a similar trend to relative humidity, with the mesoscale model results being much worse for February. Tables 16 a-d are fog contingency tables for the occurrence of dense fog (visibility <250 m), thin fog (visibility 250-1050 m) and no fog (visibility > 1050 m) for verification time 06 GMT.

TABLE 16a NOVEMBER (DT 18 VT 06)

		OBSERVATIONS			
		DENSE FOG	THIN FOG	NO FOG	TOTAL
F/C	DENSE FOG	1.1	1.1	2.7	4.9
	THIN FOG	0.2	0.5	1.5	2.2
	NO FOG	0.9	2.0	89.7	92.6
		2.2	3.6	93.9	99.7

TABLE 16b DECEMBER (DT 18 VT 06)

		OBSERVATIONS			
		DENSE FOG	THIN FOG	NO FOG	TOTAL
F/C	DENSE FOG	0.0	0.0	3.9	3.9
	THIN FOG	0.0	0.0	1.8	1.8
	NO FOG	0.2	0.9	93.2	94.3
		0.2	0.9	98.8	100.0

TABLE 16c JANUARY (DT 18 VT 06)

		OBSERVATIONS			
		DENSE FOG	THIN FOG	NO FOG	TOTAL
F/C	DENSE FOG	0.4	0.7	2.6	3.7
	THIN FOG	0.1	1.3	3.6	5.0
	NO FOG	3.2	4.7	83.4	91.3
		3.7	6.7	89.6	100.0

TABLE 16d FEBRUARY (DT 12 VT 06)

		OBSERVATIONS			
		DENSE FOG	THIN FOG	NO FOG	TOTAL
F/C	DENSE FOG	0.9	0.6	14.1	15.6
	THIN FOG	0.0	0.0	3.8	3.8
	NO FOG	0.3	1.3	78.8	80.4
		1.2	1.9	96.7	99.8

TABLE 16 a-d. CONTINGENCY TABLES FOR THE OBSERVED AND FORECAST (MESOSCALE MODEL ONLY) OCCURRENCE OF FOG AT 06 GMT DURING WINTER 86/87

The observations and forecasts used in the Tables above refer to a subset of low-level inland stations in England and Wales, not to the full set of stations used in the main verification. This has been done in order to try and isolate radiation fog from hill fog. For three of the months, (November, December and February), the model over-predicted the occurrence of fog for 06 GMT. The largest error in the tables occurred in the third column, top row, corresponding to dense fog predicted/no fog observed. For November and December, the over-prediction is small compared to February, when the model forecast 19% of fog but only 3% was observed. The January results were better. In Table 16c, entries in the bottom row, first two columns (corresponding to fog observed but not forecast) slightly exceed entries in the top row, columns 2 and 3 (corresponding to fog forecast but not observed). January was rather a mixed month for fog, with most of it occurring in the dull, somewhat milder period (17th-27th) but some patches of freezing fog also occurred. The figures for February in Table 16d, refer to an 18-hour forecast from DT 12. The excess moisture was apparent at T+12, VT 00 GMT as well, as shown in Table 16e.

FEBRUARY (DT 12 VT 00)

		OBSERVATIONS			
		DENSE FOG	THIN FOG	NO FOG	TOTAL
F/C	DENSE FOG	0.0	0.1	11.5	11.6
	THIN FOG	0.0	0.0	2.5	2.5
	NO FOG	0.3	0.9	84.7	85.9
		0.3	1.0	98.7	100.0

TABLE 16e CONTINGENCY TABLE FOR THE OBSERVED AND FORECAST OCCURRENCE OF FOG AT 00 GMT DURING FEBRUARY 1987.

3. e) CLOUD FORECASTS

In this sub-section, we compare cloud forecasts from both models at two specific times; 06 GMT and 15 GMT. The results from November and December have been combined, since they were similar. Three categories of total cloud amount have been used in the assessment;

B = ≤ 4 octas
P = 4-7 octas
C = > 7 octas

i) Verification time 06 GMT

In Tables 17a and 17b we compare the total cloud amount forecasts and the lowest cloud base forecasts from the two models for 06 GMT during November and December, the two mild, wet months.

		MESOSCALE MODEL						FINE-MESH MODEL			
		OBS						OBS			
		B	P	C				B	P	C	
F/C	B	8	2	4	14	F/C	B	15	6	8	29
	P	3	13	4	10		P	5	3	7	15
	C	17	18	46	76		C	8	9	39	56
		28	18	54				28	18	54	

TABLE 17a. CONTINGENCY TABLE FOR TOTAL CLOUD AMOUNT (EXPRESSED AS A PERCENTAGE AT 06 GMT DURING NOVEMBER AND DECEMBER

	110	310	610	1010	1510	TOTAL LOW CLOUD
% OBSERVED	6	9	13	7	6	41
% MES FCST	16	27	25	3	1	72
% FM FCST	15	8	6	5	2	36

TABLE 17b. FORECASTS OF LOWEST CLOUD BASE ≥ 5 OCTAS FOR A SUBSET OF 30 STATIONS IN UK DURING NOVEMBER AND DECEMBER

The 30 stations used in the cloud base verification shown in Table 17b are those with cloud base recorders, and were chosen for the accuracy of their cloud base observations. The mesoscale model has tended to predict too much total cloud, with the main error being C Forecast/B or P observed. (See Table 17a.) Table 17b shows that the model has predicted too much low cloud (41% obs, 72% forecast), with the excess low cloud being in the bottom three levels. In contrast, the fine-mesh model has predicted total amounts accurately but has too much cloud in the bottom level. This bottom level represents both fog and fine-mesh model level 2 cloud together.

The mesoscale model did better at predicting total cloud amounts in the two cold months, January and February, although the cloud base was still too low. In Tables 18, a and b, we show the results for January for verification time 06 GMT. Total cloud amounts are well-predicted by the mesoscale model but it has still forecast too much cloud in the bottom two

		MESOSCALE MODEL						FINE-MESH MODEL			
		OBS						OBS			
		B	P	C				B	P	C	
F/C	B	13	3	6	22	F/C	B	16	5	17	38
	P	3	2	6	11		P	4	2	16	22
	C	8	6	53	67		C	4	3	33	40
		24	11	65				24	10	66	

TABLE 18a. CONTINGENCY TABLE FOR TOTAL CLOUD AMOUNT (EXPRESSED AS A PERCENTAGE) FOR 06 GMT DURING JANUARY

	110	310	610	1010	1510	TOTAL LOW CLOUD
% OBSERVED	11	13	17	10	3	54
% MES FCST	20	21	17	8	1	67
% FM FCST	18	5	7	5	3	38

TABLE 18b. FORECAST OF LOWEST CLOUD BASE ≥ 5 OCTAS FOR A SUBSET OF 30 STATIONS IN UK DURING JANUARY

levels 110 and 310. The fine-mesh model has a marked deficit of cloud, with the main errors, shown in Table 18a being B/P forecast/C observed. The results for the mesoscale model during the very cold month, January, show a marked improvement on the results for the coldest winter month, (February), last year. [Reference 1.]

		MESOSCALE MODEL OBS				FINE-MESH MODEL OBS			
		B	P	C		B	P	C	
F/C	B	6	4	6	16	11	6	12	29
	P	2	2	5	11	6	4	11	21
	C	14	11	50	75	5	7	38	50
		22	17	61		22	17	61	

TABLE 19a. CONTINGENCY TABLE FOR TOTAL CLOUD AMOUNT (EXPRESSED AS A PERCENTAGE) FOR 06 GMT DURING FEBRUARY

	110	310	610	1010	1510	TOTAL LOW CLOUD
% OBSERVED	11	12	11	15	9	58
% MES FCST	40	22	3	3	1	45
% FM FCST	32	6	3	3	1	45

TABLE 19b. FORECAST OF LOWEST CLOUD BASE ≥ 5 OCTAS FOR A SUBSET OF 30 STATIONS IN UK DURING FEBRUARY

February results, shown in Tables 19a and b above, are similar to those of January. The mesoscale model has predicted total amounts accurately but the base is too low, with an excess of 40% forecast in the bottom two levels. Similarly, the fine-mesh has an overall deficit of cloud, but an excess in the bottom level.

ii) VERIFICATION TIME 15 GMT

These results show a similar trend to the 06 GMT results. The mesoscale model over-predicted total cloud amounts during the two mild wet months, November and December, but was more accurate during the cold, drier months, January and February. Again, cloud base was predicted to be too low. During December, November and February, the model forecast twice as much cloud in the bottom three layers as was observed. The January results were the most accurate overall. This was probably due to the extremes which occurred during the month, i.e. either there was no cloud at all or it was overcast with fog/low stratus.

The major feature from the fine-mesh forecasts was the under-prediction of cloud amount; with the biggest error being P or C observed/B forecast. However, no model convection cloud is included in the verification.

The contingency tables for total cloud amount are shown in Table 20 below. Again, the results for November and December have been combined.

NOV/DEC		MESOSCALE MODEL OBS DT 06 VT 15				FINE-MESH MODEL OBS DT 06 VT 15			
		B	P	C		B	P	C	
F/C	B	6	4	5	15	11	11	14	36
	P	3	3	6	12	2	3	8	13
	C	7	15	51	73	3	8	40	51
		16	22	62		16	22	62	

JAN		MESOSCALE MODEL OBS DT 06 VT 15				FINE-MESH MODEL OBS DT 06 VT 15			
		B	P	C		B	P	C	
F/C	B	13	4	7	24	10	11	11	32
	P	1	2	8	11	1	4	8	13
	C	5	8	52	65	2	9	44	55
		19	14	67		13	24	63	

FEB		MESOSCALE MODEL OBS DT 06 VT 15					FINE-MESH MODEL OBS DT 06 VT 15			
		B	P	C			B	P	C	
F/C	B	6	7	6	19	B	16	9	22	47
	P	3	5	8	16		2	2	13	17
	C	4	13	48	65	C	2	4	30	36
		13	25	62			20	15	65	

TABLE 20. CONTINGENCY TABLES FOR TOTAL CLOUD AMOUNT (EXPRESSED AS A PERCENTAGE) AT 15 GMT DURING PERIOD NOVEMBER-FEBRUARY 1987

Overall cloud amounts were better forecast by the mesoscale model, with an average 62% correct forecasts compared to 53% for the fine mesh model, for the whole 4 month period. Cloud base results for 15 GMT are shown in Table 21 below.

	110	310	610	1010	1510	TOTAL LOW CLOUD
NOV/DEC						
% OBSERVED	5	10	14	6	4	39
% MES FCST	10	26	25	4	1	66
% FM FCST	4	9	6	6	2	27
JAN						
% OBSERVED	9	17	18	11	3	60
% MES FCST	13	24	23	7		68
% FM FCST	7	7	7	5	2	28
FEB						
% OBSERVED	8	10	12	15	11	56
% MES FCST	14	27	21	5	3	70
% FM FCST	14	8	2	3	3	30

TABLE 21. FORECAST OF LOWEST CLOUD BASE ≥ 5 OCTAS FOR A SUBSET OF 30 STATIONS IN UK

This table shows the excess cloud at 310 m and 610 m predicted by the mesoscale model. The differences between the models are clearly shown in the Table. The mesoscale model has predicted an excess of low cloud (average 16%) whereas the fine-mesh model has a substantial deficit (average 24%).

4. SUBJECTIVE VERIFICATION RESULTS

Subjective verification is important since it shows how accurate the mesoscale model forecasts are in comparison with those prepared by human forecasters. It gives an indication of the usefulness of the model forecasts in different synoptic situations. Two different methods of subjective assessment are described in this section.

i) BRACKNELL LOCAL AREA FORECAST

During the period November 1 to February 4, only the mesoscale model morning forecasts, covering the period 06-24, were tested against CFO forecasts. A special Bracknell local area forecast covering the period 09-24 was prepared daily in CFO using the mesoscale model output alone. This forecast was compared with a similar one issued by the British Isles Forecaster using only fine-mesh model guidance. With effect from 12 GMT, February 4, the starting times of mesoscale model forecasts were changed to 00 GMT and 12 GMT. Since then, both forecasts (covering the periods 03-18 and 15-06) have been included in the daily accuracy check against CFO forecasts. In the assessment, each forecast period was sub-divided into five three-hour sections, during which forecasts of temperature, wind, weather and cloud were compared. The results are described below.

a) TEMPERATURE FORECASTS

The accuracy of the CFO and mesoscale model temperature forecasts are compared in Table 22a, which shows the percentage of forecasts correct within 2° degrees Celsius.

D.T. 06 GMT	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
NOVEMBER	93	93	97	90	83	80	80	70	67	83
DECEMBER	100	100	100	100	96	86	86	71	79	68
JANUARY	93	93	93	93	87	84	87	83	90	83

D.T. 00 GMT	VT 6 GMT		VT 9 GMT		VT 12 GMT		VT 15 GMT		VT 18 GMT	
FEBRUARY	87	100	92	87	96	96	96	92	100	92
D.T. 12 GMT	**VT 18 GMT**		**VT 21 GMT**		**VT 00 GMT**		**VT 03 GMT**		**VT 06 GMT**	
FEBRUARY	92	100	92	92	92	84	68	76	76	76

TABLE 22a. PERCENTAGE OF BRACKNELL TEMPERATURE FORECASTS CORRECT WITHIN 2 DEGREES CELSIUS

During the November to January period, the mesoscale model forecast temperatures compared very favourably with the CFO forecasts, with an overall accuracy of 89% compared to 86%. This small difference is equivalent to one extra temperature forecast per month reaching the desired

accuracy. The mesoscale model was less accurate only for VT 00 GMT in November, when the model was too warm by an average 1.5 degrees celsius due to forecasting too many occasions of fog and low cloud. CFO, on the other hand, tended to forecast too many clear periods for this time and their temperatures tended to be too low by an average 0.7 degrees Celsius.

In Table 22b, we summarise the percentage of occasions on which the CFO forecast was more accurate than the mesoscale model forecast and vice-versa for the period November to January.

VERIFICATION TIME	12 GMT	15 GMT	18 GMT	21 GMT	00 GMT	OVERALL
CFO MORE ACCURATE	26%	27%	36%	37%	38%	33%
FORECASTS EQUAL	41%	31%	28%	29%	18%	29%
MES. MORE ACCURATE	33%	42%	36%	34%	43%	38%

TABLE 22b. COMPARATIVE ACCURACY OF CFO AND MESOSCALE MODEL TEMPERATURES FOR BRACKNELL DURING THE PERIOD NOVEMBER TO JANUARY

This table confirms the impression that the mesoscale model temperature forecasts were at least as good as CFO's for Bracknell during the given period. The corresponding figures for February are given separately in Table 22c below.

VERIFICATION TIME	06 GMT	09 GMT	12 GMT	15 GMT	18 GMT	OVERALL
CFO MORE ACCURATE	37%	29%	29%	25%	21%	28%
FORECASTS EQUAL	42%	38%	42%	58%	42%	44%
MES MORE ACCURATE	21%	33%	29%	16%	37%	27%

VERIFICATION TIME	18 GMT	21 GMT	00 GMT	03 GMT	06 GMT	OVERALL
CFO MORE ACCURATE	48%	48%	24%	36%	28%	37%
FORECAST EQUAL	36%	24%	40%	28%	20%	30%
MES MORE ACCURATE	16%	28%	36%	36%	52%	33%

TABLE 22c. COMPARATIVE ACCURACY OF CFO AND MESOSCALE MODEL TEMPERATURES FOR BRACKNELL DURING FEBRUARY 1987

The February temperature forecasts were close in overall accuracy. For both the mesoscale model and CFO, the least accurate forecasts were those verifying at 03 GMT and 06 GMT. The model was better on cloudy nights, CFO better on the clearer nights.

b) WIND FORECASTS

The comparison between CFO and mesoscale wind forecasts for Bracknell is shown in Table 23a. The criteria used to judge which forecast was more accurate is described below:

The CFO forecast was more accurate if the magnitude of the mesoscale model wind vector error > 5 KT larger than the magnitude of the CFO wind vector error, and vice-versa.

FORECAST PERIOD	09-12	12-15	15-18	18-21	21-00	OVERALL
CFO MORE ACCURATE	16%	11%	14%	16%	21%	16%
FORECASTS SAME	69%	74%	72%	73%	68%	71%
MES MORE ACCURATE	15%	15%	14%	11%	11%	13%

TABLE 23a. SUBJECTIVE ASSESSMENT OF THE ACCURACY OF CFO AND MESOSCALE MODEL WIND FORECASTS FOR BRACKNELL DURING THE PERIOD NOVEMBER TO JANUARY

Overall, as Table 23a shows, there was very little to choose between the wind forecasts issued by CFO and the mesoscale model, except possibly during the early part of the night (21-00) when the mesoscale forecast wind tended to be too strong on occasions. The corresponding figures for February are shown in Table 23b below.

FORECAST PERIOD	03-06	06-09	09-12	12-15	15-18	OVERALL
CFO MORE ACCURATE	29%	21%	0%	17%	17%	17%
FORECASTS SAME	58%	75%	92%	66%	66%	71%
MES MORE ACCURATE	13%	4%	8%	17%	17%	12%

FORECAST PERIOD	15-18	18-21	21-00	00-03	03-06	OVERALL
CFO MORE ACCURATE	16%	16%	20%	16%	20%	18%
FORECASTS SAME	76%	80%	80%	80%	80%	79%
MES MORE ACCURATE	8%	4%	0%	4%	0%	3%

TABLE 23b. SUBJECTIVE ASSESSMENT OF THE ACCURACY OF CFO AND MESOSCALE MODEL WIND FORECASTS FOR BRACKNELL DURING FEBRUARY

Again, these results show that CFO tend to be more accurate during the night period 21-09 due to the model forecast wind speed being too strong.

c) FORECASTS OF CLOUD AMOUNT

Cloud forecasts are given in three categories only:

B (0-4 octas) to represent clear/sunny periods,

P (5-6 octas) to represent partial cloudiness,

C (7-8 octas) to represent cloudy/overcast periods.

Table 24a shows the results of the subjective assessment of the accuracy of CFO and mesoscale model cloud forecasts for Bracknell in three-hour sections during the period November to January.

FORECAST PERIOD	09-12	12-15	15-18	18-21	21-00
CFO MORE ACCURATE	13%	18%	25%	24%	33%
FORECASTS SAME	68%	62%	59%	52%	48%
MES MORE ACCURATE	19%	20%	16%	24%	19%

TABLE 24a. SUBJECTIVE ASSESSMENT OF THE ACCURACY OF CLOUD FORECASTS FOR BRACKNELL DURING THE PERIOD NOVEMBER TO JANUARY

There was little to choose between the two sets of forecasts during the early stages, but CFO were better on more occasions during the early part of the night. (21-00Z). For the mesoscale model, the accuracy of cloud forecasts decreased with time; with the best results in the driest coldest month January. This is shown by the results in Table 19b.

	NOVEMBER		DECEMBER		JANUARY	
PERIOD	MES	CFO	MES	CFO	MES	CFO
09-12	63	63	72	69	81	69
12-15	65	67	65	62	79	66
15-18	61	60	50	61	66	73
18-21	64	59	48	45	63	63
21-00	51	59	48	63	55	55

TABLE 24b. PERCENTAGE OF CORRECT CLOUD FORECASTS AT 3-HOURLY INTERVALS DURING PERIOD NOVEMBER TO JANUARY

The least accurate time for the mesoscale model was the period 21-00Z; especially during November and December, when the model forecast too many cloudy periods. [% cloud cover 7-8 octas: obs 53, MES F/C 79, CFO F/C 42]. The CFO forecasters erred in the opposite direction by forecasting the cloud to break too early on many occasions. The observed and forecast cloud climatologies for the period November to January are shown in Table 24c for the time periods 12-15 and 21-00.

	12-15			21-00		
	B	P	C	B	P	C
% OBS	21	19	60	24	17	58
% MES F/C	17	23	60	13	16	71
% CFO F/C	22	28	50	36	21	43

TABLE 24c. OBSERVED AND FORECAST CLOUD CLIMATOLOGIES FOR PERIODS 12-15 AND 21-00 NOVEMBER-JANUARY

Table 24c shows the tendency for the mesoscale model to forecast too much cloud during the night period 21-00, although the cloud climatology is correct for the afternoon period 12-15. In contrast, CFO forecast too few cloudy periods.

The corresponding cloud results for February are shown in Table 25a, b, c below.

FORECAST PERIOD	03-06	06-09	09-12	12-15	15-18
CFO MORE ACCURATE	33%	29%	37%	25%	25%
MES MORE ACCURATE	13%	21%	21%	25%	25%

FORECAST PERIOD	15-18	18-21	21-00	00-03	03-06
CFO MORE ACCURATE	20%	16%	16%	20%	24%
MES MORE ACCURATE	20%	20%	28%	16%	24%

TABLE 25a. SUBJECTIVE ASSESSMENT OF CLOUD FORECASTS FOR FEBRUARY

00-18 FORECAST			12-06 FORECAST		
PERIOD	MES	CFO	PERIOD	MES	CFO
03-06	45	73	15-18	70	66
06-09	64	65	18-21	78	70
09-12	68	71	21-00	74	60
12-15	64	63	00-03	64	56
15-18	67	58	03-06	56	56

TABLE 25b. PERCENTAGE OF CORRECT CLOUD FORECASTS DURING FEBRUARY

	15-18			03-06		
	B	P	C	B	P	C
% OBS	8	12	80	26	16	58
% MES F/C	12	15	73	10	0	90
% CFO F/C	16	39	44	24	20	56

TABLE 25c. OBSERVED AND FORECAST CLOUD CLIMATOLOGIES FOR PERIODS 12-15 AND 03-06 DURING FEBRUARY

During February, the overall accuracy of cloud forecasts from the mesoscale model compared well with those from CFO. Again, the errors were similar to those seen in the three earlier months. Table 25c shows that for the period 15-18 the mesoscale model predicted cloud amounts well, whilst CFO under-predicted amounts. The reverse occurred for the period 03-06, with the mesoscale model over-predicting amounts, whilst CFO predicted amounts well.

d) WEATHER FORECASTS

Table 26a gives the results of the subjective assessment of weather forecasts from CFO and the mesoscale model during the period November to January.

	09-12	12-15	15-18	18-21	21-00
CFO MORE ACCURATE	18%	12%	19%	16%	21%
MES MORE ACCURATE	20%	18%	14%	15%	10%
CFO % CORRECT FCSTS	76%	77%	72%	69%	72%
MES % CORRECT FCSTS	82%	77%	66%	62%	62%

TABLE 26a. SUBJECTIVE ASSESSMENT OF WEATHER FORECASTS FOR BRACKNELL FROM CFO AND THE MESOSCALE MODEL NOVEMBER-JANUARY

In general, the mesoscale model weather forecasts compared well with those from CFO. The most common error from both was the forecasting of light precipitation when none was observed. In fact, this was the chief error from CFO. However, CFO were better during the evening due to the mesoscale model forecasting fog when none was observed.

The results for February are shown in Table 26b below.

	03-06	06-09	09-12	12-15	15-18
CFO MORE ACCURATE	25%	25%	21%	29%	12%
MES MORE ACCURATE	17%	17%	14%	15%	10%
CFO % CORRECT FCSTS	71%	75%	83%	87%	52%
MES % CORRECT FCSTS	67%	67%	75%	58%	60%
	15-18	18-21	21-00	00-03	03-06
CFO MORE ACCURATE	24%	32%	24%	24%	28%
MES MORE ACCURATE	12%	4%	8%	8%	8%
CFO % CORRECT FCSTS	64%	84%	76%	72%	64%
MES % CORRECT FCSTS	60%	62%	58%	58%	44%

TABLE 26b. SUBJECTIVE ASSESSMENT OF WEATHER FORECASTS FOR BRACKNELL FROM CFO AND THE MESOSCALE MODEL - FEBRUARY

During February, CFO were more accurate in forecasting the weather for all periods except 15-18. The two major mesoscale model errors were:

a) Dry period forecast/light precipitation observed.

b) Fog forecast/no fog observed (mainly overnight).

The main CFO error was again in forecasting light precipitation too often.

ii) TEMPERATURE FORECASTS TO THE GAS INDUSTRY

A useful way of assessing the accuracy and reliability of model temperature forecasts is to see how well they compare with temperature forecasts issued by Weather Centres to the Gas Industry for a period up to 18 hours ahead. Temperatures taken from the mesoscale and fine-mesh model forecasts for 7 stations were compared with those issued by forecasters at the respective Weather Centres. The results for the four months, November to February are given in Tables 27 a-d below.

% FORECAST CORRECT WITHIN 2 DEG C	DT 18Z VT 09Z WC ISSUE 0030Z			DT 06Z VT 15Z WC ISSUE 0830Z		
STATION	FCR	MES	FM	FCR	MES	FM
GLASGOW	60	76	56	83	93	72
SOUTHAMPTON	87	84	68	93	90	83
WATNALL	83	56	96	96	97	79

TABLE 27a. COMPARISON BETWEEN MODEL TEMPERATURE FORECASTS FOR 09Z, 15Z DURING NOVEMBER AND CORRESPONDING TEMPERATURE FORECASTS ISSUED BY WEATHER CENTRES

% FORECAST CORRECT WITHIN 2 DEG C	DT 18Z VT 09Z WC ISSUE 0030Z			DT 06Z VT 15Z WC ISSUE 0830Z		
STATION	FCR	MES	FM	FCR	MES	FM
GLASGOW	82	76	83	82	86	79
LWC	92	72	66	92	93	64
RHOOSE	72	62	79	81	89	96
SOUTHAMPTON	79	69	69	93	96	89
WATNALL	81	62	76	90	96	96

TABLE 27b. COMPARISON BETWEEN MODEL TEMPERATURE FORECASTS FOR 09Z, 15Z DURING DECEMBER AND CORRESPONDING TEMPERATURE FORECASTS ISSUED BY WEATHER CENTRES

% FORECAST CORRECT WITHIN 2 DEG C	DT 18Z VT 09Z WC ISSUE 0030Z			DT 06Z VT 15Z WC ISSUE 0830Z		
STATION	FCR	MES	FM	FCR	MES	FM
GLASGOW	73	63	65	93	90	69
LWC	96	55	43	86	68	59
NEWCASTLE	86	79	82	81	77	76
RHOOSE	89	31	71	93	68	62
SOUTHAMPTON	80	77	72	81	87	76
WATNALL	86	93	79	96	90	89

TABLE 27c. COMPARISON BETWEEN MODEL TEMPERATURE FORECASTS FOR 09Z, 15Z DURING JANUARY AND CORRESPONDING TEMPERATURE FORECASTS ISSUED BY WEATHER CENTRES.

% FORECAST CORRECT WITHIN 2 DEG C	DT 00Z VT 15Z WC ISSUE 00Z			DT 12Z VT 03Z WC ISSUE 1530Z		
STATION	FCR	MES	FM	FCR	MES	FM
GLASGOW	79	54	33	77	64	60
LWC	77	79	67	100	72	36
MANCHESTER	82	83	58	73	64	68
NEWCASTLE	77	75	67	-	88	64
RHOOSE	80	96	92	70	56	92
SOUTHAMPTON	79	96	75	77	76	92
WATNALL	79	87	67	-	80	68

TABLE 27d. COMPARISON BETWEEN MODEL TEMPERATURE FORECASTS FOR 15Z AND 03Z DURING FEBRUARY AND CORRESPONDING TEMPERATURE FORECASTS ISSUED BY WEATHER CENTRES TO THE GAS INDUSTRY

5. CONCLUSIONS

a) Maximum temperatures were very well predicted by the mesoscale model during last winter, with an average 87% of forecasts being correct within 2 degrees Celsius.

Minimum temperatures were less well predicted, with an average 60% of forecasts being correct within 2 degrees Celsius. The model had an overall warm bias of 1.5 degrees Celsius for minimum temperature forecasts. This warm bias could be associated with an excess of low cloud in the overnight

forecasts and it was larger in the mild, wet months. In January, when the model predicted clear skies correctly, the very low temperatures were forecast well.

In the subjective comparison, model daytime temperature forecasts compared quite well with temperature forecasts issued by CFO for Bracknell and by Weather Centres for the Gas Board Industry. However, for overnight temperatures, the forecasters were slightly more accurate.

b) Peak rainfall accumulations over high ground were better forecast by the mesoscale model than the fine-mesh due to more detailed orography. However, the mesoscale model still over-predicted amounts of rain in the east over low ground and the fine-mesh was more reliable. The excess of convective rain was less marked than in the summer months, although it was the cause of the mesoscale model forecasting twice as much rain as observed along the east coast in January. Significant amounts of rain (≥ 5 mm in 12-hour period) were more often forecast by the mesoscale model but with no more accuracy than the fine-mesh model. [≥ 5 mm of rain were observed on 10% of occasions. The mesoscale model forecast ≥ 5 mm of rain on 12% of occasions but was only correct on 5%. The corresponding figures for the fine-mesh model were 10% and 5%.]

c) Mesoscale model cloud forecasts during the cold spell in January were generally quite good. In this, the model's performance was far better than in the corresponding coldest spell during February 1986. However, the model was still too moist in the boundary layer and generated too much low cloud, particularly in the milder months.

REFERENCES

1. MET.O.11 TECHNICAL NOTE NR.234
Results from the Mesoscale Model Trial from February to April 1986
O.Hammon 1986

LIST OF FIGURES.

DISTRIBUTION OF MAXIMUM TEMPERATURE R.M.S ERRORS FOR JANUARY 1987 - MESOSCALE MODEL

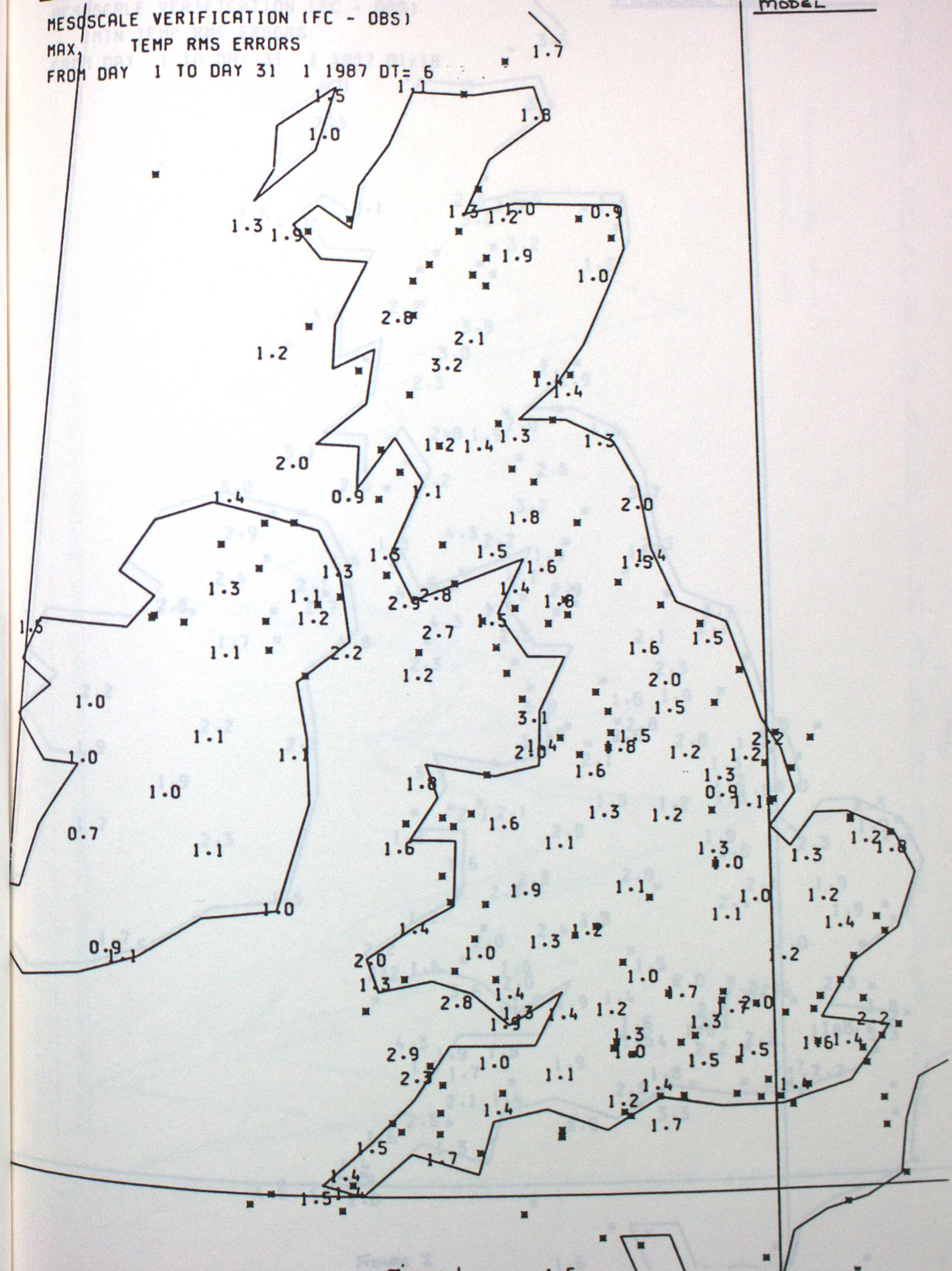


FIGURE 1.

Distribution of Minimum Temperature R.M.S Errors for January 1987 – Mesoscale Model

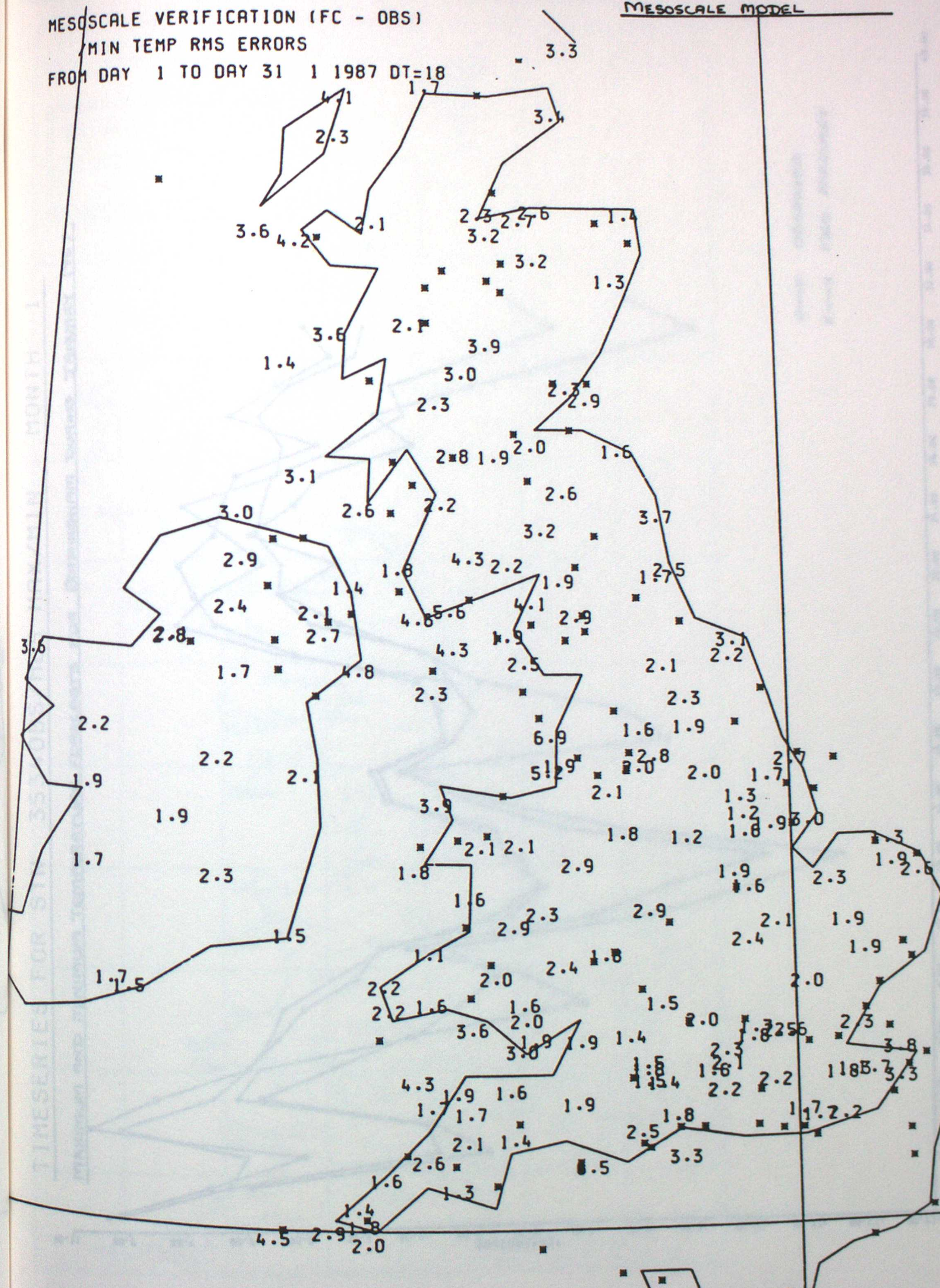


Figure 2

TIMESERIES FOR STN 3534OBS/MES MAX/MIN MONTH 1

MAXIMUM AND MINIMUM TEMPERATURE FORECASTS FOR BIRMINGHAM DURING JANUARY 1987

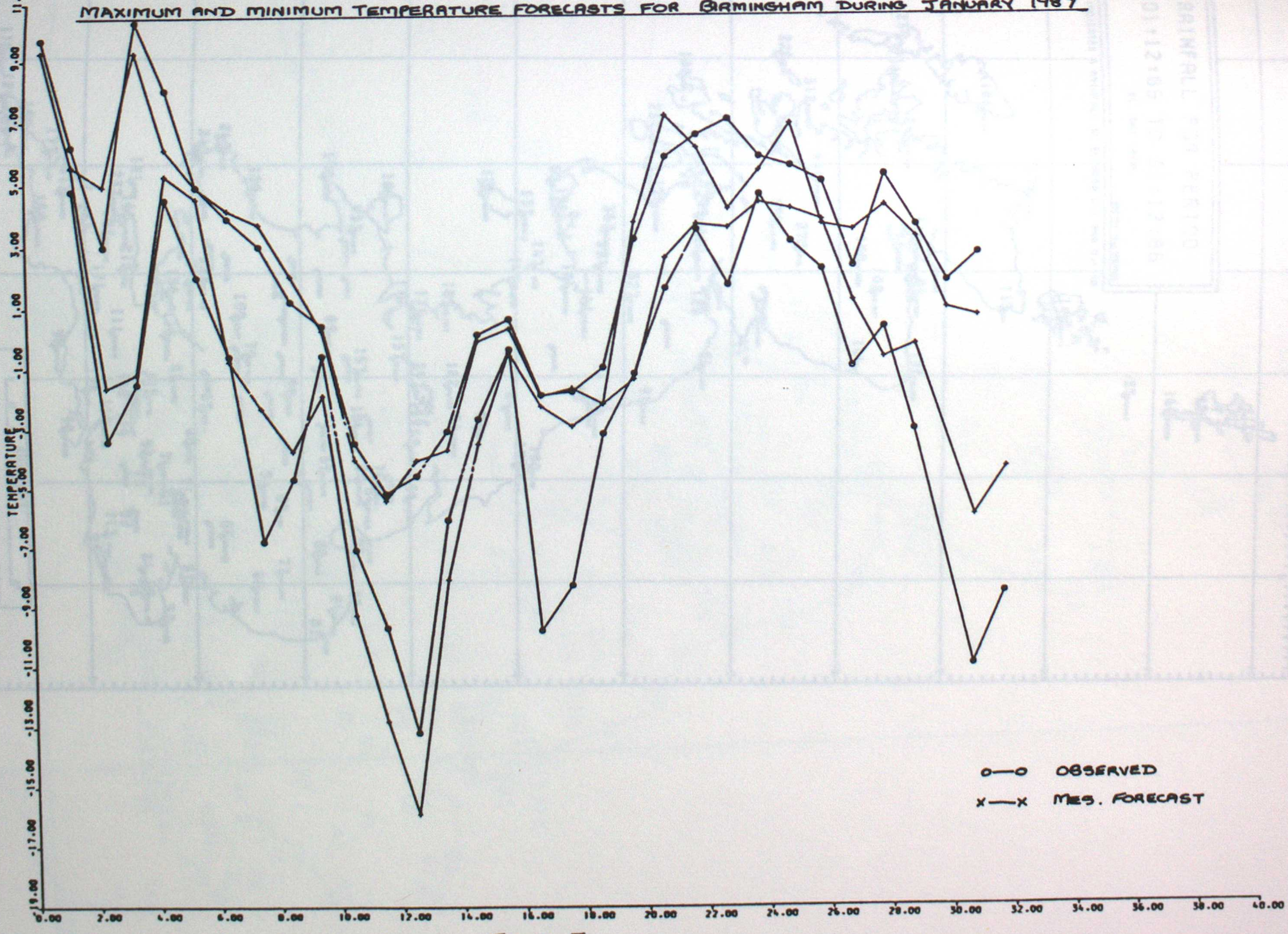


FIGURE 3.

OBSERVED RAINFALL ACCUMULATIONS FOR DECEMBER 1986

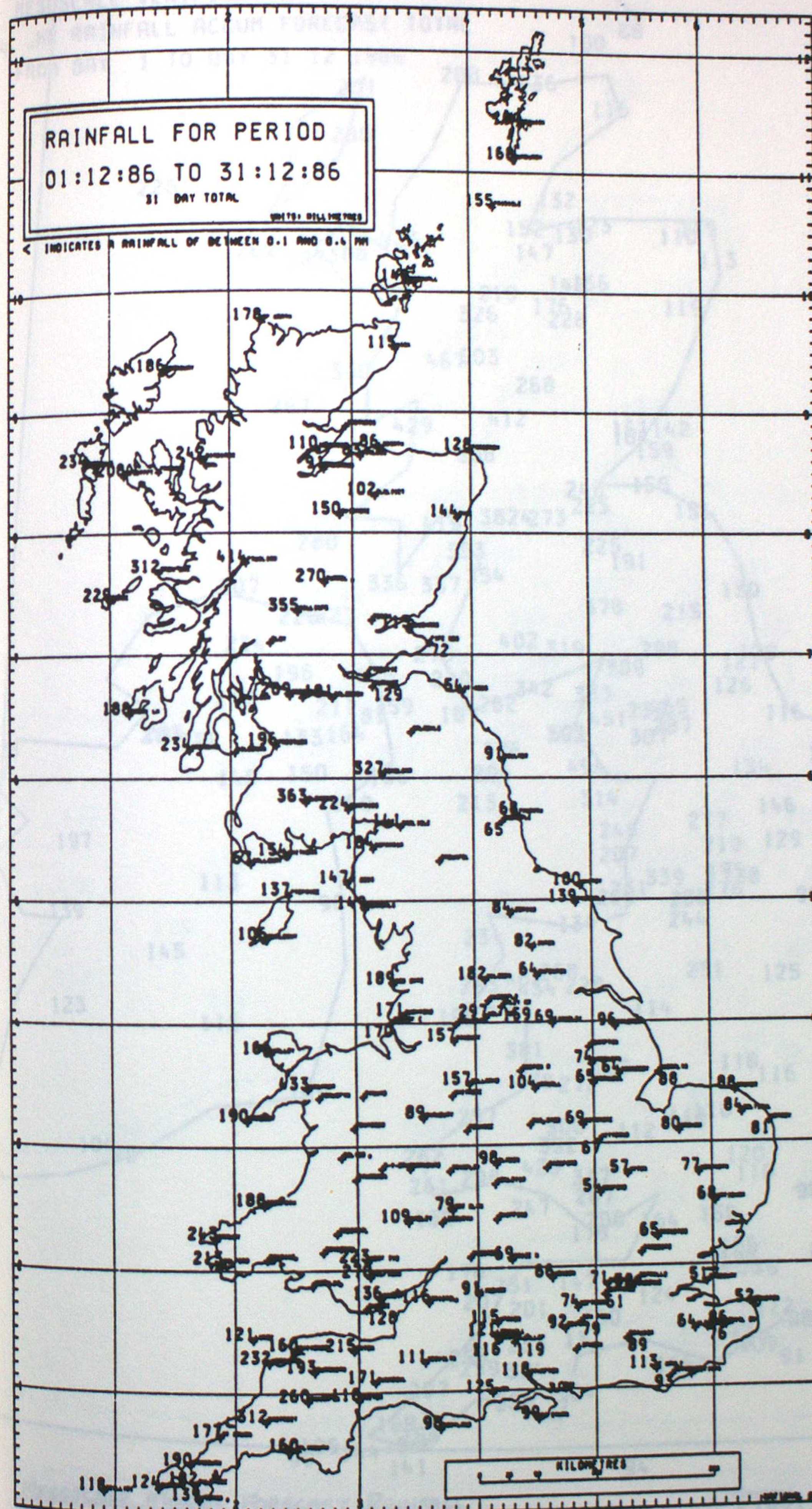
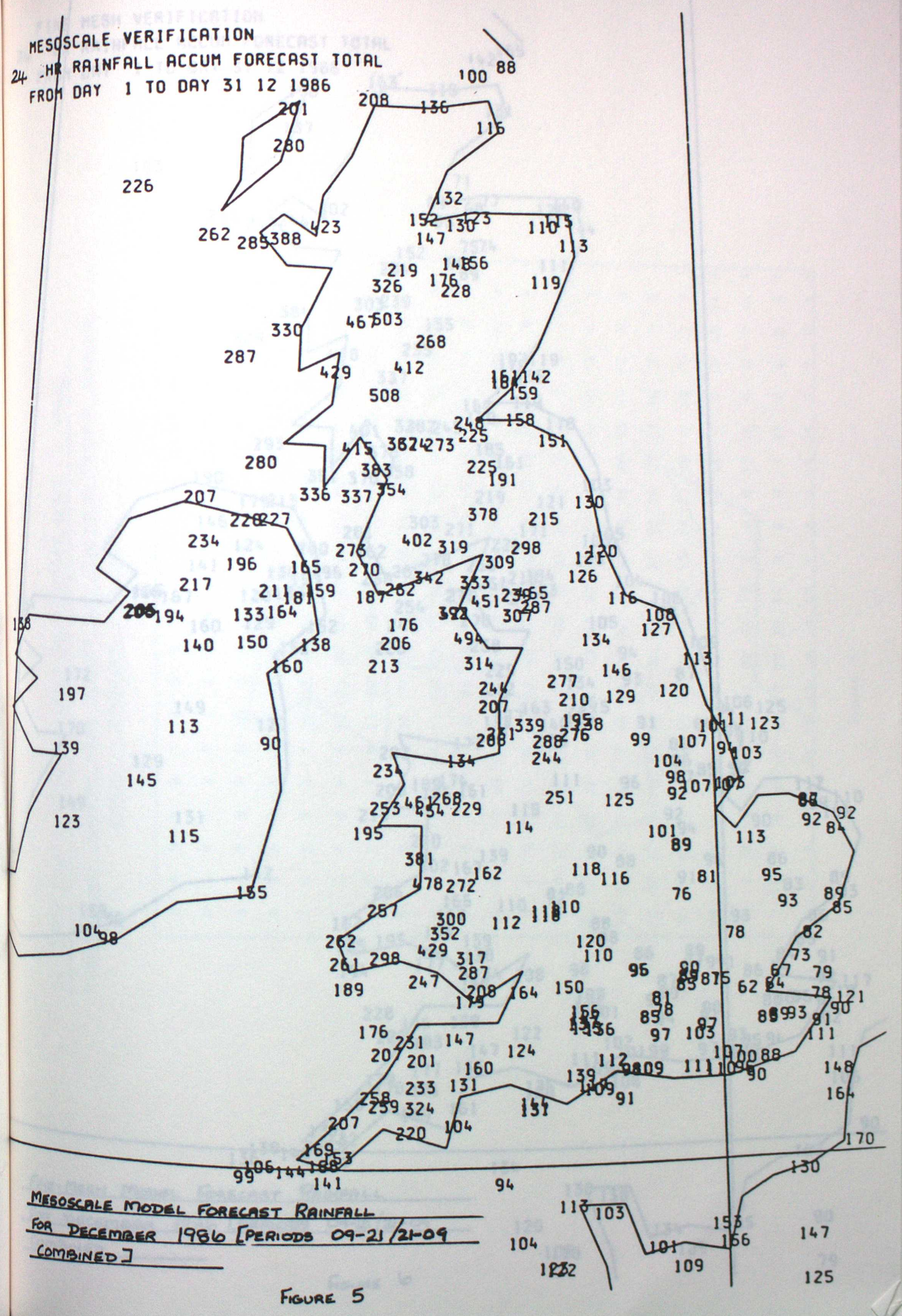


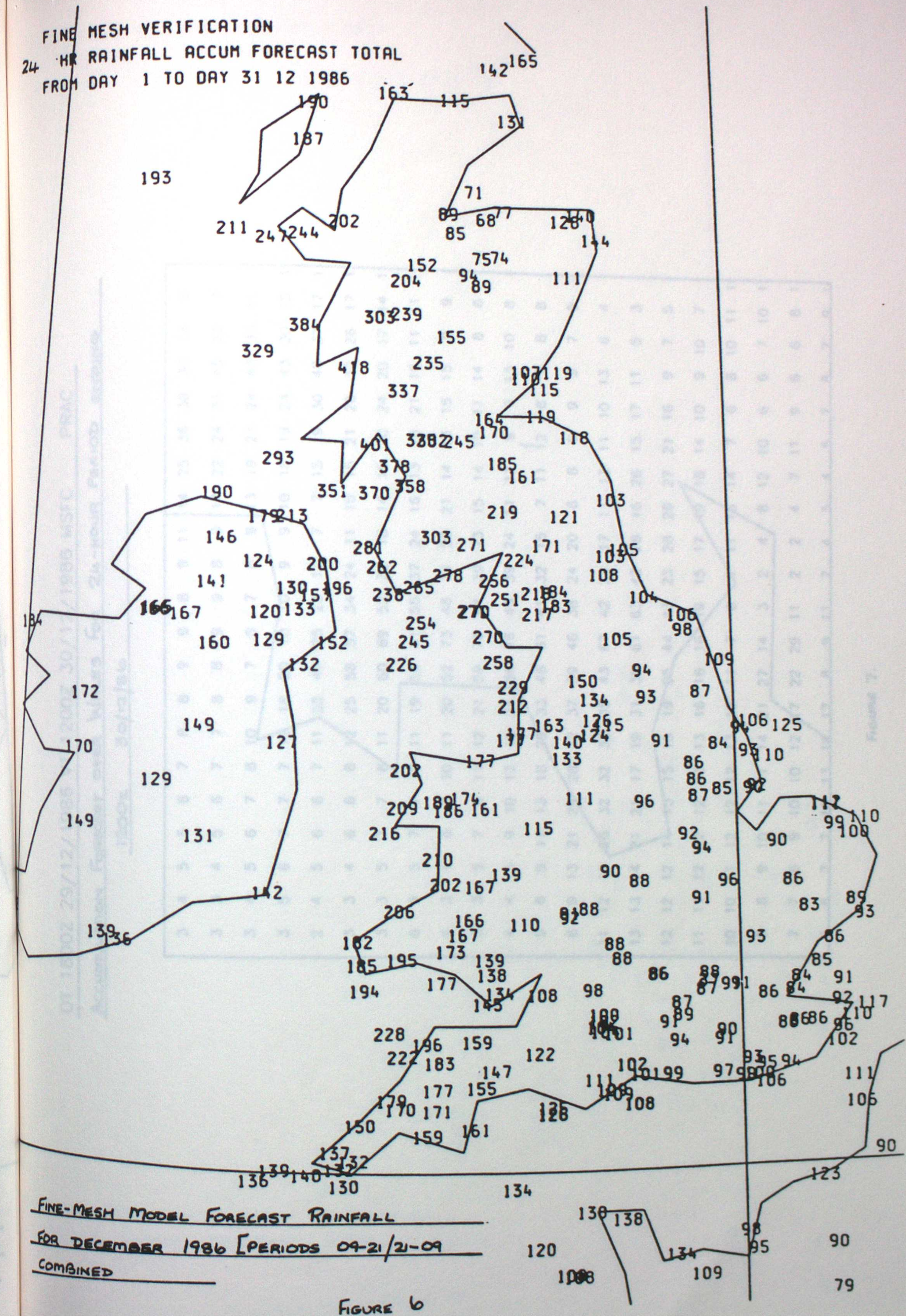
FIGURE 4

MESOSCALE VERIFICATION
24 HR RAINFALL ACCUM FORECAST TOTAL
FROM DAY 1 TO DAY 31 12 1986



Mesoscale Model Forecast Rainfall
for December 1986 [Periods 09-21 / 21-09 combined]

Figure 5



FINE-MESH MODEL FORECAST RAINFALL FOR DECEMBER 1986 [PERIODS 09-21/21-09 COMBINED]

FIGURE 6

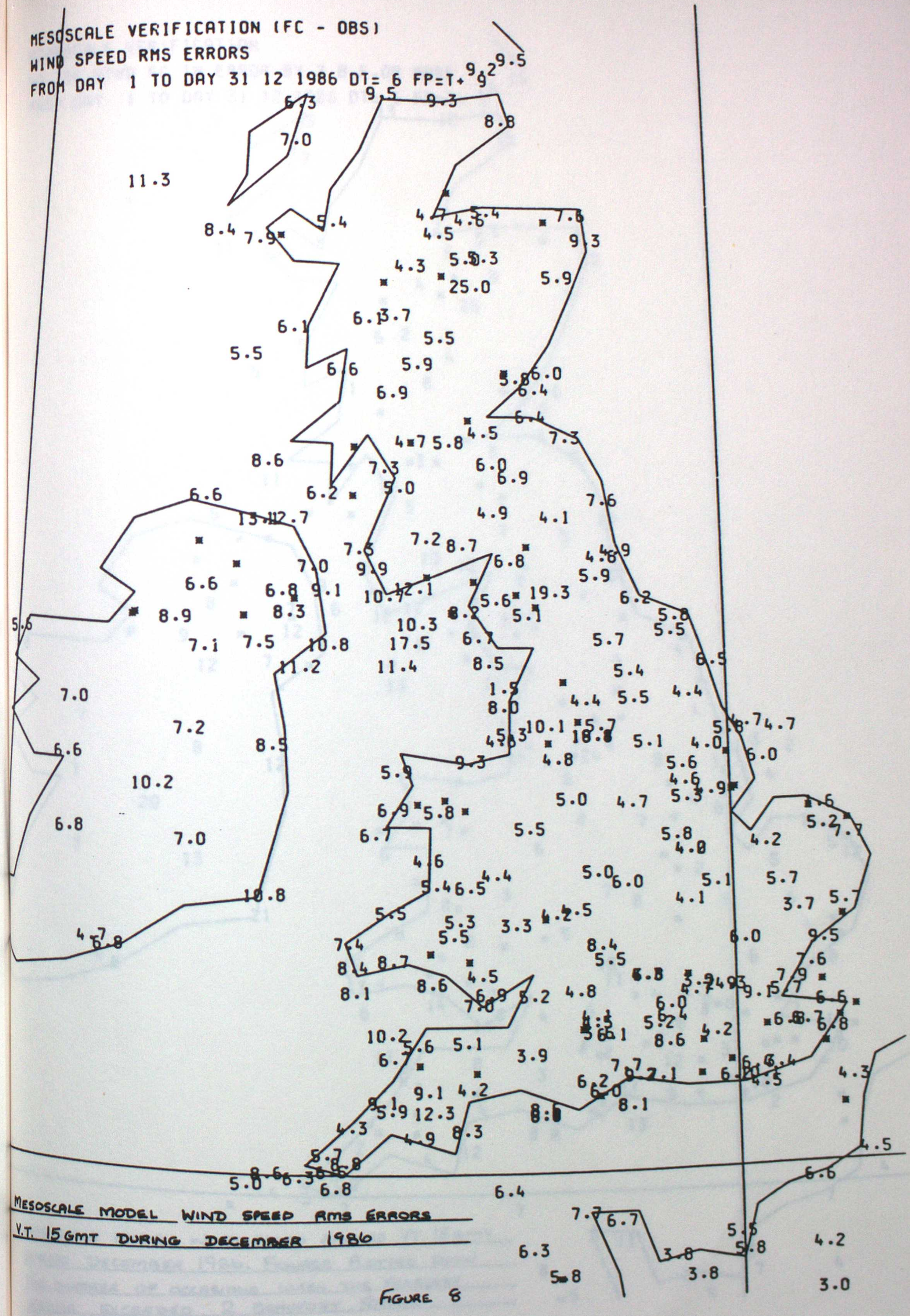
DT 1800Z 29/12/1986 VT 1200Z 30/12/1986 MSFC PRAC

ACCUMULATION FORECAST OVER WALES FOR 24-HOUR PERIOD ENDING

1200z 30/12/86

3	4	5	5	6	7	8	8	9	9	8	9	11	14	25	36	38	33	14	8	
3	3	4	5	6	7	7	8	8	9	9	8	9	14	22	24	31	45	22	7	
3	4	5	6	7	8	10	9	7	8	7	8	9	13	19	21	24	43	33	11	
3	5	6	7	7	7	12	18	20	10	10	9	9	10	16	19	24	43	30	15	1
2	4	5	6	6	7	11	32	47	25	23	11	7	7	15	19	30	48	37	17	1
3	3	4	6	6	8	12	25	58	57	34	24	11	10	15	21	28	32	26	17	1
3	3	5	7	7	8	11	20	60	69	52	32	18	14	15	20	24	20	17	14	1
6	5	5	7	7	9	11	19	56	61	55	37	24	16	13	18	21	16	11	11	1
4	3	4	6	7	10	11	20	52	73	46	31	25	21	14	13	15	15	9	9	
3	3	5	7	8	11	12	21	59	78	44	39	23	15	14	10	11	14	8	8	
4	4	6	9	10	12	15	24	56	76	45	39	24	11	11	9	9	13	10	8	
5	6	9	11	13	18	29	33	46	61	41	32	15	7	11	12	8	9	8	8	
8	9	13	21	29	28	32	37	39	46	38	24	20	6	8	9	9	9	7	5	
11	12	16	26	32	32	32	35	43	67	42	22	17	11	13	11	10	13	6	4	
13	13	14	21	21	17	19	31	38	61	63	42	28	16	26	15	17	11	5	3	
12	12	12	14	15	15	15	19	25	44	43	23	28	26	27	21	16	9	7	5	
11	11	12	12	12	13	13	16	16	16	19	15	17	19	18	14	10	9	10	7	
10	10	11	12	12	12	13	15	14	7	6	7	11	16	14	7	6	8	10	11	1
8	8	9	10	11	11	14	21	27	14	3	2	4	8	12	10	6	6	7	10	1
7	7	8	9	10	10	12	17	22	29	11	2	2	4	7	11	9	6	6	8	1
5	6	7	7	10	13	18	12	8	9	11	7	4	3	4	5	7	8	7	9	1

FIGURE 7.



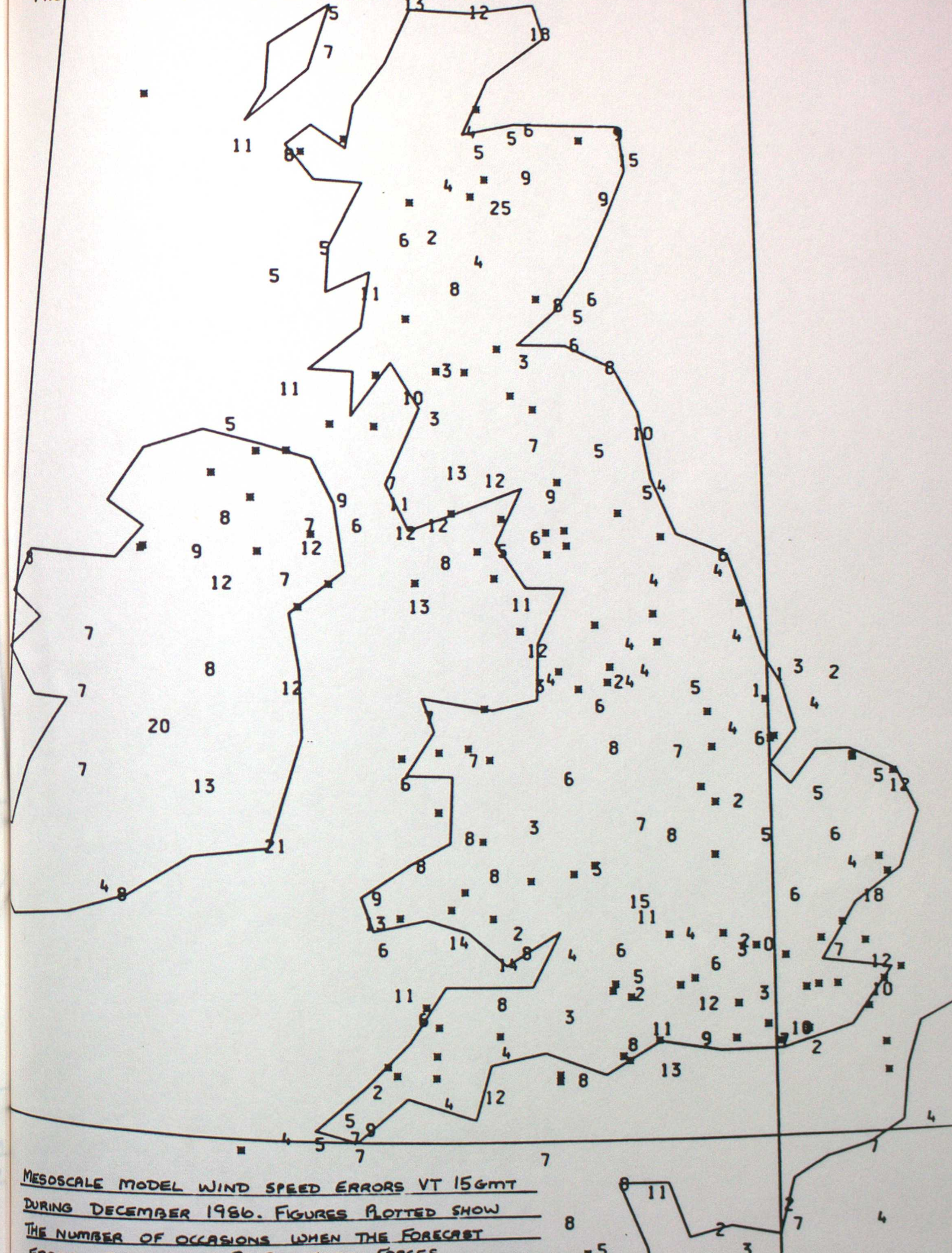
Mesoscale Model Wind Speed RMS Errors
V.T. 15GMT during December 1986

Figure 8

MESOSCALE VERIFICATION

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

FROM DAY 1 TO DAY 31 12 1986 DT= 6 FP=T+ 9



Mesoscale model wind speed errors VT 15GMT during December 1986. Figures plotted show the number of occasions when the forecast error exceeded 2 Beaufort forces

Figure 9