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Met.O.11 Technical Note No. 235

Snow forecast from NWP models during the winter
1985/86.

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SNOW FORECASTS FROM NWP MODELS DURING THE WINTER 1985/86

1. INTRODUCTION

The aim of this report is to provide a summary of the snow forecasts given to forecasters from the numerical models in the winter 1985/86 and to highlight any model or predictor deficiencies. The SNOW FORECASTS FROM THE FINE MESH MODEL AND MESOSCALE MODEL DURING THE WINTER 1985/86 are evaluated. The two models assessed in this report are the fine mesh model and the mesoscale model.

In section 2, we shall concentrate on the quality of forecasts from the fine mesh in some situations. The precipitation scheme used in the fine mesh model has been described by Dickinson. Successful guidance depends upon accurate forecasting not only of the area of precipitation but also of the chosen predictor. In section 2.1, we shall concentrate on assessing the accuracy and usefulness of a variety of snow predictors using fine mesh output. The eleven forecasts mentioned above were run up to obtain extra information on forecast temperatures and humidities in the lowest four levels of the model. In section 2.2, a cross-section of fine mesh snow forecasts, good and bad, are described.

by Olive Hammon

In section 3, we will describe the forecasting of snow by the mesoscale model. First, in section 3.1, some objective verification results on precipitation will be given. Snow forecasts from the mesoscale model are compared with those from the fine mesh model in section 3.2 and the accuracy and usefulness of the more detailed short range forecast are assessed. The precipitation scheme used in the mesoscale model is described by Collins.

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2. FINE MESH SNOW FORECASTS

The operational fine mesh model output for snow is given by the 50%, 60% and 70% snow probability lines, which are based upon the 1000-850 mb layer mean temperature for both sea level pressure. In a similar way, the 1000-850 mb layer mean temperature was found to be slightly inaccurate.

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However, during December 1985, a deep soil climatology scheme was added to the fine mesh model and this resulted in a marked improvement in forecast temperatures in the model's boundary layer. This encouraged us to repeat the verification for the winter 1985/86 in order to judge whether the model's low level and boundary profiles were now accurate enough to provide useful guidance in snow situations. In section 2.1 we assess the accuracy and usefulness of various snow predictors using the fine mesh forecast, whilst in section 2.2, snow studies which highlight model successes and failures are described.

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1. INTRODUCTION

The aim of this investigation is to assess the quality of the guidance given to forecasters from the numerical models in snow situations during the winter 1985/86 and to highlight any model or predictor deficiencies. Eleven cases of borderline rain/snow situations were chosen from the period December 26th 1985 to April 7th 1986 and the forecasts for these days were evaluated. The two models assessed in this report are the fine mesh model and the mesoscale model.

In section 2, we shall concentrate on the quality of forecasts from the fine mesh in snow situations. The precipitation scheme used in the fine mesh model has been described by Dickinson.¹ Successful guidance depends upon accurate forecasting not only of the area of precipitation but also of the chosen predictor. In section 2.1, we shall concentrate on assessing the accuracy and usefulness of a variety of snow predictors using fine mesh output. The eleven forecasts mentioned above were rerun to obtain extra information on forecast temperatures and humidities in the lowest four levels of the model. In section 2.2, a cross-section of fine mesh snow forecasts, good and bad, are described.

In section 3, we will describe the forecasting of snow by the mesoscale model. First, in section 3.1, some objective verification results on precipitation will be given. Snow forecasts from the mesoscale model are compared with those from the fine mesh model in section 3.2 and the accuracy and usefulness of the more detailed short range forecast are assessed. The precipitation scheme used in the mesoscale model has been described by Golding.²

2. FINE MESH SNOW FORECASTS

The operational fine mesh model prediction of snow is given by the 80%, 50% and 20% snow probability lines, which are based upon the 1000-850 mb thickness, corrected for mean sea level pressure. In a similar investigation last year, this predictor was found to be slightly inaccurate in critical conditions ahead of a warm front and this led sometimes to rain being forecast in error instead of snow (Hammon³). Evidence suggested that the 1000-850 mb thickness value associated with snow should be higher ahead of an active warm front. Low level temperatures were also found to be inaccurate. However, during December 1985, a deep soil climatology scheme was added to the fine mesh model and this resulted in a marked improvement in forecast temperatures in the model's boundary layer. This encouraged us to repeat the verification for the winter 1985/86 in order to judge whether the model's low level and humidity profiles were now accurate enough to provide useful guidance in snow situations. In section 2.1 we assess the accuracy and usefulness of various snow predictors using the fine mesh forecast, whilst in section 2.2, case studies which highlight model successes and failures are described.

2.1 Accuracy of snow predictors forecast by the fine mesh model

Very little is done operationally to verify fine mesh snow forecasts. The only operational verification of snow forecasts from the fine mesh model is the subjective assessment at T+24, which is made by the senior forecaster in CFO. The assessment is based on the forecast position of the 20% snow probability line and the forecast precipitation area at T+24. This assessment is made only when the pressure pattern has a good score (A or B) and the 20% snow probability line lies over the UK. The scores are shown in Table 1 below for the period December 26th 1985 to April 11th 1986.

SCORE	CRITERIA	NR OF FORECASTS
A	SNOW WELL FORECAST	28
B+/-	SNOW SLIGHTLY OVER/UNDER ESTIMATED	47
C+/-	SNOW BADLY OVER/UNDER ESTIMATED	29

TABLE 1. CFO SUBJECTIVE ASSESSMENT OF FINE MESH SNOW CASES AT T+24, DURING PERIOD DECEMBER 26TH TO APRIL 7TH 1986

Of the 29 forecasts marked as C, 14 underestimated amounts of snow, 8 overestimated and the remaining 7 were a mixture of precipitation error and forecast thickness error. The majority of errors were due mainly to errors in precipitation rather than thickness. Several of the forecasts scored as 'C' were due to the model underestimating areas of very light snow during February. Based on these results, we can say that 72% of fine mesh snow forecasts gave reasonably good guidance of areas of snow (scores A and B combined).

The accuracy of the following snow predictors using fine mesh model forecasts were assessed;

a. The 1000-850 mb thickness. [The 1000-500 mb and 1000-700 mb thickness were not assessed since they were considered to be of no practical use in forecasting snow at the surface].

b. The dry bulb freezing level.

c. The wet bulb freezing level.

d. Screen temperature.

e. The mean temperature of the lowest 100 mb.

2.1.a. The forecast 1000-850 mb thickness is the main operational snow predictor. The 80%, 50% and 20% probability lines are based on the values derived by Boyden⁴, and shown in Table 2.

% PROBABILITY OF SNOW	90	80	70	60	50	40	30	20	10
1000-850 mb thickness	1281	1285	1290	1291	1293	1295	1298	1300	1303

TABLE 2. PROBABILITY OF SNOW BASED ON VALUES OF 1000-850 mb THICKNESS IN GPM

Due to the chaos caused by snow, it is important for the fine mesh snow probability forecast to be accurate at T+24 to enable adequate warning to be given to local authorities. Table 2 shows that there is a difference of only 15 gpm between an 80% probability of snow and 20%. If this predictor is to be useful, the fine mesh model must be able to forecast the 1000-850 mb thickness to a high degree of accuracy (error < 1%). No official statistics are available for the operational verification of the 1000-850 mb thickness. To get some idea of the skill of the fine mesh model in predicting this thickness, we compared forecast values at T+24 at the positions of the nine UK/Irish upper air stations with the actual sonde values. The forecast values were taken from the eleven cases used in the assessment. Mean and rms values were calculated at each upper air station position and the average value is given in Table 3.

ERROR IN GPM	T+24
MEAN	1.5
RMS	6

TABLE 3. FINE MESH MODEL FORECAST 1000-850 MB THICKNESS ERRORS AT T+24 FOR 11 SNOW CASES BETWEEN DEC 1985 AND APRIL 1986

The fine mesh model needs to be accurate to within 8 gpm if it is to be a useful guide for the prediction of snow. Table 3 shows that the mean and rms errors were generally <1% in the 11 cases examined, comfortably within the required range. One case out of the 11 had thickness errors >10 gpm due to inaccurate evolution (DT 12Z 23/3/86).

b. Boyden⁴ also suggested criteria for using the height of the dry bulb freezing level above ground as a snow predictor. The suggested criteria are shown in Table 4.

HEIGHT OF FREEZING LEVEL ABOVE GROUND IN MB	12	25	35	45	61
% PROBABILITY OF SNOW	90	70	50	30	10

TABLE 4. CRITERIA FOR USING THE HEIGHT OF THE FREEZING LEVEL ABOVE GROUND TO PREDICT SNOW

In order to be able to use these criteria, the model must be able to forecast the freezing level accurately to within 20 mb. Forecast values of the wet and dry bulb freezing levels from tephigrams, VT T+24, taken from the 11 trial cases, were compared within the relevant sonde values, whenever the observed freezing level was less than 60 mb. The mean and rms errors are shown in Table 5.

FREEZING LEVEL	MEAN ERROR IN MB	RMS ERROR IN MB	% CORRECT WITHIN 20 MB	% WITH ERROR >+20 MB
DRY BULB	15	26	72	26
WET BULB	20	29	56	43

TABLE 5. ERRORS IN FINE MESH FREEZING LEVELS AT T+24 FOR 11 TRIAL CASES

Table 5 shows that the fine mesh model has a warm, wet bias in the lowest 60 mb. The wet bias is due to excessive evaporation from the surface. The wet bulb freezing level is a useful aid in predicting snow, but these results show that the fine mesh forecast of this parameter could not be used with confidence.

A new predictor which uses the mean temperature of the lowest 100 mb to forecast the type of precipitation is currently being tested by W Hand (personal communication). The suggested criteria, derived from comparison with the observed weather, are given in Table 6. This predictor will be called 'M100' henceforth.

Unlike the 1000-850 mb thickness, which must be corrected for height above mean sea level, the 'M100' predictor can be used directly from fine mesh output. A correction need only be applied if the fine mesh orography differs markedly from the true orography. (A correction will need to be applied for high ground in Wales, since the fine mesh orography is too low).

MEAN TEMPERATURE OF LOWEST 100 MB IN °C	PRECIPITATION AT SURFACE
<-1.5	SNOW
-1.5 to +0.5	SLEET
>0.5	RAIN

TABLE 6. MEAN TEMPERATURE OF LOWEST 100 MB USED TO PREDICT TYPE OF PRECIPITATION.

This predictor, when used with the fine mesh forecast, gave useful results with the 0.5°C isotherm giving the rain/sleet boundary and the -0.5°C isotherm giving the sleet/snow boundary. The -1.5°C isotherm suggested by comparison with observations, was not accurate when used with the fine mesh model, possibly due to the slight warm bias.

d. Following the implementation of the fine mesh deep soil climatology scheme, forecast values of screen temperature improved markedly. In Table 7, we have listed results of the mean and rms errors of fine mesh temperature forecasts in the intercomparison trial with the mesoscale model.

MONTH	T+9 FORECAST VT 15 GMT		T+12 FORECAST VT 18 GMT		T+12 FORECAST VT 06 GMT	
	MEAN ERROR	RMS ERROR	MEAN ERROR	RMS ERROR	MEAN ERROR	RMS ERROR
January 1986	0.2°C	1.8°C	0.5°C	1.9°C	0.4°C	2.3°C
February 1986	1.0°C	2.2°C	1.5°C	2.5°C	1.4°C	3.1°C
March 1986	-1.0°C	2.2°C	0.1°C	1.7°C	0.4°C	1.9°C
April 1986	-1.4°C	2.3°C	-0.6°C	1.7°C	0.6°C	1.9°C

TABLE 7. 1.5 m TEMPERATURE ERRORS FOR FINE MESH MODEL

Screen temperature, used by itself, is not a reliable snow predictor because of the difficulty in forecasting it accurately enough in cold weather. In addition, the temperature falls sharply as rain changes to snow. Screen temperature needs to be used in conjunction with surface humidity, and this the fine mesh model does not forecast with sufficient accuracy. An accurate screen temperature forecast of 1°C or less could give useful guidance in a borderline situation. However, the fine-mesh model has only a climatological snow cover. This means that in general there is no snow cover over the UK in the model. (Apart from 2 grid-points in the far north of Scotland, which were set as snow-covered in error). This will obviously affect the accuracy of the fine mesh forecast temperatures over snow-covered land. However, Met 0 2b now have the capability to intervene manually to set individual grid points in the fine mesh model to be snow covered.

2.2 Fine Mesh Snow Case Studies

Three fine mesh case studies are described briefly in this section to show good and bad features of snow forecasts. We have chosen to concentrate on the accuracy of the forecasts at T+24 and T+30.

a. 4th January 1986

During the evening, a frontal system crossed Wales and England. Figure 1 shows the frontal position and associated weather at 18 GMT. Please note that the cloud has been omitted in Figure 1. Ahead of the warm front, rain turned readily to sleet and wet snow for a time over Eastern England north of London, the Midlands and Scotland. Figure 2 shows a fine mesh forecast of the pressure pattern and precipitation rate verifying at 18Z 4/1/86. This is a 30-hour forecast starting from data time 12Z 3/1/86. The forecast frontal position over western Scotland, Wales and south-west England was very accurate, and the forecast 1000-850 mb thickness was equally accurate. The associated precipitation area has been well forecast in the north, but the model has kept south-east England and East Anglia incorrectly dry. As can be seen from Figure 2, the model has pushed the 50% snow line too quickly into the North Sea; and most of the observed snow lies between the forecast 20% and 50% snow probability lines. Even allowing for the correction we must make for the height of the ground above mean sea level, this would only increase the forecast probability of snow to 40 to 60% over Eastern England, instead of the 80% we would prefer to see. Since the 1000-850 mb thickness was predicted accurately by the fine mesh model on this occasion, this example shows that when it is used as a snow predictor ahead of a warm front, it is slightly inaccurate, giving too small a value for the probability of snow, especially for low lying areas.

Figure 3a shows the 18 GMT forecast positions of the critical isotherms for the M100 predictor; which uses the mean temperature of the lowest 100 mb above the ground to predict the type of precipitation. We need to adjust these isotherms only in areas where the fine mesh orography is inaccurate. The 0.5°C contour has accurately forecast the position of the rain/sleet boundary. However, the -1.5°C contour, which is supposed to mark the sleet/snow boundary is too far north over Scotland and the predictor forecasts too large an area of sleet. The -0.5°C contour would give a better forecast for the boundary between sleet and snow.

Figure 3b shows the forecast screen temperature for 18 GMT. When used in conjunction with the forecast precipitation area (Figure 2), the forecast temperatures of less than zero over central and eastern areas of England and Scotland would give extra useful guidance of the wintry precipitation to be expected.

Figures 4a and 4b show the forecast dry and wet bulb freezing levels respectively for 18 GMT. Although the forecast values are less than 1500 feet over Central and Eastern areas of England and Scotland, and would give some guidance towards wintry precipitation, the forecasts are higher than the true values, which are on or near the surface.

b. 7/8th January 1986

During the 7th and 8th of January, moderate locally heavy falls of snow were reported over parts of Wales, the Midlands, north-west England and East Anglia. The accuracy of three fine mesh model snow forecasts (DT 12 GMT 6/1/86, DT 00 GMT 7/1/86 and DT 12 GMT 7/1/86) was crucial, particularly at T+24 in order that ample warning could be given to local authorities, airfields, etc. The first two of these forecasts gave very good guidance but the third was disappointing. In this section we will briefly describe the first and the third forecast.

During the 7th January, an active warm front moved slowly northwards over southern England and Wales. Outbreaks of rain and sleet in the extreme south turned quickly into sleet and snow inland, especially over hills, as the front moved north. The snow reached the Midlands during the afternoon and extended into north-west England and East Anglia during the evening. Over southern England and south Wales the snow did not last long, turning to rain and sleet, but further north the snow was persistent. Figure 5 shows the synoptic situation at 18 GMT, with the heaviest snow over the Midlands. During the evening the warm front became quasi-stationary from Sussex to Central Wales with moderate locally heavy snow to the north of this line. Figure 6a shows the fine mesh model's forecast precipitation area and snow probability lines for 18 GMT. This was a very accurate 30 hour forecast from the fine mesh model from data time 12 GMT 6/1/86. The only slight defect is that the area of heavier precipitation does not extend quite far enough north into the Midlands, but the model is only one grid length out. Errors in the forecast 1000-850 mb thicknesses at 7/12 GMT and 8/00 GMT were small. If we compare Figures 5 and 6a, then the observed snow area lies between the forecast positions of the 20% and 50% snow probability lines. If we consider the area of heaviest snow over the Midlands, then a correction of 1 to 4 gpm must be subtracted from the 1000-850 mb thickness to allow for station height above mean level. This increases the forecast probability of snow in this region to 30 to 70%. This is good guidance for the Midlands received more than 24 hours in advance. The main problem area is Sussex where the model prediction was for rain rather than the sleet observed. Figure 6b shows an alternative version of the model's precipitation area. This chart has the same verification time, 18 GMT, as 6a, but crosses and star symbols have been used to indicate the model's snow areas (effectively where the temperature at level 1 (25 m) is less than or equal to zero). This has the advantage of spotting possible snow areas on the warm side of the 20% snow line. In particular, the model has forecast snow over south-east Wales and this is

confirmed by the observation of moderate snow at station 521. However, the model is indicating rain rather than snow over the Wash but this may be a fine mesh sea point. Figure 7a shows the critical values of the M100 predictor (mean temperature of the lowest 100 mb above the ground). The forecast positions of the 0.5, -0.5, -1.5 degree centigrade isotherms are drawn, with the shaded area (≥ 0.5 degrees centigrade) indicating areas of no snow risk. Bearing in mind that a small negative correction must be made over Wales due to inaccurate fine mesh orography, then the position of the 0.5 degree centigrade accurately marks the boundary between rain and sleet, whilst the -0.5 degree isotherm gives the boundary between sleet and snow. The -1.5°C isotherm suggested from comparison with observations is too far north in this case. Figure 7b shows the fine mesh forecast temperatures at 1.5 m for 18 GMT. Only the 0, 1, 2, 3 degree centigrade isotherms are shown; with the shaded area indicating temperatures greater than 3 degrees centigrade. Forecast temperatures over the observed snow areas 18 GMT were between 0°C and 2°C; an accurate forecast which would have helped to confirm the probability of snow. Figures 8(a) and 8(b) show the model's prediction for the height of the dry and wet bulb freezing levels respectively in thousands of feet above mean sea level. Values greater than 2000 feet have been shaded to indicate low risk areas. Over the Midlands, for example, freezing levels are forecast to be mainly less than 1000 feet, giving an indication of the wintry precipitation expected. However, observed values are on or near the surface. The main error is over Sussex and Kent where forecast freezing levels of 1500 to 2000 feet indicate that the model has pushed the warm air slightly too far east.

This was one of the best fine mesh snow forecasts of the winter and it gave very good guidance for the probable snow areas at T+30. In contrast, the T+24 forecast from DT 12 GMT 7/1/86 was disappointing.

Figure 9 shows the synoptic situation at 12 GMT 8/1/86. The warm front has become quasi-stationary over Southern England and Wales, and the main snow area lies north of a line from Stansted to Shawbury. Further south, the situation is borderline between rain and sleet. Figure 10 shows the T+24 hour forecast from the fine mesh model, verifying at 12 GMT 8/1/86. The fine mesh model has continued to push the warm air slowly northwards in error, and as a consequence, the forecast precipitation area is much too far north. All the forecast snow predictors in this case were equally incorrect and misleading.

c. 2nd February 1986

During the early morning of the 2nd February, an area of sleet and snow moved from Lincolnshire southwestwards across the Midlands. Figure 11 shows the position of this area at 06 GMT. Again, please note that the observed cloud has been omitted from this chart. The T+30 hour forecast from the fine mesh, verifying at 06Z was too warm, with the 20% snow line advected too far westwards into the Irish Sea (see Figure 12). Although the area

of precipitation has been forecast correctly, the guidance to a forecaster of the likelihood of snow is poor (probability < 20%). Figure 14a shows the forecast positions of the critical isotherms of the "M100" predictor. In the snow area over Lincolnshire and the Midlands, the mean temperature of the lowest 100 mb was forecast to be greater than 0.5°C, leading to a forecast for rain rather than sleet or snow. The screen temperature forecasts (shown in Figure 14b) were between 2°C and 4°C in the critical area, higher than the observed values of 1°C or 2°C.

Figures 13a, 13b indicate the areas where the zero degree isotherms (dry and wet bulb respectively) were forecast to be less than 2000 feet. Over the relevant areas, (Lincolnshire and the Midlands) the freezing levels were forecast to be about 2000 feet, too high for any forecast of sleet or snow.

3. Snow forecasts from the mesoscale model

In contrast to the fine mesh model which forecasts a probability of snow, the mesoscale model is more ambitious in that it aims to predict the exact position of the rain/snow boundary. Sleet is not included in the model output. The criterion used is that snow will be predicted at the surface if the forecast temperature at model level 3 (310 m above ground) is less than zero. Some results from the mesoscale model trial objective verification results are discussed in section 3.1, whilst some mesoscale snow forecasts are compared with those from the fine mesh model in section 3.2.

3.1 Objective verification of precipitation type

The type of weather (ie rain, snow or dry) forecast by the mesoscale model is verified against observations in the objective verification scheme. Sleet observations are included with snow. The results at T+12 are given below in Table 8 for both the 06-18 GMT and the 18-06 GMT forecast periods.

April 86	SNOW	0.2	1.0	0.3	1.5	SNOW	0.2	1.2	0.1	1.5
	DRY	0.2	73.4	9.9	73.8	DRY	0.4	69.4	6.5	74.5
	RAIN	0.3	13.2	6.3	19.8	RAIN	0.4	11.8	9.5	22.0
		0.7	87.0	11.5	100.1		1.0	82.4	14.6	100.0

The main diagonal values of the contingency tables above show that an average of 75% of mesoscale 'weather' forecasts were correct at T+12. However, Table 8 also shows that errors in the type of precipitation forecast are twice as likely to be rain forecast/snow observed than the reverse. This is partly due to a small warm bias in the low level temperatures forecast by the model and partly due to the inclusion of sleet in the observations. A better criterion for the model would have been 0.5°C instead of 0°C. There is some evidence of a slight warming in the model during the course of a forecast. Errors at T+2 are unbiased, ie errors are equally likely to be snow forecast/snow observed as the reverse. The model tends to forecast too much precipitation as shown by the 18% in the error category precipitation

TABLE 8. VERIFICATION OF MESOSCALE MODEL WEATHER FORECASTS

MONTH	DT 06Z VT 18Z					DT 18Z VT 06Z				
	OBS	SNOW	DRY	RAIN		OBS	SNOW	DRY	RAIN	
	FC					FC				
January 86	SNOW	1.1	1.1	0.2	2.4	SNOW	0.6	1.1	0.3	2.0
	DRY	0.8	57.0	6.0	63.8	DRY	0.5	59.1	7.1	66.7
	RAIN	1.7	22.4	9.7	33.8	RAIN	1.0	17.2	13.1	31.3
		3.6	80.5	15.9	100.0		2.1	77.4	20.5	100.0
February 86	SNOW	2.7	12.9	0.8	16.4	SNOW	3.1	17.1	0.6	20.8
	DRY	2.1	67.7	1.4	71.2	DRY	3.7	62.9	1.2	67.8
	RAIN	1.1	8.7	2.5	12.3	RAIN	0.8	8.9	1.7	11.4
		5.9	89.3	4.7	99.9		7.6	88.9	3.5	100.0
March 86	SNOW	0.1	1.3	0.1	1.5	SNOW	0.3	1.1	0.1	1.5
	DRY	0.1	75.3	5.3	80.7	DRY	0.3	68.1	7.5	75.9
	RAIN	0.1	11.5	6.4	18.0	RAIN	0.3	11.5	10.8	22.6
		0.3	88.1	11.8	100.2		0.9	80.7	18.4	100.0
April 86	SNOW	0.2	1.0	0.3	1.5	SNOW	0.2	1.2	0.1	1.5
	DRY	0.2	73.6	5.0	78.8	DRY	0.4	69.4	6.7	76.5
	RAIN	0.3	13.2	6.3	19.8	RAIN	0.4	11.8	9.8	22.0
		0.7	87.8	11.6	100.1		1.0	82.4	16.6	100.0

The main diagonal values of the contingency tables above show that an average of 75% of mesoscale 'weather' forecasts were correct at T+12. However, Table 8 also shows that errors in the type of precipitation forecast are twice as likely to be rain forecast/snow observed than the reverse. This is partly due to a small warm bias in the low level temperatures forecast by the model and partly due to the inclusion of sleet in the observations. A better criterion for the model would have been 0.5°C instead of 0°C. There is some evidence of a slight warming in the model during the course of a forecast. Errors at T+2 are unbiased, ie errors are equally likely to be snow forecast/rain observed as the reverse. The model tends to forecast too much precipitation as shown by the 18% in the error category precipitation

forecast/nil observed. A notable feature of the February verification is the comparatively large percentage of snow forecast when the observed weather was dry. This was due to ice cloud falling out as light snow. In the very cold weather the model was unable to maintain a layer of stratocumulus. This fault has now been corrected.

3.2 Mesoscale model case studies

The mesoscale model has a much finer resolution than the fine mesh model and is being developed to give extra detailed guidance on local weather for a period up to eighteen hours ahead. However the model is dependent upon the fine mesh model for boundary updating so that it will be unable to correct gross fine mesh errors. The model should be of most use in slow-moving situations when orographic enhancement of rain or snow should be more accurately forecast than in the fine mesh model.

The following case was chosen for the mesoscale model because it featured a slow moving frontal system over South Wales and Southern England. We are comparing the 12 hour forecast from the mesoscale model verifying at 18 GMT 7/1/86 with the 18 hour forecast from the fine mesh model. This fine mesh forecast, DT 00 GMT 7/1/86 also provided the boundary updates for the mesoscale forecast, DT 06 GMT. Figure 5 shows the observed weather at 18 GMT, 7/1/86. Rain over southwest England and Central Southern England was turning to sleet and snow, moderate at times over Southeast England, the Midlands and Wales. The fine mesh forecast precipitation area was good guidance for this time although it did not predict enough precipitation over the East Midlands and Southern Pennines. The warmer air has been pushed slightly too far north with some observations of sleet and snow south of the 20% snow probability line (see Figure 15a). By comparing Figures 15a and 16 we can see the differences between the fine mesh and mesoscale forecasts. The mesoscale model has followed the fine mesh evolution closely but there are some differences in detail. Figure 16 shows the more positive output of the mesoscale model forecast with the rain/snow boundary clearly depicted. A transitional zone would have been advantageous in this case to alert the forecaster to the possibility of sleet further south (note the comment on the 0.5°C criterion above). The mesoscale model forecast has extended the snow area slightly further north, with an improved forecast over the Southern Pennines and East Midlands. A major fault of the mesoscale model during this period was that it tended to forecast spurious areas of light precipitation. If the forecast cloud in the model was at a temperature less than zero, it was said to be composed of ice crystals, and these separated out readily to give areas of light snow. This effect can be seen in the mesoscale forecast over Northeast England and the North Sea. The fine mesh has kept this area dry correctly. Figures 15b and 17 compare the forecast accumulations from the fine mesh model and mesoscale model for the period of 12-18 GMT 7/1/86. The mesoscale model has forecast larger accumulations generally, especially over high ground.

4. Summary

a. FINE MESH MODEL

The 1000-850 mb thickness, adjusted for mean sea level pressure, is the most useful predictor of snow when used with the fine mesh model. Its advantage over other predictors, is the model's accuracy in predicting it. Provided that the model evolution is correct, the fine mesh model forecast of the 1000-850 mb thickness, generally has an error of less than 1%. In the situation where warm air is being pushed slowly northwards towards much colder air, this predictor is slightly inaccurate. The 1000-850 mb thickness is relatively high, due to warming occurring in the upper portion of the 1000-850 mb layer; thus giving a comparatively low probability of snow. However, in reality, the type of precipitation at the surface will depend critically on the temperature and dewpoint in the lowest 50 mb above the ground. In a cold stable southeasterly flow ahead of a warm front, the temperature may be nearly isothermal at 0 or -0.1°C from the surface to 850 mb, giving snow even at low levels with a comparatively high thickness of approximately 1300 gpm, which corresponds to only a 20% probability of snow. The success of the 1000-850 mb thickness as a snow predictor really depends upon the forecaster knowing how to interpret the results. A general rule is; use the 20% snow probability line to predict sleet or snow even at low levels ahead of a warm front, and the 50% snow probability line in other circumstances.

Other snow predictors, which placed more emphasis on the lowest 50-100 mb, were given a trial in the 11 forecasts rerun. A major fault of the fine mesh model during last winter was the wet bias in the lowest levels, which meant that surface relative humidity and dew point forecasts tended to be too high. In the critical rain/snow cases, it also had a slight warm bias. The wet bulb freezing level should be a good guidance of likely snow areas, particularly ahead of a warm front. This is the predictor that many outstation forecasters prefer to use. However, the warm, moist bias in the fine mesh model near the surface, meant that the wet bulb freezing level forecast by the model could not be used with any confidence at all to predict snow. Similarly the forecast dry bulb freezing level was also unreliable. The "M100" predictor, which uses the mean temperature of the lowest 100 mb above the ground, as a guidance to the likely precipitation was given a trial because it uses a shallower layer than the 1000-850 mb layer, and hence reduces the bias due to warming at the top of the layer in warm front situations. This predictor gave useful, accurate guidance with the 0.5°C isotherm giving the rain/sleet boundary. However, inaccuracies in the model's lowest layers mean that the -0.5°C isotherm needs to be used to indicate the sleet/snow boundary instead of the -1.5°C suggested from results using observations. The advantage of the "M100" predictor over the 1000-850 mb thickness is that it distinguishes better between rain, sleet and snow. The model's forecasts of screen temperature were much improved last winter following the introduction of the deep soil climatology scheme. On occasions, the temperature forecasts at the lowest 2 or 3

model levels gave additional helpful guidance in a borderline rain/snow situation. However, temperature forecasts are more likely to be too high rather than too low ahead of a warm front.

The major fault to be corrected in the fine mesh model before next winter is the wet bias near the surface. If this is corrected by the proposed changes to the fine mesh model (ie retention of resistance to evaporation during the period September to April plus the implicit boundary layer scheme), then the accuracy of the forecast wet and dry bulb freezing levels and screen temperature could be further improved. It would then seem a good idea to consider an operational trial for early winter to test the above snow predictors from the fine mesh in CFO. The forecasters could then choose the predictors which are of most help.

b. MESOSCALE MODEL

Several case studies of mesoscale model forecasts of snow have indicated that the model is possibly too ambitious in attempting to forecast an exact dividing line between rain and snow. The model snow output is still experimental, nevertheless the single criterion (snow predicted at surface if the temperature at level 3 is less than zero) gave encouraging results in many cases, but a critical temperature 0.5°C is more appropriate to include the possibility of sleet. The predictor has an obvious blind spot. If the temperature at level 3 is 0.01°C and less than zero elsewhere, then the model will still predict rain at the surface, when snow is much more likely. The model was more likely to be too warm at level 3 than too cold in the cases examined and there was a hint of a slight warming during the course of the forecast. During the winter, the mesoscale model over-predicted amounts of precipitation substantially. Nevertheless it was better than the fine-mesh model in forecasting orographic enhancement of precipitation. The fine mesh model tended to under-estimate the effect of shower penetration inland in unstable easterly airstreams. Precipitation enhancement due to orography is poorly simulated by the fine mesh model, notably over Wales, because the model orography is too smooth.

An improved scheme for forecasting snow is planned for the mesoscale model next winter. Rather than a simple yes/no criterion, the new scheme will take account of the temperature below the freezing level to decide how much of the snow will melt before reaching the ground. The following equation briefly describes the process.

$$\frac{\Delta m}{m} = 5.4 \times 10^{-3} \Delta T \frac{\Delta z}{v}$$

$\frac{\Delta m}{m}$ - represents the proportion of snow melted.

ΔT - mean temperature in degrees centigrade below the freezing level

Δz - height of freezing level in metres

v - speed of fall = 2 ms^{-1}

References

1. A Dickinson 1984 The Operational Numerical Weather Prediction System. Documentation Paper No. 4.
2. B W Golding 1986 The Meteorological Office Mesoscale Model: An Overview (Met O 11 TN 231).
3. O Hammon 1985 Snow forecasts from Numerical Weather Prediction Models during the winter of 1984/85. (Met O 11 TN 204).
4. C J Boyden 1964 A Comparison of Snow Predictors, Met Mag December 1964.

Figures

- Figure 1. Synoptic situation at 18 GMT 4/1/86 showing frontal analysis with observations of weather, temperature and dew point.
- Figure 2. Fine mesh dynamic rainfall rate forecast VT 18Z 4/1/86 (T+30 hr forecast).
- Figure 3. Fine mesh forecast for T+30 hr, VT 18Z 4/1/86 of;
- a. Mean temperature of lowest 100 mb in $^{\circ}\text{C}$. (Critical isotherms only).
 - b. Screen temperature in $^{\circ}\text{C}$.
- Figure 4. Fine mesh forecast for T+30 hr, VT 18Z 4/1/86 of;
- a. Dry bulb freezing level in thousands of feet (critical contours ≤ 2000 ft shown).
 - b. Wet bulb freezing level in thousands of feet (critical contours ≤ 2000 ft shown).
- Figure 5. Synoptic situation at 18 GMT 7/1/86 showing frontal analysis with observations of weather, temperature and dew point.
- Figure 6a. Fine mesh dynamic rainfall rate forecast for T+30, VT 7/1/86 18 GMT.
- Figure 6b. Fine mesh snow forecast at T+30, VT 18 GMT 7/1/86.
- Figure 7. Fine mesh snow forecast at T+30 hr, VT 18 GMT 7/1/86 of;
- (a) Mean temperature of the lowest 100 mb in $^{\circ}\text{C}$ (critical isotherms only).
 - (b) Screen temperature in $^{\circ}\text{C}$ (0 to 3 degree C isotherms).

Figure 8. Fine mesh forecast for T+30 hr, VT 18 GMT 7/1/86 of;
 (a) Dry bulb freezing level in thousands of feet) critical
 (b) Wet bulb freezing level in thousands of feet) ≤ 2000 ft

Figure 9. Synoptic situation at 12 GMT 8/1/86, showing frontal analysis with observations of wether, temperature and dew point.

Figure 10. Fine mesh precipitation forecast, T+24, VT 12 GMT 8/1/86.

Figure 11. Synoptic situation at 06 GMT, 2/2/86, showing observations of rain/sleet/snow over Lincolnshire and the Midlands.

Figure 12. Fine mesh precipitation forecast at T+30, VT 06 GMT 2/2/86.

Figure 13. Fine mesh forecast for T+30 hr, VT 06 GMT 2/2/86, of;
 a. Dry bulb freezing level in thousands of feet (critical contours ≤ 2000 ft shown).
 b. Wet bulb freezing level in thousands of feet (critical contours ≤ 2000 ft shown).

Figure 14. Fine mesh forecast for T+30 hr, VT 06 GMT 2/2/86 of;
 a. Mean temperature of lowest 100 mb in $^{\circ}\text{C}$ (critical isotherms only shown).
 b. Screen temperature in $^{\circ}\text{C}$.

Figure 15a. Fine mesh dynamic rainfall rate forecast for T+18, verifying at 18 GMT 7/1/86.

Figure 15b. Fine mesh accumulation forecast for period 12-18 GMT 7/1/86.

Figure 16. Mesoscale model 12-hour forecast, verifying at 18 GMT 7/1/86.

Figure 17. Mesoscale model accumulation forecast for period 12-18 GMT 7/1/86.

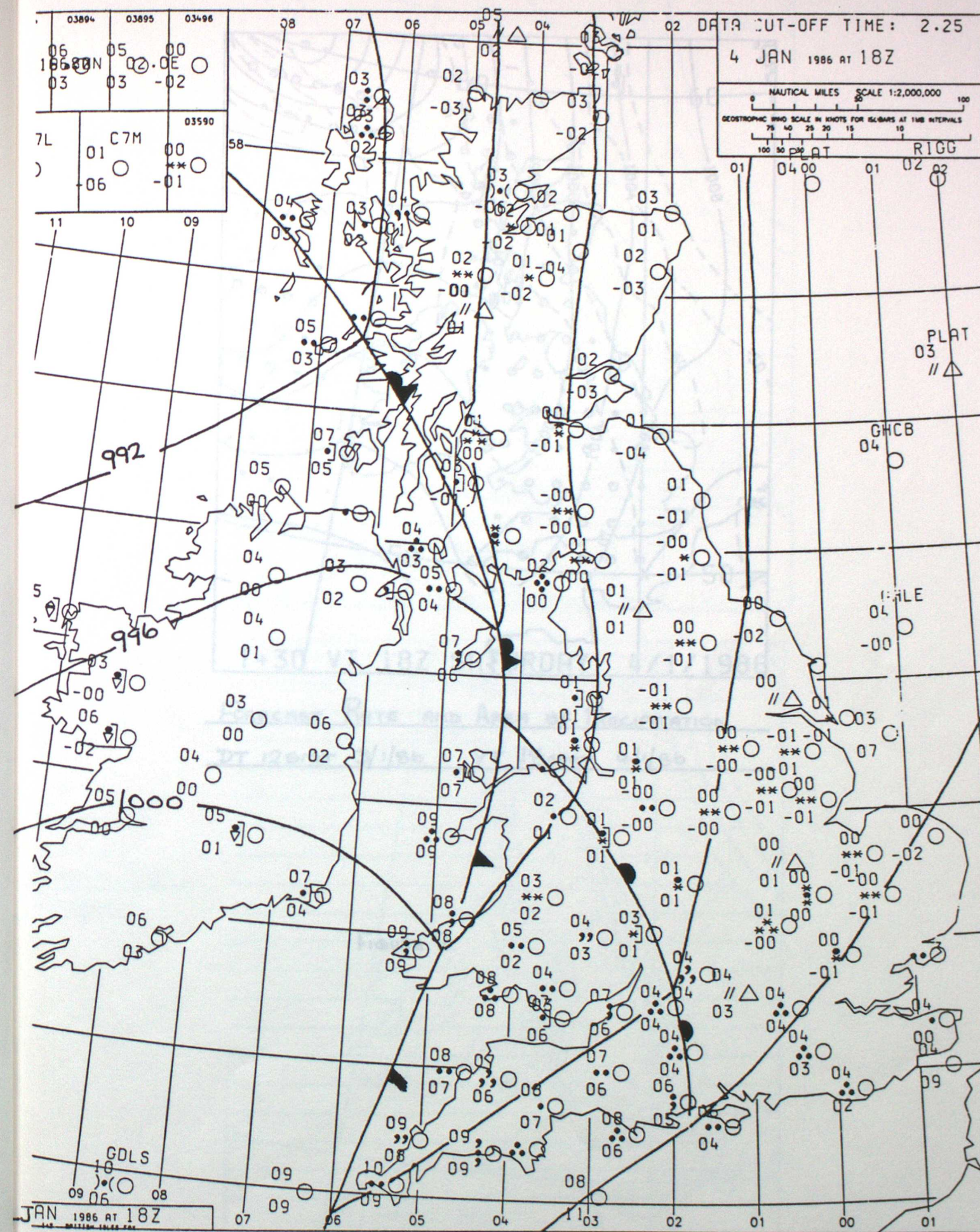
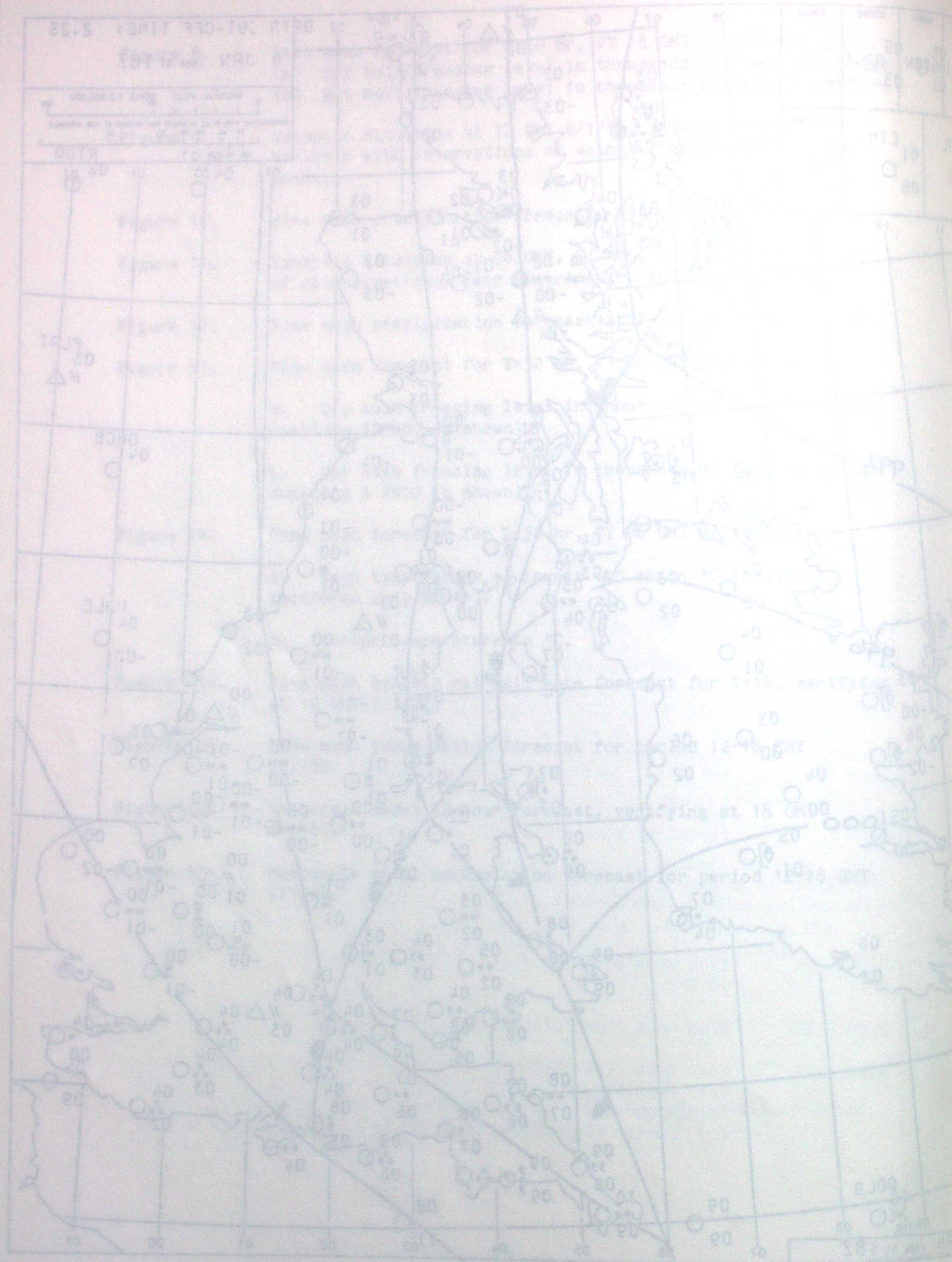
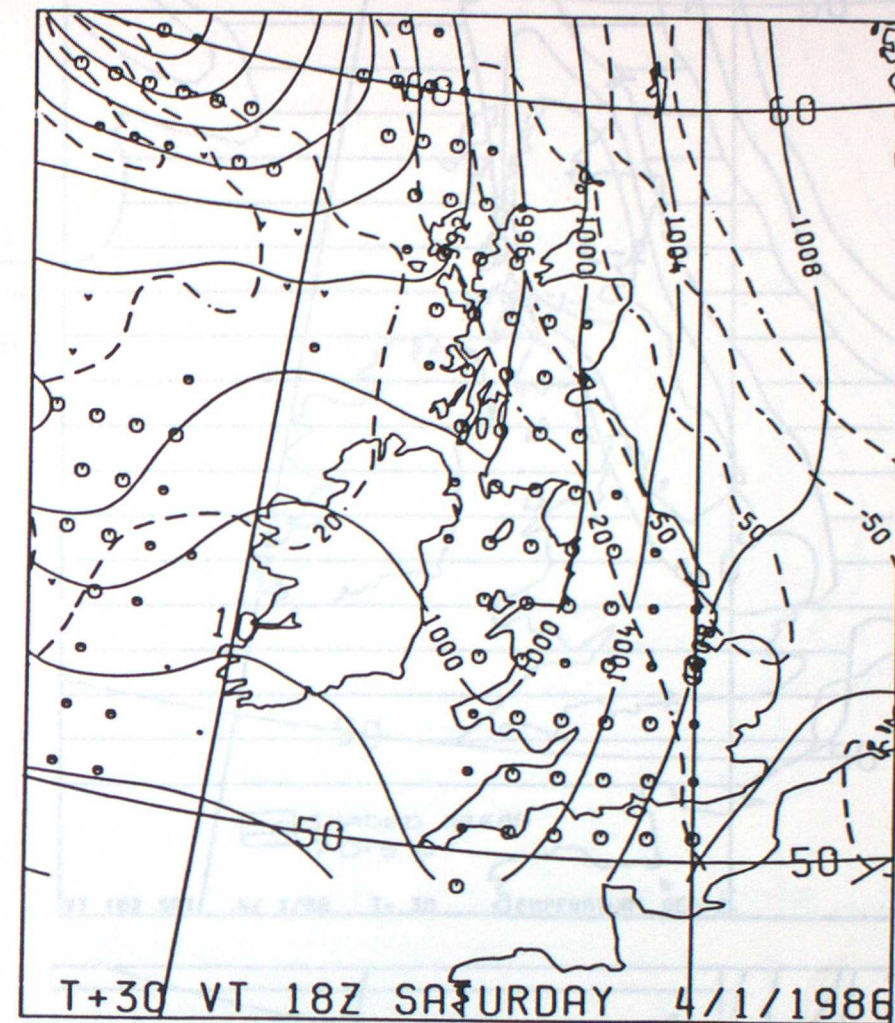


FIGURE 1. SYNOPTIC SITUATION AT 18GMT 4/1/86, SHOWING FRONTAL POSITION AND ASSOCIATED WEATHER, TEMPERATURE AND DEWPOINTS



SYNOPTIC SITUATION AT 1800Z APRIL 1/1986
 AND ASSOCIATED WEATHER FORECASTS AND TENDENCIES



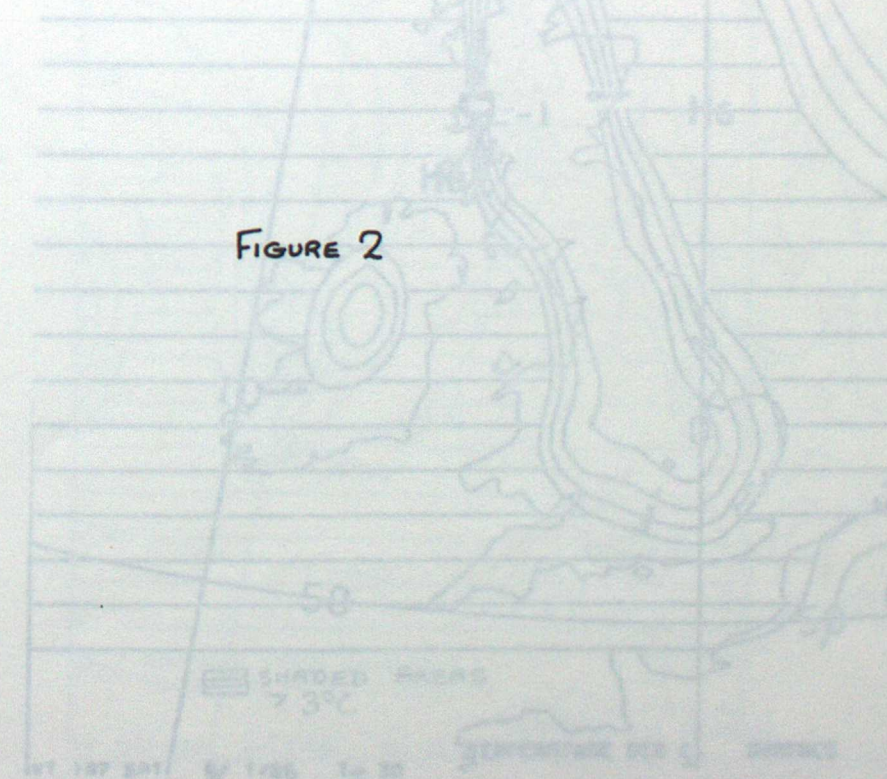
FORECAST RATE AND AREA OF PRECIPITATION

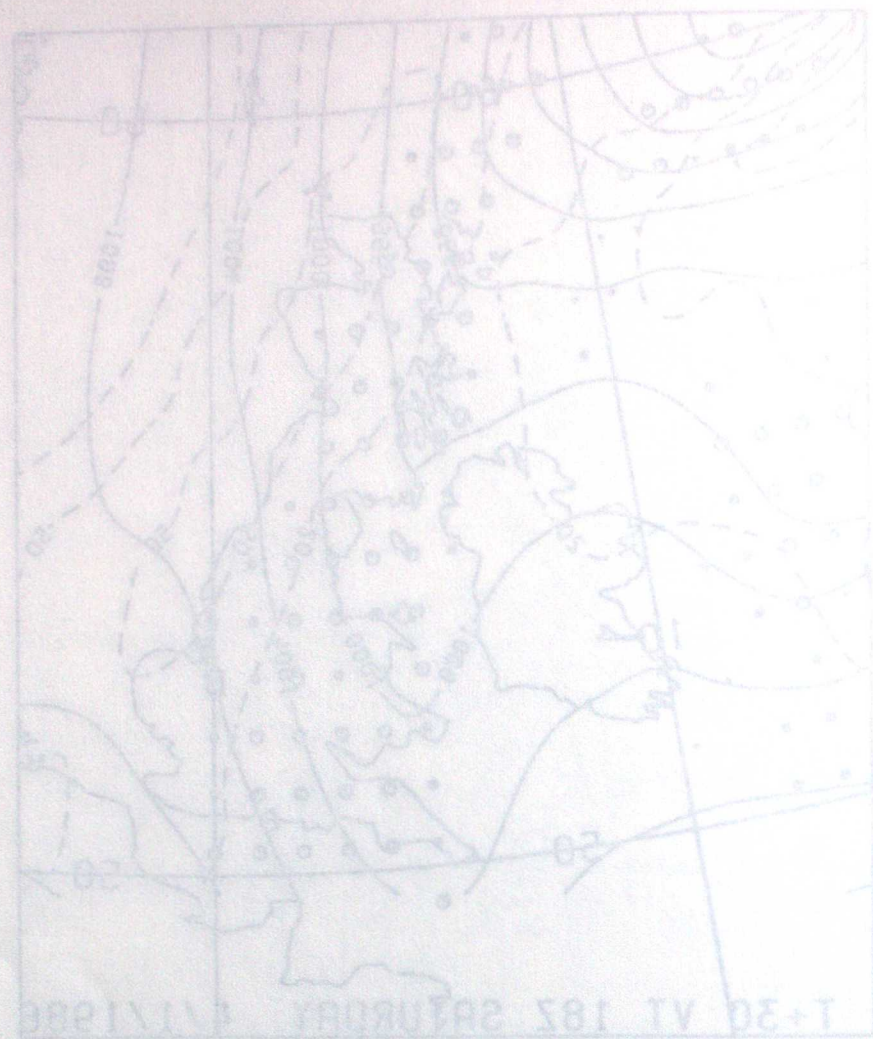
DT 12GMT 3/1/86 VT 18GMT 4/1/86

Figure 3b

Season Temp
 Forecast

FIGURE 2





Forecast Rate and Area of Precipitation
 DT 1200T 3/100 VT 1800T 4/100

Figure 2

FIGURE 3a

M100 PREDICTOR
 [MEAN TEMPERATURE
 OF LOWEST 100MB
 ABOVE GROUND]

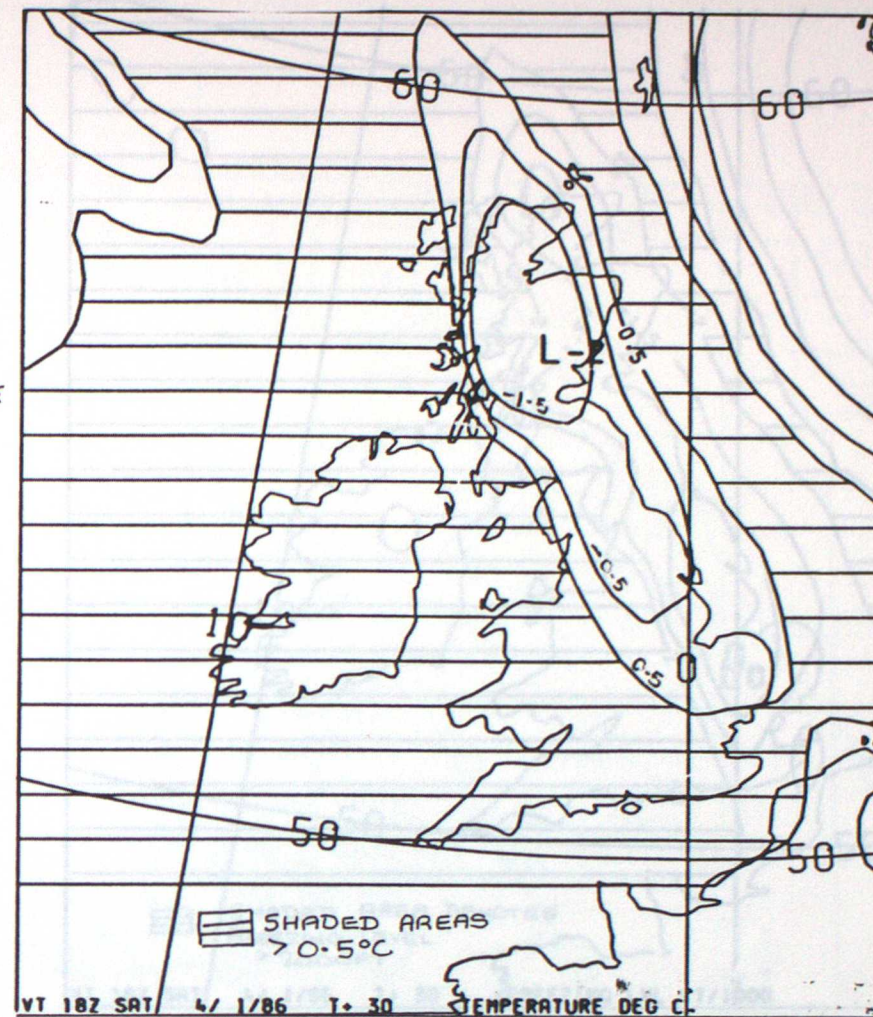
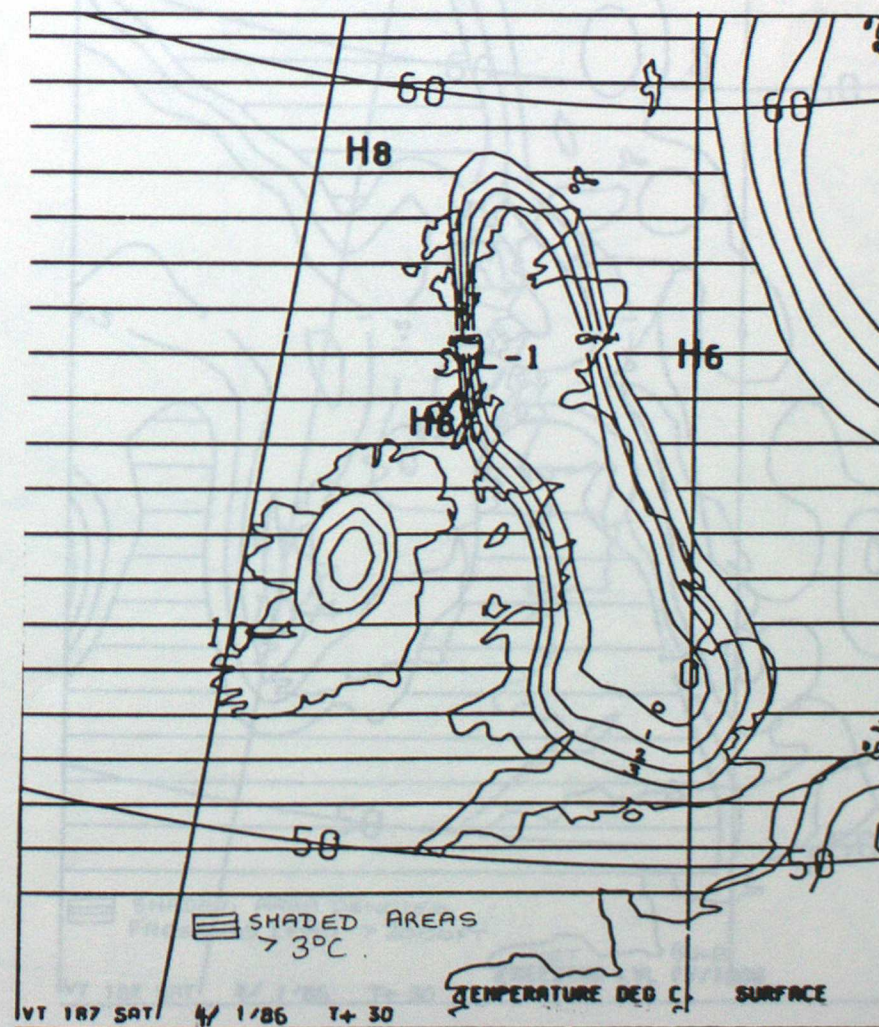


FIGURE 3b

SCREEN TEMP.
 FORECAST



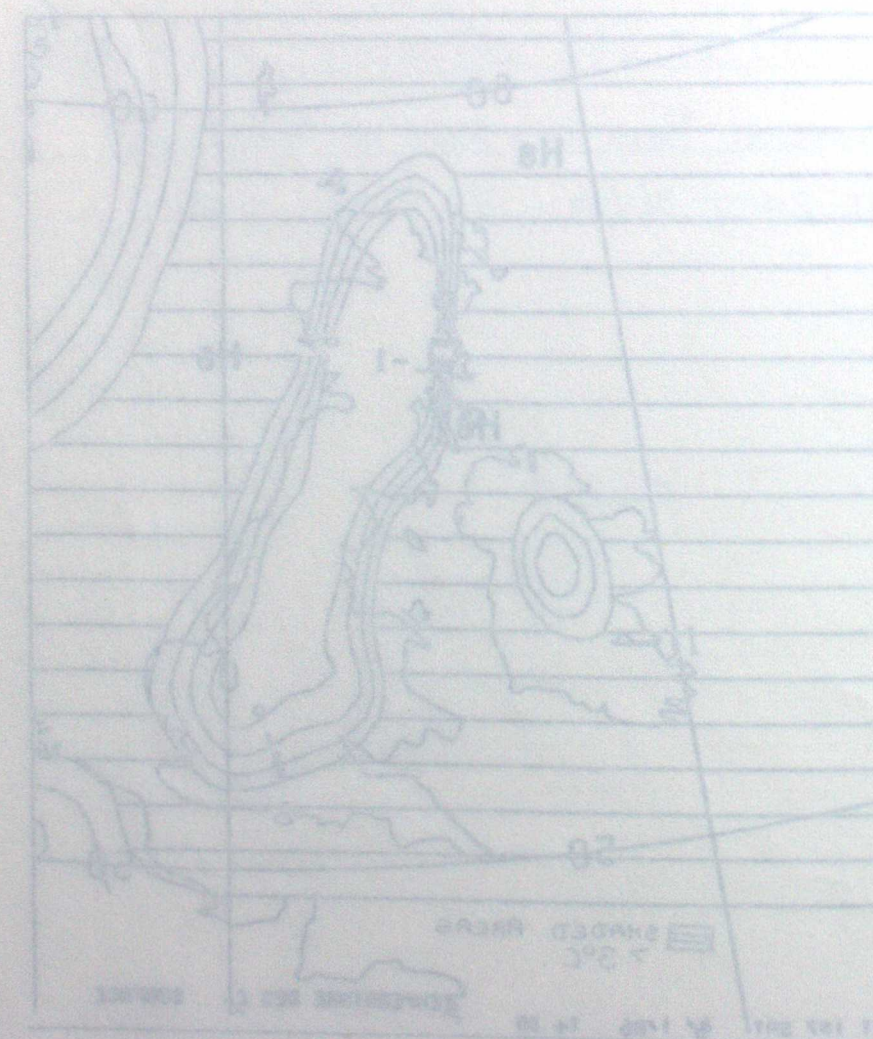
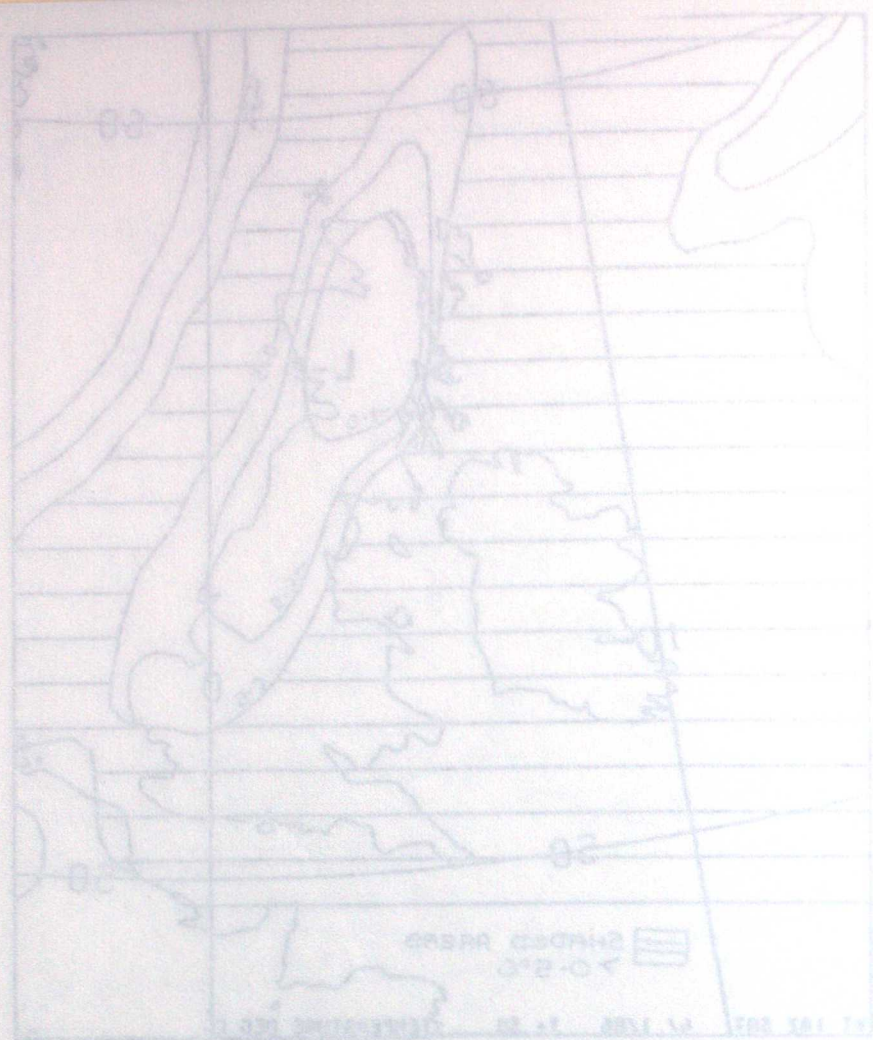


FIGURE 4a

DRY BULB
FREEZING LEVEL

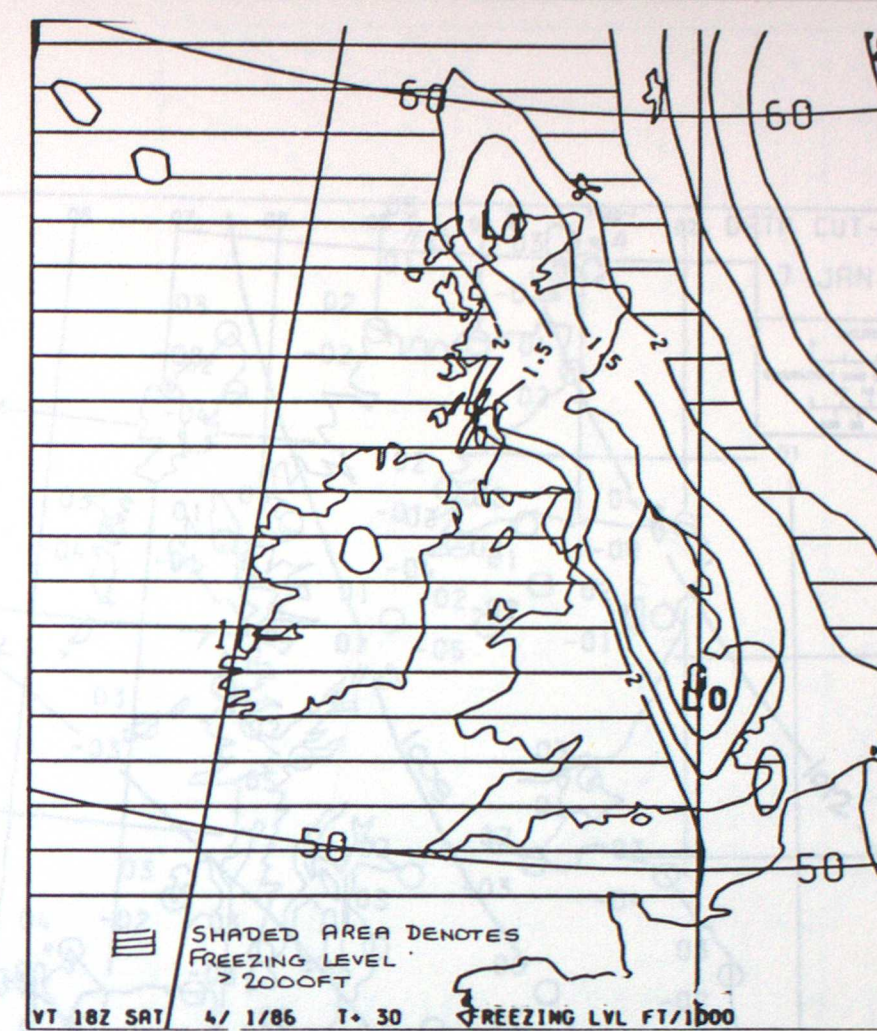
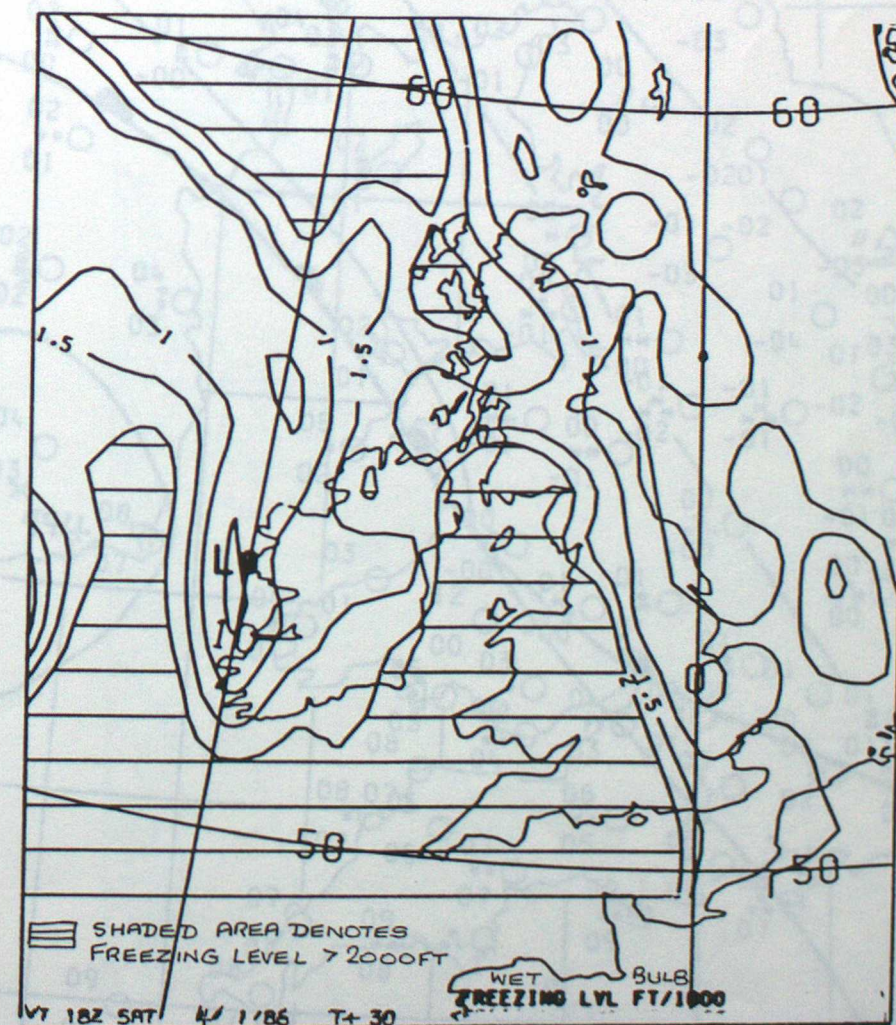


FIGURE 4b

WET BULB
FREEZING LEVEL



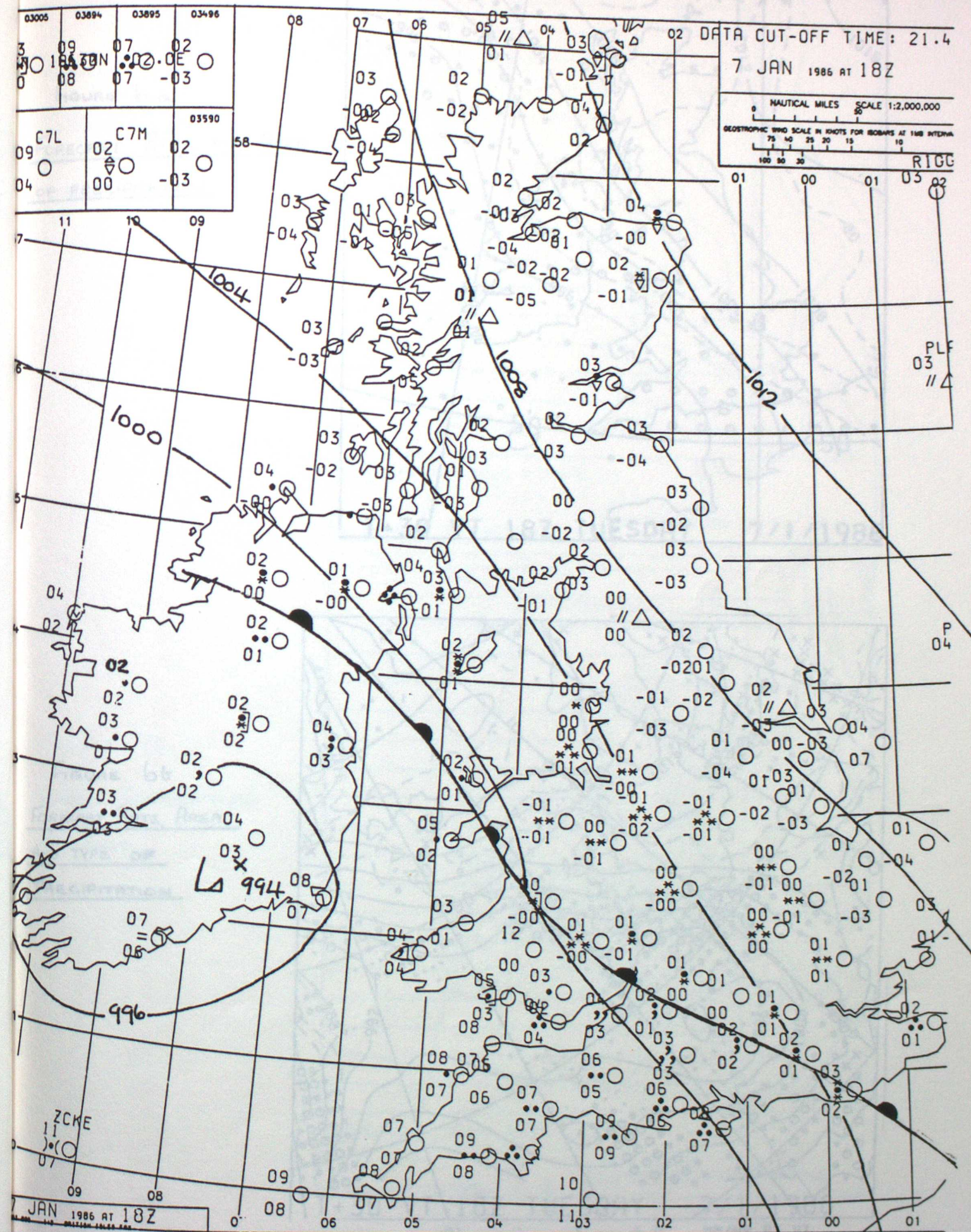


FIGURE 5 SYNOPSIS SITUATION AT 18GMT 7/1/86

FIGURE 6a

FORECAST RATE AND AREA
OF PRECIPITATION

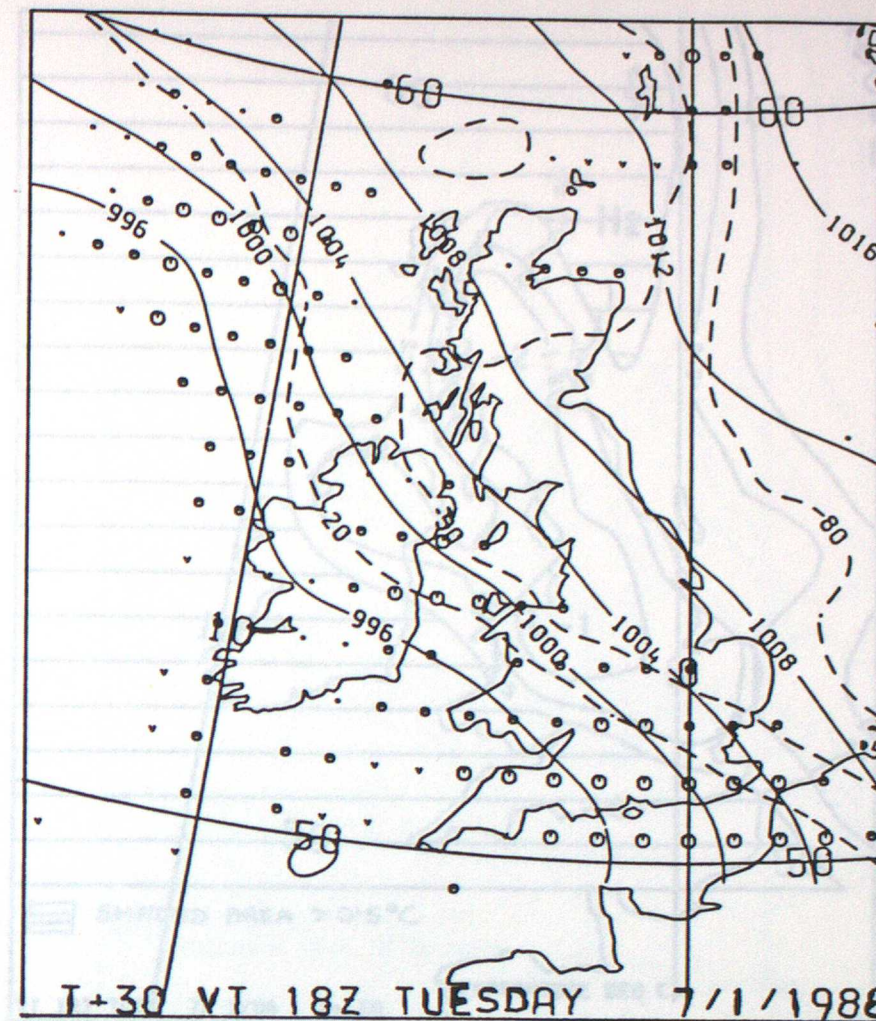


FIGURE 6b

FORECAST RATE, AREA
AND TYPE OF
PRECIPITATION

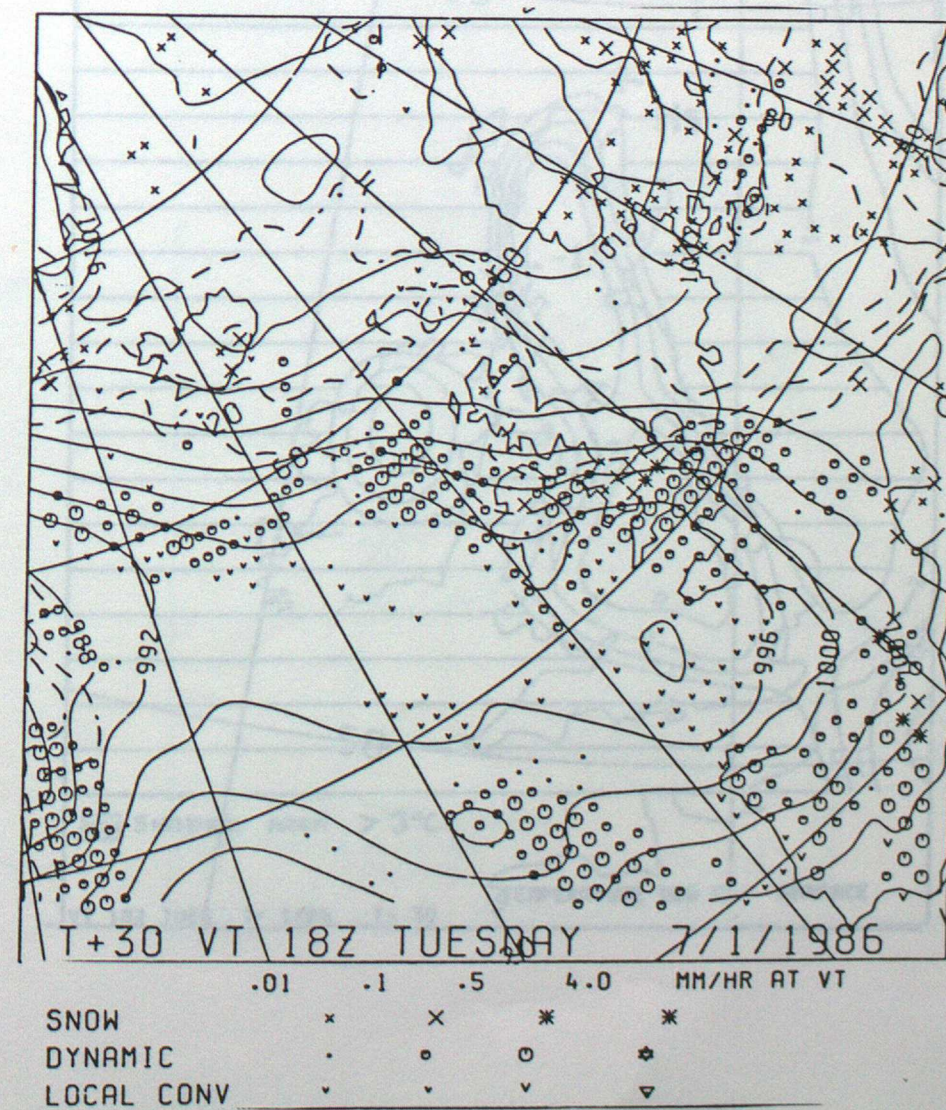




FIGURE 7a
 M100 PREDICTOR.
 MEAN TEMPERATURE OF
 LOWEST 100 MB

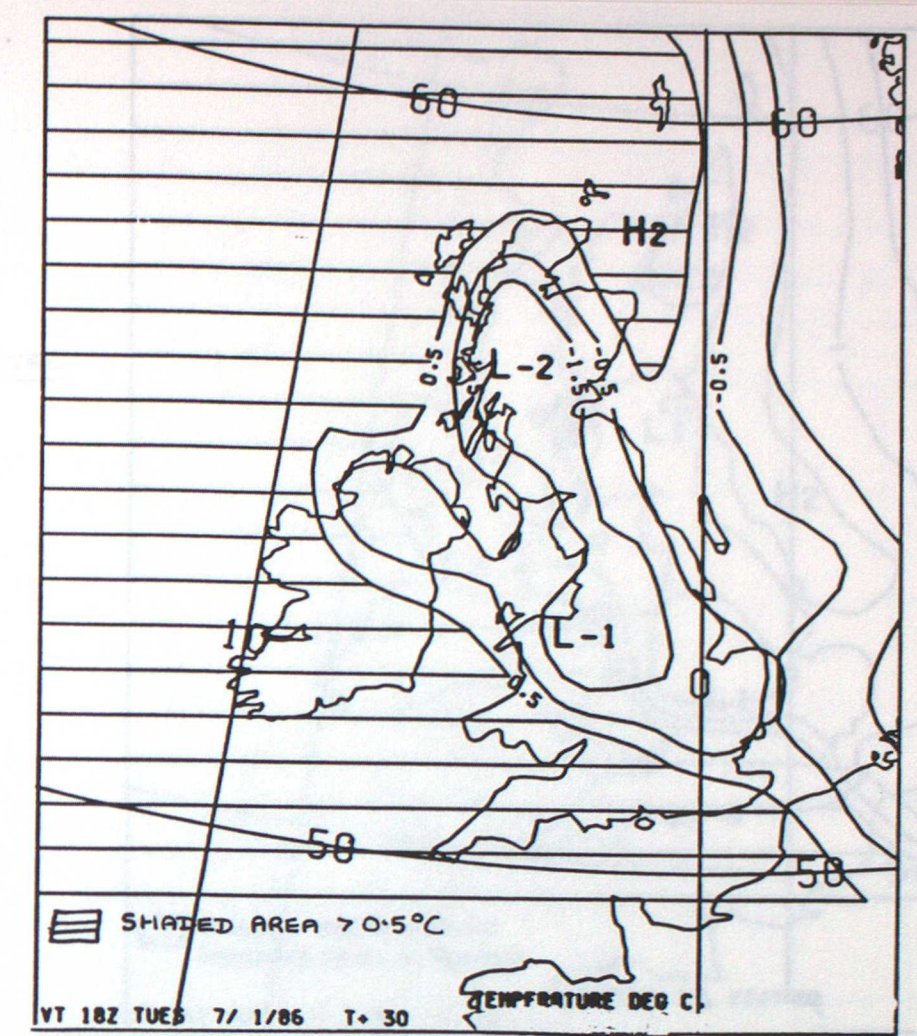


FIGURE 7b
 SCREEN TEMPERATURE
 FORECAST

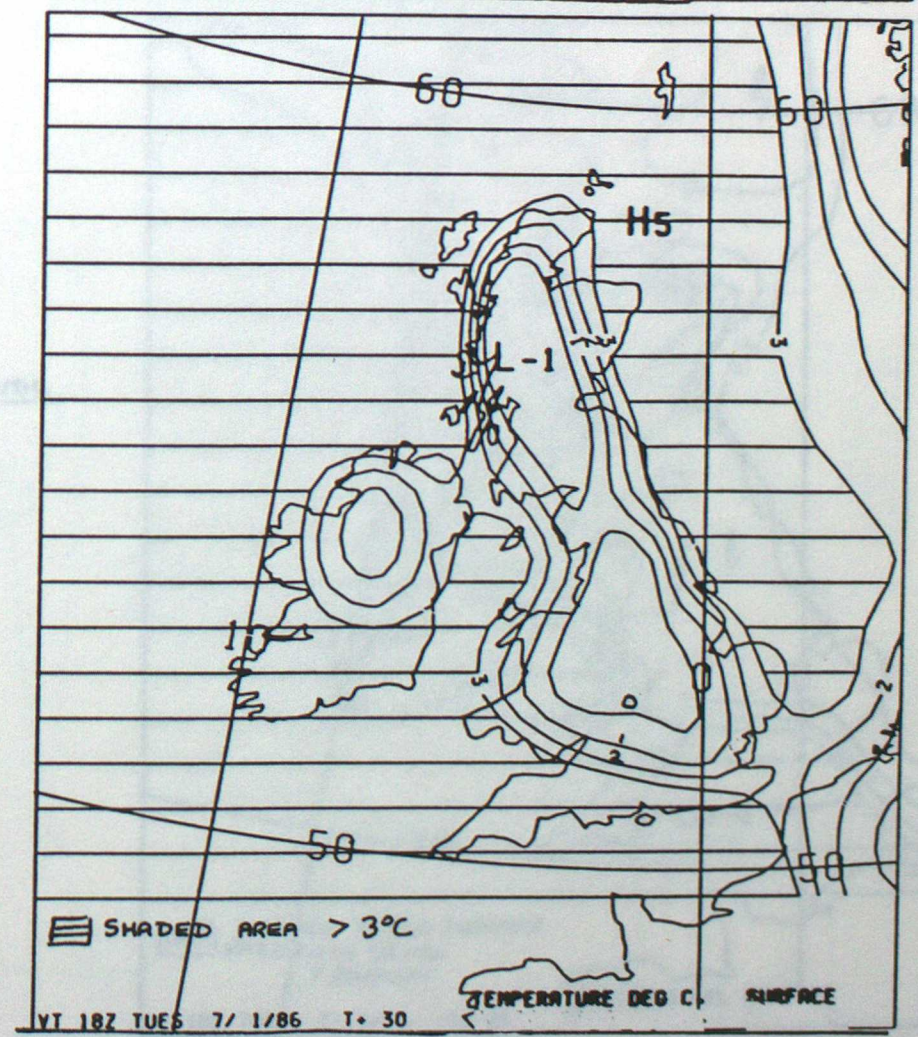


FIGURE 8a

DRY BULB FREEZING LEVEL

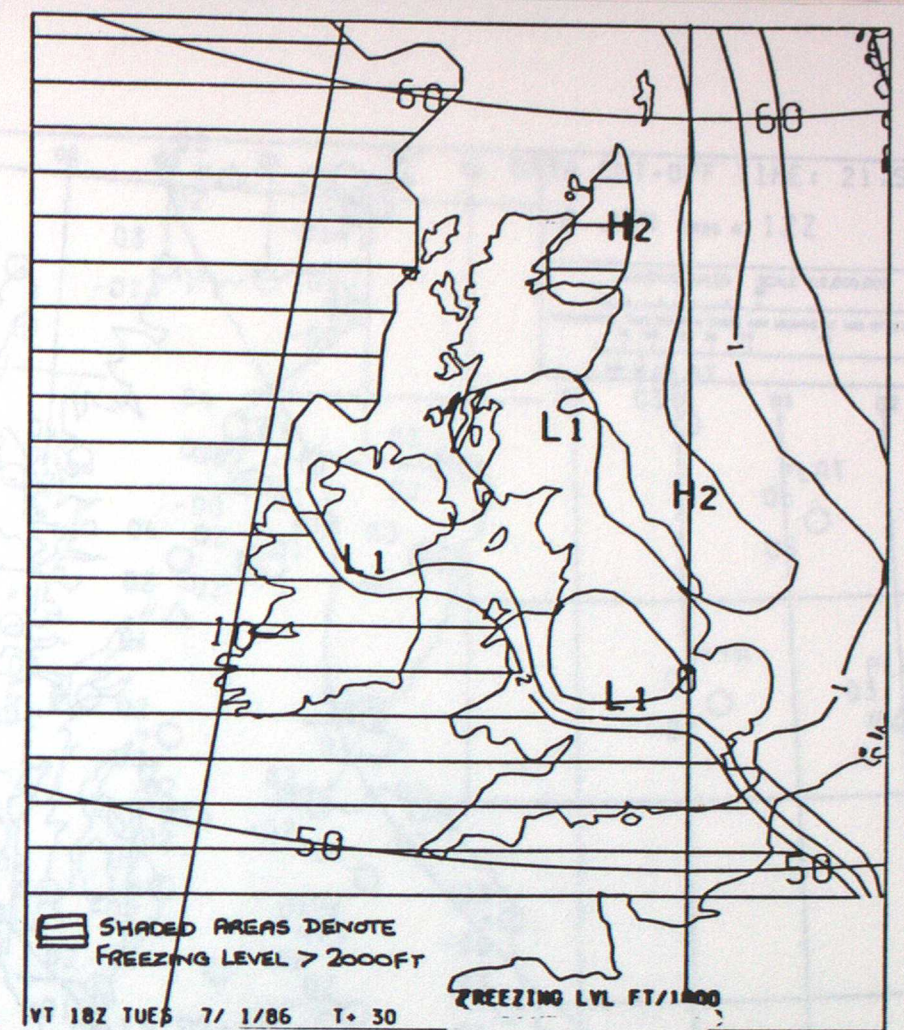
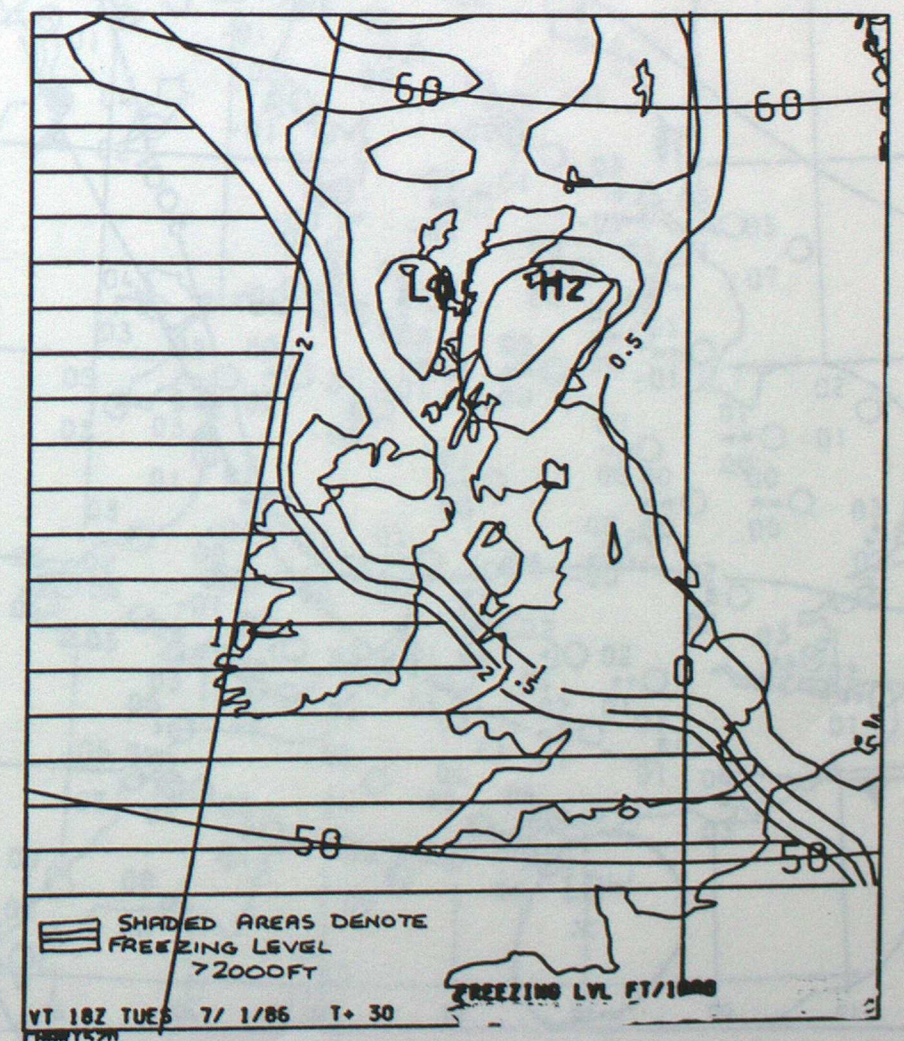


FIGURE 8b

WET BULB FREEZING LEVEL



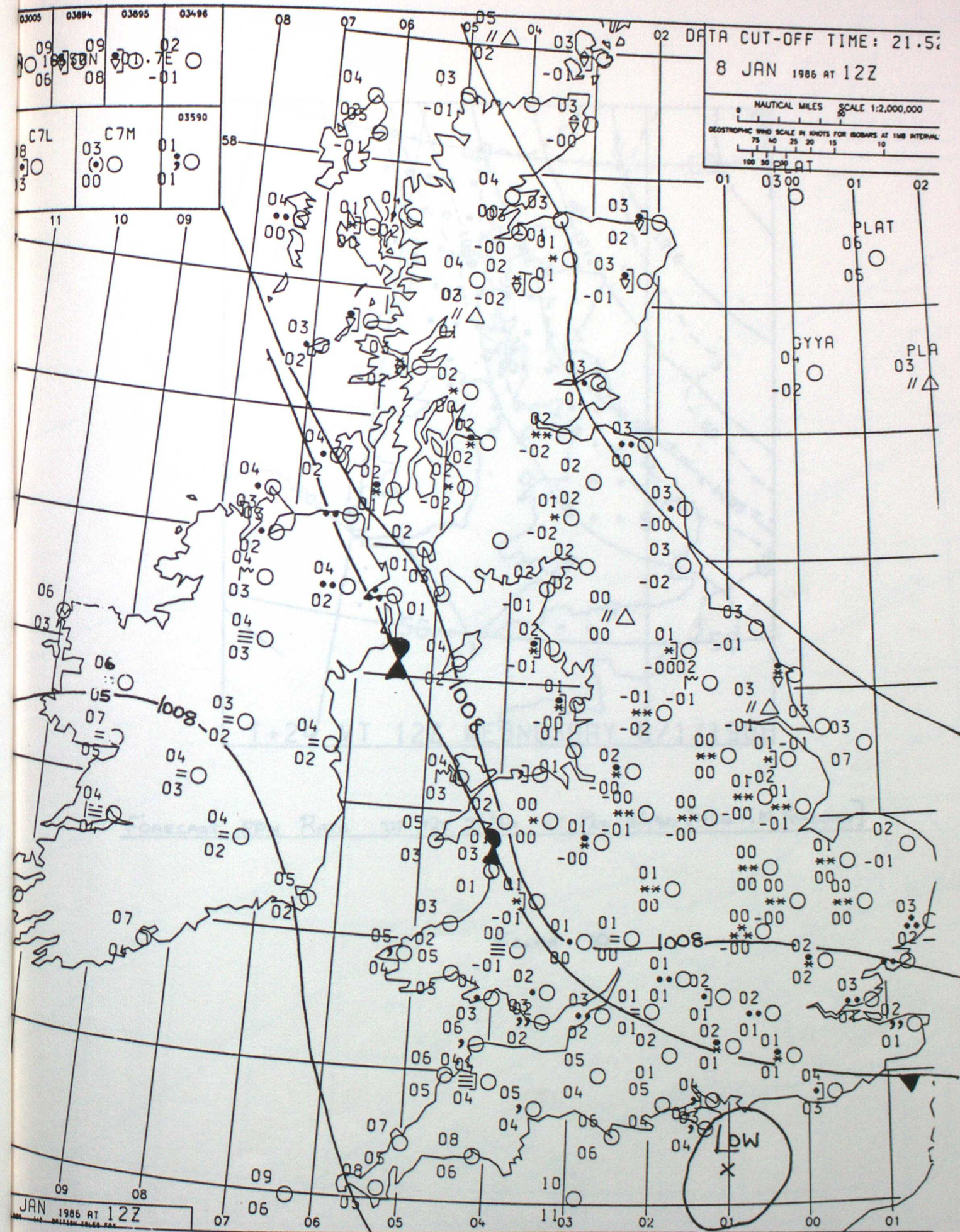
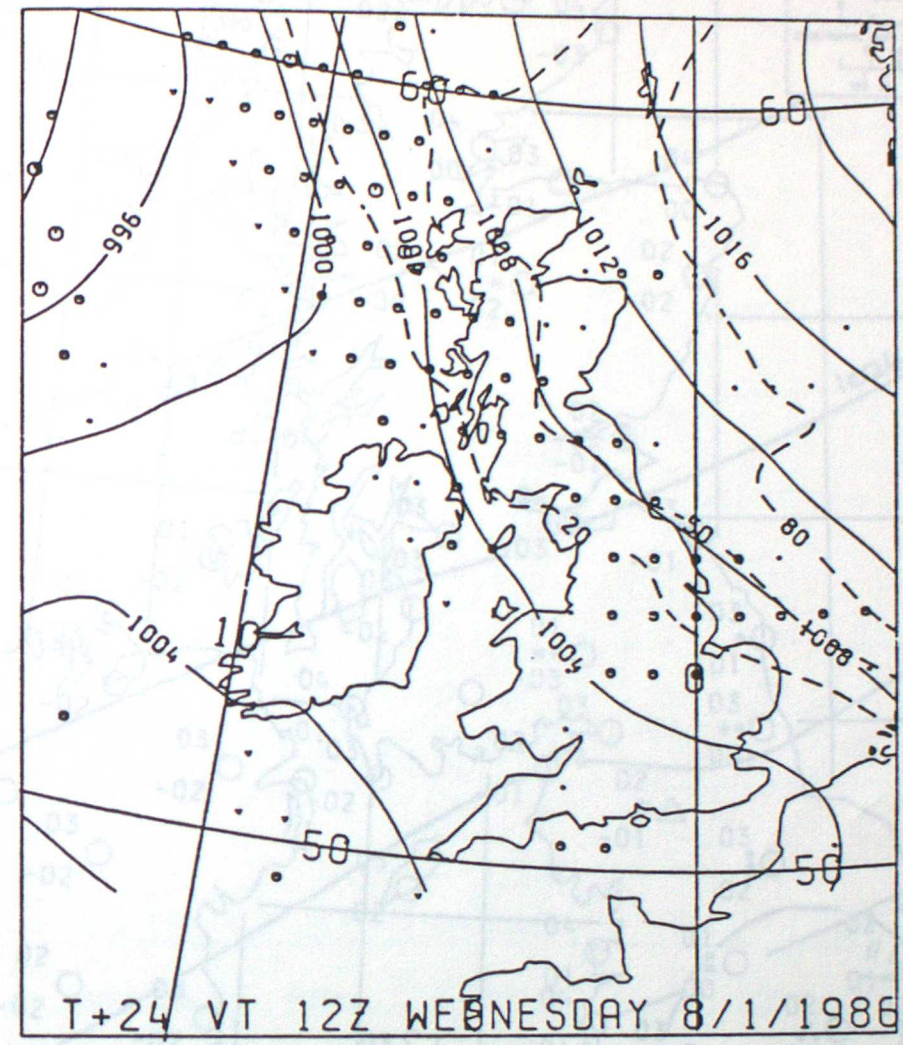
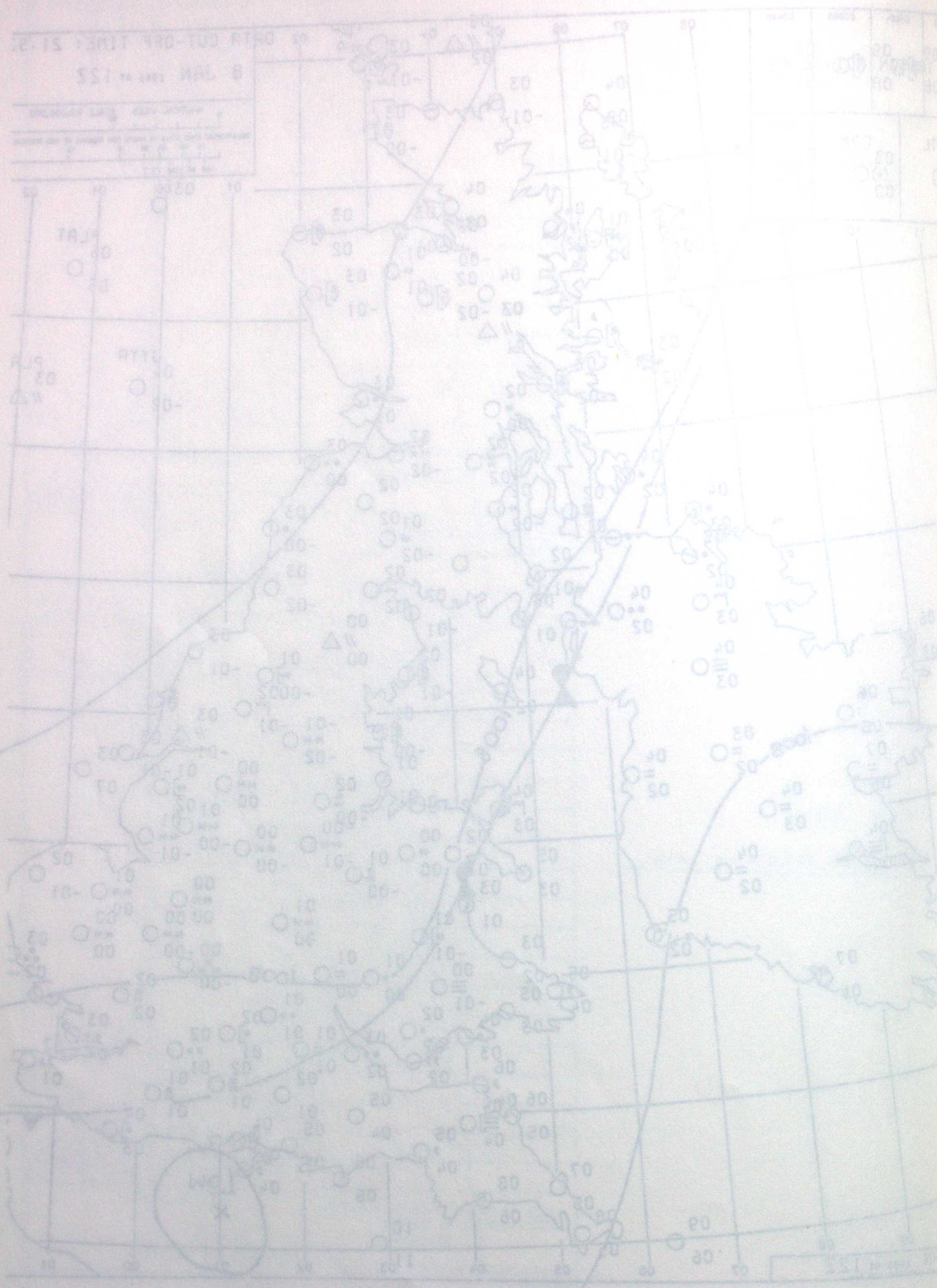
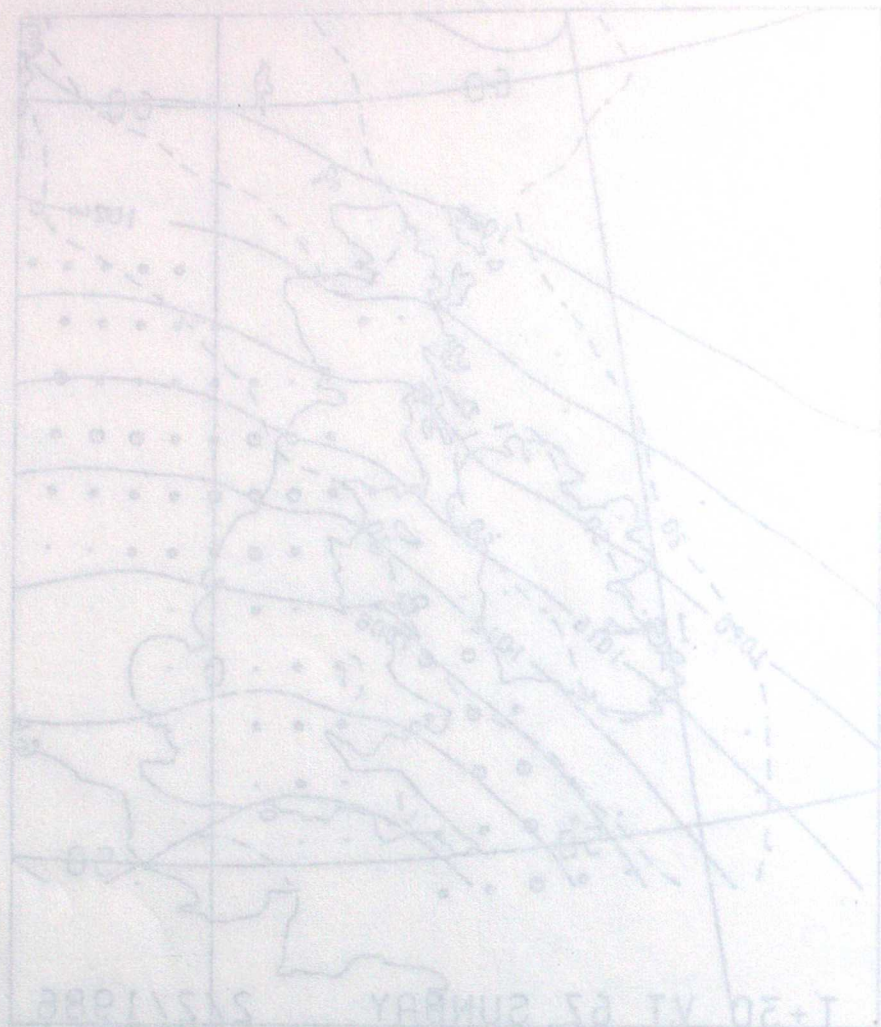


FIGURE 9 SYNOPTIC SITUATION AT 12GMT 8/1/86



FORECAST PPN RATE DT 12z 7/1/86 VT 12z 8/1/86 [T+24 F.M. FORECAST]

FIGURE 10



PT 00Z 1/18/86 VT 00Z 2/18/86
 FORECAST FOR 1730 FM 2/18/86
 T+30 VT 6Z 2/18/86

FIGURE 13a

DRY BULB FREEZING LEVEL

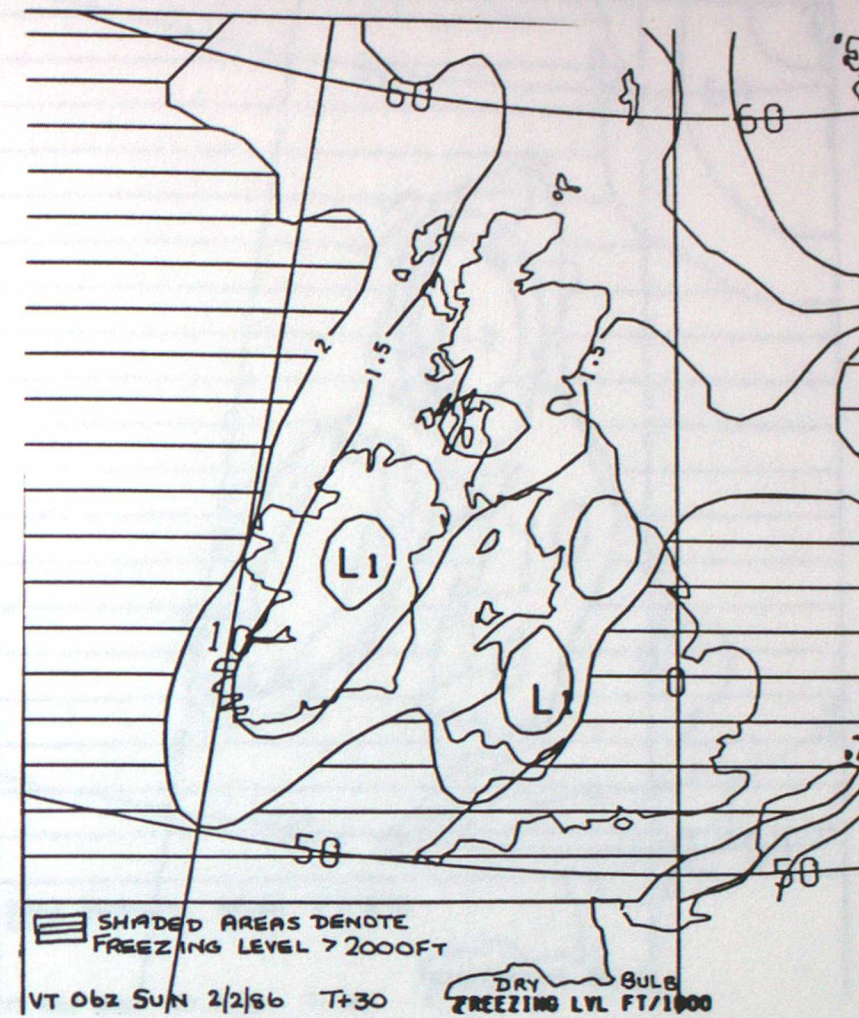


FIGURE 13b

WET BULB FREEZING LEVEL

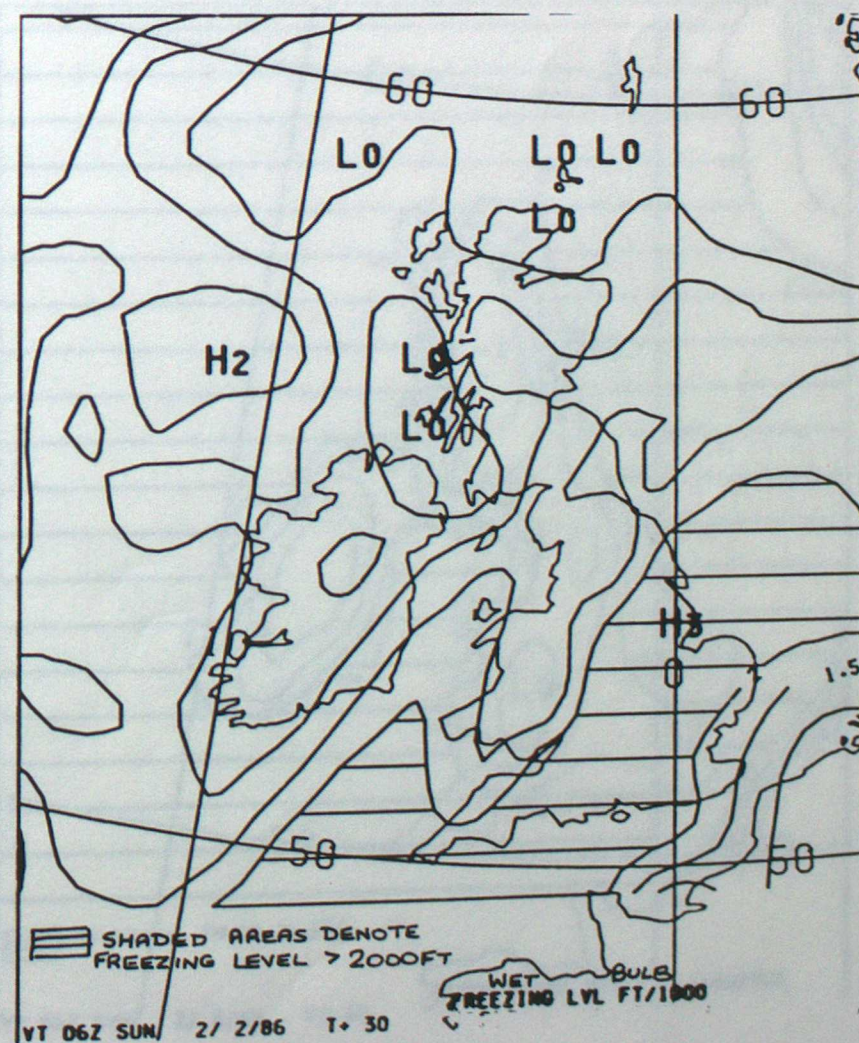


FIGURE 14a

M100 PREDICTOR.

MEAN TEMPERATURE OF
LOWEST 100MB

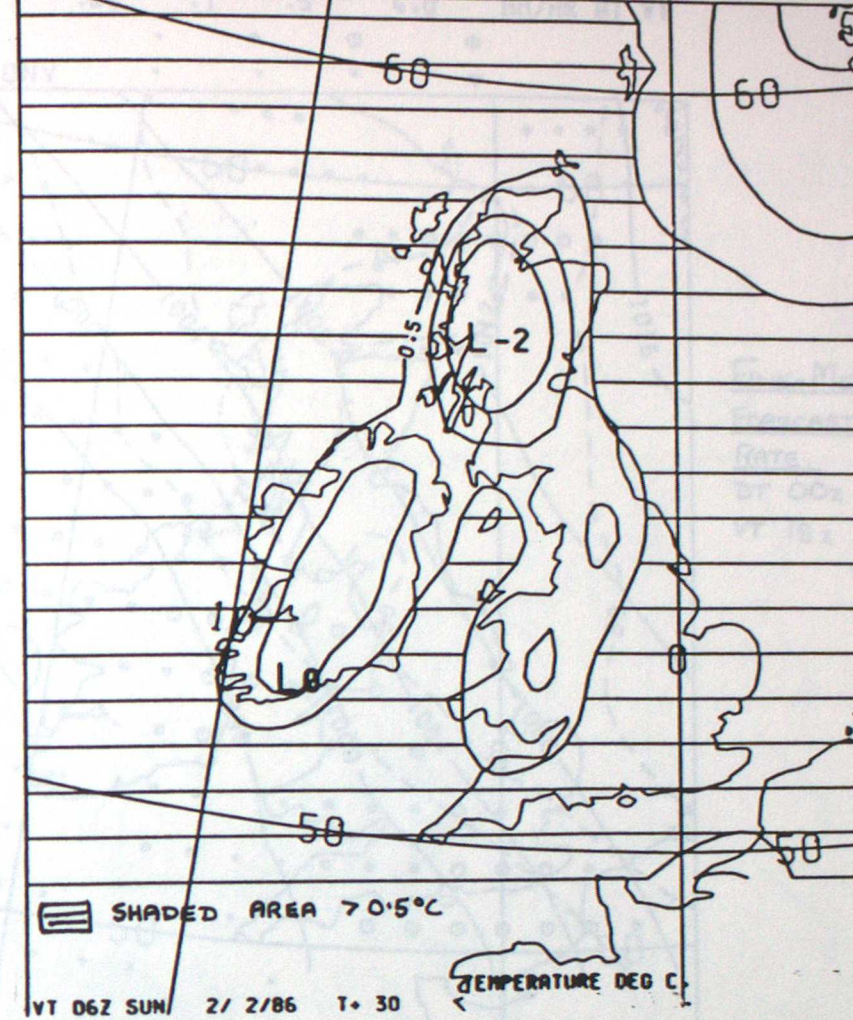


FIGURE 14b

SCREEN TEMPERATURE

FORECAST

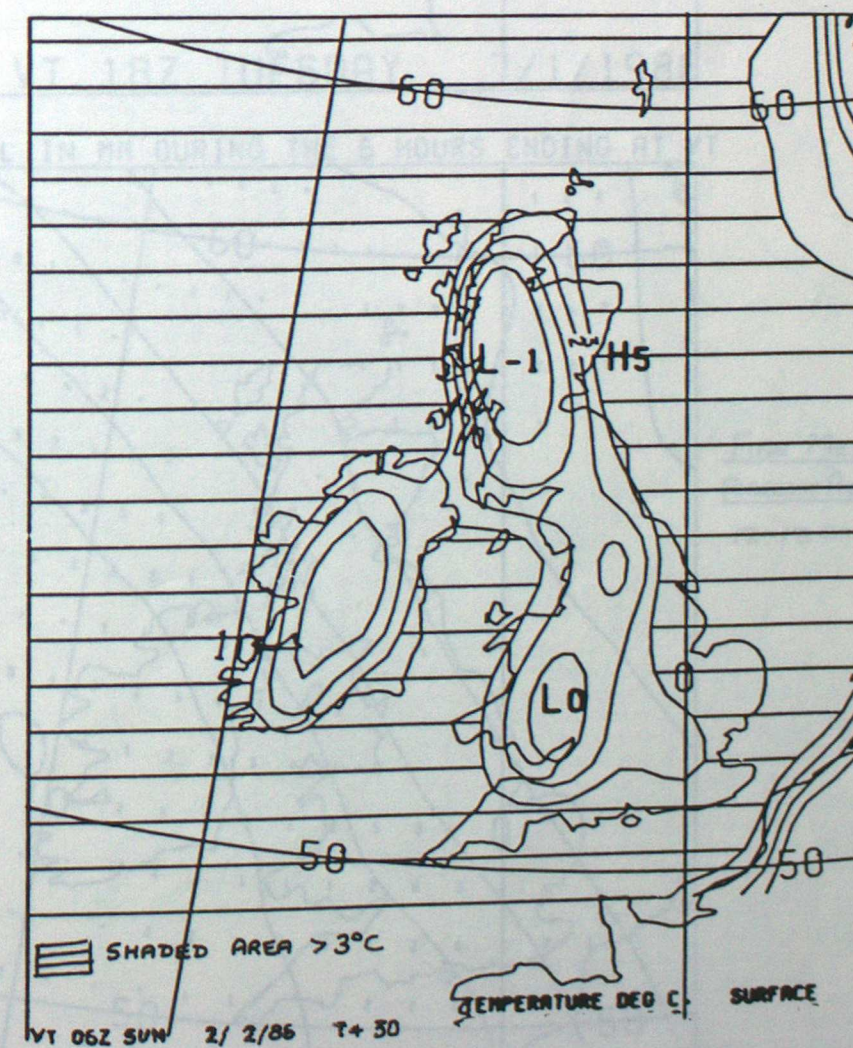
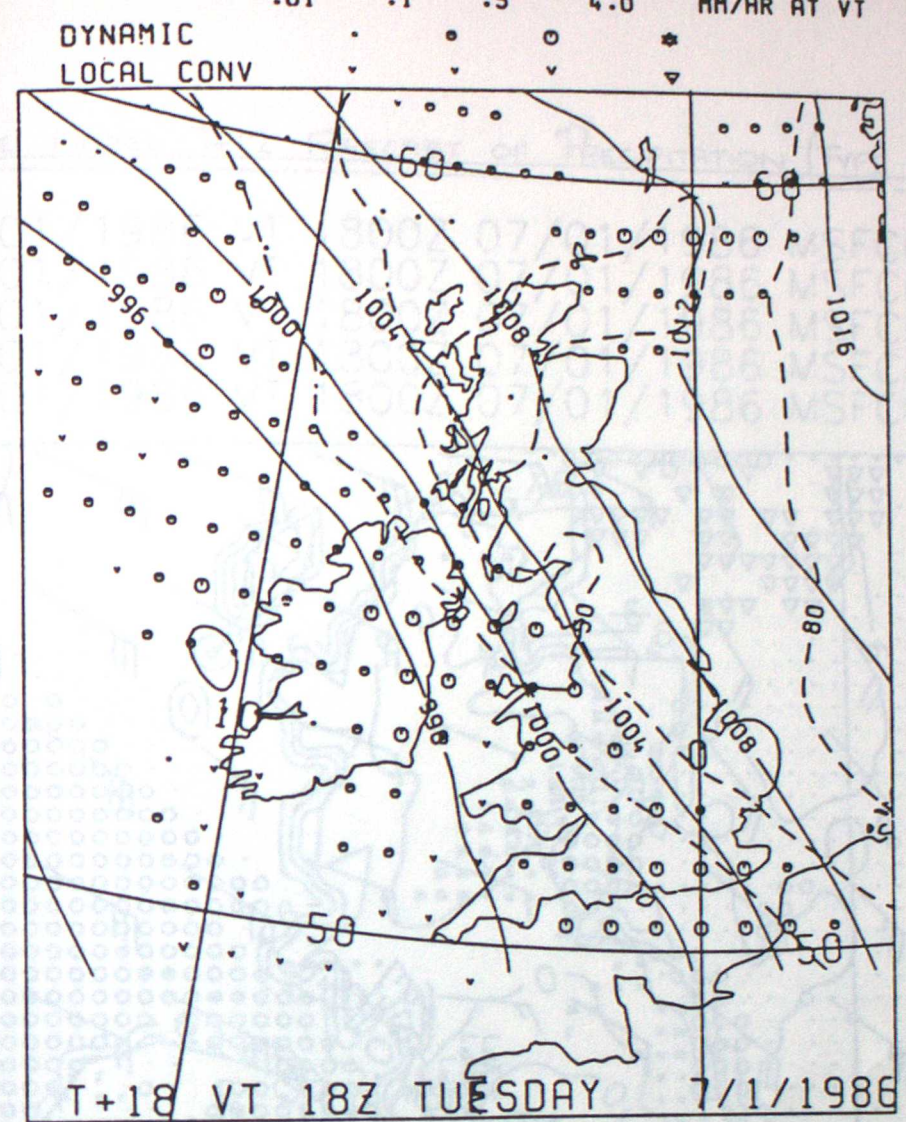
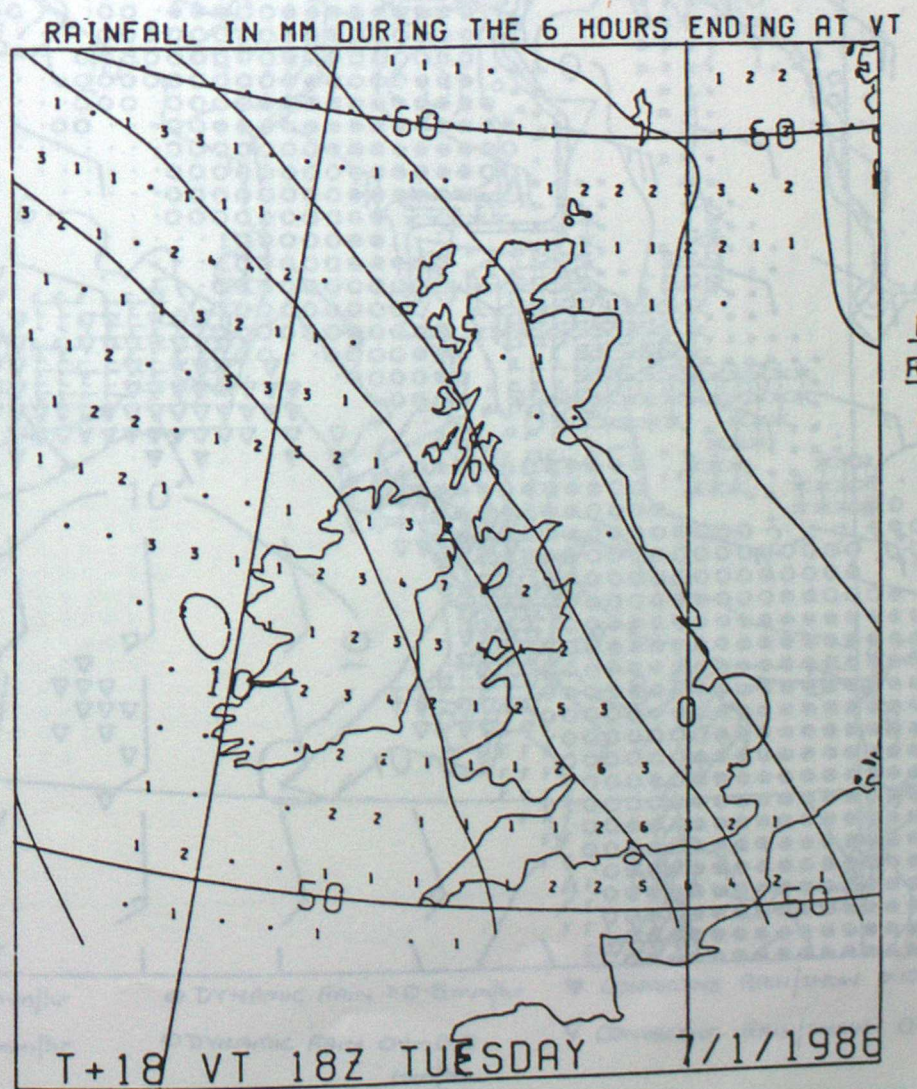


FIGURE
15a



FINE-MESH
FORECAST PPN
RATE:
DT 00z 7/1/86
VT 18z 7/1/86

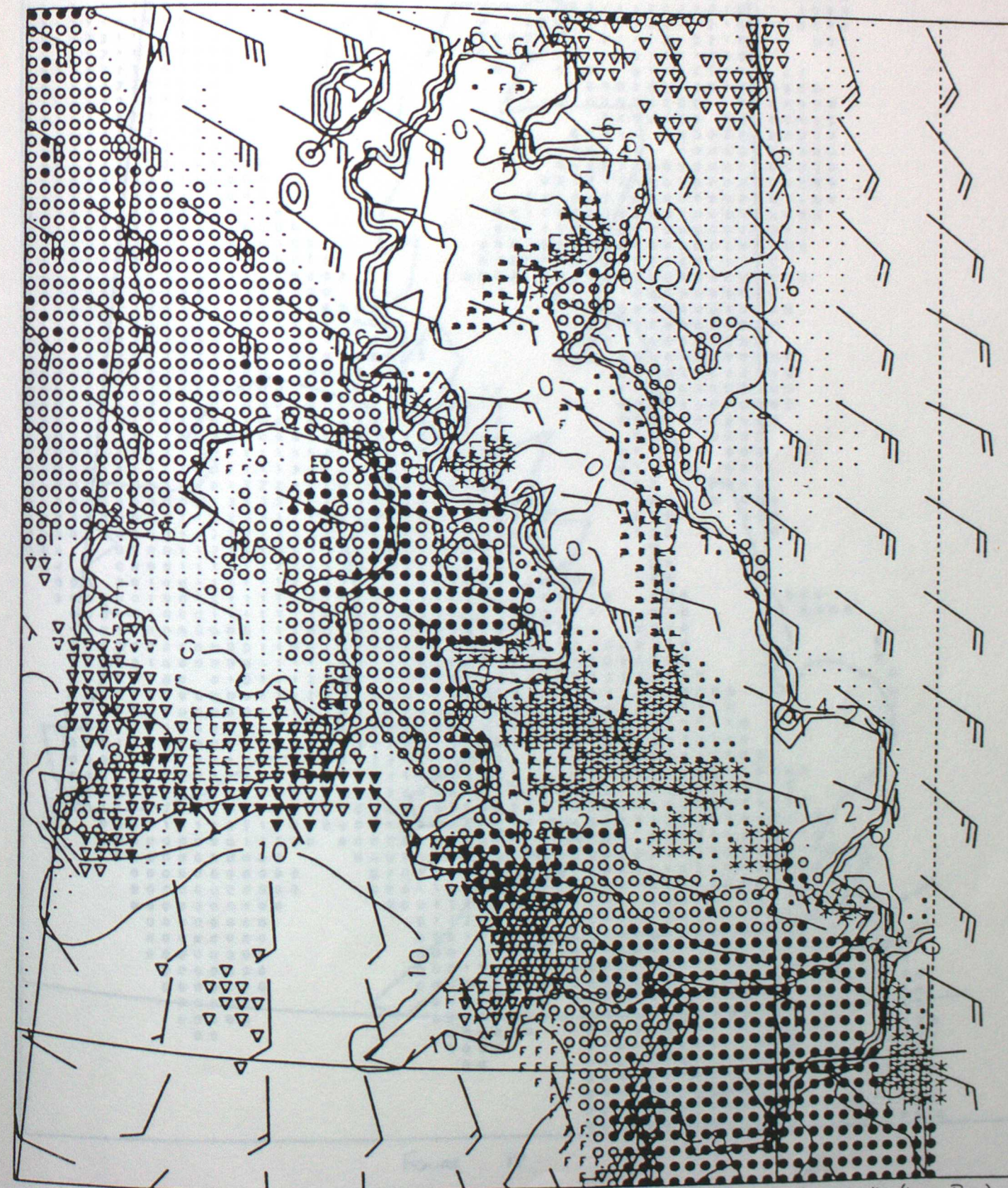
FIGURE
15b



FINE MESH
FORECAST ACCUMULATION
12-18 GMT 7/1/86

MESOSCALE MODEL T+12 FORECAST OF PRECIPITATION (TYPE AND RATE)

DT 0600Z	07/01/1986	VT	1800Z	07/01/1986	MSFC06	TT
DT 0600Z	07/01/1986	VT	1800Z	07/01/1986	MSFC06	DDFF
DT 0600Z	07/01/1986	VT	1800Z	07/01/1986	MSFC06	PR
DT 0600Z	07/01/1986	VT	1800Z	07/01/1986	MSFC06	PR
DT 0600Z	07/01/1986	VT	1800Z	07/01/1986	MSFC06	W



* SNOW > 0.5 mm/hr • DYNAMIC RAIN > 0.5 mm/hr ▼ CONVECTIVE RAIN/SNOW > 10.0 mm/hr (LOCAL RATE)

* SNOW < 0.5 mm/hr ○ DYNAMIC RAIN 0.1-0.5 mm/hr ▽ CONVECTIVE RAIN/SNOW 0.4-10.0 mm/hr (LOCAL RATE)

• DYNAMIC RAIN < 0.1 mm/hr.

DT 0600Z 07/01/1986 VT 1800Z 07/01/1986 MSFC06 PRAC

MESOSCALE MODEL ACCUMULATION FORECAST 12-18 GMT 7/1/86

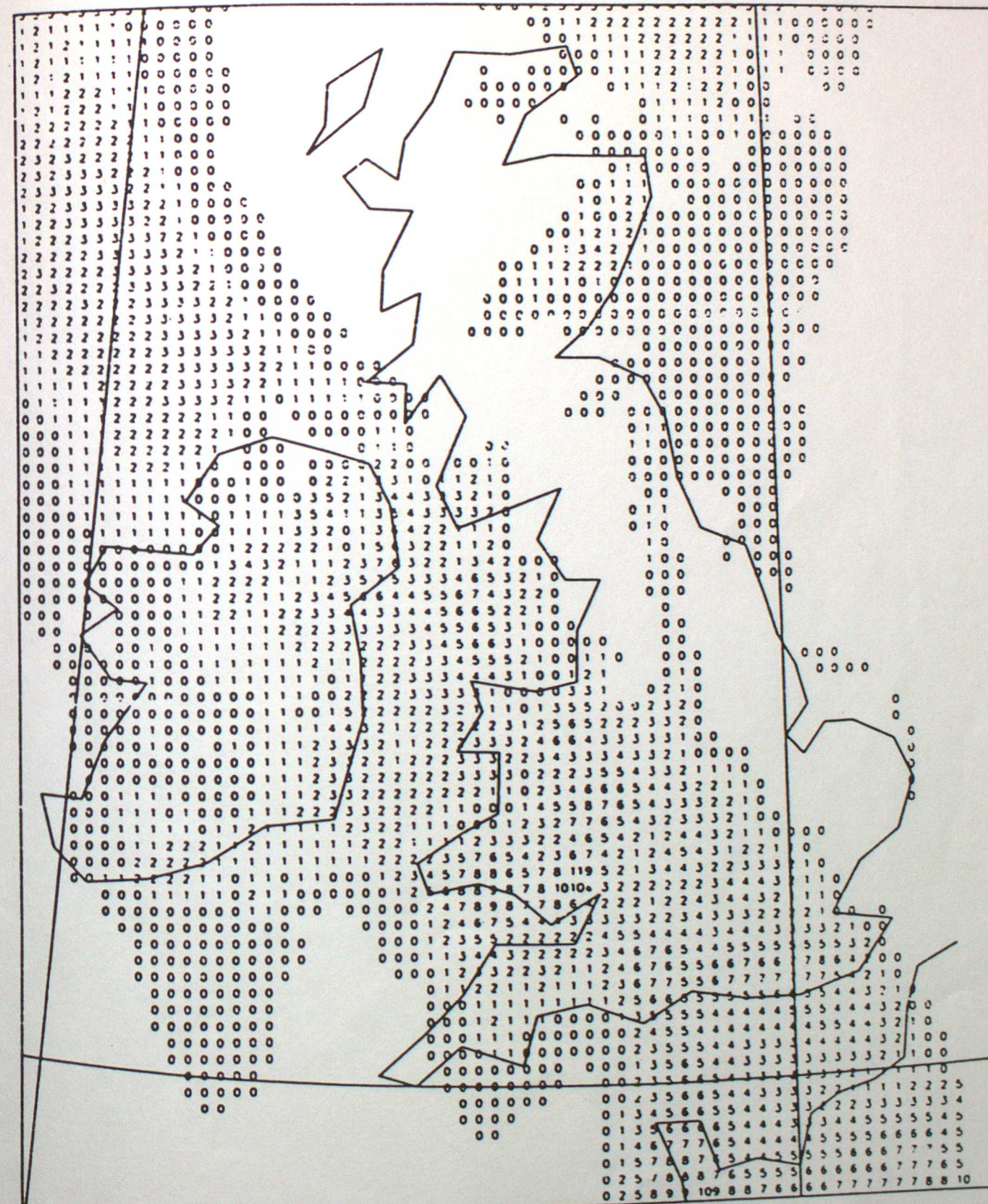


FIGURE 17

