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MET O 11 TECHNICAL NOTE NO. 239

MESOSCALE Case Study

PROJECT HAAR

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Aim of Project

The aim of this project was to simulate a case of sea fog studied in Project Haar using the mesoscale model. Project Haar was a study coordinated by the Special Investigations Branch of the Met Office, and involving the meteorological station at Lossiemouth and the Hercules of the Met Research Flight based at Farnborough. The onset and clearance of Haar has long been a major problem to forecasters on coastal airfields on the North Sea. Met O 9 are at present preparing a paper 'The Haar of Northeast Scotland', which describes the project and reports its findings.

Introduction

Sea fog affects north eastern coasts of UK during spring and early summer, causing considerable disruption to many activities, noteably aviation.

The onset of fog may be sudden with a large fall in temperature and visibility over coasts down to as little as 10 metres. Fogs may originate in the Atlantic and enter the North Sea between Scotland and Norway, or they may form on the North Sea in a warm south easterly airstream. Formation occurs when warm air moving over a colder sea is cooled below its dew point. Long wave radiation from the fog top gradually cools the fog and leads to an unstable temperature lapse rate within the cloud. Further cooling may see the fog mass becoming colder than the sea surface and mixing is then enhanced by convection from the sea surface. Weak convection patterns may be viewed in the fog tops on such occasions (Douglas 1930).

Haar is often associated with fine settled weather inland and coastal air temperatures may differ from those inland by more than 15°C; local conditions are thus drastically changed.

Description of April 1984 Haar Case

An anticyclonic situation on 25th April caused sea fog in the eastern Atlantic to be advected around the north of Scotland into Moray and Cromarty. The fog spread southwards to eventually reach the Netherlands and affect all the east coast of UK. By late 27th the anticyclone had moved over the North Sea causing the fog to retreat northwards again influenced by the south south easterly winds. The fog finally cleared the Scotish east coast on 29th.

The 27th was declared an investigation day for Project Haar. (Findlater 85)

Heat Low - April 27

The formation of a Thermal low requires a horizontal temperature gradient of at least 1°C/25 km and a differential between the warmest and coolest areas of at least 3°C. Differences of this order are most commonly found between the mountain areas and the coast. (Bishop, 74)

Normally an initial low forms over Strathspey and later a further centre developes over Easter Ross. On the 27th these were perhaps more west than is usual which may be attributable to the cooling presence of the Haar over the east coast.

On several occasions, where Haar was over the coastal regions of north east Scotland, but only reaching a couple of miles inland, the formation of a heat low, producing drier land wind in the afternoon, has achieved a clearance of the fog from the Moray coast just west of Lossiemouth eastwards. This may be due in part to burning off locally, but the heat low circulation leads to the transfer of the effects of the Haar to the west coast of the Firth. This feature was well demonstrated on the 27th April case.

An indication of the temperature disparity between the Haar and the area affected by the heat low is that at 15Z the air temperature at Lossiemouth was 8.7°C, in the fog and at Killin (highlands) it was 24.7°C.(Fig 4). The pressure difference between the centre of the heat low and Lossiemouth was over 3 mb MSLP at 15Z.

Mesoscale Model

The dynamics of the mesoscale model used for this study is described by Tapp and White (1976) and Carpenter (1979) and a general description of the current forecasting system is described by Golding (1986). This model is constantly being updated and the experiments were performed around spring 1986. Where necessary, dates are included to indicate the changes incorporated into the mesoscale model. These changes were generally related to the radiation scheme used in the model. Also a point to note, is that the fine mesh forecast at the time did not include a soil temperature scheme and screen temperature forecasts have improved with the inclusion of the scheme.

The area used for the experiments was a grid of 50 x 50 points separated by 15 km, centred at $57\frac{1}{2}$°N $2\frac{1}{2}$°W with 16 vertical levels up to about 12 km. (Fig. 1).

Description of data available

Surface Observations

Surface observations are scarce in the area of the experiment. Scotland itself is very sparsely populated, with less than 200 people per square mile and the rest of the area is composed of sea. Since the advent of North Sea energy, offshore platforms have provided a useful source of data from the sea and in fact over the area at 06Z more data was received from sea stations than land. (Figs 2,3,4). Of particular relevance to project Haar 2 stations reported from the Moray Firth; the oil platform Beatrice A at 58° 06'N 03° 06'W and due north of this, also stationary at the time of the experiment was MV 'Seaboard Illustrious' at 58° 18'N.

Radio Sonde at Shanwell

Shanwell was affected by the Haar on the 27th April. The ascents analysed were for 00Z 27/4, 12Z 27/4 and 00Z 28/4. (Fig. 5). This data was referred to extensively when the initial data for the Meso scale runs were amended by hand; in order to produce a more valid starting point for the experimental runs of the model. The points to notice particularly, are the temperature and relative humidity profiles at the fog top.

Description of Data available

Satellite Images

At 0836 and 1448 GMT on 27th.

Noteable is the extent that the fog has moved inland along the valleys during the night, (Fig. 8) assisted by radiation cooling. The 1448 picture (Fig. 9) demonstrates the fog being burnt off during the day. A well defined clearance is also observed on the south coast of the Moray Firth. This is probably due to the sea breezes of the east and north facing coasts together with the circulation associated with the heat low over the highlands, thus producing an offshore component. (Bishop 74). Also cumulus cloud developed over the central highlands as a result of the hot surface temperatures. Patches of snow are visible in the central highlands.

Minisonde data at Lossiemouth

In 1983 a small portable radio sonde station (Kaymont Airsonde System) was installed at Lossiemouth. The site is 1 km from the shore and was used extensively for producing rapid sequential soundings during Haar events.

For this case data from 5 flights were available

i) 23.30 on 26/4

Observations were taken every 5 seconds approximately from 23.30.21 till 23.39.01 when the sonde had attained a height of 1007 metres.

ii) 08.50 on 27/4

This relates closely to the satellite image, in time.

Observations are available for about every 30 seconds between 08.52.32 till 08.58.01 when the sonde was about 1000 metres.

iii) 10.38 on 27/4

Again every 5 seconds up to 1000 metres.

iv) 12.15 on 27/4

5 seconds till 1000 metres.

v) 14.30 on 27/4

Coinciding with the satellite image and the clearance reaching Lossiemouth.

5 seconds till 1000 metres.

Each observation generated the following data

i)	Time	Seconds
ii)	Calculated Altitude	Metres
iii)	Observed Pressure	mbar
iv)	Dry Bulb Temperature	°C

v) Wet Bulb Temperature °C

vi) Relative Humidity %

vii) Dew Point °C

Data recorded by MRF Hercules flight H656

The Hercules, based at Farnborough, was mobilised for Project Haar and deployed at the fog top over the Moray Firth. Examples of soundings through the Haar are shown in Fig. 10.

Interesting features of April Haar

The Main features of the observations taken in Project Haar were:

i) A very sharp temperature inversion just above the fog top. A change of 10°C in about 100 m.

ii) The lapse rate is close to the saturated adiabatic lapse rate, and the fog is unstable relative to the sea surface temperature.

iii) The liquid water content of the fog is close to a simple adiabatic ascent. The fog top is very pronounced, changing from maximum liquid water content to clear air within 20 m. At the fog top liquid water content was about 0.5 grams/cubic metre.

Targets Of Simulation

There are 4 features of the April 27 Haar event which we might use as bench marks with which to subjectively assess the performance of the mesoscale model experiments.

The extent of the fog is an obvious feature to try to simulate, and its effects were most dramatic. The satellite images are a good guideline for this target.

The heat low was the other prominent feature to study. The high temperatures over the highlands in the afternoon reached over 24°C in places. Because of the mountains it would be perhaps invalid to compare pressures but associated circulation patterns could be studied.

In the afternoon convection effects were observed in the form of fair weather cumulus cloud over the highlands. Often such local convection may produce Cumulonimbus and moderate showers, especially to the north east of the heat low centre (Bishop 74). The occurrence of some convective activity forecast by the model would also be regarded as a good point in favour of that particular run.

Initial data for Mesoscale Forecasts

1. FMMS

A run was executed using the fine mesh model and starting from actual operational data for 00Z on the 27th April. This run was to provide a first guess background data field (fig. 11a) and also boundary data for the subsequent mesoscale forecasts by interpolating 3 hourly fields to the mesoscale grid.

2. MSMS

Using the fields generated by FMMS, a mesoscale forecast was run, starting with the interpolated fine mesh fields for 06Z. This was to produce a first control run.

3. MERG

Surface observations for 06Z were analysed and merged into the interpolated fine mesh 06Z fields to produce corrected initial data. (Fig. 11b). This attempts to correct any errors in the fine mesh forecast for 06Z.

The only observations included were the data available for a normal operational forecast run and did not include any of the special data generated by Project Haar.

4. FOGN

The initial data was amended using the extra data available to try to produce more realistic fields for the model. Using the satellite data to ascertain the extent of the fog and the various vertical profiles to show the likely real values within the fog, the lowest levels of the initial model fields were amended. Figures 12 and 13 show the extent of the changes. The cloud moisture (M) in the designated area was increased from 0.0003 kg/kg at level 10 metres adiabatically to 0.0006 kg/kg at level 310 metres as shown in figure 10. The value of M at level 610 metres was also dropped to 0.0003 kg/kg over most of the area of fog cover shown by the 0833 satellite image. Above this level the cloud moisture values were left as they had been for MERG. Similarly the Relative Humidity (RH) fields were amended. The same areas were used as for the equivalent cloud moisture at that level, and were set to 100% humidity up to and including level 610 m. At level 1010 metres the humidity in the key area was lowered to 90%. Levels 1510 metres and above were left as for MERG. The most obvious changes (figure 11(c)) are that the fog is removed from the Grampians, added in the North Sea and generally made wetter.

5. POTN

For this run the potential temperature field allied to those changed fields described above was also amended in an effort to better simulate and maintain the fog top inversion. (Fig 14). The main difference being at the 310 m level. The 10° isotherm is moved westward in the area of fog, in an attempt to better simulate the cooler temperatures below the fog top inversion, and allowing a faster warming to the 610 m level.

The initial data for the remaining experiments was left unchanged. A new radiation scheme was introduced and then the roughness coefficient (Z0) of the land was increased. Normally set to 0.1 m Z0 was increased to 1 m and then 2 m.

Description of Experiment Results

1. FMMS

In the interpolated fine mesh (T + 6) forecast for 06Z (Fig. 11a), the fog, although dense was generally badly placed. it was well positioned in the Moray Firth and the Forth Valley. However fog was forecast off the west coast of Scotland and the North Sea was virtually free of fog, a state of affairs which was eminently unsatisfactory.

By 18Z (Fig. 15) the fine mesh forecast had completely removed the fog. Lifting it off the surface to form stratus cloud.

The initial surface temperatures seemed satisfactory but despite there being no fog to burn away the temperatures over the highlands barely exceeded 16°C. The subsequent wind fields were unsatisfactory, showing no circulation around a heat low, and no convective cloud or showers were developed over the highlands.

2. MSMS (Fig. 16)

The fog was again cleared from the North Sea. However fog/low cloud did remain all day on the windward side of the Grampians.

The land however was heated much more realistically although of course there was not the dramatic change from the foggy coast to the baking highlands. Temperatures rose to over 22°C, at 15Z. The winds however were not significantly altered. No showers were generated over the highlands.

3. MERG

With the benefit of surface observations the initial positioning of the fog was much more satisfactory (Fig. 11b). However, there was perhaps too much over the Grampians and much of the North Sea was still clear, (this was because of the lack of observations in the North Sea to correct the first guess fine mesh forecast of no fog at 06Z.

However in the forecast (Fig. 17) the fog was very quickly removed from the sea. being raised to form stratus. Fog remained all day over the East Grampians and over the windward slopes of the North West Highlands and the Southern Uplands. There was much precipitation from this low cloud throughout the day.

Western Scotland heated up most satisfactorily. There was very sharp temperature gradient at the fog edge, with a change of 10°C in 50 miles along the Tay Valley.

The wind field at the surface verified well displaying a distinctive heat low circulation pattern. No showers were developed in the afternoon, however some convection was generated on the windward slopes out of the fog.

4. FOGN (Fig. 18)

The fog was maintained much better in the Forth Valley but over the Grampians it was not burnt away. The fog was lifted along the coastline and the sea fog slowly left the surface. However the first clearance was along the south Moray coast as in reality.

The temperatures over the highlands away from the fog rose very quickly, broaching 22°C before midday. The surface temperature gradient at the edge of the fog was again satisfactory.

The winds again were very realistic. This time showery activity was also developed over the highlands in the afternoon.

5. POTN (Fig. 19)

Results were very similar to the above with no dramatic differences in scale or timing.

6. NEW2 (Fig. 20)

The radiation scheme was updated in May 1986 to include a radiation budget at cloud top and the forecast was rerun, the results, if anything being slightly less true to life.

The fog is maintained, and indeed the area covered over land is enlarged during the day and is not burnt off at all. The area of the Highlands heated by short wave solar radiation is thus diminished, however temperatures on exposed high ground do get to more than 22°C.

There was a marginal increase in showers in the afternoon.

Winds are not noticeably altered.

7. CTR2 (Fig. 21)

The roughness of the surface parameter Z_o was changed from 0.1 to 2.0, and the cloud top radiation scheme introduced in May was maintained. The fog over the west Grampians was removed with the subsequent increase in surface temperatures over these highlands.

8. TEST

In August several changes were made to the model noteably transmission of short wave radiation and the reduction of horizontal diffusion of thermodynamic variables and the experiment with the Haar data was rerun. The initial data field was the same as POTN and runs since (Fig. 11c).

The fog was reduced and cleared almost the whole of the Grampians (Fig. 22).

Temperatures were increased over the Grampians and an attempt was made to produce a double centre shape to the heat low as occurred in reality and which is similar to many previous cases. (Bishop 74). Showers appeared by 18Z over the Grampians.

Summary

The example involves a very complex interplay between the circulation associated with the sea fog, that associated with the heat low, with inland temperatures being almost 20°C higher than on the coast, and the sea breezes. The development of heat low may be influenced by snow cover, cloud cover and general wind direction. Indeed the situation, occurring as it does in a data sparse region, with complex orography, provides an excellent test for mesoscale forecasting techniques, in forecasting the encroachment and clearance of the Haar.

On the whole the mesoscale model made a good attempt at forecasting the heat low with its associated temperatures, winds and late afternoon convective activity. The scale of the gradient was also accurately predicted in the runs.

However the model had difficulty in maintaining the fog in a valid position. Fog was always lifted, at the coastline, off the surface, remaining as a large mass of low stratocumulus. Also the model tended to hold the fog and indeed increase the extent of the fog over the Grampians. There was much precipitation from the fog on the windward side of the mountain mass.

Conclusion

These experiments with the mesoscale model indicate the value of the continuous observations of cloud cover and cloud top temperature provided by satellite, when combined with detailed local vertical information, provided by aircraft, and sonde, in the forecasting of fog. The sparse coverage of conventional surface based observations could not sufficiently improve the initial conditions where the background fine mesh forecast was seriously in error, as shown by the comparison of Fig. 11 a and b. In the North Sea, fog was initialised around

the observations at the oil rigs but surrounding areas were left clear. Also it can be seen that in the analysis, problems occur over land due to changes in topographic height. Because analysis is performed along [illegible] surfaces (height above topography), fog in valleys can be spread over the tops of mountains causing problems over East Scotland. Figure 2, shows that the surface observations are at coastal sites and in the valleys in Scotland. Inspection of the satellite image for 08:33 allows the erroneous fog to be removed over the land and the addition of a continuous fog layer over the North Sea.

The use of the cloud top temperature from the satellite image and the detailed vertical profiles allowed the depth of the fog and the liquid water profile to be derived. The resulting improvement in the forecast is clearly seen in the comparison of Figures 17 and 18. The unfortunate reappearance of fog over the eastern side of the Scottish Highlands is probably because the area of cloud water at 310 m and 610 m, after amendments, still incorrectly extended over land and the models advection and diffusion, interacting with the orography caused fog to form over high ground. The inclusion of an inversion in the initial potential temperatures profiles has had little effect on the forecast.

Changes to the physics of the model also had significant impact on the forecast. The inclusion of a cloud top radiation scheme preventing the fog from lifting above the surface (Figures 21 and 22) to become low stratiform cloud, as in Figures 18, 19 and 20.

Bibliography

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figure 1
Experiment area for mesoscale runs.

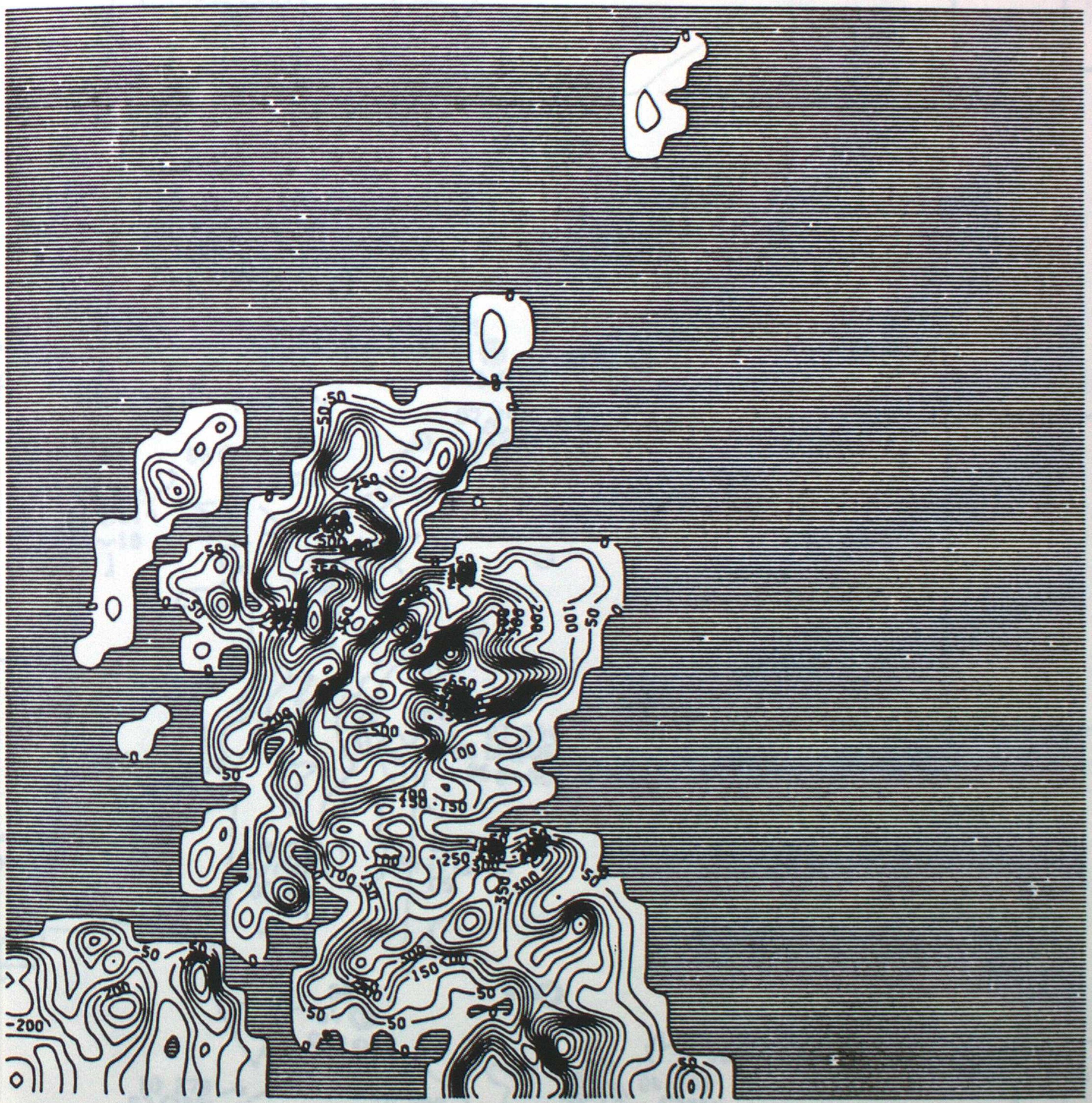


Figure 2 Actual observations Ø6Z

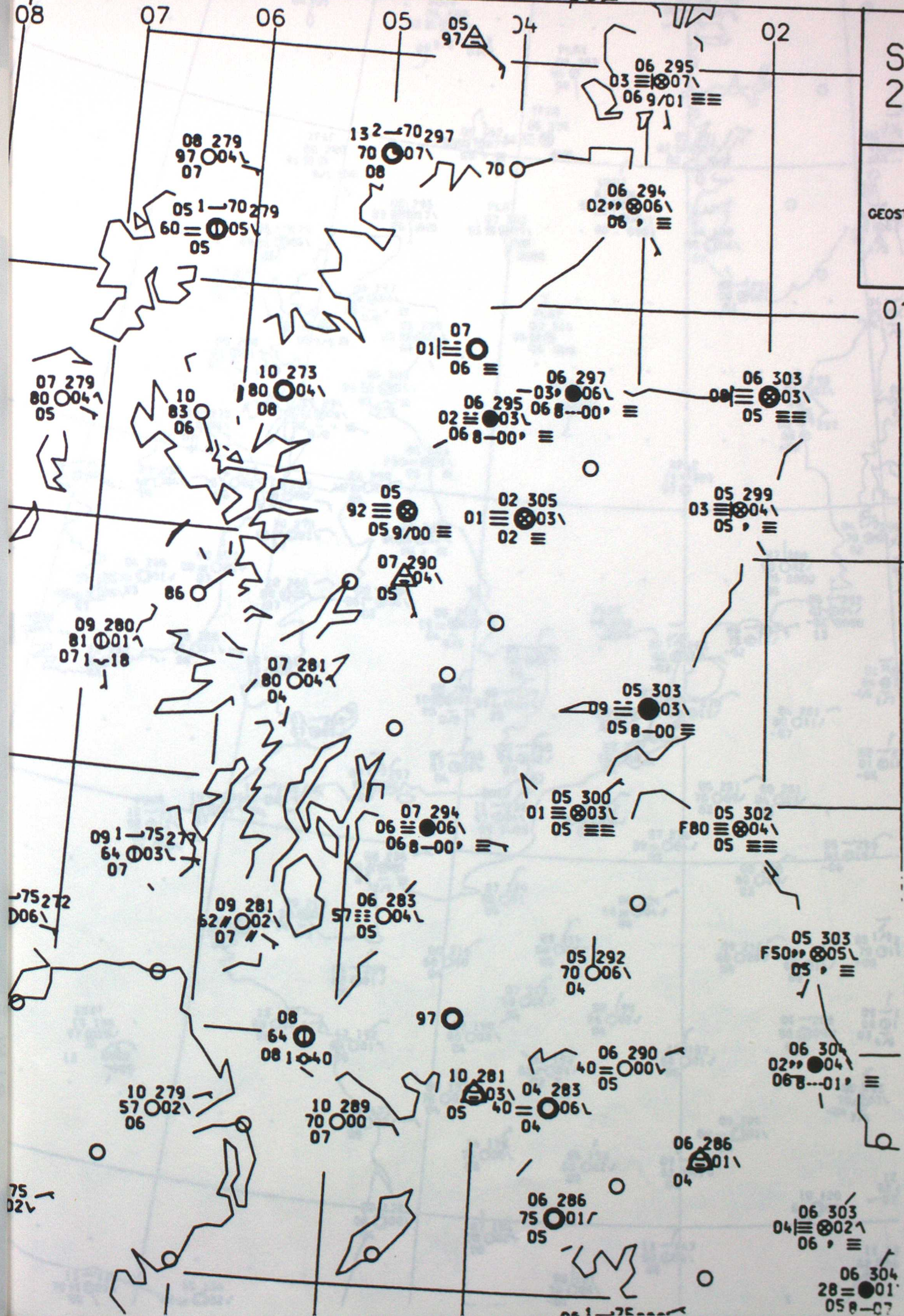
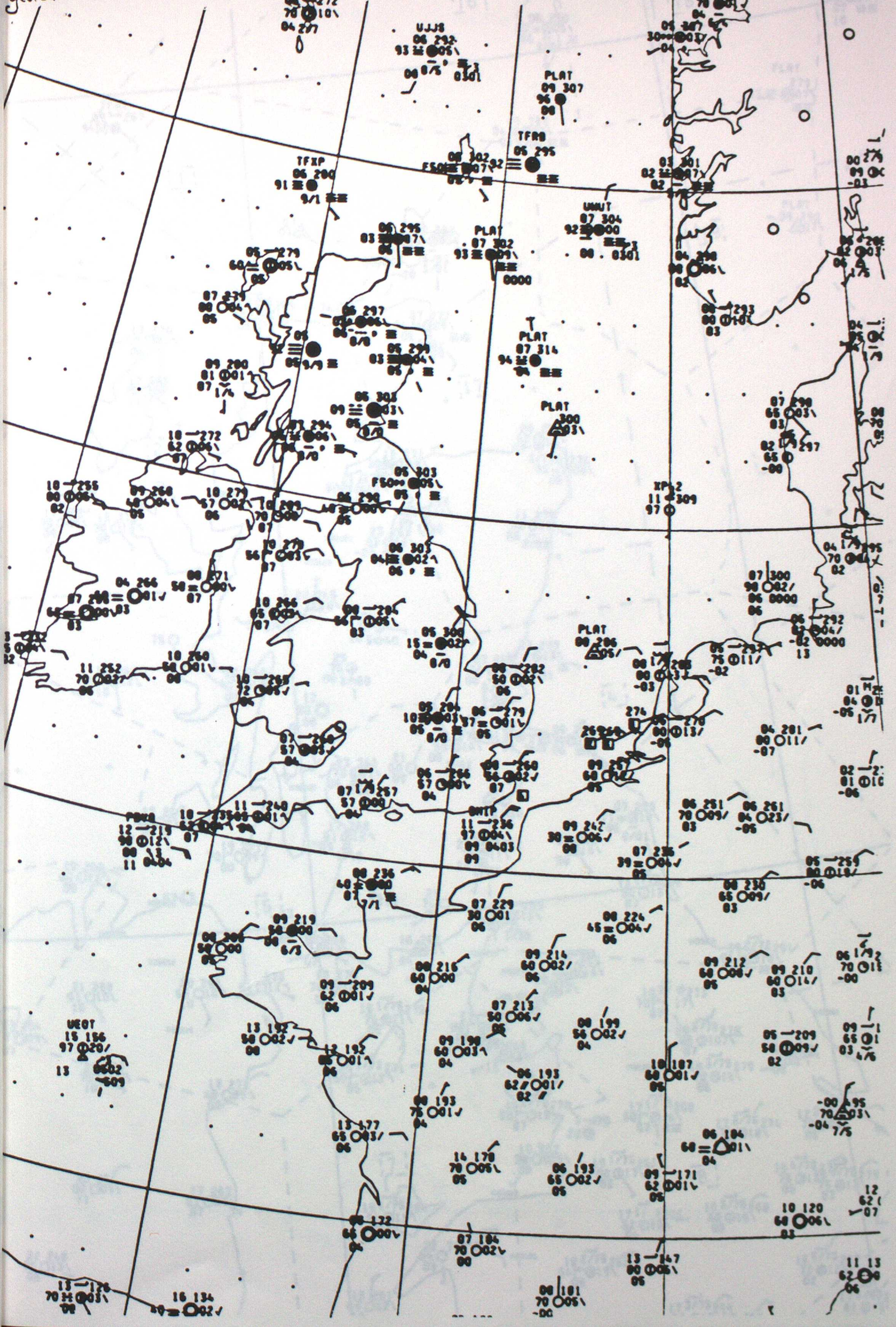


Figure 3 Actual Surface Observations at Ø6Z.



ure.4 Surface observations at 15Z.

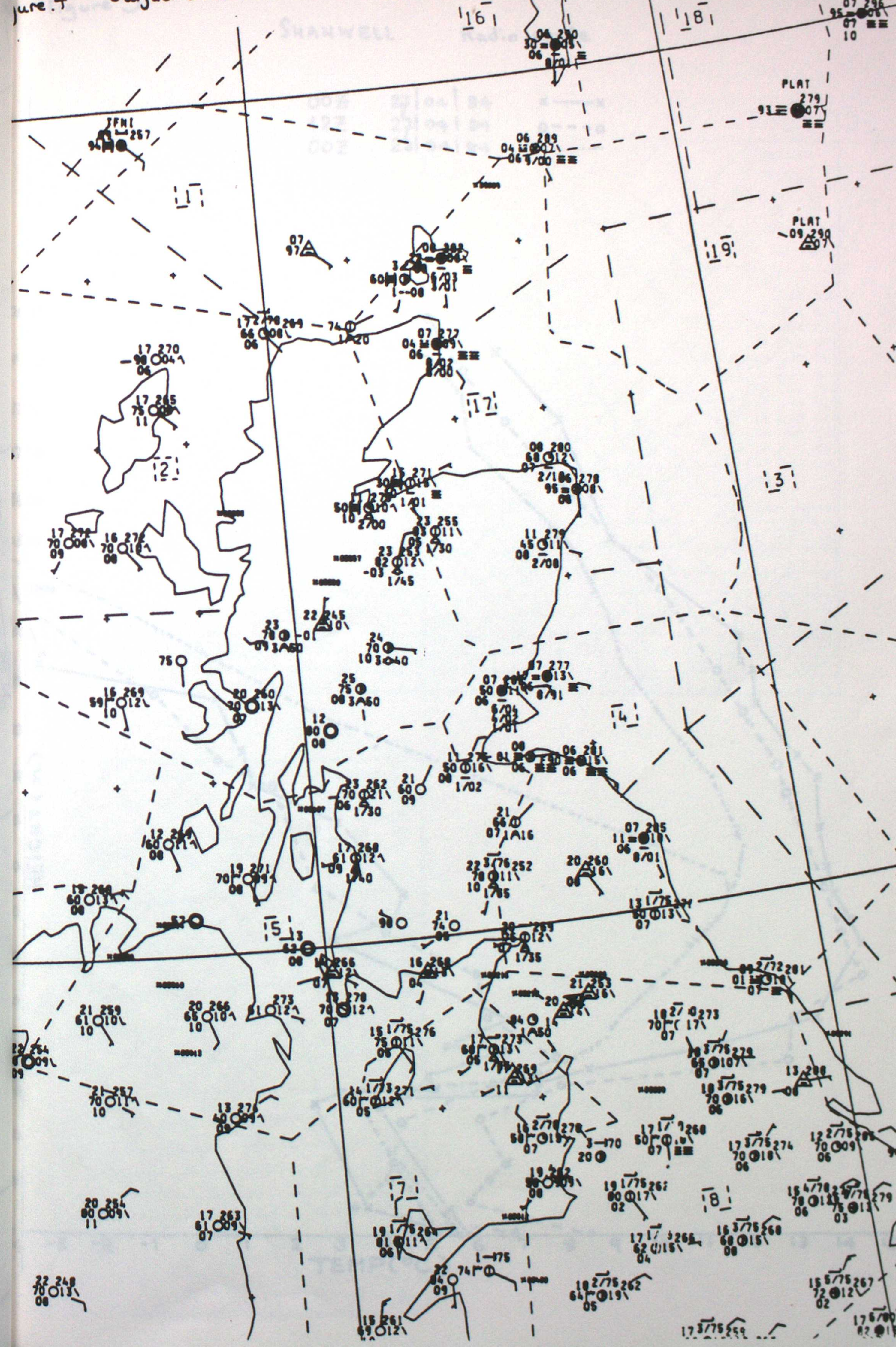


figure 5.

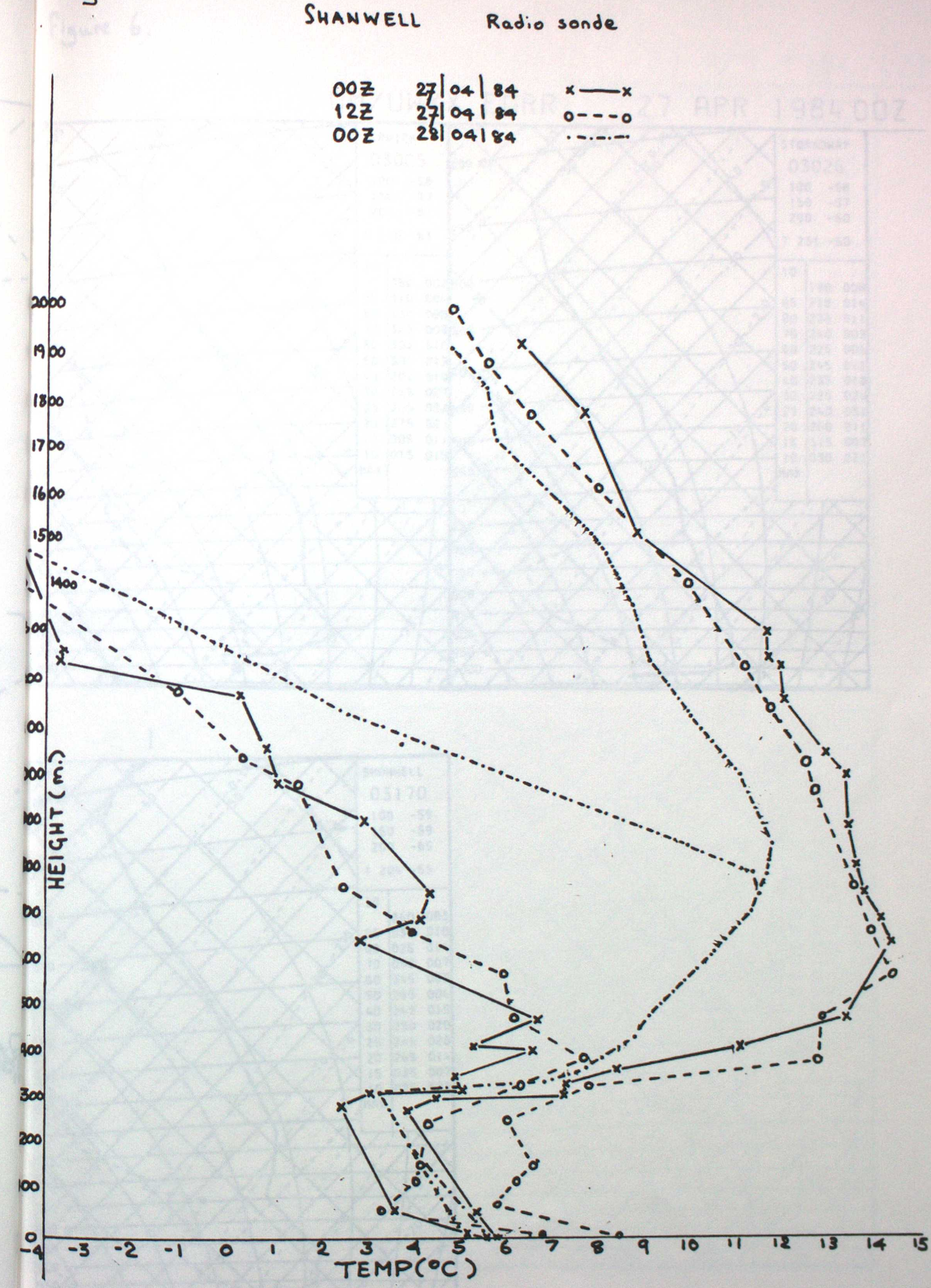
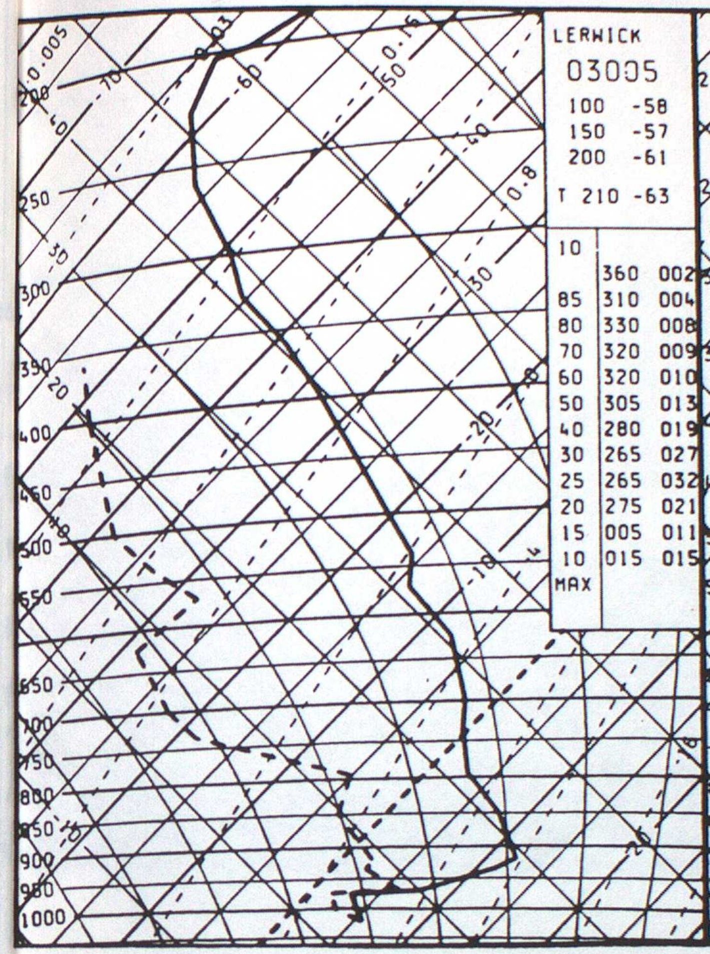
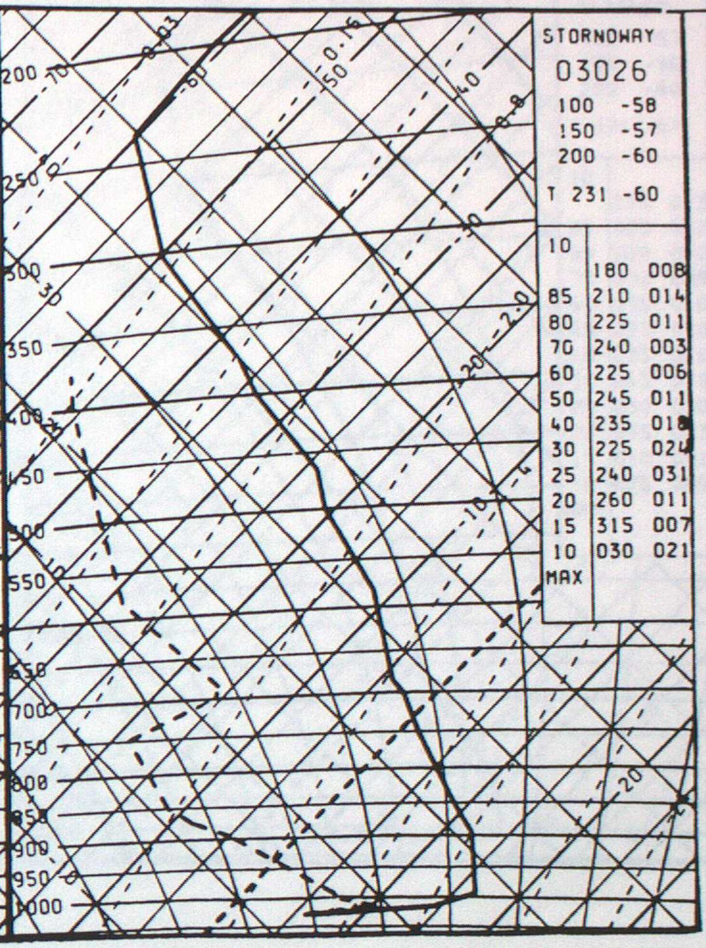

SHANWELL Radio sonde
00Z 27|04|84 x——x
12Z 27|04|84 o- - -o
00Z 28|04|84 -·-·-
HEIGHT (m.)
TEMP (°C)
2000
1900
1800
1700
1600
1500
1400
0
100
200
300
400
500
-4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Figure 6.

UM/UWXX EGRR 27 APR 1984 00Z





1

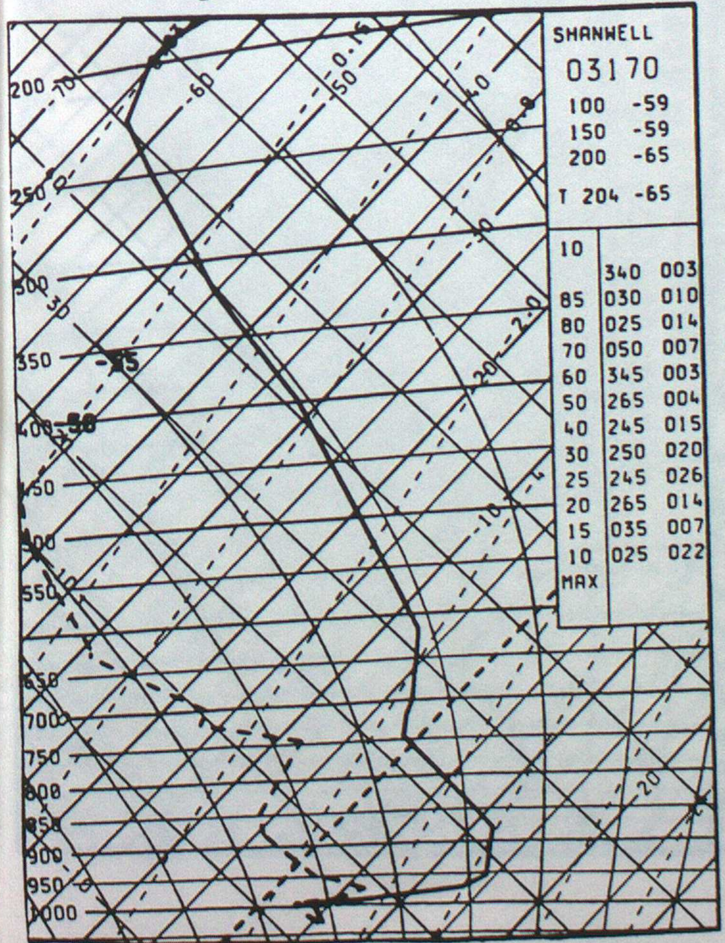


figure 7.

UM/UWXX EGRR 27 APR 1984 12Z

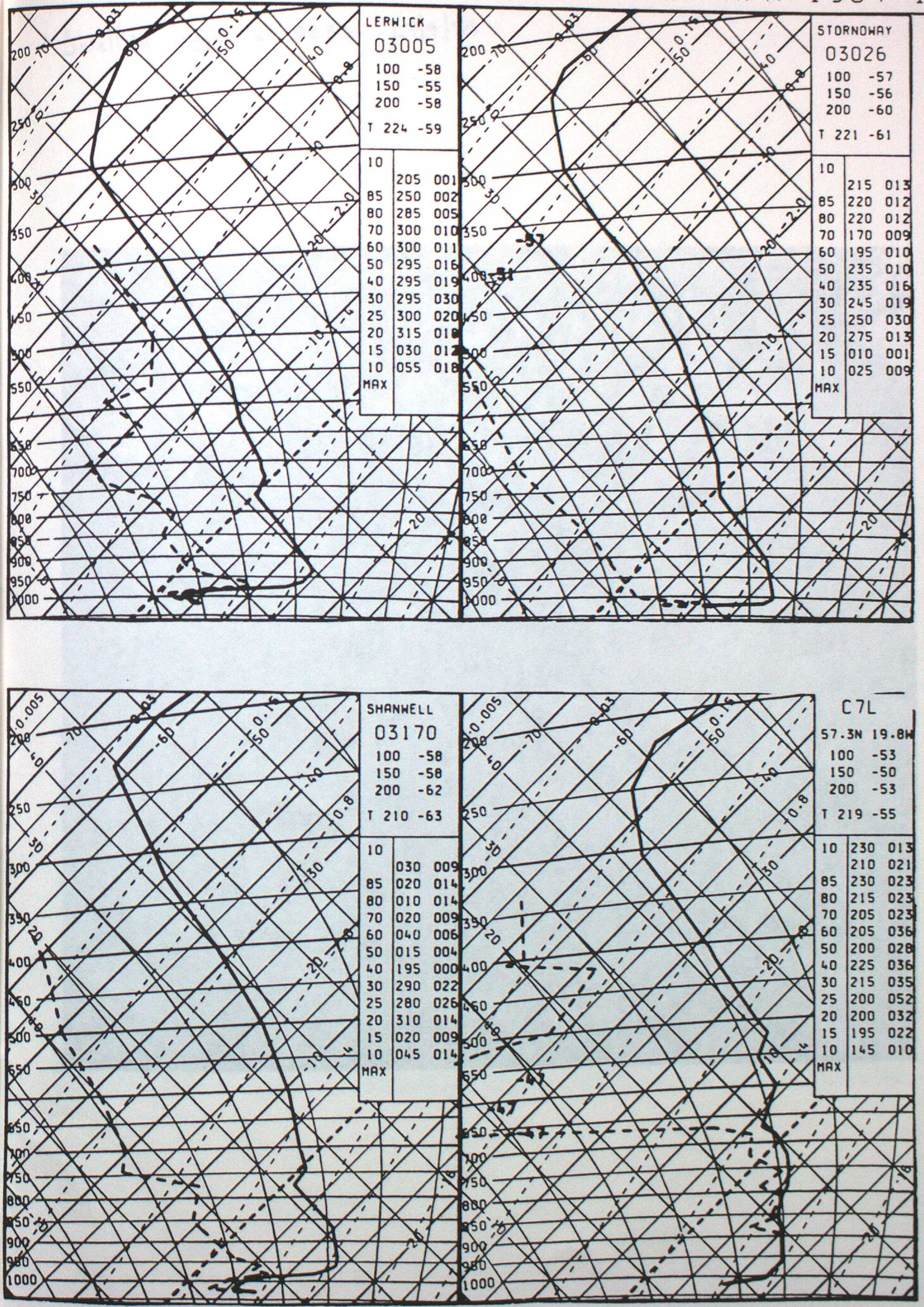


figure. 8.

Satellite image at Ø833 27/4/84

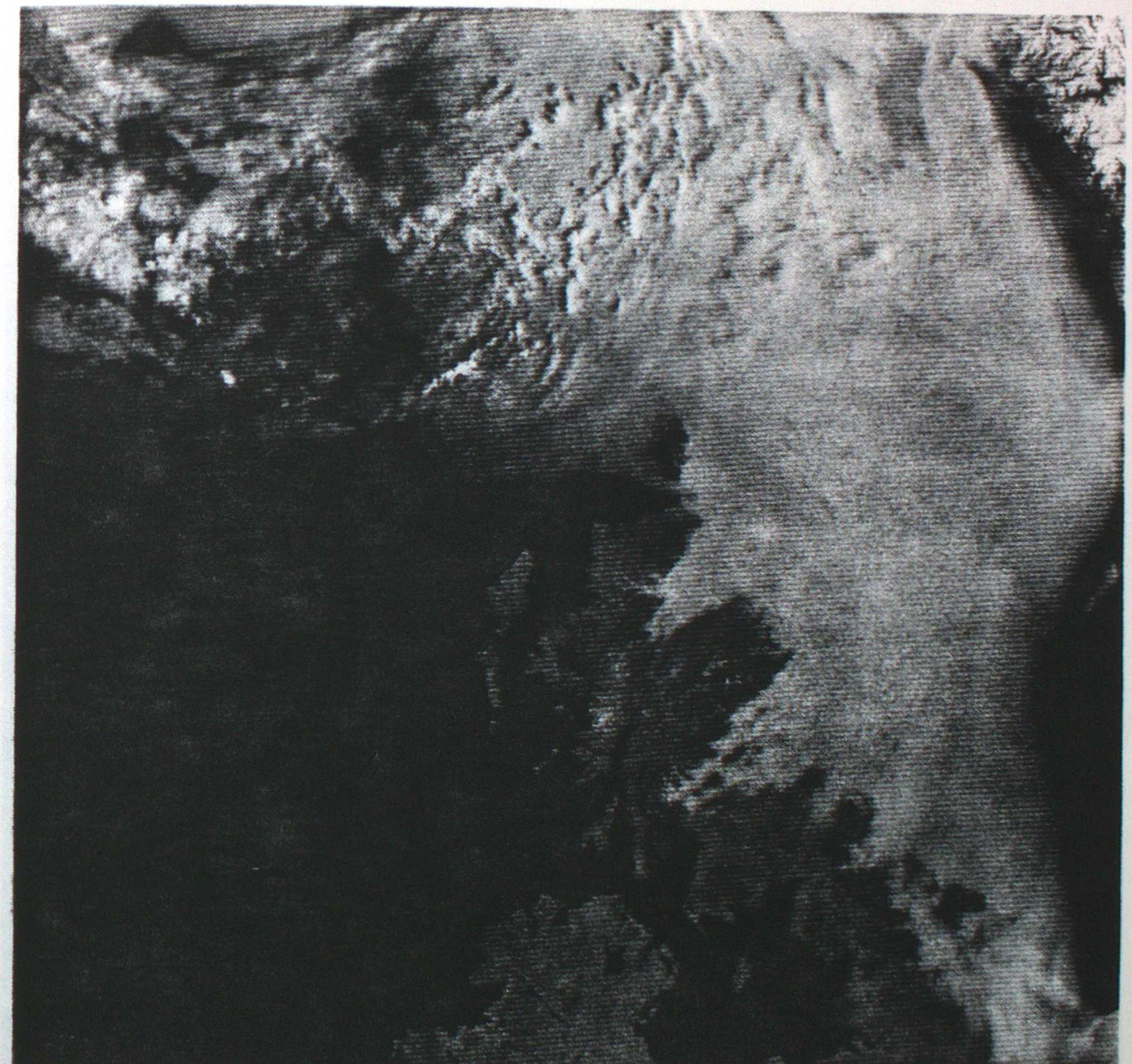


figure. 9.

Satellite image at 1446 27/4/84.

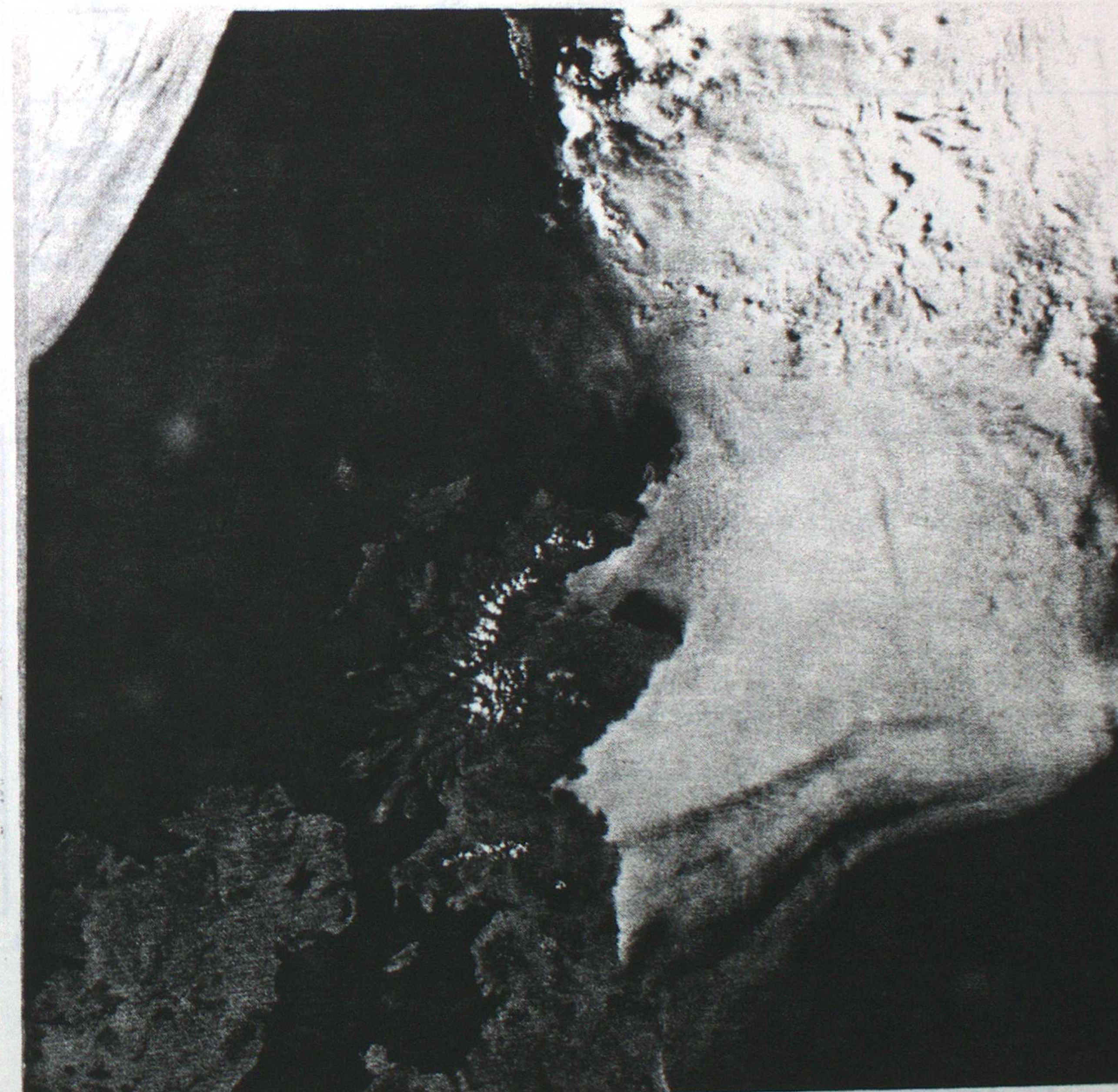
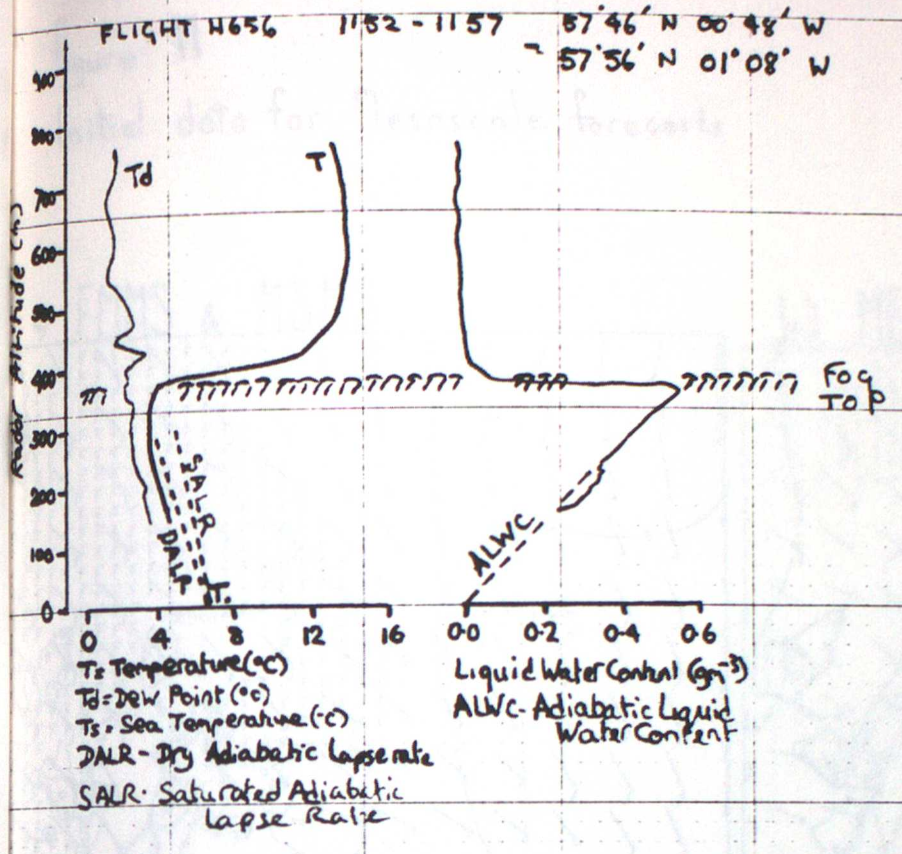
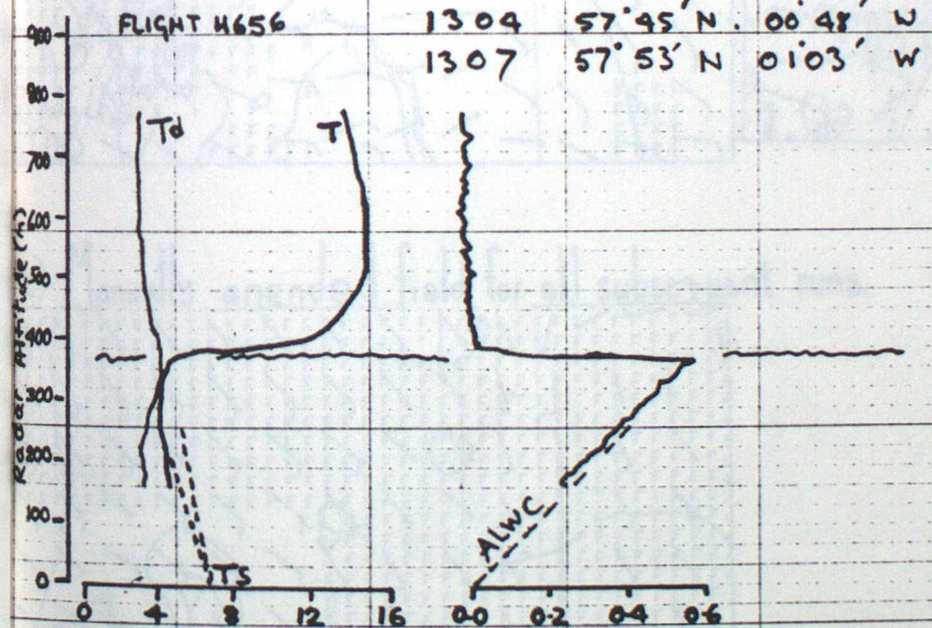


figure 10.



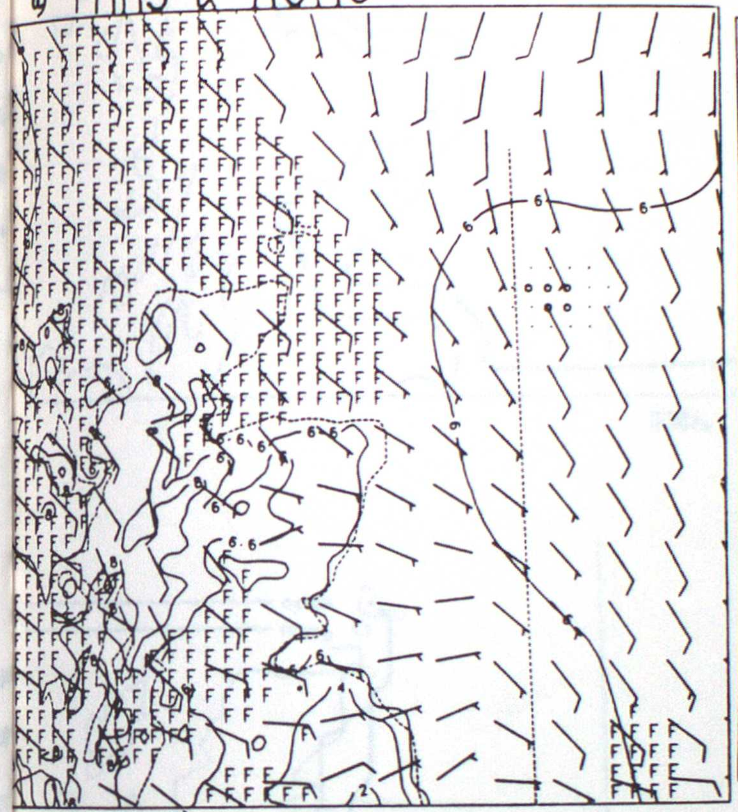


graphs presented by Project Haar report. Findlater et al.

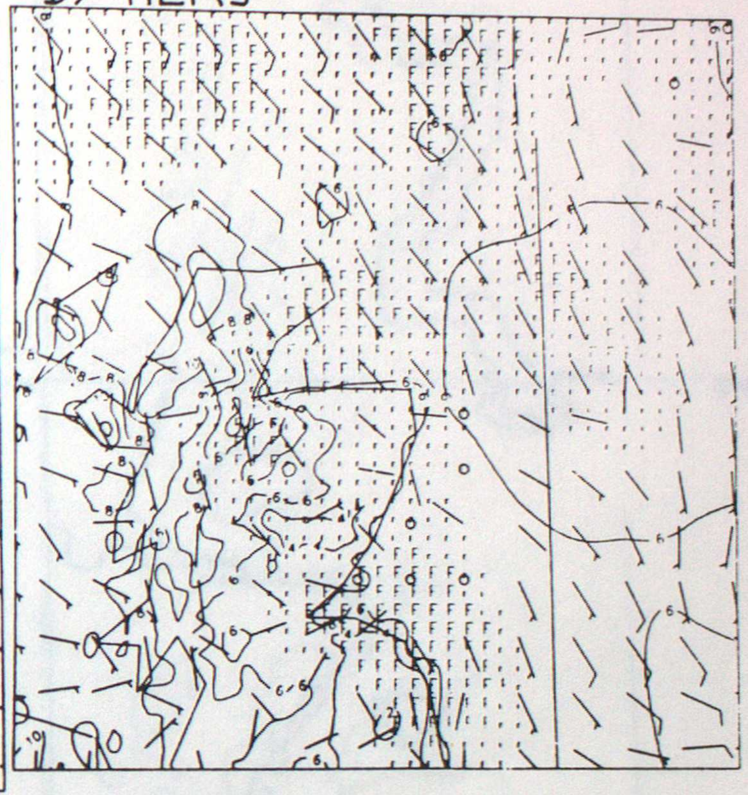
figure. 11

Initial data for Mesoscale forecasts

a) FMMS & MSMS



b) MERG



c) Manually anended field for all subsequent runs.

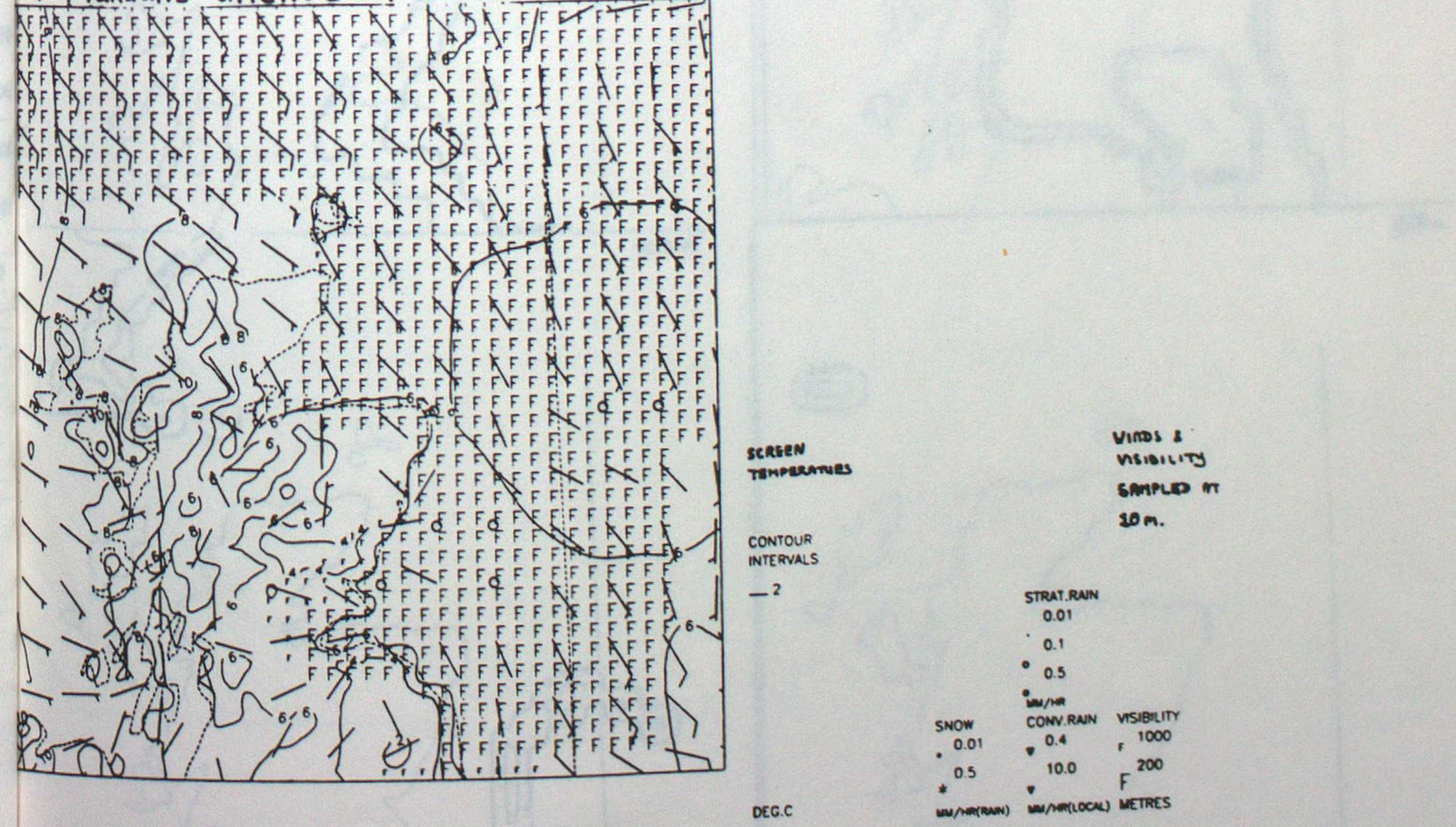


figure. 12.
Cloud moisture content. (kg/kg)

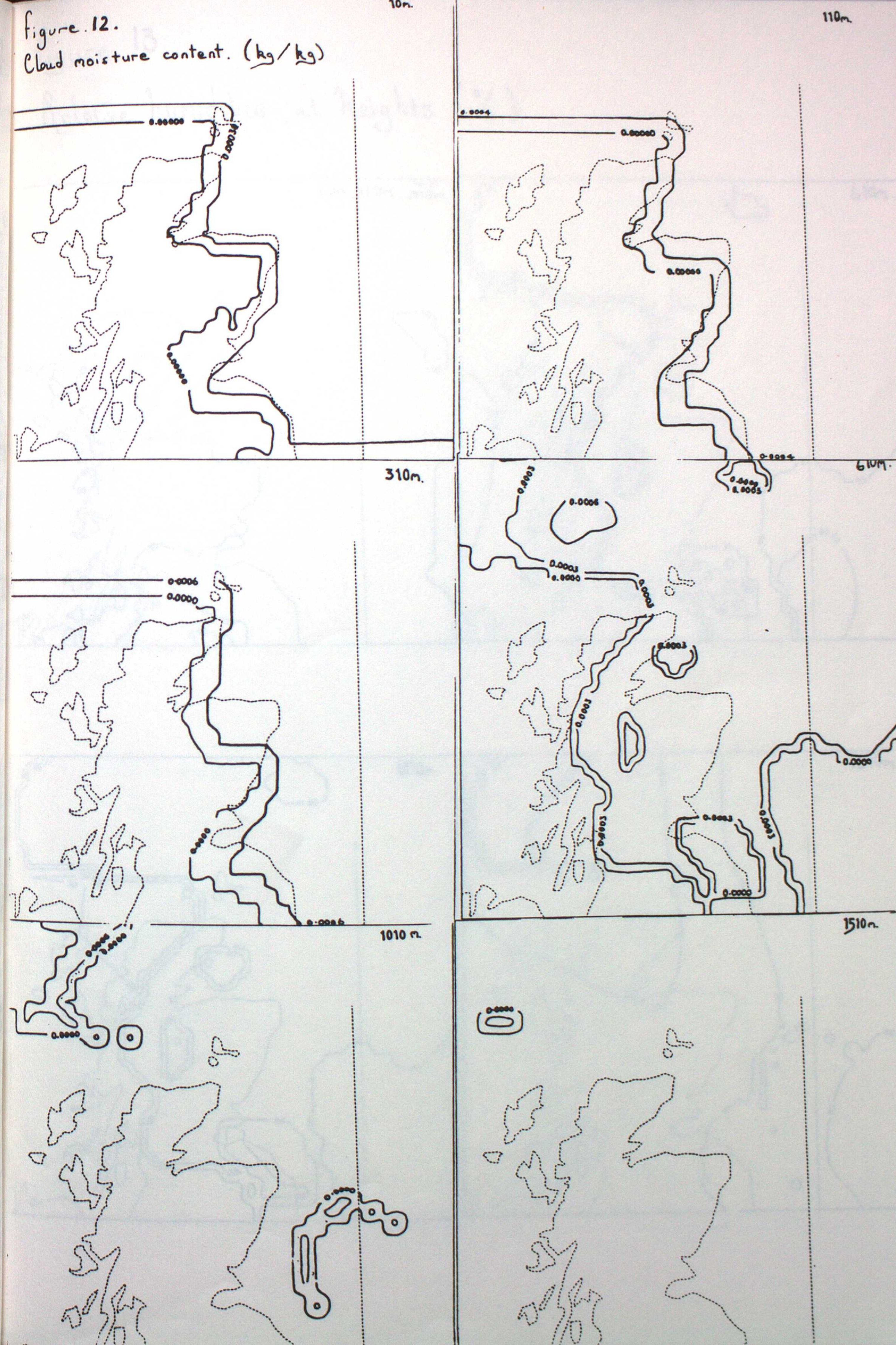


figure. 13

Relative humidities, at heights (%)

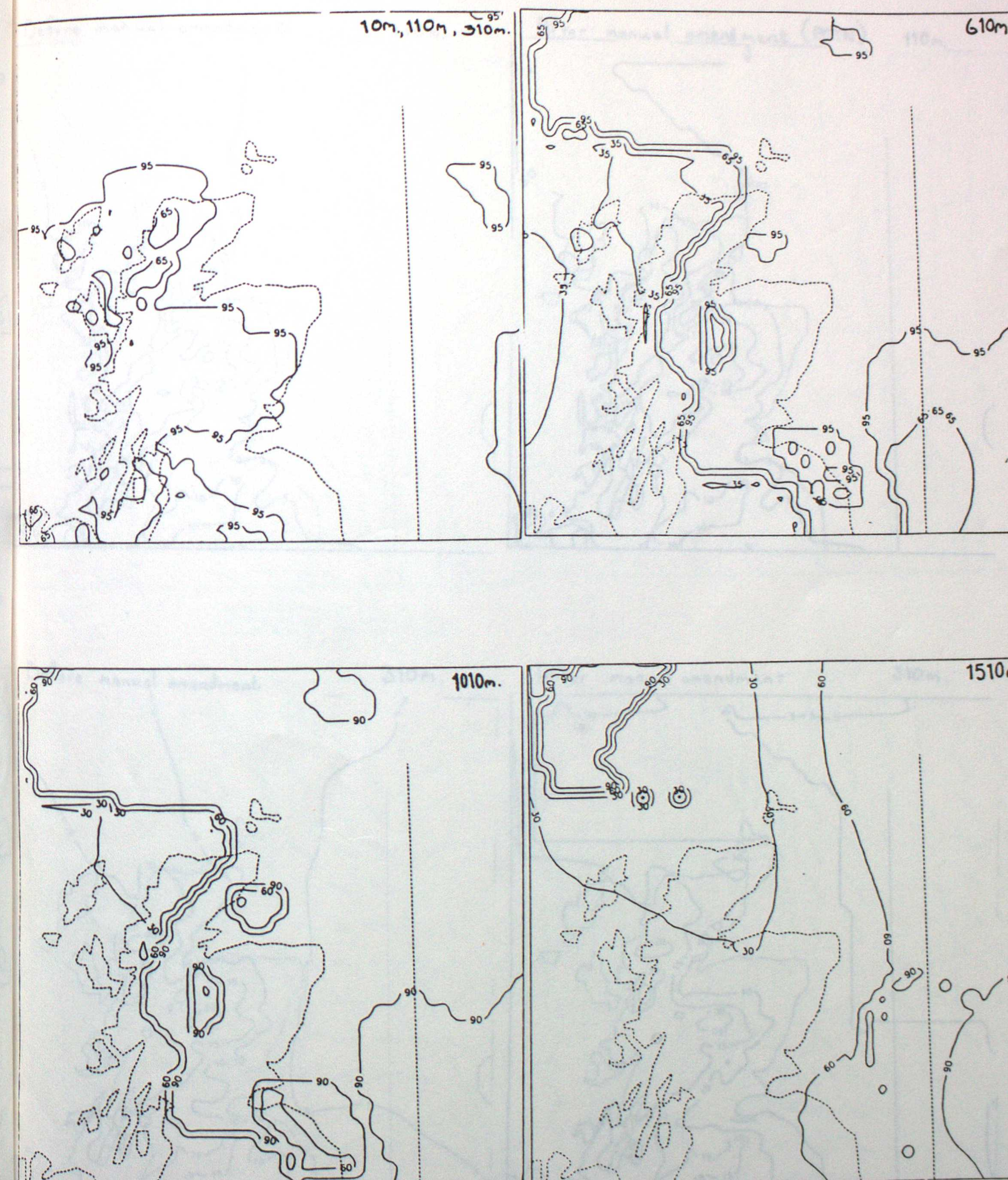


figure 14.

Potential temperatures

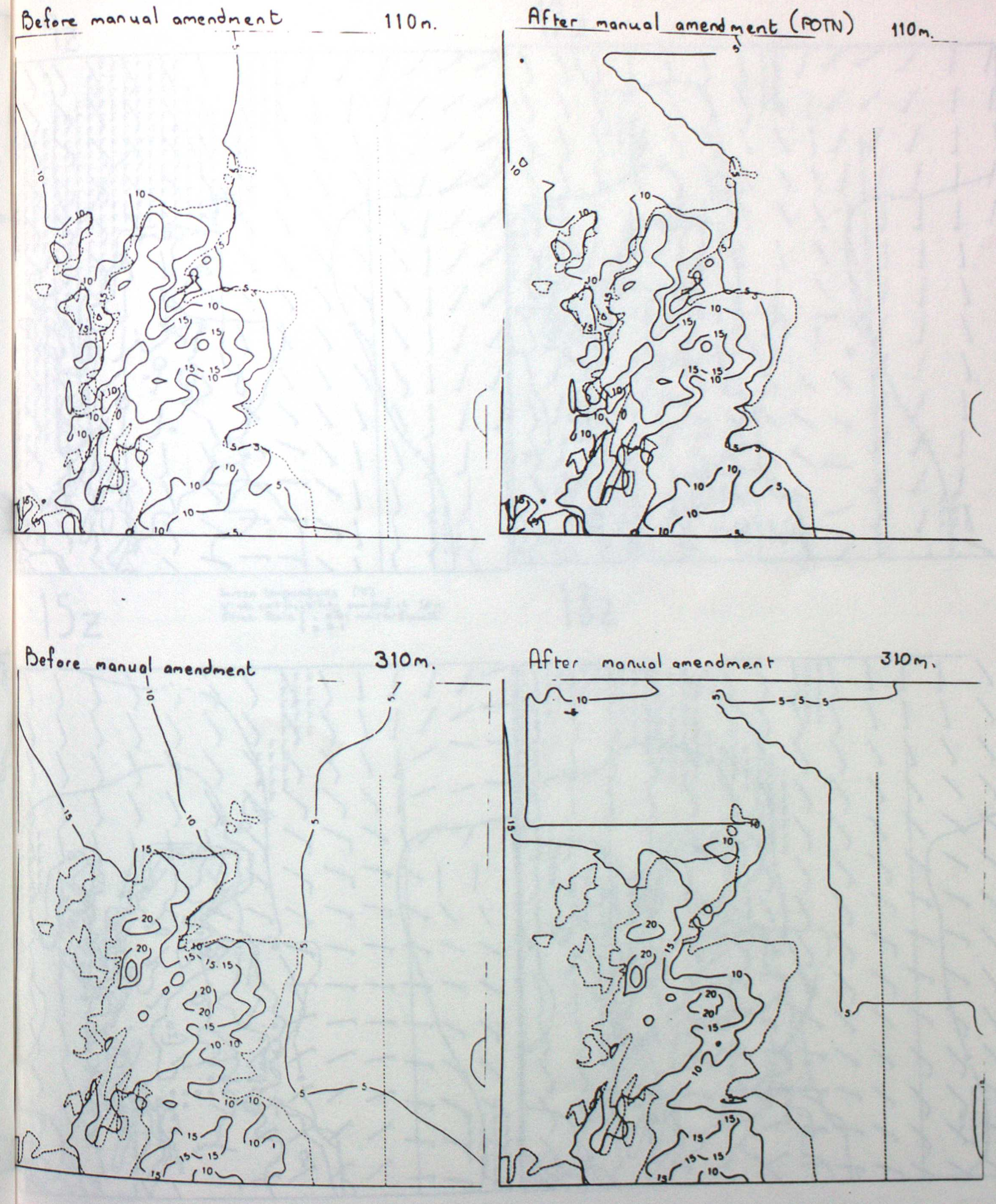


figure 15

Fine Mesh forecast.

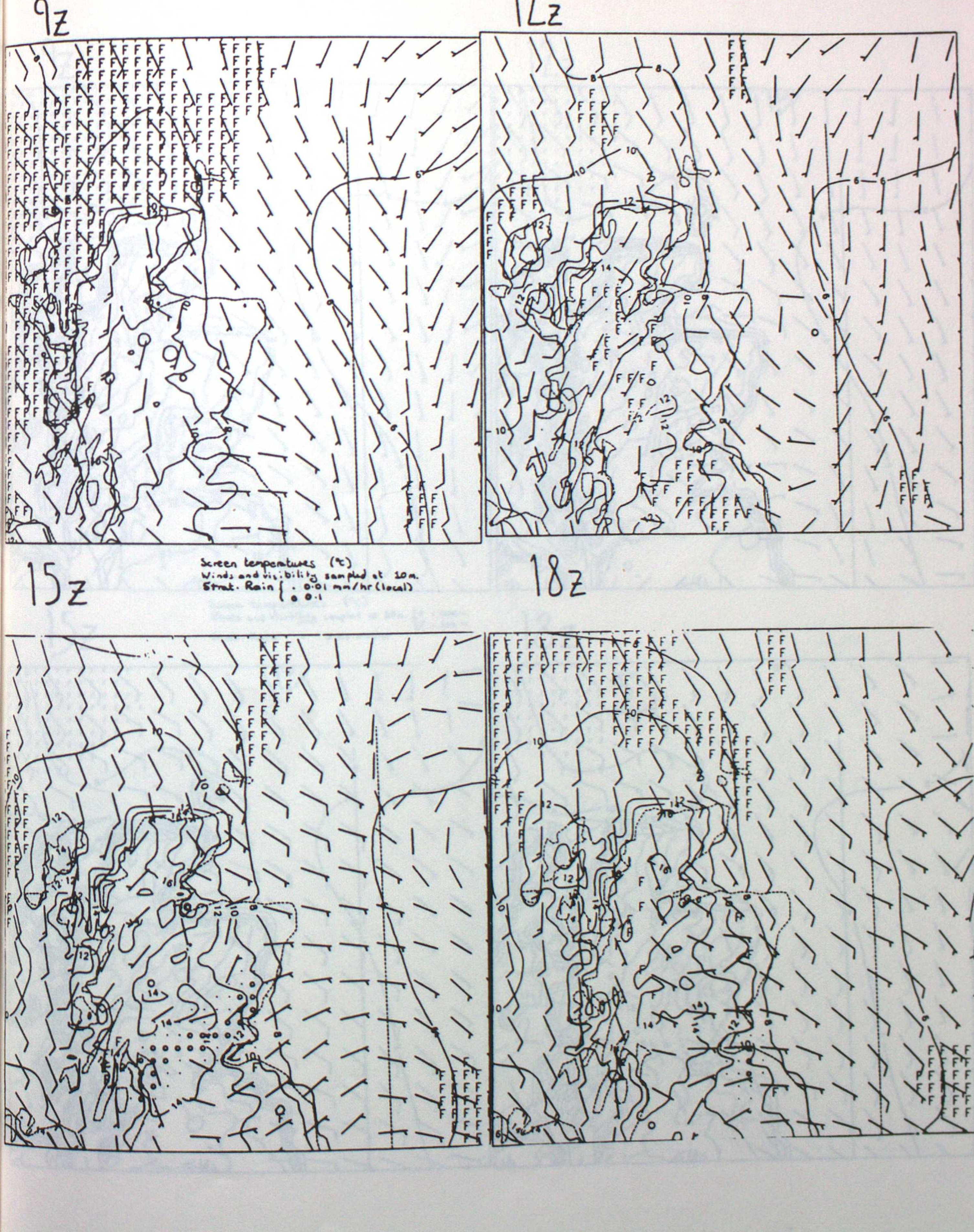


figure 16

MSMS - mesoscale forecast based only on fine mesh background data.

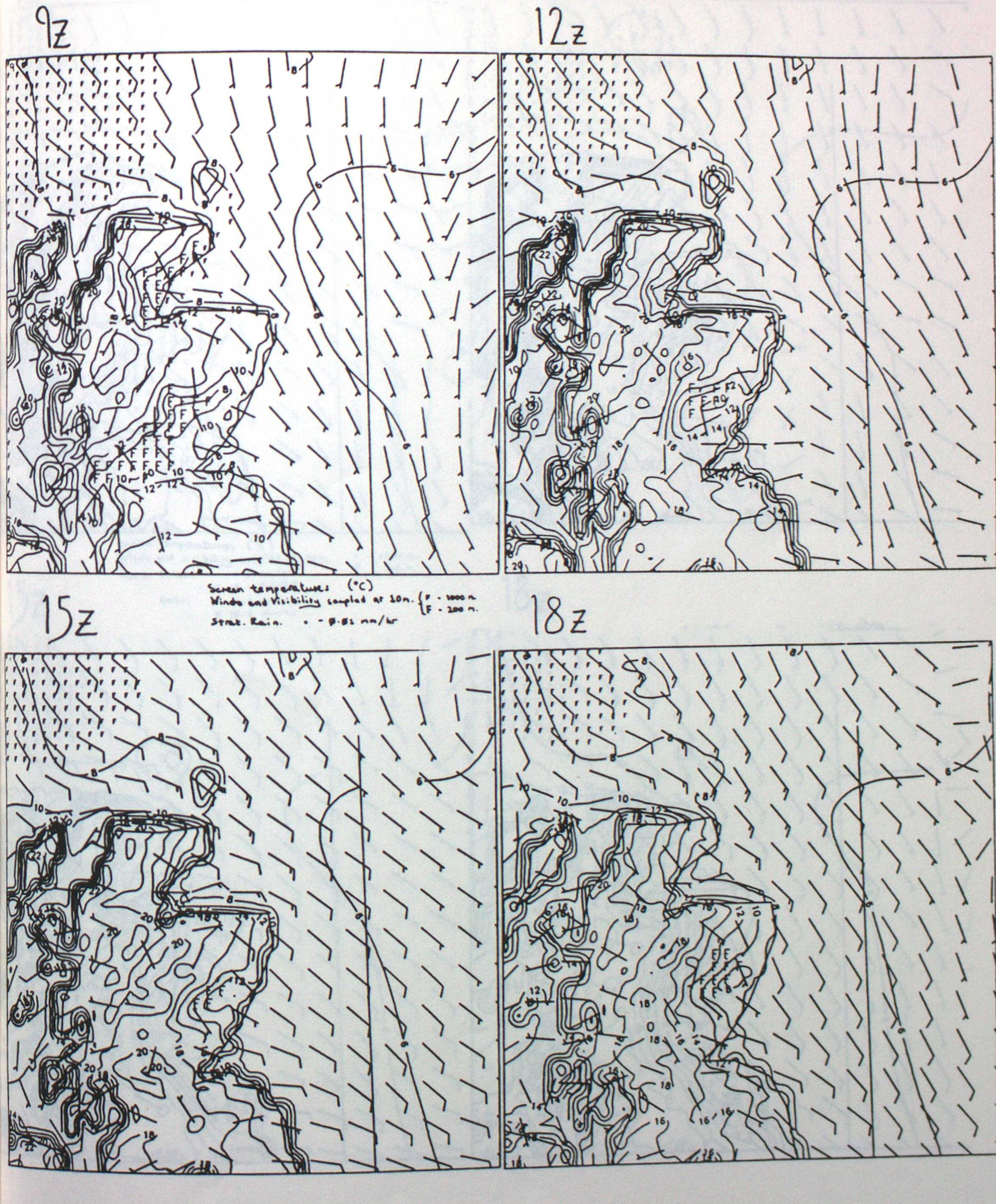
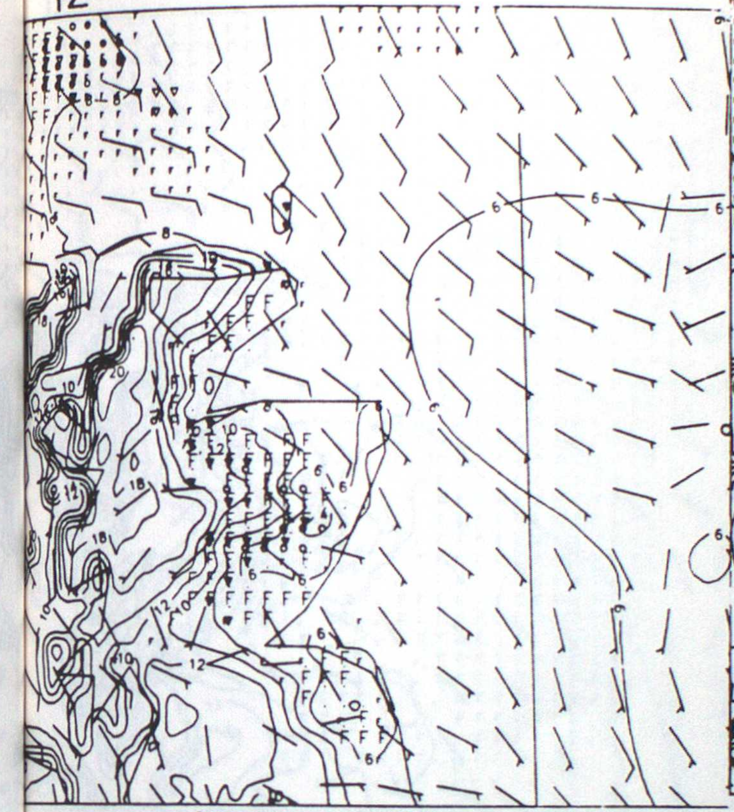


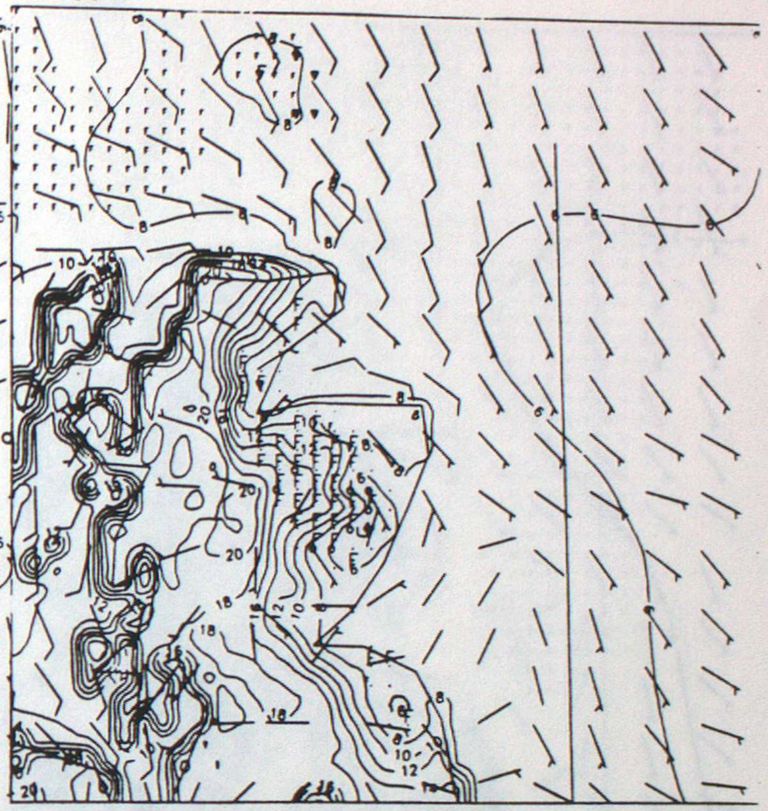
figure 17

MERG

9z

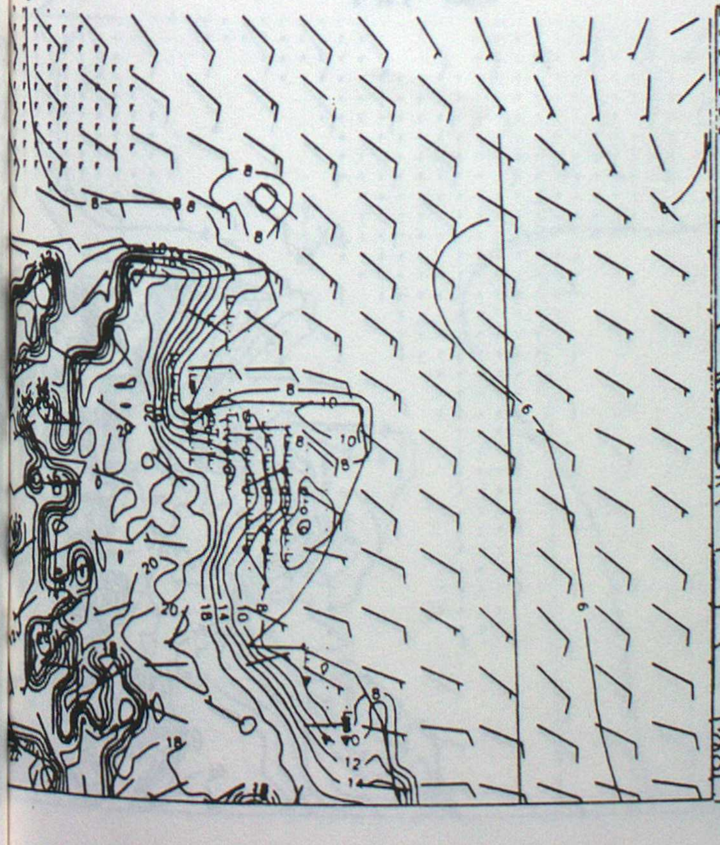


12z



Screen temperatures (°C)
Winds and visibility sampled at 10 m.
Rain. Strat. • 0.01 mm/hr
o 0.1 mm/hr
Conv. ▽ 0.4 mm/hr
▼ 10.0 mm/hr
▪ . 1000 m.
F . 200 m.

15z



18z

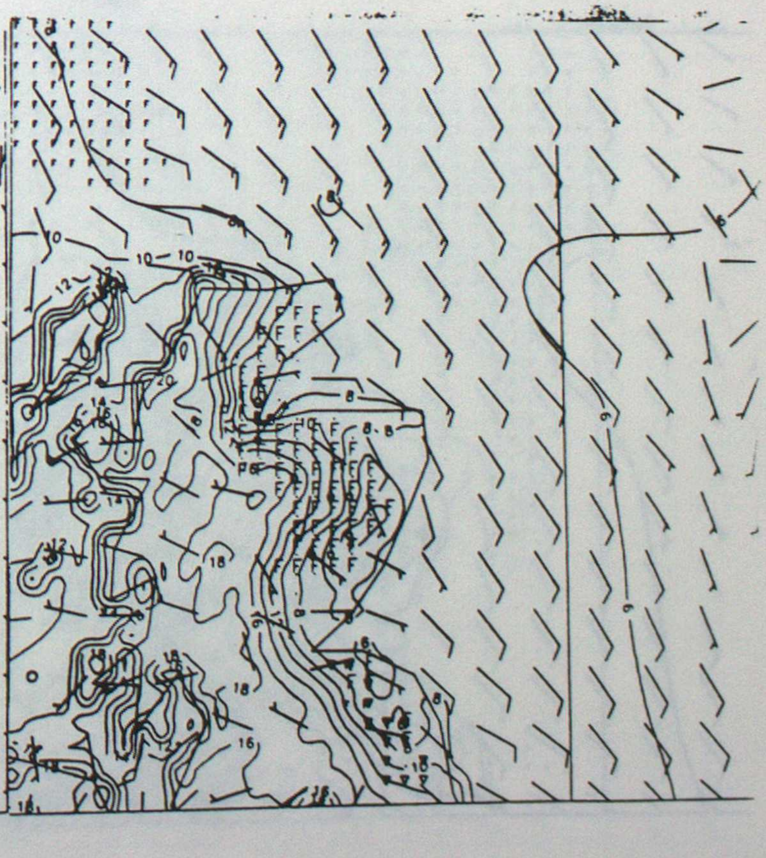


figure 18.

FOGN. - The initial fog area has been fixed manually.

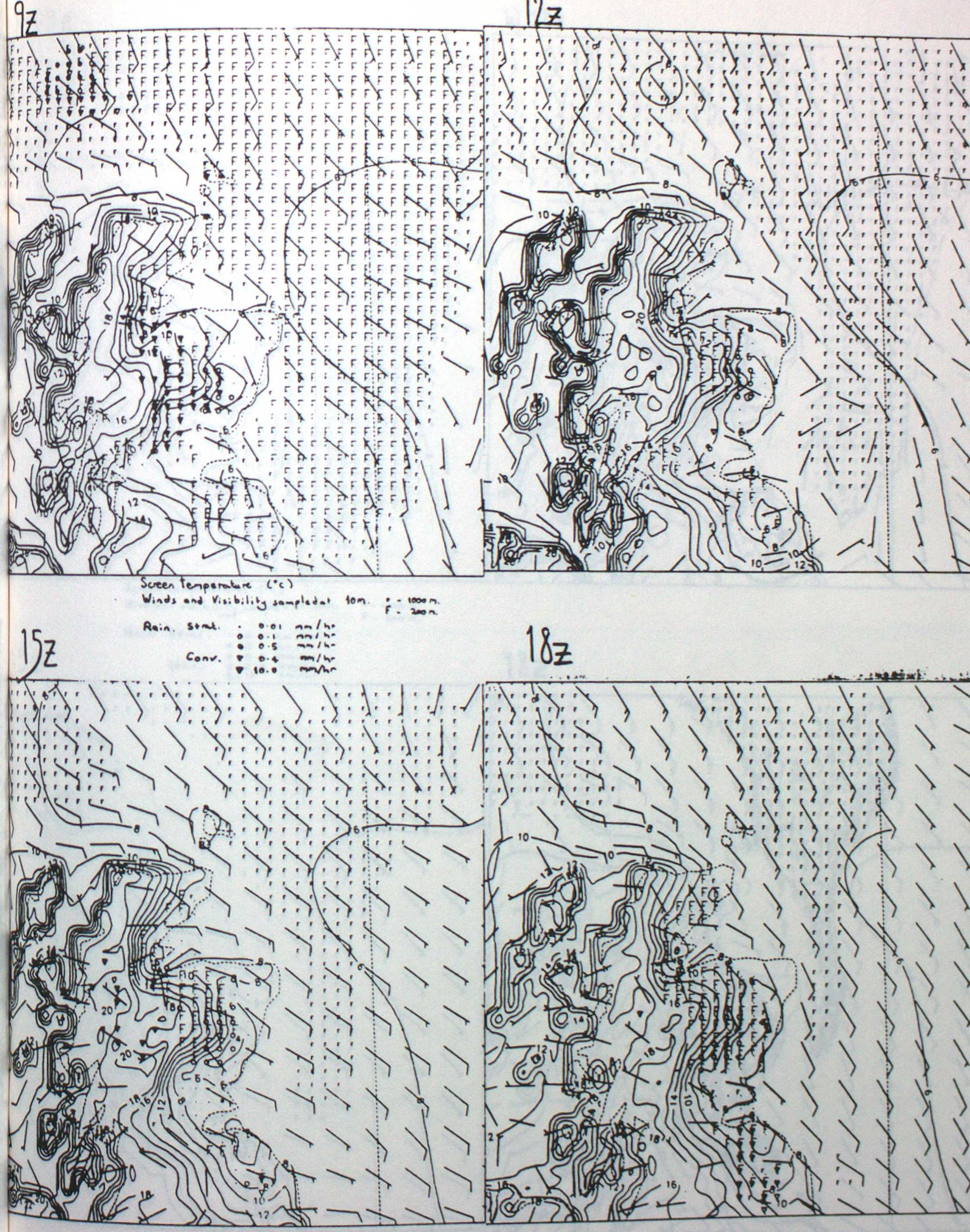


figure 19.

POTN.

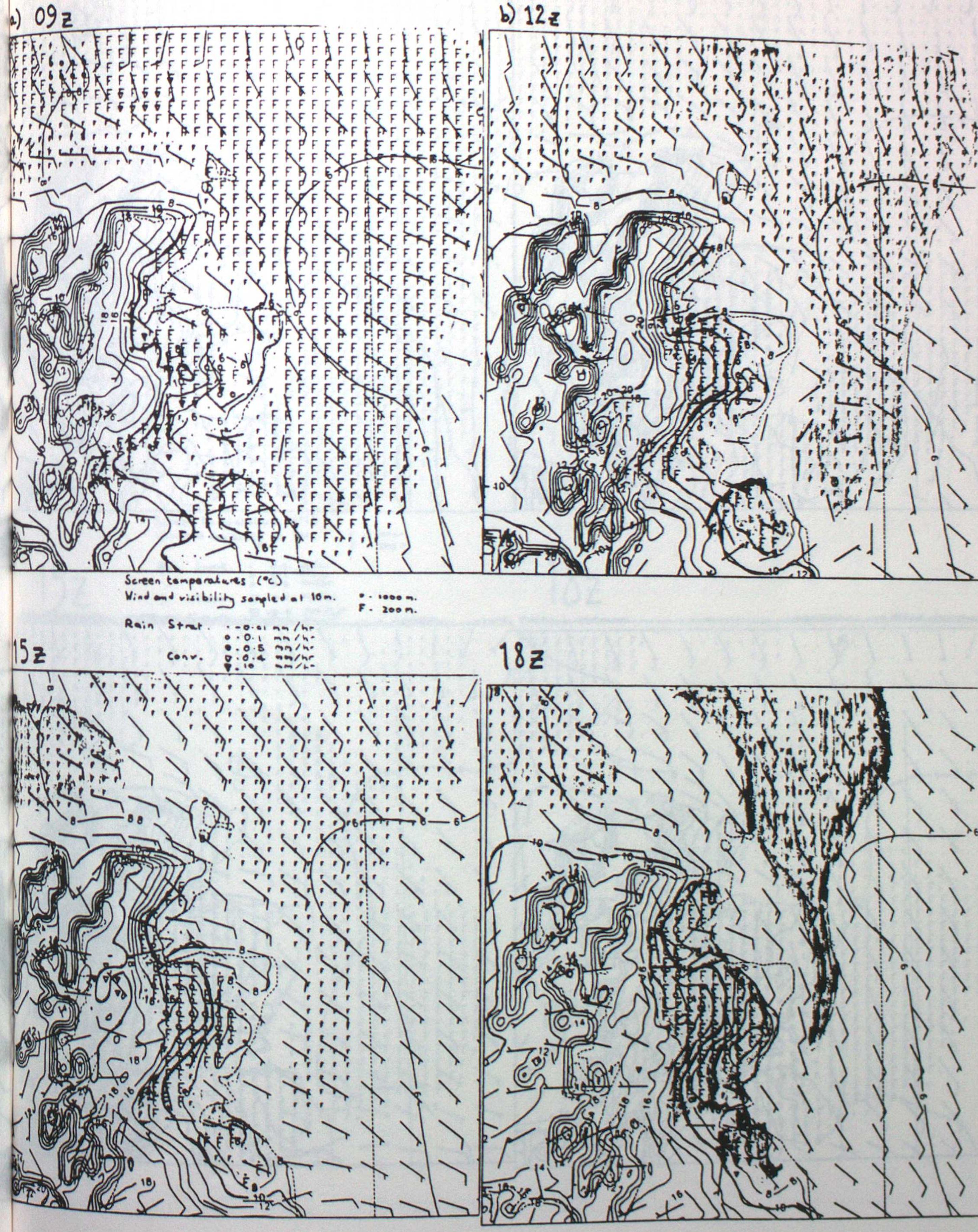


figure 20.

NEW2

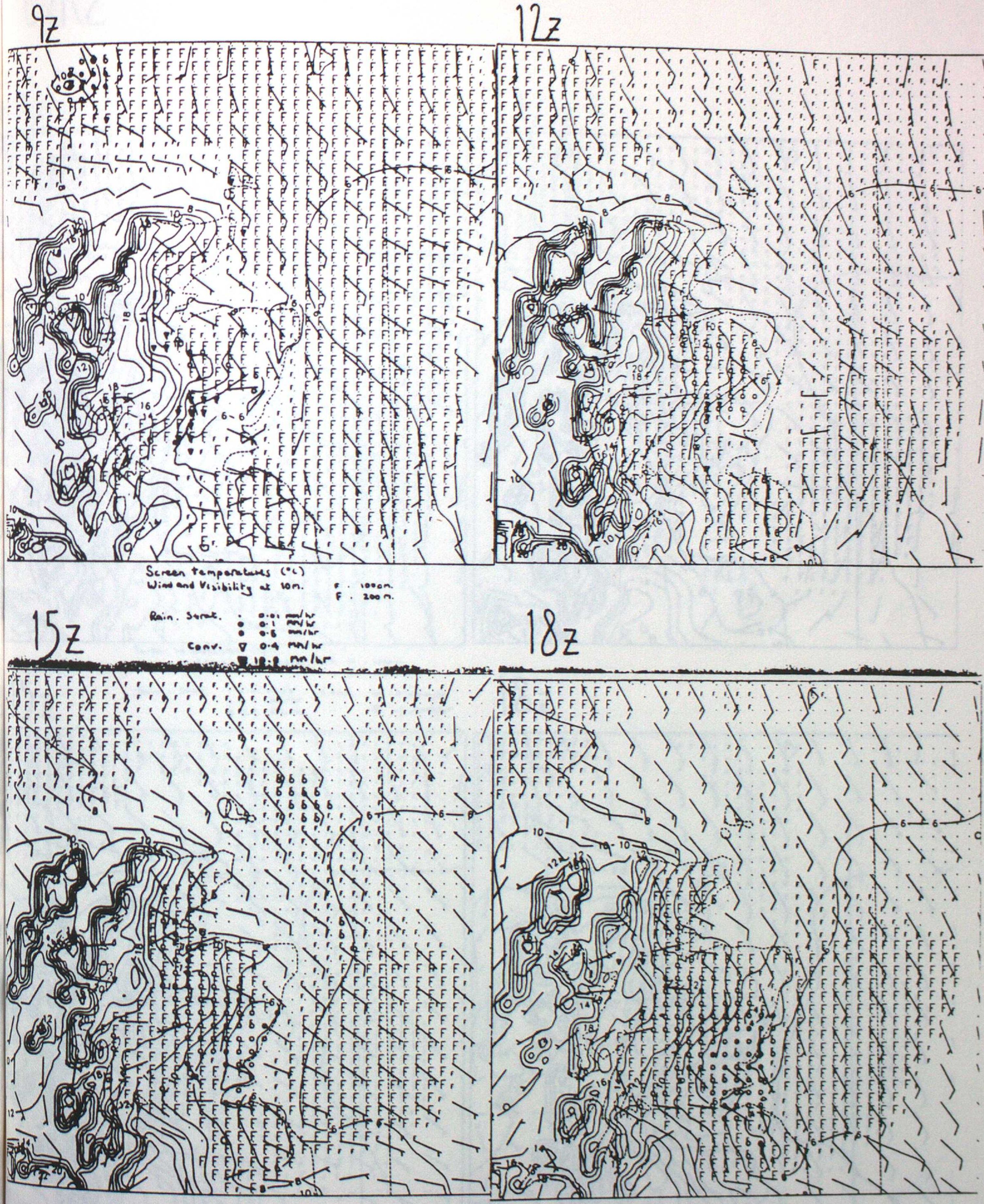


figure 21.

CTR2

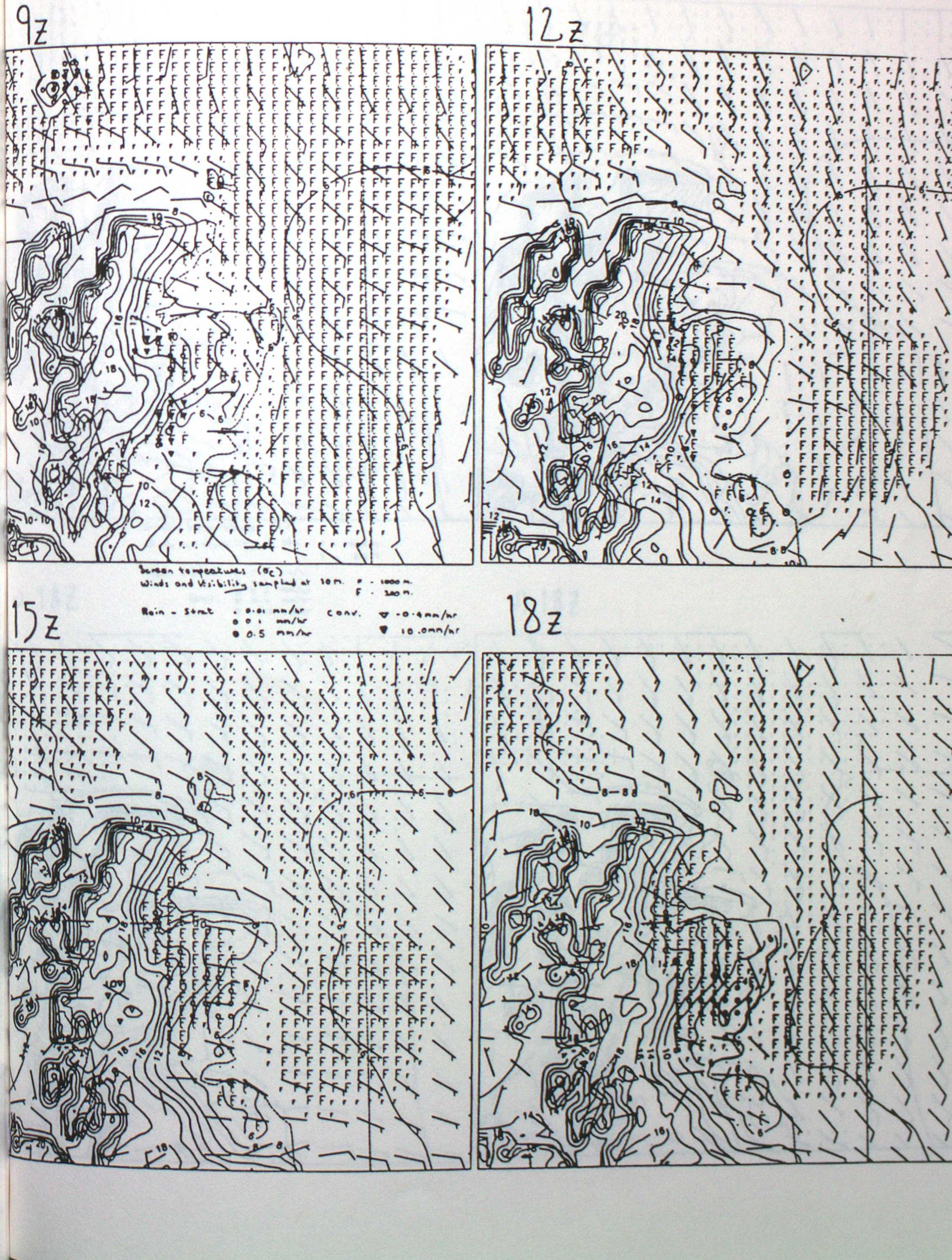


figure 22

TEST