Forecasting Research

Forecasting Research Division
Technical Report No. 157

Formulation & Performance of an Algorithm for Determining Precipitation Type from a Rain Rate Forecast, Using NWP Model Parameters

by

B.W. Golding

7 April 1995

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Introduction

The Nimrod project has three main forecast product areas: precipitation, cloud and visibility. One of the requirements on the first is to provide precipitation type. This is important for many users of precipitation forecasts: in the transport sector, snow, hail and freezing rain are much greater hazards than rain; in the hydrology sector, snow will not run off into rivers and so will reduce the likelihood of immediate flooding, but may cause flooding later when it melts. Other precipitation types are of concern to particular users eg powder snow for the railways, or are used by forecasters to indicate the presence of related conditions eg drizzle associated with poor visibility.

Physical basis

Diagnosis of the precipitation type requires knowledge of the hydrometeors generated in the cloud, and their subsequent modification as they fall to ground.

The first distinction to be drawn about the initial form is between glaciated and unglaciated clouds. This is determined using model cloud top temperature. It is also necessary to distinguish clouds with updraughts strong enough to raise raindrops above the freezing level and thus form hail. To make this distinction we use an estimate of convective updraught speed based on the Convective Available Potential Energy (CAPE) of the model's dilute cloud profile.

Where precipitation falls from glaciated cloud it will melt once the wet bulb temperature is above freezing. The height of the wet bulb freezing level is taken as the main indicator of the degree of melting.

Where liquid precipitation falls into sub-zero air, freezing rain or drizzle is observed. The model surface layer temperatures are used to identify such occasions.

Snow probability is closely linked to precipitation type and is determined from cloud top temperature and height of the wet bulb freezing level.

Lightning rate is determined by the rate of separation of charge in the cloud. Given a cloud with mixed liquid and frozen phases, this is dermined by the convective updraught speed which is calculated from the model CAPE.

The model generates convective clouds where the atmosphere is unstable. In order to localise the predictions, the Nimrod rainfall forecast is used. It is assumed that hail and lightning will occur only where there is forecast precipitation greater than 2 mm/hr.

Cloud top temperature

The cloud top temperature is important for determining whether a cloud is glaciated and thus producing snow, and also whether a convective cloud is mixed phase and thus capable of producing hail and lighning.

This is defined as the temperature of the top of the highest layer producing precipitation that falls to the ground. For stratiform cloud, this is the temperature of the top of the highest cloud layer with its base below the freezing level, or if there are none, the top of the lowest cloud layer. A threshold of 1 okta is used to define cloud layer boundaries. If convective cloud is also present, the lower cloud top temperature is used.

Lightning rate

Peak updraught velocity and lightning rate are calculated at all locations where the forecast precipitation rate exceeds 2mm/hr and model convection is present, or where the precipitation rate exceeds 10mm/hr.

In the presence of model convection, the method of Price & Rind (1992) is used. They combined empirical relationships of flash rate with cloud height and peak updraught velocity with cloud height to give:

$$w_{max} = 14.66\ F^{0.22} \qquad (1)$$

where w_{max} is the peak updraught velocity in ms^{-1} and F is the flash rate in strikes min^{-1}. We combine this with the formula for conversion of potential energy to kinetic energy of the updraught:

$$w_{max}=(2.CAPE)^{0.5}$$

where CAPE is the buoyant energy released by a parcel rising from its Lifting Condensation Level to its Equilibrium Level. Use of the dilute parcel profile will avoid over-prediction associated with using the saturated adiabat. Inversion of equation (1) then yields the required flash rate subject to constraints imposed to ensure that mixed phase hydrometeors are present. If the cloud base is colder than -15°C or the cloud top is warmer than -5°C, no lightning is diagnosed. For cloud bases between -5°C & -15°C or cloud tops between -15°C & -5°C, the flash rate is reduced linearly to reflect the decreasing likelihood of mixed phase hydrometeors.

Where there is no model convection, the relationship between flash rate and precipitation rate of Buechler et al (1994) is used. For 10km squares they obtained

$$R = 4.3\ F$$

where R is in mm hr^{-1} and F is in strikes $(15min)^{-1}$. In order to relate this to the earlier formula which is the strike rate per minute for a storm, we modify the formula to 15km squares and strikes per minute, so reducing the rate by a factor of 15x4/9 to give.

$$F = R\ /\ 28.7$$

Where F is now in strikes min^{-1}. The largest 5km rain rate in each 15km square is used for this calculation. We then use equation (1) to obtain the peak updraught.

Snow probability

The probability of snow is estimated for each 5km square and then averaged to the 15km grid. This makes some allowance for sub-grid scale orography. The method is based on the techniques of Baldwin et al (1994), Ramer (1993) and Huffman & Norman (1985).

Snow probability is calculated only where precipitation is forecast and the coldest temperature in cloud is colder than 0°C. Given these conditions, two approaches were tested, but the simpler one, using just the wet bulb freezing level, was rejected as it was unable to take proper account of the presence of cold boundary layer air.

In the approach finally adopted, the height integral (in deg.m) of positive wet bulb temperatures, from ground to freezing level, is calculated for each 5km sub-square, and the probability of snow obtained from there. The probability is 0 if the integral exceeds 450 deg.m, 1 if it is less than 25 deg.m, and it varies linearly between the two.

Precipitation type

Specification of the precipitation type uses many of the variables calculated above and is based on the papers cited there. It is easiest to list the types, giving the conditions under which each will be predicted. Type is diagnosed only in the presence of forecast precipitation.

Drizzle	Coldest cloud temperature > 0°C
Hail	Cloud base temp > -15°C, cloud top temp < -5°C, precip rate > 2mm.hr^{-1}, max updraught > 5ms^{-1}
Snow	Coldest cloud temperature < 0°C, Snow probability > 0.5
Sleet	Coldest cloud temperature < 0°C, Snow probability > 0.1
Rain	Coldest cloud temperature < 0°C, Snow probability < 0.1

Liquid or mixed precipitation is freezing if the wet bulb temperature is below 0°C throughout the lowest 50m (ie at model levels 1 & 2)
Snow is dry/powdered if the screen temp is below -1°C and dew point below -2°C.
Note that the term sleet is used here to refer both to a mixture of rain & snow at one location, and to the presence of rain in one part of the grid square and snow in another.

Input fields

Model:

- 3d height
- 3d temperature
- 3d relative humidity
- 3d cloud fraction
- screen temperature
- screen dew point
- dilute CAPE
- convective cloud base height
- convective cloud top height

Nimrod:

- Forecast rain rate

Fixed:

- 5km orography

Output fields

- Snow probability*100 (0 - 100)
- Lightning rate*100 (≥0)
- Precipitation type (Drizzle, Hail, Snow, Powder snow, Sleet, Rain, Freezing drizzle, Freezing sleet, Freezing rain)

Assessment

Results of the precipitation type algorithm have been compared subjectively with present weather observations on thirteen occasions in March 1995. The cases do not permit assessment of the lightning rate, or of the freezing precipitation, drizzle and powder snow categories of precipitation type. They do, however, cover a good range of mixed rain and snow situations, including several cases of warm air advection and several of polar maritime showers. There were two major snow events on 2nd & 28th. The method of calculation of CAPE was changed after the case on the 8th so details of the hail distribution in the earlier cases should be disregarded.

For each case, maps of the diagnosed precipitation type and the surface observations distribution are presented, together with a brief introduction.

21Z 2nd
A major snow situation with substantial falls across the Midlands and N England. Snow across Scotland, N.Ireland, Wales, N.England & SW England is well captured. In the East, the snow/sleet and sleet/rain boundaries are slightly west of the diagnosed locations. On the southern edge, the rain/snow boundary is correct except for the snow observation in London. The hail observed in Wales was diagnosed as sleet.

12Z 6th
Polar maritime showers. The mixture of rain, sleet, snow & hail over NW coasts is well captured. The snow over inland Ireland & Wales is also correct. Hail does not penetrate as far SE as observed over England, but that over France is correct. The rain/snow boundary over England is close to that observed.

11Z 7th
Warm advection in S, polar maritime showers in NW. The rain/snow boundary across England & Wales is very well diagnosed with the exception of the two 'past rain' reports in the NE. The hail across the channel follows the cold front line but is not supported. The prevalence of snow in the NW is correct but again there is excessive hail. Note the correct diagnosis of a mix of rain, sleet & snow in the Hebrides.

6Z 8th
Largely polar maritime showers. The phase of the showers in SE England agrees well with observations. With the exception of one report of snow in W.Ireland and one of rain in the Hebrides, west coast showers are also correct except for excessive hail in Ireland. The diagnosed hail off NE Scotland is coincident with the sferic report.

12Z 9th
Warm front rain. The absence of snow in the observed rain areas is correctly diagnosed.

6Z 10th
Warm conveyor belt. The rain observations are well fitted. Snow in the Scottish Highlands is consistent with sea level temperatures, but the hail in SE Ireland is doubtful.

15Z 15th
Polar maritime showers. A complex distribution with scattered hail in a mixture of rain & snow showers. The distribution is faithfully captured in most areas, the most significant error being the absence of diagnosed snow or hail in the E.Midlands.

6Z 16th
Polar maritime showers. The snow/rain boundary is well diagnosed. The hail near Manchester is captured but the past hail showers in NW Scotland are missed.

6Z 17th
Wave depression in S, polar maritime showers in N. The rain over England, Wales & much of Ireland is correctly diagnosed. Over N.Ireland & S.Scotland slightly too much snow is diagnosed. The hail distribution is good except for missing the observations in NW Scotland.

9Z 20th
Polar maritime showers. Good representation of snow/rain boundary, but the 'past hail' observed in NW Scotland is missing.

6Z 27th
Cold front & polar maritime showers. The rain/snow boundary and the hail showers in the N are well captured. There is no support for the hail in E.Anglia & Lincolnshire.

8Z 27th
Polar maritime showers. Apart from 'past rain' observed in Kent, the general presence of snow is correctly diagnosed. The hail in Scotland agrees with observations & that in E.England is coincident with the sferics reports.

10Z 28th
Warm front - a major snow situation with substantial falls in some areas. The rain/snow boundary is very accurately located.

Summary
A precipitation type algorithm has been formulated using the physics of the precipitation formation and melting processes. It has been tested on thirteen cases. In all cases the snow/rain boundary is well represented with average errors of less than one pixel (15km). The occurrence of sleet is reasonably well represented, bearing in mind the definition used here. Hail is less accurately diagnosed, though the excess in the early cases seems to have been corrected after the change to the CAPE calculation on the 8th, but it is sufficiently good to provide a useful indication on most occasions.

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Buechler,D., Christian,H.J. & Goodman,S.J., 1994, "Rainfall estimation using lightning data", Preprints 7th Conf on Satellite Meteorology and Oceanography, AMS, 171-174

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Ramer,J., 1993, "An empirical technique for diagnosing precipitation type from model output", Preprints 5th Int. Conf. on Aviation Weather Systems, AMS, 227-230

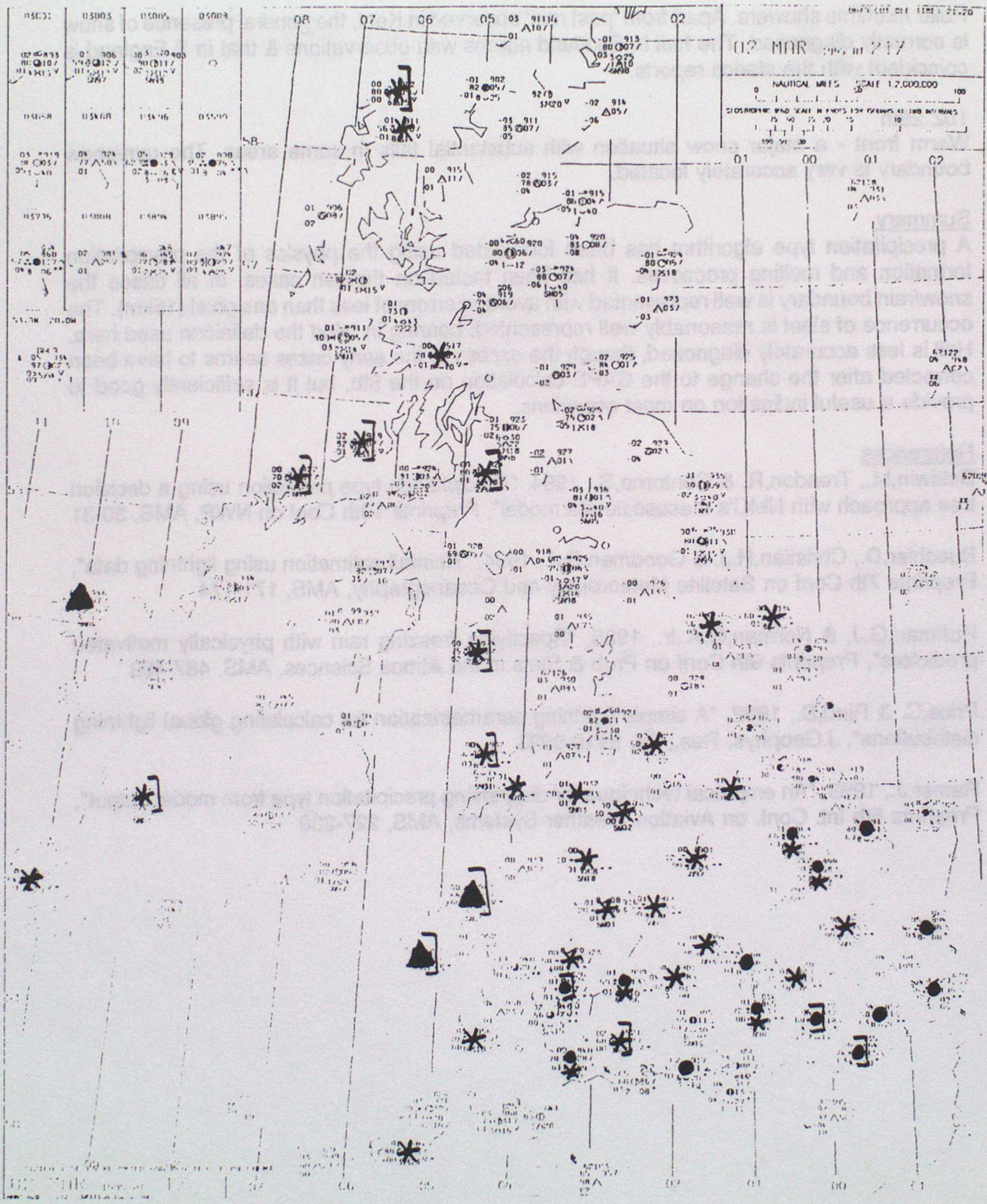


Fig. 1

Key
Hail
Snow
Sleet
Rain
Past precip

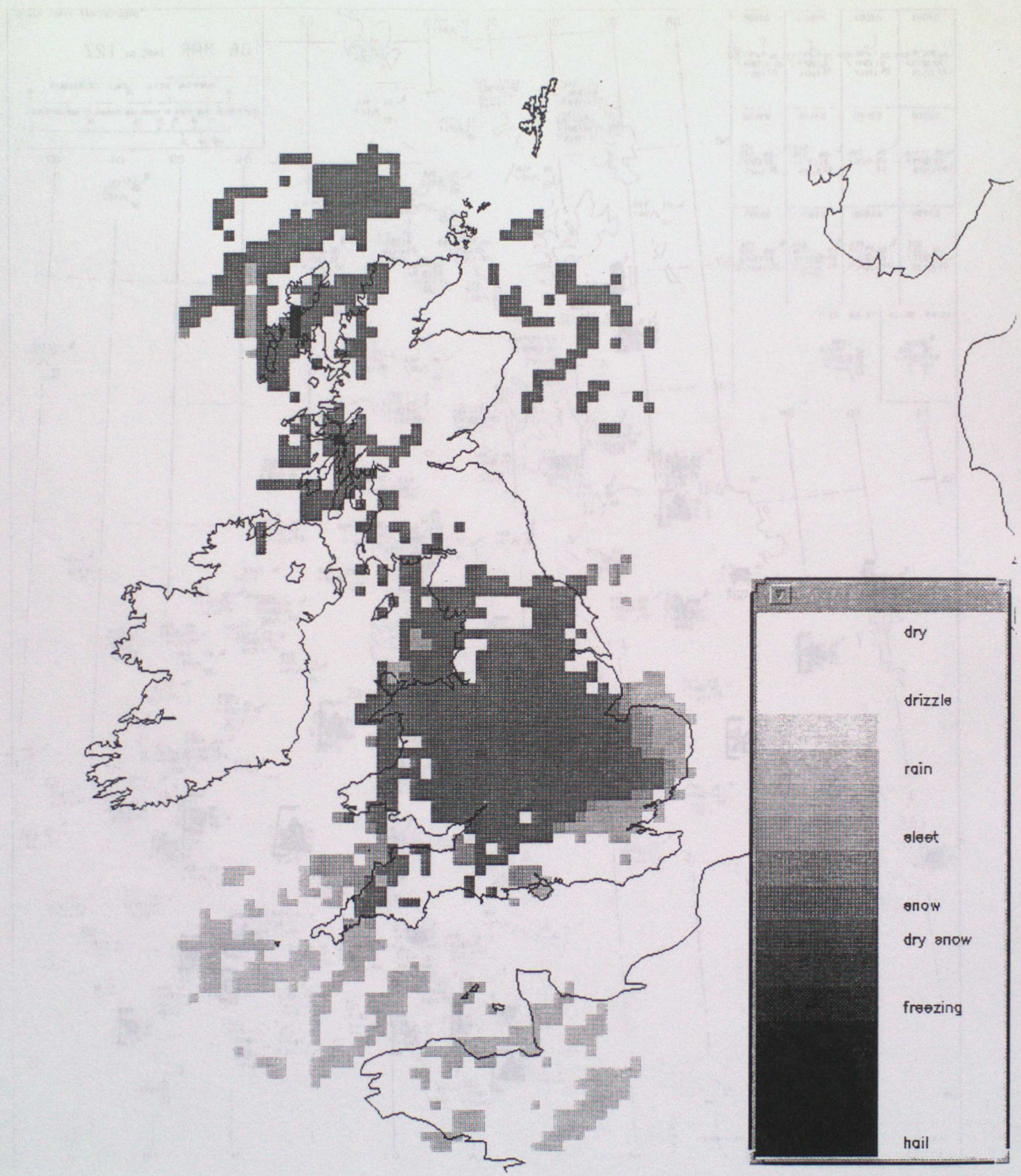
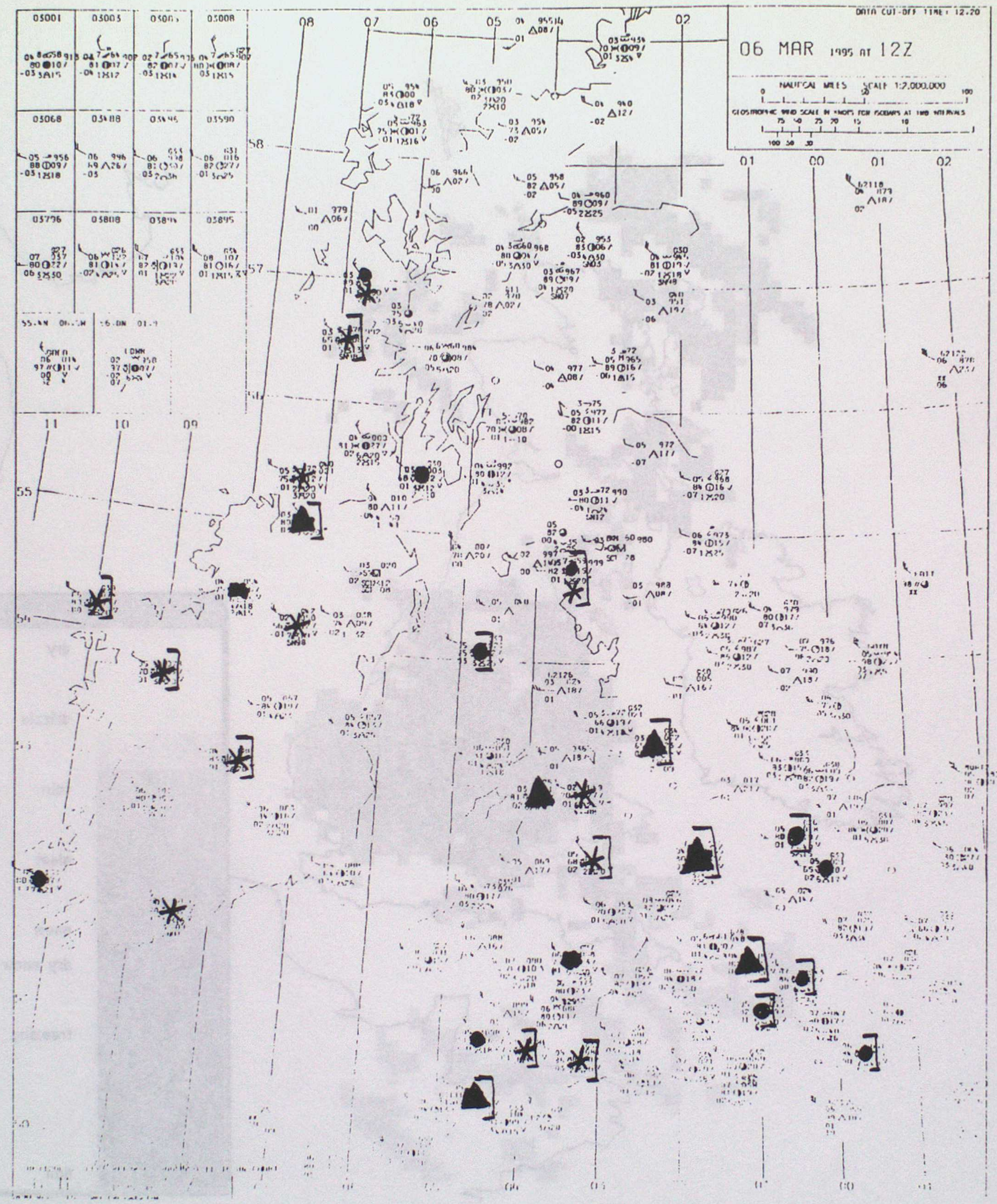


Fig. 2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06 MAR 1995 AT 12Z
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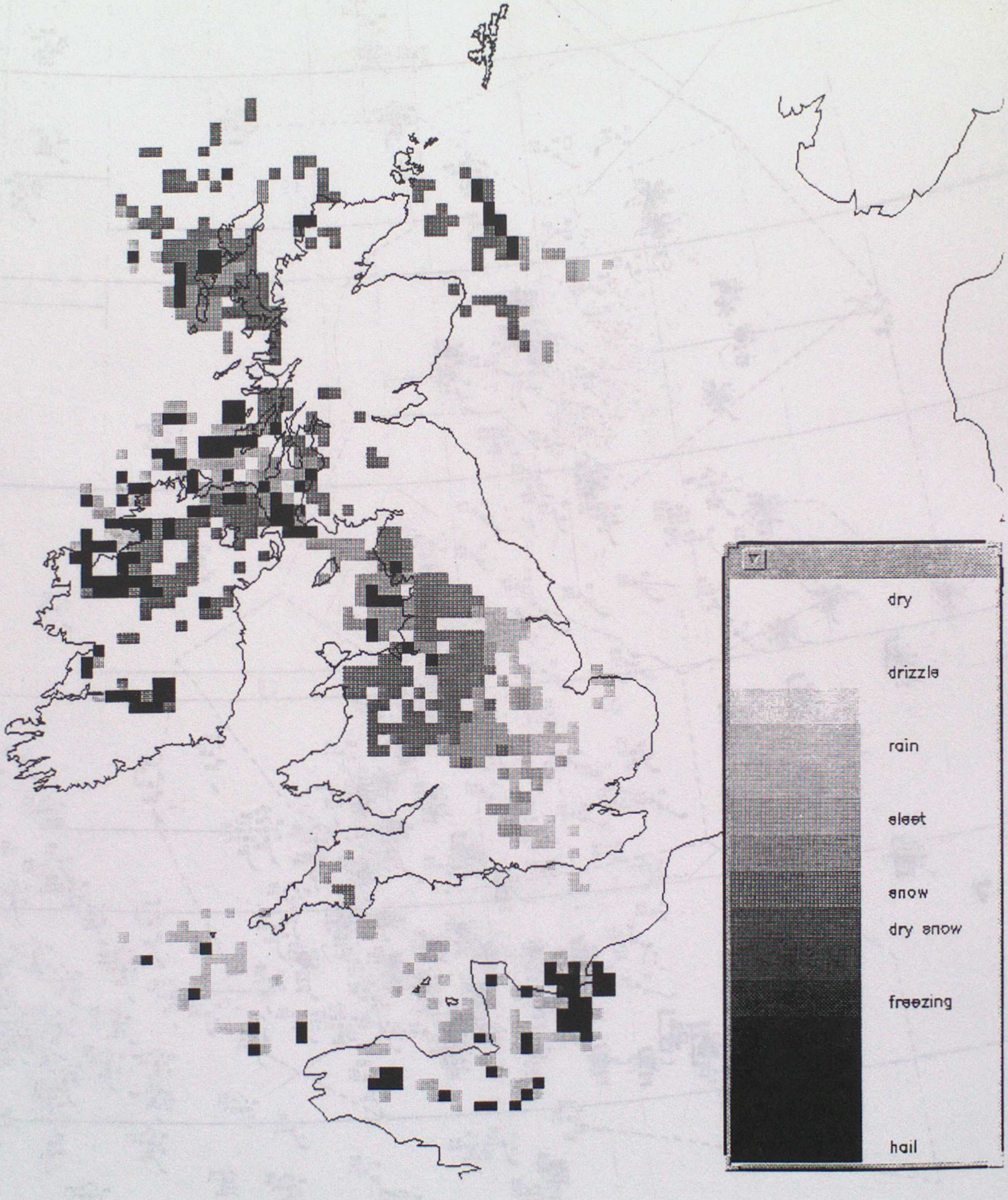
Fig. 3



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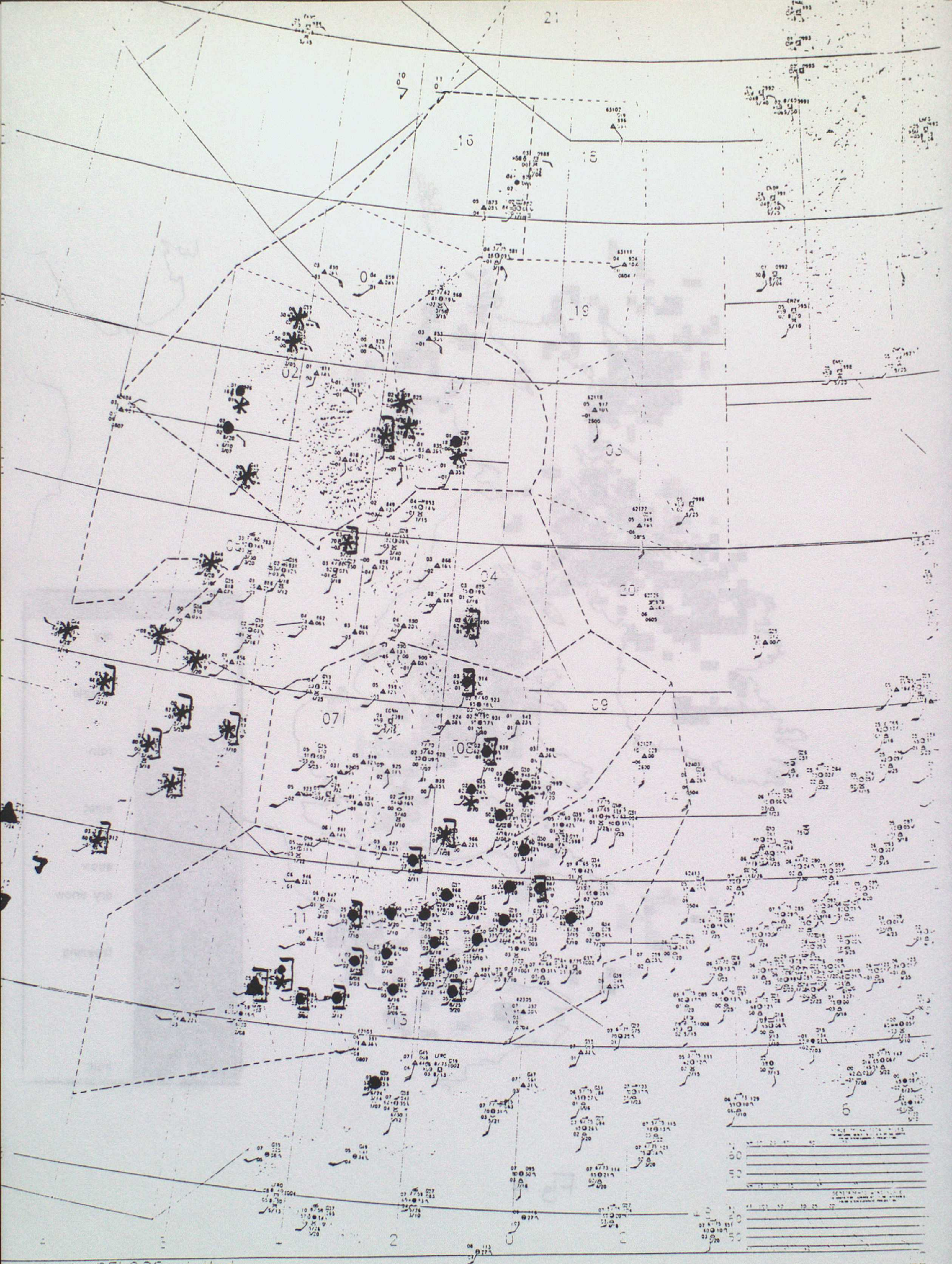


available SFLOCS plotted

Fig.5 11Z Tuesday 07th March 95

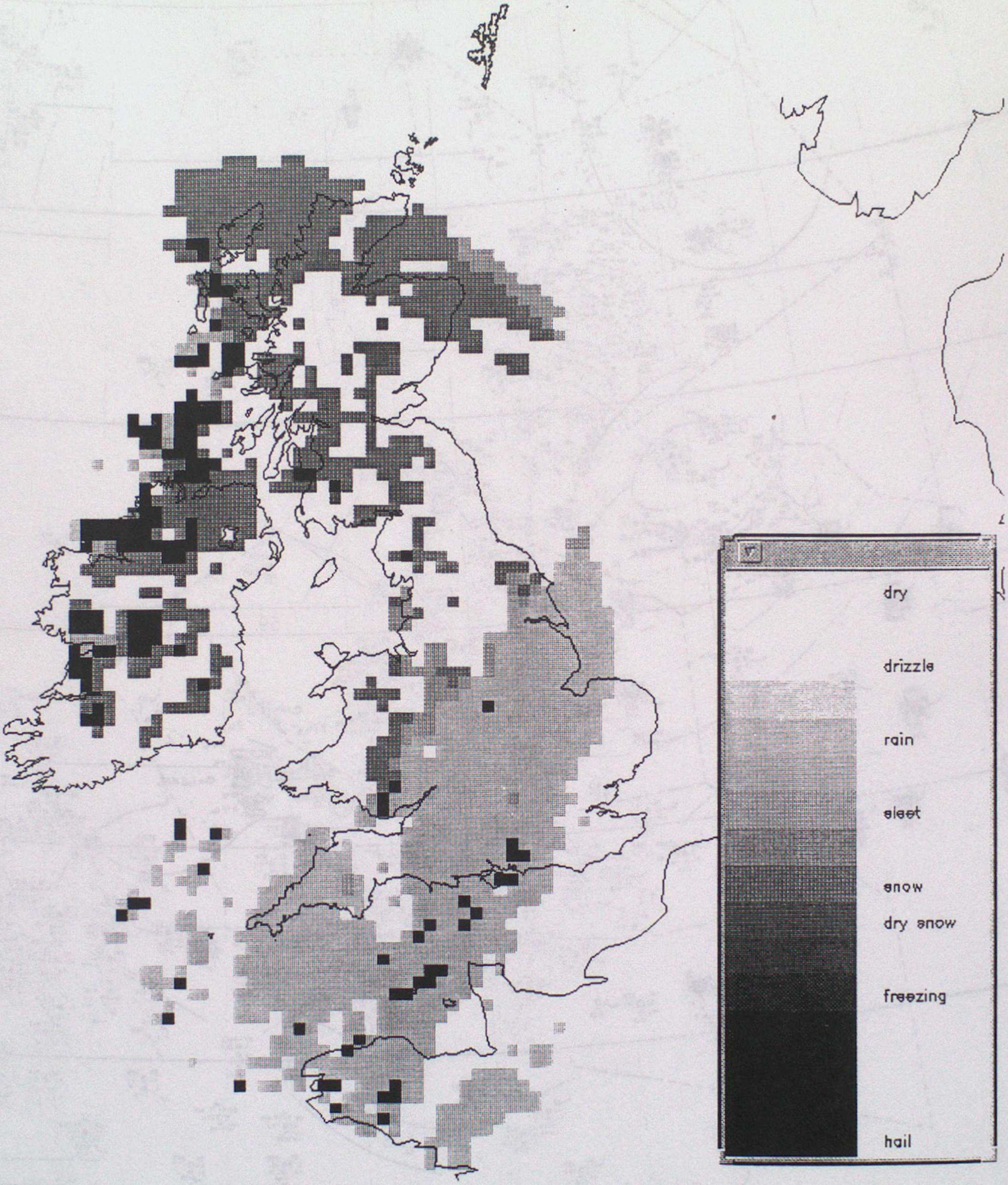
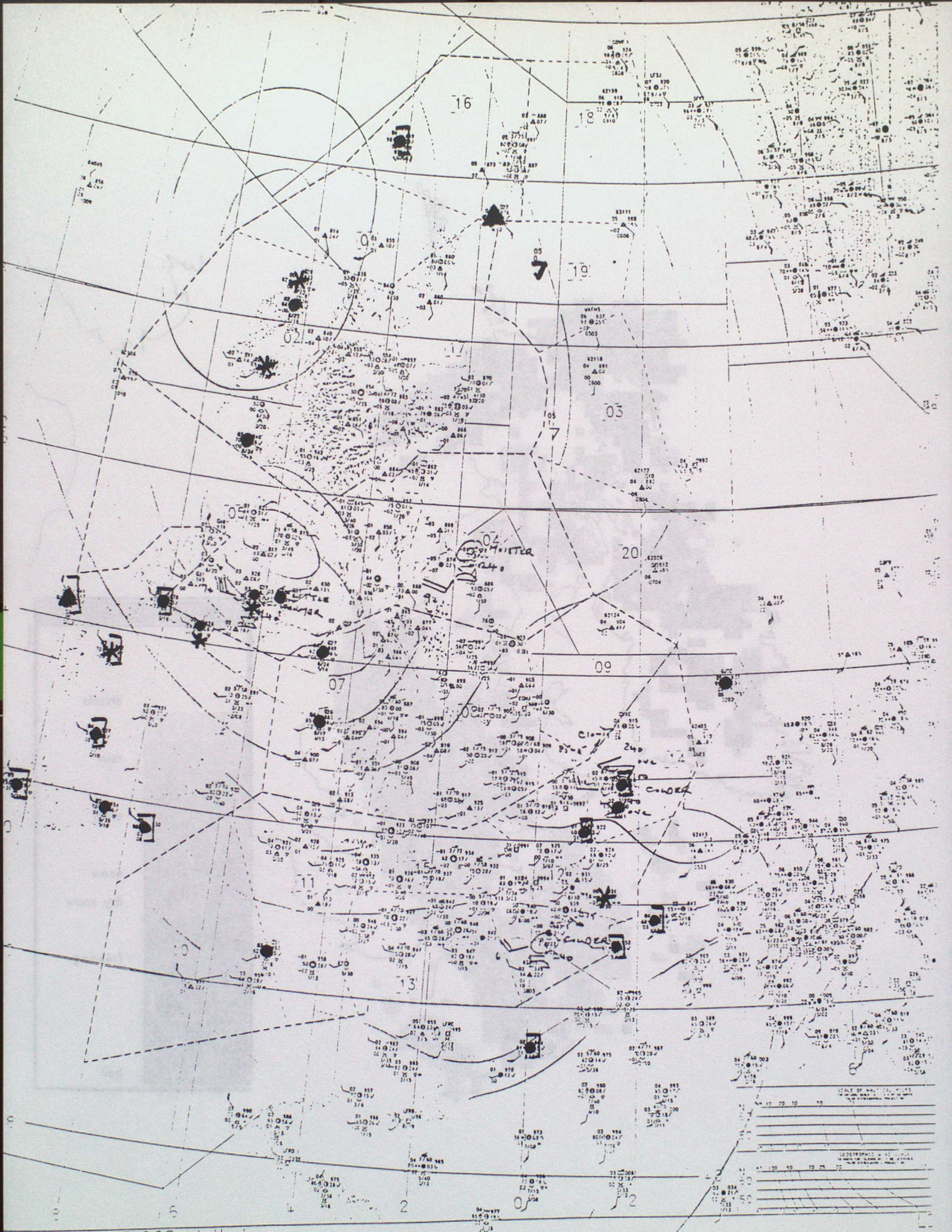


Fig. 6



l available SFLOCS plotted

06Z Wednesday 08th March 95

Fig. 7

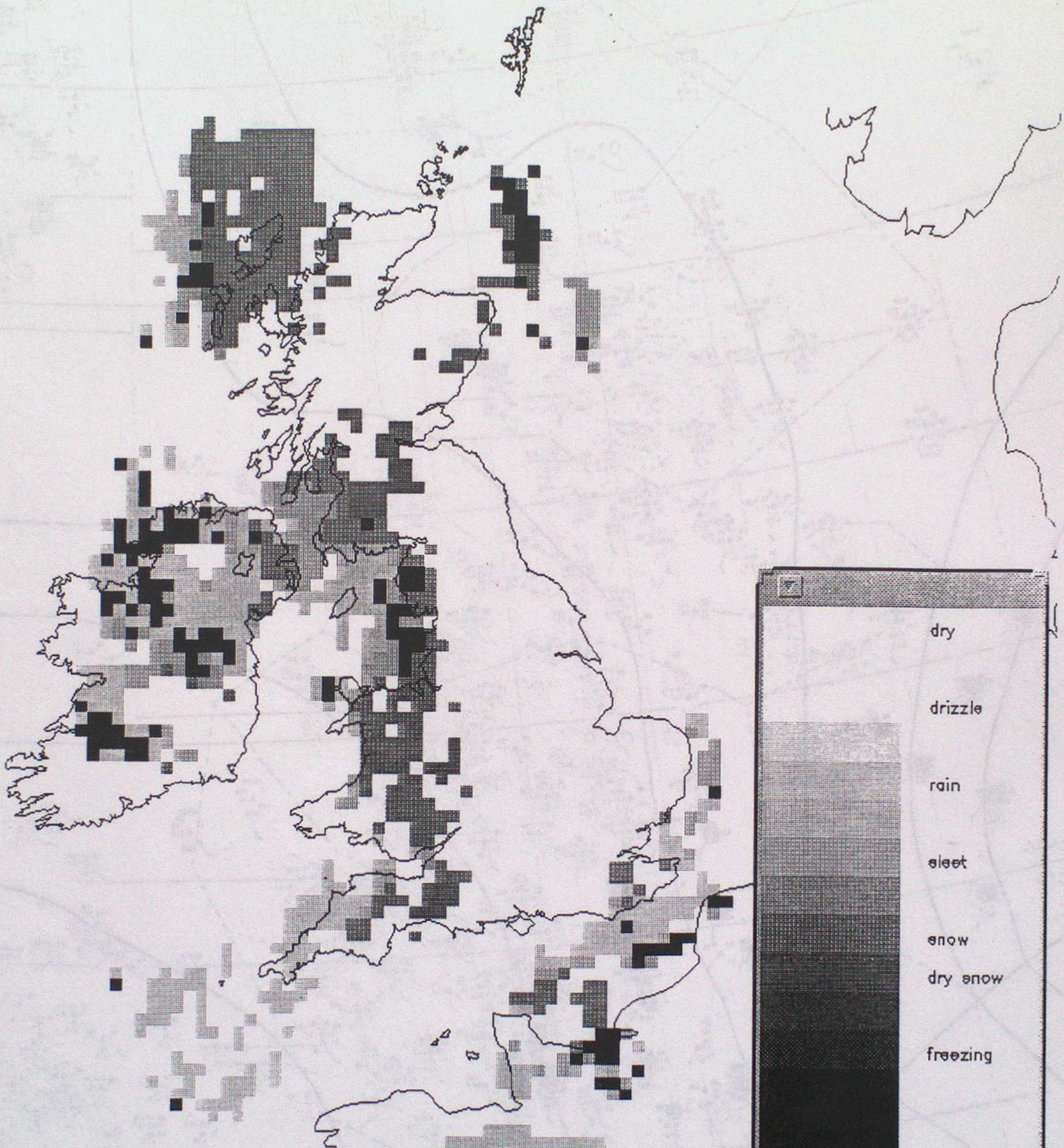


Fig.8

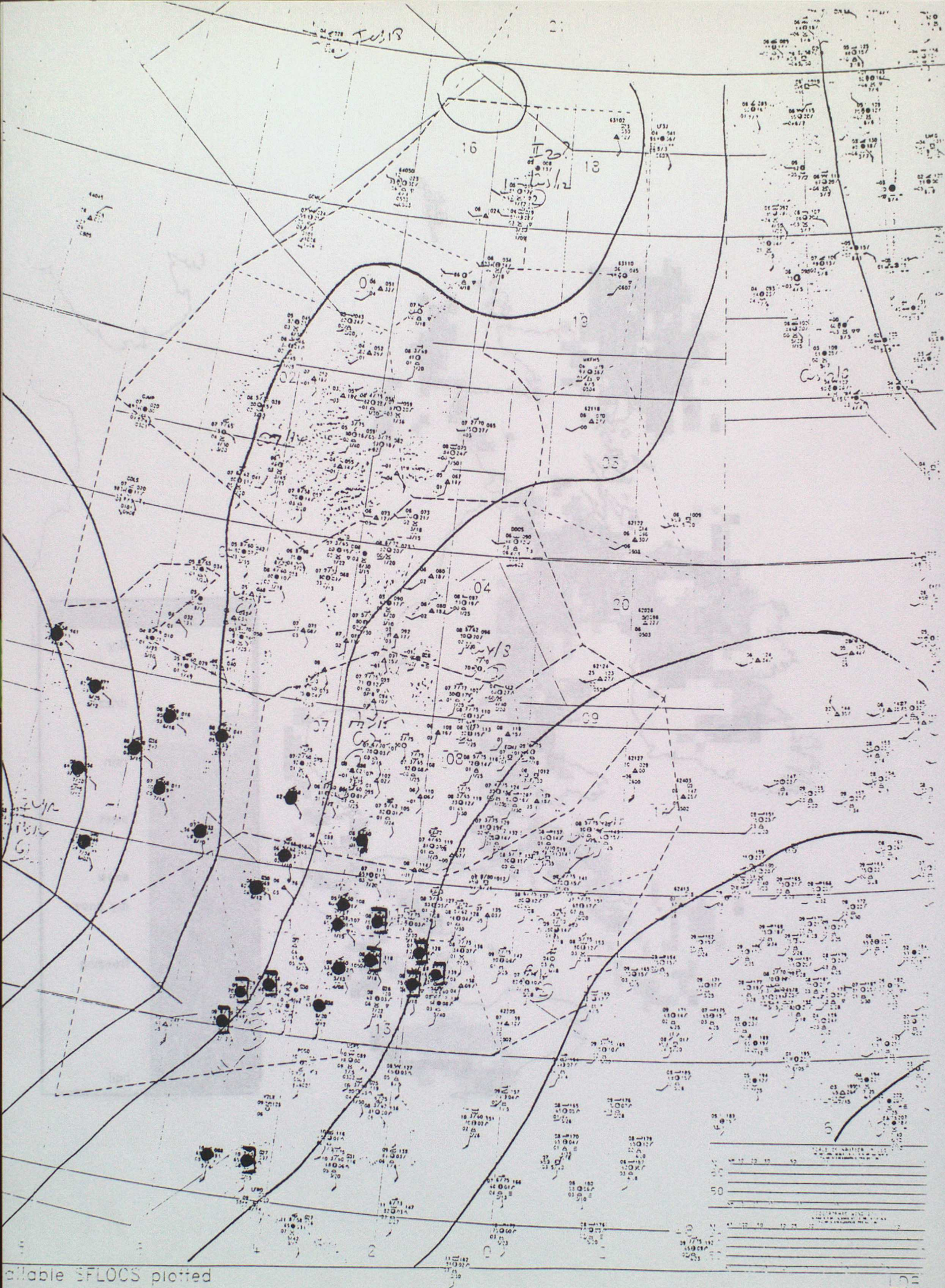


Fig 9 12Z Thursday 09th March 95

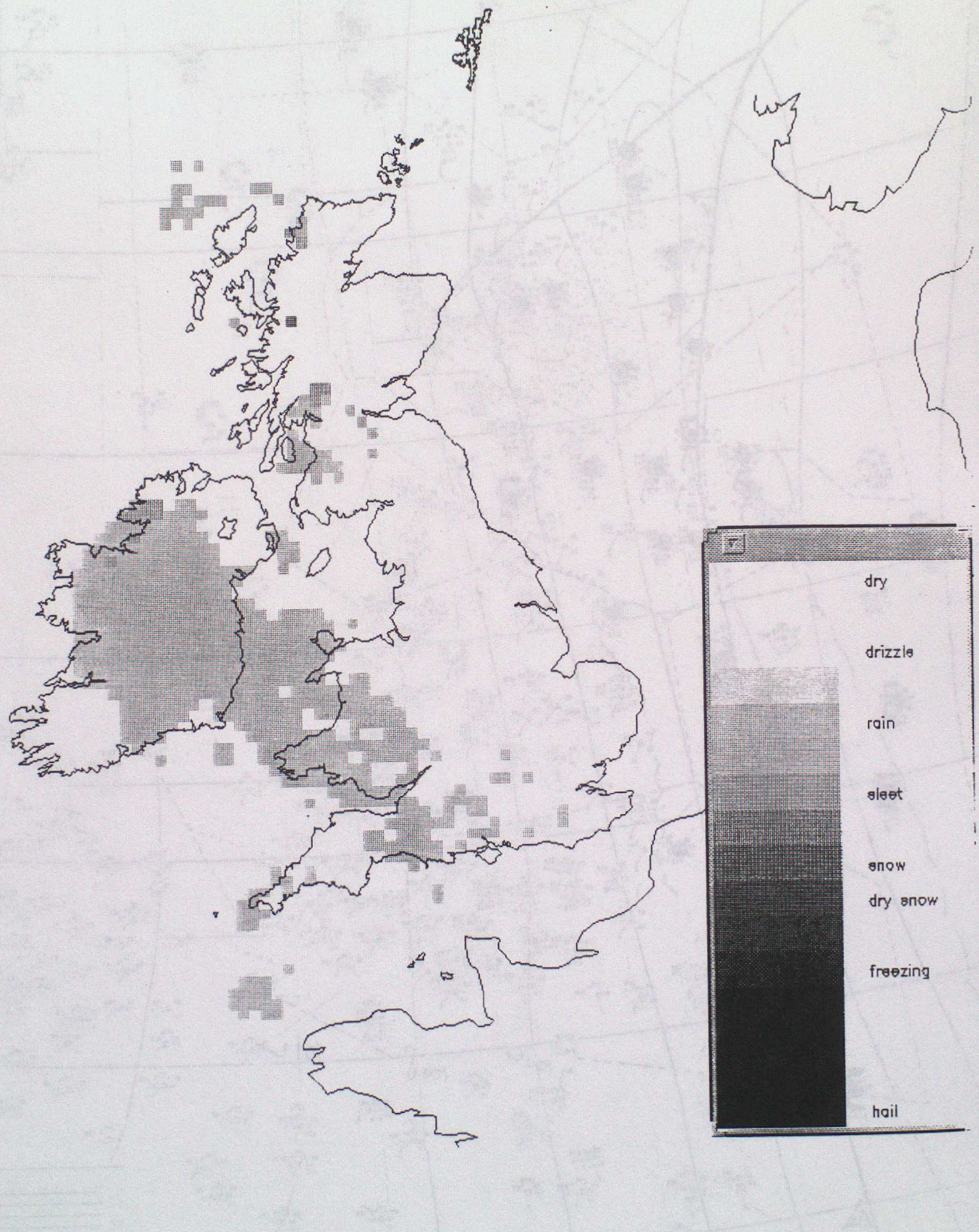


Fig. 10

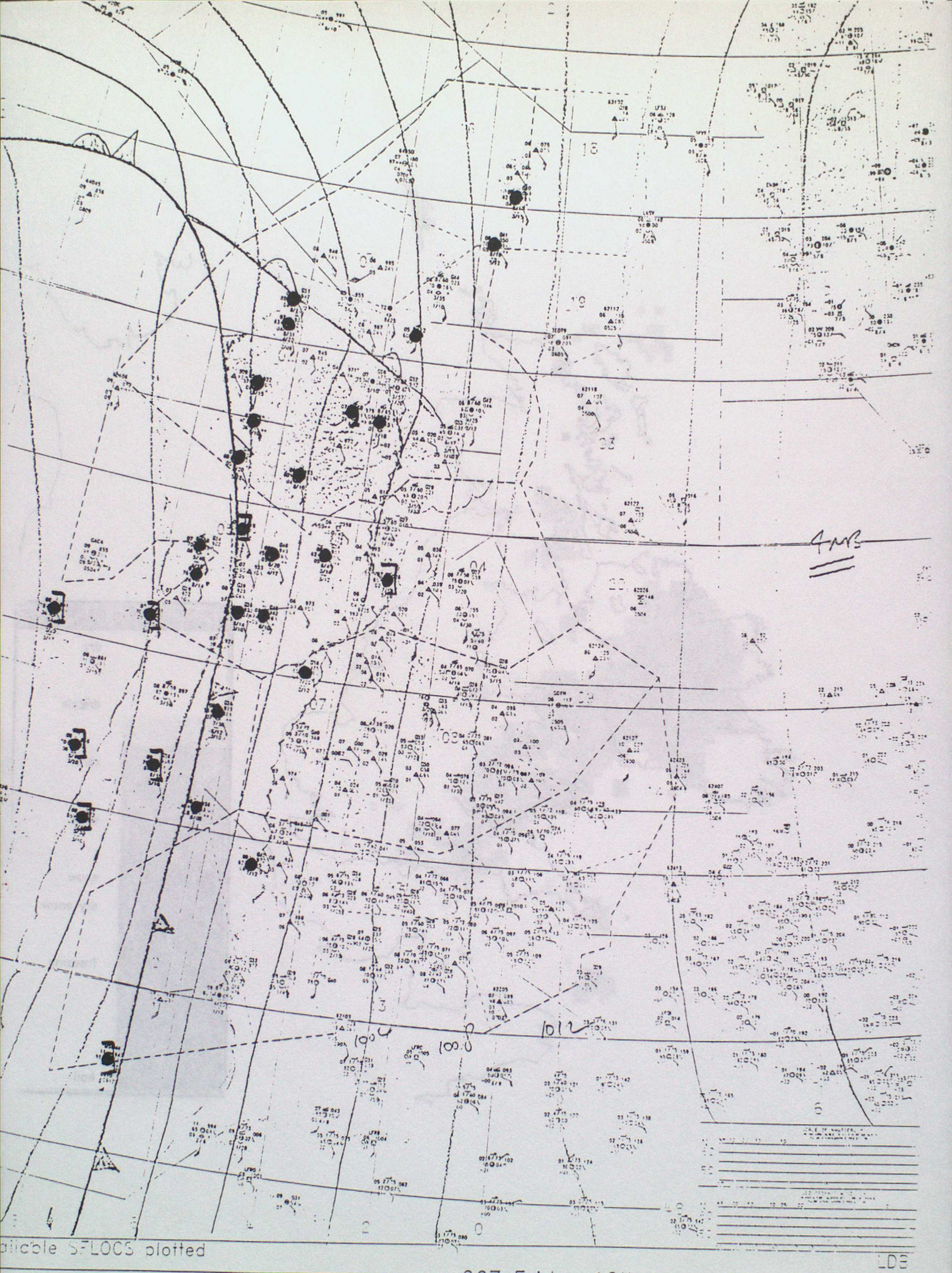
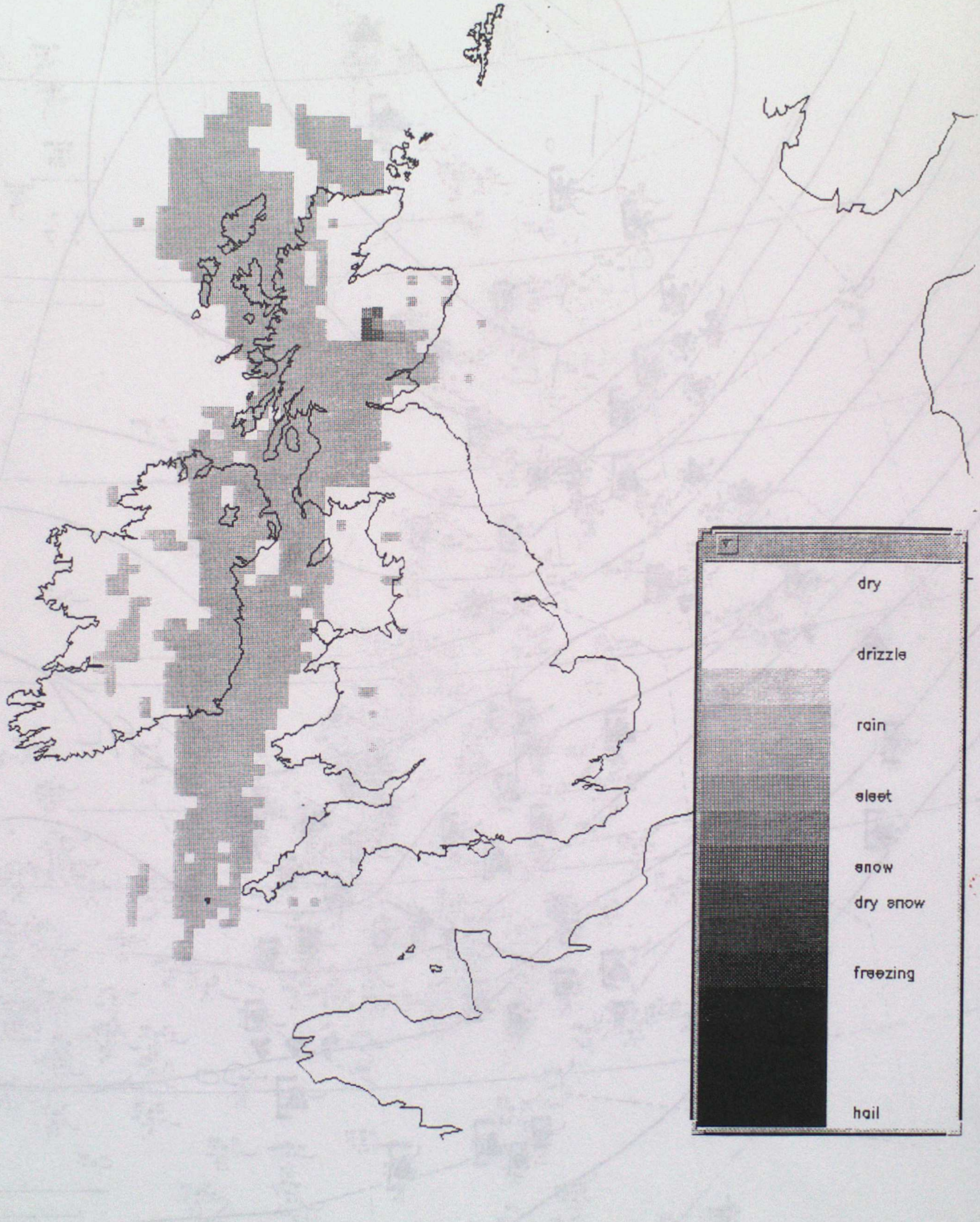


Fig. 11 06Z Friday 10th March 95



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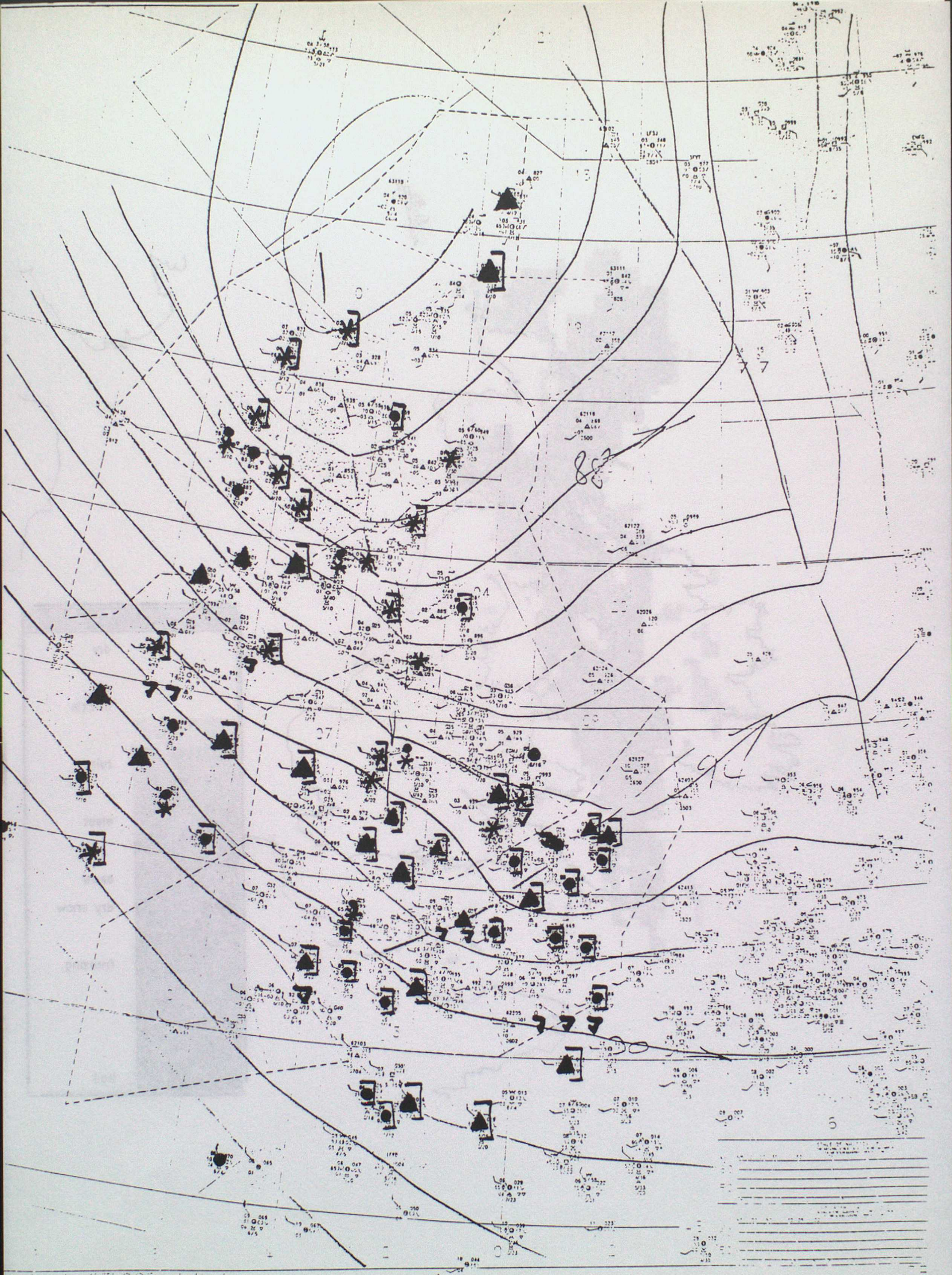
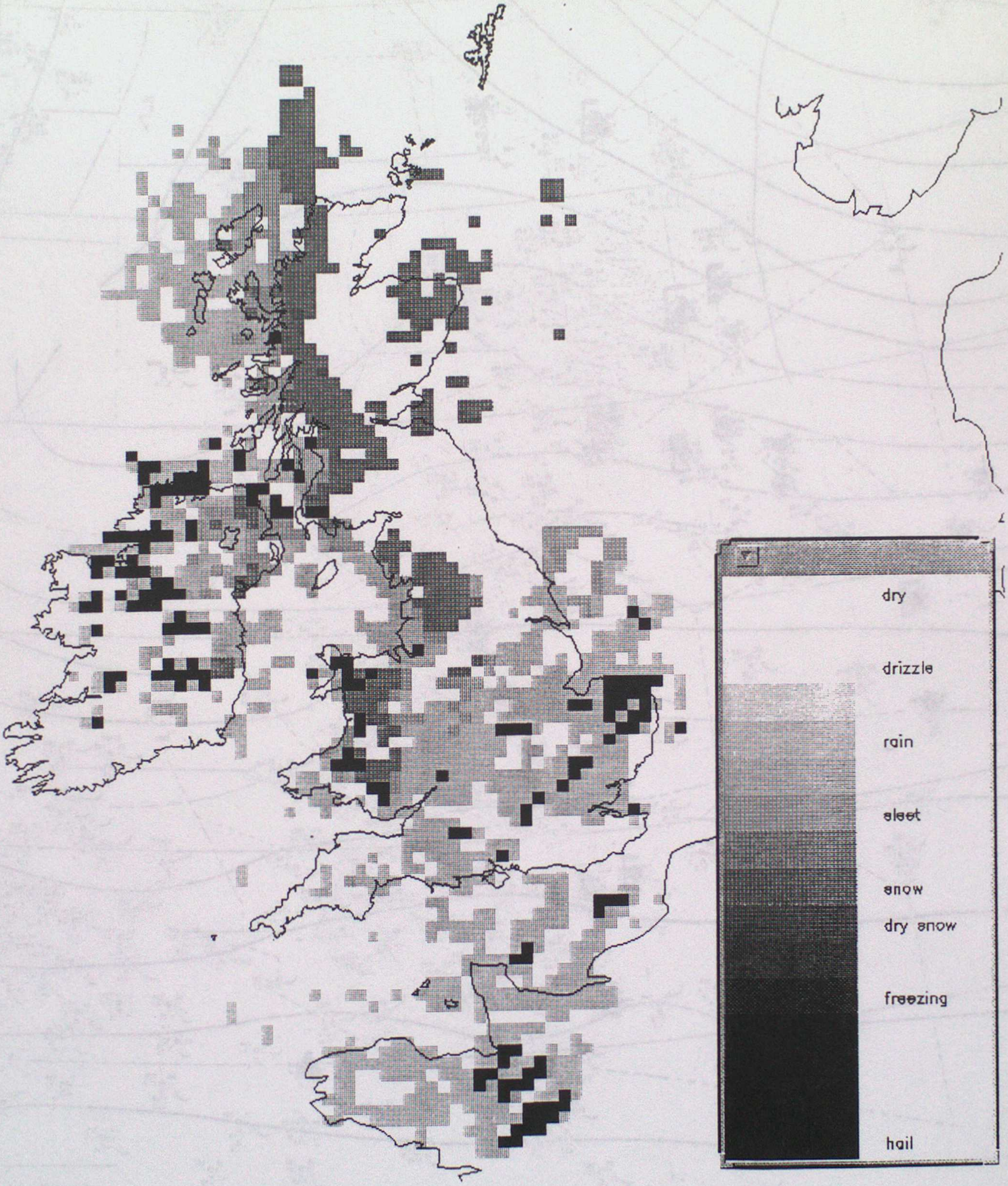


plotted

Fig 13

157 Wednesday 15th March 95



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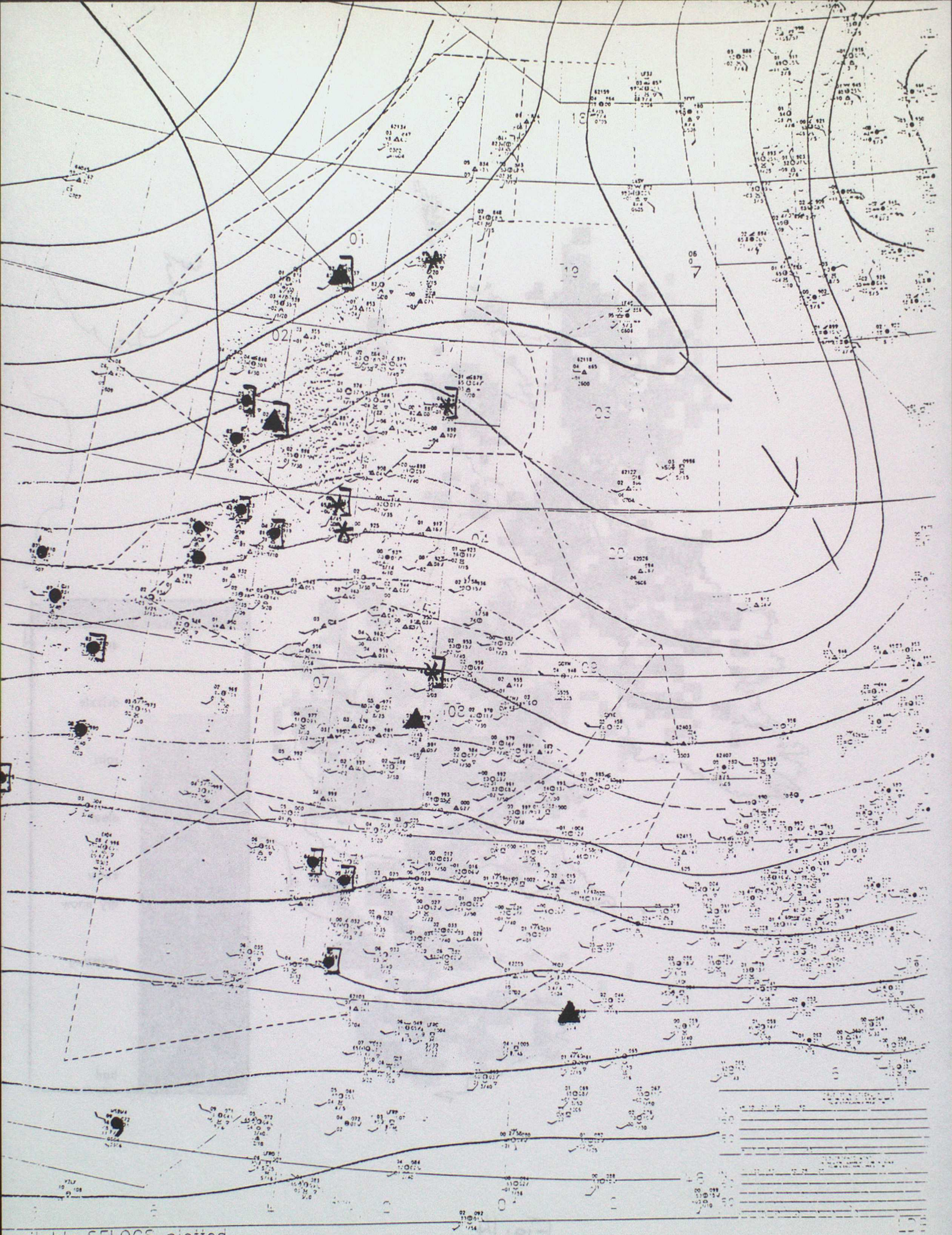


available SFLOCS plotted

06Z Thursday 16th March 95

Fig 15

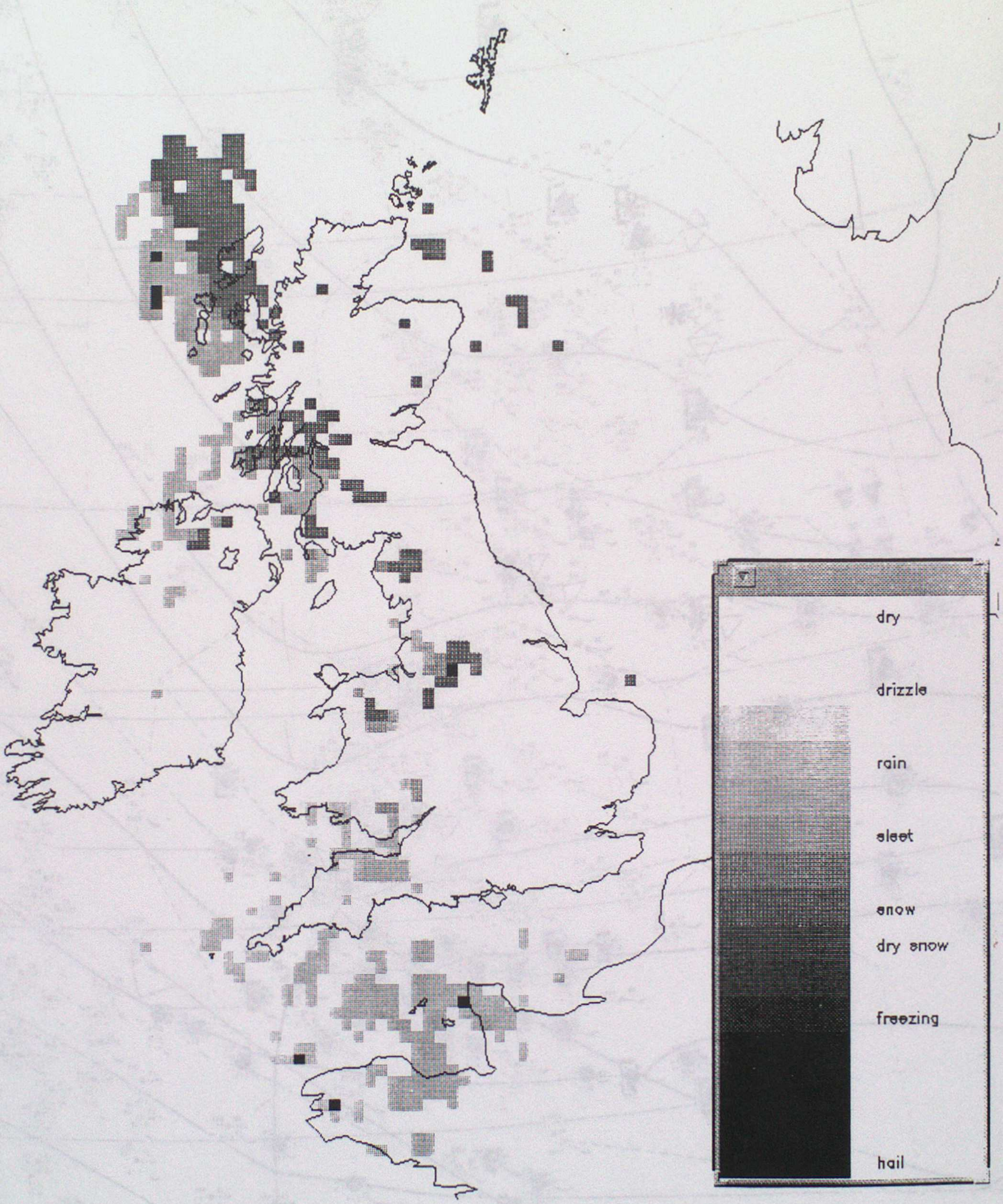
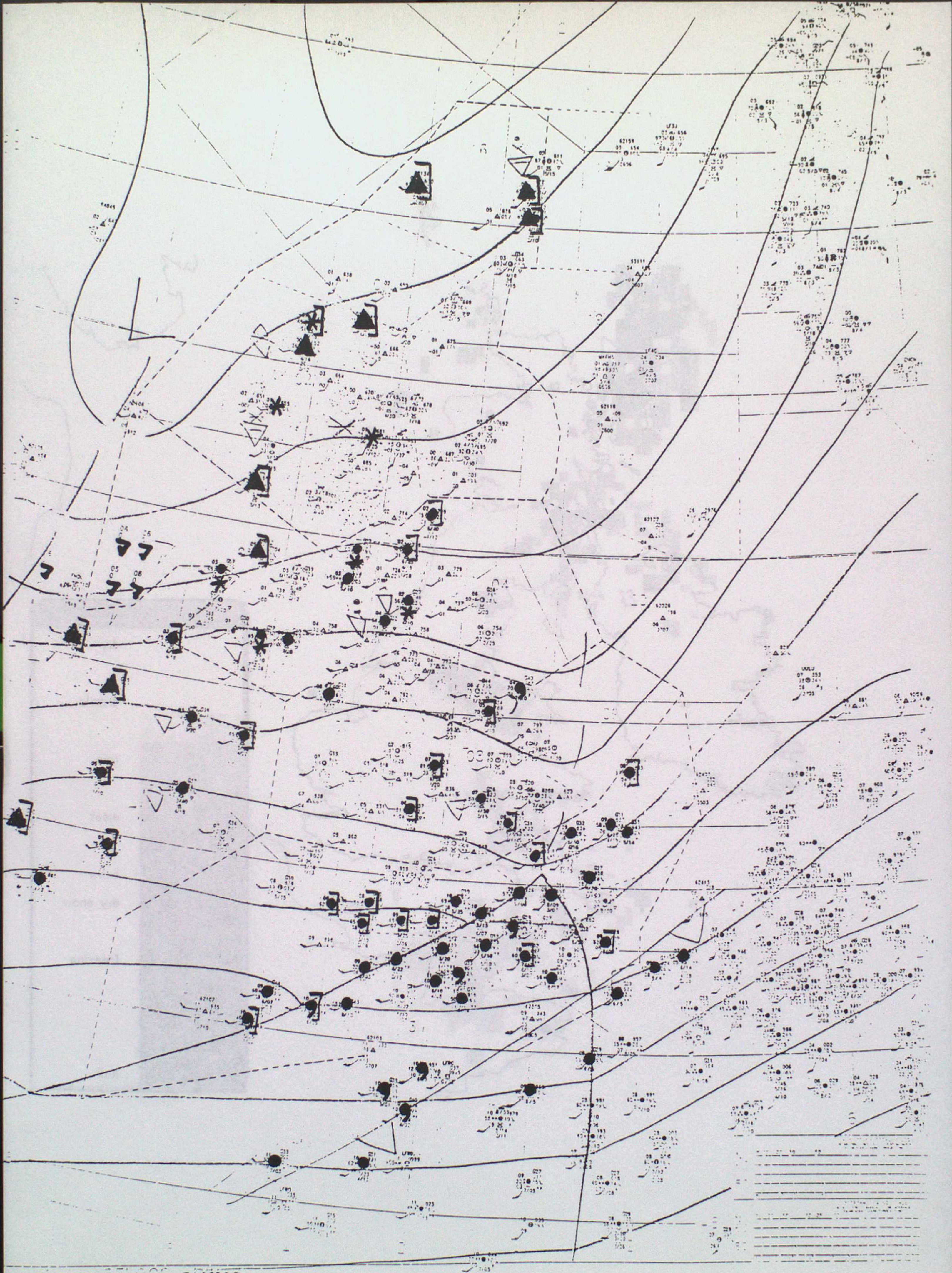


Fig. 16



SFLOCS plotted

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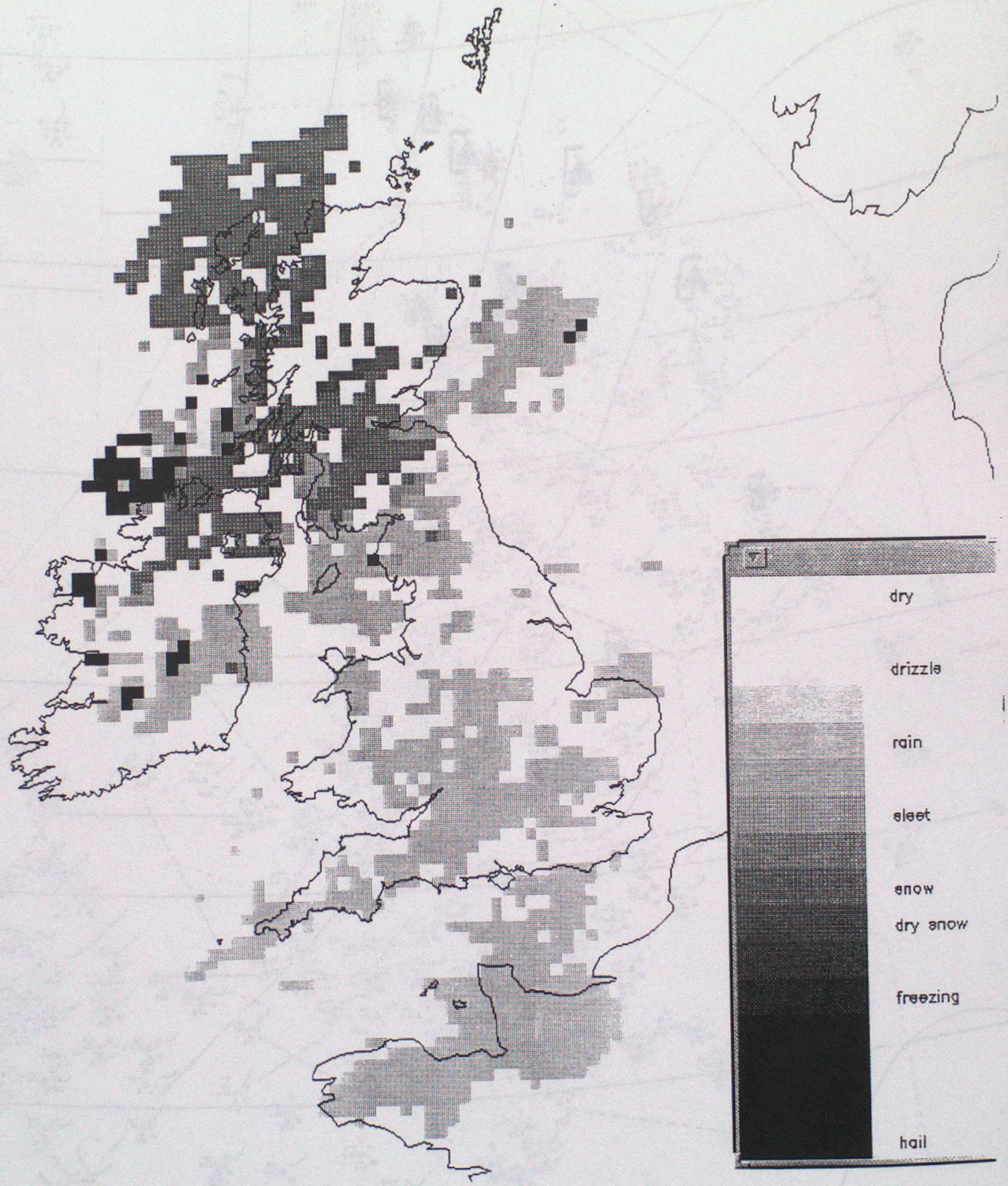
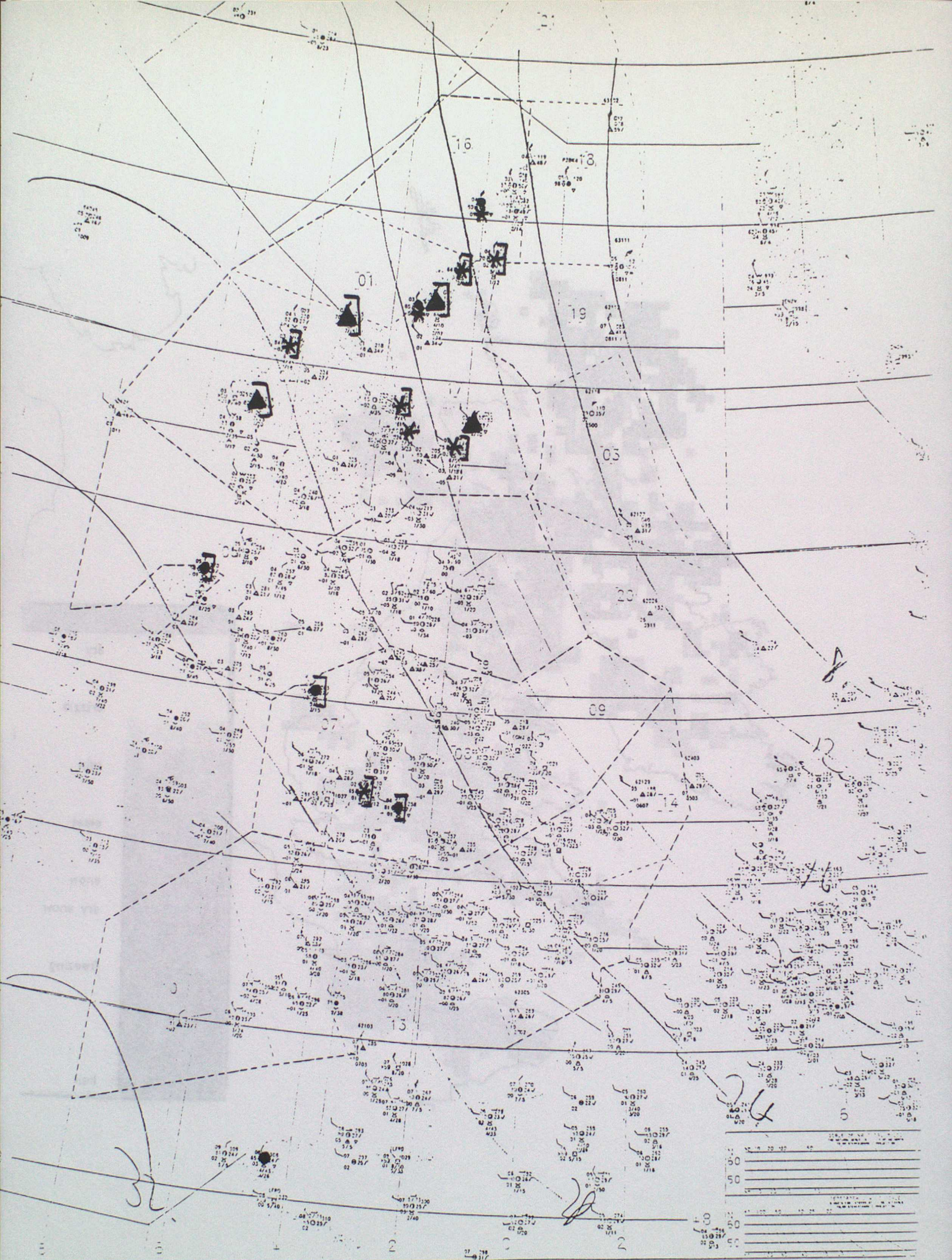


Fig. 18



available SFLOCS plotted

Fig. 19

09Z Monday 20th March 95

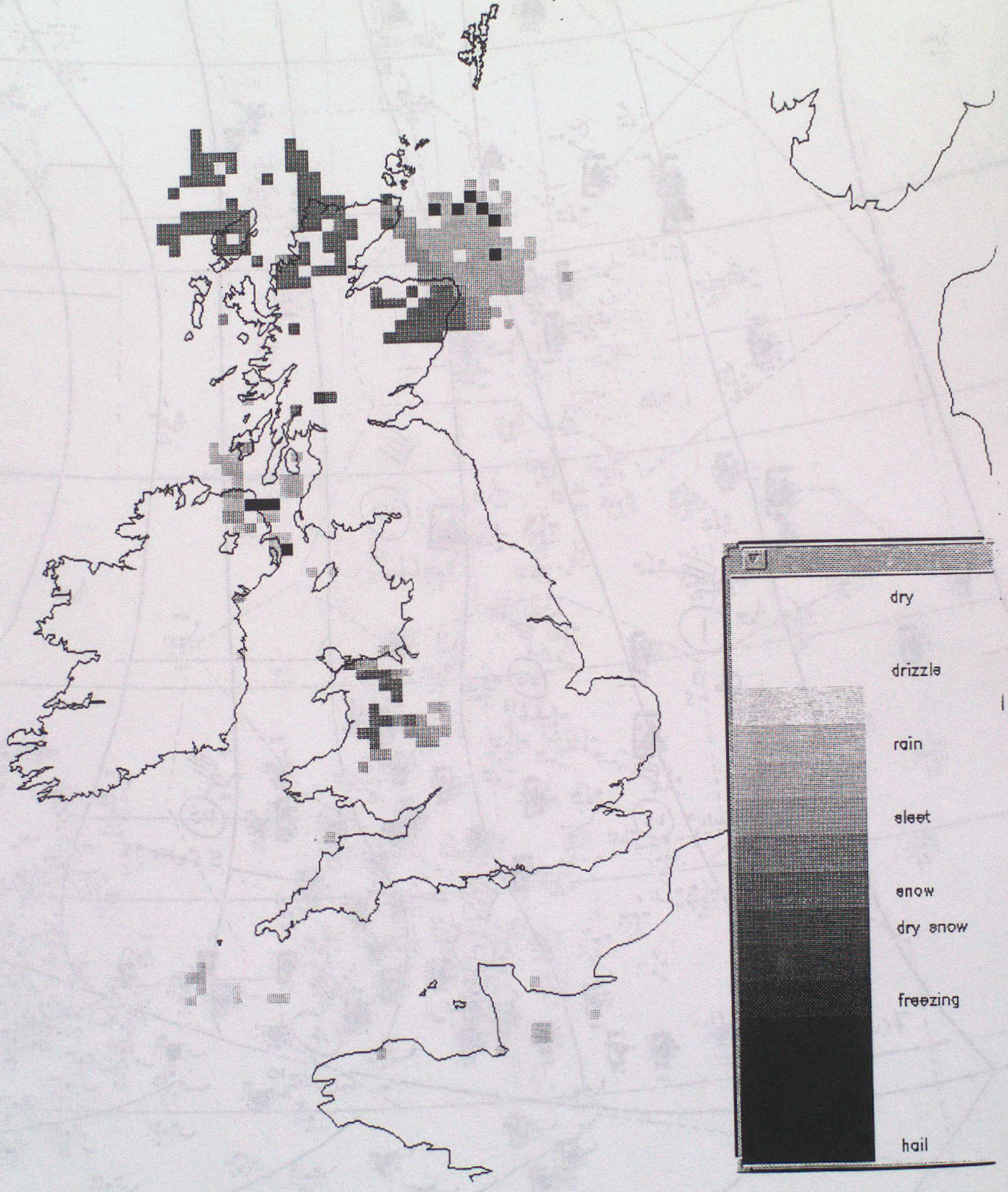


Fig. 20

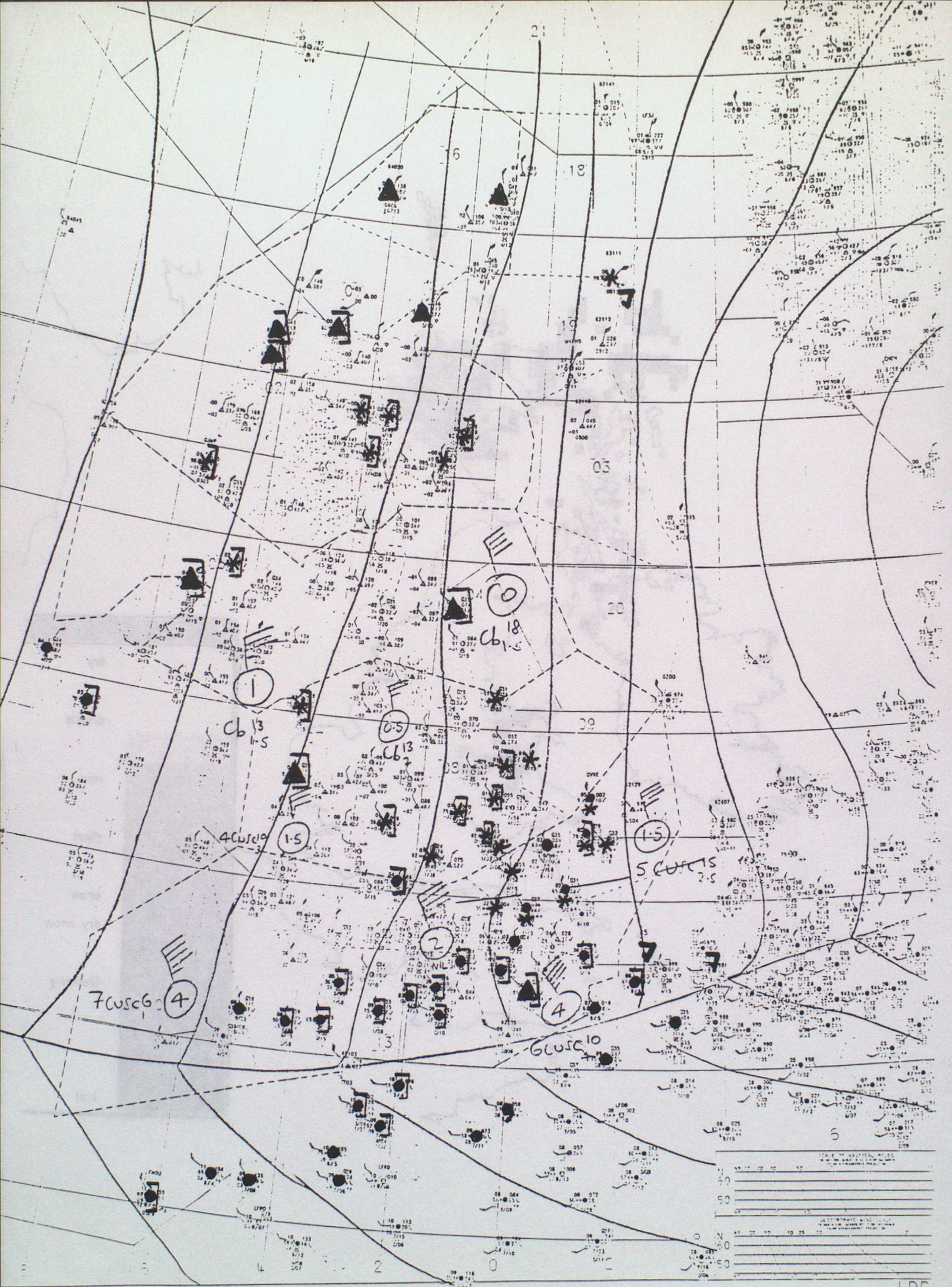


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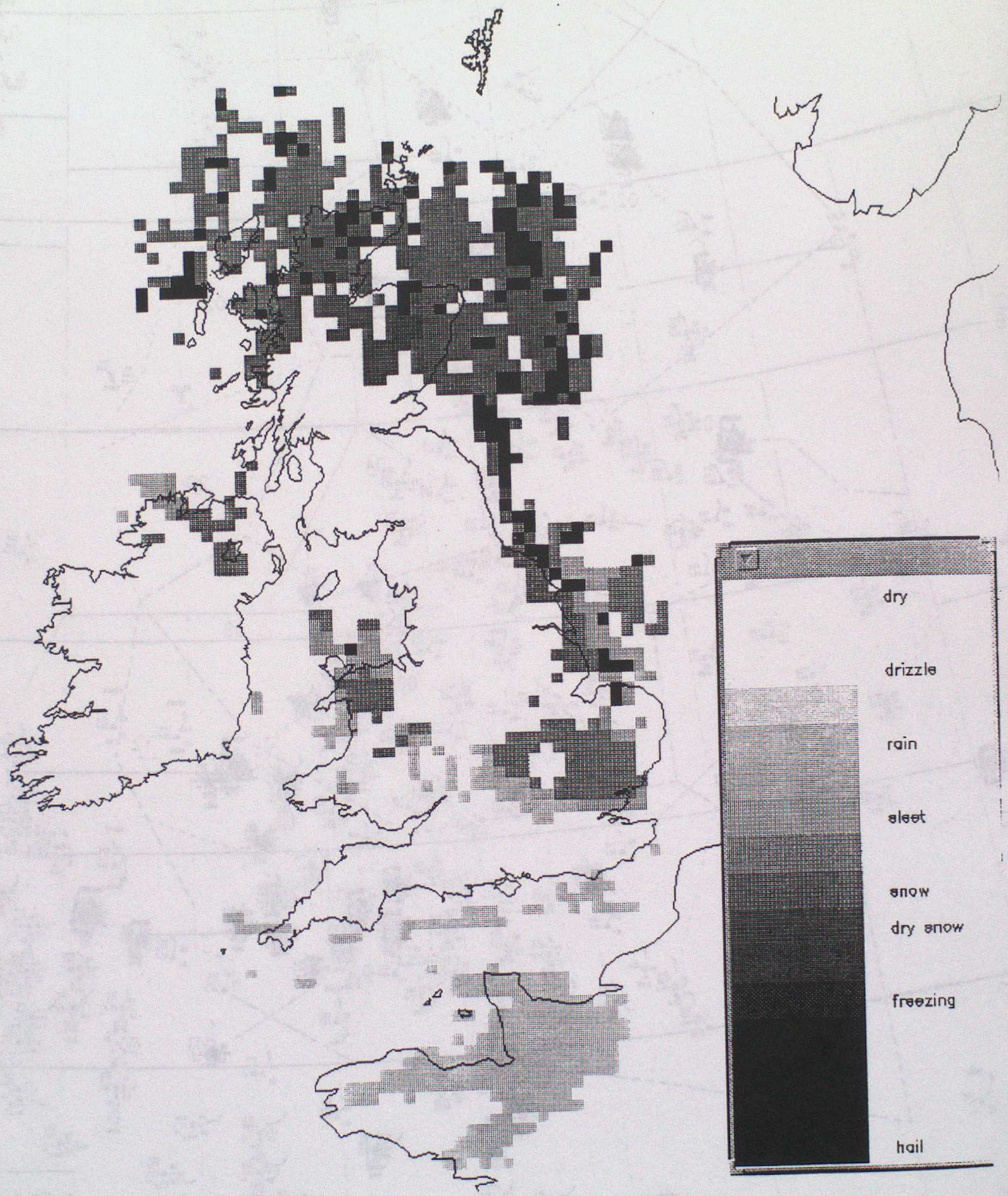
Fig. 21

06Z Monday 27th March 95



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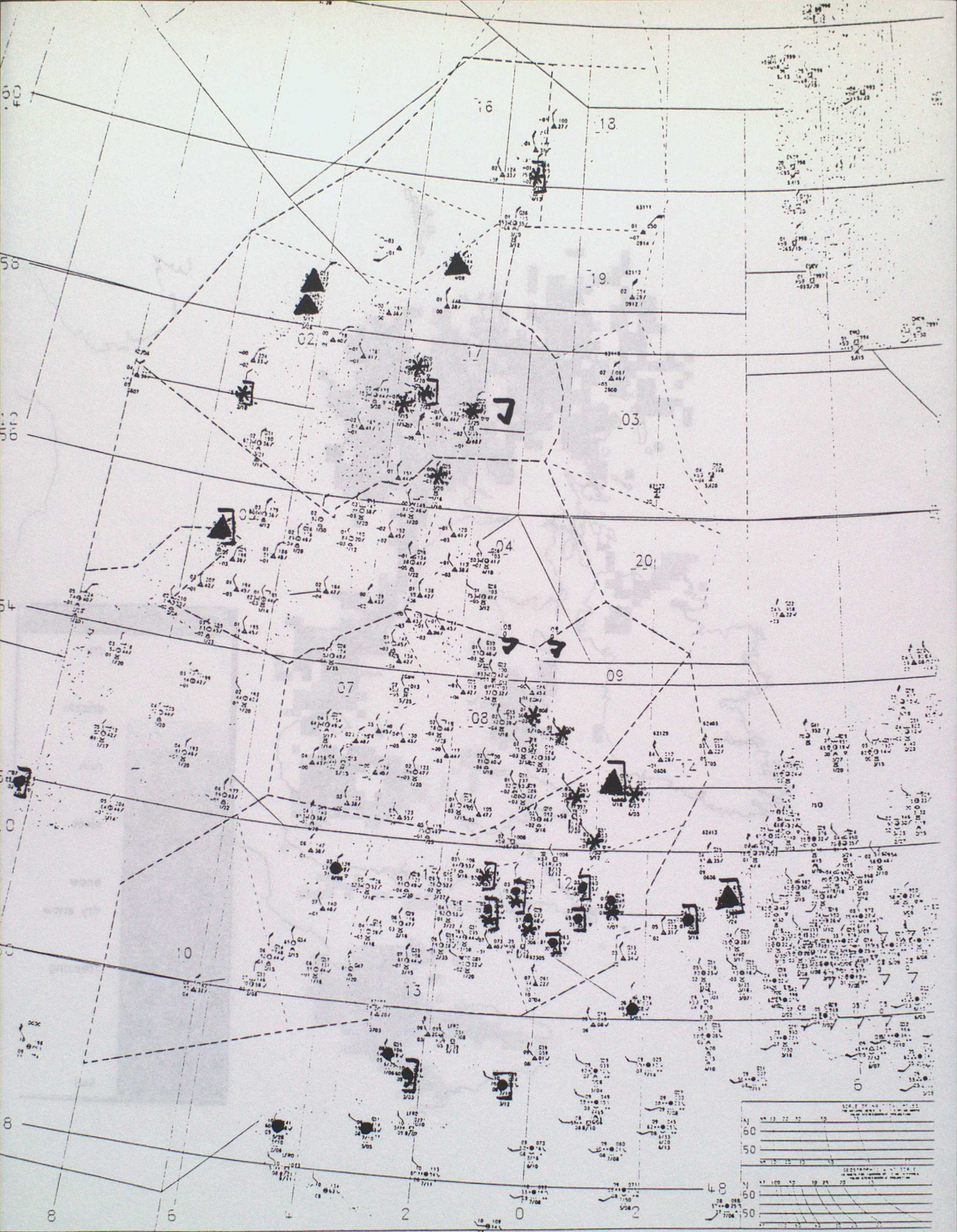

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Fig.23 08Z Monday 27th March 95

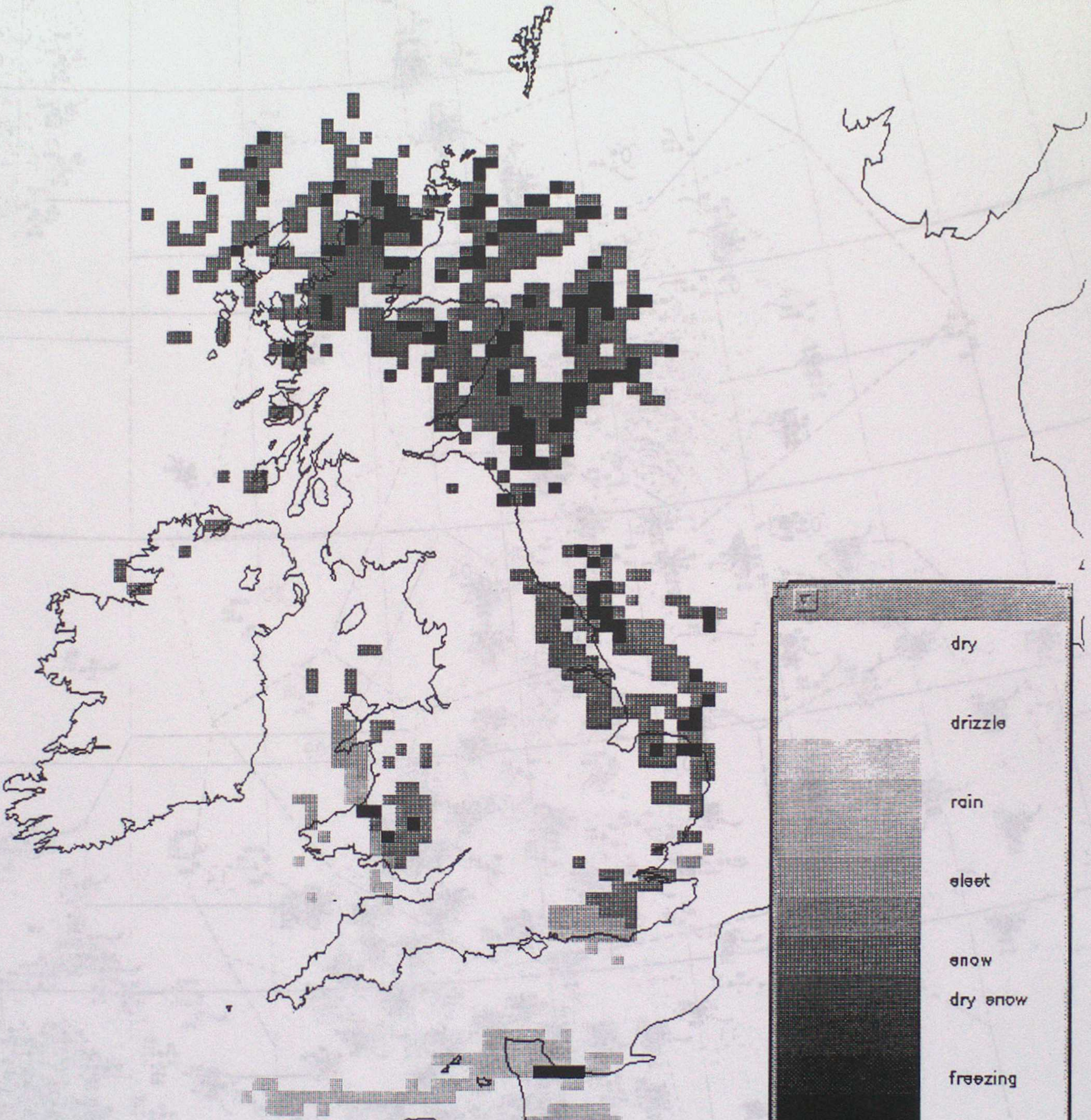
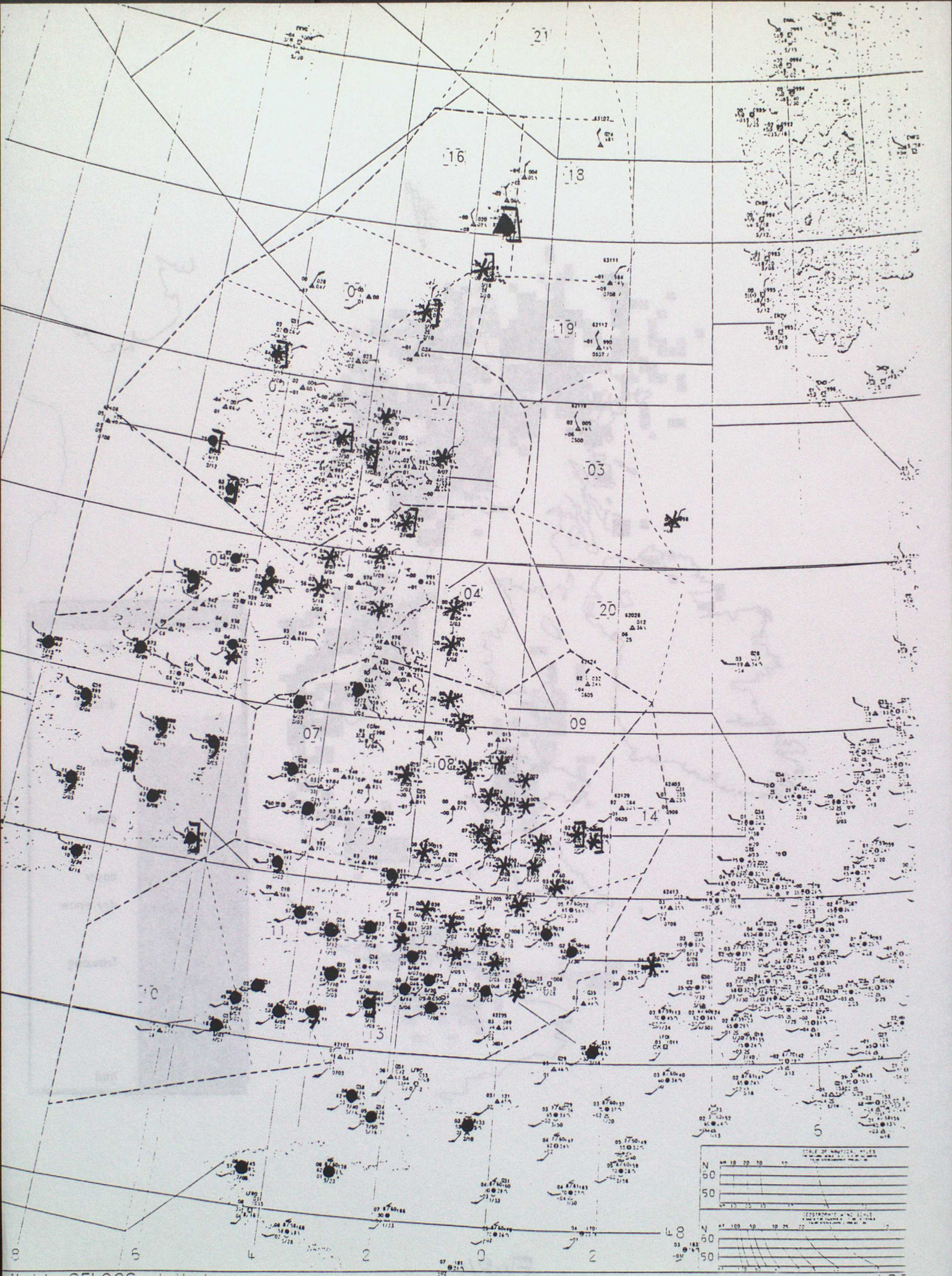


Fig24.



ailable SFLOCS plotted

Fig.25

10Z Tuesday 28th March 95

LDE

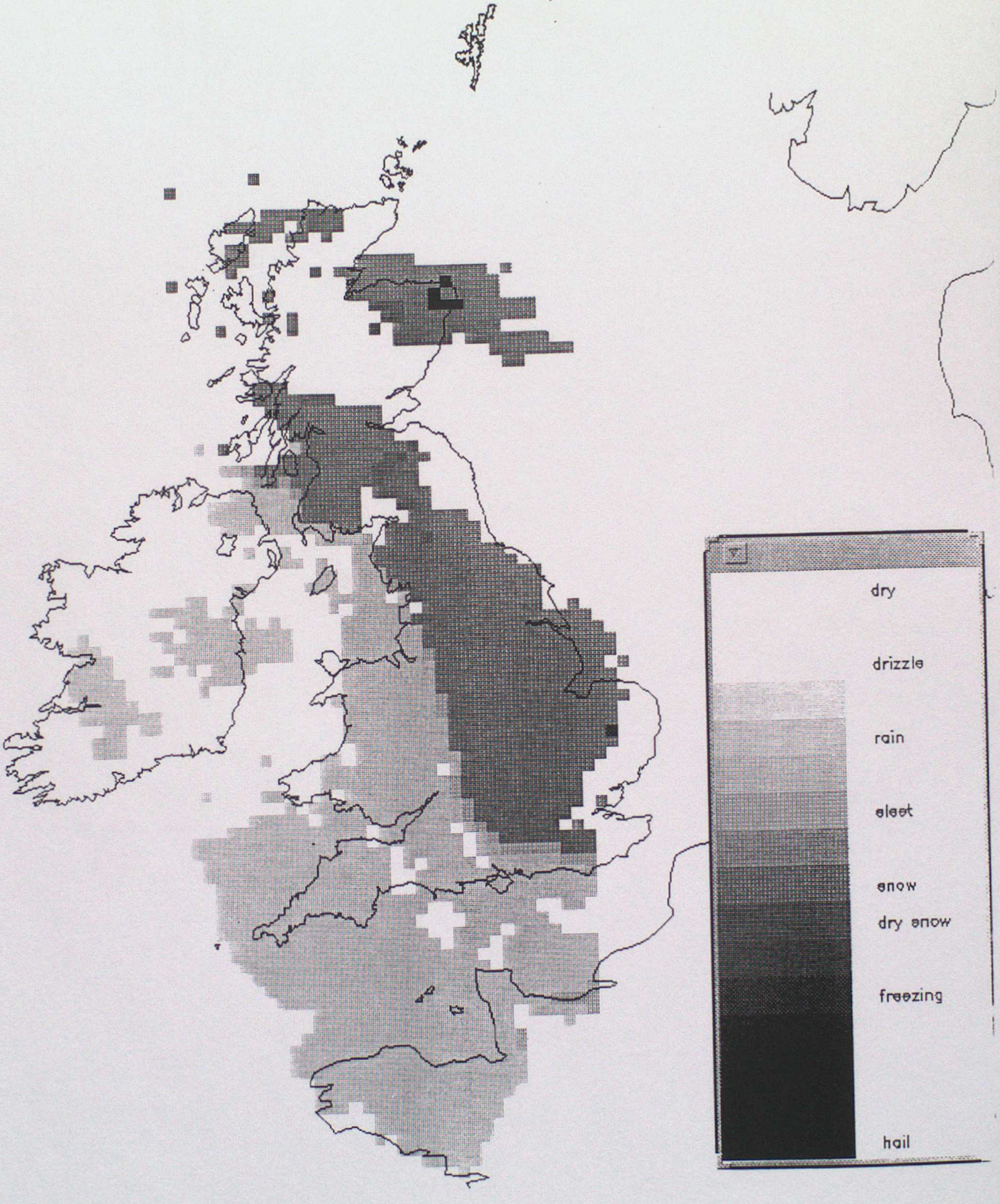


Fig. 26