METEOROLOGICAL OFFICE RADAR RESEARCH LABORATORY

RSRE MALVERN ENGLAND

RESEARCH REPORT

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SEVERE WINTERTIME HAILSTORM IN SOUTH DEVON

by

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INTRODUCTION

The "South Devon" storm on the afternoon of the 13th December 1978 became front page news in the Kingsbridge Gazette when greenhouses, glass windows, perspex roofing and the body work of cars all suffered from the effects of large hail. According to Charles Boland, Insurance Brokers of Kingsbridge, the cost of the damage to property has run to many hundreds of thousands of pounds. Wintertime hailstorms such as this appear to be rare. An analysis of the hailstorms reported in British Rainfall and the Meteorological Magazine during the 50-year period, 1906 - 1955, shows that of 169 cases of damaging hail only six occurred in the winter months November to February. Of these none at all occurred in December.

Fig 1 shows the hailswath and precipitation reports deduced mainly from eye witness information, newspaper stories and insurance claims. The storm approached south Devon from the southwest crossing the coast at Thurlestone at 1530 GMT. The hailfall was brief but intense; the heavy rain, however, lasted for 20 minutes. At Kingsbridge eyewitnesses described the hail as first falling in the form of "irregular chunks of ice" before later becoming more spherical in form. A full description of the storm at Strete (location shown in Fig 1) has been supplied by Mrs D Dugdall. She described the hailfall as beginning at 1551 GMT with small hail but with increasing numbers of large hailstones. This phase lasted for about 45 seconds, being followed by a period of about 15 seconds when only large hail fell. She estimated the ground coverage of these large hailstones at 15-25 per square metre and measured the diameter of one hailstone as 3 cm. A photograph of some of the hailstones which fell at Strete is shown at Fig. 2.

The hail was confined within a narrow band, the southern edge of which was well defined near Kingsbridge. While large hail fell at the town centre at Kingsbridge, West Charleton less than 2 km to the southeast experienced heavy rain but no hail. To the north, the extent of the hail was not so well defined but at Loddeswell, 4 km from Kingsbridge, only heavy rain occurred. To the east the observation from Berry Head coastguard station at 1600 G.M.T. shows a violent thunderstorm with rain but no hail, although the storm centre lay less than 5 km to the south at that time.

SYNOPTIC SETTING

During the three days before the 13th December the northern Atlantic was dominated by a large area of low pressure.

Very cold air had been swept south and then east from eastern Canada to the southwest approaches of the United Kingdom, developing a strong baroclinic zone oriented east-west approximately along 45° north. A vigorous depression developed near Nova Scotia on 10th December and moved rapidly eastwards. On 12th December it slowed and turned north in the vicinity of the British Isles as it encountered a persistent upper ridge lying from Europe to Iceland. Fig 3 shows the surface and 1000 - 500 mb thickness analyses at 1200 G.M.T. on 13th December. Showery weather was experienced throughout southwest England during the morning of 13th December with frequent blustery showers of rain and hail quickly passing on the 25 ms^{-1} southwesterly winds. A short wave trough could be identified in the early morning over Cornwall and this travelled rapidly eastwards bringing heavy rain showers to some locations. A similar trough advanced eastwards across the same area during the afternoon and, with the aid of radar and satellite data, this trough was revealed to be associated with a discontinuous line of deep convection trailing southwestwards to the rear of the South Devon hailstorm.

WIND STRUCTURE IN THE VICINITY OF THE HAILSTORM

The radiosonde stations nearest to the severe storm are those at Camborne in Cornwall and Brest in northwest France. The locations of these stations are shown in Fig 3 which put them about 250 km east and eastsoutheast of the storm respectively at 1200 G.M.T. The Brest and Camborne midday soundings show rather similar wind structures. Since both stations are approximately equidistant from the storm at 1200 G.M.T. an average of these two wind soundings has been taken as representative of the wind structure at most levels in the vicinity of the storm - see Fig 4a. Analysis of hourly isallobars and surface pressure patterns reveals some backing in the direction of the isobars near south Devon just before the arrival of the storm. Moreover the anemograph trace recorded at Plymouth shows a backing of some 20^{o} in wind direction at 1405 G.M.T. in advance of a squall. Consequently the 900 mb wind velocity in fig 4 is shown backed by 20^{o} from the average value given by the Brest and Camborne soundings.

Also plotted in fig 4a are the velocities of propagation of the South Devon storm before (C1) and after (C2) it became severe and of a storm (D) selected as representative of nearby weaker convection. Consideration of the winds relative to the severe hailstorm show an inflow of air at low levels (V_L) from 160^{o} at 14 ms^{-1} while at anvil level (400 mb) the relative velocity (V_H) is 230^{o} at 14 ms^{-1}. The mean wind shear in the layer from cloud base to cloud top (910 mb to 317 mb) is computed to have been $4 \times 10^{-3} s^{-1}$. This shear is small compared with that found by Ludlam (1963) and Chisholm and Renick (1972) in association with severe hailstorms but, according to Marwitz (1972), it can be classified as moderate shear typical of environmental conditions surrounding multicell hailstorms.

THERMODYNAMIC STRUCTURE IN THE VICINITY OF THE STORM

At high levels both Camborne and Brest soundings exhibited similar temperature and humidity structures. However, the important low-level flow (V_L in fig 4a) with its southerly component, is better described by the midday Brest ascent. Thus the 1200 GMT sounding at Brest (Fig 4b) has been selected as representative of the atmospheric conditions in the environment of the hailstorm for the purpose of evaluating the convective instability. Surface observations at stations on the channel coast show the air to have been fairly dry with relative humidity about 77% and humidity mixing ratio of about 5.5 gkg^{-1}. Throughout the afternoon dry-bulb temperatures remained constant at about 9°C. The surface temperature and humidity mixing ratio reported from Brest (9.5°C and 5.8 gkg^{-1}) thus appear to be representative of the lowest layer during the afternoon. It is this air which is assumed to have fed the updraught of the South Devon hailstorm.

On the basis of Fig 4b the lifting condensation level is seen to have been at 667m AMSL (910 mb) and this agrees well with cloud-base levels of 600 m or 700 m as estimated at nearby reporting stations. Notice, however, that the implied cloud-base temperature is 1°C colder than the environment and further lifting to 1085 m (865) mb) is required before free convection can commence. According to Browning (1977) this helps in the maintenance of a severe storm by inhibitng premature release of convective instability in the region ahead of the storm.

Vertical velocity profiles for an air parcel within the storm updraught have been computed using the loaded moist adiabatic model of Chisholm (1973). This model assumes a one-dimensional steady-state updraught, free of entrainment, with all condensed water being carried within the updraught. Latent heat of freezing is neglected. Following Chisholm, a standard cloud-base vertical velocity of 5 ms^{-1} has been assumed. The computed variation of vertical velocity with height for the South Devon hailstorm is shown in Fig 5, together with the inferred vertical distribution of liquid water content within the updraught.

The energy available to the storm updraught, given by the area between the parcel curve and the environment curve, was not particularly great in the South Devon hailstorm and, according to Chisholm (1973), it would qualify as a medium-energy hailstorm. Table 1 compares parameters computed by Chisholm, based on a sample of 12 medium-energy summertime hailstorms in Alberta with parameters computed for the South Devon storm. A good deal of similarity is apparent, although high surface temperatures in the Alberta storms enforce a cloud-base rather higher than that of the South Devon storm.

RADAR DATA

The Meteorological Office has installed a weather radar at Camborne as the first of a series of such radars to collect data on the plan distribution of rainfall both for dissemination to users in real time and for experimental use within the Meteorological Office to devise improved procedures for short period weather forecasting. The rate of rainfall is at present derived from the strength of the radar echoes from the precipitation using a standard relationship. A network of telemetering raingauges, yet to be incorporated in the system, will eventually be used to calibrate the radar and to increase the accuracy of the data. The inferred rainfall rate at a given location is the mean of the rainfall values at all heights within the radar beam at that location. Because the beam broadens and rises to higher altitudes with increasing range, the surface rainfall rate is capable of being quantitatively defined only out to about 80 km from a well-sited radar. Nevertheless, a useful qualitative assessment of the surface rainfall rate can be inferred out to much longer ranges from the rainfall rate measured at mid-tropospheric levels. Thus, although at long ranges light rainfall emanating from low level cloud may be missed, heavy precipitation from deep convection will be observed and can be assumed to reach the surface of the earth at approximately the observed rate.

The rainfall data observed by the radar at Camborne are degraded to 5 km spatial resolution and 15 minute time resolution to ease the problem of data transmission and processing. These data are disseminated to stations remote from the radar where they may be stored and replayed on colour televisions. This kind of data was monitored in real time on 13th December. The appearance of the colour television display at 1547 G.M.T. when the South Devon storm was at its maximum intensity is shown at Fig. 6. The highest precipitation rate within the storm (shown red) shows the position of the hail cell on the coast of Devon near Strete. Strete is at a range of 120 km from Camborne and so the radar is detecting precipitation between 3 km and 9 km above the earth. Other precipitation areas may also be identified in Fig.6. Scattered light showers, for example, can be seen off the north coast of Cornwall with a rather heavier rain cell near the Gower peninsula in South Wales. Autographic records from a rainguage on the Gower peninsula show this shower to have produced 10 mm of rain shortly after the time of this radar picture. A well-defined band of rain cells also lies southwest from near Plymouth. This and other bands were tracked throughout the afternoon; these were well defined over the sea but decayed over land.

Individual showers and rain areas, including the South Devon storm, were tracked throughout the period 1300 to 1600 G.M.T. A continuity diagram showing the progression of six storm cells is shown at Fig. 7. The motion of rain areas A, B, E and F is seen to have been regular over a period of at least two hours. Rain shower D was less vigorous and shorter-lived. Rain area C, the South Devon storm, was first identifiable at 1300 G.M.T. as an area of light rainfall but quickly became more vigorous and may be traced until it went out of radar range after 1615 G.M.T. The motion of the storm was constant until 1515 G.M.T. at which time the maximum intensity increased rapidly and the storm slowed down and veered by about 5° from its previous direction of motion (see Table 2). Soon after, while still progressing to the right of its previous motion, the storm crossed South Devon. A slowing down and a veer in the direction of propagation of the storm is typical of severe hailstorms as reviwed by Browning (1977). The 5 km resolution of the radar was not adequate to resolve the growth of new cells within the storm. However, inspection of 2 km radar data available off-line shows some evidence of multicellular structure at least during the earlier stages of the storm's life history.

SATELLITE DATA

Infra-red imagery in digital form is available at nominally half-hourly intervals from the European geostationary meteorological satellite METEOSAT in orbit at 0°N 0°W. The satellite of necessity has a foreshortened view of the British Isles but, by processing the imagery to correct for picture distortion, satellite data can be displayed on a colour television in a similar manner and format to the radar data. (Ball et al 1978). Imagery for 13th December was received irregularly and no satellite infra-red pictures were available at the time of the hailstorm; however, the 1420 G.M.T. and 1650 G.M.T. pictures, approximately one hour before and after the hailfall respectively are shown at Fig. 8. The colours represent infra-red radiances of cloud surfaces observed by the satellite radiometer and the boundaries between colours may be assigned temperatures as listed in the legend to Fig. 8. For clarity, data associated with low-level, and relatively warm, cloud have not been displayed.

The major feature of Fig. 8a is the band of convective cloud tops (red and white) extending southwestwards from the Lizard peninsula. This formed part of the tail of a so-called comma cloud formation, the head of which may be seen off the north-west coast of Cornwall. By 1650 G.M.T., (Fig.8b), the head of the comma cloud pattern has moved over South Wales and the convective cells within the tail have intensified in the portion over the English Channel. Comma cloud formations, described for example in the W.M.O. publication by Anderson et al (1973), result from the preferential release of convection in the region of increased vertical motion associated with the local maximum of positive vorticity advection ahead of a short wave upper trough. Identification of these areas of organized vertical motion is important since heavy precipitation is often associated with them. The short wave trough was not resolved by radiosonde ascents on this occasion owing to the sparse distribution of upper air stations in the area southwest of the British Isles. However the satellite pictures clearly showed the associated convective region.

A comparison of satellite and radar pictures shows a correspondence between heavy rain and the coldest (highest) convective tops. This is especially true for those clouds which have recently grown rapidly, an effect noted by Scofield and Oliver (1977). Note how the rather discontinuous cloud band over and to the south of Cornwall at 1420 G.M.T. developed into an extensive area of cloud by 1650 G.M.T. with at least three distinct regions with cloud top temperatures below -42°C, implying that invigoration of the convection has taken place. At this time heavy rain and thunder was reported by stations in the vicinity of the newly grown cloud area. The south Devon storm lay within the area of cloud to the south of Cornwall at 1420 G.M.T. but radar observations at this time show the storm to have been limited in extent and associated cloud tops may have been too small for their full height to be resolved by the satellite radiometer.

FUTURE USE OF SATELLITE AND RADAR DATA

A wide range of scales of meteorological phenomena has been depicted by radar and satellite imagery within the few hours covered by this study. Satellite pictures showed the presence of a comma cloud system with associated cloud bands of the order of 200 km in length; with convective areas organized in bands which persisted for about three hours. Within the system the radar was able to depict individual showers whose dimensions were about 5 km or more and observations were frequent and detailed enough to enable individual storms to be tracked for periods of one to three hours and to give early warning of intensification and decay of the rain cells. In the case described it would have been possible to have forecast heavy precipitation in south Devon at least an hour beforehand on the basis of the radar observations since up to the time the storm hit Devon it not only had moved uniformly in the same northeasterly direction but also had intensified consistently during the previous two hours. However, further resarch is required on the relationships between observed cloud and rain patterns so that the combination of satellite and radar data can be more fully utilized to extend the forecast period up to several hours ahead.

ACKNOWLEDGEMENTS

The author wishes to thank the Climatological Services Branch of the Meteorological Office for supplying an analysis of hailstorm occurrence and Miss J Rogers of the Kingsbridge Gazette and Mr C Boland of Charles Boland Insurance Brokers for their help in determining the extent of the hailstorm. Special thanks are due to Mrs D Dugdall who not only supplied a written account of the storm but collected, measured and stored sample hailstones. I am also indebted to Dr K Browning for his many helpful comments and advice.

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Table 1. Comparison between parameters computed for the South Devon storm and those computed by Chisholm (1973) in his study of Alberta hailstorms.

PARAMETER	MEDIUM ENERGY ALBERTA STORMS			SOUTH DEVON STORM
	MIN	MAX	AVG	
Computed Values				
Max. available energy (J_g^{-1})	0.21	0.41	0.31	0.38
Max. storm top (km A.G.L)	7.5	11.6	9.7	8.3
Max. vertical velocity (ms^{-1})	21.1	29.0	24.6	19.2
Max. water content (gm^{-3})	2.6	4.9	3.4	3.7
Cloud base temperature (^oC)	- 0.7	11.2	4.3	4.0
Storm top temperature (^oC)	-41.7	-66.2	-56.2	-58.0
Tropopause penetration (km)	- 2.0	0.9	0.0	1.1
Observed Values				
Max. hailstone size (cm)	1.7	5.0	3.1	3.0

TABLE 2. Analysis of the velocities of propagation of the rain areas shown in Fig 7. C1 and C2 refer to the South Devon storm before and after it became severe.

RAIN AREA	PERIOD G.M.T.	DIRECTION ^{o}TRUE	SPEED ms^{-1}
A	1300-1415	235	22
B	1300-1545	230	22
C1	1300-1515	248	22
C2	1515-1615	252	18
D	1445-1545	245	25
E	1300-1415	250	20
F	1445-1600	230	19

Fig. 1 The bold arrow represents schematically the hailswath affecting south Devon on the afternoon of 13th December 1978. Symbols refer to the most severe form of precipitation experienced during the passage of the storm.

Fig. 2 A sample of the hailstones collected at Strete, south Devon. The scale is marked in centimetres.

Fig. 3 Surface and 1000-500 mb thickness analyses at 1200 G.M.T. 13th December 1978. The approximate position of the south Devon storm at this time is shown by a cross. Locations of the radiosonde stations at Brest and Camborne are shown by a triangle and circle respectively.

Fig. 4 Wind, temperature and humidity structure of the atmosphere in the vicinity of the storm. Fig 4a shows the hodograph of an average of the 1200 G.M.T. wind soundings at Brest and Camborne. The 900 mb wind has been plotted backed by 20^{o} with respect to the two soundings to be consistent with the observed low level flow just ahead of the short wave trough. The bold arrows V_L and V_H, respectively, represent the low level inflow and high level outflow of the storm. Also plotted are the velocities of propagation of the south Devon storm before (C_1●), and, after (C_2✳, it became severe and of a storm (D□) selected as representative of nearby weaker convection. Fig. 4b portrays the 1200 G.M.T. radiosonde temperature and dewpoint curves for Brest selected as representative of the air approaching the hailstorm.

Fig.5 Computed variation with height of vertical velocity (W) and liquid water content (LWC) within the updraught of the storm.

Fig.6 Radar picture for 1547 G.M.T. 13th December 1978 when the south Devon storm was depositing large hail near Strete. The intensity of rainfall is given by the colour code in the lower left corner of the picture: the numbers represent approximate rainfall rate in millimetres per hour average over each 5 km square. L represents a rainfall rate less than approximately 1 mm^{-1}, while T and H qualitatively represent echo intensity thresholds of 32 and 64 mm h^{-1} averaged over 5 km squares which are considered likely to be associated with Thunder and Hail. At the time of the picture the radar was not calibrated by surface raingauges and the implied rainfall rates must be considered as qualitative representations of rainfall rate.

Fig.7 Continuity diagram showing the progression of six precipitation cells during the afternoon of 13th December 1978 as observed by the Camborne weather radar. Solid shading represents rainfall rates in excess of 32 mmh^{-1}, hatcing represents rainfall rates in excess of 8 mmh^{-1} and less intense rainfall is unshaded. The time of observation (G.M.T.) is shown against position at hourly intervals. Note how rain area C, the south Devon storm, veers and slows at about 1515 G.M.T. The circle in the digram is drawn at a radius of 160 km from the radar.

Fig.8 Satellite pictures for 1420 and 1650 G.M.T. 13th December 1978. The colours correspond to infra-red radiance data and may be thought of as cloud top temperature ranges. Blue represents $-33^{\circ}C$ to $-36^{\circ}C$; Red $-36^{\circ}C$ to $-39^{\circ}C$; White $-39^{\circ}C$ to $-42^{\circ}C$ and Green represents cloud tops colder than $-42^{\circ}C$. Suppression of coastline and latitude/ longitude markers, which were superimposed on the raw satellite data by Meteosat ground processing as an aid to picture navigation, has led to the dark areas within the cloud over South Wales and the English Channel.

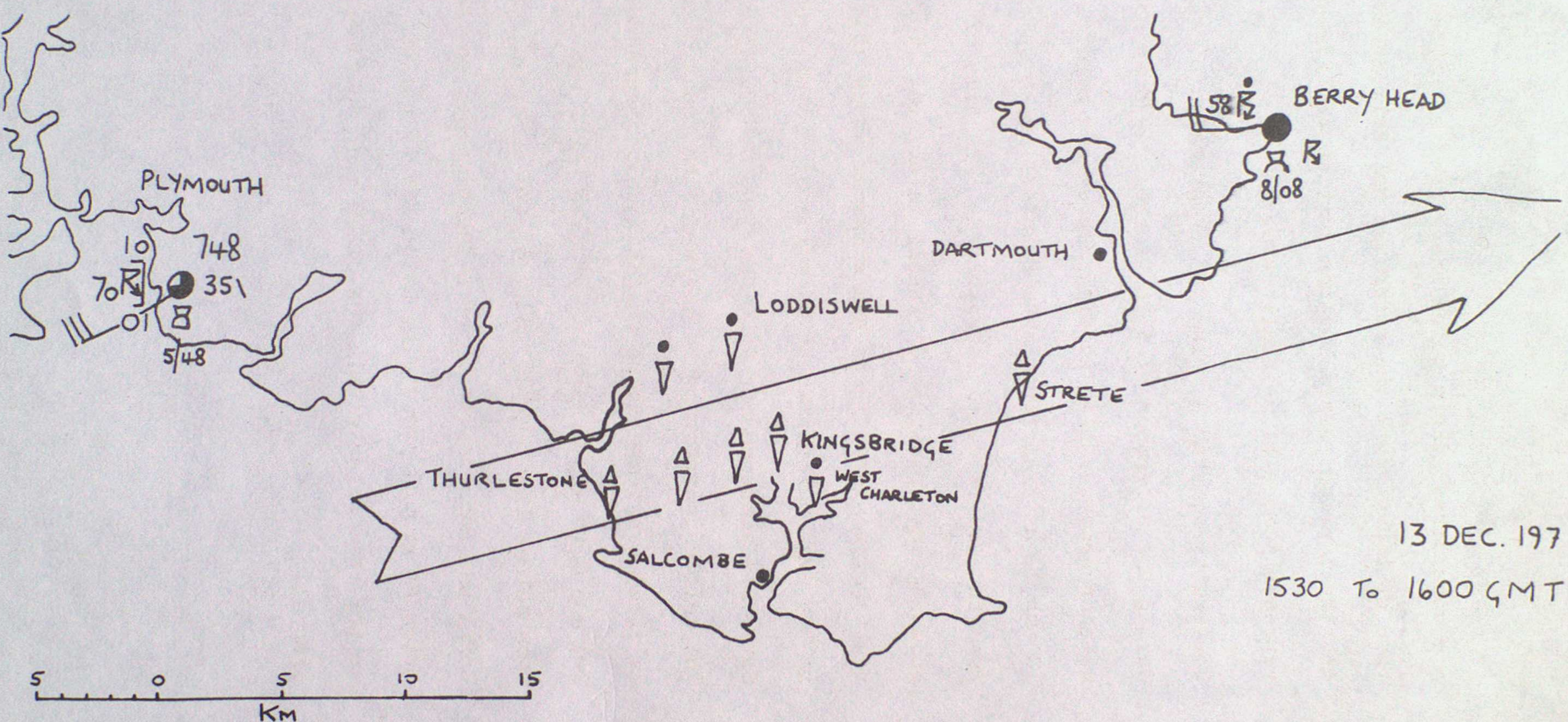
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Fig 1

Fig 2.

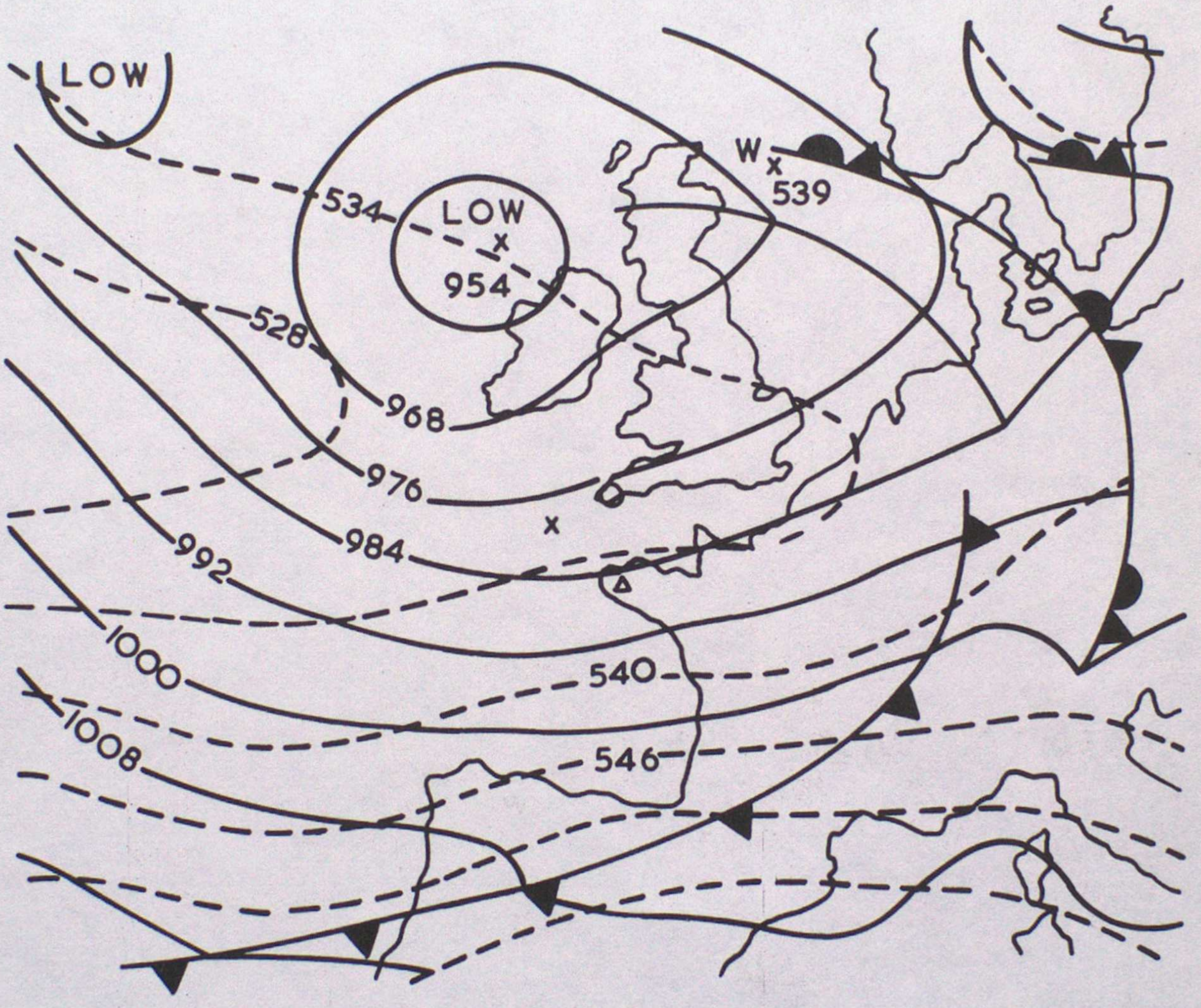

Fig 3

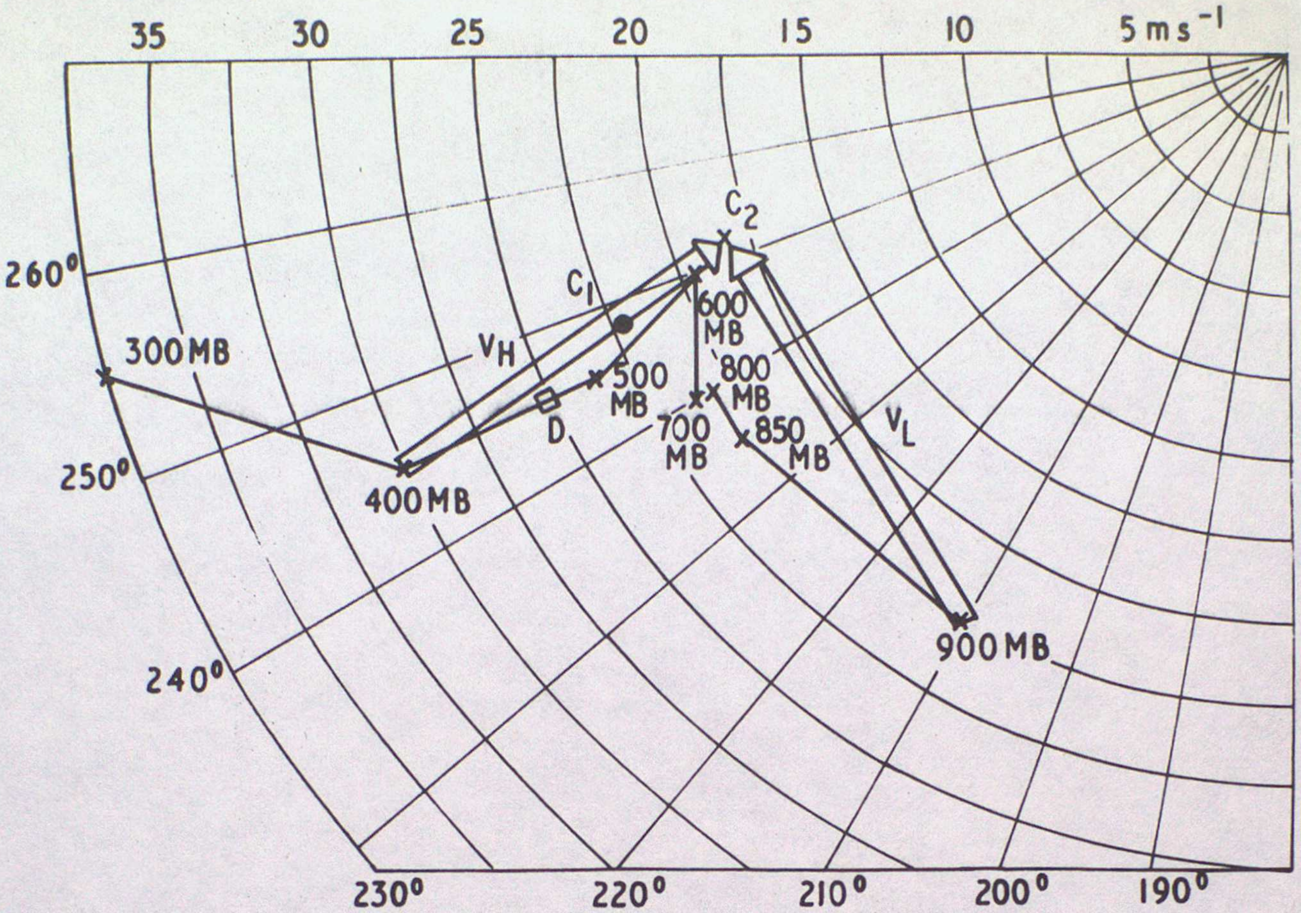
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Fig 4(a)

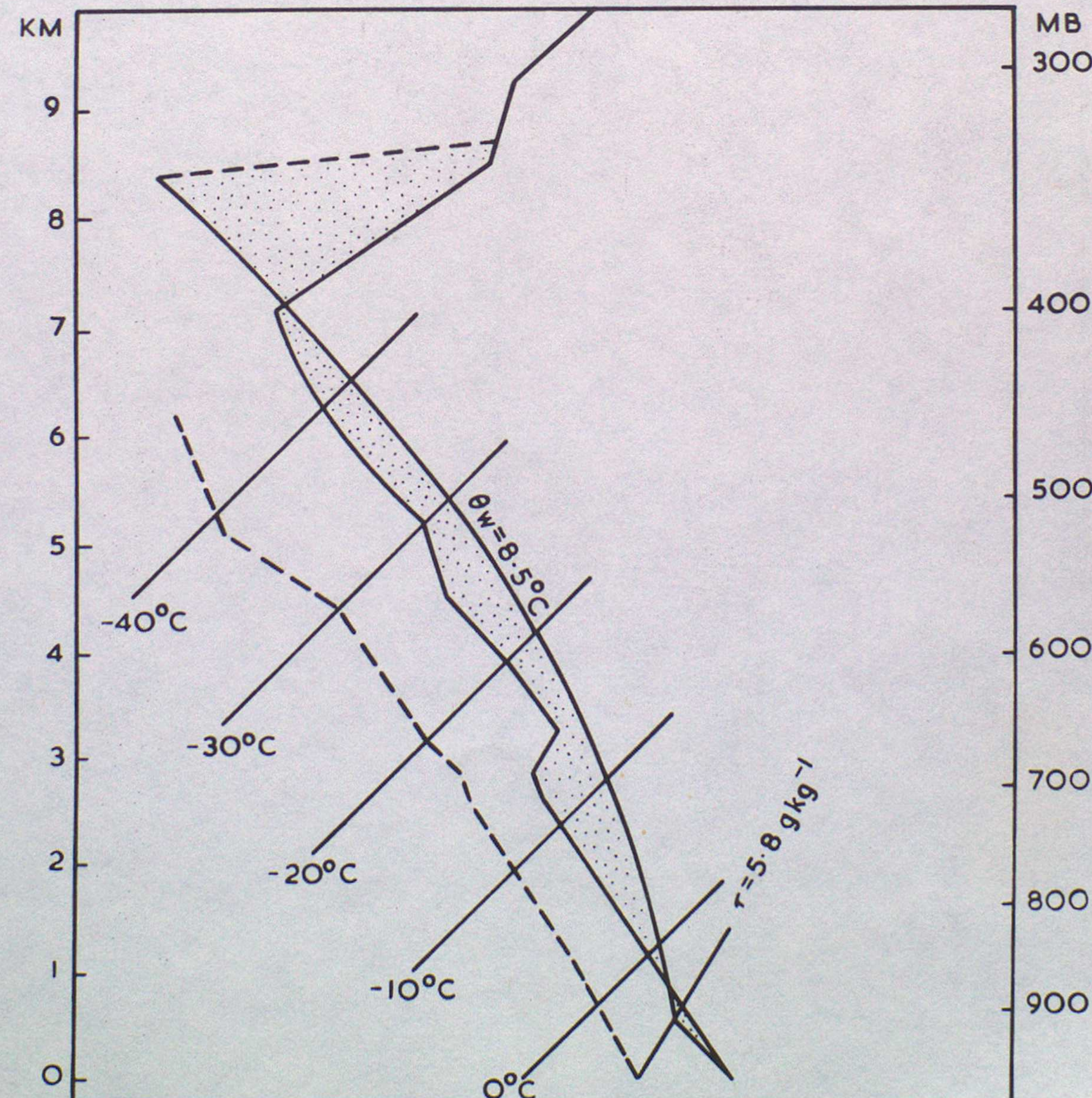
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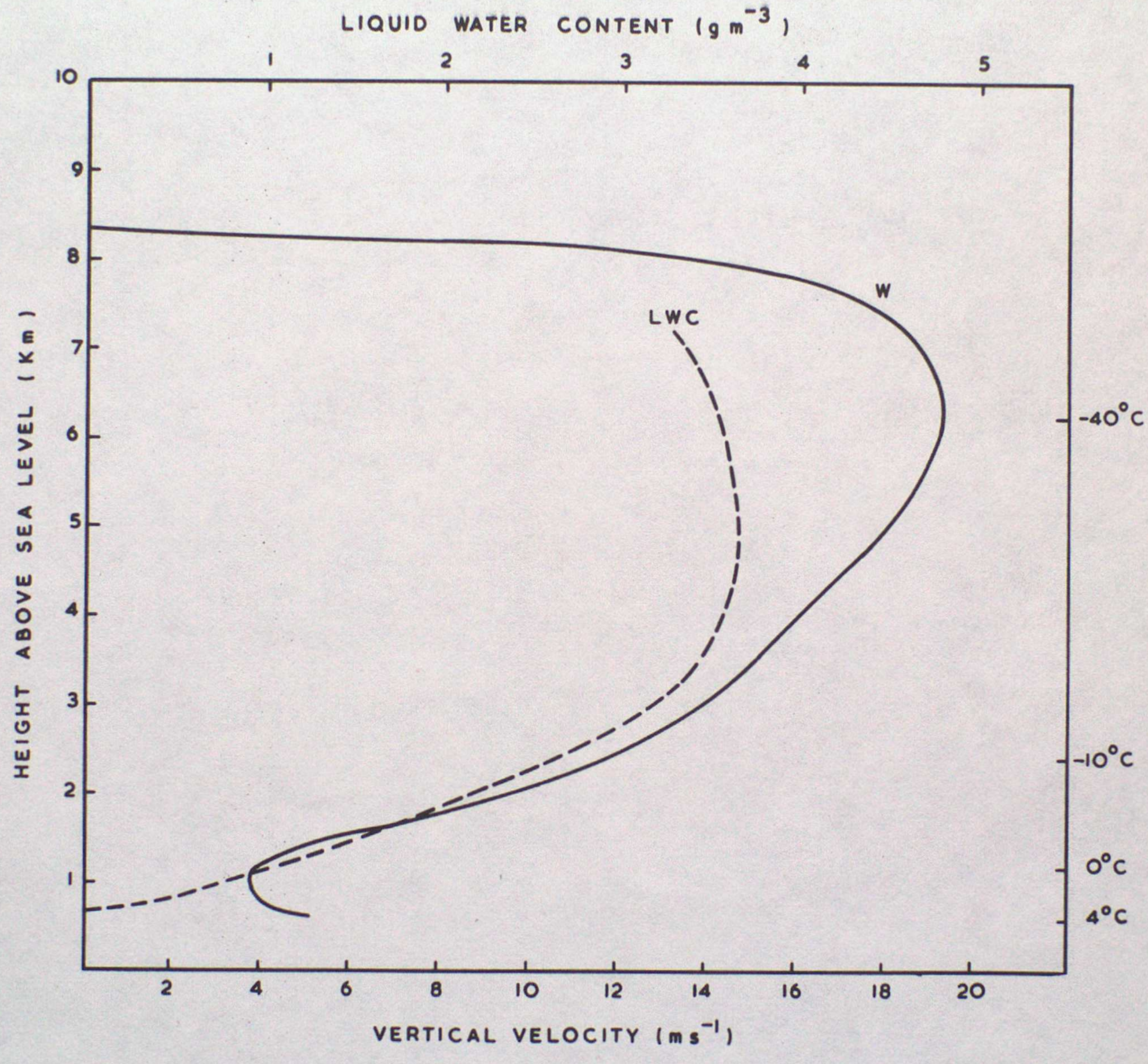
Fig 4(b)


LIQUID WATER CONTENT (g m^{-3})
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VERTICAL VELOCITY (m s^{-1})

Fig 5

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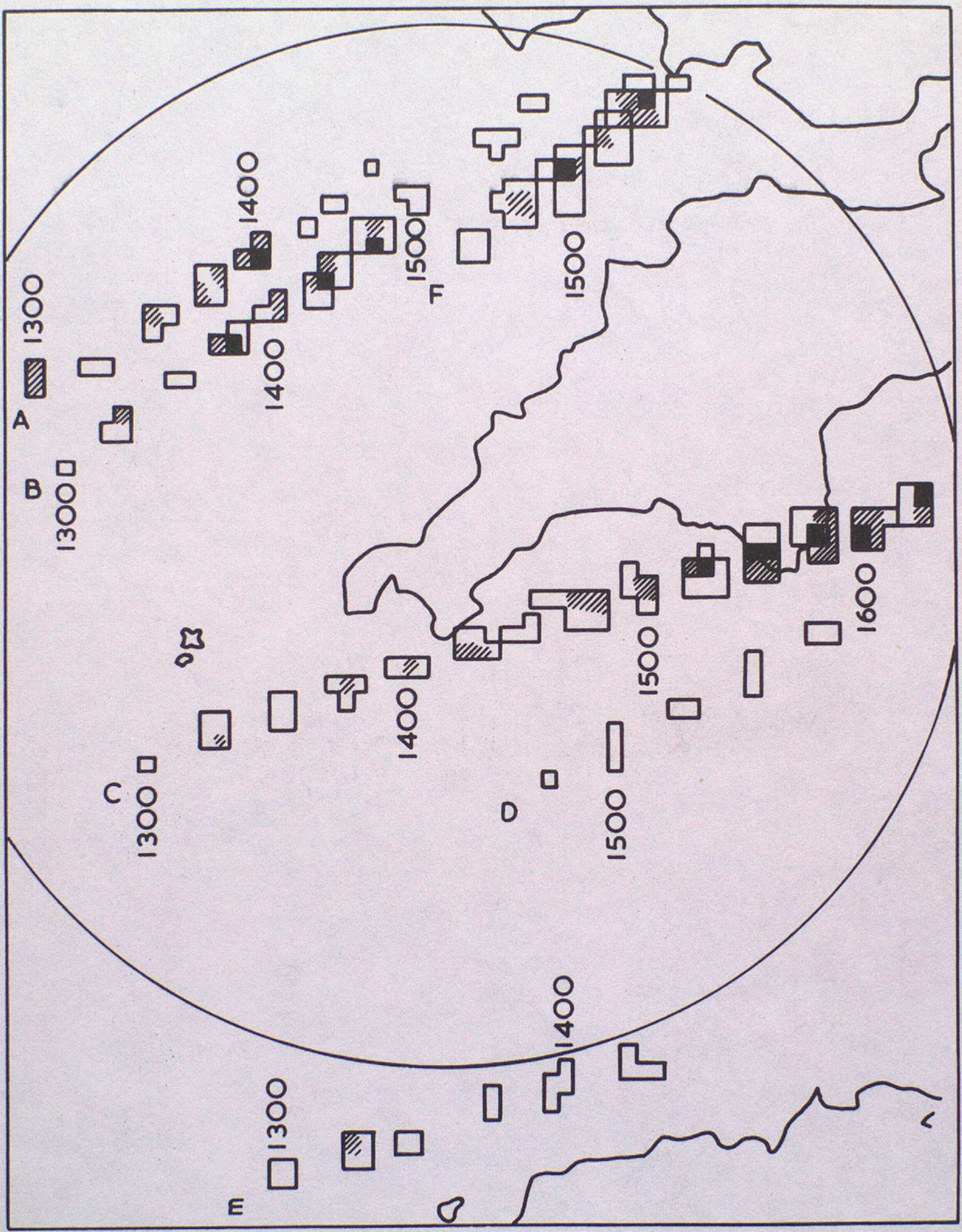
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Fig 7

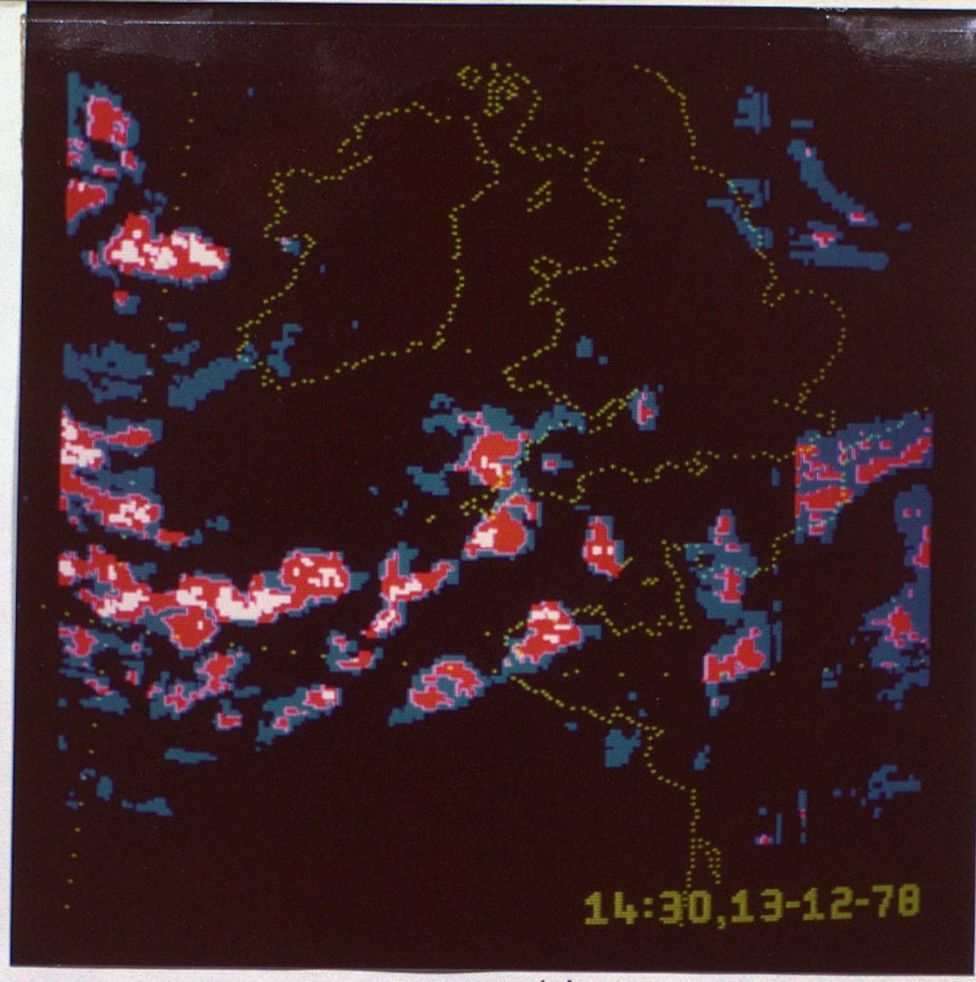

Fig 8(a)

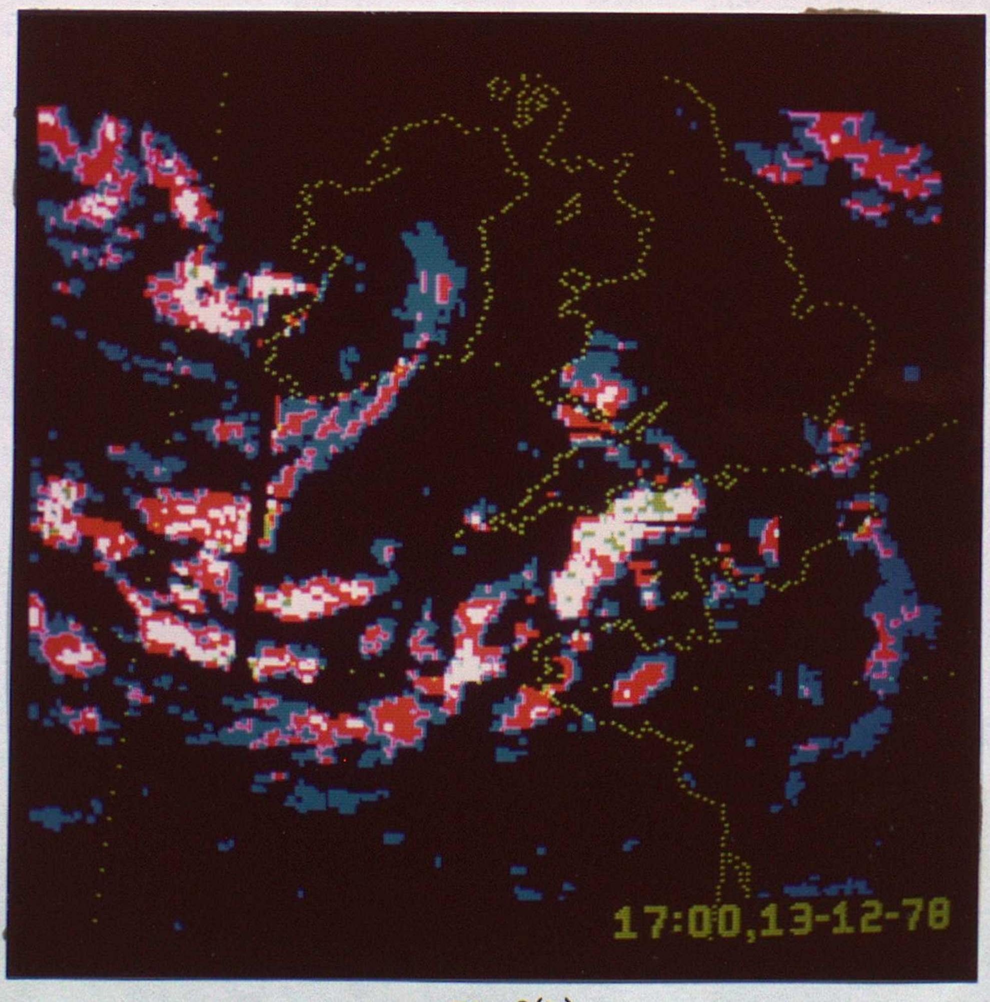

Fig 8(b)

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