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Large hail over north-west England, 7 June 1983

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Summary

An account is given of a series of severe thunderstorms which produced large hail and developed 'severe-right' supercell characteristics. The Malvern network radar display was used operationally for forecasting the movement of the storms, and the Hameldon Hill radar data to identify individual storm cells in retrospect.

Synoptic developments

The period May–June 1983 has been declared one of 'outstanding meteorological interest' over England following a long spell of unsettled weather which culminated in widespread thunderstorms and severe hailstorms. In May, Manchester experienced seven consecutive days of thunder (compared with a long-term average of 2.5 for the month) and on 18 May 55.6 mm of rain fell in two hours at Finningley, South Yorkshire during a thunderstorm. On 5 June hailstones up to 70 mm in diameter were reported along the south coast from Dorset to Kent (Royal Meteorological Society 1983).

Two days later exceptionally severe storms swept north-east from Cornwall across Wales, north-west England and eventually north-east England, producing a swath of large hail of up to 70 mm in diameter over Greater Manchester and adjacent areas.

On 6 and 7 June an anticyclone intensified to 1032 mb as it moved across Scotland towards Denmark and eastern Europe. As it moved away eastwards a south-easterly airflow developed over England on 7 June bringing warm unstable air northwards ahead of a cold front which crossed the country from west to east during the morning of 8 June.

Computer predictions from the Meteorological Office 15-level coarse-mesh operational model for 1200 GMT on 7 June, based on data for 0000 GMT on 7 June, indicated warm advection of moist air ahead of an advancing upper trough implying marked mass ascent (Figs 1(a) and 1(b)). The model predictions showed wet-bulb potential temperatures (θ_w) at 850 mb of 16 °C extending over much of England and Wales. Of particular interest is the area of strong horizontal wind shear on the warm exit side of the forecast upper-level jet stream (Fig. 1(b)). The actual upper winds reported at Camborne, compared with other stations, at 1200 GMT on 7 June confirm strong vertical wind shear between the 900 and 300 mb levels as shown in Table I.

Table I. *Upper winds reported at 1200 GMT on 7 June 1983*

	Camborne		Crawley		Aberporth		Aughton	
	(degrees)	(knots)	(degrees)	(knots)	(degrees)	(knots)	(degrees)	(knots)
900 mb	200	10	155	19	200	22	160	29
300 mb	190	68	210	40	185	53	195	46
Vector wind diff.		58		33		34		28

Ludlam (1963) found a striking relationship between severe storms over England and the neighbouring Continent and the presence of strong vertical wind shear, with the hail or tornado located on the warm side of the jet. The Meteosat infra-red satellite photograph at 1400 GMT on 7 June (Plate I, page 264) shows the presence of an area of deep convective cloud in exactly the same area as the strong wind shear.

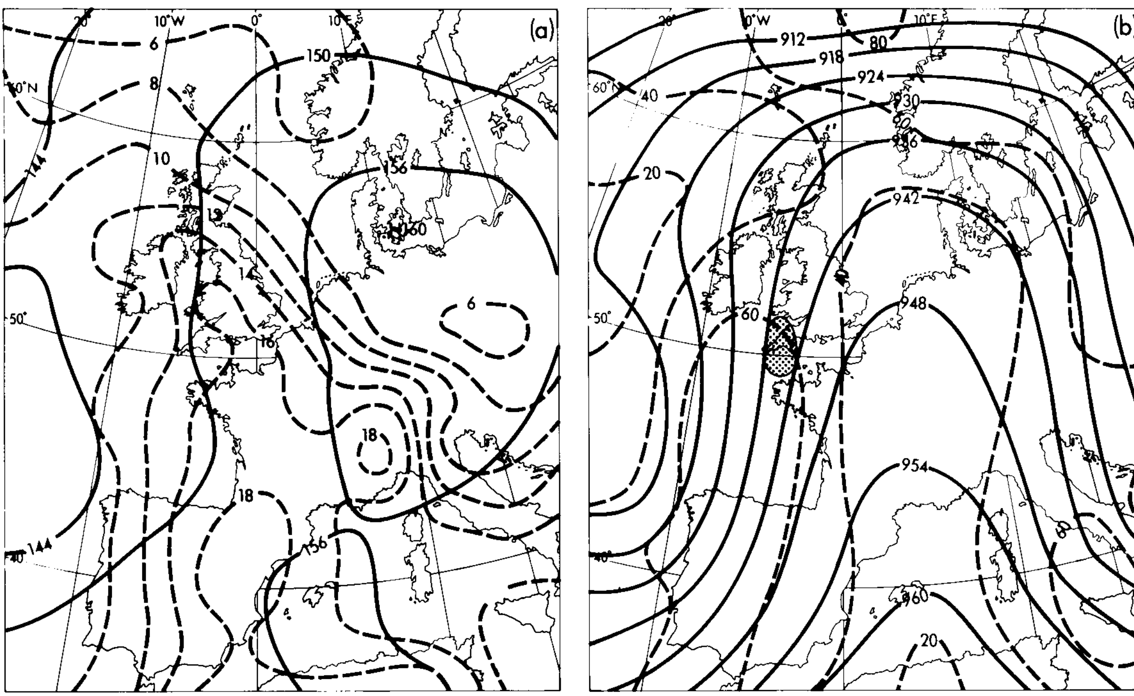


Figure 1. 15-level model forecast charts for 1200 GMT on 7 June 1983 showing (a) 850 mb wet-bulb potential temperatures (pecked lines) and 850 mb contours (solid lines), and (b) 300 mb isotachs (pecked lines) and 300 mb contours (solid lines). The stippled area over Cornwall (Fig. 1(b)) represents an area of strong horizontal wind shear.

The Aughton sounding for 1200 GMT on 7 June (Fig. 2) suggested deep convection of air from the 900 mb level to around 11 km (36 000–37 000 ft), with the possibility of some cumulonimbus tops bursting through the tropopause to around 13.5 km (45 000 ft) given sufficiently undiluted updraughts. Surface temperatures over north-west England increased from 9 °C at dawn to 23 °C in mid-afternoon, but the maximum updraughts were probably associated with air that had crossed south-east England and the Midlands where temperatures reached 25 °C in places. This air probably became the warm layer at the 900 mb level on the Aughton sounding. Another feature of this sounding was the temperature inversion between 750 and 700 mb and the dry layer above, which, combined with the low-level south-easterly inflow and the south-westerly upper flow on the right flank of the storm area, is a characteristic of severe tornadic storms often giving large hail. Fawbush and Miller (1953) found that, although hail exists to some extent in all thunderstorms, great convective or potential instability is necessary for the production of large hail. This is provided in this case by the dry air overlying the moist air below 750 mb on the Aughton sounding. Palmen and Newton (1969) also refer to this instability and the similarity of temperature soundings for both tornado and hail situations. Thunderstorm warnings had in fact been issued soon after 0800 GMT for civil airfields over northern England and the Midlands, and public forecasts mentioned the possibility of spectacular storms overnight.

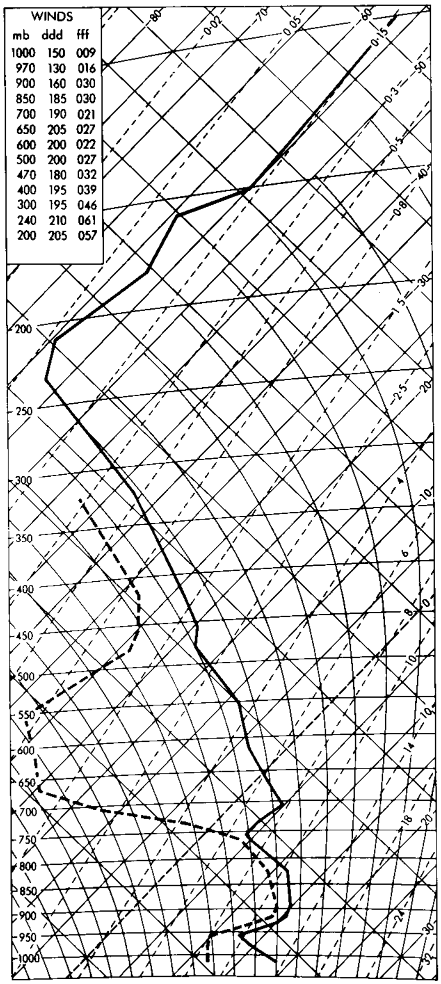


Figure 2. Upper-air sounding for Aughton at 1200 GMT on 7 June 1983. Winds are in degrees and knots.

The extent of the thunderstorm development at 1600 GMT on 7 June is shown on the SFLOC chart, Fig. 3. The reports, made by the Cathode Ray Direction Finding (CRDF) system are only made to an accuracy of half a degree of latitude and longitude, but it is clear from the plotted reports that a large area of thunderstorms extended from Cornwall to mid-Wales and subsequently moved north-eastwards across North Wales, Cheshire and Greater Manchester between 1800 and 2000 GMT. It was from within these latter areas that the reports of large hail were received. Only two reports of hail were received from the routine meteorological network of observing stations. These were from St Harmon in mid-Wales at 1800 GMT and Manchester Weather Centre at 1955 GMT and are included in Table II as items numbered 1 and 41. All the remaining sixty or so hail reports were gleaned retrospectively from local newspapers, individual members of the public and meteorological staff off duty at the time. A number of interesting photographs of hailstones and hail damage were received and a selection of these has been included in this account (Figs 4(a), (b) and (c), 5 and 6). The complete collection —30 in all — has been deposited in the National Meteorological Library at Bracknell. The selected photographs are discussed in a later section of this report.

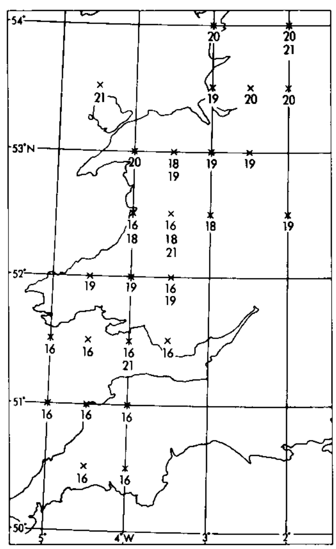
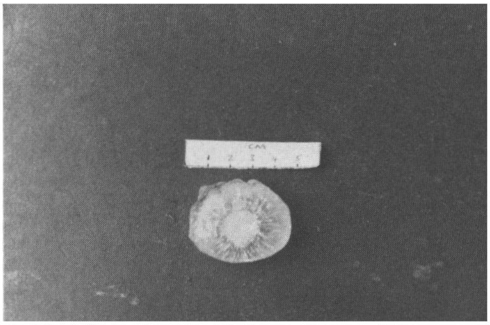


Figure 3. SFLOC chart for 7 June 1983. Figures are times in GMT.

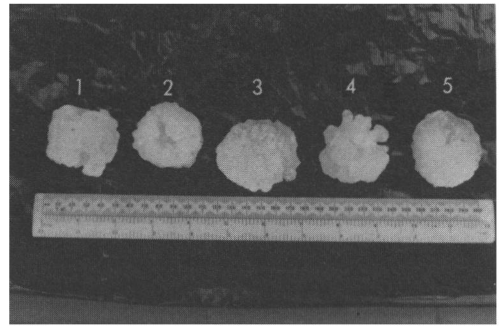
Hail reports

Table II has been compiled from all the reports of hail received, and also those where only rain fell near the swath. Accounts of hail from individuals or newspapers have, so far as possible, been checked and were only included where a specified location was named. Some newspapers carried headlines of hail damage, but not all referred to the actual site where hail occurred. The times are less certain in some cases but seem to fall into the 1600–1800 GMT period over North Wales and 1800–2000 GMT over Greater Manchester. Table II lists the reports from south to north. This investigation only extends as far south as mid-Wales but in view of the distribution of SFLOC activity at 1600 GMT it is considered more than likely that some hail fell over South Wales.

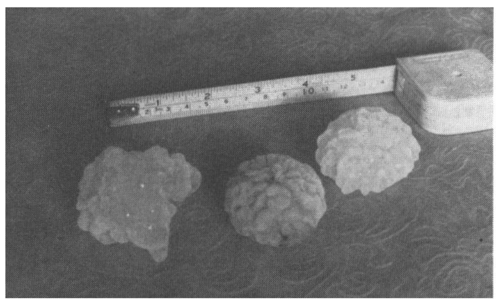
The first hail recorded in Table II was from St Martin near Ruabon (item 5) at 1615 GMT in a severe thunderstorm: more fell at 1705 GMT in another separate storm. These storms produced hailstones of 10–30 mm in diameter. Further south-west the Meteorological Office auxiliary station at St Harmon reported a severe thunderstorm with hail while another Meteorological Office station at Cynwyd reported a severe thunderstorm with rain at the the same time.



(a) *Photograph by courtesy of Mr M. J. Leeson*



(b) *Photograph by courtesy of NWWA*



(c) *Photograph by courtesy of NWWA*

Figure 4. Selection of photographs of hailstones taken on 7 June 1983, (a) at Urmston, Greater Manchester, (b) at Kelsall, Cheshire and (c) at Weaverham, Cheshire.

Photograph by courtesy of Northwich Guardian

Figure 5. Largest hailstone found in Antrobus on 7 June 1983.

Table II. *Reports of hail (△) and no hail (○) near swath listed south–north*

Abbreviations: MO — Meteorological Office; Stn — Station; A/P — Airport; P — Photograph; WC — Weather Centre; ⚡ — Thunderstorm; ⛈ — Severe thunderstorm; ⛈• — Severe thunderstorm with rain; ⛈△ — Severe thunderstorm with hail

Item no.	Place	Grid reference		Source	Time (GMT)	Size (mm)	△/○	P	Remarks
1	St Harmon	2990	2730	MO Stn 505	1700–1800	50–75	△		⛈△ Hail damage, two bursts
2	Shawbury	3560	3200	MO Stn 414	1700		○		No hail, trace rain
3	Cynwyd	3070	3400	MO Stn 408	1800		○		⛈ No hail
4	Overton	3375	3418	*Shropshire Star*			△		Huge hail
5	Ruabon	3300	3440	J. M. Thompson	1600–1800	10–30	△	P	Two ⛈△ 1615 and 1705 GMT
6	Lower Eyton	3342	3442	Mrs D. Moreton	1740		△		Letter, > golf ball hail
7	Cefendre	3340	3490	*Shropshire Star*			△		Golf ball hail
8	Wrexham	3360	3500	Mr Watkiss-Thomas	1745		△		Letter, giant hail
9	Kelsall	3520	3680	NWWA	1815	60	△	P	Knobbly hail, lobes
10	Cuddington	3595	3720	Airline pilot		70	△		Sketch, jagged ice, tail
11	Weaverham	3611	3743	NWWA	1830–1900	50	△	P	Knobbly hail, lobes
12	Knutsford	3760	3760	MO staff			○		No hail
13	Antrobus	3650	3810	*Northwich Guardian*		73	△	P	65 grams, £5 prize
14	Wilmslow	3840	3810	*Wilmslow World*			○		No hail
15	Runcorn	3530	3820	Manchester WC call	1925	25	△		
16	Liverpool A/P	3437	3825	Weather reports			○		No hail
17	High Legh	3700	3835	Nurseryman		10–20	△		No large hail, little damage
18	Appleton	3640	3840	V. Molloy			△		Hail Appleton but none, only heavy rain, M6 from Carnforth
19	Manchester A/P	3824	3847	MO Stn 334			○		No hail, 0.1 mm rain
20	Bramhall	3880	3860	C. Combe, MO			○		No hail
21	M56, junction 7	3744	3852	P. Josty, MO	1920	25	△		Ice cubes 1½ mins, then mod/heavy rain for 30 miles west
22	Grappenhall	3640	3860	*Warrington Guardian*			△		Kennels and nurseries damaged, runaway horse killed on M6
23	Lymm	3680	3870	Capt. C. Cruickshank	1800	63	△		Sketches, two storms 4 mins and 2 mins
24	Lymm	3680	3870	Janet Sheehan	1800–1900	30–50	△		
25	Thelwall	3650	3874	NWWA	1800–1815 (1850?)	20–45	△	P	Hailstones mixed, some smooth, some knobbly
26	Altrincham	3770	3880	Altrincham			△		Bus windows smashed
27	Rixton	3685	3895	DHAO MAFF			△		} Mainly crop damage outdoors
28	Woolston	3660	3905	DHAO MAFF			△		}
29	Carrington Moss	3750	3915	*Altrincham Guardian*			△		Golf ball hail, two farmers hurt
30	Partington	3720	3917	*Manchester Evening News*			△	P	Greenhouses damaged, youth died in car avoiding floods
31	Locking Stumps	3646	3917	Mr Sinuks	1800–1900	26	△		Hail 20 mins, average 15 mm, max 26 mm
32	Heaton Moor	3880	3920	G. Marshall, MO			○		No hail
33	Ashton-on-Mersey	3780	3920	R. King, acquaintance	1830–1900	50	△	P	Golf/tennis ball hail
34	Glazebrook	3695	3925	Nurseryman					Large hail, much damage
35	Glazebrook	3695	3925	DHAO MAFF			△		} Mainly crop damage outdoors
36	Irlam	3720	3940	DHAO MAFF			△		}

Item no.	Place	Grid reference		Source	Time (GMT)	Size (mm)	%	P	Remarks
37	Urmston	3750	3950	*Manchester Evening News*, E. Graham	1900		Δ	P	Newspaper cutting
38	Urmston	3750	3950	M. J. Leeson, MO	1930–2000	40–50	Δ	P	Lobed hailstones, radial bubble structure
39	Stretford	3795	3950	G. Butler, MO	1830, 1930	50	Δ		Golf ball hail, two distinct bursts one hour apart, marked wind increase each time
40	Barton A/P	3745	3972	Mr Young, SATCO	1900		Δ		Golf ball hail
41	Manchester WC	3840	3986	MO Stn 335	1955	25–50	Δ		Hail 5 mins, gust 37 kn, $\overset{\Delta}{K}$ 4.3 mm rain
42	Eccles	3780	3987	*Manchester Evening News*			Δ	P	Newspaper cutting, golf ball hail
43	Crosby	3300	4000	MO Stn 316			O		No hail 6 mm rain
44	Prestwich	3810	4030	*Manchester Evening News*			Δ		Roof collapsed on elderly couple
45	Clifton	3770	4035	G. Wood, local weather observer	1845	35	Δ		K 1700 GMT, 25 mm rain, jagged ice
46	Middleton	3870	4050	Mrs D. Berry			Δ		Also *Rochdale Observer*
47	Simster	3840	4055	*Bury Times*, Sue Campbell		25	Δ		2 × 5 min bursts
48	Formby	3300	4070	M. J. Robinson, MO	2325		Δ		K 1800–2325 GMT, hail 3 mins, broken window, storm ended suddenly
49	Little Lever	3750	4075	Manchester WC call	1910	25–50	Δ		
50	Radcliffe	3780	4080	*Bolton Evening News*, Mr Greenhalgh		25–50	Δ		
51	Parbold	3500	4110	G. Monk, MO	2140		Δ		Tiny hail, 15.9 mm rain
52	Tottington	3775	4125	Manchester WC call	1920	25–50	Δ		
53	Bamford	3860	4130	W. Malley	1900–2000		Δ		Large hail, pulled off road for safety, worst hail ever seen
54	Walmersley	3810	4140	Mrs M Berry	1930	50	Δ		Golf ball hail
55	Greenmount	3770	4140	*Bury Times*	1910	> 25	Δ		
56	Rochdale	3890	4140	*Rochdale Observer*		35	Δ	P	Newspaper photo, greenhouses smashed
57	Southport	3340	4170	A. Cook, MO	2330	30	Δ		Hail, 30-second burst
58	Blackpool	3320	4310	MO Stn 318			O		No hail, 16.8 mm rain
59	Warton	3410	4290	DHAO MAFF	After 2300	50–75	Δ		At least 11 greenhouse holdings damaged, most greenhouse roofs devastated in parish, 2.2 hectares of glass on 9 holdings damaged, losses to standing crops estimated at £30 000 for 1.2 hectares
69	Kirkham	3430	4320				Δ		
70	Kirkham	3430	4320	*Lancashire Evening Post*			Δ	P	G. Book, golf ball hail
71	Burnley	3845	4325	*Burnley Express*			O		No hail
72	Foulridge	3890	4423	*Burnley Express*, Ann Knowles		40–50	Δ		Golf ball hail
73	Kelbrook	3900	4450	*Craven Herald*	2000		Δ		Widespread damage to cars and greenhouses, one factory had 450 panes of reinforced glass (1m × 0.5 m) broken; cost £7000 to repair
74	Barnoldswick	3875	4465	*Craven Herald*	2000		Δ		
75	Earby	3905	4465	*Craven Herald*	2000		Δ		
76	Thornton in Craven	3905	4485	*Craven Herald*	2000		Δ		
77	Elslack	3930	4493	*Craven Herald*	2000		Δ		

Item no.	Place	Grid reference		Source	Time (GMT)	Size (mm)	△/○	P	Remarks
78	Skipton	3990	4510	*Craven Herald*			O		No hail
79	Leeming	4290	4900	MO Stn 257			O		No hail
80	Richmond	4170	5020	} *Darlington*			O		No hail
81	Darlington	4290	5150	} *Evening*			O		No hail
82	Bishop Auckland	4220	5300	} *Despatch*			O		No hail
83	Newcastle A/P	4200	5720	Weather reports			O		No hail, ⛈ 2020–2320 GMT

The lines of the reference grid used in this paper coincide with those of the National Grid, but for ease in locating points across the whole extent of the storm the references are given not in National Grid form, but in a completely numerical form with point of origin at the south-west corner of National Grid square SV.

There were clearly several severe storm cells over Wales at this time: the *Shropshire Star* subsequently described the fall of huge hail of golf ball size at Overton and Cefendre near Wrexham. The storm damage in the Wrexham area was considerable; there were raging floods and a bridge was swept away. The devastation was vividly described in a letter from Mrs Dorothy Moreton of Lower Eyton (item 6 Table II): her cottage had ten windows and the front door smashed, and the ensuing floods brought in three tons of silage from the farm opposite. The garage was split in two, paving stones were ripped out and the car was filled with water.

At Kelsall and Weaverham in Cheshire the North West Water Authority (NWWA) staff kindly supplied photographs of hail 50–60 mm in diameter. Captain C. Cruickshank of Britannia Airways, while at home in Lymm, collected a variety of interesting hailstones and kept them in a freezer, as did Janet Sheehan, also of Lymm. Captain Cruickshank later assisted in producing some sketches which

Photograph by courtesy of Manchester Evening News

Figure 6. Greenhouses at Partington wrecked by hail on 7 June 1983.

included hailstones of 25 mm diameter with smooth egg shapes, some of 35–40 mm diameter resembling chestnuts with spikes, and others 60 mm in diameter of flat disc shapes with central indentations. The storm was so severe that Captain Cruickshank phoned to advise Air Traffic Control at Manchester Airport to warn controllers not to route aircraft over Lymm. The hail fell in two separate bursts lasting four and two minutes respectively and damaging his car and greenhouse. The largest hailstone brought to our attention was reported in the *Northwich Guardian,* measured 73 mm across and weighed 65 grams. It was collected by Lorraine and Bernice Riley and taken to Mr Colin Campbell, a local business man who offered a £5 reward for the largest hailstone in Antrobus (Fig. 5). Two farmers at Carrington Moss were hurt when hit by hail of golf ball size, and bus windows were smashed in Altrincham. A market gardener at Partington had several greenhouses wrecked by hail (Fig. 6) over a width of 70 metres, although a polythene structure survived intact and nearby houses escaped unscathed. Several other nurseries in this area suffered similar damage. The Divisional Horticultural Advisory Officer (DHAO) for the Ministry of Agriculture, Fisheries and Food (MAFF) assessed damage ranging from 20 to 100 per cent for 776 hectares of outdoor crops in the parishes of Rixton, Woolston, Glazebrook and Irlam (Table II items 27, 28, 35 and 36).

The hail swath continued to move north-north-east over Thelwall, Urmston and Eccles where photographs were taken of hailstones 25–50 mm across. It missed Manchester Airport by some 5 km where only 0.1 mm of rain was recorded in a thunderstorm. However, Peter Josty, one of the day shift forecasters, having observed the passage of thunderstorms northwards over Wales and the Irish Sea on radar, set off home soon after 1900 GMT. He travelled about six miles west along the M56 motorway to near junction 7 in intermittent light rain and then quite suddenly encountered irregular-shaped ice cubes about 25 mm in size which just 'plonked down' unlike normal driven hail. This lasted for about one-and-a-half minutes and forced motorists to pull off the road onto the hard shoulder. The hail then turned suddenly to torrential rain and after another minute or two Mr Josty continued his 30-mile homeward journey to near Southport in moderate to heavy rain with thunder. At Manchester Weather Centre, in the city centre, thunder was heard at 1844 GMT and rain commenced at 1905 GMT continuing until 2115 GMT. A burst of hail at 1955 GMT lasted about five minutes with hailstones estimated to be 25–50 mm in diameter. The total rainfall recorded was only 4.3 mm of which 3.6 mm fell in three minutes, an average rate of 72 mm per hour. Gust fronts reached both Manchester Airport and the Weather Centre during this time and are clearly shown on the anemograph trace for Manchester Weather Centre (Fig. 7) and for comparison in Table III.

Table III. *Gust speeds recorded at Manchester Airport and Manchester Weather Centre, 14 km apart*

Time (GMT)	Airport (knots)	Weather Centre (knots)
1942	17	
1955		37
2015	25	
2025		20

Hailstones of golf ball size were observed at Prestwich, Bolton, Bury, Rochdale and a number of other places north and north-west of Manchester. A local weather observer at Clifton near Bolton recorded 25 mm of rain and for a few minutes saw 'lumps of jagged ice' falling. The main hail swath was later observed over the Craven area and a number of reports in the *Craven Herald* mentioned widespread damage to cars and greenhouses. Earby and Barnoldswick were badly hit but there was no hail in Skipton. So far as can be judged the hail swath then dispersed over the Pennines; in North Yorkshire, Durham and Tyneside only rain accompanied the vivid thunderstorms. A final but separate burst of hail was reported at several places along the Lancashire coast sufficient to damage

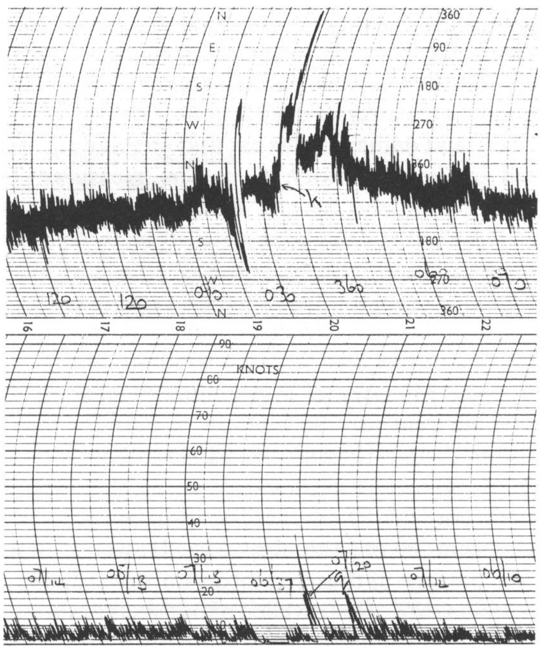


Figure 7. Part of anemograph trace for Manchester Weather Centre, 7 June 1983.

greenhouses badly and to break the window of a house occupied by an off-duty meteorological assistant at Formby. The 2315 GMT launch of the radiosonde ascent from Aughton near Ormskirk was curtailed at 500 mb because of thunderstorm activity — the plotted ascent showed some very moist layers with superadiabatic lapse rates indicative of the chaotic vertical ascent likely to be found in a thunderstorm. However, a second sounding was made at 0100 GMT and this reached a level of 10 mb. Although no change in airmass had occurred the still-unstable atmosphere was much drier with more normal lapse rates.

The full extent of the hailstorms from mid-Wales to Elslack-in-Craven covered 200 km although we cannot be sure it was an unbroken swath. Fire brigades within the Greater Manchester region received 189 emergency calls for assistance between 8.00 p.m. and midnight on 7 June and the Clwyd fire services received 150 calls. A comprehensive estimate of the cost in terms of damage and compensation is very difficult to make for a number of reasons, and we can only quote figures available from individual sources as a partial estimate. These amount to £1.1 million, but could well be an underestimate by a factor of three. One insurance company alone paid out claims of more than £650 000.

Radar and rainfall analysis

Earlier expectations of spectacular storm activity were realized in late afternoon when the senior forecaster at Manchester Airport identified intense precipitation echoes, inferred to be thunderstorms, advancing northwards over Wales. Warnings of heavy rainfall were issued at 1620 GMT to the NWWA for the Mersey–Weaver, Lancashire and South Cumbria catchment areas for falls of around 20 mm. The radar display was used later in the evening by the forecaster in drafting the aviation TREND* forecasts, giving warning of thunder and hail, although in the event the hail narrowly missed the airport.

*A TREND is a 2-hour landing forecast which is routinely added to hourly observations at some airfields.

Rain-gauge and radar data from Hameldon Hill (inset Fig. 8) were used in retrospect to examine the distribution of precipitation, primarily to identify and track individual storm cells. A number of intense cells were located, mostly of short duration, but six separate long-lasting cells were also found. The cells labelled 1 to 5 in Fig. 8 were the only cells from which hail was reported. The lifetimes, velocities and number of hail reports definitely attributable to each cell are shown in Table IV. Cell 6 may have

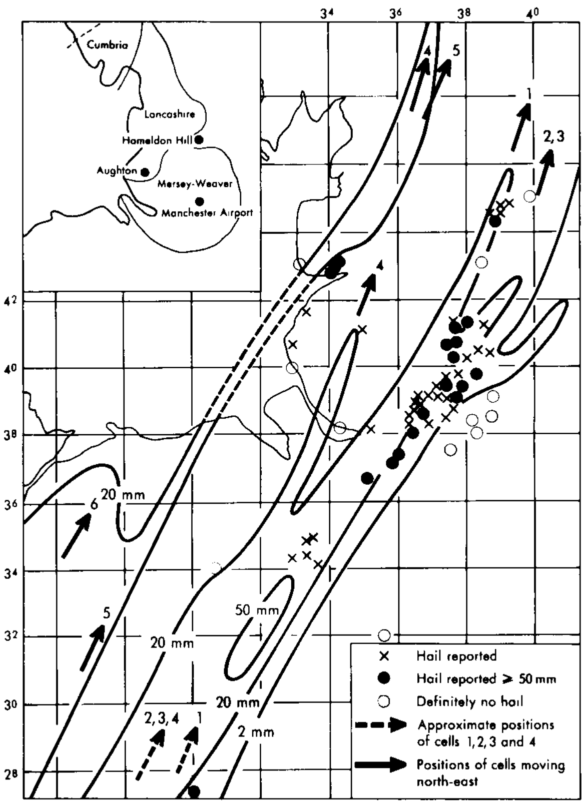


Figure 8. Distribution of hail and rainfall reports. Rainfall analysis is for 24 hours commencing 0900 GMT on 7 June 1983. Isohyets shown by solid lines.

Table IV. *Characteristics of the six hail cells*

Cell no.	Average velocity (degrees)	Average velocity (knots)	Estimated deviation to right of the average velocity during severe-right phase (degrees)	Duration of severe-right phase (hours)	Lifetime of cell after entry into Hameldon Hill radar coverage (hours)	No. of reports of hail attributable to each cell
1	200*	28	20	1	5½	25
2	200*	32	25	2	6 †	5
3	200*	31	25	1¾	5	1
4	200	30			6¼ †	1
5	200	30	25	½	4¾	14
6	200	28			3	0

*Does not include period when cells deviated to right
† Passed out of Hameldon Hill coverage without decay

produced hail but crossed Cardigan Bay and sparsely-populated Snowdonia before decaying. It also remained at long range from Hameldon Hill radar and its behaviour is excluded from subsequent discussion.

The radar wind sounding for Aughton at 1800 GMT (Fig. 9) shows a shallow surface layer of south-easterly winds, less than 1 km deep, above which winds generally veer and increase with height. The surface flow backed north-easterly prior to the onset of thunderstorms thus increasing the vertical shear. Between 3 km and 6 km there is little shear suggesting a well mixed convective layer with a velocity of 200° 30 kn, close to that of cells 1 to 6. However, cells 1, 2, 3 and 5 show an anomaly in that they all deviated temporarily to the right whilst maintaining similar speeds. The path of each cell is shown in Fig. 10 — cells 1, 2 and 3 all turned right on entry to the Cheshire Plain immediately after leaving the hilly terrain of north-east Wales. Each cell returned to its original direction of movement over or north of Greater Manchester. We believe these cells became severe-right supercells during this period with the shallow north-easterly inflow providing the necessary updraught into the storm (Browning 1964).

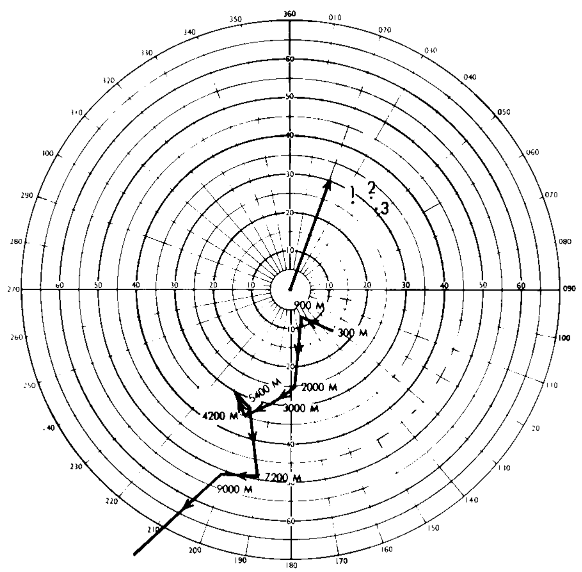


Figure 9. Radar wind sounding for Aughton at 1800 GMT on 7 June 1983. Arrow at top of diagram depicts the mean motion of cells 1 to 6. Numbered points refer to the velocities of cells 1, 2 and 3 during anomalous movement to the right.

Flash flooding occurred in the Wrexham area where the passage of cells 1 to 4 on similar tracks resulted in total accumulations of nearly 50 mm (47 mm fell in Wrexham). Gauge totals in excess of 40 mm probably extended along a narrow band, less than 10 km wide, from Wrexham as far as Warrington, north-east of which the diverging paths of the four cells (see Fig. 10) resulted in smaller spot totals. Cells 1 to 4 were positioned at the extreme right edge of a large cluster of storms visible on radar (Plates II and III, page 264), but individual storm tops were indistinguishable in enhanced infra-red imagery at 1630 GMT (Plate IV). Analysis of cloud-top temperatures (not shown) indicated a uniform temperature within the red area of cloud, with tops near the tropopause, at the eastern limit of the cloud mass. Successive thunderstorm cells taking similar tracks have been noted on a number of previous occasions, for example the south coast hailstorms two days earlier (Wells 1983), and a flash flood at Darwin, Lancashire on 5 June 1980 (Carpenter and Owens 1981).

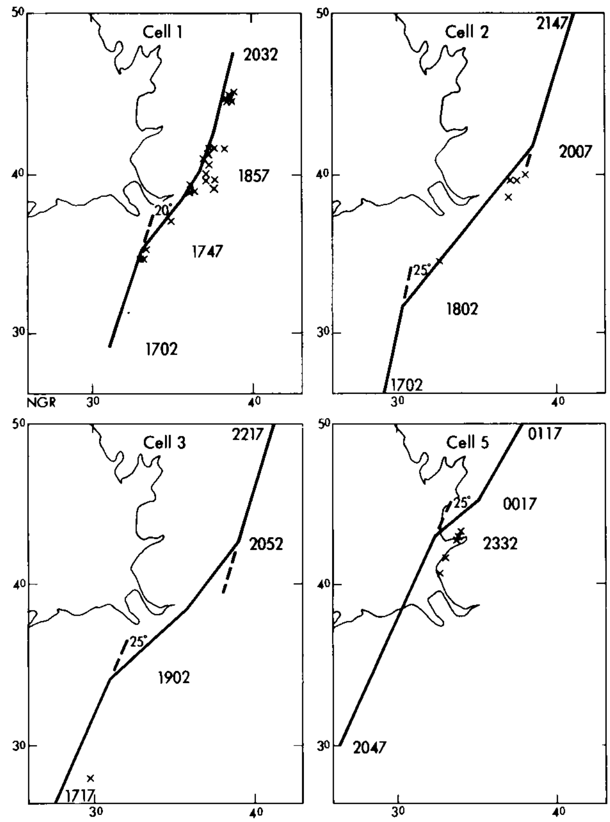


Figure 10. Radar tracks of centroids of hail cells 1, 2, 3 and 5 together with locations of hail (XXX) associated with each cell. Times in GMT.

Cell 5 was observed later in the evening at the south-eastern limit of a completely separate cluster of cells and turned right briefly as it crossed the Fylde near Blackpool. This storm occurred near midnight with a stable layer at the surface, and convection took place owing to the ascent of air of high θ_w located just above the 900 mb level. All hail reports, with only one exception, were located close to or east of the centroid of each cell. The exception was an unsubstantiated report from Runcorn (Table II item 15), made by telephone to Manchester Weather Centre, of hail 25 mm in diameter. Damaging hail fell from cells 1, 2, 3 and 5, but only one report could definitely be attributed to cell 3, St Harmon (Table II item 1), although subsequently we learned of others in the area that are not listed in Table II. Since cells 1, 2 and 3 were on similar paths, at least over Cheshire and south of Greater Manchester, some of the hail reports, not accompanied by a specific time, may have been associated with cell 3. All damage, with the exception of that in the St Harmon and Craven areas, corresponded with the severe-right phase of the appropriate cell, although that at Formby and Southport was immediately prior to the severe-right phase of cell 5 (Fig. 10). Hail was reported as far as 15 km to the right of the centroid of each echo, many reports being at the extreme right flank. Perhaps this is typified by Mr Josty's experience (Table II item 21) of encountering large hail immediately on entering what has been identified as cell 2 from the east, and later driving through rain, heavy at times, beneath and to the west of the cell centre. According to Browning (1964) it is common for large hail to occur on the right flank of severe hailstorms. This is a size-sorting effect such that, when a variety of particles descends through a wind field relative to the moving storm, the largest particles descend on the right flank close to the axis of the updraught, whilst the smaller particles get carried further towards the left flank. There is also some suggestion in Mr Josty's observation of a rather lower vertical velocity to the hail despite its size. Perhaps at this point on the extreme right of the storm the vigorous updraught was initiated very close to the ground.

Hailstone structure

The lobe structure of giant hailstones has been discussed by Browning (1966) and the selection of photographs (Figs 4(a), (b) and (c) from these storms make interesting comparisons with Browning's findings.

The photograph in Fig. 4(a) was taken by Mr M. J. Leeson, an off-duty meteorologist from Manchester Airport, at Urmston (Table II item 38). This shows the central opaque embryo surrounded by alternate layers of transparent and relatively opaque ice with a radial array of air bubbles visible between the external lobes. Differential melting at the surface could have produced the asymmetric arrangement of knobbles.

The photographs in Figs 4(b) and (c) were taken by NWWA staff from Kelsall and Weaverham respectively (items 9 and 11 in Table II). They illustrate very clearly the knobbly, lobed structure discussed by Browning. In the Kelsall photograph (Fig. 4(b)) the hailstones numbered left to right as 2, 3 and 5 exhibit radial symmetry indicative of random tumbling motion during descent. Numbers 1 and 4 on the other hand have become more convoluted possibly owing to preferential growth into the airstream during a period of more or less constant orientation, although some of the asymmetry (especially on hailstone 4) may be due to differential melting.

Browning points out that practically all hailstones are built up of successive layers of ice of different opacity and crystal structure. The opacity depends upon the number and size of entrapped air bubbles. For the growth of large hailstones the pronounced surface knobs are the rule rather than the exception.

Comparisons and conclusions

Large or giant hail is uncommon in Great Britain, but it has been reported and documented on numerous occasions. The south coast storms of 5 June 1983 have already been mentioned in this discussion. Owens (1980) described hail of 30 mm diameter in the south Devon winter hailstorm of 13 December 1978, and the Wiltshire storm of 13 July 1967 was discussed by Hardman (1968) with hail of 50-75 mm diameter. Browning and Ludlam (1962) reported hail of 25 mm diameter or more in the Wokingham storm of 9 July 1959. However, the heaviest hailstone observed in Britain fell at Horsham in Sussex on 5 September 1958 (Ludlam and Macklin 1960) and was reported to weigh 190 grams. The present authors understand that there are an average of about 5 damaging storms per year in Britain.

Mason (1975) reproduces a table (Table V) for the size distribution of the largest hailstones in Denver, Colorado 1949-55 (631 cases).

Table V. *Size distribution of the largest hailstones in Denver, Colorado (1949–55)*

Diameter of largest hailstones		No. of cases	
Grain	< 6 mm	10	
Currant	6 mm	122	
Pea	13 mm	282	
Grape	19 mm	149	
Walnut	25-30 mm	38	Fell at least twice a year
Golf ball	45-50 mm	26	Fell at least twice a year
Tennis ball	60-75 mm	4	Fell at least twice a year

The largest hailstone reported in the United States fell in Nebraska, was 138 mm in diameter and weighed 670 grams (Mason 1975).

Although such storms are much less frequent in Great Britain than in the United States those of 7 June were clearly unusual. They developed as the culmination of a period of unsettled weather which in fact continued for another week before a changeable westerly type gave way to anticyclonic conditions on 15 June. It is our view that the storms were forced dynamically by a combination of favourable factors — the advancing upper trough, strong vertical windshear and warm advection into the trough. The developing storms then encountered suitably cold dry air above an inversion which, together with the strong low-level windshear in the updraught regions, enabled the storms to develop the self-perpetuating characteristics of severe-right supercells.

Acknowledgements

The authors wish to thank all those members of the public and Meteorological Office staff who contributed information used in this report. We would especially mention the following newspapers: *Altrincham Guardian*, *Bolton Evening News*, *Burnley Evening Star*, *Burnley Express*, *Bury Times*, *Craven Herald*, *Darlington Evening Despatch*, *Lancashire Evening Post*, *Manchester Evening News*, *Northwich Guardian*, *Rochdale Observer*, *Shropshire Star*, *Warrington Guardian*, *Wilmslow World* and *Wrexham Evening Leader*.

We gratefully acknowledge the helpful comments and advice given by Dr Keith Browning, Chief Meteorological Officer, Radar Research Laboratory, Royal Signals and Radar Establishment, Malvern. We are also indebted to the Divisional Horticultural Advisory Officer of the Ministry of Agriculture, Fisheries and Food for the reports on damage to crops and greenhouses and to a number of insurance companies for estimates of claims.

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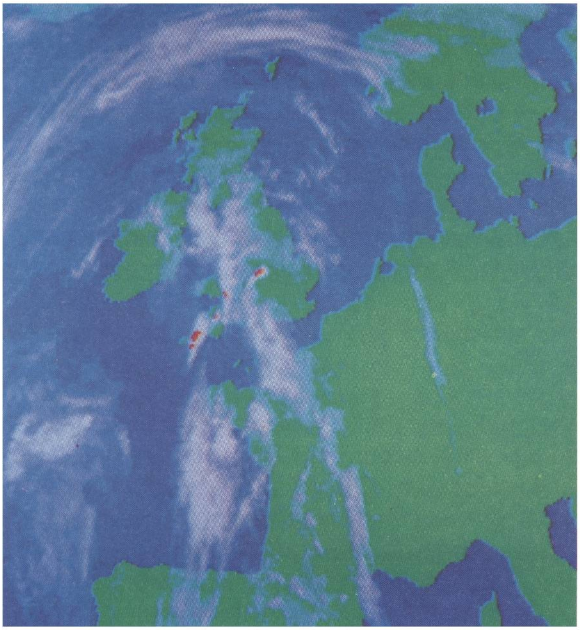

Plate I. Meteosat infra-red image at 1400 GMT on 7 June 1983.

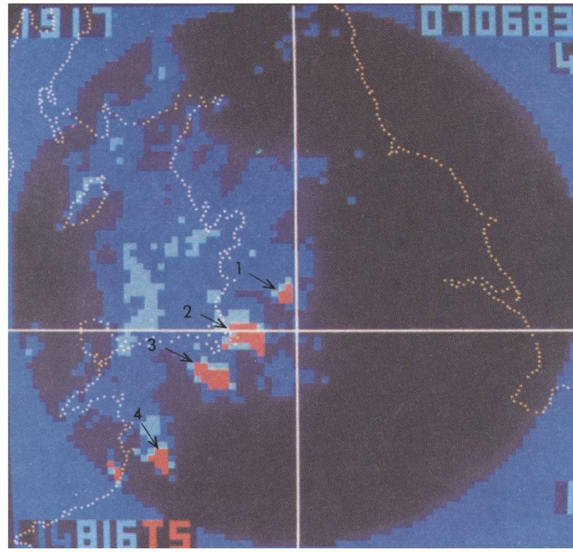

Plate II. Hameldon Hill radar display for 1917 GMT on 7 June 1983 with cross wires intersecting on Manchester Airport. Numbers indicate cells 1 to 4. Rainfall intensities (mm h^{-1}) are represented as follows: dark blue 8 (and also area outside radar range), light blue 8–32, red >32. The dark blue area south-west of Manchester is anomalous propagation.

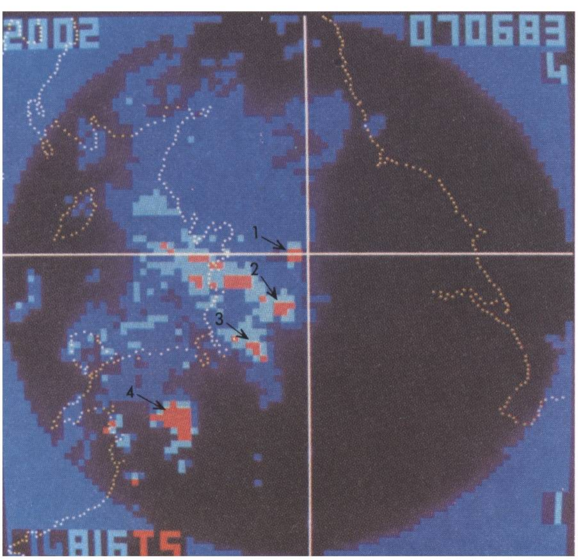

Plate III. Hameldon Hill radar display for 2002 GMT on 7 June 1983 with cross wires intersecting on Skipton. Cell 1 west of Skipton was producing large hail but none fell on the town. See Plate II for details of the colour key.

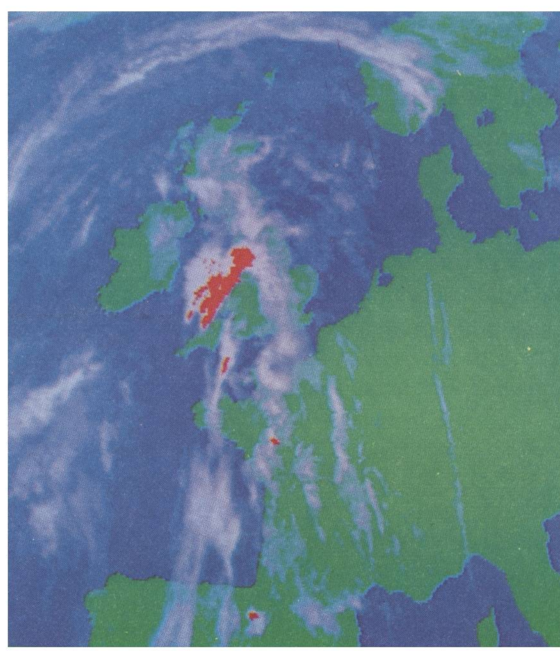

Plate IV. Meteosat infra-red image at 1630 GMT on 7 June 1983.

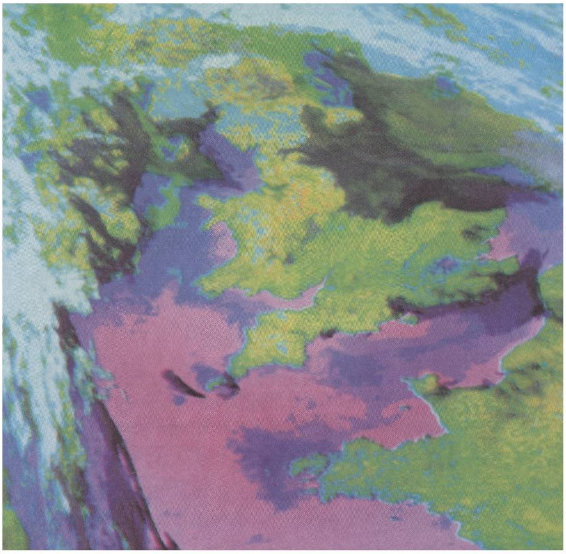

Plate I. Bispectral image from AVHRR channels 3 and 4 of 1024 × 1024 pixels at 0330 GMT on 28 August 1981. Areas of fog appear as shades of grey. (For other colour coding see text.)

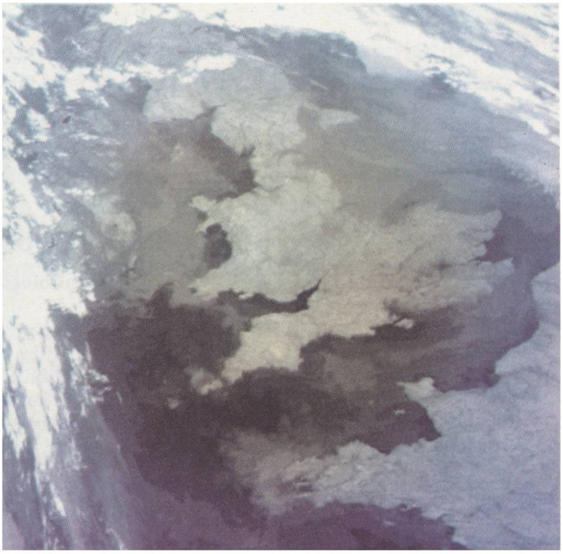

Plate II. Monochrome image from AVHRR channel 4 equivalent to Plate I.

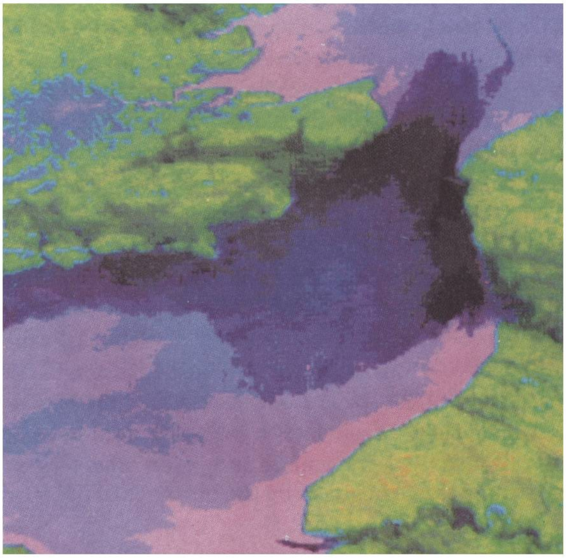

Plate III. Section of Plate I (enlarged four times) centred on eastern end of English Channel.

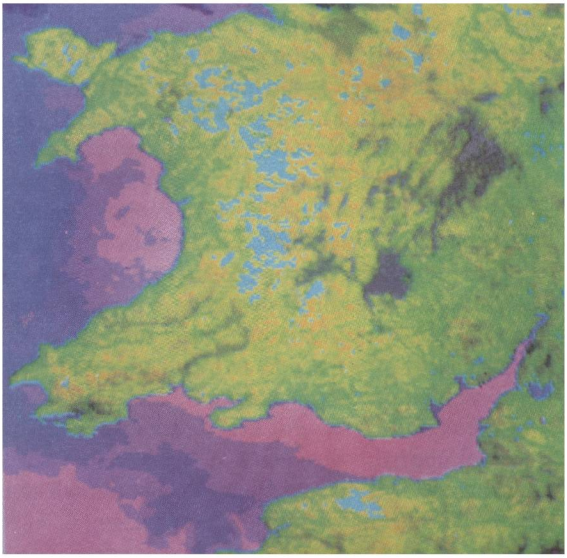

Plate IV. Section of Plate I (enlarged four times) centred on Wales.

551.507.362.2:551.521.325:551.575.2

Detection of fog at night using Advanced Very High Resolution Radiometer (AVHRR) imagery

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Summary

A method of detecting fog at night using a combination of infra-red images at different wavelengths is presented as an example of a meteorological application of remote sensing. The variation of emissivity with infra-red wavelength exhibited by fog is used to distinguish it from land or sea surfaces at similar temperatures. An interactive image display system has been used to provide a false-colour representation of a combination of AVHRR images at 11 and 3.7 micrometres (μm) in such a way as to highlight areas of fog and low stratus cloud.

1. Introduction

For some years satellite images have been used routinely in operational weather forecasting as a means of detecting the positions and development of cloud systems and for analysing their characteristics. Such applications have mainly been limited to interpretations which can be made using conventional visible and infra-red images displayed in varying shades of grey by facsimile recorder. The usual quality of images obtainable with such a system and the inflexibility of the display place a severe limitation on the amount of useful information which can be extracted, and recent developments have therefore sought to improve display techniques. Systems have been developed which present the image on a display screen and which have sufficient interactive capability to allow enhancement of each image through changes to the grey-scale contrast, magnification, etc. Also, increasing use is envisaged for colour display systems further to extend the amount of information which can be conveyed with a single image. This paper presents an example of such an application: an interactive image display system has been used to provide a false-colour representation of a combination of two infra-red images of the same scene but at different wavelengths, in such a way as to highlight areas of fog and low stratus cloud.

Detection of fog during the day-time is relatively straightforward using conventional visible and infra-red images. Areas of fog are characteristically bright in the visible image since, in common with most other types of cloud, they strongly reflect solar radiation at visible wavelengths. In contrast to other forms of cloud, however, fog and low stratus appear relatively warm on infra-red images since their temperature is close to that of the underlying land or sea surface. It is because of the latter characteristic that detection of fog on satellite images is difficult at night when visible images are not available. The thermal contrast between the fog top and the surface is usually very small, and, even where this is measurable, it is often difficult to distinguish changes in temperature caused by the presence of fog from spatial variations in surface temperature.

In this study the variation of fog emissivity with infra-red wavelength has been used to distinguish it from land or sea surfaces using infra-red images only. This allows fog and low stratus to be detected effectively at night, when fog usually develops and when it is most important to have a good description of its horizontal extent for forecasting purposes.

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2. Basis of technique

The AVHRR on the National Oceanic and Atmospheric Administration (NOAA) series of polar-orbiting satellites produces images in five spectral bands or 'channels' with a horizontal resolution of about 1 km. Three of these channels are located in the thermal infra-red region of the spectrum. In this spectral range most of the radiation measured at the satellite has been emitted by the underlying surface (land, sea or cloud top). All three channels are situated in infra-red 'windows' — spectral regions in which the atmospheric absorption is relatively low and in which we are able to 'see' down to the surface in the absence of cloud. Channel 3 is centred in a window region at about 3.7 μm, and channels 4 and 5 (centred at about 11 μm and 12 μm respectively) are in another window, in the spectral region conventionally used for thermal infra-red imaging.

A property of fog (and other water cloud), which can be used to characterize it in the absence of visible channel data, is the variation of its emissivity with wavelength. At around 11 μm opaque water clouds emit radiation as though they were almost perfect black bodies (i.e. they have an emissivity of almost one). Therefore, if the radiance measured at the satellite is converted to an equivalent black-body temperature (or 'brightness temperature') this will be almost equal to the physical temperature of the cloud top (assuming that the effects of the intervening atmosphere are small). At 3.7 μm opaque water clouds have an emissivity significantly less than one: calculations from the present study based on the brightness temperatures measured over fog suggest that it is around 0.8–0.9, which is in broad agreement with theoretical calculation (Hunt 1973). Therefore the measured brightness temperatures will be significantly lower than the physical temperature. This property is not exhibited by land or sea surfaces to the same degree, and so the difference in measured brightness temperature between channels in the two spectral regions can be used to distinguish fog or low stratus from other surfaces (land or sea). In this study we have used channels 3 and 4 of AVHRR. Although the effects of atmospheric absorption are different in the two channels, the difference is sufficiently small for the emissivity effect to dominate the difference in brightness temperature between them.

3. Details of image processing

The difference in brightness temperature between channels 3 and 4 is the principal quantity on which we have based the discrimination of fog and low stratus, and the details of the AVHRR data processing required are as follows. The raw image data in channels 3 and 4 are calibrated into radiance units and then expressed as brightness temperatures. For each pixel (picture element), the difference in brightness temperature between the two channels is then calculated. From here on it would be possible to use a number of different methods for converting the data into a colour display which highlights the areas of fog. We have chosen to construct a combined image in which each pixel is represented by 8 bits (i.e. an integer in the range 0 to 255). The 6 most significant bits (an integer in the range 0 to 63) represent the brightness temperature (K) in channel 4 minus 240K, and the 2 least significant bits (an integer in the range 0 to 3) represent the brightness temperature difference between channels 4 and 3, ΔT, defined as follows:

$$
\begin{aligned}
0 &: \Delta T < 0.5, \\
1 &: 0.5 \leqslant \Delta T < 1.5, \\
2 &: 1.5 \leqslant \Delta T < 2.5, \\
3 &: 2.5 \leqslant \Delta T.
\end{aligned}
$$

These intervals were chosen empirically following a study of the ΔT values for different scenes.

By assigning an appropriate colour to every pixel value between 0 and 255 the image can be displayed in false colour. The technique is illustrated in Plate V, page 265 using AVHRR data from 28 August 1981 at 0330 GMT for an occasion of widespread fog in parts of England, Wales, northern France and adjacent sea areas.

In this example the transformation table used to convert a pixel value in the digital image to a colour on the display has been derived as follows:

(a) For $\Delta T < 0.5$, a range of colours is used depending on the brightness temperature in channel 4:

white	:	$T < 273$ K
white - cyan	:	$273 \text{ K} \leqslant T < 281$ K
yellow - green	:	$281 \text{ K} \leqslant T < 286$ K
blue - violet	:	$286 \text{ K} \leqslant T < 289$ K
violet	:	$T \geqslant 289$ K

These ranges were chosen interactively for this particular image to give the best discrimination between land and sea, and to provide a good representation of the temperature field for sea and land.

(b) For $\Delta T \geqslant 2.5$, the colour transformation gives shades of grey depending on the temperature in channel 4:

white	:	$T < 273$ K
white - black	:	$273 \text{ K} \leqslant T < 289$ K
black	:	$T \geqslant 289$ K

This corresponds to areas of opaque water cloud, with the level of grey representing the temperature. Fog and low stratus therefore appear as areas of grey, with the darker areas being warmer.

(c) For intermediate values of ΔT, a colour intermediate between the values given by (a) and (b) is used. Such values occur if opaque water cloud fills only part of a pixel or if semi-transparent fog or cloud covers a whole pixel. Other physical reasons for this state may also exist but they do not appear to affect the detection of fog.

The overall effect of this scheme, as illustrated in Plate V, is to show cloud-free and fog-free areas in bright colours, depending on temperature, and areas of fog and stratus in shades of grey.

The display technique chosen has the following advantages:

(i) It compresses the information required to represent the features of interest into only 8 bits — an important consideration if such images are to be transmitted and displayed routinely.

(ii) It provides a 'natural' colour representation (land—green, sea—blue, cloud—grey) and so is easily interpreted.

(iii) It retains good discrimination between bodies at different temperatures and even resolves sea surface temperature features, with only a moderate amount of interactive manipulation.

This particular display method has been developed empirically; similar methods may convey the same information equally well, and other schemes would be required to optimize the discrimination of different phenomena. An important aspect of the system used in this case is its interactive capability which allows a colour transformation suitable for the image in question to be derived very quickly.

For comparison, Plate VI, page 265 shows the same scene displayed as a monochrome image (AVHRR channel 4). A contrast higher than that usually used on conventional images has been obtained by stretching the grey-scale linearly from white to black over the brightness temperature range 270–295 K. It can be seen that, even with this degree of enhancement, the presence of either fog or stratus in many areas cannot be detected unambiguously.

Plate VII, page 265 shows an enlargement of an area centred on the eastern end of the English Channel. Again, this scene was obtained interactively using facilities of the display system. It illustrates the vast amount of detail available from suitably enhanced AVHRR imagery at its highest spatial resolution. Over the English Channel we can see an area of fog depicted in dark grey and shades of dark blue. The gradations of colour within this area are probably related to the thickness of the fog; as the transparency of a vertical path through the fog increases, the contrast between channels 3 and 4 is reduced. The contrast in temperature between London and the surrounding area is clearly shown, as are variations in sea surface temperature. The detailed structure of the fog over Kent, Sussex and northern France is also portrayed.

Plate VIII, page 265 shows a similar enlargement of an area centred on Wales. Again, the presence of fog in some valleys is detected and is shown in shades of grey. The land-surface temperature features in fog-free areas are also depicted at high resolution by a range of colours.

4. Comparison with conventional observations

Fig. 1 shows a synoptic analysis for 0300 GMT on 28 August 1981 constructed by an experienced forecaster. It was drawn using all the data which might have been available to an operational forecaster. These data included both synoptic information from the stations indicated in Fig. 1 and conventional satellite imagery as received on a facsimile recorder. Aspects of continuity have therefore been taken into account, and the positions of some areas of low cloud have been estimated using visible images from the preceding day.

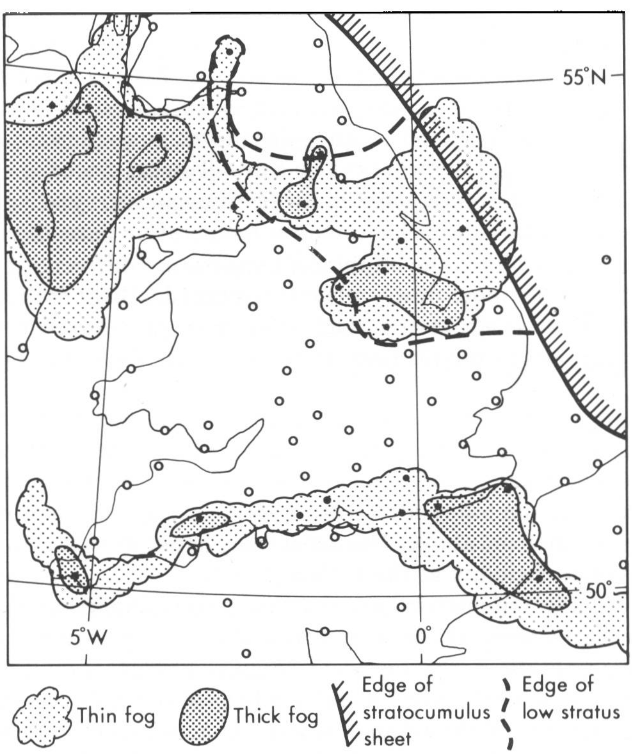

Figure 1. Analysis of areas of fog and low cloud at 0300 GMT on 28 August 1981 constructed from conventionally-available data. Closed dots correspond to reports of fog and open dots to any other reports. 'Thick fog' represents an area in which 'sky obscured' was reported.

A ridge of high pressure lay over the country giving rise to light winds. A sheet of stratocumulus thick enough to give light rain or drizzle in places lay close to the east coast of England and Scotland. A number of areas of fog and low stratus cloud are evident from the analysis.

A continuous area of fog has been inferred along the south coast of England, across the eastern end of the English channel and into northern France. The enhanced image shows that the fog in this area was quite localized inland and that the inferred continuity of the fog is an artefact caused by the sparsity of observations. The density of the observations used in this analysis can be seen in Fig. 1. The image also shows that extensive banks of fog lay off Cornwall, further west than analysed.

The analysis shows an area of fog and very low stratus which covered parts of eastern England and linked up with a further large area over the Irish Sea and parts of Ireland. The image shows the fog and low cloud over eastern England clearly, with a distinct edge to its southernmost limit. The fog over the Irish Sea is also evident. However, the image indicates that the fog near the north-west coast of England was very patchy. The analysed link between the fog in the east and that over the Irish Sea is therefore also an artefact caused by the sparsity of conventional observations.

Other areas of interest include Wales, where radiation fog formed in the valleys but was not analysed because of a lack of observations. A similar feature is evident over Essex and Suffolk where, despite the comparatively high density of observations a large area of fog lay between synoptic stations. Only later in the night (analysis not shown) was widespread fog inferred from the impingement of the expanding area of fog on the synoptic stations.

5. Discussion

Repeated reference has been made to fog and low stratus. Both of these are weather phenomena with important forecasting considerations, particularly in the aviation field. We might ask, then, whether it is possible to distinguish between fog and stratus using the technique described here. The relationship between the features and the orography will provide a useful guide, since fog will often tend to form in valleys. Also, the temperature difference between the feature and surrounding sea or land will indicate the probability of stratus, which will often have a lower temperature than that of the surface. However, this will not always be the case. Nor is the brightness temperature difference between channels 3 and 4 likely to be a good guide since it is more closely related to optical depth for both fog and stratus. The most reliable method may well be to use whatever surface observations are available to determine whether the cloud base is at the surface, and to use the imagery to define the horizontal extent of a feature and to indicate its depth.

Further work is required to examine the detailed relationship between the horizontal visibility estimated at a particular station and the difference in brightness temperature between channels 3 and 4, which is used in the enhancement process and is related to a difference in emissivity. However, it is expected that the intensity of the fog-related feature in the images will be closely correlated with the transparency of the fog as seen from above. This aspect may be as interesting to an aviation forecaster as the conventionally-measured visibility at the surface.

A potential complication in the interpretation of the imagery concerns the size of the 'atmospheric correction' (the difference between the measured brightness temperature and that which would be measured if the atmosphere above the fog were completely transparent). More precisely, we are concerned with the variation in atmospheric correction between channels 3 and 4. The magnitude of the atmospheric correction depends on the amount of water vapour in the lower layers of the atmosphere, which in turn is limited by the temperature. The fact that atmospheric correction effects do not seem seriously to complicate the interpretation for this case in August, when the temperatures of the surface and lower atmospheric layers are fairly high, suggests that differences in atmospheric correction between channels will not prejudice the detection of fog in the UK region in any season.

The application of this technique to the detection of fog at night has been demonstrated but during the day it would not be so successful. Because the fog has an emissivity at 3.7 μm significantly different from unity, it also has a sufficiently high reflectivity for reflected sunlight to contribute significantly to the measured radiance. This complicates the interpretation of the channel 3 radiances during the day-time. However, this situation arises at times when the visible channel images are also available, allowing a visible/infra-red image pair to be used for identification of fog. Alternatively, an extension to the technique presented here involving a careful interpretation of the reflected sunlight contribution to channel 3 day-time images may be useful.

6. Conclusions

In this paper we have demonstrated the detection of fog and low stratus at night using channels 3 and 4 of AVHRR. This technique is expected to have considerable potential for application in operational weather forecasting. In addition this work provides an example of one particular application of full-resolution digital AVHRR data and illustrates the wealth of information which can be extracted from the images using suitable processing and interactive display techniques.

Acknowledgements

The images presented in this paper were produced on the HERMES (High-resolution Evaluation of Radiances from Meteorological Satellites) system at the Meteorological Office using an ARGS 7000 series interactive image display system. However, much of the preliminary work for this study was performed on the GEMS image-processing and display system of the National Remote Sensing Centre at the Royal Aircraft Establishment (RAE), Farnborough. The assistance and co-operation of Mr M. R. Boswell of RAE is gratefully acknowledged.

We also wish to acknowledge the assistance of Mr J. Findlater (Meteorological Office) in the analysis of conventionally available data.

Reference

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551.593.653(4)

Noctilucent clouds over western Europe during 1983

By D. M. Gavine
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Table I summarizes the noctilucent cloud (NLC) reports received by the Aurora Section of the British Astronomical Association (BAA) during 1983, from Great Britain, Finland and Denmark.

Times (UT) in the second column of the Table are of reported sightings, not necessarily the duration of a display. Maximum elevations of the upper border are given, with limiting azimuths where possible. Co-ordinates of the observing stations are given to the nearest half-degree.

Only two meteorological stations continued to send routine hourly sky reports so a full assessment of 'negative' nights (i.e. clear with no visible NLC) was not possible. Such negative reports are indicated (B) Belgium, (F) Finland and (G) Great Britain. However, thanks to the efforts of observers in 11 UK stations, some 15 amateur astronomers, the active 8-man NLC network in Finland co-ordinated by Mr Mäkelä, and Mr Olesen and Mr Andersen in Denmark, a reasonable coverage was obtained for positive sightings between latitudes 50.5° N and 62.5° N and longitudes 29° E to 4.5° W.

Again tropospheric cloud and haze interfered, especially over Scotland, only 6 nights averaging 3 oktas or less at Eskdalemuir from mid-June to mid-July; and Iceland's summer was so bad that no NLC could be observed. Mr van Loo, a very experienced observer (Itigem, Belgium) reported 12 clear nights over the season, all negative.

Of a total of 34 positive sightings, 23 were visible in Finland, 15 in Britain and 8 in Denmark. The NLC of 30 June/1 July was well observed throughout Britain south of Fife (Crane 1983, Gavine 1984) and on 22/23 July a brilliant display, overhead at Aberdeen, was described at Alrö by Mr Olesen as the greatest amount of NLC covering the sky in his 24 years of observing.

Time-lapse cine and photometric work was continued at Aberdeen University by Dr M. Gadsden, who is organizing an amateur program of parallactic photography using fixed-bracket 35 mm cameras, with identical exposures exactly on the quarter-hours. Successful results were obtained on 30 June/1 July by Dr Simmons (Milngavie) and Dr Gavine (Joppa). Mr J. Shepherd (Edinburgh) took time-lapse and all-sky photographs.

Grateful thanks are due to all the voluntary observers, to Dr. D. H. McIntosh for his advice and for passing on data received at his Department, to Dr Gadsden for his enthusiastic encouragement, and to Mr N. M. Bone, Director of the Junior Astronomical Society Aurora Section, for helpful collaboration.
As stated before (Gavine 1984), NLC data are no longer handled by the University of Edinburgh but in the interests of continuity the survey has been taken over by an amateur group, the Aurora Section of the British Astronomical Association (Director of Section: Mr R. J. Livesey, 46 Paidmyre Crescent, Newton Mearns, Glasgow G77 5AQ). Immediate NLC news will also be announced in the monthly magazine, *The Astronomer*.

NLC data up to 1980 are now stored at Aberdeen University and 1981–83 data are at present held by the BAA Aurora Section. Instructions and report sheets may be obtained from Dr D. M. Gavine at 29 Coillesdene Crescent, Joppa, Edinburgh EH15 2JJ. The Section would also greatly appreciate any aurora sightings, especially below geomagnetic latitude 63°. Reports of these should be sent to Mr Livesey.

Table I. *Displays of noctilucent clouds over western Europe during 1983*

Date — night of	Times UT	Notes	Station position (to nearest 0.5 degree)	Time UT	Max elev. (degrees)	Limiting azimuths (degrees)
15/16 May		No NLC (B)				
18/19	1930–2000	Faint bands 2° wide at Imatra.	61°N 29°E		10	340–345
22/23		No NLC (G)				
26/27		No NLC (G)				
1/2 June		No NLC (B)				
3/4		No NLC (B)				
5/6		No NLC (G)				
6/7		No NLC (B, G)				
9/10		No NLC (B)				
10/11		No NLC (B)				
11/12	0200–0250	Veil, bands, billows into southern sky, bluish patch at 180° at Newcastle. No NLC visible at Prestwick or Edinburgh.	55°N 01.5°W	0200	90+	
				0230	50	220–280
12/13	2240–0230	Faint bands first seen at Edinburgh, brightening, rising and spreading further east, developing whirls. Visible from RGO Herstmonceux at 0145 as low band in east. Met. Station Church Fenton describes cirriform structure with bright spots. All-sky aurora over N.Y. State, dawn to dusk.	55.5°N 03°W	2240	8	060–075
				2255	10	050–070
				2315	10	050–070
				2330	10	045–055
				2342	10	050–070
			55°N 01.5°W (Morpeth)	2330	4	015–035
				2345	6	015–045
				0000	7	015–030
				0015	8	015–055
				0030	4	020–060
				0045	4	020–060
				0100	4	020–060
				0115	18	015–080
				0130	18	015–090
				0145	18	015–090
				0200	18	
			55°N 01.5°W (Newcastle)	0040	12	045
				0120	12	
				0150	25	045–068
			54°N 01°W	0045	low	030
				0145	13	060
				0215	NLC present	
			53°N 00.5°W	0145–0230	11	016–057
			51°N 00.5°E	0145–0212	7	085
14/15	2045–2100	Medium bright bands 15° wide at Imatra, no NLC (G).	61°N 29°E		35	345–025
15/16		No NLC (B, G)				
17/18		No NLC (G)				
18/19	2045–2100	Faint bans 1° wide at Joutseno. No NLC (G).	61°N 28.5°E		16	355–000
23/24	2235–0030	Faint wisps invisible to naked eye at Aberdeen, visible NLC at Vildbjerg.	57°N 02°W	2235–2335	No NLC	
				0010	5	022
				0030	No NLC	
			56°N 09°E	2310 0000	NLC present	
25/26	2030	Faint band 2° wide, Joutseno.	61°N 28.5°E	2030	17	355–005
26/27		No NLC (B)				
27/28	0045–0315	Small NLC patches at Marham, a large faint area with a bright core showing wave structure at Plymouth, the waves in a linear formation with an intense patch at lower end in north near dawn at Exeter.	52.5°N 00.5°E	0045	4	
				0125	7	358–030
				0200	15	
				0230	30	
			50.5°N 03.5°W	0250–0315	10	357–010
			50.5°N 04°W	0247	12	340–020
				0305	12	350–020
28/29		NLC in cloud breaks at Ränne.	55°N 14.5°E			–

Date — night of	Times UT	Notes	Station position (to nearest 0.5 degree)	Time UT	Max elev.	Limiting azimuths
					degrees	
30 June/ 1 July	2130–0300	Display of medium to bright irregular and twisted bands and whirls. Faint patches near Polaris in central Scotland, visible from Wirral, bright silvery or bluish curved bands described from Bedford, Ketteringham, Cambridge, Blackpool, Marham and RAF Wittering. Little wave structure reported except at Edinburgh from 0120. No NLC (F).	56°N 03°W	2245	55	280–020
				2300	35	260–060
				2315	30	280–040
				2330	22	290–040
				2345	20	320–050
				0000	20	330–030
				0015	15	cloud
				0030	15	cloud
				0045	-	330–060
				0100	16	320–060
				0115	20	330–060
			56°N 04.5°N	2230	80	
				2250	50	
				2300	30	
				2315	24	
				2330	20	
				2345	17	
				0000	14	
				0015	13	
				0030	14	
				0045	14	
				0100	15	
			55.5°N 04.5°W	2200	No NLC	
				2300	NLC in cloud	
				0015	NLC in cloud	
			54°N 03°W	2245	12	340–355
				2350	12	015
				0015	10	010
				0025	No NLC	
			53.5°N 03°W	2215	25	270–000
				2230	8	270–010
				2245	7	275–015
				2300	6	280–020
				2315	6	285–025
				2330	5	300–020
			53°N 00.5°W	0045–0220	13	332–012
			52.5°N 00.5°E	2245	5	
				0100	12	330–350
				0200	15	
				0300	25	
			52.5°N 0°	2215	NLC present	
				2250	5	330–350
				0050	5	330–030
				0152	6	330–030
			52.5°N 01°E	2245–2315	10	330–350
			52.5°N 0°	2140–2215	15	000
			51.5°N 01.5°E	0200	5	345
1/2 July		No NLC (F)				
2/3		No NLC (F)				
3/4	0100–0230	Bluish structureless veil observed at Morpeth, brightest 0130–0145. No NLC (F).	55°N 01.5°W	0100	7	010–035
				0130	7	015–038
				0145	7	035–050
				0200	7	045–058
				0215	7	045–058
				0230	7	045–058
4/5	2240–2305	Waves visible at Wirral, faint NLC at Vildbjerg. No NLC (F).	56°N 09°E	–	NLC present	
			53.5°N 03°W	2305	10	310–030
5/6	2130–0200	Low bands visible at Joutseno, no NLC at other Finnish stations. High faint NLC detected at St Andrews then parallel bands appeared low in north at Edinburgh. From 0130 these developed into large curved structures and patches of waves which rapidly moved south and disappeared into dawn.	61°N 28.5°E	2130–2150	13	340–350
			56.5°N 03°W	2215	50	330–000
				2241	No NLC	
			56°N 03°W	2345	6	350–030
				0000	10	320–050
				0015	11	325–040
				0030	11	325–050
				0045	11	330–055
				0100	10	335–060
				0115	13	330–070
				0130	30	320–070
				0145	45	315–090
				0200	55?	-

Date — night of	Times UT	Notes	Station position (to nearest 0.5 degree)	Time UT	Max elev.	Limiting azimuths
					degrees	
6/7	2215-2230	Faint veil at Turku, no NLC at other Finnish stations, or Britain.	60.5°N 21°E	2150	No NLC	
				2215	25	305–085
				2230	25	310–090
7/8		No NLC (F)				
8/9		No NLC (F, G)				
9/10		No NLC (F, G)				
10/11	2118-2335	All forms visible in bright display from N horizon into southern sky at Joutseno. No NLC at other Finnish or British stations. Faint NLC at Vildbjerg.	61°N 28.5°E	2118-2225	106	322–020
			56°N 09°E	2243-2335	NLC present	
11/12	2120–0205	Bright extensive display well beyond zenith at Rautalampi, all forms. At Turku bands developed into whirls as display moved south. NLC traces at Prestwick.	62.5°N 26.5°E	2140-2305	125	220–030
			61°N 28.5°E	2120-2200	45	293–016
			60.5°N 21°E	2155	25	345–050
				2215	40	300–045
				2230	55	300–035
				2245	70	310–040
			60°N 25°E	2120-2130	15	60° extent
				2200	30	
			55.5°N 04.5°W	0150-0205	40	
12/13		No NLC (F)				
13/14	2135–2209	Faint veil and bands at Kuopio in poor observing conditions.	63°N 28°E		5	290–010
14/15	2215-	Faint wisps and patches over most of sky at St Andrews, possibly all or part tropospheric cloud. No NLC (F).	56.5°N 03°W			
15/16	2200–0230	Low parallel bands observed at Edinburgh, Aberdeen and Milngavie, increasing in altitude from 0100, rapidly near dawn.	57°N 02°W	2200-2245	No NLC	
				2305	NLC	000–045
			56°N 03°W	2300	6	335–cloud
				2315	5	330–020
				2330	8	330–045
				2345	8	320–050
				0000	8	320–040
				0015	6	320–045
				0030	8	320–040
				0045	11	320-cloud
			56°N 04.5°W	2257	7	
				0017	7	
				0030	8	
				0045	9	
				0100	10	
				0115	13	
				0130	16	
				0145	20	
				0200	24	
				0230	38	
16/17	2200–0210	Veil, bands and waves, medium bright, beyond zenith at Turku, bands passed overhead at Aberdeen 2205 and 0210. Faint veils at Ränne, NLC in cloud breaks at Vildbjerg.	60.5°N 21°E	2200	110	
				2215	100	260–100
				2230	100	260–100
				2245	100	260–020
				2300	75	270–020
			57°N 02°W	2205	90+	
				2220	50	
				0200	70	
				0210	90+	
			56°N 08°E		NLC in cloud	
			55°N 14.5°E		NLC present	
17/18	2126-2315	All forms covering most of sky at Rautalampi. At Turku bright veil, bands and waves slowly receded north. Faint veils at Ränne. NLC seen at Kemnay near Aberdeen — no details.	62.5°N 27°E	2126–2220	156	320–080
			61°N 28 5°E	2130	No NLC	
			60.5°N 21°E	2145	80	260–060
				2215	60	270–090
				2230	50	270–080
				2245	40	275–075
				2300	40	285–115
				2315	30	295–090
			55°N 14.5°E		NLC present	
18/19		No NLC (F)				

Date — night of	Times UT	Notes	Station position (to nearest 0.5 degree)	Time UT	Max elev.	Limiting azimuths
					degrees	
19/20		No NLC (F)				
20/21	2140-2235	Waves and whirls over most of sky at Rautalampi. NLC suspected in cloud breaks at St Andrews. No NLC (B).	62.5°N 27°E	2140-2235	134	240-090
			56.5°N 03°W	2215	NLC?	
21/22		No NLC (G)				
22/23	2145-0300	Mr Kaye's pictures from Sumburgh show bright twisted bands against a faint silvery veil, waves visible briefly. Curved bands and patches at Edinburgh extended past zenith at Aberdeen. At Vildbjerg at 0043 Mr Andersen photographed a panorama of intense bands and waves, as did Mr Olesen (Alrö) with faint patches near Polaris and Vega later.	60.5°N 21°E	2145	No NLC	
			60°N 01.5°W	0000	28	338-065
				0030	30	325-050
				0100	60	303-048
				0115	60	313-040
				0130	70	325-070
				0200	60	308-090
			57°N 02°W	2200	No NLC	
				2230	15	000
				0228	100	
			56°N 03°W	0230	50	320-090
				0245	45	320-130
				0300	NLC present	
			56°N 10°E	2220	NLC present	
				0105	20	
				0145	56	
				0200	NLC present	
			56°N 09°E	0043	10	
23/24		No NLC (F)				
24/25	2130-2255	Faint bands and whirls at Rautalampi, no NLC at Turku.	62.5°N 27°E		30	300-090
25/26	2200-2208	Low, faint veil at Rautalampi, no NLC at other Finnish stations.	62.5°N 27°E		10	290-040
26/27	2130-2300	All forms visible at Imatra and Joutseno; very bright, overhead at Rautalampi. Medium bright bands against fading veil at Turku.	62.5°N 27°E	2130-2255	90	260-090
			61°N 29°E	2300	28	320-050
			60.5°N 21°E	2140	24	315-050
				2215	22	305-040
				2230	10	335-045
				2245	10	340-045
				2300	14	350-050
27/28	2215-2300	Bands and veil at Rautalampi, no NLC at Turku.	62.5 27°E		15	000-036
29/30		Faint NLC in cloud breaks at Alrö. No NLC (F, G).	56°N 10°E			
30/31	0215-0250	Faint band photographed at Edinburgh. No NLC (F).	56°N 03°W	0230	6	045
31 July/ 1 Aug	2100-2330	Bright waves and whirls against extensive veil at Rautalampi, fairly bright bands and small waves low in sky at Helsinki. Bright bands on veil described as greenish at Turku by Mr Parviainen. Bands and whirls at Imatra.	62.5°N 27°E	2100-2320	100	270-080
			61°N 29°E	2100	40	310-050
			60.5°N 22°E	2100	No NLC	
				2130	20	355-045
				2145	18	350-050
				2200	16	350-035
				2215	13	350-035
				2230	12	350-035
				2245	10	350-040
				2300	12	345-045
			60°N 25°E	2100	-	330-
				2115	12	328-
				2130	12	337-
				2145	13	339-
				2200	11	340-
				2215	13	348-
				2230	12	352-
				2245	13	347-
				2300	14	353-
				2308	12	328-070
				2315		328-065
				2330	17	329-
1/2 Aug	2015-2045, 2100-2140	Medium bright waves against veil at Imatra and Rautalampi. No NLC at Turku.	62.5°N 26.5°E	2125-2140	21	270-080
			61°N 29°E	2015-2045	45	340-045
2/3	1947-2015	Bands and whirls high in sky at Pertteli, no NLC at other Finnish stations.	60°N 23°E	1947	85	
				1953	75	
				2000	70	
				2006	60	
				2015	60	

Date — night of	Times UT	Notes	Station position (to nearest 0.5 degree)	Time UT	Max elev.	Limiting azimuths
					degrees	
3/4		No NLC (F)				
4/5		No NLC (F)				
5/6		No NLC (F)				
6/7		No NLC (F)				
7/8		No NLC (F)			Aurora at Helsinki	
8/9	2045–2055	Faint veil at Turku	60.5°N 21.5°E		3	357–003
9/10		No NLC (F)				
10/11		No NLC (F)				
13/14		No NLC (F)				
14/15	2330	Faint band at Turku	60.5°N 22°E		3	352–007
17/18		No NLC (F)				
18/19	1900–2300	Faint waves in zenith at Pertteli, no NLC at Imatra.	60°N 23°E		90	315–090
19/20		No NLC (F)				
20/21		No NLC (F)				
21/22		No NLC (F)				

Photographs

30 June/1 July	2340–0246	Edinburgh (Corstorphine)	J. Shepherd
	2249–0018	Edinburgh (Blackford)	N. Bone
	2330–0100	Edinburgh (Joppa)	D. Gavine
	2230–2330	Edinburgh (Cammo)	J. D. Waldron
	0225–0308	Edinburgh (Braids)	J. Bartholemew
	2250–0100	Milngavie	D. A. R. Simmons
4/5 July	2305	Heswall, Wirral	P. Irons
5/6	0020–0145	Edinburgh (Joppa)	D. Gavine
15/16	2330–0000	Edinburgh (Joppa)	D. Gavine
	2330–0000	Edinburgh (Blackford)	N. Bone
	2330–0130	Aberdeen	M. Gadsden
	2257–0230	Milngavie	D. A. R. Simmons
16/17	2315–0201	Aberdeen	M. Gadsden
22/23	2300–0245	Aberdeen	M. Gadsden
	0000–0200	Sumburgh	R. A. Kaye
	0105–0200	Alrö	J. O. Olesen
	0143	Vildbjerg	H. Andersen
	0230	Edinburgh (Joppa)	D. Gavine
30/31	0230	Edinburgh (Calton Hill)	J. D. Waldron
31 July/1 Aug	2138	Helsinki	D. Frydman

References

Crane, A. J. 1983 Noctilucent clouds 30 June/1 July 1983. *Weather* **38**, 323.
Gavine, D. M. 1984 Noctilucent clouds. *Weather*, **39**, 46.

Reviews

The new solar system (2nd edition), edited by J. Kelly Beatty, Brian O'Leary and Andrew Chaikin. 220 mm × 290 mm, pp. viii + 240, *illus. Cambridge University Press, 1982. Price £12.50.*

The awakening of public interest in astronomy during the past two decades, stimulated in part by the data and remarkable images of the planets from the recent American and Soviet spacecraft, has resulted in a considerable crop of popular and semi-technical books on the solar system. Few, however, have achieved the authority and breadth of coverage found in *The new solar system.* In contrast to many previous books aimed at a similar market, the editors have chosen to adopt the (more logical) modern approach of 'comparative planetology', introducing each aspect of solar system research (e.g. planetary surfaces, atmospheres, magnetospheres, etc.) topic by topic, rather than planet by planet. Each chapter is written by a leading US specialist on the particular discipline described, thereby ensuring an up-to-date and authoritative (though necessarily personal) review from an active researcher. The book is lavishly illustrated and is clearly aimed at a level familiar to readers of *Scientific American* or *New Scientist*, intermediate between the glossy popular astronomy text and the serious research review.

Most currently important areas of research are covered, ranging from the traditional studies of planetary surfaces and atmospheres, comets and meteorites, to the newer disciplines made possible specifically by space technology, such as planetary magnetospheres, lunar geology and the *in situ* search for living material on Mars. Of particular interest to atmospheric scientists are articles by James Pollack and Andrew Ingersoll. Pollack reviews the atmospheres of the terrestrial planets in one chapter, providing a personal view of his own areas of interest (the composition and origin of planetary atmospheres, and climatic variations on Mars and the Earth), together with a succinct, though remarkably comprehensive, summary of the meteorology of the inner planets. In a second short article he presents some of the latest findings from the Voyager spacecraft fly-by of Saturn's moon Titan, including the intriguing speculations concerning Titan's meteorology and surface ('does it rain methane into an ocean of hydrocarbons?'). Ingersoll's review of Jupiter and Saturn highlights many of the important questions concerning their atmospheres, especially those raised by the recent Voyager spacecraft data. The interpretations of Jovian meteorology discussed are not, however, comprehensive and clearly reflect the author's own viewpoint which is not universally accepted. Also of interest are articles by David Morrison and Dale Cruikshank on the outer planets (Uranus, Neptune and Pluto), including a discussion of the recent ground-based data on their atmospheres, and by Jack Eddy on the latest views of the Sun (including recent spacecraft measurements of secular variations in the solar 'constant'!).

The new solar system is already into its second edition, published only one year after its first edition, mainly in order to include some more up-to-date results from the Voyager 2 encounter with Saturn. Despite the potential pitfalls in attempting to combine the efforts of so diverse a team of authors, the editors are to be congratulated on achieving a remarkably uniform and cohesive production of a consistently high standard, and for so reasonable a price.

P. L. Read

Man-made carbon dioxide and climatic change: a review of scientific problems, by P. S. Liss and A. J. Crane. 147 mm × 230 mm, pp. vii + 127, *illus.* Geo Books, Norwich, 1983. Price £3.95, US $7.90 (paperback), £8.50, US $17.00 (hardback).

Originally produced as an internal report within the Central Electricity Generating Board, this short book is a very readable introduction to man's impact on the atmospheric carbon dioxide concentration and the possible climatic consequences of this concentration increasing. A background in mathematics or physics at university level is probably necessary fully to appreciate this book.

The book is divided into two main parts. In Part I the authors deal with the global behaviour of man-made carbon dioxide. Starting with an outline of the observational evidence for the increase of atmospheric carbon dioxide they go on to give a fairly detailed description of the carbon cycle. The authors correctly stress the large uncertainties in man's knowledge of the carbon cycle and the consequent difficulties in estimating future trends.

Part II deals with the 'climatic consequences of increased carbon dioxide concentrations'. This starts with a description of the 'greenhouse effect'. One-dimensional climate models are discussed as a method of estimating the global mean warming due to a doubling of the atmospheric carbon dioxide concentration. The theory behind global climate models is presented next; two areas of difficulty are identified, the modelling of cloud and the necessity of including the feedback between the ocean and the atmosphere. Finally, in this section, a broad survey is given of the results of doubling carbon dioxide as predicted by various global climate models in the United States and the United Kingdom.

There is a short section at the end of the book on the 'implications of increased carbon dioxide for the use of energy in the future'.

Overall this is a very readable introduction to, and survey of, this very difficult area of climate research. For someone entering this field of research this review would give a good introduction to the relevant literature. For the scientist not specializing in this area most of this book would be rewarding. One possible exception to this is the chapter on the 'uptake of carbon dioxide by the oceans' which would be heavy-going for the reader with little knowledge of chemistry. The diagrams are generally clear and well labelled without too much information being presented at once. I would recommend this book to any scientist, non-specialist or specialist, interested in this topic. It would also be a welcome addition to any scientific library.

J. F. Dyson

Books received

The stratospheric aerosol layer, edited by R. C. Whitten (Berlin, Heidelberg and New York, Springer-Verlag, 1982. DM 54 (approx), US $25.20) is a comprehensive treatment of the structure of the stratospheric sulphate aerosol layer and its physical, chemical, optical, and morphological characteristics. Included are chapters on observations of precursor sulphur-bearing gases, *in situ* aerosol particle sampling, lidar and satellite measurements, pertinent laboratory experiments, models and model applications, and climate effects. Much of the work is very new, some of it being published for the first time.

The theory of homogeneous turbulence, by G. K. Batchelor (Cambridge, Cambridge University Press, 1982. £6.95) is a reissue of Professor Batchelor's text on the theory of turbulent motion, first published in 1953. This classic account includes an introduction to the study of homogeneous turbulence, including its mathematical representation and kinematics. Linear problems, such as the randomly-perturbed harmonic oscillator and turbulent flow through a wire gauze are then treated. The author also presents the general dynamics of decay, universal equilibrium theory, and the decay of energy-containing eddies. There is a renewed interest in turbulent motion, which finds applications in atmospheric physics, fluid mechanics, astrophysics, and planetary science.

Intense atmospheric vortices, edited by L. Bengtsson and J. Lighthill (Berlin, Heidelberg and New York, Springer-Verlag, 1982. DM 56, US $23.40) examines the different mechanisms for vorticity intensification that operate in two different kinds of meteorological phenomena of great importance, namely the tropical cyclone and the tornado. The understanding of these phenomena has grown in recent years owing to increased and improved surveillance by satellites and aircraft, as well as to numerical modelling and simulation, theoretical studies and laboratory experiments. The book summarizes these recent works with contributions from observational studies (from radiosonde data, aircraft, satellites and radar) and from studies concerning the physical mechanism of these vortices by means of theoretical, numerical or laboratory models. The book contains articles by the leading world experts on the meteorological processes and on the fundamental fluid-dynamic mechanisms for vorticity intensification.

Environmental isotopes in the hydrosphere, by V. I. Ferronsky and V. A. Polyakov, translated by S. V. Ferronsky (Chichester, John Wiley and Sons, 1982. £31.00) presents a discussion of the distribution and geochemistry of the naturally-occurring stable isotopes of hydrogen, oxygen and radioactive tritium, and also of radiocarbon and other cosmogenic isotopes and radiogenic isotopes of the thorium–uranium series, in the ocean and in atmospheric, surface and ground waters. The use of environmental isotopes in three main areas of investigation in the study of natural waters is discussed. These are their genesis, dynamics and residence time in natural reservoirs. The origin of the hydrosphere is examined in the light of isotopic, new cosmochemical and recent theoretical results. This is a revised and supplemented edition of a work first published in Russian in 1975.

Cloud dynamics, edited by E. M. Agee and T. Asai (Tokyo, Terra Scientific Publishing Co., Dordrecht, Boston and London, D. Reidel Publishing Co. 1981. Dfl 115, US $49.50) serves as a brief introduction to the study of cloud dynamics, with primary emphasis on current international research efforts. The book contains papers presented at the Cloud Dynamics Symposium held at the Third General Assembly of the International Association of Meteorology and Atmospheric Physics, held in Hamburg, 17–28 August, 1981, as well as introductory and summary material provided by the co-editors. Convective phenomena are addressed in terms of shallow versus deep convective systems, with the emphasis on the comparison of theoretical model results and field observations. Cloud phenomena considered range from cumulus and cloud streets to organized mesoscale cellular convection, and wintertime lake-induced snow squalls. Deeper convective systems are also considered, including thunderstorms, hailstorms and tornadoes. Comparisons are made between Doppler radar observations and thunderstorm model results.

Turbulent shear flows 3, edited by L. J. S. Bradbury, F. Durst, B. E. Launder, F. W. Schmidt and J. H. Whitelaw (Berlin, Heidelberg and New York, Springer-Verlag, 1982. DM 140 (approx), US $56.00) is a collection of papers from the Third International Symposium on Turbulent Shear Flows held at the University of California, Davis, September 1981. The papers are divided into four sections: wall flows, scalar transport, recirculating flows and fundamentals. As with previous volumes, each section is preceded by a brief introductory article whose purpose is to make some general observations about the various sections and to fit the individual papers into the context of the general topic.

Air pollution: Assessment methodology and modeling, edited by Erich Weber (New York, Plenum Press, 1982. US $39.50) explores the fundamental steps in developing a worldwide coherent pollution control policy on air quality management systems, air quality modelling and assessment methodology. Experts from eight industrialized countries have contributed, drawing on their practical experience. Methods of management, modelling and assessment discussed in this volume have been selected because they were successfully applied in specific cases. The Gaussian method for pollution modelling, now almost universally employed, is described, and calculations for its practical application are included. The volume also provides a glossary explaining in detail about three hundred terms used in air quality management.

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