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WATERSPOUTS OFF THE STRAITS OF GIBRALTAR

By G. W. HURST, B.Sc.

Whilst flying about 60 miles west of the Straits of Gibraltar on November 21, 1955, Wg-Cmdr J. D. E. Hughes and Flt-Lt A. R. Jackson of 224 Squadron noted a number of waterspouts which appeared to lie in a line, and were up to two miles apart; at least four were seen. It is felt that a record of this occasion is worth while, both because it occurred close in time and place to an upper air sounding and to surface observations, and because a number of quite good photographs were taken; the best of these are reproduced.

The photograph in the centre of this magazine was taken at 1150 G.M.T. and shows a spout from the surface to about 500 ft. into a cumulonimbus from a distance of about half a mile. The direction of view is towards the south-east, and the slope of the spout from west (at the base) to east. Movement is with the winds towards the north-west. Interesting features of this print are the shoulders surrounding the spout at the cloud base, the slight curvature of the column, the area of disturbance on the sea surface (which shows clearly a movement on the surface towards the camera, and to the right) and the dark central core of the main-spout column; the lightness of the outer core, lit directly by the sun, and the darkness of the centre show strongly the hollow nature of the column. The aircraft was at 300 ft., and the dimensions of the spout are 500 ft. high, 30 ft. in diameter, with a central core of about 5 ft. The surface water is disturbed over an area some 50-100 ft. across. The wind at sea level is obviously not more than moderate, as the sea is little more than gently rippled. There is an active shower to the east.

The upper photograph facing p. 337 was taken a few minutes later, and shows a second spout from rather closer and nearer the sea surface. Very similar characteristics to the first are evident, and again the shoulders are clearly visible. The lighting is not so good as in the first case, and the indirect illumination shows the central core as lighter than the main body of the column. The line running across the foreground is a real phenomenon, and was noted by the crew of the aircraft. It may have been an oil streak, or less likely the wake of a ship, or the track of an earlier spout.

The lower photograph facing p. 337 is a close-up from about 150 yd. of the sea surface in spout conditions; the aircraft was at about 100–150 ft. when it was taken. In this case there was no actual spout above the sea disturbance; it could not be kept in view long enough to decide whether or not it was the beginning, or less probably, the termination of a spout. The direction of movement is clearly from right to left with the wake to the right (the view is now to the west or north-west), the spray from the sea disturbance reaches a height of fully 50 ft., and judging by its appearance the sense of the rotation is anti-cyclonic. This photograph brings out vividly the very localized nature of these disturbances, as the sea immediately adjacent shows no signs of agitation, and appears gently rippled, as in the other two prints. The writer has seen very similar effects with much rougher sea to the lee of the Rock of Gibraltar in strong west-south-westerly winds; in these cases too, no spout was seen, though they are not uncommon in such circumstances.

The meteorological situation on November 21 was typically that for water-spout formation west of the Straits, and a portion of the 1200-G.M.T. chart surrounding the area is reproduced as Fig. 1. There was a well developed levanter blowing to the east of Gibraltar, and the northern Straits and Cadiz Bay were in this régime. Further south there was a ridge, and the flow to the south-west of the Straits area was mainly southerly. The 1500 G.M.T. radio-sonde ascent for Gibraltar, shown in Fig. 2, was most unstable with practically a dry adiabatic lapse rate from the surface to over 1,700 ft., even with a surface temperature as low as 59°F. The air was very moist from the surface up to the 10,000-ft. level, and the day was one of exceptionally heavy rain at Gibraltar itself, with measurements for 24 hr. varying from 4.02 in. at North Front to over 7 in. at different parts of the Rock. It happened that

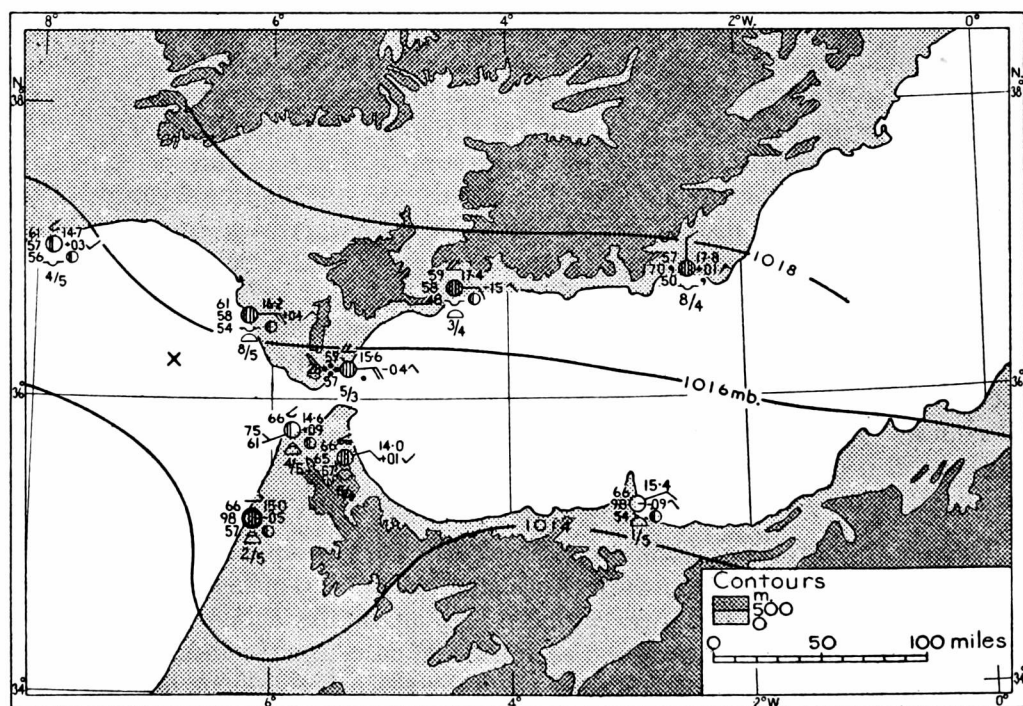


FIG. 1—SYNOPTIC CHART 1200 G.M.T. NOVEMBER 21, 1955 SHOWING VICINITY OF WATER SPOUTS (X)

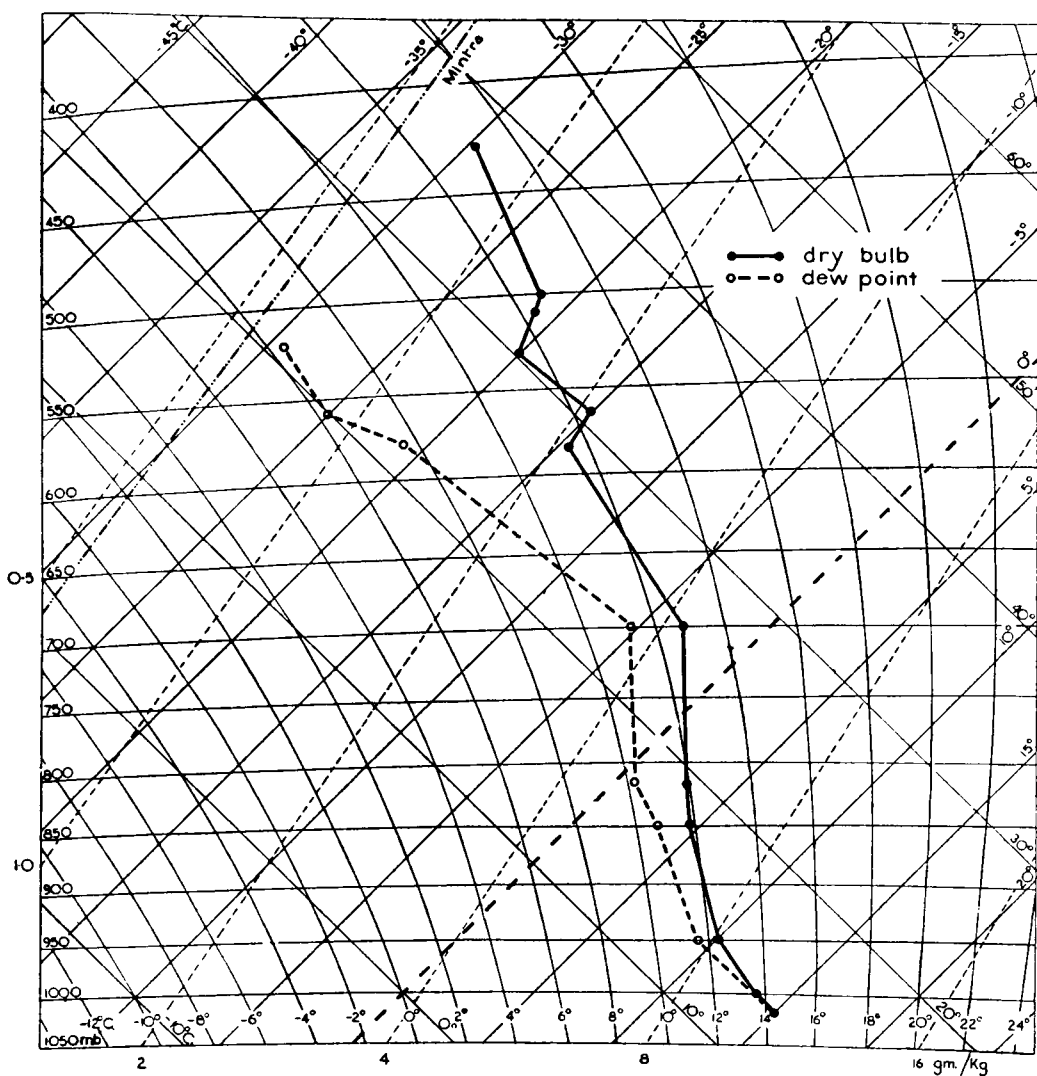


FIG. 2—TEPHIGRAM FOR GIBRALTAR 1500 G.M.T. NOVEMBER 21, 1955

there were few ship's reports available near the Straits for 1200 G.M.T. but reports a few hours different in time suggest that a sea temperature of about 63°F. would have been expected in the northern Straits—high enough to give rise to a superadiabatic lapse rate from the surface to at least 1,000 ft. No definite information can of course be given regarding variation from place to place of sea or air temperatures as discussed by Gordon¹, but the conditions were obviously most favourable for such differences to exist, with easterlies to the north of the spout area, and southerlies to the south. The direction of slope of the spout would be consistent with a decrease in the easterlies with height; the Gibraltar winds cannot be broken down into detail at heights appreciably less than 3,000 ft. above the surface, but the winds at 0900 G.M.T. of 110° 22 kt. at the surface, 110° 25 kt. at 3,000 ft., and 130° 18 kt. at 5,000 ft. suggest that allowing for the surface frictional layer, the easterly was strongest near the surface.

It is interesting to compare these photographs with the close-up of a water spout discussed by Johnson². Most of the characteristics which he deduced

for the spouts in the eastern Mediterranean applied in this case, as far as examination is possible with differing distances from the spouts and differing view-points, but two points of difference are that the hollow core does not appear to extend to the lower diffuse region of broader diameter, seen faintly in the first photograph up to about a quarter of the spout height, and the shoulder seen in the first two photographs were not features of the earlier spouts. It is thought probable that the shoulder is in fact a hollow cone, the section of which is seen in silhouette. This may well have formed by the vortex action at the point of exit of the spout from the cloud dragging down part of the cloud in its vicinity along the line. The shoulder is of restricted length with the dissipation in the drier air below cloud.

REFERENCES

1. GORDON, A. H.; Waterspouts. *Mar. Obs.*, London, **21**, 1951, pp. 47 and 87.
2. JOHNSON, SIR NELSON; The structure of a waterspout. *Quart. J. R. met. Soc.*, London, **70**, 1944, p. 127.

PROLONGED HEAVY RAIN AT GIBRALTAR, NOVEMBER 20-26, 1955

By G. W. HURST, B.Sc.

Introduction.—During the period of a week starting at 0900 G.M.T. November 20, the total rainfall measured at North Front, Gibraltar, was 14·97 in., which is the highest fall recorded in one week for at least this century; earlier readings for a seven-day period were 15·17 in. in December 1861, and 17·17 in. in November 1858, both of which were taken west of the Rock in the town area. The average rainfall for November (the wettest month) is 6·28 in. Considerable damage to property and telephone installations due to flooding occurred on the 21st and again in the shorter but very intense fall on the 26th; even more serious damage was reported in Spanish towns near Gibraltar, where bridges were carried away, new roads subsided and houses were demolished. Figures for the daily rain (with the conventional day 0900–0900 G.M.T.) at several stations in the town are given in Table I.

TABLE I—DAILY RAINFALL MEASUREMENTS AT VARIOUS STATIONS IN GIBRALTAR
NOVEMBER 20-26, 1955

Date	North Front	Convent Garden	City Hall	Moorish Castle	Green Lodge	Willis Gate
1955	<i>inches</i>					
Nov. 20	2·62	4·38	3·59	2·31	2·53	2·48
Nov. 21	4·01	7·02	5·53	5·49	5·89	5·48
Nov. 22	2·21	2·32	2·34	2·53	2·39	2·36
Nov. 23	1·01	1·02	1·00	1·13	1·13	1·13
Nov. 24	0·63	0·68	0·67	0·71	0·75	0·66
Nov. 25	2·18	2·62	2·12	2·20	2·10	2·11
Nov. 26	2·31	2·98	3·00	3·42	3·00	3·22
Total	14·97	21·02	18·25	17·79	17·79	17·44

Of these stations, North Front is the R.A.F. Station a few feet above sea level to the north of the Rock, Convent Garden and City Hall are also low-level stations near each other in the town to the west of the Rock, and Moorish Castle is on the north-west slope of the Rock at a height of 260 ft. The other two stations are 810 ft. and 460 ft. above sea level respectively, both to the north-west of the main body of the Rock. As discussed later there is reason to

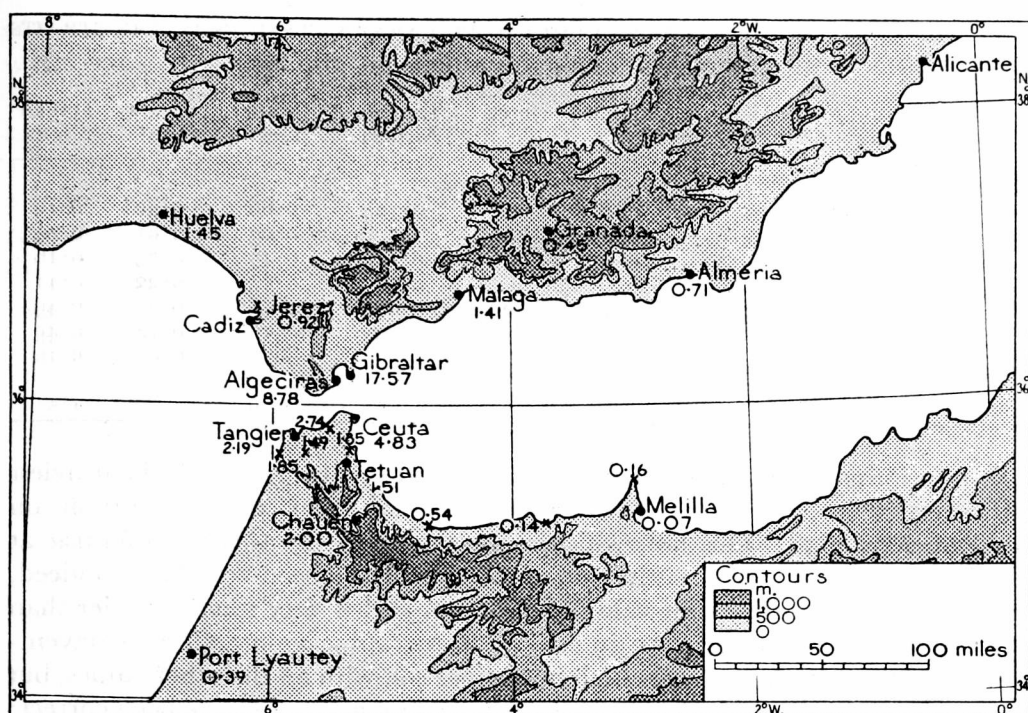


FIG. 1—TOPOGRAPHY AND RAINFALL OF THE GIBRALTAR-STRAITS AREA
Sites indicated by crosses are rainfall stations. Rainfall amounts shown are in inches.

believe that the North-Front site is not always typical of conditions in the town and it is probable that rain at South Bastion, the locale of the earlier records quoted above, would have been of the same order as that at City Hall, and that Gibraltar town suffered appreciably more rain in a week than had fallen in the same period for at least 100 yr. In fact the whole of the North-Front fall of 14.97 in. fell in the exact six-day period 1300 G.M.T. November 20–26.

Rainfall data have been obtained for a number of places in the Straits area, and these are shown as totals for the week 20th–26th on Fig. 1. It is immediately obvious that rainfall at Gibraltar was far in excess of any other recorded rainfall, Algeciras, less than 6 miles to the west across the bay, receiving just under half the Gibraltar fall, and other stations very much less. The increase in rainfall westwards along the narrowing channel is also marked, with maximum falls at Gibraltar and Ceuta, opposite each other across the Straits. Rainfall further west was very low. In Table II daily rainfall totals are given for a number of stations within reach of Gibraltar; the fall for Gibraltar itself is a weighted mean, giving equal weights to data for North Front, City Hall, Moorish Castle and Willis Gate, and half weight to the Convent-Garden and Green-Lodge readings as the data for these two stations are not felt to be quite so representative as those for the other stations.

It is seen that in the vicinity of Gibraltar the very heavy fall of the 21st was reflected clearly at Algeciras and Ceuta, but negligibly so at places even as near as Tangier, Tetuan and Malaga. In fact, throughout the whole week, only on one day, the 24th, was Gibraltar rainfall not far in excess of other regions; even on this day, only Algeciras and Tangier Airport recorded heavier falls.

TABLE II—DAILY RAINFALL MEASUREMENTS AT VARIOUS STATIONS IN THE STRAITS OF GIBRALTAR AREA NOVEMBER 20–26, 1955

Date	Gibraltar	Algeciras	Malaga	Jerez	Tangier Airport	Tangier Town	Ceuta	Tetuan
1955					<i>inches</i>			
Nov. 20	2.89	1.97	0.10	...	0.12	0.66	0.32	0.12
Nov. 21	5.39	2.97	0.03	0.09	Tr.	0.03	2.81	0.04
Nov. 22	2.36	0.52	0.09	...	0.19	0.17	0.73	0.16
Nov. 23	1.07	0.63	0.05	...	0.54	0.65	0.22	0.11
Nov. 24	0.68	1.30	0.47	0.23	0.87	0.58	0.47	0.49
Nov. 25	2.19	1.39	0.36	0.48	0.13	0.10	0.24	0.49
Nov. 26	2.99	...	0.31	0.12	...	Tr.	0.04	0.10
Total	17.57	8.78	1.41	0.92	1.85	2.19	4.83	1.51

It is interesting to compare the falls at Gibraltar on the 21st with the heaviest fall recorded in over a century for a conventional 24-hr. period: 7.31 in. on November 7, 1858. This fall, which from a note in the *Gibraltar Chronicle* at the time took place almost entirely at night, must have been very heavy indeed, as it dwarfs the North-Front value of 4.01 in., and is very much heavier than the City-Hall reading of 5.53 in. on an autographic gauge. The Convent-Garden value of 7.02 in. seems high in comparison with all the other values, but the gauge is in a well protected site, and the reading may well have been correct; the gauge itself is standard, and of reasonable exposure, but it is possible that in really heavy rain there might be a slight splash-back from nearby vegetation.

Precipitation during the week is shown graphically in Fig. 2. The fall, very heavy at times, occurred during five periods varying in length from 18 to 31 hr., and in amount from 0.82 to 5.78 in. It will be seen that nearly 40 per cent. of the fall (5.93 in. in fact) fell in a total of 8 hr. The longest break in precipitation was 15 hr. in mid-week, and the heaviest fall in 60 min. was 1.18 in. on the 26th, 1045–1145 G.M.T. Close examination of the anemograph and other

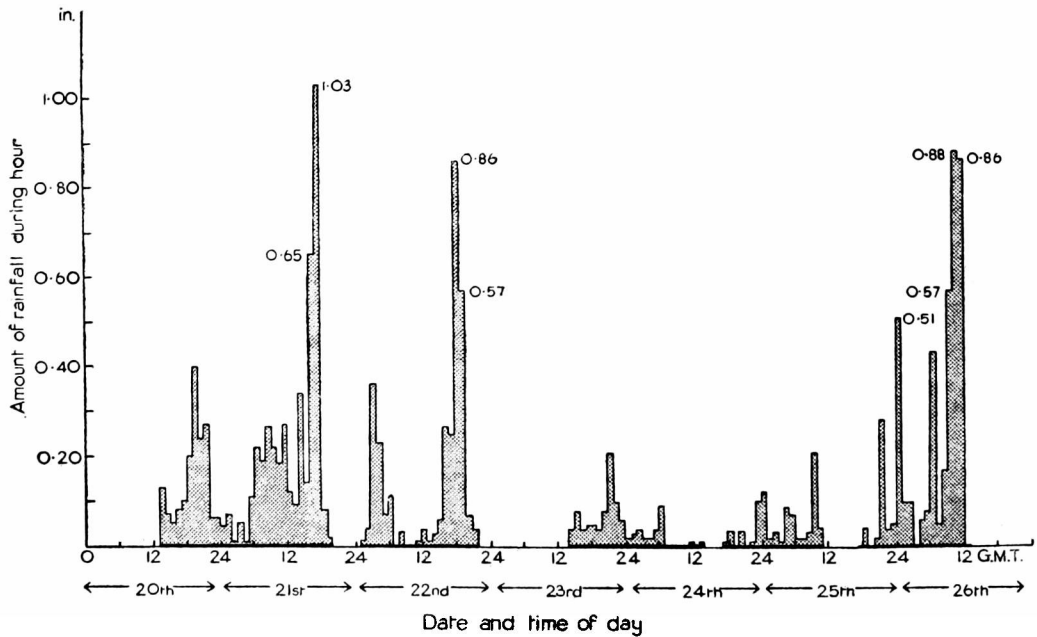


FIG. 2—HOURLY RAINFALL AT NORTH FRONT, GIBRALTAR, NOVEMBER 20–26, 1955

records was made, particularly during the incidence of heavier falls. There was a distinct and sharp veer of wind from 050° to 080° at 1655 G.M.T. on the 21st; no front could be traced on the chart, and there was no apparent modification in the surface air. Similarly at 1815 G.M.T. on the 22nd there was a rather less sharp veer from 050° to 110° , though again with no evidence of a front on the chart. Both these occasions coincided with some of the heaviest rain in the period, and probably represented minor troughs moving across the Straits. Precipitation on the evening of the 20th was accompanied by thunder. A weak warm front was traced through Gibraltar about 2100 G.M.T. on the 23rd; there was a slight veer from 110° to 130° at the time, and the rain, though it continued after 2200 G.M.T., was of decreased intensity. Other temporary anemograph discontinuities were associated with some of the heavier hourly downpours, but the 3-hr. period of really heavy rain on the 26th showed no anemograph discontinuity, nor was thunder heard.

Synoptic situation.—There was little change in the surface chart as it affected Gibraltar in the whole period, 18th–28th, with low pressure to the west or south-west of Gibraltar, and an anticyclone over or to the west of north-west Europe. On the 18th and 19th small amounts of rain fell in the Gibraltar area, but the weather experienced on the 18th could be regarded as typically cloudy with slight rain at times. The significant feature from the 19th to the 20th was the rise in dew-point as the low-level winds backed slightly and the sea track lengthened; temperatures at Gibraltar at 0600 G.M.T. from the 18th to 21st were: 60° – 48° F., 63° – 52° F., 63° – 56° F. and 63° – 58° F. The latter temperatures were maintained with minor variations for the remainder of the week. Sea temperatures in the Straits area and immediately to the east were reported in the range 62° – 67° F.; probably 62° – 64° F. would be representative in the west of the Mediterranean area.

The chart for 1200 G.M.T. on the 21st showed several interesting features, can be regarded as fairly typical of the period, it is seen (Fig. 1, p.322) that there is a good feed of easterlies along the western Mediterranean to the Straits, and that there is a slight tendency to blocking west of the Straits with a southerly component across. There is heavy continuous rain at Gibraltar, with no other station in the vicinity reporting anything other than slight drizzle. The great majority of the rain which fell was non-frontal in character: the only front which passed through was the warm front at 2100 G.M.T. on the 23rd with relatively slight precipitation.

The flow at 500 mb. was dominated on the 16th by a low near Sicily and another near the Azores, resulting in a north-westerly air stream in the Gibraltar area. The Atlantic low naturally became the dominant feature and from the 20th to 24th there was an upper Atlantic feed from the west-south-west to the Straits area; there was slight troughing from Portugal towards French Morocco. The air aloft which thus affected the Straits was of a long sea fetch, and of cold origin with showers at times in the Azores from the 16th to 20th. There was little significant change in the situation until after 26th. Typical upper winds reported from Gibraltar itself in the period are given in Table III.

It is seen from this table that the height of the overrunning south-westerlies varied during the week; variation was between about 4,000 and 8,000 ft. The

TABLE III—UPPER WINDS AT GIBRALTAR, NOVEMBER 18–26, 1955

Height	1500 G.M.T. Nov. 18		0300 G.M.T. Nov. 21		1500 G.M.T. Nov. 23		0300 G.M.T. Nov. 26		1500 G.M.T. Nov. 27	
ft.	°	kt.	°	kt.	°	kt.	°	kt.	°	kt.
25,000	250	21	250	23	240	66	270	20	280	17
18,000	240	15	230	18	230	61	240	11	270	13
10,000	200	9	220	8	240	39	220	15	190	8
5,000	100	22	190	8	200	21	180	13	100	16
3,000	100	25	110	25	120	14	130	16	100	22
Surface	100	22	090	21	080	12	060	10	100	22

only important change which took place was the temporary increase in mid-week in the strength of the south-westerlies at 10,000 ft. and above, with the corresponding fairly strong vertical wind shear.

Study of the upper air ascents for Gibraltar, Madeira and Port Lyautey showed varying conditions during the period. The Gibraltar ascent on the 18th was unstable above 700 mb., but was very dry. By the 19th, the south-westerlies above 5,000 ft. were very much moister, and scattered showers might be expected. There were in fact outbreaks of slight rain at Gibraltar throughout the day. By the 20th however, the ascent was completely unstable for surface temperatures 63°–58°F., and with very moist air to 400 mb., heavy precipitation would be expected. The tephigram on the 21st was even more unstable, but from the 22nd to the 24th, the conditions were far less unstable, and on the 24th, 800 mb. was about the limit of convection. The ascent on the afternoon of the 25th indicated an inversion at 930 mb., with instability from 800 to 400 mb. The ascent in the afternoon of the 25th was much more stable, and rain had virtually died out by then. Port Lyautey reflected a similar picture, increasing humidity and instability from the 17th to 19th, with, on the 20th, instability from 860 to 300 mb.; a thundery situation. Again during mid-week, drier air had come in above 900 mb., with less instability, but the early morning ascent on the 26th suggested instability from 950 to 250 mb. Madeira was similar, with a cooling of 10°F. or more in two days from the 18th to 20th in the 7,000–20,000 ft. zone.

Mechanism of fall.—Gibraltar is, fortunately for the water engineers, uniquely placed in that a combination of events will provide rainfall of tropical intensity and persistence, although places only a few miles distant may be clear. It happened on several occasions during the almost sunless period at Gibraltar of the 20th to 26th that skies at Tangier were broken or almost clear, and aircraft flying between the two places on more than one occasion reported a complete break-up of cloud near Tarifa, about 10 miles south-west of Algeciras. The rainfall can almost be regarded as monsoon both in its origin and in its intensity.

Such a combination probably arises on many occasions each decade, though its persistence on this occasion was very unusual. The fundamental requirements for such heavy rain in the Gibraltar neighbourhood are:

- (i) warm moist easterly wind to a few thousand feet with a fairly long Mediterranean fetch
- (ii) overrunning moist unstable south-westerly wind.

Both these requirements were met in the period 20th–26th, the former continuously, and the latter from the 20th to the 22nd, and on the 26th; on these occasions air was unstable to great heights.

The peculiar geographical situation of Gibraltar and district is shown on the map in Fig. 1. It will be seen that from Almeria to east of Melilla there is a chain of hills almost unbroken to the Gibraltar Straits to a height of 500 m., and without important gaps to a height of 1,000 m. At the former level the channel therefore narrows from 140 miles near Almeria to about 40 miles in the west; there is similar narrowing at 1,000 m. from 160 to about 70 miles. Clearly then with easterly winds, a considerable degree of convergence is being imposed upon the air in its passage of 170 miles from Almeria to Gibraltar. This convergence will express itself both in greater wind speeds in the Straits area, and also in forced ascents. It is not easy to assess accurately the increase in wind speed, as North Front is very open indeed to winds from the east, whereas observations from really well exposed places are not frequent on the south-east Spanish coast. Comparison of the Malaga and Gibraltar wind ascents for the only two occasions the former were received are given in Table IV.

TABLE IV—COMPARISON OF UPPER WINDS AT MALAGA AND GIBRALTAR

Height	1500 G.M.T. Nov. 18, 1955				1500 G.M.T. Nov. 19, 1955			
	Malaga		Gibraltar		Malaga		Gibraltar	
ft.	°	kt.	°	kt.	°	kt.	°	kt.
8,000	360	21	200	9	110	7	110	9
3,000-2,000	360	20	100	25	...	...	090	22
1,000	360	20	...	...	110	7	...	...
Surface	010	20	110	22	110	8	090	18

No other observations above the surface were available from Spanish stations in the south-east during the period. The observations plotted on Fig. 1, p. 322 however paint a typical picture, Almeria 360° 6 kt., Oran 110° 6 kt., Melilla 070° 6 kt. and 070° 5 kt. at Tetuan, compared with 090° 15 kt. at Gibraltar. It is a feature of this chart that winds to the south-west of the Straits (Tangier etc.) were light, whilst those to the north-west were strongish easterly; this is a natural result of the southerly drift to the west of the Straits area.

Vertical convergence was in this period aided by several other factors. The Rock itself, nearly 1,400 ft. high, presents a formidable barrier to the easterlies in their sweep, coming as it does more or less centrally between adjacent higher ground; the effect was most noticeable in the rainfall on this occasion, as the precipitation was distinctly higher in the town than at North Front. The presence of the Rock, with air flow round and over it, must make itself felt over a range of a mile or two, but "triggering" effects are most felt over and to the immediate lee of the Rock, the ridge of which is only 300-500 yd. from the east coast. Thus fresh or strong low-level winds from east or a point just north deliver somewhat more than the normal convergence rainfall to the North-Front site, but carry additional orographic rain formed over the Rock itself to the town area just to its lee. Much more carry-over from the Rock to North Front occurs with winds south of east. Thus on the 20th and 21st, the winds were from 070-090° about 20 kt., so that a considerable difference might be expected between North-Front and town falls; the percentages of rainfall at North Front to a weighted-mean town fall were 88 and 70 per cent. respectively, with rather more north in the winds on the 21st. From the 22nd to the 25th, the percentage ranged between 92-100 per cent., and the North-Front wind during nearly all the periods of rain was from a point south of

east, and was considerably lighter than earlier in the week. On the 26th, the percentage was only 73 per cent., again with winds of about 20 kt. from east or a point just north.

Another factor which was present to a greater or lesser degree during the week was slight blocking action to the west of the Straits, where the light low-level southerly drift which was maintained most of the week acted as a further bar to the free passage of the Mediterranean easterlies. This shows up on Fig. 1, p. 322 to a limited extent in the light winds to the south, and the stronger easterly winds to the north.

A further favourable circumstance for the heaviness of the rain on the 20th, 21st and 26th was the lack of vertical shear in the upper winds, so that developing cumulonimbi were not distorted before they had attained full stature. In the middle of the week, vertical shear alone militated against prolonged heavy rain.

Conclusion.—By reason of geographical circumstances, with marked orographic tendencies, Gibraltar receives about 50 per cent. more rain than most places nearby on the Spanish coast, and twice as much as places inland. The period from November 20th to the 26th brings out the tremendous effect of topography in favourable meteorological conditions.

DAMAGE TO AIRCRAFT BY HEAVY HAIL AT HIGH ALTITUDE

By T. N. S. HARROWER, M.A., B.Sc. and D. C. EVANS

Introduction.—Not more than ten years ago a civil airline pilot would have taken every possible step to avoid flying into an area of cumulonimbus activity but in recent years, with the increased efficiency of de-icing equipment and the improvement of instrument-flying techniques, civil aircraft are, when necessary, flown through thundery areas in which hail, turbulence, icing and lightning are encountered. For such flights by pressurized aircraft it is normal procedure to enter a cumulonimbus at maximum altitude and at minimum air speed, but on some occasions an aircraft will encounter hazardous conditions, and it is thought that a report of one such incident will be of value.

Narrative of the incident.—Captain Marks was the pilot of a British European Airways Ambassador-Elizabethan class aircraft (see photograph facing p. 336) which left Nice at 1417 G.M.T. on August 14, 1954, on a scheduled flight to London. At 1507 near Lyons, at the head of the Rhône valley, while flying in thick cloud at an indicated altitude of 20,500 ft. (450 mb.) and at an indicated air speed of 140 kt., the aircraft encountered a heavy thunderstorm and flew into cumulonimbus cloud. The reported outside air temperature was -10°C . Although the pilot closed the throttles, the aircraft gained both altitude and air speed, the rate-of-climb indicator showing a climb of 4,000 ft./min. and the air speed indicator showing 190 kt. Only moderate turbulence and light rime icing were experienced but extremely heavy hail shattered the outer lamination of the wind-screens, and damaged propeller bosses and engine cowlings. An emergency descent was commenced in case of explosive decompression and the flight was continued at 8,500 ft., unpressurized, to Paris. Further damage to the nose and tail was discovered after landing.

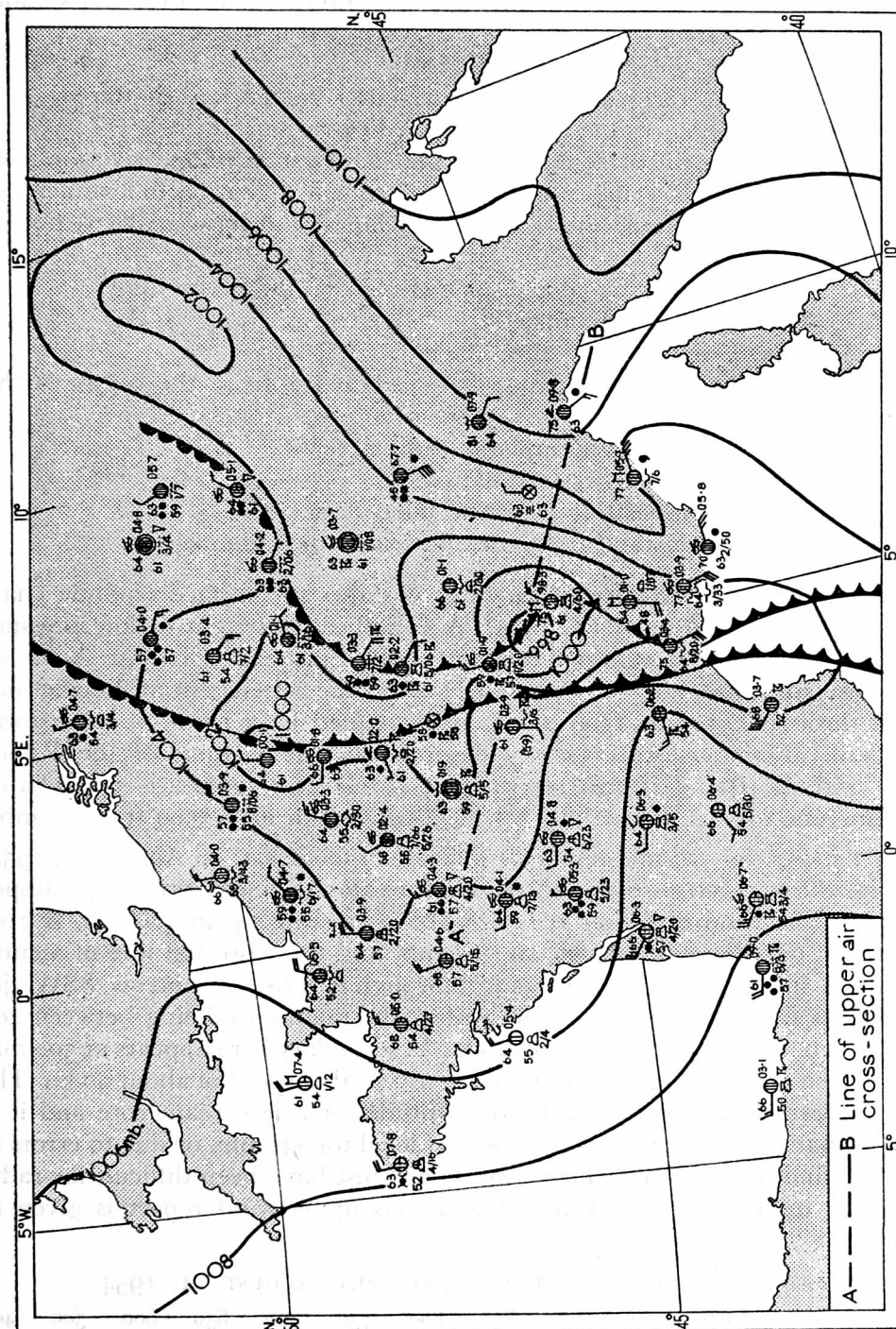


FIG. 1—SYNOPTIC CHART, 1500 G.M.T. AUGUST 14, 1954

Damage to the aircraft.—The following is a full list of the damage sustained by the aircraft

- (i) Nose of aircraft holed in three places (see photographs in the centre of this magazine); (the nose is constructed of three 1/16-in. plywood sections bonded together)
- (ii) Both pitôt-head attachments dented
- (iii) Port and starboard wind-screens, outer laminations shattered
- (iv) Cabin hooding and fuselage dented in various places
- (v) Tailplane fins and rudder leading edges damaged and rivets missing (see photographs in the centre of this magazine) (central-fin leading edge 0.028-in. aluminium alloy, outer tailplane-fin leading edge 0.036-in. aluminium alloy)
- (vi) Tailplane leading edge damaged (0.036 aluminium alloy)
- (vii) Engine cowlings damaged
- (viii) Indentations on propeller blades
- (ix) Propeller spinners damaged (see photographs in the centre of this magazine)
- (x) Rivets sprung on mainplane leading edges
- (xi) Navigation light screens shattered
- (xii) Centreplane leading edge and fillets damaged
- (xiii) Aerial shields and tailplane anti-icing intake damaged.

The meteorological situation.—Fig. 1 shows the surface synoptic chart for 1500 G.M.T. on August 14, 1954. A complicated system of low pressure covered France and a low of 998 mb. was centred just east of Lyons. A double cold-front structure was moving slowly east, the surface front having just passed through Lyons at 1500 G.M.T. accompanied by a heavy thunderstorm with hail. Thunderstorms were widespread in the vicinity of the Rhône valley and the thunderstorm reported at Lyons at 1500 G.M.T. is probably the same one as that flown into by the Elizabethan at 20,500 ft. (450 mb.)

Fig. 2 shows the 500-mb. upper air chart for 1500 G.M.T. on August 14, 1954, and Fig. 3 shows a cross-section through Lyons along a line normal to the upper air flow. The wind direction at Lyons above 750 mb. up to 400 mb. is 210° apart from one direction of 200° at 500 mb. and therefore the line of section was taken in the direction 300° – 120° through Lyons. A narrow SSW. jet stream was flowing over the Rhône valley, the main core being between 400 and 350 mb. with a speed of about 120 kt. A secondary core appears at 500 mb. with a speed of 100 kt. and another at 650 mb. with a speed of about 90 kt. The latter appears at an exceptionally low altitude for a jet-stream core and it is thought that it is either due to the effect of local topography or due to errors in the wind finding at Lyons where conditions must have been difficult for radio theodolite tracking at that time. The Lyons upper-wind report is given in Table I.

TABLE I—LYONS ASCENT AT 1500 G.M.T. AUGUST 14, 1954

Pressure (mb.)	976	950	900	850	800	750	700	650	600	500	400
Wind direction ($^\circ$)	180	190	190	190	190	210	210	210	210	200	210
Wind speed (kt.)	6	11	23	38	45	47	75	88	75	81	83

There is an additional report of 210° 81 kt. at a height of 695 mb. The position E at which the Elizabethan encountered the strong up-current and the severe

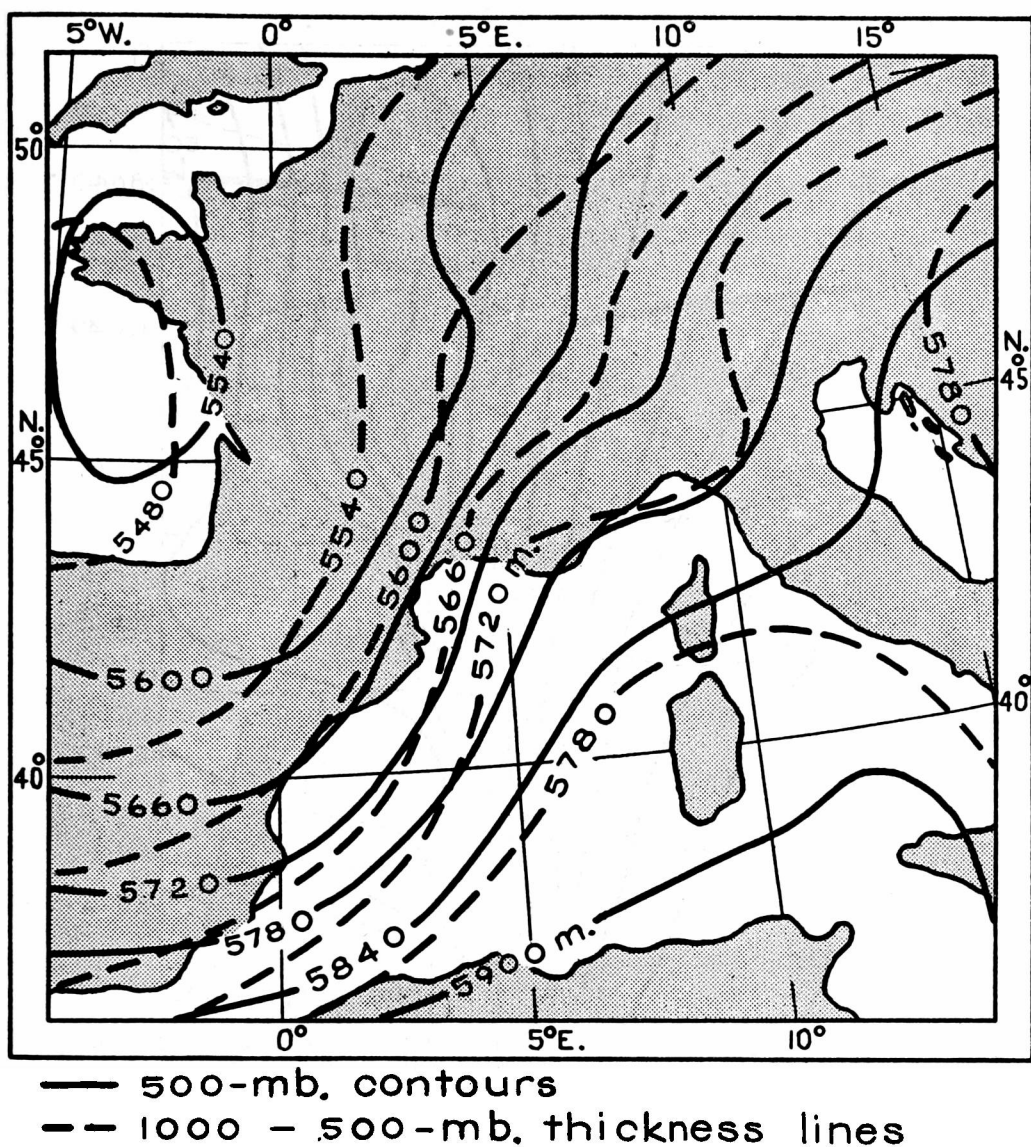


FIG. 2—500-MB. CONTOUR CHART FOR 1500 G.M.T. AUGUST 14, 1954

hail is shown at 450 mb. on the "cold" side of the jet. There is marked horizontal shear but no indication of vertical shear.

Severe turbulence was encountered elsewhere within this jet stream at a position marked B, by a B.O.A.C. aircraft at about the same time. This aircraft was flying at 19,500 ft. on track from Paris to Nice and reported by radio "severe to very severe turbulence, moderate to heavy icing, occasional hail and lightning, outside air temperature $-17^{\circ}\text{C}.$, wind 230° 100 kt." Several other aircraft reports indicated cloud tops to at least 30,000 ft. above the Rhône valley with severe to very severe turbulence but exact positions are not known.

Fig. 4 indicates the upper air ascents from Nîmes and Payerne made on the afternoon of August 14. The ascent at Nîmes is warmer at all levels and much drier aloft and this is to be expected from the relation of the ascents to the main jet stream. It is obvious that the instability of the Nîmes ascent would be

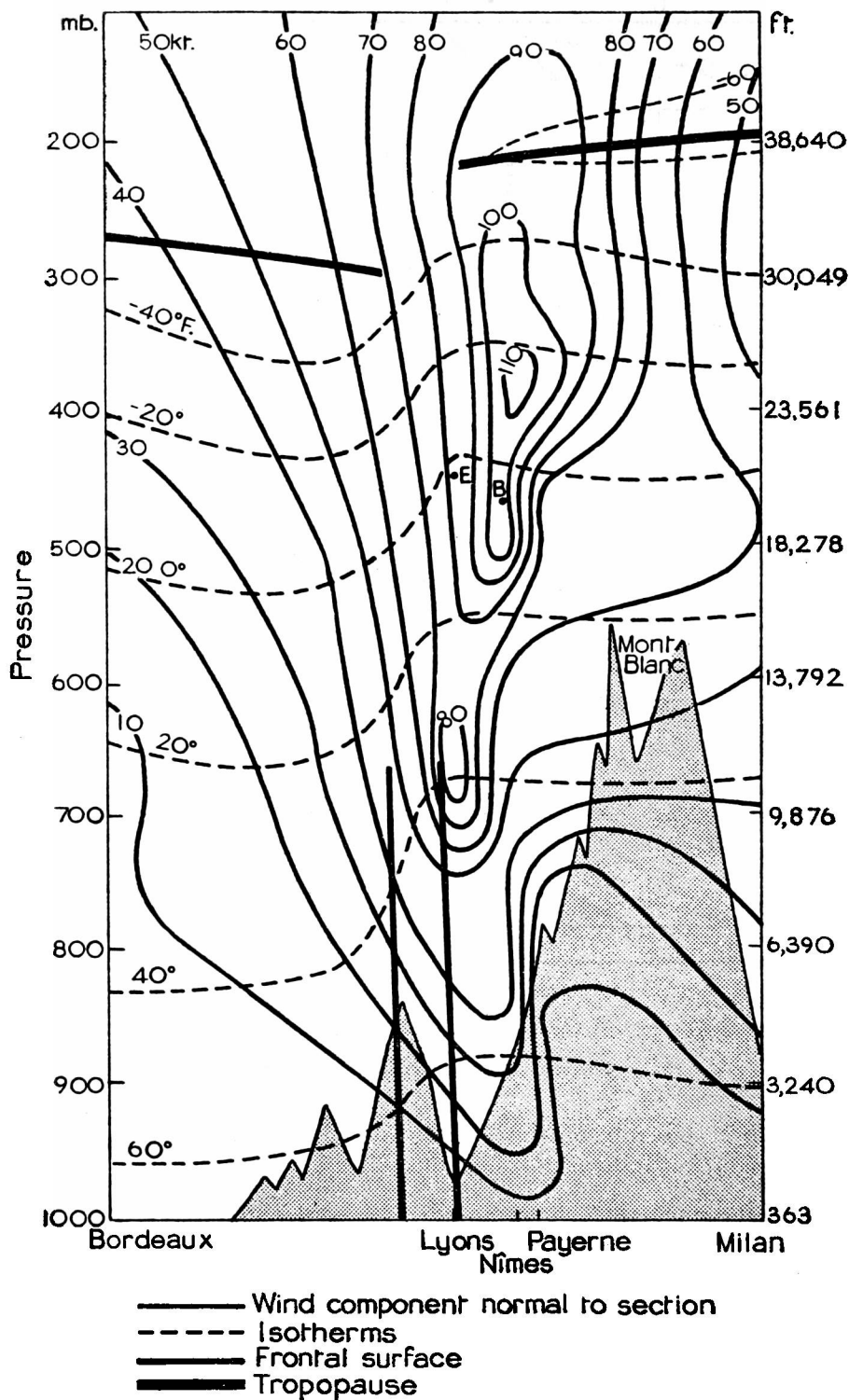


FIG. 3—CROSS-SECTION THROUGH LYONS, NORMAL TO UPPER AIR FLOW,
AT 1500 G.M.T. AUGUST 14, 1954

The approximate profile of highest ground within 30 miles of line of section (marked AB in Fig. 1) is shown in the background.

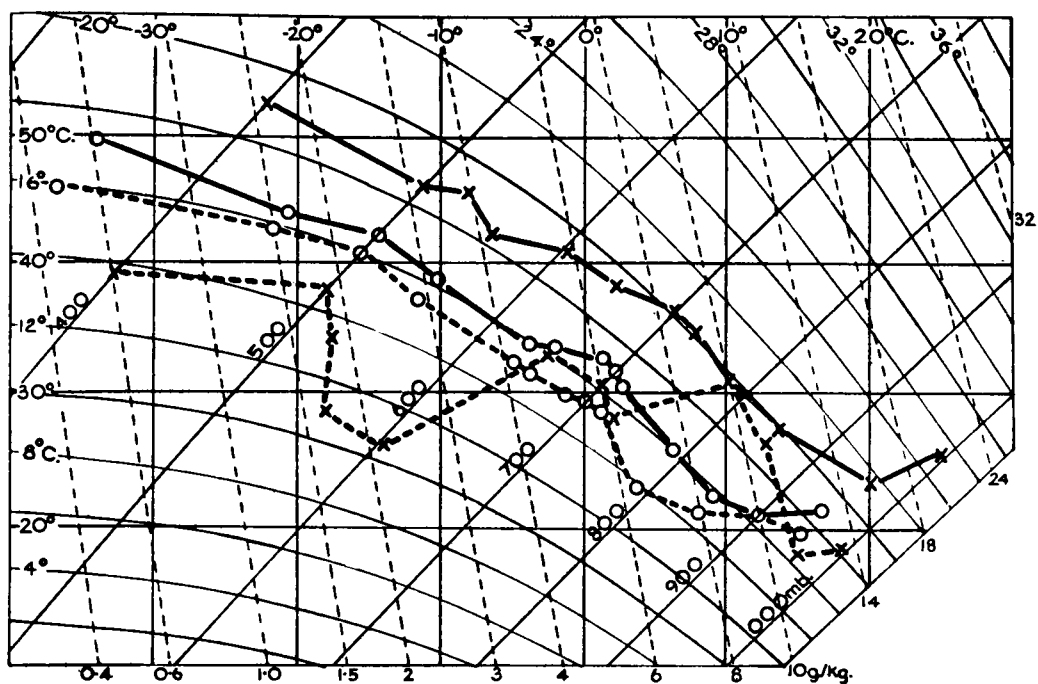


FIG. 4—UPPER AIR ASCENTS FROM NÎMES AND PAYERNE 1400 G.M.T. AUGUST 14, 1954

Nîmes x——x Dry bulb	x-----x Dew point
Payerne o——o Dry bulb	o-----o Dew point

greatly increased by any lifting of the layers between 780 and 600 mb. where the wet-bulb potential temperature decreases with height and this potential instability is undoubtedly the cause of the widespread thundery activity over the high ground. There also must have been considerable channelling and subsequent lifting of the warm southerly air stream in the lower layers by the narrowing of the Rhône valley, but it is impossible to assess the vertical rate of ascent of air due to the topography. However, as an average uplift of only 50 ft./min. results from the steady flow at 30 m.p.h. up a slope which rises 5,000 ft. in 50 miles, it is difficult to imagine that purely topographical effects can account for much of the uplift of over 4,000 ft./min. which was experienced. It seems therefore that a large up-current over 4 miles wide within the cumulonimbus was responsible for the forced ascent.

All factors in this situation combined to produce severe activity over the upper reaches of the Rhône valley and we have, in this relatively small area, the rather unusual combination of a jet stream with severe thunderstorms with heavy hail, very severe turbulence, heavy icing and strong smooth up-currents.

Discussion of the Elizabethan case in relation to existing literature.—

Capt. Marks reported the hail which damaged his aircraft to be the size of small eggs.

The most comprehensive literature on the subject of hail damage to aircraft is contained in a publication by Souter and Emerson¹, which includes a summary of hail literature and the effect of hail on aircraft in flight. This is undoubtedly the document which should be studied by anyone interested in

this subject. There is an analysis of 131 cases of hail damage to aircraft together with a comprehensive series of photographs.

When the Elizabethan encountered the hail at 450 mb. originally, the true air speed was 200 kt. rising to 280 kt. during the forced ascent of 4,000 ft. If we take a mean true air speed of 250 kt. during the encounter and taking into account the thickness of the surfaces damaged and the experimental evidence given in the United States report, we arrive at a hailstone diameter of about 1.6 in. which agrees well with the estimated size of "small eggs" reported by Capt. Marks.

The outside air temperature reported also indicates that the aircraft must have been caught in a rising bubble of air warmer than the general surroundings. The outside air temperature which might have been expected would have been about -16°C . and the height above mean sea level 21,280 ft. Freezing level was about 14,000 ft.

Only one case can be found in the literature where severe hail (1.6 in. ± 0.2) was encountered higher than this. This was on June 17, 1948, in a thunderstorm in Nebraska at 25,000 ft. and at a temperature of -28°C .

In a review of hailstone sizes in the central U.S.A., the United Air Transport Corporation Inc.,² found that hailstones over 1 in. in diameter only occur in about 1 out of 800 thunderstorms.

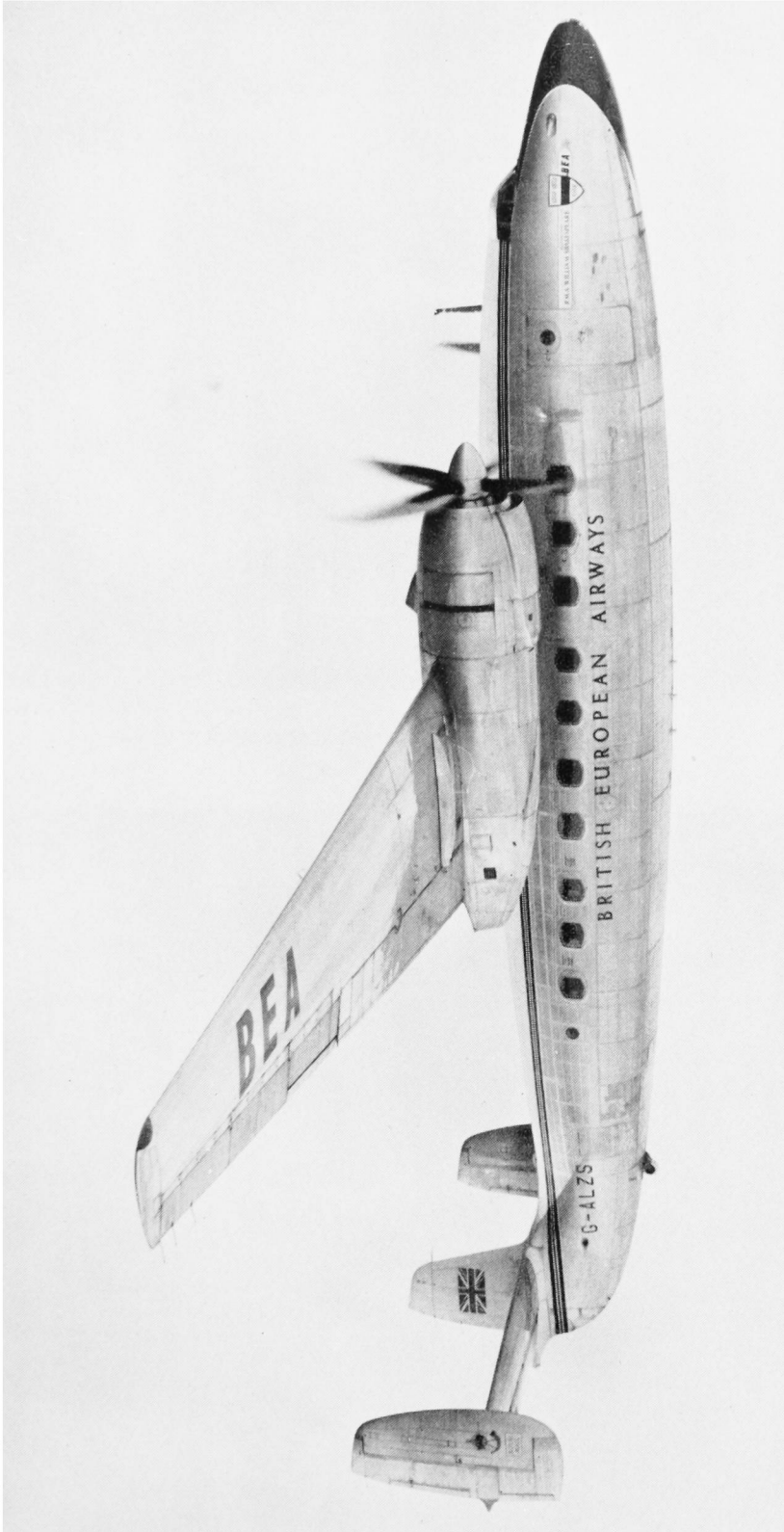
Very little data are available on the distribution of hail in the vertical. The Thunderstorm Project³, although not carried out in areas of maximum hail occurrence, presents some facts. During 511 cloud traverses in thunderstorms or potential thunderstorms over Florida in 1946 hail was reported in 4 per cent. of the cases. In Ohio in 1947 in 812 traverses hail was reported in 6 per cent. of the cases. Hail was encountered most often at 16,000 ft. over Florida and at 10,000 ft. over Ohio. It appears that the region of hail in any storm and the duration of hail in that region are relatively small.

Generally it appears that hail occurs in very narrow bands within thunderstorm clouds and occurs less frequently above 20,000 ft. In fact in these 1,333 traverses no heavy hail was ever encountered at 20,000 ft. or above.

Souter and Emerson, on the basis of all the evidence available, state that the largest hailstones likely to be encountered in flight would be about 2 in. in diameter.

Studies were conducted to ascertain the weather factors associated with hail encountered by aircraft. The thunderstorms associated with the American encounters were classified as to type; cold front, warm front, or air mass. Of the cases of severe hail encountered 59 per cent. could be attributed to cold-front action, 28 per cent. to air-mass activity, the remaining 13 per cent. to warm-front thunderstorms. This analysis will not be strictly applicable to Europe but it would indicate that pilots should be particularly cautious when flying in or near cold-front thunderstorms, particularly in the summer months. The Rhône-valley thunderstorm which we are discussing comes into this category.

In all the American cases investigated when severe hail was encountered a thunderstorm was present or in the vicinity.



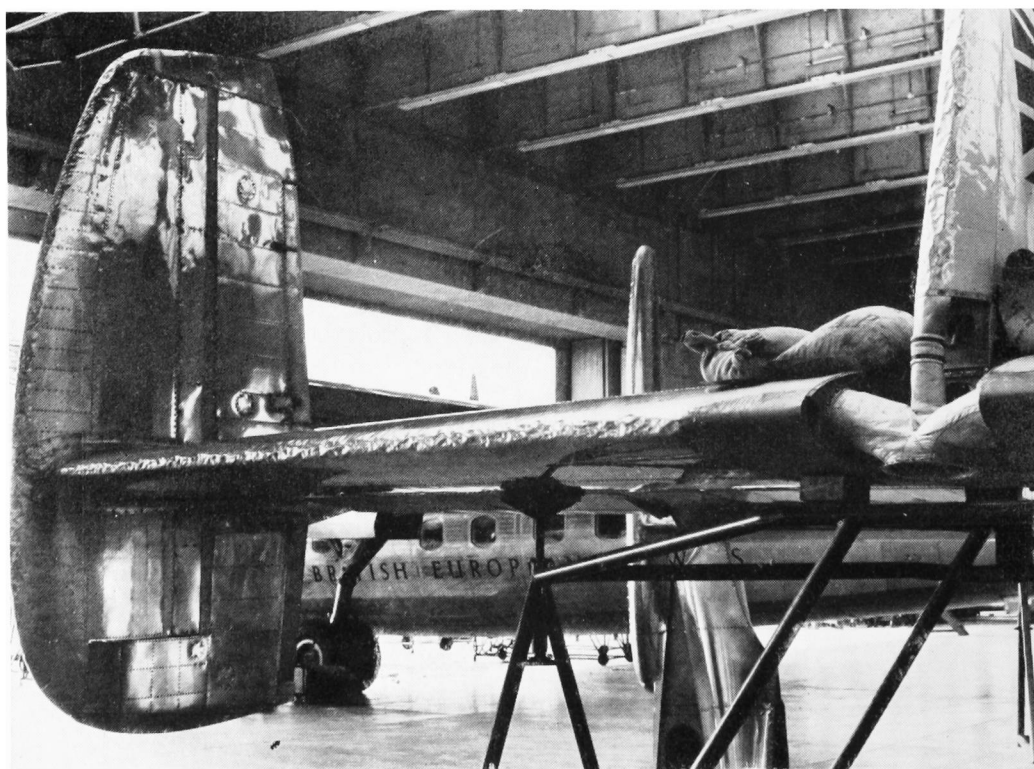
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ELIZABETHAN AIRCRAFT IN FLIGHT
(see p. 330)



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DAMAGE TO NOSE OF AIRCRAFT



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DAMAGE TO LEADING EDGES OF TAILPLANE, CENTRAL FIN AND STARBOARD FIN
(see p. 332)



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DAMAGE TO PROPELLER SPINNERS
(see p. 332)



Photo by R.A.F.

WATERSPOUT SEEN OFF THE STRAITS OF GIBRALTAR, NOVEMBER 21, 1955
1150 G.M.T.
(see p. 321)



Photo by R.A.F.



Photo by R.A.F.

WATERSPOUTS SEEN OFF THE STRAITS OF GIBRALTAR, NOVEMBER 21, 1955

(see p. 321)

Souter and Emerson, give much useful advice on the general features in relation to hail, airline operation and hail and the question of forecasting this phenomenon.

Frost⁴ reports little difficulty from hail encounters during flights through cumulus and cumulonimbus cloud over Malaya although an up-draught of 53 ft./sec. was recorded on one occasion.

In a review by Browne, Palmer and Wormell⁵, it is mentioned that Weickmann suggests an approximate formula for the terminal velocity of hailstones; $V = 200 D^{\frac{1}{2}}$ where V is in cm./sec. at ground level and D is the diameter in mm. Allowing for the necessary change in V with increase in height, at 20,000 ft. in an up-draught of 66 ft./sec. measured by the Elizabethan aircraft this would give a size of stone of average density, which could be supported, of 1.7 in. diameter.

According to Gaviola and Fuertes⁶, in the Rhône-valley cumulonimbus, which may have extended to over 30,000 ft. the free fall of a particle from the upper layers, could produce hailstones up to the suggested diameter of 1.6 in. by the time it reached 21,000 ft.

In addition to the literature quoted, there are included in the Bibliography further references⁷⁻¹⁶ to some works of interest to those who wish to pursue this subject which is of increasing concern to commercial aviation as major structural damage can be caused by brief encounters with large hailstones. Nearly all external components of an aircraft, especially the nose section and leading edges, are subject to damage and encounters with hail lasting only 10 to 30 sec. have caused damage severe enough to warrant scrapping very expensive aircraft. Wind-screens may be shattered completely by hail and this is particularly dangerous in that explosive decompression may take place in high-flying pressurized aircraft.

Conclusions.—From experience of forecasting for the Rhône-valley area it is suggested that the frequency of the occurrences of hazardous thundery conditions is greater in this area than in the area of the U.S.A. dealt with in The Thunderstorm Project and in the United Air Lines report on thunderstorms and it is considered that in similar synoptic situations the occurrences might be frequent.

One of the findings of The Thunderstorm Project was that "in general, the worst conditions were encountered at the altitude at which modern airplanes with supercharged cabins are most frequently flown". Until airborne radar is installed as a means of picking a safe path between thunderstorm cells, it is important that the forecaster should be aware that the forecast of an area of thunder activity will seldom cause a pilot to alter his planned route and flight altitude drastically, and that only by emphasis of the hazards, when necessary, can he contribute towards the safety of the intended flight.

Acknowledgement.—We wish to thank British European Airways for permission to include in this report details of this incident and for supplying and giving permission for the publication of the photographs.

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METEOROLOGICAL RESEARCH COMMITTEE

At the 38th meeting of the Physical Sub-Committee held on July 10, 1956, the first three papers considered were from the Meteorological Research Flight. The frost-point observations, obtained to heights of about 50,000 ft. by the Canberra aircraft during 1955¹ broadly confirm those obtained in 1954 and show that frost-point tends to a constant value of about -117°F. (-83°C.) at about 50,000 ft. It is proposed to obtain corresponding observations at considerable distances to north and south of the British Isles, but it is to be hoped that other countries will undertake similar high-altitude exploration in meteorological régimes differing from those normally experienced in the British Isles. Mr. G. J. Day summarized the report² on the main features of the instrumental and other observations obtained during a series of flights through large cumuliform clouds on nine occasions in 1953. There was discussion on the representativeness of the data presented on cloud-droplet size and on the significance of the model proposed for the distribution of the liquid-water content within the type of cloud examined. Mr. W. G. Durbin presented his analysis³ of droplet samplings made in cumulus cloud on ten occasions in 1951. An interesting point is that the constants in A. C. Best's expression for the relation between liquid-water content and droplet-size distribution appear to depend on the maximum droplet diameter present. Mr. B. C. V. Oddie said that the value of visibility in cloud as calculated from the droplet-size

distributions presented in the paper markedly exceeds the observed visibility at the lowest (and presumably more accurate) observed visibilities. A similar discrepancy was noted by Mr. Day. Dr. Best suggested that the discrepancy might be due in part to non-allowance for the effect of variation, with visibility, of the threshold contrast of the human eye. Mr. W. G. Harper⁴ described the quantitative use of 3-cm. radar at East Hill in the study of rainfall. In the work cited it was found that on occasions of widespread moderate rain there is little vertical variation in the drop-size distribution in precipitation below the level at which snow-flakes have melted and achieved their terminal velocity. This is contrary to the conclusions, from computations, of some other workers that growth of drops should occur in cloud below the melting level and below the cloud. A deduction in the paper is that below a warm front the cloud below the melting point level is thin i.e. of small liquid water content. In the discussion it was accepted that there are still uncertainties in the use of radar for the absolute measurement of rainfall. It is hoped to obtain more information on this point from radar observations on rain falling into a network of recording rain-gauges at Cardington. The Sub-Committee also discussed proposals concerned with cloud seeding and a suggestion that chemical sampling of air and rain-water should be undertaken at additional stations in the United Kingdom.

The 40th meeting of the Synoptic and Dynamical Sub-Committee was held in the Napier Shaw Laboratory, Meteorological Office, Dunstable, on July 19, 1956. After corporate consideration of three scientific papers, members of the Sub-Committee discussed work in progress with members of the Forecast Research Division and visited other Departments of the establishment at Dunstable. The most interesting preliminary study by Mr. G. A. Corby⁵ of the evidence, obtained from the data of routine radio-sonde—radar wind soundings, of the occurrence of atmospheric waves generated by the effects of mountains on air flow was warmly welcomed. Some of the deductions from the data considered confirm conclusions from perturbation theory. There was discussion on the possibility of modifying the rate of ascent or the drag of the balloon assemblage to achieve greater accuracy in the determination of wave amplitude on investigation of the extent of the waves across wind and on the application of deductions from radio-sonde data to operational forecasting. Mr. F. H. Bushby then described further trials in the Meteorological Office on the objective analysis of pressure-contour charts for 500 mb. with the aid of an electronic computer⁶, with the aim of preparing charts (much more quickly and with no less accuracy than by conventional analysis) for use in the production of forecast charts by the process of numerical integration. The Sub-Committee concluded that the technique used was well justified and suggested that effects of variation of density of observations in the area of interest (e.g., as between the Atlantic and Europe) might be further examined. The paper presented by Mr. P. Graystone⁷ dealt with a statistical method for the fairly rapid computation of the frequency distribution of equivalent headwinds on variable flight tracks, from knowledge of mean vector wind and standard vector deviation. Illustrations were given for the London to New York route, comparing the merits of two, and three tracks. In the discussion, it became evident that the procedure described in the paper will be valuable in civil aviation planning and the adaptation of the method to machine computation was suggested.

ABSTRACTS

1. HELLIWELL, N. C.; MACKENZIE, J. K. and KERLEY, M. J., Further observations of humidity up to 50,000 feet made from an aircraft of the Meteorological Research Flight in 1955. *Met. Res. Pap., London*, No. 976, S.C. III/205, 1956.

In continuation of M.R.P. 877, 1954, observations, with a pressurized frost-point hygrometer and flat-plate thermometer around and over the British Isles, are tabulated for 45 occasions, 5,000–50,000 ft. Means and standard deviations are given for 1954 and 1955. The mean frost point decreases about $3\frac{1}{2}^{\circ}\text{F.}/1,000$ ft. from 20,000 to 40,000 ft. and then more slowly to approach -117°F. at 50,000 ft. With a high tropopause frost point is generally lower than with a low tropopause.

2. DAY, G. J., Further observations of large cumuliform clouds by the Meteorological Research Flight. *Met. Res. Pap., London*, No. 980, S.C. III/207, 1956.

A number of observations in flights through upper parts of cumulus clouds are tabulated (maximum and mean water content, icing, height, temperature, excess temperature in cloud, and turbulence). Cells were about $2\frac{1}{2}$ miles across, with cloud asymmetric around them. Life cycle of a cell was 20–25 min. The structure accords with the bubble theory; interaction with environment is weak, with little entrainment. Droplet size was 40μ at first, increasing to 120μ ; the suggested rain-producing mechanism is Bergeron below 10°F. , coalescence above 20°F. , and a combination in 10 – 20°F. Vertical motion, turbulence, water content, temperature and electrical activity are also dealt with in this exhaustive discussion.

3. DURBIN, W. G., Droplet sampling in cumulus clouds. *Met. Res. Pap., London*, No. 991, S.C. III/211, 1956.

Samples of droplets obtained by aircraft impactor were analysed photographically. Results are tabulated in full. Clouds 750–2,500 ft. and 3,850–7,000 ft. thick are discussed separately. The droplet sizes were arranged in 10 categories ($5\cdot28$ – 119μ). There was great variation in range of drop diameters in different flights, but mode was $7\frac{1}{2}$ – 9μ with in some cases a secondary maximum at 15μ . The water content of the different categories is examined in detail. It tends to increase with height and to be larger in thicker clouds averaging $0\cdot5$ gm./m.³ below 2,500-ft. thickness, $1\cdot0$ gm./m.³ above, but up to 5 gm./m.³ content is generally below adiabatic value. Mean diameter increased from 1 – 13μ at base to 23 – 27μ at top of cloud, but no systematic variation of number of droplets (100 – $300/\text{cm}^3$) was found. B. C. V. Oddie discusses discrepancy between estimated visibility and that calculated from droplet-size distribution.

4. HARPER, W. G., Variation with height of rainfall below the melting level. *Met. Res. Pap., London*, No. 984, S.C. III/209, 1956.

Slant radar echoes at East Hill from 500–6,000 ft. (i.e. below freezing level) in widespread warm-front rain were converted to rates of rainfall. Theory and correction factors are set out. The calculated rate was only $0\cdot01$ – $0\cdot21$ of that given by the rain-gauge; the reason is discussed and a factor $0\cdot2$ is applied. No trend towards increase or decrease of rainfall with height was found; this suggests that cloud-water below freezing level was much less than $0\cdot2$ gm./m.³.

5. CORBY, G. A., A preliminary study of atmospheric waves using radio-sonde data. *Met. Res. Pap., London*, No. 985, S.C. II/211, 1956.

Rates of radio-sonde ascents at Leuchars, Stornoway, Aldergrove and Liverpool, November 1953–April 1954 were computed and variations exceeding 300 ft./min. plotted against height. On 48 occasions (27 at Leuchars), of which 34 were at 1400 G.M.T. and 14 at 0200 G.M.T. these showed a pattern of vertical currents, mostly < 500 ft./min. but one $> 1,000$ ft./min. The amplitude was generally greatest at 5,000–10,000 ft. The associated wind speed and direction (mostly over high ground) at 900 mb. are shown. The wave-length was $2\cdot6$ – $14\cdot4$ miles, average 6–7 miles. The distortion of the temperature structure is discussed. An appendix assesses the errors in evaluating the rate of ascent.

6. BUSHBY, F. H., The objective analysis of some 500-mb. charts. *Met. Res. Pap., London*, No. 986, S.C. II/212, 1956.

An experiment was made in analysing the 500-mb. field by electronic computer direct from the observed 500-mb. heights or winds, as a basis for time integration. The method is to find the quadratic or cubic surface which best fits the observations. Three situations were analysed (N. Atlantic and W. Europe). It appears that the objective technique can produce sufficiently smooth and accurate results more quickly than manual plotting; the quadratic surface is considered better than the cubic.

7. GRAYSTONE, P., Equivalent head-wind statistics for variable tracks. *Met. Res. Pap., London*, No. 987, S.C. II/213, 1956.

For practical reasons aircraft must fly the most favourable of several tracks from the point of view of headwinds, instead of the actual minimal track. A statistical method is given for rapid computation of the frequency distribution of equivalent headwinds along two or three alternative tracks in temperate latitudes, and so assessing the relative merits of the different tracks. The frequency distribution is computed for three routes London–New York. Errors of wind prediction are not considered.

ROYAL METEOROLOGICAL SOCIETY

At the meeting of the Society held on May 16, 1956, the President Dr. R. C. Sutcliffe in the Chair, papers were read on local temperature variation in the Reading area, the temperature profile above bare soil on clear nights and on the space and time distribution of showers in a tropical region.

*Parry, M.—Local temperature variations in the Reading area**

The first paper was read by Dr. Parry and gave a comparison of temperature observed at twelve stations in Reading and the surrounding rural areas at heights ranging from 120 to 200 ft. above mean sea level. Mean temperatures showed the urban heating effect to amount to about $\frac{1}{2}^{\circ}\text{F}$. Maximum temperatures varied very little. Minimum temperatures showed two distinct patterns of distribution, one associated with cloudy disturbed weather and another with anti-cyclonic weather. On nights with the first kind of weather there was little variation. On most clear quiet nights there was an inversion giving minimum temperature differences of up to 8° between the high- and low-level rural stations but in the centre of Reading the inversion usually did not exist. Some radiation nights which gave no inversion were probably nights of deep inversion undetected because of the lack of stations high enough up on the Chilterns.

Curves of minimum temperature differences for specified wind forces show that a force 4 wind and sometimes even a force 3 wind can entirely destroy the urban warming effect.

Lake, J. V.—The temperature profile above bare soil on clear nights.†

Dr. J. V. Lake described observations of the temperature profile over bare earth on radiation nights made with thermistors and spirit-in-glass minimum thermometers at heights of 0.0, 0.1, 0.5, 1.5, 2.5, 3.5 and 54.0 in. The observations were made under very calm conditions over level ground at a distance of 120 yd. from the nearest boundary. The striking result was the existence of a very steep fall of temperature, of the same order of magnitude as that occurring on sunny days between the surface and heights ranging between 2.5 and 6.0 in. At greater heights temperature increased with height. On one occasion the temperature fell from 18.6°F . at 0.1 in. to 16.6°F . at 1.5 in. increasing to 16.8°F . at 3.5 in. Such a difference corresponds to a lapse rate about 2,000 times the dry adiabatic value and 800 times the auto-convective value. Analysis of the time variation of the lowest value showed the fall was closely proportional to the square root of the time as is to be expected from Brunt's theory of the fall of surface temperature on clear nights which is based on a balance between outgoing radiation and upward conduction of heat in the soil neglecting any contribution of heat from the air. Such a temperature profile had been reported before by several workers but had not hitherto been regarded as a normal feature. The results, said Dr. Lake, showed the air must lose heat on a clear night by some mechanism other than convection and conduction to the surface and he suggested that the explanation lay in radiation. On the question of radiative heating and cooling of the layers concerned Dr. Robinson showed that heating at the rate of about 1°C./hr . could occur by radiative effects but he was doubtful about the development and persistence of a sharp lapse rate because of the unstable nature of the stratification. Dr. Monteith said he had observed a lapse rate developing over grass at a rate approaching 1°C./min .

Soane, C. M. and Miles, V. G.—On the space and time distribution of showers in a tropical region.‡

The third paper, by two members of the staff of the Rhodesian Meteorological Service, was read by Dr. A. G. Forsdyke. It described radar observations of the movement of rain showers near Salisbury, Southern Rhodesia. The authors found that the majority of echoes occurred in groups, called progressives, in elongated areas which moved at right angles to the length. Individual echoes lasted for about an hour and new ones continually formed in the moving area. Occasionally isolated echo points formed. No connexion could be established between the movement of a progression and the upper wind, in fact on one occasion two progressions moved towards each other in opposite directions. Since the published paper was written, however, the authors had obtained evidence that the progressions tended to move with the wind at 10,000 ft. With the approach of a progression the surface wind changed to blow from the approaching rain and minor cold-front phenomena occurred at the passage of the group. No conclusive evidence of the mechanism of the group was found.

There was a short Special General Meeting of the Society on June 20, 1956, to elect officers for the coming year. At the Ordinary Meeting which followed, with the President, Dr. Sutcliffe,

* *Quart. J. R. met. Soc., London*, **82**, 1956, p. 45.

† *Quart. J. R. met. Soc., London*, **82**, 1956, p. 187.

‡ *Quart. J. R. met. Soc., London*, **81**, 1955, p. 440.

in the Chair, it was announced that the first winner of the Napier Shaw Memorial Prize, on this occasion for an original essay on "The energetics of the general circulation", would be Dr. N. A. Phillips of the Institute for Advanced Study, Princeton. Dr. Phillips then read his paper.

*Phillips, N. A.—The general circulation of the atmosphere: a numerical experiment.**

In the past, experiments with a rotating fluid heated differentially in a cylinder or ring have shown flow patterns very similar to those encountered on weather maps. Dr. Phillips's paper attempts the same sort of experiment for the atmosphere using similar calculations with the same quasi-geostrophic equations as those used in numerical forecasting. To make his equations tractable at the two working levels of 250 and 750 mb. Dr. Phillips makes the following assumptions among others: the working area is rectangular, 6,000 Km. from east to west and 10,000 Km. from north to south; the Coriolis parameter is constant over the whole area; there is cyclic continuity, i.e. the motion is the same in an infinite number of exactly similar rectangular regions placed side by side; the north and south walls have the properties that at them there is no change in horizontal vorticity and no normal geostrophic motion; the atmosphere is heated non-adiabatically with a linear variation from south to north, being zero in middle latitudes; and the thermal stability, defined as the difference of potential temperatures at 250 and 750 mb. divided by the potential temperature at 500 mb. is constant. Surface friction was allowed for. The calculations are made by finite-difference methods using an electronic computer, the grid intervals being 375 Km. longitudinally and 625 Km. latitudinally.

Starting with the atmosphere at rest with uniform initial temperature and assuming there are no changes longitudinally, integration at intervals of a day produced after a 4-month season of 130 days a nearly uniform temperature gradient from north to south, a zonal easterly surface wind about 1 m./sec., a broad westerly stream at 250 mb. with a maximum of 36.3 m./sec. in middle latitudes and a minute southerly drift of about 0.3 m./sec. in most latitudes at 250 mb. A random disturbance (with root-mean-square velocity 8.8 m./sec.) was then imposed identically at 750 and 250 mb. and the subsequent motion calculated in 2-hr. steps. After 5 days the main features of the flow were a high and a large central low moving eastwards at 1,800 Km./day and having many of the features such as jet streams and V-shaped troughs typical of reality. After 26 days truncation errors, inherent in finite-difference calculations, vitiated any further progress—the resultant motion then being unreal.

Prof. Sheppard, among other questions, asked if it would not have been better to start from some real atmospheric situation rather than from rest. Dr. Phillips said that Dr. Charney had suggested starting from a sinusoidal motion but it was thought to be artificial. Dr. Eady thought that starting from a given real situation would not show much; it was desirable not merely to get the answer right but also to find out how the atmosphere works and therefore it was right to start from rest. It was difficult in meteorology to perform a laboratory experiment in which to separate the wood from the trees.

Dr. Scorer asked why the situation produced by the truncation errors which terminated the experiment could not be treated as another random disturbance. Dr. Phillips said that although the field of flow at the end looked random presumably it was not random. Mr. Sawyer drew attention to the calculated meandering jet stream and the "subtropical" jet stream. Although sharp troughs had been produced he had not noticed the corresponding sharp ridges and thought this might be explained by the cross-isobar flow at the surface due to friction. Dr. Phillips pointed out that the equations were symmetrical and demonstrated by reversing one of the slides that the ridges were just as sharp as the troughs. Dr. Sutcliffe did not find the preliminary calculations very exciting because of the insistence on uniform winds; he also thought it hardly fair to base the general circulation on one high and one low. He wondered too if the heating and friction terms really contributed anything to the solution; would not a similar flow equally result from a disturbance of merely zonal flow? Dr. Phillips stressed that if there was an initial flow pattern there was always a doubt that the derived theory might be biased. Friction had an effect on the momentum process at the ground. Dr. Forsdyke and Mr. Mason wondered if some of the short-comings of the solution might not be accounted for by latent heat but Dr. Phillips did not hold out much hope of taking a latent-heat term into his equations.

LETTER TO THE EDITOR

Night cooling under clear skies

Using a relationship between T_r and T_{min} (T_r being the temperature at the time of the evening discontinuity and T_{min} the minimum temperature during the following hours) to predict the lowest minimum temperature possible at a given place, W. E. Saunders¹ gives 16° or 17°F. for Northolt in the absence of snow-cover. W. E. Richardson² gives about 15°F. for Alston, and later³ appears

* *Quart. J. R. met. Soc., London*, 82, 1956, p. 123.

to imply that this figure is likely to apply anywhere in the British Isles without snow-cover. Dr. J. Glasspoole is cited as having corroborated this during recent severe spells. However, I found it difficult to accept this limit without further evidence. Investigation of the records at Wrexham nevertheless failed to provide evidence to the contrary; but this was not unexpected, as the severe spells under consideration are so often accompanied by snow-cover, as even a light snowfall will persist night and day. In the meantime Mr. E. L. Hawke was kindly investigating the Rickmansworth records for 1930-44 and he found 13 minima of 12°F. or below, all in the complete absence of snow-cover. The lowest was 7°F. and the investigation was such that the list was not guaranteed complete. The site at Rickmansworth was in a notable frost-hollow, but it would appear that the possibilities of Alston, in an elevated valley, are not much inferior. However I sought information elsewhere and referred to the *Monthly weather report*, and chose, more or less at random, a cold month, February 1929. Daily values of snow-cover are not given in the report, but I found about a dozen stations at which there was no snow lying at the morning observation at any time during the month, which would imply that none had lain during the night either. Of these, seven, including Bournemouth, gave at least one minimum below 15°F. , the lowest being 10°F. The report does not enable one to say how many further minima below 15°F. occurred at these, or at other stations during that month.

This evidence, all from standard instruments and nearly all of it from official records, makes it clear that it is quite wrong to suppose that the lowest possible minimum without snow-cover is about 15°F. It would appear that evaluation of this figure has been based on an over-simplification of the relationship between T_r and T_{min} (see Saunders¹, p. 610-11) and on a too bold extrapolation on a graph containing rather too few points (see Richardson², p. 303).

11 *Percy Road, Wrexham, North Wales, June 10, 1956.*

S. E. ASHMORE

[The implication that the graphs in my recent contribution² suggested that an air minimum below 15°F. might be impossible if snow cover was absent was intended to be provoking rather than conclusive. I am very grateful therefore to S. E. Ashmore for the information forwarded. However, it would appear worthwhile to point out that the fault in the suggestion was not so much the result of an over-simplification of the relationship between T_r and T_{min} and the extrapolation which followed, as a wrong interpretation of the graph itself. It was suggested by my graphs that around 15°F. T_r and T_{min} were about equal, but as S. E. Ashmore has pointed out in private correspondence there is no reason why T_r itself cannot be less than 15°F. Nevertheless to achieve T_r below 15°F. demands conditions which must be quite rare. For example, by using Saunders' formula. to gain the 7°F. of the Rickmansworth record an afternoon maximum of 21°F. with 11°F. dew point would give the required minimum if a constant of -9°F. were used. This is approximately the constant for Alston when inversions occur below the 850-mb. level, so that these extremes are still consistent with Saunders' work.

S. E. Ashmore's letter concludes discussion of the point that temperatures below 15°F. are impossible without snow-cover, for he has shown that records of the phenomena do exist. However, this does not prove that the "fall-away" shown in the Alston graphs² is faulty. He may be correct in his censure of the

bold extrapolation but not only do the curve fittings for the observations to date seem justified, but the "fall-away" is consistent with the physics of thermal conductivity without snow-cover. Alston is the only station which has contributed sufficient snow observations to use for this problem, and the possibility of two separate curves for the different snow conditions is a necessary extension of the research into night cooling if a minimum forecast system is to be complete.

W. E. RICHARDSON.]

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NOTES AND NEWS

Damaging hailstorms

Hailstorms reported to have caused damage or sufficiently severe to be likely to have caused damage to crops or glass-houses, and which were mentioned in the various volumes of *British Rainfall* and the *Meteorological Magazine*, for the years 1906 to 1955, have been listed under calendar days. The total number of occasions for the 50 years was 169 and the monthly distribution is given in Table I.

TABLE I—DAYS WITH DAMAGING HAILSTORMS IN ENGLAND, SCOTLAND AND WALES,
1906–55

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
No. of days	2	2	1	9	25*	44	41	25	14	4	2	0	169

* 10 of the 25 days for May fell in the last week, 25th–31st.

The type of damage was also noted and of those storms listed as causing severe damage, the majority occurred during the three months May to July, on 14 days in May, 20 in June and 28 in July.

Under the classification using calendar days, storms as far apart as Devonshire and Ayrshire were credited to the one occasion since they occurred on the same day and were associated with the same unstable airstream. A further grouping was made of the location of the storms by listing them under counties, but the number per county depends on three factors, the county area, the efficiency of reporting and the extent to which damage was possible—a hailstorm in the Peak District or on Salisbury Plain, however severe, might not do any damage. This last factor is largely eliminated since the investigation is concerned with damaging hailstorms. With regard to the second factor, efficiency of reporting, we can only accept the data now available, based on accounts from rainfall and climatological observers and on newspaper reports, the amount of information depending on the interest of the observers, the network of stations and the news value of a storm. The variations in county areas were compensated by computing the frequency of hailstorms per 100 square miles.

The distribution of damaging hailstorms per 100 years per 100 square miles, on a county basis, is shown in Fig. 1. The frequencies are clearly greatest in

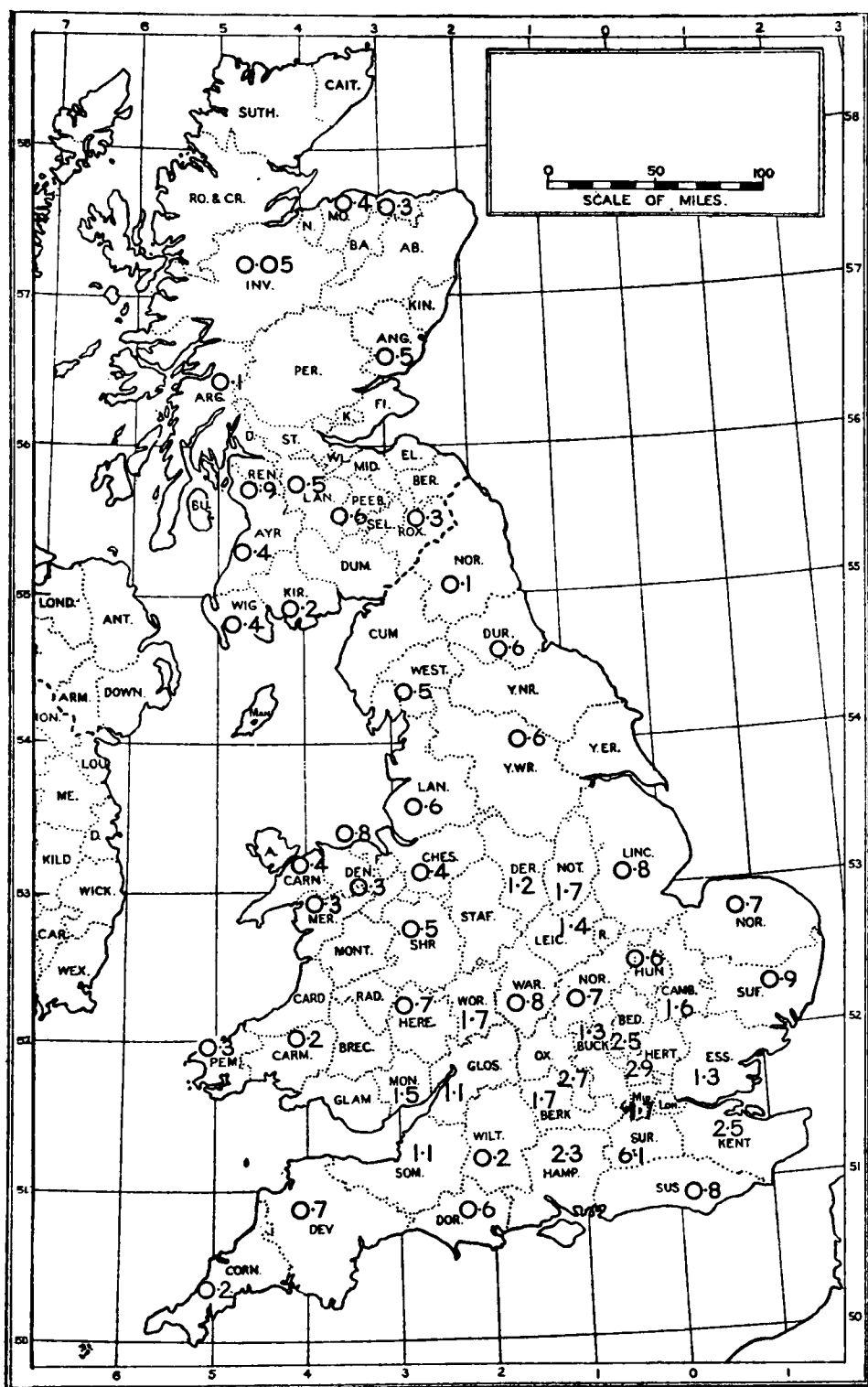


FIG. 1—DISTRIBUTION OF DAMAGING HAILSTORMS PER 100 YR. PER 100 SQ. MILES the Home Counties and in Hampshire, Bedfordshire, Oxfordshire and Cambridgeshire; the Buckinghamshire value seems too small; the Oxfordshire value may be too big. The high frequencies for London and Middlesex and for Surrey are probably a result of exaggerated reports, but on the other hand a damaging

type of hailstorm over these two counties could hardly fail to find a target of gardens, glass-houses and lights. Two other areas of secondary maxima are in the north-east Midlands and over the lower valley of the Severn and around the Bristol Channel.

Allowing for the fact that not every hailstorm which has caused severe damage has been recorded, the risk of any place being extensively damaged twice in a lifetime is small but since in 1955 the damage on one farm alone was reported to be £15,000, this is small consolation to the victims.

E. H. ROWSELL

High-level icing

A case of clear-air icing at low temperatures has been reported by Sqd.-Ldr C. B. Owen, D.S.O., D.F.C., A.F.C., who is on a conversion course at the R.A.F. station, Bassingbourn, Hertfordshire. The aircraft concerned was a Canberra and the icing occurred at approximately 1030 G.M.T. on December 6, 1955.

Sqd.-Ldr Owen reports that he was climbing on a heading of 290° from Bassingbourn, and the icing was first noticed on the front of the canopy near the top of the climb between 35,000 and 40,000 ft. At 40,000 ft. the aircraft levelled out and made a high-speed run on a northerly heading changing to a south-easterly heading. During the northerly run the ice on the canopy thickened appreciably, became thick enough to obscure visibility and persisted on the south-easterly run. Sqd.-Ldr Owen states that the ice was confined to the front of the canopy, and that the sides of the canopy remained completely clear. The icing disappeared during a maximum-rate descent and had all gone by the time the aircraft was down to 25,000 ft. All told the icing lasted for about 10 min.

At the time of the occurrence a cold front lay west to east across Scotland with broad westerly warm-sector conditions over England and Wales. The afternoon ascents from Hemsby, Crawley and Shoeburyness are probably most representative of the air in which the icing occurred, and detailed temperatures are given in Table I.

TABLE I—UPPER AIR TEMPERATURES REPRESENTATIVE OF AIR IN WHICH ICING OCCURRED

	Liverpool		Crawley		Hemsby		Shoebury- ness
	0200 G.M.T.	1400 G.M.T.	0200 G.M.T.	1400 G.M.T.	0200 G.M.T.	1400 G.M.T.	1400 G.M.T.
ft.	Tropopause						
°C.	42,000 -68	39,000 -63	44,000 -69	44,000 -68	44,000 -68	41,000 -63	42,000 -70
ft.	degrees Celsius						
40,000	-63	-63	-63	-63	-61	-61	-66
35,000	-52	-54	-50	-52	-51	-51	-54
25,000	-28	-28	-26	-27	-28	-28	-28

Although temperatures were generally low at 40,000 ft., there was a difference of 5°-7°C. between Hemsby and Shoeburyness from 36,000 to 42,000 ft. with Hemsby the warmer.

In the *Meteorological Magazine* for September 1954 Mr. G. W. Hurst has put forward an explanation of a case of clear-air icing. The Hemsby-Shoeburyness temperature gradient and the increase of ice on the northerly run

are consistent with this explanation. What is more interesting, is that the ice first formed when the aircraft was climbing from warmer air to colder air.

W. B. PAINTING

[Mr. R. F. Jones points out that the high speed and low temperature at which the ice formation on the canopy reported by Sqd.-Ldr Owen occurred make it improbable that the formation can be ascribed to either impact and freezing of supercooled water droplets or to hoar frost. Mr. Jones considers it significant that many of the icing encounters at low temperatures report icing on the canopy only. He suggests that the aircraft reporting ice accretion at very low temperatures were, in fact, flying in thin cirrus—it is known from the experiences of the Meteorological Research Flight that it is very difficult to distinguish when an aircraft is in thin cirrus—and that the canopy, which is made of insulating material, is frictionally charged so that the ice crystals striking the canopy are held to it by electric force.

In this connexion it is noteworthy that Norinder and Siksna^{1,2} in their papers on the electrification of snow found that an air blast containing snow crystals produced a positive charge on a plexiglas surface.

The canopy of the Canberra aircraft is made of polymethylmethacrylate and we are informed by the Government Chemist's Department that plexiglas (which is the United States term for "perspex") is a plastic of the methacrylate class.

Mr. R. Davis, Electricity Division, National Physical Laboratory informs us that the Aerodynamics Division, N.P.L. have experienced trouble, attributed to electrification, with perspex in wind tunnels.

Norinda and Siksna found the snow crystals carried away after impact to be positively charged. Chalmers³ found the friction of ice on ice in absence of an air blast gives rise to a negative charge on the ice which agrees with the ice-friction theory of Simpson and Scrase⁴ for the upper electric dipole of the thundercloud. Possibly the ice crystals striking the canopy were, if the electrical explanation is correct, already negatively charged and the adhesion between the negatively charged crystals and the positively charged canopy is responsible for the phenomenon.

Ed., M.M.]

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REVIEWS

Theoretical Hydromechanics. Pt. I, 5th edn. In Russian. By N. J. Kotschin, I. A. Kibel and N. W. Rose. 8½ in. × 5½ in., pp. 560, *Illus.*, Gos. Izdat. Tekh-Teoret. Lit., Moscow, 1955. Price: 11 roubles 70 kopecks.

The German translation by J. Sauer of the 4th edn of this book was reviewed by Sir Graham Sutton in the January 1955 number of the *Meteorological Magazine*.

We have now received from the authors a copy of the 5th edn. A number of additions have been made to the text and two of them are of meteorological interest. The first is an account of Dorodnitsyn's theory of the flow of a compressible fluid over infinitely long ridges at right angles to the wind, neglecting the rotation of the Earth. This has hitherto not, so far as the writer knows, been available in Great Britain. It is similar to Scorer's theory with the important difference that the wind is taken as constant with height. The boundary conditions of flow over an arbitrary surface are set up and elaborate formal solutions given. The description would have been greatly improved and comparison with British work facilitated if diagrams of the flow over ridges of definite shape had been included. The second is an account of Blinova's theory of the mean distribution of pressure at the earth's surface as a function of temperature, described as a theory of the "Centres of action", Icelandic low pressure, etc. Here again we have an elaborate formal theory lacking entirely in vividness by the absence of any diagrams or tables of numerical values to show how theory corresponds with fact.

G. A. BULL

Atmospheric pollution: its origins and prevention. 2nd edn. By A. R. Meetham, 8½ in. × 5½ in., pp. x + 304, *Illus.*, Pergamon Press Ltd., London and New York, 1956. Price: 63s.

The fact that this book, which first appeared in 1952, should qualify for its second edition within four years is remarkable testimony to the growing awareness of atmospheric pollution as a problem which can and must be controlled. The author may also claim that the book is meeting successfully his main objective in writing it—to provide a comprehensive technical account of air pollution, with particular reference to Great Britain.

In the relatively short time since publication of the first edition, much has happened in connexion with pollution both in the research field and in the readiness of our legislators to introduce measures designed to abolish or reduce the worst effects. The London smog of December 1952 resulted in the formation by the Government of a committee of inquiry to examine the nature, causes and effects of atmospheric pollution and to make recommendations. The report of this committee led to the passing of the Clean Air Act and to a number of steps initiated by local authorities to keep specified areas free from industrial smoke. On the research side technical conferences in this country, in the United States and elsewhere have helped in the pooling of information and have been productive of a wealth of new ideas. In this second edition of his book, it is clear Dr. Meetham has taken account of all this new material not only in revising the original book but also in an additional chapter which contains, among other matters, a brief discussion of pollution from nuclear reactors.

The new edition is therefore thoroughly up to date and covers a wide range—the origin and use of fuels, domestic fires and industrial furnaces, the nature of pollution, its measurement and prevention, the meteorological and health aspects, the law and its administration. Each chapter is followed by a list of references to important papers and a classified bibliography is given at the end of the book. The printing, the diagrams and the photographs are of high order.

The book is warmly recommended to all whose work has a bearing on atmospheric pollution.

P. J. MEADE

HONOURS

Awards to civil airline personnel

It was reported in the July 1955 number of the *Meteorological Magazine* that in recognition of the value of weather reports from civil aircraft on standard routes the Air Ministry had decided to institute a number of awards to civil airline pilots providing the best series of such reports.

Captains A. Caesar-Gordon and F. A. Tricklebank, both of British European Airways Corporation, are the first recipients of these awards. They were presented with brief cases by the Director of the Meteorological Office at a ceremony held by the Guild of Air Pilots and Navigators at Londonderry House on July 24, 1956. Both Captains fly Viscount aircraft to most parts of Europe.

OBITUARY

Gustav J. H. Swoboda, Ph.D.—It is with very deep regret that we learn of the death in Geneva on September 4, 1956, after an operation, of Dr. Gustav J. H. Swoboda, recently Secretary-General of the World Meteorological Organization, and famed international figure in meteorology.

Dr. Swoboda was born in Prague in 1893 and was awarded his Ph.D. there in 1920. For the next 18 years he served as chief of the forecasting services in the State Meteorological Institute in Prague. He also lectured to the Technical College in Prague on meteorology. He made numerous contributions to scientific journals, mainly on synoptic meteorology. His best known work is probably "Wellen und Wirbel an einer quasistationären Grenzfläche über Europa" which was undertaken with T. Bergeron. He subsequently completed a translation into German of Khromov's classical textbook "Einführung in die Synoptische Wetteranalyse".

Dr. Swoboda soon became associated with international meteorology. He was a member of the International Meteorological Organization Commissions for Synoptic Weather Information and for Aeronautical Meteorology. This experience together with his unusual linguistic ability and other qualifications well fitted him to succeed Dr. Cannegieter in 1938 as Chief of the Secretariat of the International Meteorological Organization which at that time had its Headquarters at De Bilt in Holland. Soon after taking up his appointment he carried out the plan already agreed by the International Committee to transfer the headquarters from De Bilt to Lausanne, Switzerland. As a consequence of this transfer Dr. Swoboda took up Swiss nationality.

After the Second World War the old I.M.O. which was a non-governmental organization composed of the Directors of the various national meteorological services, was transformed into the World Meteorological Organization, a specialized agency of the United Nations Organization, possessing official governmental status. It was natural that Dr. Swoboda should be appointed the first Secretary-General of this new organization.

For the next four and a half years Dr. Swoboda successfully guided the Organization from birth to its present maturity. In 1953 he was awarded the

Buys Ballot Medal by the Royal Netherlands Academy of Sciences. He retired as Secretary-General in August 1955 and was appointed professor of Meteorology in the Technical University of Istanbul.

Those of us who knew and worked with Dr. Swoboda will always remember those kindly and lovable personal qualities which so endeared him to all who had the privilege and pleasure to work with him. The helpful friendliness which he showed to all who sought his advice irrespective of race or nationality, and his rare charm will never be forgotten by his staff at the Secretariat who were not only his colleagues, but also his friends.

A. H. GORDON

METEOROLOGICAL OFFICE NEWS

Ocean weather ships.—The following are extracts from the Master's report of Voyage 72 of the *Weather Observer*.

There has been quite a lot of swimming and the usual whist drives, and the following classes are in progress; meteorology, radio, French, cinematograph operation, navigation, mathematics, photography and first aid. These classes are always popular in good weather.

August 7, 1956, 2100–2200. Ship's company exercised at "Night Air/Sea Rescue Drill", during which a flare path was laid, a lifebuoy dropped to represent survivors and a lifeboat recovered the "survivors". This was a very good exercise. The visibility was only 500 yd. at the time which added to the natural hazards. The lifeboat steamed down the flare path to recover the lifebuoy and used a compass on the way back. It was a pleasure to see the way in which the ship's company entered into the spirit of the exercise.

Note: During this voyage the ship's radar became defective owing to a damaged valve. A R.A.F. aircraft of Coastal Command during an air/sea rescue exercise successfully dropped a new valve in a watertight canister attached to a parachute (together with some newspapers) and the radar was soon serviceable again. This is the first time a parachute has been used for the purpose of dropping "spares" from aircraft to weather ships; if a parachute is not used the valves are invariably damaged.

WEATHER OF SEPTEMBER 1956

Mean pressures for the month showed departures up to -5 mb. in 50°N . 20°W . over the Atlantic and $+3$ to 4 mb. over eastern Europe, where a 1020-mb. anticyclone appeared near the Russo-Polish frontier. Pressure was lowest (1006 mb.) over the Atlantic south-west of Iceland. The pattern so defined differs considerably from the normal over the eastern Atlantic, where a fairly sharp trough occurred, and western Europe where there was a mean pressure gradient for rather weak southerly winds. Over north America the pattern and the pressure values were close to normal.

The September distribution also marked a radical change from August in the nearer parts of the hemisphere. As early as August 24 the anticyclone which had been prominent over Greenland began to move south-east towards Europe: this cell became stationary off Ireland about the turn of the month and depressions continued to affect Britain and central and southern Europe during the first part of September. Further anticyclonic cells moved from northern Greenland to central Europe, and two more moved east from the Atlantic. By about the middle of September slow-moving anticyclones were dominating most of Europe and continued to do so till almost the end of the month. This was the first real break in the wet weather of the summer in many parts of the region.

Temperature averages were slightly above normal for September over nearly all western and central Europe, being warmer than August 1956 in some places especially in the west. Canada and the eastern half of the United States were generally cooler than normal (anomaly -3° to -5°C . between the Great Lakes and Hudson's Bay: the axis of the cold region in terms of surface temperatures was about 80°W .).

Rainfall was below normal over the eastern half of Europe. In the western half the distribution was more patchy with over twice the normal over central France, Brittany and parts of south-west England. There was also above-normal rainfall in north-west and north-east Canada (over 400 per cent. at St. John's, Newfoundland). Most of the United States and central Canada were dry, widely scattered points having almost no rain.

In the British Isles the weather during the first 17 days of the month, apart from a few days around the 12th, was dominated by shallow depressions off the south-west coasts; the remainder

of the month was generally dry and mild, although the last four days were cooler and rather stormy.

The first week was dull and in places very wet. A shallow depression, which was situated over the Bay of Biscay on the 1st, moved slowly northward until it was centred over Cornwall on the 3rd; outbreaks of thundery rain occurred extensively in England and Wales with scattered thunderstorms; rain was heavy at times particularly in the south. On the 4th a depression from the Atlantic moved east-north-east to the Irish Sea where it became very active the following day as it was joined by a cold-front wave depression from the Bay of Biscay. Rain, heavy locally, was widespread on the 5th and 6th (2½ in. fell at Aberdeen in 24 hr.) and on the 7th showers were frequent as the depression moved eastward to the North Sea. The second week was drier though the weather remained dull. Easterly or south-easterly winds were maintained over the British Isles, with occasional slight rain or drizzle, principally in the south during the 8th and 9th by a quasi-stationary depression off the south-west coasts which later moved southwards to Madeira. On the 11th the Azores anticyclone began to spread eastwards, but there was widespread rain over the British Isles as a trough, associated with a complex depression in the region of Iceland, crossed the country. By the 13th the anticyclone from the Azores was centred over north-west France and tropical air spread over the British Isles from the south-west as a low-pressure system, which had developed from a tropical storm off the United States, approached Iceland. There were severe gales in the north of Scotland but temperatures in England exceeded 70°F. at a number of places and reached 76°F. at London Airport and Dishforth, Yorkshire. Humidities were high and fog was persistent along the eastern coasts of England and Scotland and developed at times in the English Channel. On the 14th, a depression which had been off the south-west coasts on the 8th returned to that area after an excursion in the meantime to Madeira, and for the next few days pressure remained low to the south-west and high over the north of the British Isles. Most of the third week was cloudy in the south with a little rain here and there and fog at sea, but in the north weather was mainly dry and sunny with 10 hr. of sunshine on some days in northern England and southern Scotland. Pressure was low in the eastern Atlantic from the 18th to the 23rd and winds over the country were mainly from the south or south-east. Warm air spread slowly northwards and fairly widespread morning fog became a daily feature, and there was an increasing tendency for thunderstorms. After nearly two weeks with only slight rainfall, thundery rain broke out on the 21st and continued for several days in some western districts, but weather remained mainly dry in the east and Midlands for much of the fourth week. Temperatures rose again to the middle seventies locally on the 22nd–25th and remained above 60°F. at night in many places in England and Wales on the 21st and 23rd. On the 25th fog was widespread over much of the country although parts of East Anglia remained fine and warm. Wind freshened and rain spread from the Atlantic across the British Isles on the 27th; rainfall was heavy locally with falls of more than 2 in. in some places; wind reached gale force with gusts of 50–60 kt. A strong south-westerly and showery air stream covered the country during the last few days of the month.

Rainfall was heaviest during the first week being three times the average in the south of England, but taking the month as a whole it was above the average over most of the country except in east coast regions from Kent to Durham, much of East Anglia and the east Midlands, Cumberland and north-west Scotland. It was twice the average over a large part of south-west England. Many places in southern England reported a period of absolute drought from the 12th to the 26th and many others only missed recording one because of local thunderstorms on the 21st. Except for the first week, temperatures were generally above normal. Sunshine was almost everywhere below average and generally amounted to only three-quarters of the normal. At Pembroke Dock it was the dullest September since records began in 1892. The warm dry period during the latter part of the month was the first break in the very wet weather which prevailed throughout most of the summer, and has enabled farmers to finish work on what might otherwise have been a disastrous harvest. The late summer rainfall has ensured good vegetable crops for the early winter.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	80	30	+1·1	146	0	75
Scotland ...	76	26	+1·1	131	0	73
Northern Ireland ...	72	36	+0·9	122	+3	69

RAINFALL OF SEPTEMBER 1956

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
<i>London</i>	Camden Square ...	2·14	118	<i>Glam.</i>	Cardiff, Penylan ...	5·46	179
<i>Kent</i>	Dover ...	2·21	96	<i>Pemb.</i>	Tenby ...	4·69	149
<i>"</i>	Edenbridge, Falconhurst	3·04	134	<i>Radnor</i>	Tyrmynydd ...	6·54	169
<i>Sussex</i>	Compton, Compton Ho.	4·71	49	<i>Mont.</i>	Lake Vyrnwy ...	5·20	144
<i>"</i>	Worthing, Beach Ho. Pk.	3·17	148	<i>Mer.</i>	Blaenau Festiniog ...	9·60	122
<i>Hants.</i>	St. Catherine's L'thouse	3·68	154	<i>"</i>	Aberdovey ...	5·16	161
<i>"</i>	Southampton (East Pk.)	4·38	201	<i>Carn.</i>	Llandudno ...	2·63	124
<i>"</i>	South Farnborough ...	3·50	183	<i>Angl.</i>	Llanerchymedd ...	4·83	164
<i>Herts.</i>	Harpenden, Rothamsted	2·14	110	<i>I. Man</i>	Douglas, Borough Cem.	4·45	136
<i>Bucks.</i>	Slough, Upton ...	2·58	146	<i>Wigtown</i>	Newton Stewart ...	4·72	138
<i>Oxford</i>	Oxford, Radcliffe ...	2·36	138	<i>Dumf.</i>	Dumfries, Crichton R.I.	5·10	188
<i>N'hants.</i>	Wellingboro' Swanspool	1·70	94	<i>"</i>	Eskdalemuir Obsy. ...	4·79	129
<i>Essex</i>	Southend, W. W. ...	1·73	104	<i>Roxb.</i>	Crailing ...	1·89	93
<i>Suffolk</i>	Felixstowe ...	1·48	89	<i>Peebles</i>	Stobo Castle ...	2·99	119
<i>"</i>	Lowestoft Sec. School ...	1·13	58	<i>Berwick</i>	Marchmont House ...	3·42	142
<i>"</i>	Bury St. Ed., Westley H.	1·74	87	<i>E. Loth.</i>	North Berwick Gas Wks.	3·49	169
<i>Norfolk</i>	Sandringham Ho. Gdns.	1·48	71	<i>Mid'l'n.</i>	Edinburgh, Blackf'd. H.	3·83	187
<i>Wilts.</i>	Aldbourne ...	3·60	171	<i>Lanark</i>	Hamilton W. W., T'nhill	4·48	167
<i>Dorset</i>	Creech Grange ...	5·91	216	<i>Ayr</i>	Prestwick ...	3·58	139
<i>"</i>	Beaminster, East St. ...	6·50	254	<i>Renfrew</i>	Glen Afton, Ayr San. ...	5·08	130
<i>Devon</i>	Teignmouth, Den Gdns.	5·80	296	<i>Bute</i>	Greenock, Prospect Hill	4·75	106
<i>"</i>	Ilfracombe ...	5·32	198	<i>Argyll</i>	Rothestay, Ardenraig ...	5·30	131
<i>"</i>	Princetown ...	12·96	254	<i>"</i>	Morven, Drimnin ...	5·24	93
<i>Cornwall</i>	Bude, School House ...	...	...	<i>"</i>	Poltalloch ...	5·27	115
<i>"</i>	Penzance ...	6·67	228	<i>"</i>	Inveraray Castle ...	7·54	117
<i>"</i>	St. Austell ...	5·95	187	<i>"</i>	Islay, Eallabus ...	4·31	103
<i>"</i>	Scilly, Tresco Abbey ...	4·38	171	<i>"</i>	Tiree ...	4·22	114
<i>Somerset</i>	Taunton ...	4·93	248	<i>Kinross</i>	Loch Leven Sluice ...	3·82	149
<i>Glos.</i>	Cirencester ...	4·18	183	<i>Fife</i>	Leuchars Airfield ...	4·19	217
<i>Salop</i>	Church Stretton ...	3·77	179	<i>Perth</i>	Loch Dhu ...	8·13	142
<i>"</i>	Shrewsbury, Monkmore	2·36	145	<i>"</i>	Crieff, Strathearn Hyd.	6·00	210
<i>Worcs.</i>	Malvern, Free Library...	3·86	200	<i>"</i>	Pitlochry, Fincastle ...	5·78	230
<i>Warwick</i>	Birmingham, Edgbaston	2·88	146	<i>Angus</i>	Montrose, Hospital ...	4·35	219
<i>Leics.</i>	Thornton Reservoir ...	2·47	137	<i>Aberd.</i>	Braemar ...	4·36	174
<i>Lincs.</i>	Boston, Skirbeck ...	1·44	82	<i>"</i>	Dyce, Craibstone ...	4·79	198
<i>"</i>	Skegness, Marine Gdns.	1·22	67	<i>"</i>	New Deer School House	2·51	100
<i>Notts.</i>	Mansfield, Carr Bank ...	2·76	150	<i>Moray</i>	Gordon Castle ...	2·26	90
<i>Derby</i>	Buxton, Terrace Slopes	4·11	127	<i>Nairn</i>	Nairn, Achareidh ...	2·95	140
<i>Ches.</i>	Bidston Observatory ...	2·94	122	<i>Inverness</i>	Loch Ness, Garthbeg ...	5·15	167
<i>"</i>	Manchester, Ringway...	2·10	93	<i>"</i>	Loch Hourn, Kinlochourn	8·72	98
<i>Lancs.</i>	Stonyhurst College ...	4·86	127	<i>"</i>	Fort William, Teviot ...	7·79	122
<i>"</i>	Squires Gate ...	2·93	108	<i>"</i>	Skye, Broadford ...	5·69	82
<i>Yorks.</i>	Wakefield, Clarence Pk.	2·53	158	<i>"</i>	Skye, Duntulm ...	4·33	94
<i>"</i>	Hull, Pearson Park ...	1·39	81	<i>R. & C.</i>	Tain, Mayfield... ..	3·53	154
<i>"</i>	Felixkirk, Mt. St. John...	2·44	134	<i>"</i>	Inverbroom, Glackour...	2·57	58
<i>"</i>	York Museum ...	1·86	114	<i>"</i>	Achnashellach ...	6·01	87
<i>"</i>	Scarborough ...	1·24	69	<i>Suth.</i>	Lochinver, Bank Ho. ...	2·38	68
<i>"</i>	Middlesbrough... ..	1·43	86	<i>Caith.</i>	Wick Airfield ...	1·89	76
<i>"</i>	Baldersdale, Hury Res.	4·45	174	<i>Shetland</i>	Lerwick Observatory ...	2·39	79
<i>Nor'l'd.</i>	Newcastle, Leazes Pk....	3·05	154	<i>Ferm.</i>	Crom Castle ...	4·31	154
<i>"</i>	Bellingham, High Green	2·75	115	<i>Armagh</i>	Armagh Observatory ...	3·17	129
<i>"</i>	Lilburn Tower Gdns. ...	2·65	112	<i>Down</i>	Seaforde ...	4·67	170
<i>Cumb.</i>	Geltsdale ...	2·69	96	<i>Antrim</i>	Aldergrove Airfield ...	2·34	94
<i>"</i>	Keswick, High Hill ...	4·10	97	<i>"</i>	Ballymena, Harryville...	2·55	82
<i>"</i>	Ravenglass, The Grove	3·06	91	<i>L'derry</i>	Garvagh, Moneydig ...	3·68	124
<i>Mon.</i>	A'gavenny, Plâs Derwen	5·18	202	<i>"</i>	Londonderry, Creggan	4·08	124
<i>Glam.</i>	Ystalyfera, Wern House	8·09	185	<i>Tyrone</i>	Omagh, Edenfel ...	3·08	101