Meteorological effects of the solar eclipse of 11 August 1999

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A rare and spectacular total solar eclipse crossed the south-west tip of Britain, sweeping swiftly onwards into continental Europe, during the late morning of 11 August 1999 (Fig. 1). (The last total solar eclipse in the UK barely clipped Shetland in 1954, and the next will not occur until 2081, in the Channel Islands.) The rest of the country was subjected to a deep partial eclipse. For most of Britain, the eclipse lasted from about 1000 to 1235 BST, with maximum obscuration of the Sun by the Moon between about 1112 and 1122 BST, exact timings being later further east (Bell 1997). Unfortunately the surface pressure analysis (Fig. 2) shows a weak low approaching Ireland, with an associated cloudy trough hitting the south-west peninsula just at the crucial hour when avid eclipse watchers could well have done without this nuisance! Ahead of the front, winds were light in a slack south or south-east airflow resulting from a weak transient ridge. Cloud conditions further east and north in Britain were still patchy but generally clearer (Fig. 3). While many of the south coast resorts east of the Isle of Wight had largely clear skies, with typically 7 or 8 hours of bright sunshine, those further west were mainly cloudy with only an hour or less of sunshine.

Because of the extensive cloud – extending also over much of neighbouring Europe, and widely spoiling the view in France and Germany – for many the eclipse was probably of greater meteorological than astronomical significance. Moreover, it was exceptional in having a track crossing densely populated land masses (most eclipses occur over the sea), and was a near-midday, summer eclipse. Therefore it provided a unique opportunity to assess the influence on meteorological parameters such as surface air temperature (SAT), wind, radiation and cloud, and I received a tremendous response (>140 replies) in answer to my request for relevant observations (Hanna 1999). These came from an array of (usually) well-equipped amateur and professional weather stations, with reports not only from the UK but also several from abroad, and they are summarised below.

Observational reports

Some 81 observational reports were deemed good enough to be used in the analysis because they included frequently and carefully measured readings of the above-mentioned elements. An eclipse summary was compiled for each of these stations but only the more representative summaries for each geographical region, starting in and around the area of totality and generally working outwards, are presented here. I plan to make the full report available in certain specific libraries and archives and/or on the Web; please consult me for the latest status.

South-west England

Neville Bailey at Denbury, Newton Abbot (Devon), measured a slight but nevertheless apparent temperature drop from 15.6 °C at 1105 to 15.2 °C between 1140 and 1145 BST, using his Davis instrument package. The temperature sensor was in a Stevenson screen (SS) with standard exposure. There were 8 oktas of stratocumulus (Sc) and low stratus (St) with altocumulus (Ac), with occasional partial breaks allowing the eclipse to be seen. Solar radiation peaked at 232 $W m^{-2}$ at 1010 BST, then fell back to zero by 1110 BST and for the next two 5-minute readings, but was back up

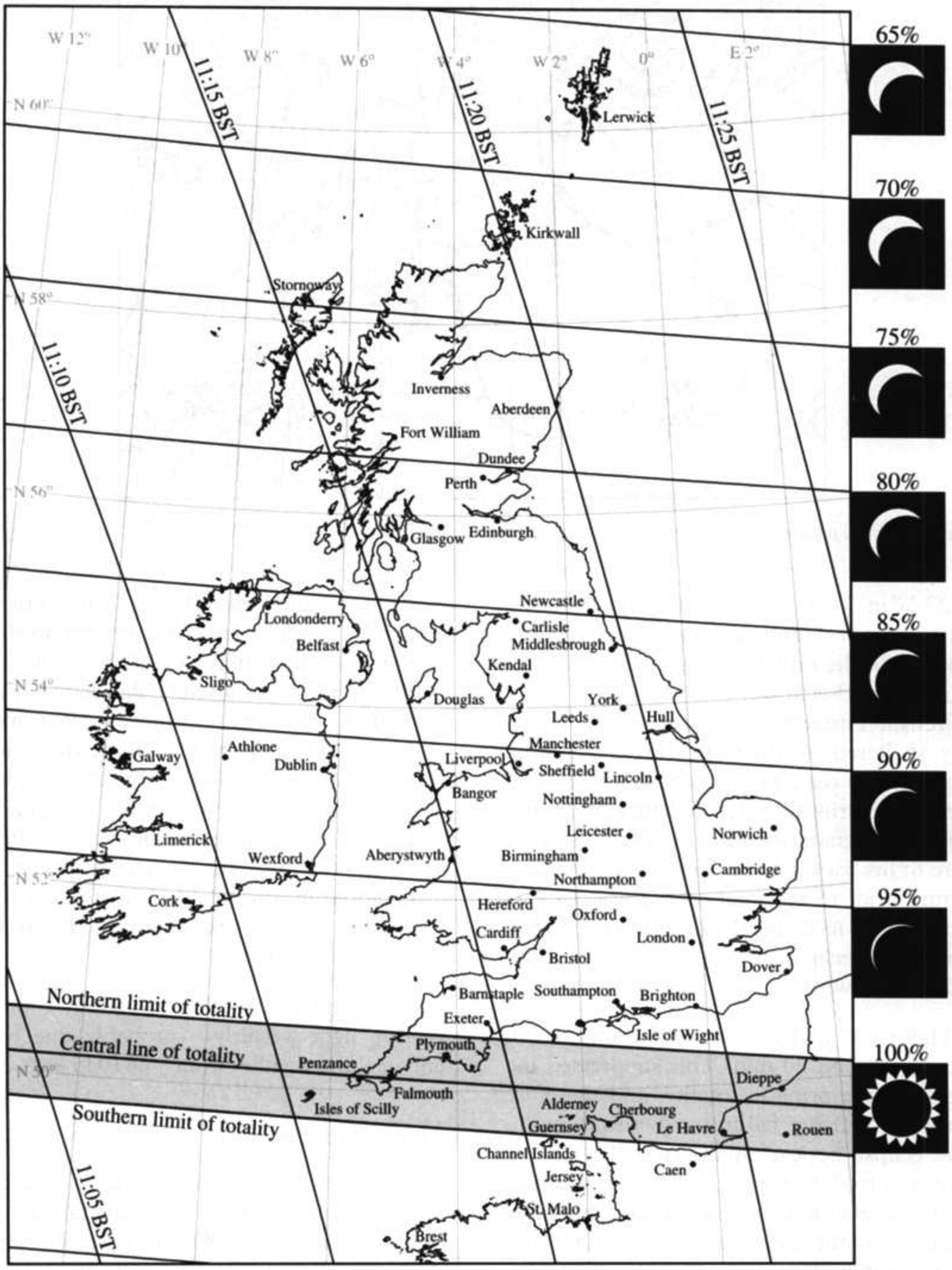

Fig. 1 The circumstances of the solar eclipse of 11 August 1999 for the British Isles. The near-horizontal dark lines mark the degree of obscuration of the Sun (shown as percentages on the right) at maximum eclipse. The nearly vertical curved lines mark the times of greatest eclipse (progressively later eastwards) at five-minute intervals. The zone of totality, over Cornwall, south Devon and much of the Channel, is shown. (From Bell 1997.)

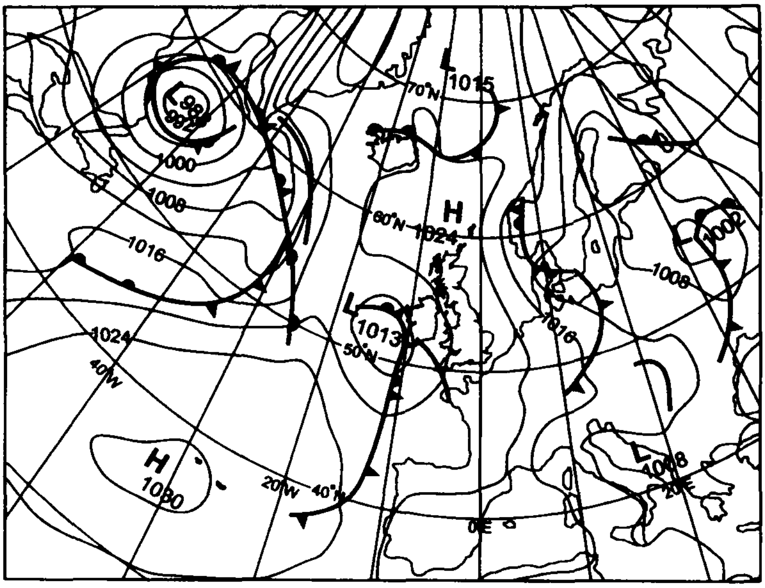

Fig. 2 Surface pressure analysis for 1300 BST *on 11 August 1999 (from The Met. Office* Daily Weather Summary*)*

to 123 W m^{-2} by 1150 BST. A 1 mph* zephyr with gusts to 3–4 mph fell calm or almost calm (0 mph with the odd 1 mph gust) for the hour centred on mid-eclipse.

Graham Easterling took data from a relatively sheltered, south-east-facing site, about 1 km from the sea and 60 m above sea-level, at Penzance (Cornwall). He used maximum and minimum thermometers in a standard SS in the centre of his back garden. The maximum temperature prior to the total eclipse was 15.7 °C at about 0945 BST, and the minimum recorded during the eclipse was 15.0 °C at about 1140 BST. He wrote:

"There was a sharp shower around 1000, lasting around 20 min. This suppressed the temperature prior to totality, and therefore made the further fall in temperature due to the eclipse appear small. Had the shower not occurred, the [pre-totality] temperature would certainly have risen more, probably peaking about a degree higher. The maximum temperature of 17.8 °C [recorded during an evening clearance] was very low for August, and [it] was the coldest day since June 29.

August 11 was the most consistently cloudy day for some time. After a clear sunrise, Ac and Sc quickly spread in from the west, and there was little blue sky left by 0900. From this time Cu [cumulus] developed quickly over the land, giving showers from around 0930, but it remained somewhat clearer over the sea. As totality approached the Cu tended to melt away, leaving medium-level cloud. It was noticeably clearer over the sea. After totality, the partial eclipse was glimpsed at around 1145, as the Cu development reached its minimum. From 1200 the Cu started to re-form."

The wind was south-east light at 1000 BST, veering light westerly – probably due to the encroaching weather front – at 1045 BST.

Channel Islands

At Guernsey Airport Met. Office (data courtesy of Tim Lillington), air temperature monitored by a Vaisala HMP35 sensor clearly dipped from 16.9 °C at 1031–1036 to 16.0 °C at 1120–1135 before rebounding to 16.9 °C by 1220 BST. The near-surface grass temperature fell from 22.9 °C at 1023 to 15.5 °C at 1124 BST, and that over concrete from 22.1 °C at 1021 to 16.8 °C at 1121–1124 BST, these obviously being much larger changes (Fig. 4,

* 1 mph = 0.86 kn

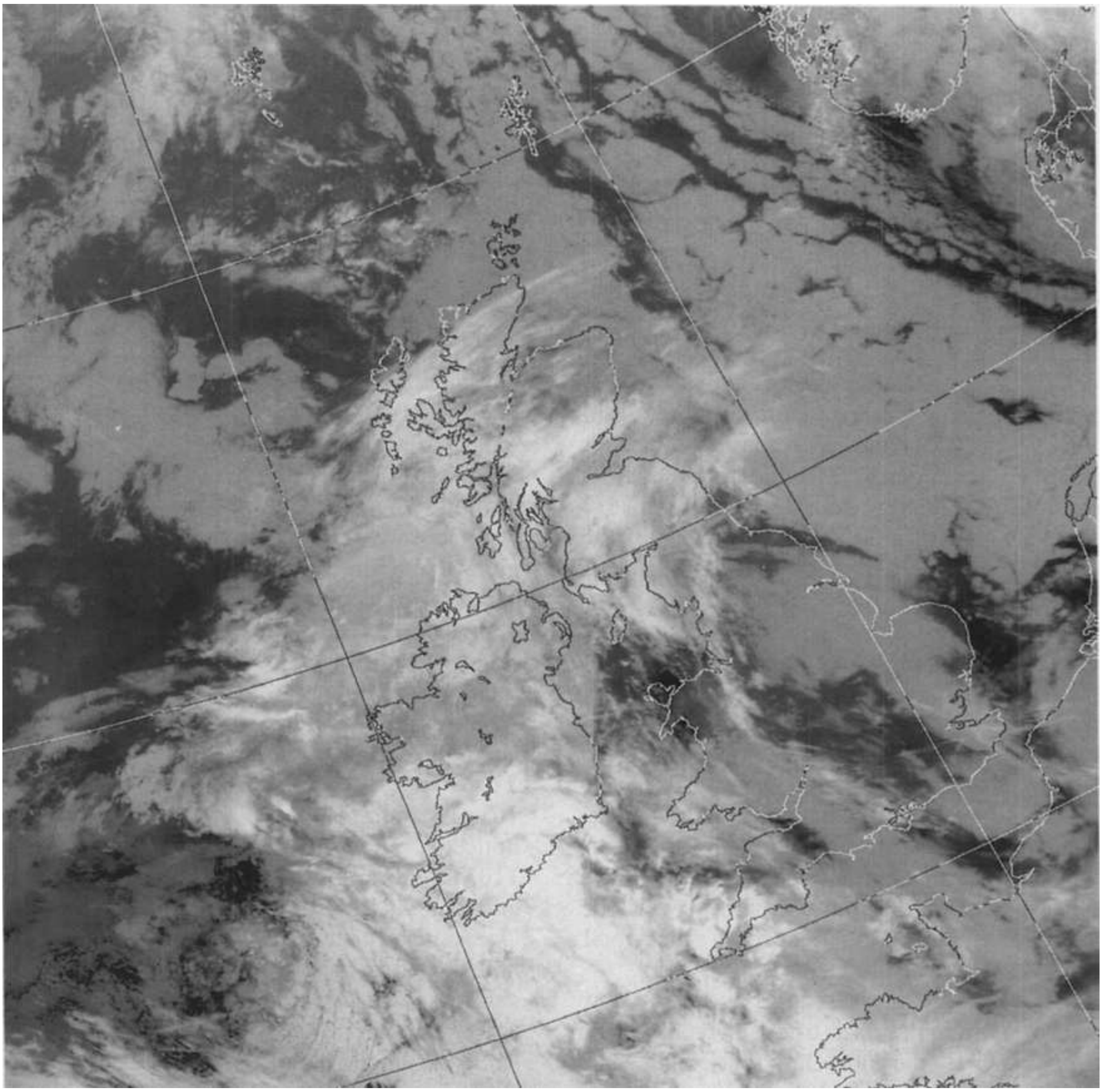

Fig. 3 AVHRR infrared satellite picture of the UK for 0820 BST *on 11 August 1999. Note the colder (higher/thicker) cloud spilling in across south-west England. (MP © University of Dundee.)*

see back cover). However, there was no noticeable change in the 15 cm depth soil temperature, which hovered at around 17.1 °C. No sunshine was recorded between 1000 and 1300 BST; solar radiation gauged by a Kipp & Zonen CM 11/14 pyranometer fell from 53.89 W m^{-2} at 1001 to 1.13 W m^{-2} at 1116, then rose to 58.89 W m^{-2} at 1226 BST. The light south-south-east wind, measured using a Vaisala WA21M anemometer at the end of the runway, slackened off from around 6 to 4 kn from 1121 to 1143 BST.

At Jersey Airport (data courtesy of Anthony Pallot), an open-site air temperature, measured using a Rosemount platinum resistance thermometer, fell from 18.3 °C at 0936 to 16.4 °C at 1124 BST. There was extensive (6–7 oktas) Sc/Ac at about 2100 m and 1–3 oktas Cu at about 500 m. "It was possible to obtain the odd glimpse of the sun through the Ac layers sufficient to observe the eclipse process." Wind was south-east veering south, about 4–9 kn.

Central southern England

Nigel Paice, observer at Middle Wallop Met.

Office, Stockbridge (Hampshire), took a comprehensive set of standard manual readings at 10 min intervals throughout the eclipse period. He found little effect on air temperature, although there is a slight and suggestive time-lagged fall from 16.3 °C at 1050 to 15.8 °C at 1140 BST. Grass temperature fell more substantially, from 20.4 °C at 1040 to 14.7 °C at 1120 BST. The prevailing cloud was Sc, with Ac around mid-eclipse and a little Cu throughout, giving a total cover of 7 oktas. The thick Sc thinned and broke a little to reveal the eclipse from just after first contact to a few minutes beyond the maximum obscuration of 98%. Mr Paice suggested that cloud cover might have muted the air temperature drop at this location. Wind was 4–6 kn, south-east.

Malcolm Walker, Education Officer of the Royal Meteorological Society (RMS), and his wife were on the Isle of Purbeck, 1.5 km west-south-west of Kingston (Dorset), 150 m above sea-level. They took a comprehensive suite of observations on a bridle path beside a field of maize where the plants were mostly 1.0–1.5 m high; there is a very slight slope upwards to the south, beyond which the land falls away quickly to the English Channel, 1.7 km distant. There is a fairly steep slope to the north, down a field to a tarmacked country lane and, on the other side of the lane, a narrow belt of woodland. Their site experienced a near-total (99.8%) eclipse at 1117 BST.

The Walkers measured ground (T_g) and screen (T_s) temperatures using a Maplins electronic digital thermometer that had been checked for accuracy against eight or nine mercury-in-glass thermometers owned by the RMS. T_s was recorded 1 m above the ground by the external thermometer probe in a portable shield attached to a fence post, and represents air temperature. T_g was recorded 7 cm above the ground by the sensor inside the thermometer. The instrument itself sat on an empty leather case and a box lid was used to shield it from direct, but not indirect, solar radiation. A Casella whirling psychrometer was used to measure dry- and wet-bulb temperatures at about 1.75 m height. T_s (T_g) fell from 15.7 (17.3) °C at 1024 BST, values at which they had been fairly steady for 15 min beforehand, to 14.7 (14.8) °C at 1119 (1124) BST. The whirling dry (wet) temperatures fell from 16.1 (15.0) °C at 1014 to 15.0 (14.3) °C at 1109 (1114) BST and then followed a plateau until after 1124 BST before rising. Temperatures were back up to their initial values by about 1200 BST, and rose about a degree or so higher by 1215 BST. Relative humidity (RH) rose from 89% at 1009 and 1014 to 94% at 1109 and 1119, then fell to 85% by 1215 BST.

At 1009 BST the weak trough that gave showers at about 0915–0930 BST was moving away eastwards, visible as a line of Cu and cumulonimbus (Cb) to the east and north-east. Cloud at 1010 BST was about 3 oktas Sc and 4 oktas Cu with Ac above. Over the next half an hour Cu decreased while Sc increased to around 6 oktas. There was Ac and cirrostratus (Cs) above, with only very occasional, fleeting glimpses of the Sun. These generally heavily overcast or gloomy conditions persisted until after 1200 BST, after which the Sc decreased to 3 oktas, and two or three very tiny patches of blue sky were finally seen at 1215 BST.

A sensitive Deuta Anemo hand-held cup anemometer was used to measure wind speed. There was a very light (2–4 kn, gusting 6–10 kn) south-south-east wind. Mr Walker noticed a sudden rustling of the maize leaves at 1103 BST but the anemometer recorded no gusts; could this have been a downdraught? Occasional rustling of the maize leaves was noted again at 1119 BST.

Chris Watts at Romsey (Hampshire) used an Environmental Measurements Ltd (Sunderland) automatic weather station (AWS) in an open exposure, on a gentle slope facing north. Air temperature fell from 17.8 °C at 1030 to 15.9 °C at 1130 and 1140 BST:

> "Early morning cloud cover averaged 6 oktas, mainly Ci [cirrus], Ac and Sc. The clearest skies were to the north-east. In the early stages of the eclipse cloud increased to 7 oktas, but the Sun could still be seen in cracks between the clouds and also behind the lighter clouds, However, about 30 min before maximum coverage [at Romsey about 99%], St approached and soon the sky was completely overcast. The Sun was obliterated and did not reappear during the rest of the eclipse."

There was only 72 s of bright sunshine, as measured by an R&D Electronics sun recorder, between first contact and maximum coverage. The south-easterly wind, which had frequently been averaging around or over 3 (gusting 6–11) mph from 0820 to 1020 BST, temporarily dropped back to about 1–1¾ (gusting 3–6) mph at 1100–1150 BST.

South-east England

Researchers at Alice Holt (Forestry Commission), near Farnham (Surrey) (data courtesy of Mark Broadmeadow), used a Solent sonic anemometer to measure wind speed and direction 8 m above the 20 m oak canopy of a forest stand. Temperature and global radiation data were measured at a standard weather station 3 km away on a fairly exposed sandy heath. Screened air temperature fell from 18.2 °C at 1030 to 14.7 °C at 1130 BST. Cloud was said to be variable and the partial eclipse just about visible. Global radiation fell from 613 W m^{-2} at 1000 to 13.2 W m^{-2} at 1120 BST. Wind speed hovered at about 1.0–2.5 m s^{-1}; although the wind was already light, perhaps it did not drop off perceptibly around mid-eclipse (unlike at other stations) because the Alice Holt measurements were (unconventionally) taken higher up in or above the atmospheric boundary layer. In confirmation, the weather station readings show a marked drop off in wind speed from about 1.5 to 0.2 m s^{-1} at about 1135 BST.

At Beaufort Park, Bracknell (Berkshire) (data courtesy of Michael Collins, The Met. Office), air temperature fell from 17.5 °C at 1023 BST (still 17.3 °C at 1043 BST) to 14.5 °C at 1132 BST. RH rose from 62.2% at 1027 to 88.5% at 1146 BST. The ground temperature, measured by a freely exposed grass minimum thermometer, fell more starkly from 28.0 °C at 1024 to 12.5 °C at 1125 BST. Ceilometer (cloud-base height) data (of cloud directly above the station) suggest dissipation of convective cloud for an hour or so centred on mid-eclipse, with the lower cloud layer base rising from 968 m at 1047 to 2164 m at 1205 BST (Fig. 5). Direct (diffuse) short-wave radiation fell from 766.3 (246.0) W m^{-2} at 1009 (1039) to 0.0 (3.3) W m^{-2} at 1052–1100 (1119) BST, and global radiation followed suit from 679.5 W m^{-2} at 1015 to 14.0 W m^{-2} at 1119 BST (Fig. 6). Wind was variable, mainly south-easterly 1–6 kn, falling entirely calm from 1049 to 1155 BST. However, "The anemometer logger was a Munro Mk4 with a starting speed of about 4 kn. This was very disappointing ...

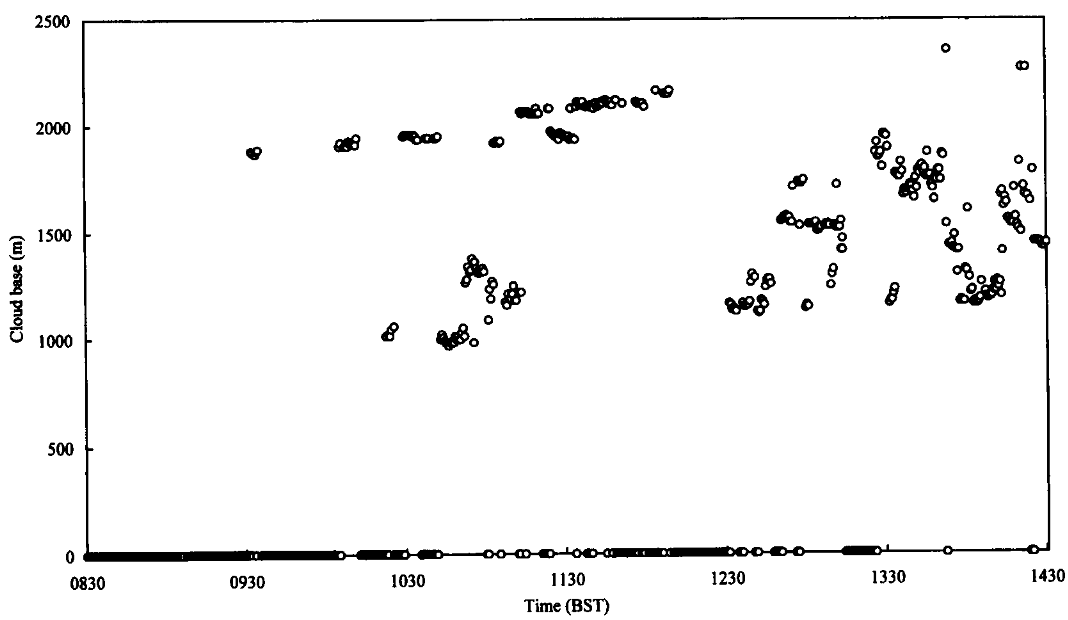

Fig. 5 Lower cloud base from Model C ceilometer at Beaufort Park (Berkshire) on 11 August 1999

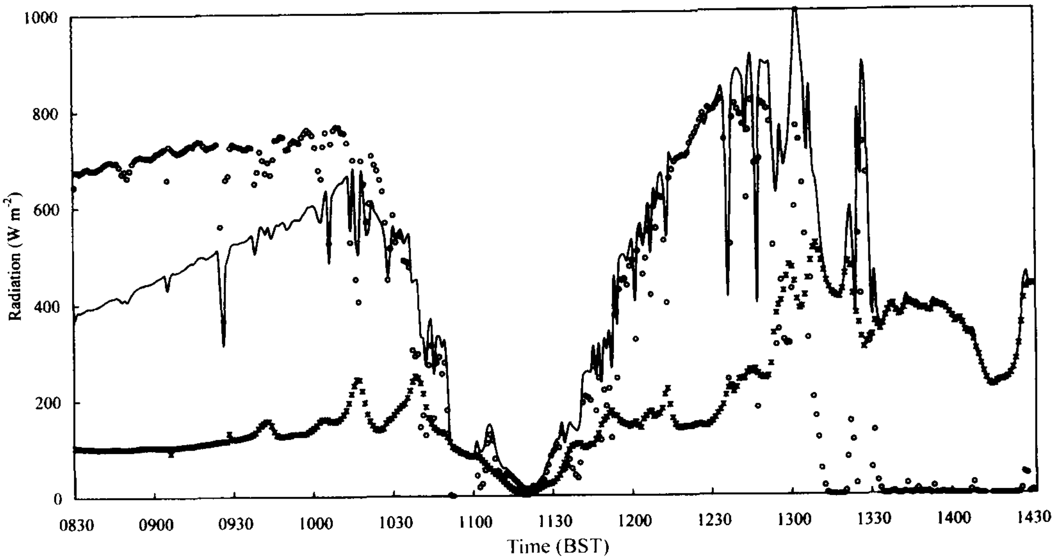

Fig. 6 Short-wave radiation at Beaufort Park (Berkshire) during and around the solar eclipse of 11 August 1999. Direct radiation indicated by open circles, diffuse by crosses and global by solid line.

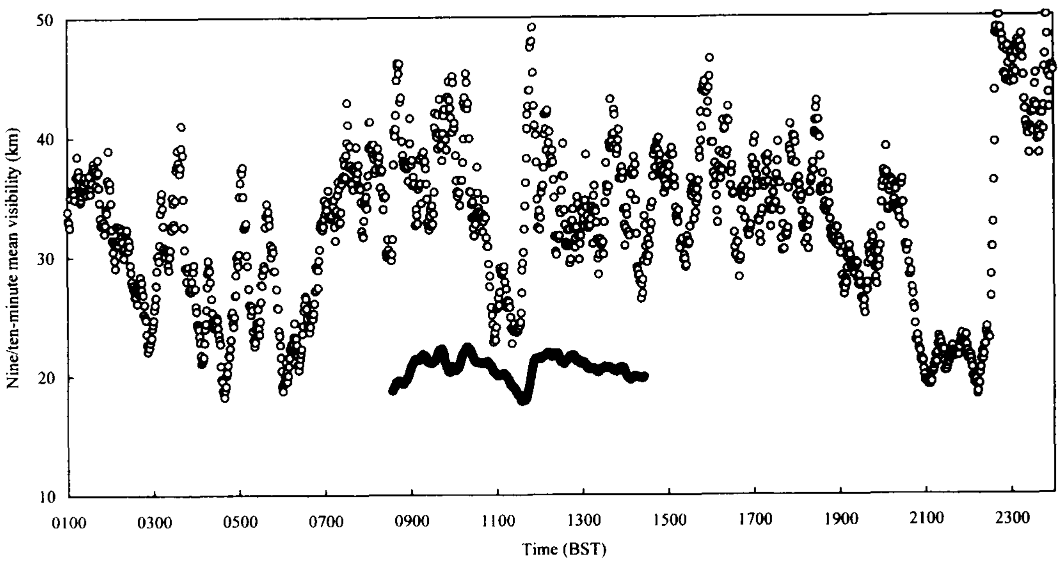

Fig. 7 Visibility at Beaufort Park (Berkshire) (solid line) and Corsock (Kirkcudbrightshire) (open circles) on 11 August 1999

The Met. Office is upgrading its wind systems from Munro to Vector precisely to obtain better low-speed performance." Visibility dropped from 22.86 km at 1015 to 17.25 km at 1132 BST but was back up to 22.08 km by 1154 BST (Fig. 7).

Martin Rowley at Bracknell (Berkshire), in a typical suburban garden situation, close to the Beaufort Park Met. Office site, used standard mercury-in-glass thermometers calibrated by the supplier, Casella, in a home-built SS. The reading interval varied from 10–15 min at the start of the period to 1 or 2 min either side of maximum eclipse, lengthening again on the other side. Screen temperature fell from 17.6 °C at 1038 to 15.9 °C at 1143 BST. The temperature indicated by a (non-standard) thermometer exposed to direct-sky radiation at approximately 0.7 m, shielded from ground-based (back-scattered earth) radiation and insulated from its supports and stand, fell from 25.4 °C at 1018 to 15.5 °C by 1125 BST, and climbed up to 27.4 °C by 1223 BST. The Sun was directly visible for most of the time, with hard shadows and clearing skies after initially building Ac/Cu, and winds were light and variable falling to calm for several minutes around mid-eclipse. Thick, high Sc moved in from the west after 1300 BST.

Hugh Thomas sent data from Hurstpierpoint (West Sussex) – a Met. Office-approved, relatively sheltered, back garden station on a low sandstone plateau about 12 km north of the coast and 2.6 km north of the crest of the South Downs. He used standard maximum, minimum and dry-bulb thermometers and a Casella thermograph:

> "At 1000 the screen max registered 20.0 °C and the thermograph 19.5 °C. By 1045 the dry bulb was down to 19 °C. At the height of the partial eclipse at 1118, the dry bulb was down to 16.5 °C and the thermograph 16.6 °C. I had put a max/min thermometer on the clothes line. At 1010 it registered 20.5 °C and by 1118 it had fallen to 13.5 °C. At the height of the eclipse, in the still air with very weak sunshine, it felt distinctly chilly and the clothes line max/min seemed to give the more realistic readings. A large area of Sc cloud cleared away *c.* 0950 and during the period of the partial eclipse there was unbroken sunshine [Fig. 8(a)]. From about 1057 to 1127 the sunshine card was not burnt. There was a slight increase in wind for a moment around 1115 but, overall, there was virtually no wind during the period of the eclipse."

Maurice Brockman at Watford (Hertfordshire) had telemetered probes: one for air temperature (T_a) inside an SS; another for Sun temperature (T_{sun}) from a probe inside a black bulb mounted on the roof. T_a (T_{sun}) fell from 17.4 (24.6) °C at 1024 (1000) to 15.2 (14.6) °C at 1127–1136 (1121–1125) BST, highlighting the approximate 10 min lag of T_a changes in response to changing insolation. The Sun was partially obscured for a period about 1125–1135 BST by thin Ac. During the eclipse the Cu, about 3 oktas, cleared completely to reappear again after 1210 BST. The wind was very light and did not appear to change in either strength or direction.

Bernard Burton at Wokingham (Berkshire) recorded a "very marked eclipse signature" using his aspirated psychrometer and anemometer (10 m effective height) (Figs. 9 and 10):

> "The psychrometer is exposed in the front garden in a suburban environment. It is at a height of 1.5 m, and samples dry and wet bulb [temperature, screened in plastic tubes with aluminium foil] at 1 s intervals, logging the averaged data over 1 min. Values of humidity mixing ratio are calculated using an assumed air pressure of 1013 mbar.
>
> The solar eclipse depressed the air temperature by >2 degC [from 17.88 °C at 1026 to 15.35 °C at 1128 BST]. The associated rise in dew point can be attributed to decreased mixing as the lower boundary layer became decoupled [there was a marked effect of the eclipse on the 1 min variation in humidity mixing ratio, which temporarily became much less variable as convection/turbulence decreased]. The subsequent gradual increase in dew-point evident after 1300 is due to background synoptic advection. During the eclipse the light wind decreased.
>
> During the period 1000 to 1045, Cu cloud (Cu humilis and Cu mediocris) continued to increase in amount and development, with the bases gradually rising in line with normal boundary layer diurnal heating and mixing. Between 1045 and 1130 it was noted the Cu development became suppressed, firstly with the Cu tops becoming less 'rounded' and more ragged, and then with the amount gradually decreasing. Between 1130 and 1215 there was virtually no Cu. Fresh Cu began to develop at 1215, but the bases seemed a little higher than before. During the whole period, there was 2–4 oktas of Sc near 2000 m, all thin (Sc stratiformis translucidus perlucidus), not enough to prevent the R&D sunshine recorder recording sunshine, and 3–6 oktas thin Ci. Cloud in the Sc layer was gradually increasing due to the synoptic-scale advection of moister air, and this had thickened to

Fig. 8 Sunshine records from a Campbell–Stokes recorder for (a) Hurstpierpoint (West Sussex), (b) University of Reading (Berkshire), (c) Northamptonshire Grammar Pitsford Hall, and (d) Moel y Crio (Flintshire) for 11 August 1999 (times are GMT)

give 8 oktas cover in the early afternoon."

The air minimum temperature in the screen during the eclipse was 15.6 °C. The grass minimum thermometer, which had been reading about 18 °C after resetting at 1000 BST, probably fell to a minimum of around 11 °C during the same period. An open-scale barograph, even using a scaled magnifier which has a resolution of 0.05 mbar, showed no marked variation in pressure during the eclipse.

East Anglia/eastern England

R. W. Selfe and family at Benfleet (Essex) used French-style maximum and minimum thermometers in an SS at the lower (east) end of their garden, about 3 m from a tall (approximately 12 m) tree hedge running north–south. The measured temperature rose from 13.0 °C at 0900 to 15.4 °C at 1050, then dropped back to 14.0 °C by 1130 BST. Between 0900 and 1000 BST there was about 7 oktas of Sc, but the sky then soon cleared from the west, leaving scattered Ci and continuous sunshine. Around mid-eclipse, Mr Selfe noted the chill in the air at 14 °C, when he reckoned that under normal circumstances for that day the temperature should have been about 19 °C (the eventual maximum temperature was 19 °C on a sunny afternoon). The wind remained flat calm, except for a very slight breeze for a few seconds just before 1100 BST.

Dr Charles Briscoe at Buxton (Norfolk) used a Davis Groweather AWS. The temperature/humidity sensor – within a white, louvred radiation shield – and solar recorder were on a standard Davis mounting in a properly exposed

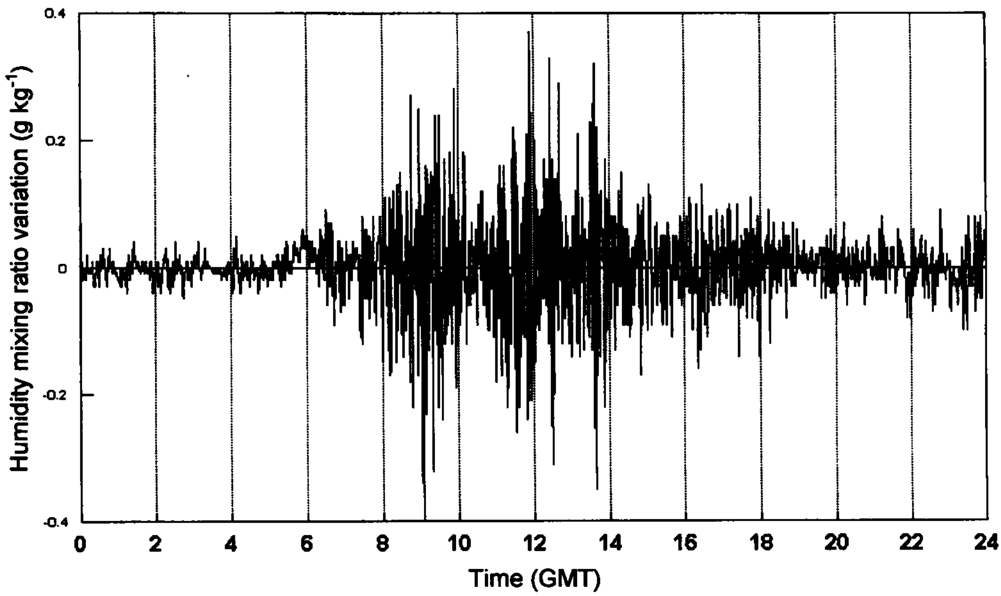

Fig. 9 One-minute variation in humidity mixing ratio from the Wokingham (Berkshire) psychrometer for 11 August 1999

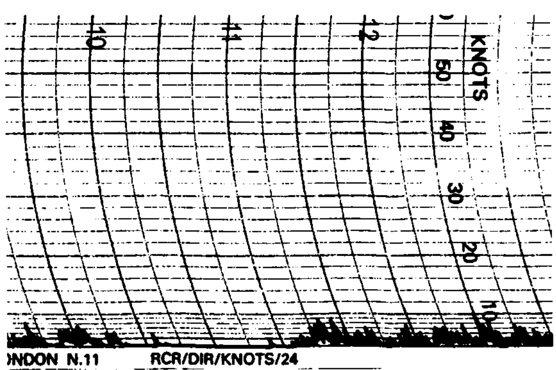

Fig. 10 Part of the Wokingham (Berkshire) anemograph trace for 11 August 1999 (time is GMT)

(river authority-approved) park site with trees, but none closer than twice their height, and an anemometer was mounted atop his house. Data were recorded every 10 min. Air temperature fell from 15.4 °C at 1040 to 13.1 °C at 1150 BST. At the same time, RH peaked sharply at 82%, having risen by about 12%, and the already light (3 mph) north wind distinctly fell calm. The temperature recovered more rapidly than it had fallen, to 16.2 °C at 1250 peaking at 16.9 °C at 1340 BST. Conditions were probably mainly sunny, as nearby Cromer recorded the highest sunshine in the country (10.5 hours). The solar radiation data show a morning peak of 479 W m^{-2} at 1020, followed by a fall to 62 W m^{-2} at 1130 BST (just after mid-eclipse), then a rise to a much greater peak of 765 W m^{-2} at 1330 – already 745 W m^{-2} by 1250 BST. Hourly measured evapotranspiration suffered a lull at 1200 BST when it was just 0.108 mm, compared with 0.204 mm at 1100 and 0.407 mm at 1300 BST.

Reporting from Greetham (Rutland), former Met. Office professional Paul Bartlett took temperature readings from two garden U-type thermometers, both north-facing, well exposed over grass, right in the middle of nearly open countryside, and checked for accuracy (estimated ±0.5 degC) against values from nearby RAF stations. After rising to an initial peak of 17.0 °C at 1005 and again at 1025 BST, the temperature fell dramatically to 11.0 °C at 1132, but was back up to 17.0 °C at 1249 BST. It was pretty overcast with Sc around 0945 BST, despite just being able to glimpse the Sun, but the Sc thinned and cleared from the west during the height of the eclipse, allowing an increasing view of the Sun; shadows eventually emerged after the main event. Winds were light with initially a north-north-east, then a south-east drift, or occasionally calm. Mr Barlett did not:

"think the [6 degC] temperature drop was that surprising in retrospect. Convection at 17 °C had just begun so there was probably a super-adiabatic lapse rate at/near the surface. Then convection died as the temperature dropped, and resumed at the same temperature after the eclipse ... I admit the deficits of my thermometers, but in such light winds would an SS have altered them? And if they were [indicating too] high or low it wouldn't change the observed [temperature] drop."

Midlands

At Halesowen Climatological Station in the West Midlands, part of the Met. Office Co-operating Network (data supplied by Cedric Roberts), dry- (wet-) bulb temperature decreased from 16.5 (13.6) °C at 1020 (1013) to 14.1 (12.1) °C at 1124 (1121) BST. Grass (slab) temperature fell from 28.6 (18.5) °C at 1013 (1026) to 11.6 (14.0) °C at 1122 (1123) BST, and surface soil temperature from 25.8 °C at 1016 to 14.6 °C at 1124 BST. The decline in soil temperature was largely muted at even a few centimetres depth. Global radiation fell from 661 $W m^{-2}$ at 1016 to 20 $W m^{-2}$ at 1115 BST. At 1000 BST there was 6 oktas Ac, moving from the north-west. Cloud varied quite a lot, being around 7 oktas Ac during the eclipse; at no time was the Sun completely obscured. An R&D Electronics Sun sensor, calibrated against a Campbell–Stokes, recorded intermittent sunshine, especially before mid-eclipse. The south-east wind, measured by a Vector certified anemometer, briefly died down from around 4 to 2½ kn (Fig. 11).

Mike Lewis is the Station Manager at Northamptonshire Grammar Pitsford Hall Weather Station. The station uses official Met. Office standard equipment and observation procedures. To quote from Mr Lewis's thorough report:

". . . up to 1045 a steady increase in temperature was experienced to a maximum of 16.2 °C. From 1045 the decrease in temperature was noticeable, reaching a minimum of 14.6 °C at 1130 – 11 min after maximum eclipse. [The thermograph showed a somewhat lesser drop of about 1 degC*]. The recovery of temperature was then quite rapid with pre-eclipse values reached at 1200. RH remained largely constant until 1100, increasing during and immediately after maximum eclipse and then falling after 1145. The rise in temperature up until 1045 was clearly seen in the presence of (convective) Cu as the dominant cloud type, with Ac developing from 5 to 6 oktas between 1000 and 1030. From 1100 and through maximum eclipse, Cu had disappeared completely leaving the higher-level Ac, which had formed an extensive blanket of 7 oktas. By 1145, cloud types had changed dramatically; Ac having lifted to Cc [cirrocumulus], and convective Cu having returned under the marked increase in temperature which marked the post-eclipse phase.

The pressure readings obtained from the mercurial barometer (uncorrected for gravity or sea-level) reveal a marked increase in pressure from 1000 to 1045, *i.e.* in the phase immediately following first contact, then a gradual reduction in pressure from maximum eclipse until 1145 when pressure stabilised and rose again. There was a clear lull in wind speed between 1119 and 1145, but a dramatic increase from 1200 to 1215 [and another short peak in wind strength at 1030, 49 min before maximum eclipse]".

The sunshine card tellingly shows the diminution of bright sunshine at approximately 1045 and its re-emergence at 1130 (Fig. 8(c)).

Matthew Roe at Riverside, Redditch (Worcestershire), used R&D Electronics temperature sensors housed in a standard small SS in a sheltered back garden. Air temperature fell from 16.4 °C at 1045 to 15.1 °C at 1130, and rose to 16.8 °C at 1215 BST. These data agree with those from sheathed mercury thermometers housed in the same screen. The temperature drop of just over 1 degC also shows up

* Thermographs, traces of which were available from several stations, generally showed smaller temperature drops during the eclipse than ordinary (mercury or electronic) thermometers, perhaps due to their greater thermal inertia and slower response to the relatively rapid temperature changes.

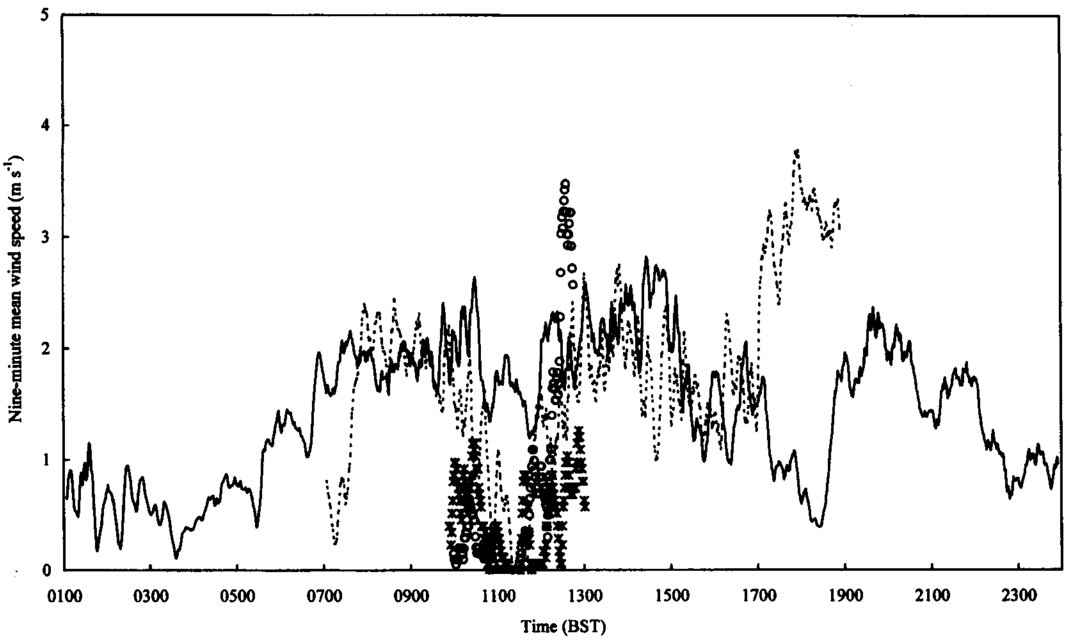

Fig. 11 Wind speed at Cranfield (Bedfordshire) (dashed line), Halesowen (West Midlands) (solid line), Normanby (North Yorkshire) (crosses) and Velindre (Powys) (open circles) on 11 August 1999

well in the Casella thermograph trace. There was no discernible change in RH, which stayed fairly steady at about 74%. Cloud was 7 oktas Cu, Sc, Ac and Ci from 1015 to 1100 BST, then 6 oktas Ac and Ci. Shallow Cu dispersed by 1115 BST, reforming about an hour later; thin Ac covered the Sun throughout. The wind, measured by an R&D Electronics anemometer, was light (2–6 mph) and from the south-east; there was a noticeable 8 mph gust of wind at 1110 BST.

Northern England

John Goulding took readings with a Davis AWS at Normanby, Middlesbrough (North Yorkshire). The temperature probe resided in an SS in a suburban garden with some shelter from surrounding trees, and the anemometer and wind vane were mounted 10 m above ground. The temperature levelled off at 15.5 °C at 1054–1055, then dropped back to 14.3 °C at 1152–1154 BST, before recommencing its rise. The weekly trace from the Casella thermohygrograph mounted within the screen also shows this effect. Cloud was thin and steadily increased from 3 oktas (Ci, Cc and Cs with small Cu) at 0930 to 8 oktas (uniform Cs) at 1200 BST, before dispersing somewhat again; the early Cu had vanished by 1130 BST. The eclipse was fully visible throughout. The light (1–3 mph, with gusts to about 5 mph) and veering westerly wind fell entirely calm during the period 1112–1135 BST (Fig. 11), then resumed from a more northerly point.

Wales

Dr Donald Perkins of Llansadwrn (Anglesey) used standard instruments in a garden weather station. He reports that:

> "partially cloudy conditions prevailed including Ci and intermittent Cu of varying thickness. The screen temperature drop was 2.1 degC (maximum to minimum) over a period of 85 min. There was an increase in RH peaking at 90% before the temperature minimum. Larger and somewhat faster changes were evident in the probe and grass temperatures. The [digital] probe [with a small white remote sensor] was small and should give a reasonable indication of air

temperature at 2.4 m [over grass]. This measured a drop of 4.2 degC over a period of 80 min. The drop in the temperature at the grass surface was 7.5 degC over a similar period.

There seems also to have been a small effect on the soil temperatures at 5 cm. Though small (only 0.3 degC), this is probably significant in view of the number of observations and comparison with data of 12 August. There is even a faint suggestion of lulls in the rise of the 20 and 30 cm depth temperatures.

There seemed to be a dispersion of [Cu] cloud during the eclipse and an increase in haze. Wind on the day was fairly light but there were some changes which could have been induced by the temperature drop and cloud dispersion."

Solar radiation, measured using a solar thermopile connected to a millivoltmeter (readings given as a percentage of the normal maximum unobscured by clouds at noon), initially peaked at 74.4% at 1000, then fell back to just 2.3% at 1115, climbing again to 90.7% at 1230 BST.

John Goodger at Velindre, Brecon (Powys), a rural Met. Office climatological station, took AWS readings, with the temperature probe inside an SS. The temperature profile shows a short, sharp jump of about 0.5 degC just before 1000 BST when the screen was opened for 0900 GMT readings and replenishing of the wet bulb. Shortly after and for the next hour, temperature levelled out at about 15.2 °C, but fell slightly and slowly from 15.4 °C at 1029 to 14.4 °C at 1138–1139, thereafter rapidly rising to 18.6 C by 1245 BST. From 0900 to 0950 BST it was bright with 7 oktas of thin Sc and 1–2 oktas of Cu mediocris and fractus below. From 0950 to 1050 BST cloud thickened and increased to 8 oktas; it remained dull for the next hour. From 1150 to 1200 BST the cloud rapidly thinned (about 7 oktas), and from then until at least 1300 BST there was broken cloud with sunny intervals. The last stages of the eclipse were visible at times. It was already overcast at the time of the main (albeit modest) temperature decrease, so most of this can arguably be attributed to the eclipse. The wind was initially light (1–3 kn) and from a northerly point, and sometimes calm, but fell consistently calm (save at 1122) from 1052 to 1133 BST (Fig. 11).

Scotland

Anthony Bowles submitted data from a sophisticated Vaisala AWS at Corsock, a fairly well-exposed moorland site in the upper Urr Valley (Kirkcudbrightshire). Screened temperature fell from 15.0 °C at 1038 to 12.2 °C at 1139 and 1145 BST. Meanwhile, RH rose from about 75 to 88%. His wife reported scattered Ac at about 3300 m at about the time of the eclipse. The wind was very light (about 1–3 kn) and variable, perhaps with a south-easterly bias. Visibility was reduced from about 30–50 km generally during daylight hours to about 25 km – not far off night-time values – from about 1045 to 1130 BST (Fig. 7).

J. K. Blackshaw of Elderslie, Johnstone (Renfrewshire), took readings from individual sheathed maximum/minimum thermometers in an SS in a sheltered garden position. He noted only a slight temperature drop, from 13.7 °C at 1100 to 13.3 °C at 1130 and 1145 BST, while the humidity rose slightly from 70 to 76%. The sky was covered with Sc and altostratus (As). A few Cu clouds formed over the hills to the south prior to the eclipse; they appeared to lose strength and decay slightly around and just after the eclipse, before growing again as the temperature began to climb. The wind fell from force 1 to calm from 1115 to 1145 BST (during and just after mid-eclipse) "but this may just be coincidence as the wind was so light anyway".

Northern Ireland

Trevor Boyd at Helen's Bay, Bangor (Co. Down), a Met. Office climate station, noted a screened dry- (wet-) bulb temperature drop from 15.8 (12.9) °C at 1030–1045 (1030) to 13.7 (11.4) °C at 1130 (1115) BST. Meanwhile grass temperature fell from 18.2 to 13.0 °C. Ground temperatures at ≥10 cm depth were not discernibly affected. It was generally cloudy (7–8 oktas) with small breaks, with the Sun often visible through cloud, but completely cloudy briefly at 1115; there were a few drops of rain shortly after 1145 BST. There was a light (2–4 kn) south-east drift.

Ireland

At Dun Laoghaire (Co. Dublin) "the slowly thinning cloud sheet (Ac stratiformis translucidus) permitted all phases of the eclipse to be seen. The air temperature fell 0.9 degC between 1030 and 1130", while the temperature taken from the grass minimum thermometer, exposed in direct sunshine over the grass surface, fell 3.4 degC. The thermograph also shows the fall.

> "The mean depression of the air temperature due to the eclipse can be shown to be around 2 degC, as the normal trend in temperature would have been upwards on a relatively sunny morning. The winds stayed constant south-east force 2 or 3. Therefore the factors of wind strength/direction and cloud amount [6 oktas] remained constant during the event itself, *i.e.* the temperature changes are due to the eclipse, not some other complicating factor."

The contemporaneous 0.3 degC decline in wet-bulb temperature was less marked than the fall in the dry-bulb temperature. Air temperature readings were taken from a standard screen exposure; the moderately sheltered station, which lies about 11 km south-east of Dublin city centre and 1 km south-west of the Irish coast, reports daily to the Irish Met. Service (this report thanks to Rob Weatherill).

Continental Europe

At Pontremoli, north Tuscany (Italy), Maurizio Ratti reports that the air temperature reached a maximum of 26.3 °C at midday, followed by a gradual decrease. The maximum eclipse of 89% occurred at 1237 local summer time (LST, 1037 GMT). The temperature dropped to 24.8 °C 25 min later (a drop of 1.5 degC). Another screen at Pontremoli gauged a 3.0 degC decrease. The former is in a suburban site near his house, while the latter is an open countryside site along the River Magra, which may explain the difference. Cu mediocris cloud was reduced to Cu humilis between 1130 and 1230 LST (during the eclipse), then it became mediocris again, and at 1530 LST congestus. The eclipse delayed subsequent thundery activity during the afternoon, and also prevented the valley breeze for two hours. The Campbell–Stokes sunshine recorder showed no trace from 1100 to 1120 LST.

Analysis of UK regional SAT drop

Screened (or properly aspirated, *e.g.* psychrometer) SAT drops and cloud cover recorded during the eclipse (usually during the hour or so centred on 1130 BST) are summarised by region in Tables 1 and 2. Most acceptable reports were submitted from south-east England (21), followed by south-west England (12) and the Midlands (12), although three other regions each have at least 6. Despite inevitable differences in station exposure, instrumentation and observation method, south-east England clearly had the largest mean SAT drop (2.3 degC). This was nearly twice that in cloudier south-west England (1.2 degC) – despite the eclipse being total or more nearly so in the latter region. Indeed, East Anglia/east England and the Midlands (where, again, cloud was much more broken) recorded markedly higher SAT drops.

SAT profiles from seven UK AWSs are plotted in Fig. 12 (see back cover). Each station is representative of a different region: Chedburgh, East Anglia/east England; Corsock, Scotland; Guernsey Airport, Channel Islands; Halesowen, Midlands; Plymouth, south-west England; Portchester, central southern England; and Reading, south-east England. They were chosen purely on the basis of being comprehensive, reliable records, already computerised, and giving a broad geographical spread. They all show a clear drop depicting the eclipse. This is clearly most marked in the case of Chedburgh (2.2 degC), Corsock (2.8 degC), Halesowen (2.4 degC) and Reading (2.1 degC), at none of which skies were overcast; the progress of the eclipse was reportedly at least partly visible from all these four stations, and indeed it was comparatively clear at Reading. All these stations are in the east or north of the UK. Portchester (central southern

Table 1 Screened (or properly aspirated) surface air temperature (SAT) drops and cloud cover recorded at various sites during the eclipse. Maximum fractional obscuration of the surface of the solar disc by the Moon is also shown.

Site	Obscuration*	SAT drop (degC)	Cloud cover (oktas)
South-west England			
Culdrose (Cornwall)	1.00T	0.4	cloudy
Denbury (Devon)	1.00T	0.4	8
Gloucester	0.96	0.3 (dry bulb) 0.8 (AWS)	7/8
Lapford (Devon)	0.99	2.9	7
Liskeard (Cornwall)	1.00T	0.8	7/8
Norman Lockyer Observatory (Devon)	1.00	1.2	8 (inferred)
Northay (Somerset)	0.99	2.0	7/8
Penzance (Cornwall)	1.00T	0.7	8
Plymouth University (Devon)	1.00T	0.5	8
Salcombe (Devon)	1.00T	2.4	8 (inferred)
Shillingford Abbot (Devon)	1.00	1.9	7/8
Westonbirt Arboretum (Gloucestershire)	0.97	0.9	7/8
Channel Islands			
Guernsey Airport	1.00	0.9	8
Jersey Airport	0.99	1.9	8
Central southern England			
Chandlers Ford (Hampshire)	0.99	1.6	6–8
Middle Wallop (Hampshire)	0.98	0.5	7
Portchester (Hampshire)	0.99	1.2	8'ish
Purbeck (Dorset)	1.00	1.0 (electronic) 1.1 (whirling psychrometer)	8
Romsey (Hampshire)	0.99	1.9	7/8
Shide (Isle of Wight)	0.99	2.2	8
South-east England			
Alice Holt (Surrey)	0.98	3.3	variable
Beaufort Park (Berkshire)	0.97	3.0	part
Birdham (West Sussex)	0.99	2.0	scattered
Bracknell (Berkshire)	0.97	1.7	3–7/8
Cranfield (Bedfordshire)	0.95	2.2	patchy
Dorking (Surrey)	0.97	2.0	not much
Dover (Kent)	0.98	2.4	6/7
Epsom Downs (Surrey)	0.97	2.7	5'ish
Guildford (Surrey)	0.97	3.2	0–2
Hurstpierpoint (West Sussex)	0.98	3.2	not much
Motspur Park (Surrey)	0.97	3.6	0–2
Northwood (Middlesex)	0.97	1.6	patchy/well broken
Reading University (Berkshire)	0.97	2.1	not much
Reigate (Surrey)	0.97	1.7	2–4
River (Kent)	0.97	1.1	7
Royston (Hertfordshire)	0.95	1.2	not much
Steyning (West Sussex)	0.99	3	not much
Warlingham (Surrey)	0.97	1½	1–7+
Watford (Hertfordshire)	0.96	2.2	patchy
Wokingham (Berkshire)	0.97	2.5	patchy
Worcester Park (Surrey)	0.97	2.7	3–6
East Anglia/eastern England			
Benfleet (Essex)	0.96	1.4	scattered
Buxton (Norfolk)	0.92	2.3	not much
Cavendish (Suffolk)	0.94	1.8	7'ish
Chedburgh (Suffolk)	0.94	2.2	7
Morley (Norfolk)	0.92	1.5	7
Stratford St. Mary (Essex)	0.95	2.4	7
Winterton (Lincolnshire)	0.89	0.7	6–8
Midlands			
Churchover (Warwickshire)	0.94	1½	7/8

Table 1 Continued

Site	Obscuration*	SAT drop (degC)	Cloud cover (oktas)
Halesowen (West Midlands)	0.94	2.4	7
Harborne (West Midlands)	0.94	2.0	6
Harriseahead (Staffordshire)	0.92	1.7	4–7
Hockley Heath (West Midlands)	0.94	1.4	4–6
Market Harborough (Leicestershire)	0.93	1.7	7
Northamptonshire Grammar Pitsford Hall	0.94	1.6	5–7+
Riverside (Worcestershire)	0.94	1.3	6/7
Sutton Coldfield (West Midlands)	0.93	1.5	3–6
Tipton (West Midlands)	0.93	1.5	2–5
Warstock (West Midlands)	0.93	1½	broken–scattered
Weston Coyney (Staffordshire)	0.92	1.4	3–6
Northern England			
Beverley (East Yorkshire)	0.89	1.0	7/8
Carlon-in-Cleveland (North Yorkshire)	0.86	1½	4/5
Chester (Cheshire)	0.91	1	5/6
Drumburgh (Cumbria)	0.85	0.7	6/7
High Bradfield (South Yorkshire)	0.90	1.8	6–8'ish
Normanby (North Yorkshire)	0.86	1.2	3–8
Pateley Bridge (North Yorkshire)	0.88	1½	7/8
Sheffield (South Yorkshire)	0.90	1.0	broken
Wales			
Llansadwrn (Anglesey)	0.91	2.1	5–7
Moel y Crio (Flintshire)	0.91	1.9	5–6+
Penmaen (Swansea)	0.97	½	8, then 8 –
Presteigne (Powys)	0.94	0.9	7
Velindre (Powys)	0.95	1.0	7/8
Scotland			
Corsock (Kirkcudbrightshire)	0.85	2.8	scattered
Elderslie (Renfrewshire)	0.82	0.4	8
Pittrodie (Perth)	0.80	1.0	7
Westruther (Berwickshire)	0.82	1.0	7/8
Northern Ireland			
Helen's Bay (Co. Down)	0.87	2.1	7/8
Ireland			
Dun Laoghaire (Co. Dublin)	0.91	0.9	6
Continental Europe			
Pontremoli (Italy)	0.89	1.5 & 3.0	patchy
Schlüchtern-Elm (Germany)	0.97	1.3	thought cloudy

*Values inferred to the nearest hundredth from Bell (1997). T indicates a total eclipse.

Table 2 Mean screened surface air temperature (SAT) drops during the eclipse for different regions

Region	Number of sites	Mean SAT drop (deg C)
South-west England	12	1.2
Channel Islands	2	1.4
Central southern England	6	1.4
South-east England	21	2.3
East Anglia/eastern England	7	1.8
Midlands	12	1.6
Northern England	8	1.2
Wales	5	1.3
Scotland	4	1.3
Northern Ireland	1	2.1
Ireland	1	0.9
Continental Europe	3	1.9

England) had an intermediate SAT drop of 1.2 degC. Much smaller (flatter) SAT declines are evident for Guernsey Airport (0.9 degC) and Plymouth (0.5 degC) in the south-west quadrant of the UK. The coincident timings in the dips of these SAT profiles from such scattered locations is impressive and leaves no doubt that they can, in large part, be attributed to the eclipse.

Conclusions

Despite the encroaching front introducing synoptic changes to the relatively static weather pattern over the UK, the above reports (mainly from the UK) together show quite convincingly that the eclipse caused a widespread decline in SAT of typically 1–3 degC at screen height. As the boundary (surface) layer temporarily became decoupled from the higher atmosphere, ground temperature (where measured) fell considerably more than this. The 'effective' decline in SAT would be expected to have often been greater than suggested, because the eclipse occurred at the time of day (late morning) when temperatures were evidently rising most steeply – and convection or mixing was strong where thick cloud layers were absent – as part of the natural diurnal cycle. Some of the largest temperature drops attributed to the eclipse (locally up to about 6 degC in SAT) were measured in south-east England and East Anglia, where skies were relatively clear and the (approximately 97%) eclipse was very near to total. However, the screened SAT drop in these regions was more generally 2–3 degC. In south-west England (across a large part of which totality occurred) generally thick cloud cover typically muted the SAT response to a modest 0.5–2.0 degC drop. Solar radiation (obviously) fell to zero or near zero at mid-eclipse. There is considerable evidence from quite a large number of stations that low-level, convective Cu cloud dispersed during and immediately following mid-eclipse, and already light winds (any changes in which were unlikely to have caused the widespread SAT drop) widely fell calm.

Practically, people felt colder during the eclipse than the above declines in SAT would suggest because of the masking of diffuse as well as direct radiation at mid-eclipse. There is a widespread misconception amongst the public of shade compared with 'sun' temperatures.

Since major solar eclipses so clearly affect local and regional weather patterns, it is hoped that this paper will stimulate similar meteorological observations and further research at future such events. The next is the totality scheduled to cross southern Africa on 21 June 2001, and here weather conditions may well be clearer, although logistics (*i.e.* a dearth of suitable *in situ* stations) may preclude widespread useful measurements. However, interesting results may be obtained through the RMS's schools' MetLink project (Walker, personal communication). Through these spectacular astronomical phenomena, we gain an insight into the workings not only of the solar, but also of our own atmosphere.

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I am deeply indebted to all those kind observers who sent me their reports; without their extensive efforts this study would have been quite impossible. As far as possible, credits and acknowledgements have been integrated into the text but it has not been possible to use all the reports (and only a sample are shown here) so please allow me to express my collective gratitude. I also thank Roger Brugge for forwarding several reports and helping me unravel the synoptic code. Graham Bartlett, Library Information Manager at the National Meteorological Library and Archive, supplied a copy of the *Daily Weather Summary* for 11 August, and the University of Dundee Satellite Receiving Station (Neil Lonie) provided high-resolution UK satellite images.

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