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The winter of 1988/89

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Forecasting night-time illumination

J.D. Turton
Meteorological Office, Bracknell
G.D. Stone
Royal Air Force, High Wycombe

Summary

With the increasing use of night vision goggles to aid night flying, there is a requirement for predictions of night-time illumination. The factors that affect the night-time illumination level are discussed and a model for determining the illumination presented. Estimates from the model are compared with those from other models and an example illustrating its use is given. The example highlights the effect that cloud can have on the illumination levels.

1. Introduction

There is currently an increase in the use of night vision aids for both fixed-wing and helicopter flying by all three Services. Night vision goggles (NVGs) are image-intensifying devices that collect and electronically enhance the available light at visible and near infra-red wavelengths. They are lightweight devices which are mounted on, or incorporated into, a pilot's helmet and they present the user with an image which is similar to that which he would see by daylight. (The use of such equipment is discussed in a recent article by Jones 1986.) Although NVGs are under continual development and their sensitivity is being increased, there is still a lower limit to the ambient light level below which they are ineffective. Consequently there is a requirement to forecast night illumination levels, both for operational sorties and for longer-term planning, particularly in respect of booking training areas for helicopter pilot training. Light levels and the times of astronomical events, e.g. sunrise/sunset, moonrise/moonset and the times of twilight, are also often required for land operations.

2. Background

The techniques for calculating light levels are conceptually straightforward and involve two aspects, astronomical and atmospheric. The light (sunlight and moonlight) incident at the top of the atmosphere is determined by the position of the Earth relative to the Sun and the Moon. However, the amount of light that actually reaches the surface is reduced because of scattering and absorption due to aerosol and water particles in the atmosphere.

An additional aspect that effects the illumination is 'cultural lighting'. This is the light which originates from towns and cities and is reflected back by cloud layers. It can significantly increase the ambient light level.

2.1 Astronomical considerations

The position of the Sun relative to an observer on the Earth defines the periods of daylight, twilight and night. These are defined by the solar zenith angle. The various phenomena are given in Table I.

Table I. Criteria for sunrise/sunset and twilight

Phenomenon	Zenith angle of centre of Sun
Sunrise, sunset	90° 50′
Civil twilight	96°
Nautical twilight	102°
Astronomical twilight	108°

Similarly, moonrise and moonset are when the lunar zenith angle has a value of $90° \ 34' + S - \alpha$ where S and α are the Moon's angular semi-diameter and parallax, respectively.

2.2 Meteorological considerations

As noted earlier NVGs are sensitive to light at visible and near infra-red wavelengths. The visible part of the spectrum is that between the dark blue and dark red limits at 0.39 μm and 0.76 μm wavelengths respectively. NVGs respond to light at wavelengths from about 0.6 μm (in the red) to 0.9 μm (in the near infra-red), a range which is sensitive to starlight.

Electromagnetic radiation at these wavelengths is scattered by particles within the atmosphere. Depending upon the particle sizes there are two mechanisms; aerosol particles, which are typically the same size as the wavelengths of interest, lead to Mie scattering, whilst the larger cloud and precipitation particles cause geometric scattering. The concentration of particles is important since the attenuation increases with concentration. Absorption effects are negligible in comparison.

A consequence of these effects is that in hazy but cloud-free conditions, the illumination is slightly reduced and due to diffuse sun/moon light; the sun/moon may be indistinct. However, the most significant effects occur in cloudy conditions, when the illumination can be much reduced, particularly if the cloud is sufficiently thick to produce rain.

2.3 Units of illuminance and typical values

The typical light levels resulting from natural illumination for clear sky conditions are illustrated in Fig. 1, where the lines refer to the illumination from the sun and the moon (for various phases) as a function of the solar/lunar altitude (90° − the zenith angle). The figure shows how, at night, the light level depends upon both the altitude and phase of the moon. Some typical night-time illumination values are given in Table II.

Note that the sensitivity of the human eye varies in proportion to the logarithm of the illumination.

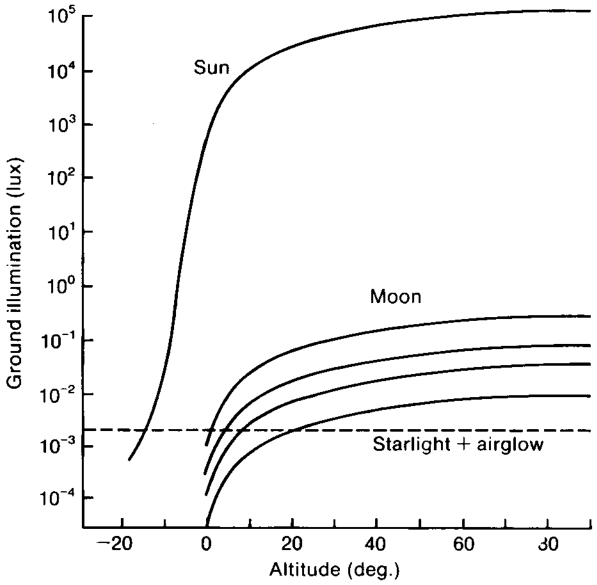

Figure 1. Illumination levels on the surface of the Earth, under clear-sky conditions, from the Sun and the Moon at various altitudes and from starlight and airglow. Phases of the Moon are 180° (line 1) (full moon), 120° (line 2), 90° (line 3) (first/last quarter) and 60° (line 4), these being the angles between the Sun and Moon. (Taken from Yallop 1986.)

Table II. Typical natural night-time light levels

Phenomenon	Light level (mlx)*
Full moon overhead	270
Full moon at 45° altitude	160
First (or last) quarter moon at 45° altitude	20
Nautical twilight	10
Astronomical twilight	3
Airglow plus starlight	2

* For a source of unit spherical candlepower, the total flux emitted is 4π lumens. 1 lx (lux) is 1 lumen incident per square metre, 1000 mlx (millilux) equals 1 lx.

3. Night illumination models

Given the astronomical and atmospheric considerations described, it is possible to estimate the level of natural illumination for a prescribed place and time. However, there is as yet no means of formalizing the effects of cultural lighting.

A model to determine the ambient light levels has been developed by the Computer and Information Systems Branch (CISB) of Royal Air Force High Wycombe, and a version of the model has been adapted to run on the Meteorological Office computer system. The model calculates the lunar and solar geometry following methods described by Duffet-Smith (1988), which use the basic orbital characteristics of the Earth and the Moon. The actual light levels are then determined using algorithms given by Yallop (1986). Results from the model are available on the RAF ASMA (Air Staff Management Aid) system, on the

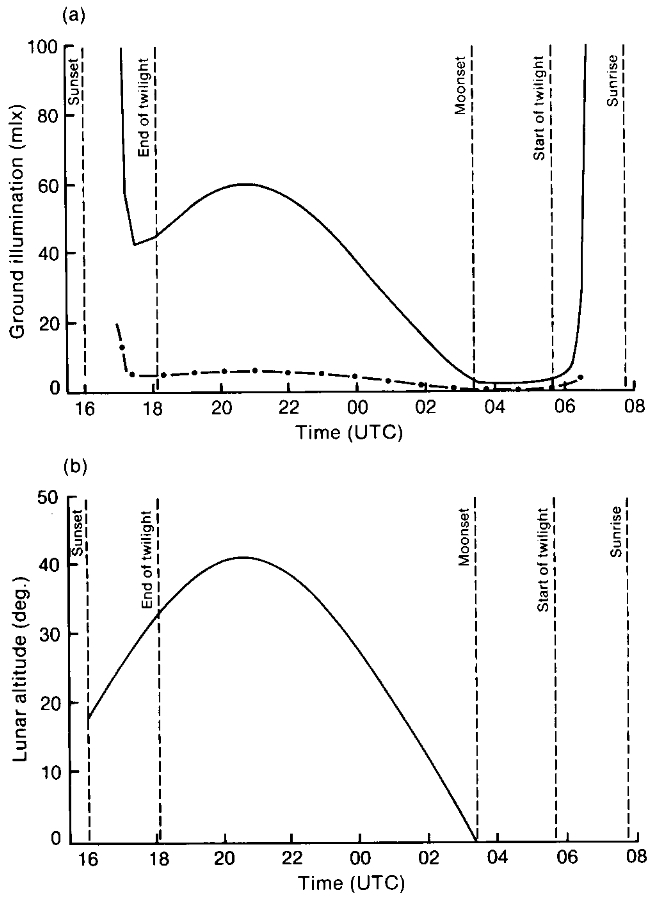

Figure 2. (a) Ground illumination for the night of 19/20 November 1988 for a location near 54°N, 1°W. The solid line shows the illumination under clear-sky conditions, the dot-dashed line for overcast conditions. (b) Lunar altitude during the night. The times of sunrise and sunset, the end and start of the twilight periods and of moonset are indicated.

Meteorological Office computer system, and microcomputer versions of the program are available at Meteorological Office outstations. A version of the model should also soon become available on the Meteorological Office Outstation Display System (Cluley and Hills 1988).

Fig. 2(a) shows an example of the night-time ground illumination for 19—20 November 1988, near 54°N, 01°W. Sunset was at 1600 UTC and the twilight periods ended at 1640 UTC (civil), 1724 UTC (nautical) and 1806 UTC (astronomical). As illustrated in Fig. 2(b) the moon rose during the early part of the night, reached a maximum elevation of 41° around 2100 and thereafter fell, setting at 0329. The estimated light level increased and fell accordingly. After moonset there was only the background starlight and airglow until the morning twilight, which began at 0537 UTC (astronomical), 0619 UTC (nautical) and 0703 UTC (civil) and ended at 0744 UTC (sunrise). The phase of the moon increased from 80% to 85% during the night.

The effect of cloud cover on attenuating the light level is simulated in the model by multiplying the clear-sky light level by a reduction factor. For thin cloud the light level is multiplied by 0.4, for medium cloud by 0.15 and for heavy overcast cloud by 0.1. As a guideline thin cloud can be taken for situations when there is a single cloud layer (e.g. stratus/stratocumulus or thick cirrus/cirrostratus) and medium cloud when there may be more than one layer and/or precipitation. Heavy cloud refers to the worst case conditions, overcast precipitating nimbostratus or cumulonimbus.

Also shown in Fig. 2(a), for comparison, are the estimated light levels for thick, overcast cloud. For NVG usage a minimum light level of 2–5 mlx is required (depending on the type of goggle) and, as illustrated in Fig. 2(a), thick cloud can bring the ambient light level down below this threshold. Consequently the ability to predict the cloud cover is of prime importance in forecasting light levels for the use of NVGs.

3.1 Comparison with other models

Night-time illumination models have also been developed by the German Military Geophysical Office (GMGO) and the US forces; the Air Force Geophysical Laboratory (AFGL) and the Army Atmospheric Sciences Laboratory (ASL). The AFGL model forms part of a Tactical Decision Aid (TDA) to support the use of NVGs and TV sights; this TDA is known as the TV TDA (Higgins *et al.* 1987). The ASL model (Duncan and Sauter 1987) is essentially the same as the AFGL model but can be run in a stand-alone mode to produce illumination estimates.

The results from the RAF/Meteorological Office model (hereafter referred to as the METO model) have been compared to those from the AFGL (Mk. II TV TDA) and GMGO models. A comparison for the night shown previously (in Fig. 2), for clear skies, is shown in Fig. 3(a). The METO and AFGL models give similar values, but the GMGO model estimates are slightly lower. Similar agreement for clear skies was also observed in a number of other direct comparisons. The close agreement between the METO and the AFGL models is not surprising since both models utilize the twilight and moonlight data of Brown (1952). The AFGL model follows the methods of van Bochove (1982) in calculating the lunar and solar geometry, which gives values virtually identical to those calculated in the METO model. No details of the methods used in the GMGO model are currently known.

As noted earlier, the effect of cloud is introduced rather simply in the METO model. However, in the AFGL model the illumination is determined from polynomial fits to calculations made using a simple two-stream broad-band (over the entire solar spectrum) radiative transfer model for a three-layer atmosphere and requires details of the cloud cover to be input. In the AFGL (and ASL) model the atmospheric transmittance also depends upon the surface albedo and the lunar zenith angle — the transmittance being greatest over surfaces with a high albedo (such as snow) and when the moon is high. The GMGO model gives three different estimates for clear, cloudy and overcast conditions.

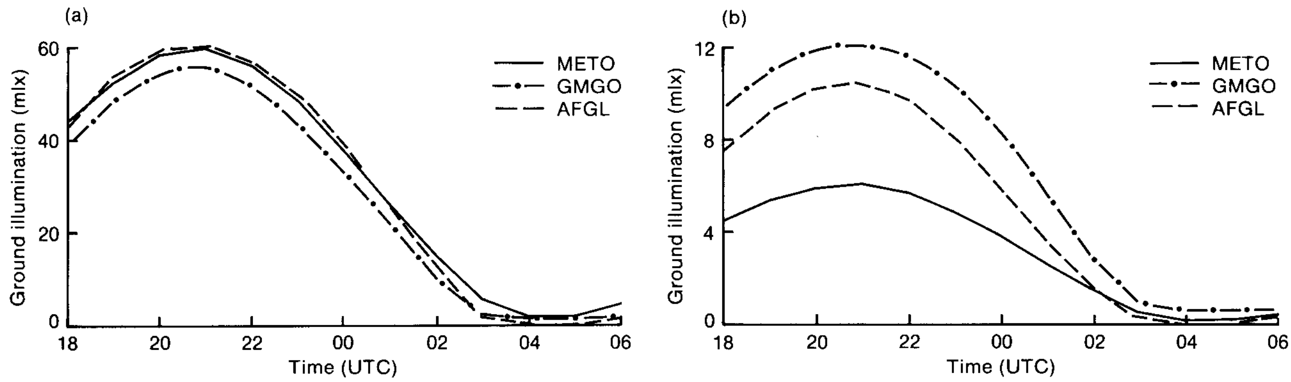

Figure 3. Comparison of estimates from different illumination models for the night of 19/20 November 1988 for a location near 54° N, 1° W. The models used are indicated, results are shown for (a) clear-sky and (b) overcast conditions.

A further comparison for 'worst light' conditions is shown in Fig. 3(b). The METO model clear-sky values are multiplied by a factor of 0.1 as appropriate for heavy cloud; the TV TDA was run with precipitation and thick overcast cloud specified and the GMGO model values were for 'overcast' conditions. The results show that the METO model values are typically half as large as the GMGO model estimates, and are also less than the values from the TV TDA (AFGL), which were closer to the GMGO estimates. Similar differences were seen in other examples.

However, whilst these differences can be marked, they should be viewed against the variability that can occur over the range of cloud conditions. Also, if the cloud is broken, then some areas will be in direct moonlight (at up to nearly clear-sky levels) and other areas will be in cloud shadows. The TV TDA actually calculates illumination levels for both direct and shadow regions, and the fraction of each. This detail is not, however, produced by either the METO or GMGO models.

3.2 Example of use

An example illustrating the use of the model is given below. Fig. 4(a) shows the synoptic chart for 0000 UTC on 17 December 1988. A frontal system had moved steadily across southern England during the afternoon and early part of the night. The position of Lyneham (51° 30′N, 1° 59′W) is marked on the chart. The change in the cloud cover at Lyneham, with the frontal cloud (only low-level stratiform cloud was visible from the ground) clearing after 2100 UTC and altocumulus then developing, is shown in Fig. 4(b). The estimated light levels (from the METO model) for Lyneham are shown in Fig. 4(c), and illustrate how the light level increased after 2100 as the frontal cloud passed. The light levels then fell as the moon sank in the night sky. Fig. 4(c) shows the existence of a window between 2100 and 0000 where the light levels were sufficient for NVG use. The existence of illumination windows such as this can be forecast using an illumination model and then overlaying the effects of the predicted cloud cover.

The effect of cultural lighting also needs to be considered. Near to towns and cities there can be a significant increase in the light level, especially when there is low-cloud cover. However, this effect can still be detectable many miles from the nearest town/city.

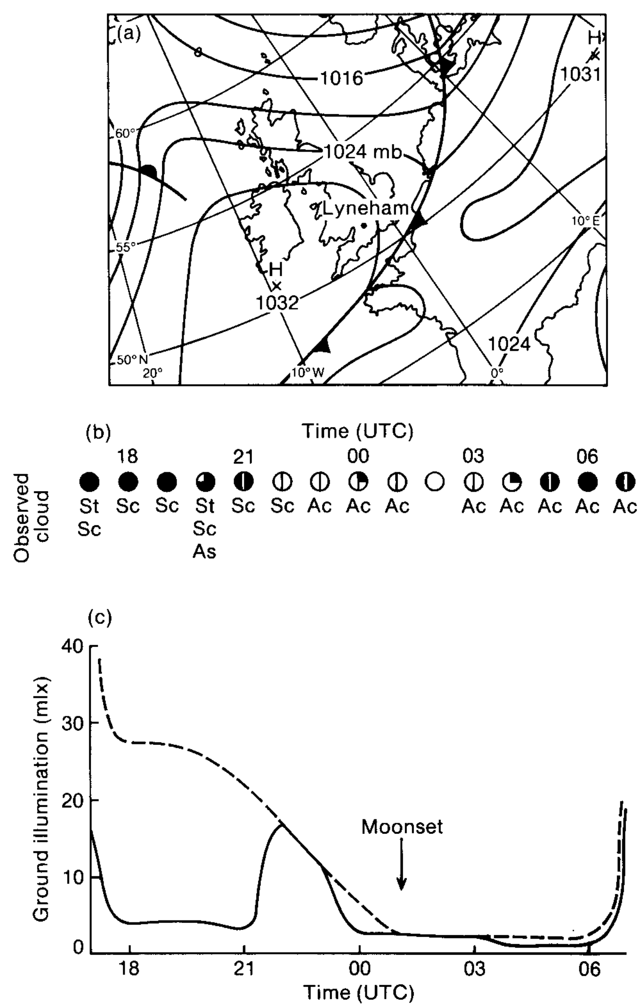

Figure 4. (a) Synoptic chart for 0000 UTC on 17 December 1988, the location of Lyneham is marked, (b) cloud observations at hourly intervals for Lyneham on this night, and (c) estimated illumination levels (continuous line) during the night (for comparison the clear-sky values are shown by the dashed line).

It should also be mentioned that the available light is not the only factor that needs to be considered when forecasting for NVGs. The range and clarity with which a particular object can be seen is determined by the contrast of the object against its background, which depends upon their relative reflectivities and the illumination, and on the atmospheric visibility.

4. Concluding remarks

This article has discussed how it is possible to make estimates of the clear-sky night-time illumination levels for a given time and place using algorithms which consider the lunar and solar geometry. The amount of light reaching the surface can be significantly reduced by the presence of cloud, and at present this is taken into account by applying simple reduction factors appropriate to the cloud cover. The examples presented have demonstrated that, in order to produce useful estimates of illumination, it is necessary to have an accurate forecast of cloud cover and type. Despite its simplicity, the method used to include cloud into the model does permit the forecaster to make reasonable estimates of the night illumination level. In the future there may be some benefit from including a more sophisticated treatment of the effect of cloud, utilizing numerical model predictions of the various cloud types and amounts which are becoming available to the forecaster.

The model is used to provide estimates of the night-time illumination, which are required to support the use of NVGs in operations and training. However, models of this sort (generally referred to as TDAs), which are used to give advice to the military, are of necessity evolutionary; enhancements and improvements being made as the needs and requirements develop.

It is anticipated that various TDAs, such as this model, may be linked to, or incorporated within, some of the computerized mission planning systems which are currently being developed by the Armed Forces. Meteorological information, and the effects of meteorology on particular military equipment, forms an integral part of these planning systems. These systems will require the forecaster to input the meteorological information and interpret the TDA predictions, and they will need improved links between Meteorological Office and military ADP equipment.

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The aurora

R.J. Livesey
Edinburgh

Summary

A brief description is given of the main features and cause of aurorae.

1. Introduction

The aurora is one of the most striking solar-geographical phenomena and one which is frequently seen by meteorologists making conventional weather observations particularly at high latitudes.

The Northern Lights (as aurora in the northern hemisphere are also known) have fascinated mankind for many centuries. References to their apparition may be traced in the written word back to the times of ancient Greece and in the old records of China, Japan and Korea. The Norsemen related the Merry Dancers or flaming aurora as we now know them, to revelry among their gods while in medieval Europe the blood-red aurora in particular was considered to be a portent from heaven of forthcoming worldly disasters. Did not Otto the Great die in 973 after the appearance of a fiery heavenly sign?

It was Gassendi in 1621 who is said to have christened it the Aurora Borealis, the Latin for northern dawn, an appropriate name for the twilight-like auroral glow when seen low down on the northern horizon. After observing the great aurora of 5 March 1616 from London, Edmond Halley was the first person to suggest that the aurora had an electrical origin by proposing the existence of a 'luminous magnetic vapour'. Captain James Cook was the first European known to have recorded a sighting of the Aurora Australis that took place on 17 February 1773 when his vessel the *Resolution* was sailing in the southern auroral zone.

From about the mid eighteenth century the scientific investigation into the nature and cause of the aurora began. Cavendish attempted height measurements in 1784 while Biot examined the polarization of the aurora from Shetland in 1817. Spectroscopy was attempted by Angström in 1866 and by 1874 Fritz had published his monumental investigations into the frequency and distribution of the northern hemisphere aurora. The International Polar Year of 1882–83 brought in much observational data.

In 1901 Birkeland commenced laboratory experiments to simulate the effects of incoming electrified particles upon the magnetized planet and by 1911 Størmer and others were carrying out an intense stereo-photographic programme to determine heights of the auroral forms. Since then many investigators, using an increasing variety of equipment from radio to artificial earth satellites, have probed the depths of space to determine the solar origins of particles and their eventual effects upon the Earth's magnetic field and the atmosphere that cause the aurora.

At present solar activity is approaching the next maximum in its 11-year cycle (estimated to occur in the period late 1989 to end of 1990) and has been predicted to reach greater levels than ever observed before. It is to be expected that the frequency of sightings of aurora will reach a maximum in the next year.

2. The effect of the geomagnetic field on charged particles

The aurora is the result of bombardment of the atoms and molecules of the Earth's atmosphere by charged particles. In a magnetic field the charges constrain the particles to move in directions parallel with the magnetic field lines of force; in effect the magnetic field guides the particles while the associated electric fields in the atmosphere determine the particle velocities.

To a first approximation the geomagnetic field is like that of a bar magnet (a dipole) at the centre of the Earth with its axis in line with the two magnetic poles (the north magnetic pole is located at approximately 79° N, 70° W). Close to the Earth the magnetic field lines would be expected to curve out in space and link the two hemispheres symmetrically. Close to the geomagnetic poles the field lines are nearly vertical and so it is into these regions that charged particles are preferentially guided down to Earth. The regions are two oval rings surrounding the north and south magnetic poles.

The Sun emits a steady stream of charged particles called the solar wind (described in greater detail later) which carries along with it its own magnetic field. This impinges on the geomagnetic dipole field and produces a distortion which remains roughly aligned with the Sun. As a consequence the instantaneous oval ring is displaced from symmetry about the poles, away from the Sun, and is narrower on the sunward side. The ring increases in diameter with solar activity and is up to 500 km in width. Averaged over all conditions the ovals define the regions call the auroral zones, as in Figs 1(a) and 1(b), where aurora is most frequently seen. An example of the relative frequency of the visibility of the aurorae with respect to geomagnetic latitude is given in Fig. 2.

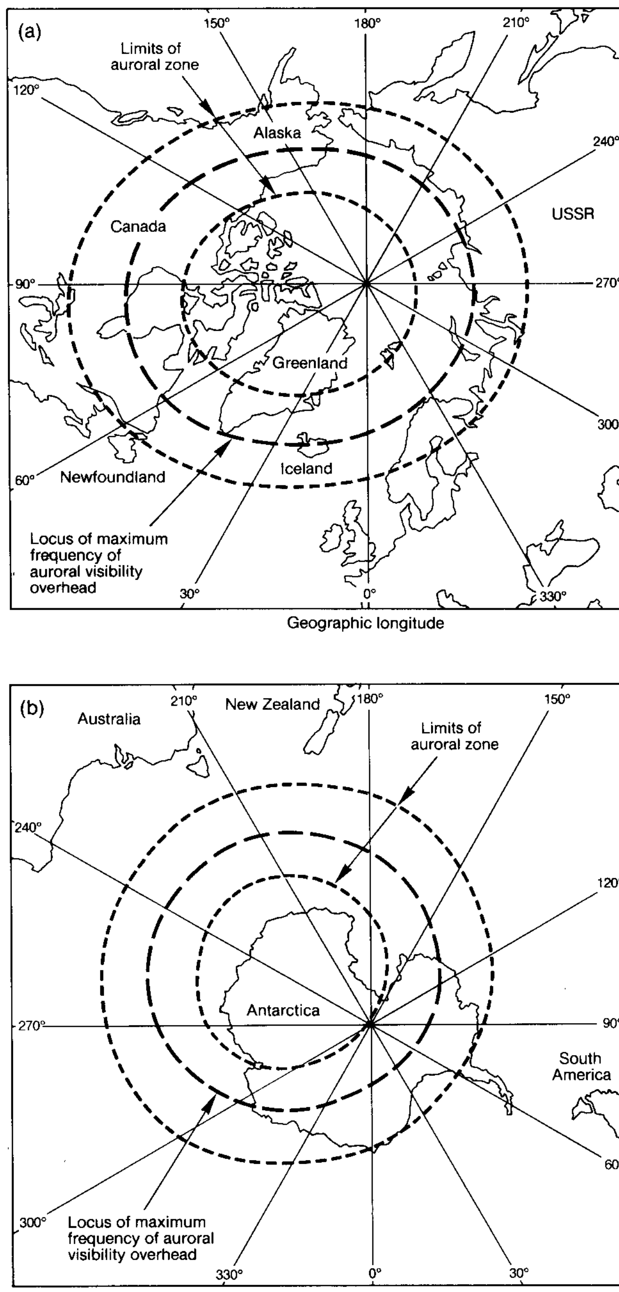

Figure 1. Approximate positions of (a) the northern and (b) southern auroral zones with the locus of maximum frequency of aurora overhead indicated by long dashed lines and the limits by short dashed lines.

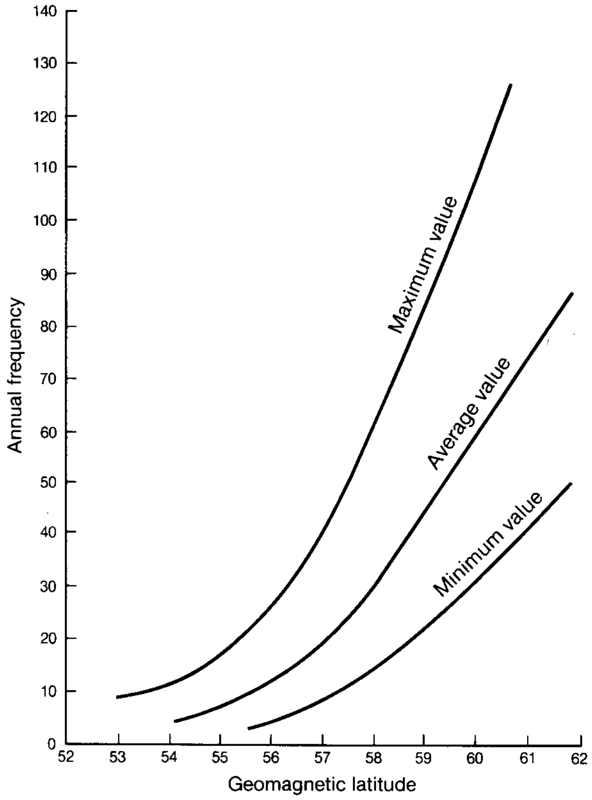

Figure 2. Comparison of frequency of occurrence per annum of aurora as a function of geomagnetic latitude and for years of maximum, average and minimum frequency (corresponding to different degrees of solar activity) in western Europe and the Atlantic area from 1962 to 1988.

3. The appearance and occurrence of aurora

The particles emitted by the Sun are mainly electrons and protons and the altitudes to which they can penetrate down into the Earth's atmosphere as a function of their energy are given in Table I. Auroral light is generated by the conversion of bombarding electron and proton kinetic energy into discrete wavelength emissions by impacting atoms and molecules in the atmosphere which become excited and then shed their energy in radiant form. A selection of auroral emissions is given in Table II, including one which is partly produced by solar ultraviolet radiation.

Table I. Penetration of particles from the Sun into the Earth's upper atmosphere

Particle	Energy (kev)	Altitude of penetration into atmosphere (km)
Electron	1	150–200
	10	100
	30	90
Proton	30 000	50
	500 000	Ground level during severe polar cap event

An auroral storm might begin with a twilight-like glow seen in the direction of the magnetic pole followed by the development of one or more homogeneous arcs slowly rising in altitude from the horizon. Rayed structures would then develop and the arcs dissolve into rayed bands. If the storm extends overhead, the rays form into a spoke-like structure with the centre of convergence situated at the observer's magnetic zenith due to the perspective effect of looking into the distance along parallel ray systems. The aurora may then break up into flickering and flaming structures which, on dying down, leave luminous patches in the sky. The whole performance may repeat itself an hour or so later.

A discrete aurora is like a curtain approximately 1 km thick and several thousand kilometres in length often accompanied by diffuse aurora on the nightward side. There is also aurora on the daylight side of the oval, seen during the polar night and mainly consisting of diffuse red emissions. These are shown diagramatically in Fig. 3 on a plot of geomagnetic latitude and local time. Figs 4, 5 and 6 show some of the banded auroral forms detailed in Table II.

During quiet periods the auroral oval remains stable, but with the onset of an auroral substorm a surge of activity passes westwards along the oval and the oval may move polewards. During great auroral storms the energy of the particles increases so that they can more readily travel down magnetic field lines and enter the Earth's atmosphere to lower latitudes. On 13/14 March 1989 a large storm occurred with aurora being seen in the tropics.

4. The solar emission of charged particles

The Sun is the ultimate source of auroral energy. It has a complicated magnetic field that controls the tenuous high temperature coronal atmosphere that surrounds it, together with the protons, electrons and other particles which escape into outer space. The field activity is related to the rise and fall of the sunspot cycle. There are points of weakness in the Sun's magnetic field that generate what are called coronal holes through which material may leave the Sun in a steady high-speed stream. Coronal holes are most active during the declining years of the sunspot cycle. There is also a steady evaporation of particles from the Sun at lower velocities called the solar wind. The Sun's magnetic field pervades the solar system as the interplanetary magnetic field which contains variations in polarity.

Associated with the sunspot cycle are eruptive events that can cause clouds of high-speed particles and magnetic bubbles to leave the Sun and encounter the Earth. Proton events can cause effects in the Earth's polar regions that appear to correlate with solar flares. These are eruptive disturbances associated with individual sunspots. The classical storm aurora is not now thought to be necessarily the result of flare activity but the result of some process in the inner corona of which the flare phenomenon is but an adjunct and not an origin.

Table II. A selection of auroral spectral emission lines

Type and emission (nm)	Target particle	Bombarding particle	Auroral height (km)	Colour	Comment
Type A 630.0 636.4	Oxygen*	Electron Low energy	> 150	Blood-red	High altitude aurora. Above green aurora.
Type B 666.1 669.6 686.1	Nitrogen*	Electron High energy	65–80	Red	Lower border of arcs and bands.
Type C 557.7	Oxygen*	Electron	90–150	Green	Glows, arcs, bands, rays, patches. Normal aurora.
Type D 630.0 636.4	Oxygen*	Electron	> 105	Red and green alternate	Associated with rapid horizontal auroral movement up to 10 km s^{-1}.
Polar cap 656.3	Hydrogen alpha	Proton	20–60	Red	Diffuse.
Sunlit 630.0 391.4 427.8	Oxygen* Nitrogen† Nitrogen†	Electron plus UV rays	110 to 1100	Red Blue Blue	Tops of rays.
427.8	Nitrogen†	Electron	< 90	Blue-purple	Base of bright arcs.

* Atomic
† Molecular

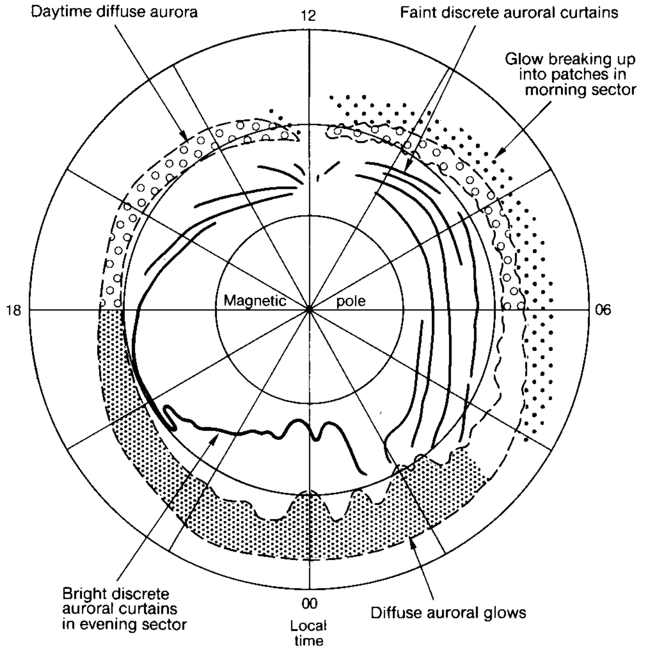

Figure 3. Approximate positions of different auroral types within the auroral oval (after S.-I Akasofu).

Figure 4. Aurora of type C (green, 557.7 nm) partially obscured by cloud.

Figure 5. Aurora of types A and B (red, 630.0 to 686.1 nm).

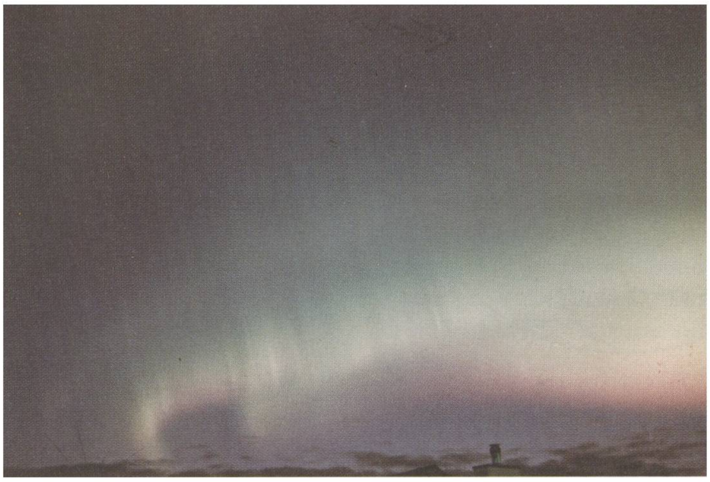

Figure 6. Aurora of type C (green 557.7 nm) overlying type B (red, 666.1, 669.6 and 686.1 nm).

Multiple flares in quick succession often correlate with active auroral storms. The interplanetary situation is shown schematically in Fig. 7.

The solar wind alters the shape of the quasi-dipole geomagnetic field considerably and it takes up a shape similar to the head and tail of a comet. A bow shock wave forms on the sunward side, like that of a ship cutting through the water, where the geomagnetic field and the solar wind magnetic field collide. The magnetosphere forms the head of this structure and within it are found the Van Allen radiation belts of trapped particles, the equatorial ring current and the plasmasphere that stretches down inside the magnetotail to form the plasmatail. There is a region of open magnetic field lines related to the poles that enables the interplanetary magnetic field to connect with the geomagnetic field and there is another region of closed field lines linking the two magnetic poles. The whole system of magnetic fields and plasmas forms a huge natural dynamo and large electric currents can be generated in the outer atmosphere. A representation of the magnetospheric structure is given in Fig. 8.

Active conditions on the Sun influence the stability of the magnetosphere and magnetotail to cause magnetic storms and substorms that in turn generate the storm aurora. The quieter aurorae associated with the wind streams emanating from coronal holes tend to peak in frequency in the declining years of the sunspot cycle. The transient explosive type of activity tends to intensify and decline with the cycle. Coronal hole aurorae can repeat themselves every 27 days for several rotations of the Sun each time the high-speed stream of particles encounters the Earth. Transient events may repeat themselves only if the disturbed area of the Sun remains active for more than a solar rotation. In Fig. 9 a comparison is given between sunspot, magnetic and auroral activities as measured in recent years by the Aurora Section of the British Astronomical Association.

A high-speed stream of particles forms a shock wave by driving into the slower-moving solar-wind particles. When this shock encounters the magnetosphere the field structure is compressed and the field strength is intensified to show up on ground-based magnetometers as a storm sudden commencement (SSC). This may or may not be followed by a main-stage magnetic storm in which the intensity of the field quickly falls and then slowly recovers to normal. The cause is due to the intensification of the equatorial-ring currents in the upper atmosphere that effectively act as a 'degaussing' device to reduce the field strength. Main-phase storms

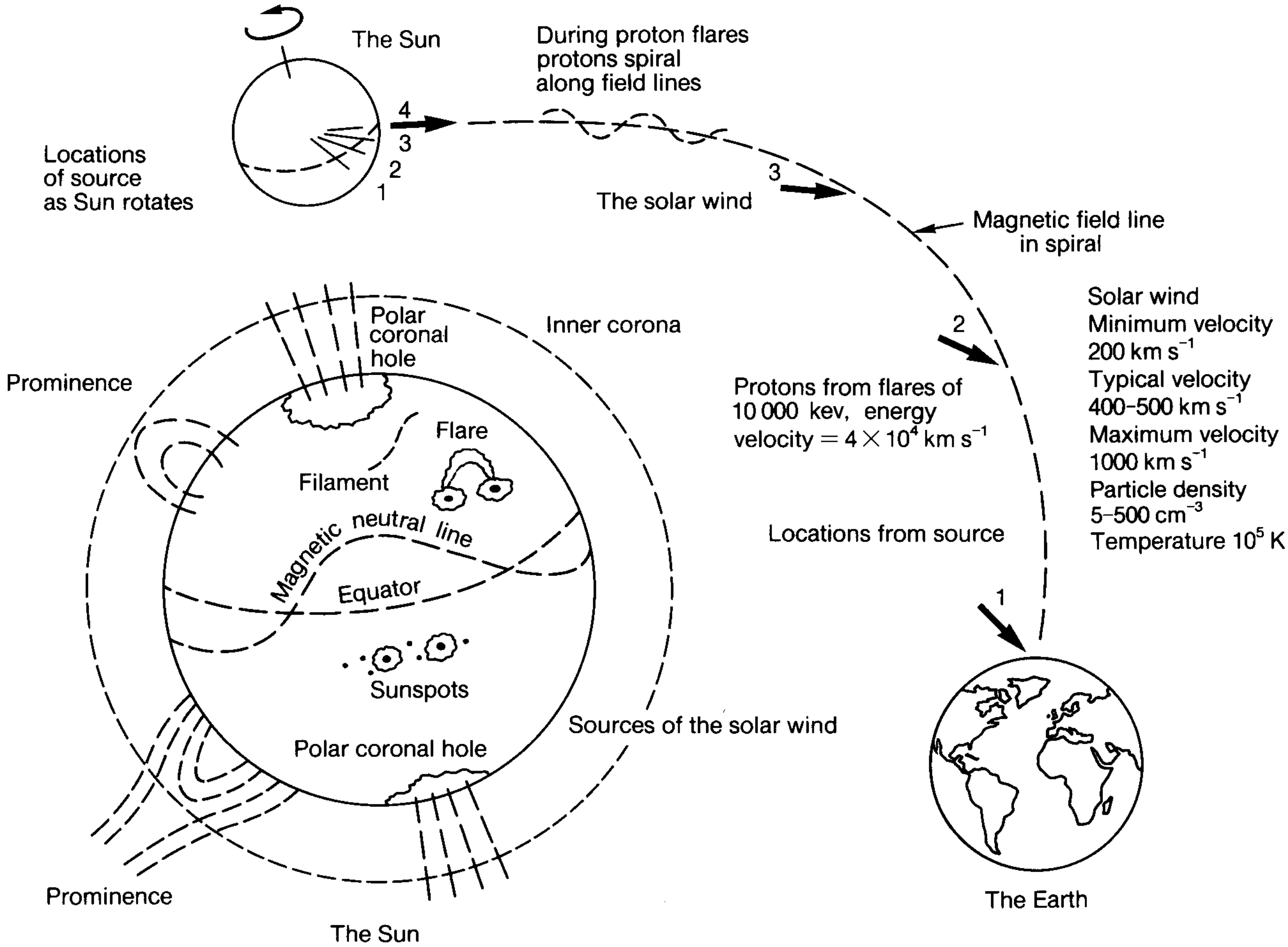

Figure 7. Solar features and the solar wind.

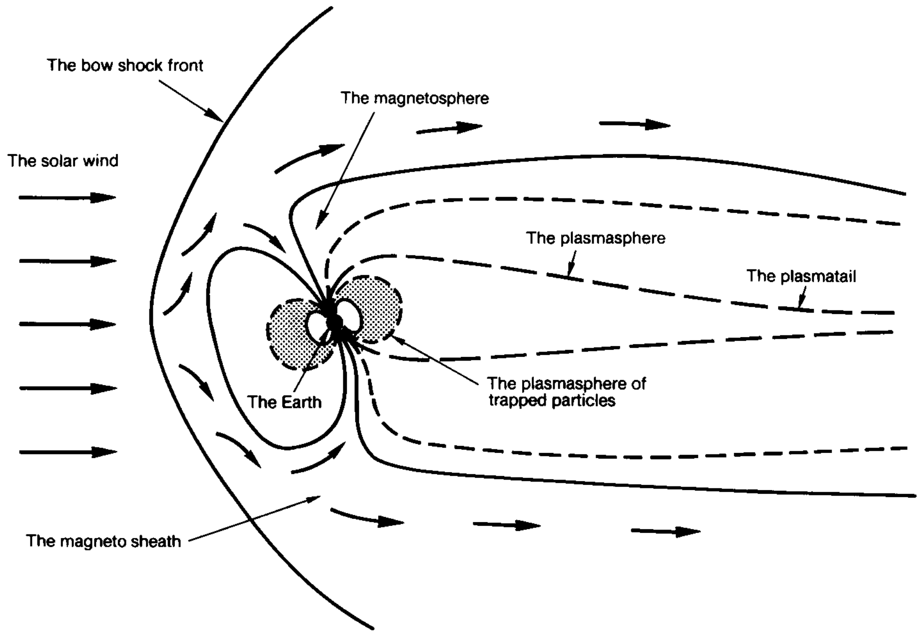

Figure 8. Diagrammatic representation of the magnetosphere.

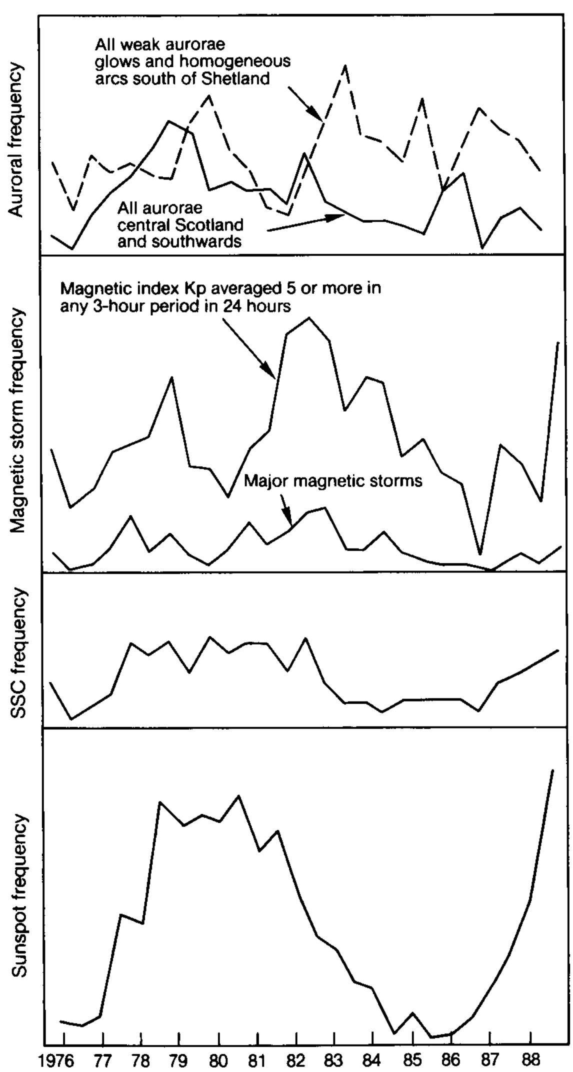

Figure 9. Schematic comparison of sunspot, magnetic, auroral and storm sudden commencement (SSC) activity 1976–88.

may occur without SSC or may slowly, rather than quickly, evolve. Idealized examples of magnetograms giving various types of storm are shown in Fig. 10.

The interplanetary magnetic field (IMF) is very variable and it is thought that the vector direction of the north–south component parallel with the Earth's magnetic axis is the key to the aurora. If the component points north then the IMF does not interlink with the Earth's field. If the component progressively turns south then the IMF lines can interlink with the Earth's field to cause magnetic and auroral activity. The direction of the IMF component appears to set the level of the dynamo generation irrespective of the speed of the solar wind. Although a major storm involves both the velocity of the high-speed solar wind and the IMF component direction the auroral substorm is triggered by the field direction on its own.

It would appear that low energy particles from the solar wind may enter the polar atmosphere by travelling down the connected field lines. The high particle-energy substorm aurora derives its material from the magnetotail, the particles being driven out of the tail into the polar and mid latitudes via the plasmasphere regions as the plasmatail collapses, rather like toothpaste coming out of a tube. The magnetosphere can bounce like a soap bubble and these variations in shape and other instabilities can cause particles to dribble into the atmosphere to form isolated arcs and other aurora. There are a number of observations on record of mid-latitude overhead aurorae suddenly appearing with lives of only 5–10 seconds.

5. Terrestrial effects associated with magnetic storms and aurora

The magnetic storm and its associated aurora can have far reaching consequences to the human race as the

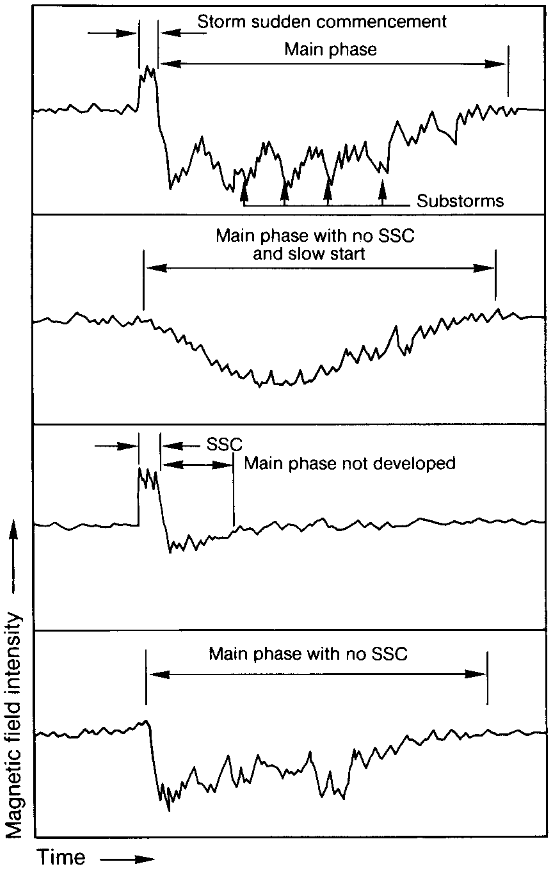

Figure 10. Idealized magnetograms of typical magnetic storms.

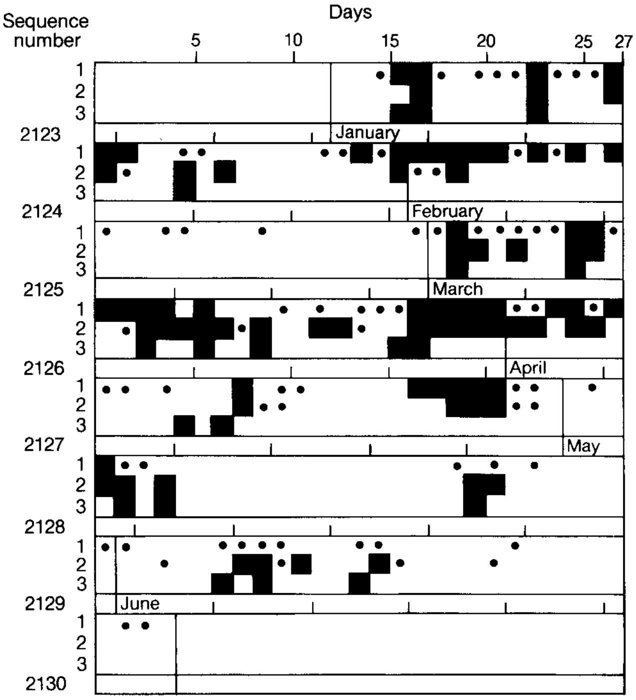

Figure 11. Bartels diagram for January to June 1989. In each sequence line 1 indicates an evening of auroral activity, line 2 is magnetic activity (K_p index averaged five or more for any 3-hour period in 24 hours) and line 3 indicates dates of sudden storm commencement. Dots denote weak activity and solid squares denote strong activity.

result of the atmospheric ionization and electrical ground potentials generated. The aurora can blot out HF radio communications but on the other hand can be used to increase the transmission path for VHF radio, a technique commonly used by amateur operators. Ground potentials can induce overloads in electricity transmission lines and on 13/14 March 1989 sections of Quebec Hydro in Canada were without electricity as the circuit breakers responded to excessive currents. New York was blacked out by the same process in 1969 and 1972. Auroral potentials can also induce electrical currents in long distance conduits such as the Alaska oil pipeline with the possibility of reversing polarity in the anti-corrosion protection systems. Magnetic surveys for mineral prospecting and other purposes, including oilwell drilling instruments, can be disrupted by magnetic activity.

The forecasting of magnetic and ionospheric disturbances is carried out by various institutions such as the National Oceanic and Atmospheric Administration in Boulder, USA, which issues weekly a bulletin *Preliminary report and forecast of solar-geophysical activity.* Information can also be provided by teleprinter and by radio. The work involves observing the Sun and assessing solar activity as it develops and then estimating the next move in the poker game, rather like weather forecasting, but with the Sun holding the aces and jokers to surprise us. Forecasting can also be based upon the plotting of past geomagnetic and auroral activity as on a Bartels diagram and looking for the repetitive patterns. An example for the first half of 1989 is shown in Fig. 11. Short-range forecasting is possible from the behaviour of magnetometers and by listening for radio aurora conditions. Radio waves from the sun may also be monitored. However, experience shows that correlation with aurora may not be high while the geomagnetic latitude of the observer comes into play.

The Aurora Section of the British Astronomical Association (of which the author is the Director) acts as a collecting centre for auroral observations, and summaries of auroral and geomagnetic activity are included in the Association's bi-monthly journal.

The story of the aurora is not yet concluded and is subject to updating and rewriting. What causes the electrons to accelerate during a substorm is not completely understood while recent research is tending to alter the earlier view that solar flares were the direct cause of the high-speed particle streams of the great magnetic storms. Although artificial Earth satellites have almost taken over from ground-based observations in the surveillance of the aurora, further studies are being planned to enable satellites to unravel the complex structures of magnetic and electric fields associated with the aurora.

In spite of the technology of modern science, the aurora remains one of the most beautiful and awe inspiring of nature's phenomena, to be enjoyed on a clear dark night in open country away from the lights of civilization.

Estimating grass minimum temperature and probability of ground frost at Eelde (Netherlands)

C. Floor
Royal Netherlands Meteorological Institute (KNMI), De Bilt

Summary

Forecasts of ground frost have been issued for many years in The Netherlands; a practical forecasting tool, however, was not available for the forecaster on the bench. In this study a set of forecasting diagrams is given for use at Eelde airport, situated in the north-east of the country; separate diagrams are constructed for use in April/May and October/November. The probability of ground frost at Eelde can be estimated from the tables given in this paper. Given the appropriate data, similar tables could be constructed for use at other sites.

1. The data

The data used are observations of wind speed and total cloud amount at 03 UTC, state of ground at 06 UTC and minimum temperature and grass minimum temperature both observed in the period 00–06 UTC. Eelde (WMO number 06280, ICAO letter code EHGG, 35° 08′N, 06° 35′E, station height 4 m) was chosen because it is in an area where ground frost often damages crops. The observations were taken in April, May, October and November of the years 1983 to 1988 inclusive; this selection was made because in these months the most damage is done to growing fruit and potato plants (spring) and harvested sugar beet (autumn). Only the period 00–06 UTC was studied, as this is the most important part of the night for the occurrence of ground frost. Wind speed and cloud amount at 03 UTC were taken as estimates of the mean value during the second part of the period. Unfortunately the amount of low cloud only was not available, so total cloud cover was used; for the forecaster this is an advantage, because the method used in determining the screen minimum temperature (Roodenburg 1983) needs the same predictors. The total number of cases was 732; there were 76 (roughly 10%) nights with air frost and 145 (roughly 20%) nights with ground frost. These numbers are small when compared with the climatological mean for 1951–80 for days with air frost and for 1971–80 for days with ground frost (see Table I). The anomalies are probably a symptom of the relatively high mean surface temperatures in the 1980s observed in The Netherlands as well as in many other places.

2. Grass minimum depression

The parameter under examination was the grass minimum depression, rather than the actual grass minimum temperature itself. The grass minimum depression is the departure of grass minimum temperature from screen minimum temperature; it depends on wind speed, cloud amount (Steele *et al.* 1969), state and properties of the soil (Lawrence 1960), and during winter possibly also on the value of the minimum temperature (Saunders 1952).

In accordance with Steele *et al.* (1969), the grass minimum depression was determined from the data as a function of cloud amount and geostrophic wind speed. As in their study, three categories of cloudiness have been distinguished: little or no cloud (0–2 oktas), cloudy (6–8 oktas) and an intermediate category (3–5 oktas). However, instead of geostrophic wind, the actual wind speed has been used, as geostrophic wind and actual wind might be only weakly related in cases with highest probability of (ground) frost. Four wind speed categories were defined: Beaufort force 0 and 1, 2, 3, and 4 or more; amounting to a total number of 12 weather categories. The results (not shown here, see Floor 1989) were subjected to a statistical test (Student's t-test); weather categories that did not show significantly different results were taken together as one new category. This happened to be the case for weather categories with 0–2 oktas and 3–5 oktas of cloud, regardless of wind speed and for the weather categories with 6–8 oktas of cloud and wind speeds of Beaufort force 3, and 4 or more. For the situation most prone to ground frost — little or no cloud and low wind speeds — the importance of the state of the ground was examined; dry soil showed grass minimum depressions that are 1 °C lower than moist or wet soils, the difference being significant at the 0.1% level. The definitive results for the 24 months that have been investigated are shown in Table II.

3. Grass minimum depression in spring and autumn

When Table II was constructed, no distinction was made between different seasons. However, Saunders (1952) found higher values for grass minimum depression in summer than in winter (air temperatures near or slightly below 0 °C). Steele *et al.* (1969) also mention that there is evidence that grass minimum depressions on radiation nights are greater in spring and summer

Table I. Average number of days per year with air frost or ground frost at Eelde for the months and periods shown

Month	1951–80 Air frost	1971–80 Ground frost	1983–1988 Air frost	1983–1988 Ground frost
April/May	7	21	5.5	12.7
October/November	9	18	7.2	11.5
Total	16	39	12.7	24.2

Table II. Grass minimum depression (°C) at Eelde for April/May and October/November combined, for 1983–88

Oktas	Soil	Beaufort force	Number of nights	Grass minimum depression	Standard deviation
0–5	dry	0, 1	37	3.69	1.18
	moist		50	2.67	1.35
		2	114	1.99	1.21
		3	93	1.13	0.57
		>3	34	0.86	0.44
6–8		0, 1	62	1.41	1.52
		2	102	0.83	1.04
		>2	240	0.55	0.52

than in autumn and winter. Therefore the data have been split up into April/May data and October/November data. The results show a mean value in April/May that was 0.6 °C higher than in October/November, the difference being significant at the 0.1% level. The reason for the difference probably is the continuously wet grass in the winter time, counteracting the cooling of the soil and the nearby air. Soil temperatures of Eelde are not available; values for De Bilt (WMO number 06260, 52° 06′N, 05° 11′E, station height 2 m) were looked at instead. These soil temperatures (September 1962–August 1972) are higher on average in April/May (8.7 and 13.0 °C respectively) than in October/November (11.8 and 7.1 °C respectively) (Van der Hoeven 1974); consequently the observed difference in grass minimum depression cannot be explained in this way. The seasonal difference found made necessary the construction of new Tables III and IV, like Table II but valid for April/May or for October/November only. As was the case with the construction of Table II, weather categories in Tables III and IV that did not depart significantly from another category were taken together as one new category. Distinction between dry and moist soil is not meaningful in autumn; the number of wind categories can be reduced in most cases.

4. A simple forecasting tool

From the results, given in Tables III and IV, diagrams have been constructed for use by the forecaster on the bench (Tables V and VI). Given the expected amount of cloud and the expected wind speed, the grass minimum depression can be taken from the appropriate diagram. The difference between grass minimum depressions in situations with a wind speed of Beaufort force 3 and greater than 3 with 0–6 oktas of cloud in October and November was significant, but nevertheless too small to be of practical use; therefore all cases with a Beaufort force of 2 or more have been taken together. The forecaster not only wants to obtain a spot value, but also the interval between the extreme values that have occurred in analogous weather situations; these are taken from the data set and shown in Tables VII and VIII.

5. Probability of ground frost at Eelde

The data used for the construction of the forecasting tool for grass minimum depression, consisting of Tables V to VIII, can also be used for estimating the probability of ground frost. Table IX provides the probability of ground frost for April/May, given an observed minimum temperature. A similar table, valid for October/November, is not given here but shown in Floor (1989). The table can be rewritten, taking into account the error in the forecast value of the minimum temperature. Steele *et al.* (1969) elaborate such a case for a minimum temperature forecast with a systematic error of −0.3 °C and a standard deviation of 1.89 °C. Using these values and their method, the same was done for the Eelde data; the results are shown as Table X for April/May and give more realistic values for the

Table III. Grass minimum depression (°C) at Eelde for April/May, for 1983–88

Oktas	Soil	Beaufort force	Number of nights	Grass minimum depression	Standard deviation
0–5	dry	0, 1	26	4.03	1.09
	moist		28	2.94	1.49
		2	58	2.38	1.34
		>2	67	1.13	0.62
6–8		0, 1	33	1.83	1.64
		2	55	1.16	1.25
		>2	99	0.56	0.56
	All cases		366	1.58	1.48

Table IV. Grass minimum depression (°C) at Eelde for October/November, for 1983–88

Oktas	Beaufort force	Number of nights	Grass minimum depression	Standard deviation
0–5	0, 1	33	2.52	1.05
	2	56	1.58	0.89
	3	40	1.06	0.46
	>3	20	0.81	0.39
6–8	0, 1	29	0.94	1.20
	>1	188	0.52	0.48
All cases		366	0.97	0.93

Table V. Forecasting diagram for grass minimum depression (°C) at Eelde for April/May

Cloud amount		Wind speed (Beaufort force) <2	2	>2
0–5 oktas	dry soil	4	2.5	1
	wet soil	3		
6–8 oktas		2	1	0.5

Table VI. Forecasting diagram for grass minimum depression (°C) at Eelde for October/November

Cloud amount	Wind speed (Beaufort force) <2	2	>2
0–5 oktas	2.5	1.5	1
6–8 oktas	1	0.5	0.5

Table VII. Extreme values of grass minimum depression (°C) at Eelde for April/May

Cloud amount		Wind speed (Beaufort force) <2	2	>2
0–5 oktas	dry soil	1.9/6.0	−1.0/5.7	0.0/4.0
	wet soil	0.8/6.0		
6–8 oktas		−0.3/5.2	−0.4/5.2	−0.2/3.7

Table VIII. Extreme values of grass minimum depression (°C) at Eelde for October/November

Cloud amount	Wind speed (Beaufort force) <2	2	>2
0–5 oktas	0.0/4.5	0.0/4.2	0.1/2.5
6–8 oktas	−0.2/5.2	−0.6/2.4	

Table IX. Probability (%) of ground frost at Eelde as a function of observed minimum temperature and weather situation

Cloud amount (*oktas*)	Beaufort force	Soil	Forecast minimum (°C) 0	1	2	3	4	5	6
0–5	<2	dry	100	100	100	88	77	35	11
		moist	100	100	79	64	38	14	7
	2		98	94	70	48	20	6	1
	>2		100	97	13	3	3	—	—
6–8	<2		100	79	42	27	18	12	—
	2		100	43	7	3	1	—	—
	>2		100	73	27	15	7	2	—

Table X. Estimated probability (%) of ground frost at Eelde as a function of forecast minimum temperature and weather situation for April/May

Cloud amount (*oktas*)	Beaufort force	Soil	Forecast minimum temperature (°C) −4	−3	−2	−1	0	1	2	3	4	5	6	7	8	9
0–5	<2	dry	100	100	>99	99	97	93	85	72	56	38	22	11	5	2
		moist	100	>99	99	96	91	82	69	53	37	23	12	6	2	1
	2		100	99	98	94	86	75	59	42	27	15	7	3	1	—
	>2		100	98	96	88	75	57	37	20	9	4	1	—	—	—
6–8	<2		100	98	95	89	78	63	47	33	21	12	6	3	1	—
	2		99	97	91	80	64	44	26	13	6	2	1	—	—	—
	>2		100	98	94	87	74	56	39	23	13	6	3	1	—	—

Table XI. Estimated probability (%) of ground frost at Eelde as a function of forecast minimum temperature and weather situation for October/November

Cloud amount (*oktas*)	Beaufort force	Forecast minimum temperature (°C) −4	−3	−2	−1	0	1	2	3	4	5	6	7	8	9
0–5	<2	100	>99	98	95	89	78	62	44	28	15	7	3	1	—
	2	100	99	97	91	81	65	46	28	15	7	2	1	—	—
	>2	>99	98	95	88	74	56	36	19	8	3	1	—	—	—
6–8	<2	99	97	93	83	69	50	33	19	10	5	2	1	—	—
	>1	99	97	92	81	64	45	26	13	5	2	—	—	—	—

probability of ground frost than Table IX. Table XI contains realistic estimates for the probability of ground frost in October/November. As in Table X the values for the forecast screen minimum temperature are shown in the top line.

6. Conclusion

The grass minimum depression in spring is different from that in autumn, therefore different diagrams have been constructed for April/May and for October/November, to be used in forecasting the grass minimum depression, at Eelde, starting from the forecast screen minimum temperature and weather type. Separate diagrams show the extreme values taken by the grass minimum depression in the period examined. Using the available data and following a method described by Steele *et al.* (1969) tables are presented that give a realistic estimate for the probability of ground frost.

Acknowledgements

The advice of W.N. Lablans and H. Daan in the preparation of this paper is gratefully acknowledged.

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The winter of 1988/89 in the United Kingdom

G.P. Northcott

Meteorological Office, Bracknell

Summary

The winter appears to have been the rare combination of the mildest and driest in England and Wales during the last 260 years while in Scotland it was the mildest winter since 1932/33; although very wet in western areas of Scotland, it was exceptionally dry in some parts of eastern Scotland.

1. The winter as a whole

Mean temperatures were over 2 °C above normal in most parts of the United Kingdom and over parts of northern England and southern and eastern Scotland they were 3 °C above normal. The mean temperature in central England, 6.6 °C, made it the warmest winter since records began in 1659. In Scotland, December and January combined were the mildest on record. At Braemar, Grampian Region the departure from average of +4.0 °C may be compared with the previous highest value of +3.2 °C recorded in 1857/58.

After a generally dry December and a dry January except in Scotland, followed by rainfall amounts just above normal over England and Wales but well above normal over Scotland during February, seasonal amounts were well below normal in England, Wales and eastern Scotland but well above normal in western Scotland. Over England and Wales general rainfall for the period November 1988–January 1989 was 136 mm (50% of average), the driest November–January period since 1879. From the general values for England and Wales, 197 mm was recorded between November 1988 and February 1989 inclusive. This is the second driest November–February period this century, only November 1933 to February 1934 having been drier with only 175 mm.

Sunshine totals were above average for most of the United Kingdom, apart from western and extreme northern parts of Scotland where the amount of sunshine was below normal.

Information about the temperature, rainfall and sunshine during the period from December 1988 to February 1989 is given in Table I and Fig. 1.

2. The individual months

December. Mean monthly temperatures were well above normal everywhere in the United Kingdom ranging from 1.6 °C above normal at Lerwick, Shetland to 3.7 °C above normal at Lyneham, Wiltshire. Hampstead and Northwood, Greater London reported the mildest December since 1974. Halesowen, West Midlands reported the second warmest December in 33 years of record, bettered only by 1974; Lyonshall, Hereford and Worcester also reported the mildest since 1974. At Sheffield, Weston Park, South Yorkshire it was as mild as December 1934 in a record going back to 1882. Many places had a frost-free December, including Sheffield, where the last frost-free December occurred in 1972.

Monthly rainfall totals were well below normal everywhere except western Scotland, where 147% of average was reached at Kinlochewe, Highland Region, and a few places in North Wales and north-west England. The east coast of Scotland was very dry, with as little as 15% at Montrose, Tayside Region. In general

Table I. District values for the period December 1988–February 1989, relative to 1951–80 averages

District	Mean temperature (°C)	Rain-days	Rainfall	Sunshine
	Difference from average		Percentage of average	
Northern Scotland	+2.4	+4	202	87
Eastern Scotland	+3.0	−2	101	117
Eastern and north-east England	+2.9	−5	68	134
East Anglia	+2.2	−4	66	128
Midland counties	+2.7	−4	68	132
South-east and central southern England	+2.5	−3	64	117
Western Scotland	+2.8	+3	149	81
North-west England and North Wales	+2.7	−1	108	109
South-west England and South Wales	+2.3	−2	83	99
Northern Ireland	+2.4	+2	95	105
Scotland	+2.7	+2	162	95
England and Wales	+2.5	−3	80	120

Highest maximum: 15.5 °C in eastern Scotland in December.
Lowest minimum: −10.6 °C in western Scotland in February.

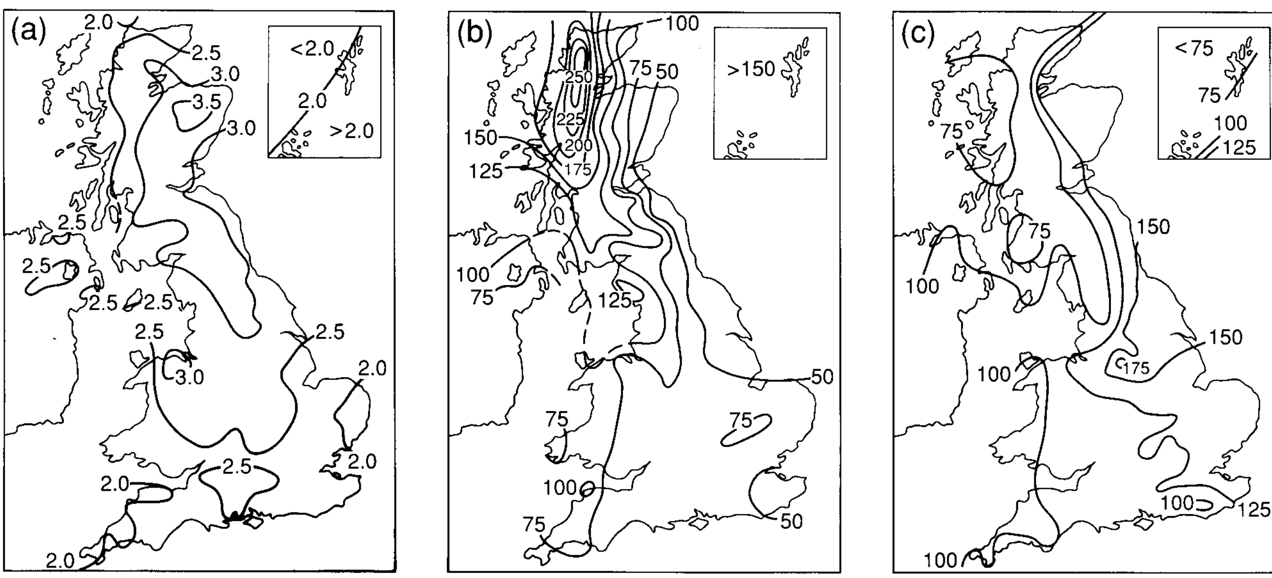

Figure 1. Values of (a) mean temperature difference (°C), (b) rainfall percentage and (c) sunshine percentage for winter, 1988/89 (December–February) relative to 1951–80 averages.

most of the month's rain fell in the first 5 days. Much of the Thames Valley, and the area just south of it, received less than 4 mm of rain after the 4th, including Benson, Oxfordshire 2.2 mm and Heathrow, Greater London 2.8 mm. Exeter, Devon had only 3.3 mm after the 5th. Hampstead reported the driest December since 1933, Lyonshall the driest since before 1947 and Northwood the driest for 30 years. Sheffield, Weston Park, had the driest December since 1971. After the 18th several places in the north had heavy falls; on the 26th Bidston, Merseyside reported very heavy rain between 1715 and 2225 UTC, with some roads in the area being flooded.

Monthly sunshine totals were kept below average in many places by persistent cloud with less than half the average in Orkney, however, sunshine was well above average in eastern areas of England and Scotland and in parts of the west Highlands, reaching more than 150% of average on the east coast. Bradford, West Yorkshire reported the sunniest December on record with 47 hours — the previous record was in 1926 (46 hours).

January. Mean monthly temperatures were well above normal everywhere ranging from just under 2 °C above normal at some places in southern England to just over 5 °C above normal in northern Scotland.

In western Scotland it was one of the wettest Januarys on record: the persistence of moist south-westerly winds created strong contrasts in rainfall across Scotland, with up to three times the average over the western Highlands and less than 10% of normal near Aberdeen. In Glen Shiel, on the road to Kyle of Lochalsh, one gauge recorded 855 mm while, in contrast, at Insch, north-west of Aberdeen, only 6 mm was recorded. At Cape Wrath, Highland Region it was the wettest January since records began there in 1941 while at Craibstone, Grampian Region it was the driest since observations started in 1925. January 1989 was the third successive month to have only about 50% of average rainfall over England and Wales, although the month itself was not exceptionally dry, January 1987 having been drier. Bradford had the driest January since 1953 and Ashover, Derbyshire the driest since records began in 1966.

Monthly sunshine totals were above normal nearly everywhere and ranged from almost half the normal in south-west Scotland to nearly twice the average in north-east Scotland. However, in western Scotland it was very dull. Wick reported its sunniest January since 1946. Bradford, West Yorkshire had the sunniest January on record.

February. Mean monthly temperatures were above normal everywhere, ranging from 3 °C above normal at Lyneham, Wiltshire and Bramham, West Yorkshire to just over 0.5 °C at Cape Wrath. Ashover reported its highest minimum temperature since records began there in 1967, 9.5 °C, and the warmest February on record, with a mean of 5.1 °C. Hampstead reported the highest mean temperature since 1966 and the highest mean maximum temperature, equal with that of 1961.

Monthly rainfall amounts were above normal nearly everywhere west of a line from Banff, Grampian Region to Beachy Head, East Sussex reaching as much as 450% of normal in the vicinity of Fort Augustus, Highland Region. In contrast, parts of Lincolnshire had less than 50% of normal rainfall. The 5th and 6th were days of contrasting weather in Scotland, when the easternmost parts of Scotland had little or no rain, while the rest of Scotland had a large amount of rain, heavy in places. As a result of the very wet January, rivers, lochs and reservoirs were already full to overflowing when exceptionally heavy rainfall occurred on 4 and 5 February. Over the western Highlands rainfall was torrential and prolonged on both days, causing flooding and landslides. Bridges, roads, housing estates and farmland were affected over a wide area and the 127-year old railway bridge over the River Ness at Inverness was swept away by flood-water on the 7th. The 2-day total of 215 mm (83.7 mm on the 5th and 131.7 mm on the 6th) at Fort William has an estimated return period of several hundred years, as does the 5-day total of 299 mm measured from the 2nd to 6th.

Monthly sunshine amounts were above average nearly everywhere and reached almost twice the average at Tynemouth, Tyne and Wear; the exception was the western side of Scotland where it was rather dull and the percentage of average was as little as 75% at Eskdalemuir, Dumfries and Galloway. Bradford had the sunniest February on record at the station.

At Fraserburgh, Grampian Region the mean wind speed increased very rapidly on the 13th from 15 kn at 1730 UTC to 60 kn at 1900 UTC as the wind direction veered from south-westerly to north-westerly, a record gust for a low-level station of 123 kn was measured; the hourly mean speed was 66 kn. The high winds disrupted traffic, brought down trees as far south as Leicestershire and North Wales, and toppled buses and high-sided lorries. In Dunfermline nine people were injured when the roof of a hospital ward was blown off.

Notes and news

The Meteorological Office to become an Executive Agency

Recently, the Director-General of the Meteorological Office, Dr J.T. Houghton, announced that the Office will be an Executive Agency within the Ministry of Defence, as from April 1990. In a letter to Office staff he stressed that in many ways there will be no change to the Office's functions; it will continue as the State Meteorological Service to meet the needs of defence, civil aviation and the general public. However, the Executive Agency status proposed will give the Office greater autonomy over its manpower and financial resources, and will thus be able to work more efficiently, to react to circumstances more quickly and, in particular, benefit from commercial opportunities.

To oversee the new Agency, the Director-General will become the Chief Executive leading a Management Team consisting of Directors of Operations, Research, Finance and Administration, and Commercial Services. Changes to the structure of the Office in the lower echelons are also envisaged to enable it to meet its new challenges most effectively.

Dr P. Ryder promoted to Director of Services

Following the move of Dr David Axford to Geneva, Dr Peter Ryder has been promoted into the post of Director of Services of the Meteorological Office.

Prior to this move, Dr Ryder occupied the posts of Deputy Director in charge of Forecasting Services and Observational Services, previously having been Assistant Director in charge of the Cloud Physics and Systems Development Branches.

The European Geophysical Society 15th General Assembly

The programme for the next General Assembly of the European Geophysical Society (EGS), to be held from 23 to 27 April 1990 in Copenhagen, is now available.

The following open sessions, workshops and symposia are on topics of interest to atmospheric physicists and climatologists.

Open sessions

Hydrology.
Meteorology and climatology.
Ocean circulation and the heat budget.
Dynamics and chemistry of the middle and upper atmosphere.
Origin and evolution of planets, atmospheres and hydrospheres.

Workshops

Scientific results of the European frontal experiments.
Usage and application of the ECMWF atmospheric general circulation model.
Physical, chemical and biological processes in the atmospheric boundary layer.
Recent campaigns on polar ozone.

Symposia

Measurement, modelling and forecasting of rainfall in space and time.
Land surface–atmospheric processes.
Verification of numerical prediction of atmospheric variables, processes and circulation.
Modelling and observation of the global thermal energy and water cycle of the atmosphere.
Polar meteorology.
Wind-generated sea-surface waves.
The global change programme: the European potential (including panel discussion on 'different scientific points of view on global change').
Chaos, turbulence and long-term predictability in geophysics.

In addition there will be Society lectures on inversion theory in geophysics, and ice and climate.

The deadline for the receipt of abstracts by the EGS office is 31 January 1990.

The aims and organization of the EGS and the scheme for assisting young scientists were described in Notes and News in the February 1989 edition of *Meteorological Magazine*, which also gives the address of the EGS office from which full details of the Assembly can be obtained.

The 16th and 17th General Assemblies are to be held in Wiesbaden, Federal Republic of Germany on 22–26 April 1991 and in Edinburgh, United Kingdom on 6–10 April 1992.

Japan to maintain World Data Centre for Greenhouse Gases

The World Meteorological Organization (WMO) has announced that the Japan Meteorological Agency will run the newly created World Data Centre for Greenhouse Gases. As such, the Centre will collect data from all parts of the world on the concentration of greenhouse gases in the atmosphere, particularly carbon dioxide, methane, chlorofluorocarbons and nitrous oxide. These gases affect the radiation balance of the earth's atmosphere and are predicted to bring about a major climate warming over the globe by the middle of the next century. The concentrations of these gases have been rapidly increasing in the past few decades due to human activites — especially the burning of fossil fuels.

These atmospheric trace gases are measured at a number of observation stations around the world as part of the background air-pollution monitoring component of WMO's Global Atmosphere Watch. However, no systematic collection and distribution of data on the greenhouse gas concentrations from all observing stations has been undertaken until now. The growing importance of these data for research and policy development on climate change now requires a much more formal approach.

The WMO works through its member countries to provide authoritative scientific information and advice on the world's atmosphere and climate. Several countries operate World Data Centres for other types of atmospheric and hydrological data: Canada for the ozone layer, the USA for chemistry of precipitation and atmospheric turbidity, the USSR for radiation data and the Federal Republic of Germany for river flow.

The new Centre will gradually develop over the next few months before its formal opening during 1990.

Reviews

Synoptic meteorology in China edited by Bao Cheng Lan. 188 mm × 263 mm, pp. vi+269, *illus.* Berlin, Heidelberg, New York, London, Paris, Tokyo, Hong Kong, Springer-Verlag 1988. Price DM 128.00.

The first impressions given by this book are good. Most of us in Europe must be conscious of how little we know about Chinese meteorology, and the appearance of a well produced book with this title certainly whets the appetite. A quick first flip through the book is promising. It is a substantial volume and the contents page shows an orderly arrangement of the material in ten chapters, based largely on a climatological framework. There are chapters on the cold winter season, the rainy seasons, the typhoons and other tropical weather systems. There is also a chapter on the weather systems on the Tibetan plateau. Altogether, the menu is a most attractive one. The quoted references are dated up to about 1984 and there are a large number of satellite images in a block at the end of the book. Most of these date from the period 1978–81 and are not of very good quality, but at least one looks forward to a fairly up-to-date account.

However, as soon as one tries to penetrate the book in detail one's views swing to the opposite extreme. Three features are immediately and frustratingly obvious. One, there is no index. Two, the book is packed with detail, particularly of a minor geographical nature which neither the book itself nor other easily accessible sources do much to illuminate. Three, the translation into English is often of a poor standard.

Because it has a clear structure of chapter topics, it is easy to forget that the book is not quite what it seems. It is in fact a compilation of individual research papers, edited by Bao into a coherent framework. That framework is such that a better title for the book might have been *Synoptic climatology of China.* There is nothing wrong with the framework, but it is as well to note that this is not a textbook on synoptic meteorology as such. It does not, in general, describe the tools of the trade of a synoptic meteorologist. What it does is to show how the already well known tools are applied in China.

And herein, to a Westerner, lies one of the big disappointments of the book. There is nothing very new in it. The synoptic models and concepts that are used are the same as in other temperate and tropical latitudes. The practical techniques are strongly redolent of the age of synoptic charts and pencils, with some overtones of satellite imagery, and a faint whisper of numerical experimentation. The approach is kinematic rather than dynamic; synoptic patterns 'evolve' and 'interact', and the evolutions are catalogued in categories, and sub-categories, which would be easier to comprehend if the printed layout and titling were better. In short, it gives a picture of old-fashioned synoptic meteorology — what happens is documented with a mass of detail, but why it happens is less easy to discover.

But for those who have patience to find their bearings in the detailed text, and who have the foresight to construct their own index as they go along, there are many interesting topics to be found. Among the less familiar ideas to those of us who work in an oceanic climate are those which derive from conditions in a vast continental area. As well as air masses, fronts and upper-level troughs, cold and warm air 'shear lines' are prominent. Dew-point fronts, the equivalent to 'dry lines' in the USA, and 'low-level jets' are important. In the tropical area, typhoons are covered in detail, most of which is standard, but slightly fresh emphases are introduced by the mention of 'ventilation' and the 'prosperity period' of storms.

There is little or nothing on mesoscale weather systems, except the statement that 'they are the key to heavy-rain forecasting'. The accent of the book is almost entirely synoptic scale, or larger. Only one diagram seems to be derived from a radar display.

This is certainly a fascinating book, but it is not easy to read or use as a casual reference book. Anybody less knowledgeable than an experienced professional could be misled by some of the many printing errors even if they have the stamina to penetrate the detail of the text. Sadly, only the most committed China lover will find this a worthwhile buy.

P.G. Wickham

Solitons: an introduction, by P.G. Drazin and R.S. Johnson. 150 mm × 226 mm, pp. xii+226, *illus.* Cambridge University Press, 1989. Price £32.50, US$59.50 (hardback), £11.95, US$19.95 (paperback).

The Edinburgh to Glasgow canal was the scene in 1834 of the first recorded scientific observation of a soliton. J. Scott Russell noted the formation of a 'great wave of translation' when a barge was brought suddenly to rest (by some agency now forgotten). This solitary water wave continued in motion for some miles with little change of shape — and with Scott Russell in pursuit on horseback. The constancy of the wave's shape showed that the motion was dominated neither by linear, dispersive effects nor by non-linear transfers of energy between different spatial scales. Applied mathematicians now know that a balance between non-linear and dispersive (or dissipative) effects can occur in many systems, thus allowing the existence of isolated, coherent disturbances of which the water-wave soliton is the prototype. Soliton theory is widely considered to be one of the major achievements of applied mathematics since 1950.

Writers of review papers and books on solitons — and even reviewers of books on solitons — rarely find themselves able to omit mention of the famous Scott Russell story. In this respect this book is not exceptional. In a much more important respect, however, it is outstanding; it achieves a brief, clear and comprehensive introduction to the non-linear mathematical theory, including the difficult and wonderful technique known as the inverse scattering transform. These seemingly incompatible objectives are achieved by adept use of fairly short chapters, clear notation, numerous worked examples and a wealth of exercises for the reader. The main text and worked examples introduce the essential theory. The exercises (146 in number) take the adventurous reader much further and introduce or illustrate the more sophisticated concepts.

Most of the analysis concerns the equation which arises in the solitary water-wave problem, namely the Korteweg–de Vries equation in one spatial dimension. A dozen or so other non-linear equations are also discussed, the stimulus for their study being drawn from a wide range of problems in science and engineering.

The authors have taken great pains to ease the task of the serious reader as he tries to assimilate soliton theory. Most chapters have useful introductory summaries, and each concludes with well chosen suggestions for further reading. Italic headlines summarize the content of most of the exercises, and answers or hints are given in a separate section. The more difficult exercises and sections of text — including two whole chapters — are marked with asterisks. The text is well presented, misprints are few (three detected during review!) and there is a good index. A comprehensive bibliography is supplemented by a list of motion pictures of solitons.

The book is one of a new series 'Cambridge texts in applied mathematics', edited by H. Aref and D.G. Crighton. It will be of particular interest to students of applied mathematics, and there are good reasons why it should appeal to many meteorologists too. The theory of solitons is of sufficient general scientific importance to prompt interest, and soliton solutions exist in many limiting cases of equations which arise in meteorological contexts. Also, the book contains several lucid summaries of various mathematical concepts and techniques which are of wide application: elementary wave theory, elliptic functions, Lie groups, similarity theory, solutions of Schrödinger's equation, discrete and continuous spectra, movable singularities and critical points, Noether's theorem, Fréchet derivatives and Bäcklund transformations.

Solitons: an introduction is a splendid book. In less skilled hands it could have grown to at least twice its present length and have become dauntingly esoteric. As it is, the clear notation and concise presentation enable the reader to follow the basic arguments easily and to believe that even the asterisked sections would be understandable with reasonable effort!

A.A. White

Glacier fluctuations and climatic change,

edited by J. Oerlemans. 163 mm × 246 mm, pp. ix+417, *illus.* Dordrecht, Boston, London, Kluwer Academic Publishers, 1989. Price Dfl.195.00, US$109.00, £64.00.

In 1890 Prince Roland Bonaparte attempted, vainly as it turned out, to initiate a programme of regular measurement of French glaciers with a view to identifying links with meteorological conditions, and so deducing a law. International monitoring of glacier fluctuations began 4 years later and gradually gathered momentum, expanding out of Europe and, especially in the last few decades, increasing in accuracy and sophistication. The quantity and quality of data now available make identification of the complex interrelations between glacial and climatic changes a much more possible objective than it was a century ago, but it is still necessary for modellers and those primarily concerned with field investigations to understand each other's problems and preoccupations, which are not always identical.

This book is the outcome of a meeting on 'Glacier Fluctuations and Climatic Change' held in Amsterdam in June 1987, and is one of a series on glaciology and Quaternary geology. The location was perhaps not altogether fortuitous, The Netherlands being acutely aware of the possible effects of global warming, especially on sea level. Significantly, the meeting was supported by the Dutch Ministry of Housing, Physical Planning and the Environment. Its purpose was to bring together scientists from a wide range of backgrounds and disciplines concerned with the history, scale, measurement and meteorological controls of glacier fluctuations. Active engagement of this sort is a necessary prerequisite to the attainment of the more satisfactory level of understanding which is required in order to make sensible forecasts.

The very heterogeneous papers in this volume have been arranged so that those dealing with the more distant past, Palaeozoic glaciations in South Africa, Quaternary history in East Africa and Holocene glaciation in Iceland and South Georgia, preface a useful account of the development and extent of the present international database. Attention then turns to matters such as the practical problems of glacier inventory and mass-balance measurement in remote areas of North America and Greenland. An overview of historic fluctuations in Scandinavia and a cautionary discussion of evidence about the decline of the Little Ice Age in the Himalayas, accounts of the variations of the Rio Plomo glaciers in the Andes and of characteristics of plateau glaciers in arctic Norway, together provide evidence of the care needed in order to obtain reliable chronologies and the need to take into account the possibility of surging, the relevance of topographic controls and the effects of debris cover and avalanching. An entertaining history of nineteenth-century ice trading stands apart from the rest of the book.

The greater part of the volume is concerned with the history, measurement and explanation of mass balance, with equilibrium-line shift and its calculation, englacial temperature distribution and energy-balance calculations, and with response times. Sufficient data are available to allow an examination of relations between climate and mass balance, and between climate and runoff in the European Alps. Comparison of mass-balance histories of the Blue and South Cascade Glaciers in Washington State reveals the importance of synoptic-scale circulation patterns. As 'there is not a single meteorological parameter on any continent, which influences the surface climate of the whole continent as much as the katabatic wind does for Antarctica' the results of measurement of blowing sand in Adelie Land are an obvious choice for inclusion. Some of the most interesting papers come from studies of individual glaciers — notably the Hintereisferner, Argentière and Rhône in the Alps — where work has been under way for a relatively long time and strong groups of researchers have been attracted. Here the modellers have found sufficient basis to indicate to the field workers where more observations are needed and to test the validity of their present approaches.

The literature concerned with glacier fluctuations is now voluminous. Without an acquaintance with the subject it would be a time-consuming business to acquire any sort of overview of the present state of research. This book goes far towards meeting that need, as well as that of people who wish to extend their knowledge of a many-faceted subject. Many outstanding workers have contributed, although the quality is inevitably somewhat uneven. It was surprising to see the resurrection of an over-simple diagram of variations in equilibrium-line altitude through the Holocene, despite a reference to Karlén's work which, despite inadequate dating, has demonstrated the complexity of the Holocene climatic succession in Scandinavia. Good abstracts and very full bibliographies are provided; the supply of clear diagrams is generous. Much has already been achieved; much remains to be done. Stroeven, Van De Wal and Oerlemans conclude that 'we are not going to understand the historic glacier variations without renewed deep and careful investigation of how mass balance of glaciers is related to climatic conditions'.

J.M. Grove

Mechanisms and effects of pollutant-transfer into forests, edited by H.-W. Georgii. 161 mm × 245 mm, pp.ix+361, *illus.* Dordrecht, Boston, London, Kluwer Academic Publishers, 1989. Price Dfl.185.00, US$94.00, £61.00.

The book contains papers presented at the third Oberursel symposium in November 1988, devoted to the problem of how airborne pollutants adversely affect forests — the trees and the soil beneath. The majority of the papers have German authors, three have Dutch authors and two Austrian, reflecting the regions of western Europe with the greatest apparent damage.

The book reflects the efforts of scientists from many different disciplines to improve our understanding of the physical and chemical processes that lead to the observed damage. No single cause can be identified — more likely several components acting together are responsible. Various hypotheses exist as to how acid rain affects trees, and each may have some validity in different conditions. Five of these are:

(i) Ulrich's hypothesis in which acid rain acidifies the soil and releases toxic aluminium ions that may damage the fine roots and result in insufficient and unbalanced uptake of nutrients.

(ii) Acidification of the soil resulting in the fine-root system being confined to the upper layers of the soil, making the trees much more susceptible to periods of water stress (Eichhorn).

(iii) Acid rain leaches essential nutrients from the leaves; an effect which is increasingly probable if the stomata have been damaged by ozone and cannot open and close as efficiently as they should.

(iv) Very acid fogs cause damage to the wax coatings of the leaves and thereby lower the water-holding capacity of the trees — a result particularly serious in times of drought (Hogrebe and Mengel).

(v) Nitrates and ammonium compounds in the rain can promote excessive growth which can make the trees more susceptible to damage from other stresses like cold.

The book is subdivided into five sections: deposition into forest areas, deposition of organic compounds, case-studies (involving models, and field and laboratory techniques), investigations on fog and dew, and the effects of atmospheric pollutants on vegetation.

Some additional points of particular interest to the reviewer emerged from reading these papers. Jaenicke explains that the greater dry deposition of particulates observed within forests is due not to enhanced impaction (wind speeds are too low for this to be efficient) but to an increase in typical residence time within the trees, allowing more coagulation of particles and resulting settling. Grosch and Georgii show that at mountain stations the ionic concentrations in snow relative to those in rain ranged by factors of 1.1 to 4.5, due, it is hypothesized, to more efficient below-cloud scavenging by snow, resulting from a slower rate of descent (longer residence time) and an improved collection of ions by the filigree structure of the snowflakes. Kroll and Winkler note that deposition of pollutants on hills, due to the direct interception of wind-blown cloud droplets, is high and can be higher than that deposited by precipitation. This confirms findings in the Great Dun Fell study in England, and it is perhaps a pity that no paper from those involved in the study was given at the Oberursel meeting.

Although normally I find books presenting the proceedings of conferences rather inadequate because of their fragmented and incomplete nature, this one is an exception. By concentrating on a rather limited number of closely related topics in which a great deal of current research is taking place, a rather useful and complete picture is given. The book has been produced with commendable speed, and although type-faces vary from paper to paper, all are easily readable. At £61, it is expected that libraries, and some individuals with an interest in forestry and acid rain, will be keen to buy it, and I would encourage them to do so.

F.B. Smith

Satellite photographs — 21 October 1989 at 1200 GMT

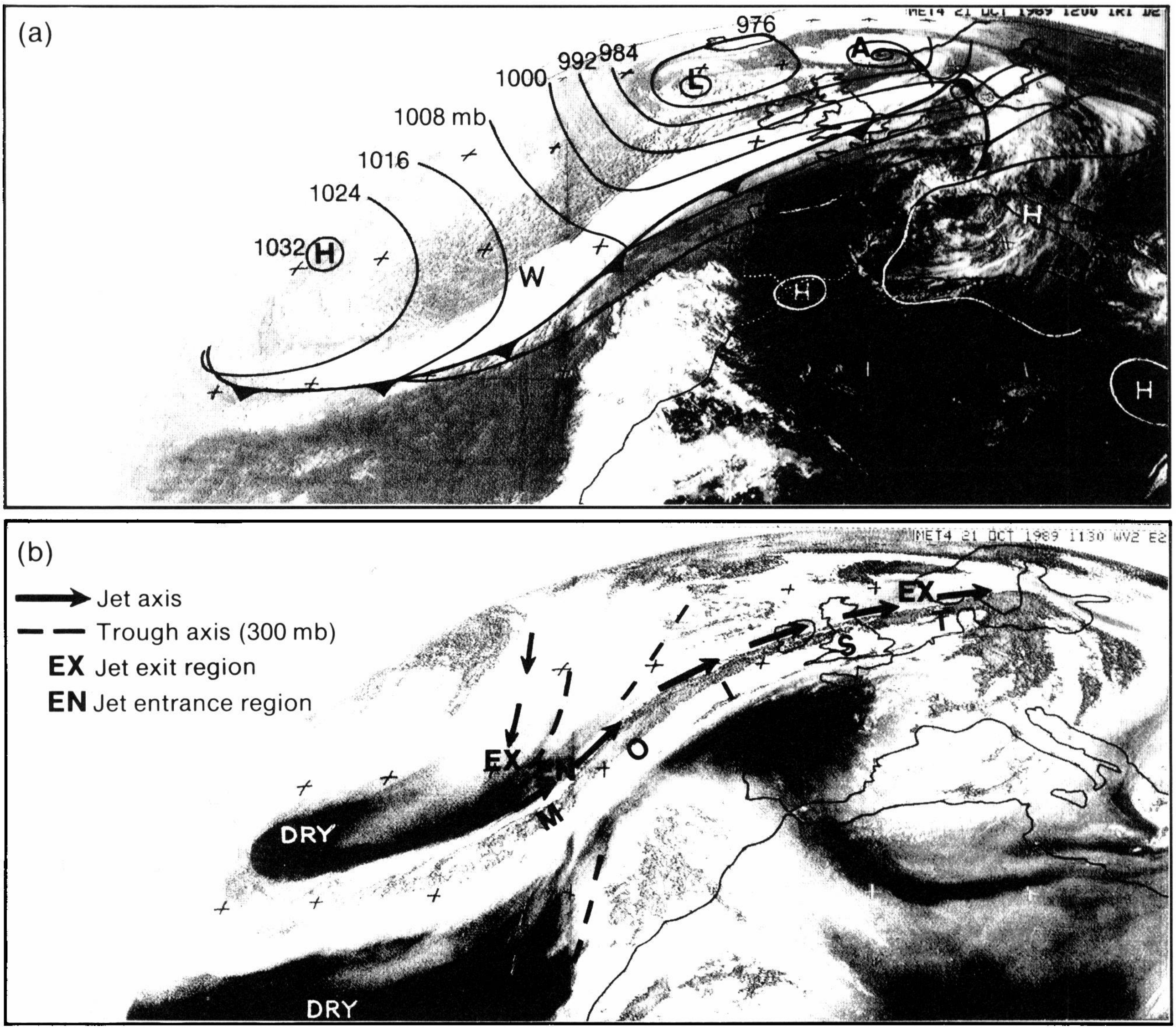

Figure 1. (a) Space-view Meteosat infra-red image with superimposed surface analysis, and (b) space-view Meteosat water vapour image with superimposed significant 300 mb features. An 'enhancement curve' has been applied so as to sharpen up the moisture boundaries. The change from black to white represents the transition from very dry to moist air in the upper troposphere. The second black to white scale within the moist region represents only very moist and saturated cloudy air (at cirrus levels). Within the latter range, the water vapour sensor acts in a similar manner to the infra-red — the whiter the shade the colder the cloud top.

The dominant feature in these infra-red and water vapour space-view Meteosat images (Fig. 1) is a distinct band of cloud and upper-tropospheric moisture associated with a classical cold front extending from western Europe to the mid-Atlantic. This band and other features on the images can be related to synoptic-scale analysis at the surface and 300 mb.

The sharp southern and northern edges of the band mark the surface cold front and jet stream respectively. (In the water vapour image, the enhancement — see figure caption — particularly highlights the rear moisture boundary.) Winds within the jet reached 190 kn at 12 GMT at Long Kesh (N. Ireland). Within its left exit is a comma-shaped cloud (labelled A on the infra-red image) depicting a vigorous depression near Scandinavia while further upstream in the entrance region, the protrusion of cloud (W) indicates possible development of a wave.

Over southern Europe and the Mediterranean, the infra-red image shows a large region of cold cloud-tops suggesting disorganized cirrus patches. However, as is frequently observed when patchy upper cloud is present, the water vapour image indicates a coherent moist envelope within which the cirrus has formed.

G.A. Monk

GUIDE TO AUTHORS

Content

Articles on all aspects of meteorology are welcomed, particularly those which describe results of research in applied meteorology or the development of practical forecasting techniques.

Preparation and submission of articles

Articles, which must be in English, should be typed, double-spaced with wide margins, on one side only of A4-size paper. Tables, references and figure captions should be typed separately. Spelling should conform to the preferred spelling in the *Concise Oxford Dictionary* (latest edition). Articles prepared on floppy disk (Compucorp or IBM-compatible) can be labour-saving, but only a print-out should be submitted in the first instance.

References should be made using the Harvard system (author/date) and full details should be given at the end of the text. If a document is unpublished, details must be given of the library where it may be seen. Documents which are not available to enquirers must not be referred to, except by 'personal communication'.

Tables should be numbered consecutively using roman numerals and provided with headings.

Mathematical notation should be written with extreme care. Particular care should be taken to differentiate between Greek letters and Roman letters for which they could be mistaken. Double subscripts and superscripts should be avoided, as they are difficult to typeset and read. Notation should be kept as simple as possible. Guidance is given in BS 1991: Part 1: 1976, and *Quantities, Units and Symbols* published by the Royal Society. SI units, or units approved by the World Meteorological Organization, should be used.

Articles for publication and all other communications for the Editor should be addressed to: The Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ and marked 'For Meteorological Magazine'.

Illustrations

Diagrams must be drawn clearly, preferably in ink, and should not contain any unnecessary of irrelevant details. Explanatory text should not appear on the diagram itself but in the caption. Captions should be typed on a separate sheet of paper and should, as far as possible, explain the meanings of the diagrams without the reader having to refer to the text. The sequential numbering should correspond with the sequential referrals in the text.

Sharp monochrome photographs on glossy paper are preferred; colour prints are acceptable but the use of colour is at the Editor's discretion.

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