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Retirement of Mr D.H. Johnson

When Derek Henry Johnson, Deputy Director Forecasting Services, retired from the Meteorological Office on 19 June 1988 he had completed almost 39 years with the Office and a little over ten years as the Deputy Director in charge of the Forecasting Services area.

Derek was born in Wakefield, Yorkshire, but was educated at Tiffins Boys School, Kingston and this mix of the north and south of England has, without a doubt, stood him in good stead over the years. He went on to Imperial College, London, where first he read Mathematics, gaining a B.Sc. and an ARCS in 1948, and then, in 1949, he took an M.Sc. in Meteorology and a DIC studying with Professor D. Brunt after graduation.

He entered the Meteorological Office on 1 October 1949 as a Scientific Officer and, after the usual training period (then at Alexandra House, Kingsway, with Mr Pat Meade in charge), his first posting was to 19 Group at Mount Batten, Plymouth as a trainee forecaster under Mr P.F. Illsley as Senior Meteorological Officer.

In January 1951 he moved to Dunstable where he joined the Forecasting Research Branch (Met O 21). They were exciting times! Mr J.S. Sawyer was the Assistant Director and Professor R.C. Sutcliffe was Director of Research at that time, and the work at Dunstable was leading up to the operational introduction of numerical weather-prediction methods in the early 1960s. Mr Johnson's work was concerned mainly with the understanding, analysis and forecasting of the wind and temperature distributions in the upper troposphere and lower stratosphere, resulting in a number of publications and well merited promotion to Senior Scientific Officer in April 1955.

In 1958 came a move which was to shape Mr Johnson's interests for the next 12 years at least. As part of a special scheme arranged between the Director of the East African Meteorological Department (EAMD) and the Director-General of the Meteorological Office for encouraging weather forecasting research in Africa, and partially funded by a Colonial Development and Welfare Grant, Mr Johnson was seconded to the EAMD as a temporary Principal Scientific Officer in charge of the Forecasting Research Section located in Nairobi, Kenya. For the next three years he was able to concentrate on the problems of tropical meteorology, becoming a leading expert in this field and doing work which led to a succession of papers both during his years in Africa and over the ensuing period. Two WMO Technical Notes on *Forecasting the Weather in East Africa*, and *Forecasting the Weather in West Africa* are of particular note. His enthusiasm for this work was clear to the Director of the EAMD, Mr J.P. Henderson, and his promotion to PSO was made substantive in June 1960.

In May 1961 he returned to the United Kingdom to take up a post in the Climatological Research Branch (Met O 13) where his research projects concerned tropical meteorology, air-sea interaction and energy exchange studies. He was retained as a consultant to WMO at a number of international seminars on tropical meteorology in Africa, and was working alongside Mr G.A. Corby and Mr J.S. Sawyer.

In 1964 after a short forecasting refresher as Senior Meteorological Officer at RAF Uxbridge, he returned to the tropics as Chief Meteorological Officer, HQFEAF (Far East Air Force), Changi, Singapore with responsibility for all the RAF meteorological offices in the FEAF arena. He was an exceptionally good C Met O dealing with the considerable administrative responsibilities competently, but still finding time to act as the UK representative at various conferences and symposia on tropical matters in such varying locations as Bombay, Tokyo, Australia (Perth, Melbourne, Brisbane and Darwin) and Miami mainly at the request of the organizing committees. During this period he also came to know the RAF more closely, and was highly thought of for his handling of major and minor crises with quiet aplomb.

Returning once more to the United Kingdom in 1968 Mr Johnson was posted to the Dynamical Climatology Branch (Met O 20) where he immediately initiated a programme of research into the role of tropical meteorology in the global circulation. This led to his giving a substantial paper on this topic at the Royal Meteorological Society Conference on the Global Circulation of the Atmosphere held at the Royal Society in August 1969.

In January 1970 however, with a posting to become Chief Instructor and Head of the Training School at Stanmore, a new area of experience opened for Mr Johnson. This was a time of intensive planning in co-operation with Mr K.H. Smith who was the Assistant Director Professional and Technical Training (AD Met O(PT)) for the move from Stanmore and the establishment of a new College at Shinfield Park. The move was completed in September 1971 and Mr Johnson became the first Principal of the Meteorological Office College. In April 1972 the jobs of AD Met O(PT) and Principal were merged, and Mr Johnson was promoted to Senior Principal Scientific Officer to take over this new post. He now had wider responsibilities for overall policy and supervision of professional and technical training in the Office, including external study, curricula, training evaluation and like matters.

After a further two years or so the new post was well established, and it was time for a further move, this time to become Assistant Director, Public Services (Met O 7). Here, with responsibility for services to civil aviation and to the general public and commercial customers, his wide experience of a mix of research and operational service posts stood him in good stead. Working for a number of Deputy Directors (Messrs M.H. Freeman, N. Bradbury and F. Bushby) over the next three and a half years his sterling qualities of thoroughness and ability to weigh up complex situations were fully used, and for the first time he came into close contact with a variety of customers (e.g. the CAA, BBC, CEEB, etc.).

On 2 May 1978 came well-deserved promotion to Deputy Chief Scientific Officer (now Grade 5) as Deputy Director of Forecasting Services. This post involves policy responsibilities within the Senior Directorate of the Office for the Defence and Public Services Branches (Met O 6 and Met O 7) and the Central Forecasting Office and its numerical weather-prediction support (Met O 2). The ten years from 1978 to 1988 have involved rapid change and development in all these areas and throughout the period Mr Johnson has steered a carefully thought out and controlled course.

Perhaps the most important negotiations during his first five years involved his work with the Civil Aviation Authority (CAA) on the new ICAO Forecasting System. The negotiations with, and through, CAA and the Department of Transport were difficult, and the successful outcome, in which Bracknell was nominated as one of the two World Area Forecasting Centres as well as a Regional Area Forecasting Centre, was largely due to Mr Johnson's knowledge and negotiating skill.

At the same time he was laying the foundations for the rationalization of the Office's Civil and Defence Outstation organization, which has been carried out during the past five years or so. This rationalization, involving reorganization of RAF stations and public-service Weather Centres, and re-deployment and reduction of staffing levels has not been easy. Much credit must go to Mr Johnson in that his exceptional qualities have enabled these substantial changes to go ahead smoothly and without disruption of the essential services. During a period when pressures to change existing procedures in order to reduce costs and staffing levels have been intense, he has striven and succeeded in maintaining a balanced programme of services, and has encouraged the development of the new commercial attitudes which have been needed while maintaining the Office's reputation for professional and scientific integrity.

It has been my pleasure to have such a reliable and knowledgeable colleague, in particular over the past six or seven years during which we have worked closely together. His wealth of experience across the spectrum of Office activities, particularly with regard to the staff of the Office (some 50% of the total complement came within his remit), coupled to a realistic view of the problems of resource management have been of great value. His judgement in these matters has always been impeccable. He will be missed, and I am sure that all those who have worked alongside and with him will join me in wishing him and his wife all happiness and good fortune in his retirement.

D.N. Axford

An investigation into stratus distribution over the United Kingdom

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Summary

Statistics of the distribution of stratus over the United Kingdom are presented in terms of the variation at individual stations with local wind direction and season, and in terms of the spatial distribution for different synoptic flow-types. Three main regimes are found and discussed in relation to the forecasting problem. Two summer regimes affecting the east and west coasts of the United Kingdom are largely associated with the advection of stratus formed by cooling over the sea. The third regime occurs in winter over most of central and eastern England and is probably due to cooling overland, though moistening of the air during its passage across the North Sea or the English Channel plays a role in its existence.

1. Introduction

In the United Kingdom one of the most difficult tasks faced by a local forecaster is the prediction of the onset and dispersal of low cloud. Flying operations, particularly at military airfields, are sensitive to changes of a few hundred feet in the base of low cloud, and on time-scales of a few hours. Improvements in the precision and accuracy of forecasts of visibility and cloud base could lead to large savings for operators by avoiding unnecessary diversions and by maximizing the use of expensive facilities, yet little effort has been channelled into this area over the last 20 years. Much of the research into short-period forecasting in recent years has been concentrated on the analysis and prediction of precipitation patterns. Although this is clearly of use for aviation forecasters it does not solve their major problem of predicting low cloud and visibility. Great progress is also being made with the development of mesoscale numerical-forecast models, but prediction of the required detailed and local changes in the boundary layer is still some years off. This paper describes the initial stages of work being carried out in the Meteorological Office to reduce this imbalance.

Many more data are available and more readily manipulated than say 20 years ago, as a result of increased automation of data collection and processing over the last few decades. It therefore seemed appropriate as a first step in this project to update our knowledge of the climatology of stratus over the United Kingdom. This is a useful exercise not only in defining more clearly the nature of the forecasting problem but also in providing some immediate help to forecasters by quantifying their own local knowledge and making data on the peculiarities of other locations readily available. Since this project is still in its infancy this paper will necessarily be largely confined to describing some of the interesting features of the distribution of stratus, and relating them to possible future forecasting techniques.

2. Data

Basic data on cloud amount and height were taken from the significant cloud groups contained in archived synoptic reports from over 100 stations which had reported hourly or 3-hourly for at least 5 years during the period 1971–1985. The data were sorted according to the height of the cloud base of layers of 3 oktas cover or more up to 1500 ft for different local surface-wind directions for each month, and also for time of day and different wind speeds for each season. The reliability of cloud-base data depends on the availability of cloud-base recorders and the degree of training and experience of the observers. The data were checked by examining the frequency at which individual cloud-base codes were reported. Some stations which exhibited a marked preference for a few round values such as 500 or 1000 ft were noted as suspect.

The data-sorting programs treated reports of sky obscured as 8 oktas cloud below 100 ft; thus, some occasions of dense fog are included in the analysis. These can be eliminated by sorting the data by present weather code in addition to the other parameters. This was carried out for a selection of stations and found to make little difference to the distributions though the overall frequency was reduced by up to 25% of the original value. Since there is no way of distinguishing between dense radiation fog and advection or hill fog, which are closely related to stratus and should be included, all occasions with sky obscured have been included in the analysis.

The second stage of the analysis was to relate the stratus occurrence to the larger-scale flow rather than to local conditions. A data set of 'Lamb' types (Lamb 1972) defined once a day was created by H.H. Lamb and has since been updated regularly by the Meteorological Office and more recently by the Climatic Research Unit of the University of East Anglia. This divided the flow, defined by the surface pressure pattern over an area slightly larger than the United Kingdom, into eight wind directions which could then be subdivided into straight flow, and anticyclonically and cyclonically curved flow types. Allowing for three extra classes for purely anticyclonic, cyclonic and undefined flow patterns there are a total of 27 types. However the synoptic types defined in this way may change rapidly during a 24-hour period. We have, therefore, created an hourly data set of 'synoptic types' based on the geostrophic wind direction defined from the surface pressure at four stations (Fig. 1). Because of the shape of the British Isles and the distribution of stations this was carried out separately for England and Wales, and Scotland. An estimate of the geostrophic vorticity was obtained by using finite differences from the non-uniform grids defined by the crosses in Fig. 1. The pressure at the centre of the cross was taken as that at Abbotsinch for the northern cross and the average of Ringway, Watnall and Elmdon for the southern cross. The vorticity was often dominated by the shear whereas we are primarily interested in

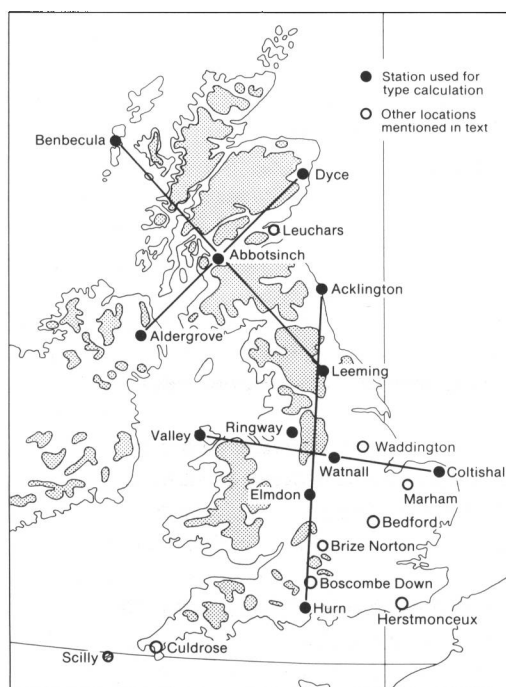


Figure 1. Distribution of stations used to calculate the synoptic type, and other locations mentioned in the text. Shaded areas denote land above 600 ft.

curvature, since different curvature for the same mean direction could result in the exposure of different locations to low cloud. An estimate of the contribution of the shear term to the vorticity was made by comparing the pressure gradient to the right and to the left of the mean wind direction. This value was then subtracted from the total vorticity to leave the contribution due to the curvature. Values of the geostrophic wind speed and 'curvature' were then used to determine if the type was straight flow, cyclonically or anticyclonically curved, purely cyclonic or anticyclonic or undefined. Before 1982, pressure values were available only every 3 hours, so values of the geostrophic wind components and the curvature were linearly interpolated to intermediate hours. Subjective assessments for two months chosen to contain a full selection of types were used to select the values of these parameters bounding the different flow types. A further two months were then used to verify the objective types against subjective assessments. On about 3% of occasions the objective type was deemed to be wrong owing to small-scale features in the pressure field affecting the estimated vorticity. On about 25% of occasions the assessments differed by adjacent categories and the remaining 72% agreed exactly.

The advantages of the 'synoptic type' defined in this way is its objectivity and the greater number of events available with hourly data. The main disadvantage is the rather small area over which the type is defined.

3. Stratus regimes

The frequency of stratus below 400 ft for given 30° sectors of local surface wind was plotted against wind sector and month. From these, the month and direction most prone to stratus were found for each station. When these data were plotted (Fig. 2) three main regimes were indicated. There are two essentially maritime regimes with maximum frequency in summer affecting (i) the west coasts of Scotland and Wales and the south-west coast of England and (ii) the north and east coasts of Scotland

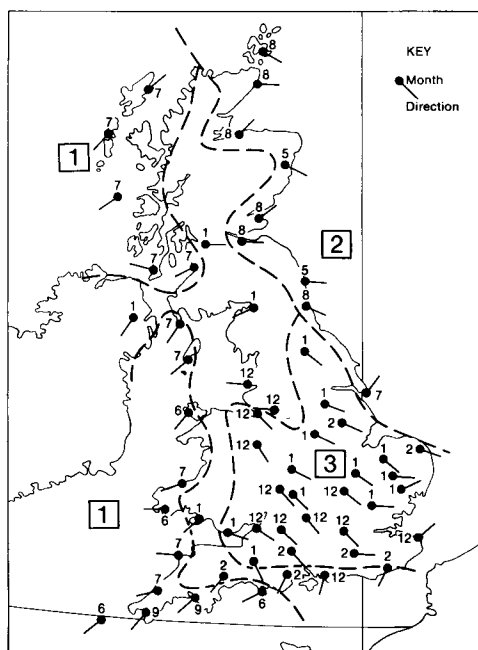


Figure 2. Month and surface wind direction most prone to stratus below 400 ft. The numbers in boxes denote the three main stratus regimes.

and the east coast of England. The third regime has a maximum frequency in winter and mainly affects most of central, southern and eastern England. There is some overlap of the second and third regimes over southern England, where the former extends all the way down the east coast and inland as far as central southern England but is masked on Fig. 2 by the higher frequencies in the winter regime. Those locations which do not fall into any of these classes have only low overall frequencies.

3.1 *South-westerly regime*

The south-westerly regime has a maximum frequency in summer and is restricted to the coastal regions by the high ground in most of western Britain; only in southern England is there much inland penetration of stratus and even here it is only a problem on relatively high ground. This regime is clearly associated with advection of moist Atlantic air as it moves north-eastwards over increasingly colder sea. An example of the distribution of stratus below 400 ft by wind direction and month is shown in Fig. 3(a) for the Scilly Isles, off south-west England. The frequencies are the percentage of occasions for each month of cloud below 400 ft, given that the wind is in the specified 30° sector. Therefore, if winds from that sector are relatively infrequent, the peak values will not necessarily indicate the direction with the greatest total number of events. At Scilly, stratus is present throughout the year, but with a maximum frequency in June. There is also a broad spread of directions affected, reflecting the exposed position of the islands. Further north, up the west coast, local shelter restricts the directions prone to low cloud and the summer maximum becomes more marked.

3.2 *Easterly regime*

This regime has a maximum frequency in August, with wind directions between north-east and south-east. Again the stratus is formed by cooling of air over a cold sea surface and the slightly later time of maximum frequency than in the south-westerly regime is probably due to the tongue of cold water that persists throughout the summer off the east coast of England and Scotland. In the south the stratus is most frequent with a wind from north of east giving a long sea-track over the North Sea whereas in the north a longer fetch over the sea is associated with south-easterly winds. However, in the north local orography has more influence on the most vulnerable direction. Also, fog or very low stratus sometimes enters the North Sea between Scotland and Norway and is advected down the east coast by north-easterly winds (Findlater *et al.* 1988). Fig. 3(b) gives an example of the distribution of stratus with local wind direction and time of year for Leuchars.

3.3 *Winter south-easterly regime*

The explanation of this regime is less obvious than for the others as it occurs in south-eastern Britain with winds from a continental source. The distribution by month and local wind direction is typified by that of Waddington (Fig. 3(c)). There is a very marked peak in December with winds from between 080 and 150°, accentuated in this case by slight upslope flow from these directions. Low stratus is very infrequent with winds between 200 and 300°, and also during spring and summer except for winds between north and north-east. This latter exception shows that this station is also affected by the easterly regime.

There is an overall increase in frequency away from the coast. This suggests that the stratus is formed in part by nocturnal cooling over land. This will be discussed further in the next section in connection with the spatial distribution of stratus for given synoptic types.

4. *Spatial distribution by type*

The statistics described above can be a useful aid for the forecaster concerned with a spot forecast for his own location but much of the commitment at RAF stations is for forecasts for areas remote from the

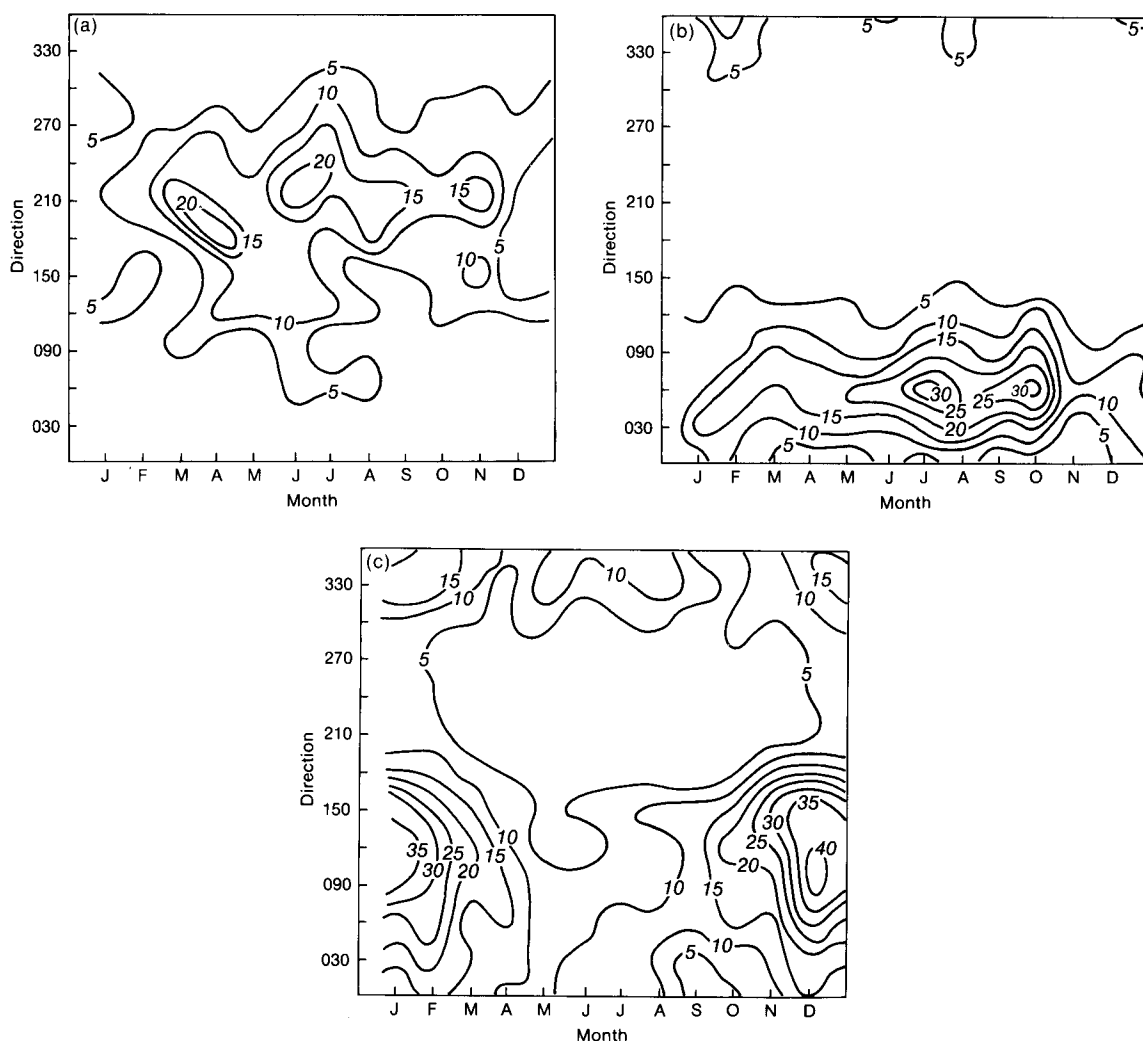


Figure 3. Percentage frequency of stratus below 400 ft given the local surface wind direction and time of year at (a) Scilly, south-westerly regime, (b) Leuchars, easterly regime, and (c) Waddington, south-easterly regime.

station. In this case it would be helpful to have an indication of how stratus is likely to be distributed spatially for a given weather situation. This has been tackled by defining synoptic types as described in section 2. The frequency of stratus below three heights (300, 700 and 1500 ft above station level, corresponding to frequently used RAF operating limits) were plotted for each of four seasons. There was an encouraging agreement between neighbouring stations, even in the less frequently occurring types with a small sample size. However, a large proportion of the variation between stations can be attributed to the height of the station. Assuming the air below the stratus base is reasonably well mixed, apart from development due to cooling or warming, even over rising ground the cloud base will be at a constant height above sea level until the cloud intercepts the hills. It therefore makes sense to correct frequencies to a common height above sea level if isopleths of equal frequency are to be drawn. This then enables the likelihood of stratus occurring at locations remote from observing stations to be estimated.

Heights above station level for spot airfield forecasts can be found by applying the correction in reverse. When winds are very light and the air is not mixed, stratus may form at a lower height on windward slopes. In this situation local effects will dominate and this approach is no longer useful.

To enable the correction to be estimated, the variation of frequency with the height of the base was found for each station and each type. The rate of increase in frequency with height varied markedly with flow type and between stations, but was nearly linear for any given station and type. The distribution of the rate of increase in frequency with height for anticyclonic southerly flow in winter is illustrated in Fig. 4. A consistent pattern appears with generally good agreement between neighbouring stations, so a reduction of frequencies to a common height using these values would appear to be valid. The increase with height in this winter case is largest furthest from the windward coasts. This is to be expected if the stratus forms owing to cooling as it moves inland. The dryer the air the higher the base, and the further air has to travel before it forms, giving a higher frequency of high bases inland. In addition any very low stratus advected onshore will be intercepted by the topography, and inland valleys will be sheltered; hence the relative frequency of high bases will increase inland. In the summer, stratus at any height is less likely to penetrate inland during the day so inland the rate of increase with height is low reflecting the overall lower frequency. There are, however, notably higher rates of increase over windward slopes.

The resultant distributions are shown for three types representing the three regimes in Figs 5, 6 and 7. Frequencies are given for 500 ft above sea level for the winter case because this height corresponds to the previously chosen 300 ft above station level at many stations. Cloud at the surface is implied at only one station (Lyneham). A height of 700 ft above sea level is chosen in the summer because of the generally higher bases in this season.

In the case of anticyclonic southerly flow in winter we see that the frequency of stratus below 500 ft generally increases with distance inland. The effect of even very modest topography is illustrated by the very low frequencies in the lee of the Cotswold Hills (situated just to the south-east of the Welsh hills). A further interesting feature is the tongue of low values extending north-westwards across south-east England, downwind of the Strait of Dover. This suggests that the stratus is perhaps being formed due to moistening of the flow over the English Channel and the North Sea, and subsequent cooling over the land. The very short sea passage across the Strait of Dover does not allow enough moistening of the air for stratus to form, at least below this height. However, there is probably also an effect due to the reduced cooling over the London area which also lies downstream of Dover.

For south-westerly flow in summer, stratus is confined to the west coasts and parts of southern England where slight upslope flow enhances its frequency.

The distribution for summer north-easterly flow illustrates the spread of stratus inland over central and eastern England in this regime. The decreasing frequency inland reflects the change in diurnal variation with distance from the coast. A further interesting feature is the appearance of a second area prone to stratus down the west coast.

5. Diurnal variation

The diurnal variation of stratus frequency is controlled largely by time of year and distance from an upwind coast. It is desirable, therefore, to investigate the variation at each station for each synoptic type and each season. In practice it is necessary to combine types having similar spatial frequency distributions to avoid spreading the data too thinly.

Fig. 8(a) shows the diurnal variation for three stations at different distances from the coast for south-westerly types in summer. There is a clear diurnal variation even at Scilly, only 1 km from the coast (though the author is at a loss to explain the phase). At Culdrose, 5 km inland, the slight increase in frequency after 10 GMT is probably associated with an increase in onshore wind due to sea-breeze effects, a more marked increase taking place after 18 GMT as the insolation begins to decrease rapidly.

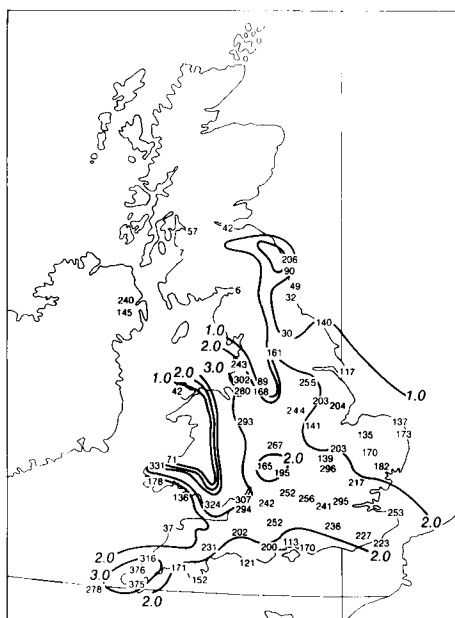


Figure 4. Distribution of increase in stratus percentage frequency with height for anticyclonic southerly type in winter. Contours in per cent per 100 ft.

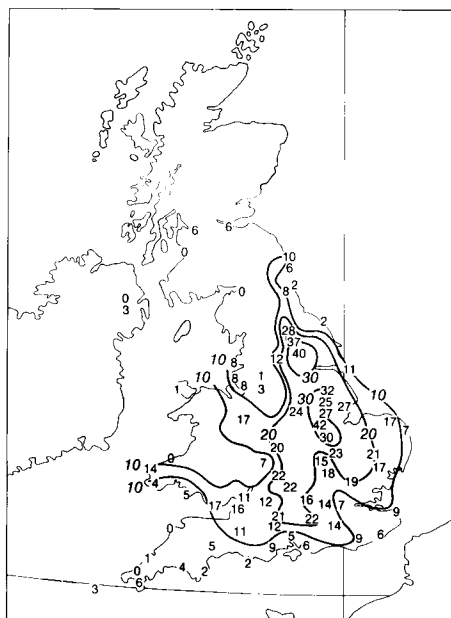


Figure 5. Distribution of percentage frequency of stratus below 500 ft above mean sea level for anticyclonic southerly type in winter.

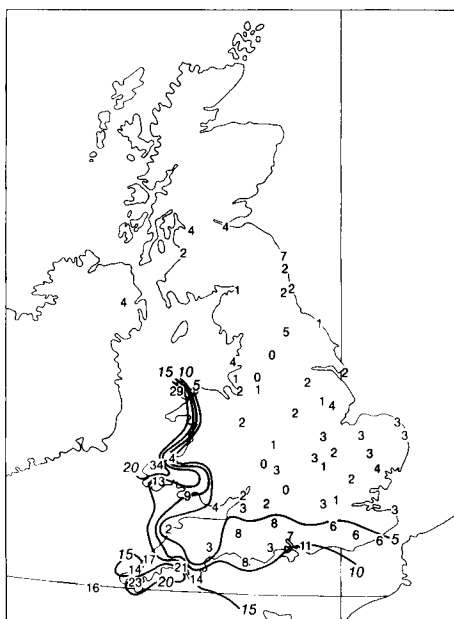


Figure 6. Distribution of percentage frequency of stratus below 700 ft above mean sea level for summer south-westerly type.

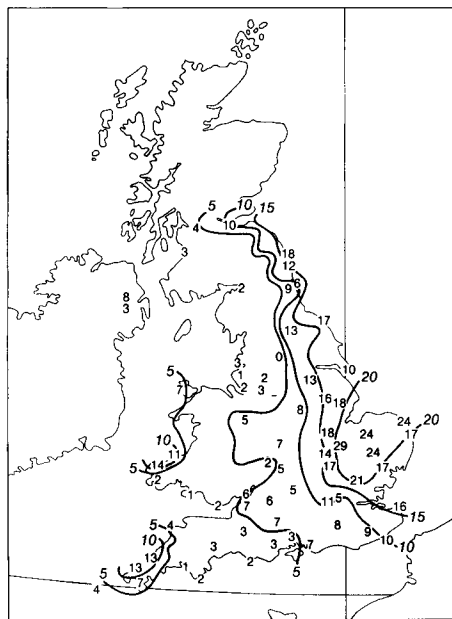


Figure 7. Distribution of percentage frequency of stratus for summer north-easterly type.

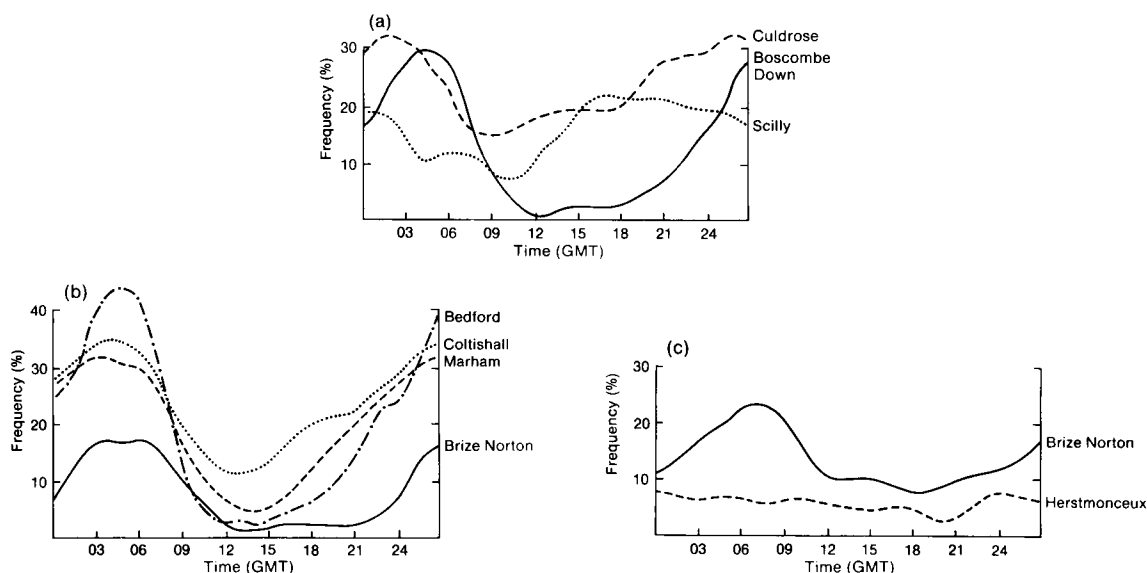


Figure 8. Diurnal variation of stratus frequency. (a) Base < 700 ft above sea level for south-westerly and cyclonic south-westerly types in summer, (b) base < 700 ft above sea level for anticyclonic northerly, north-easterly, anticyclonic north-easterly, easterly and anticyclonic easterly types in summer, and (c) base < 500 ft above sea level for anticyclonic easterly, south-easterly, anticyclonic south-easterly and anticyclonic southerly types in winter.

The overall higher frequency at Culdrose (268 ft above sea level) than Scilly is probably due to ascent over the coast. Well inland at Boscombe Down, in the early morning, stratus is almost as frequent as at the coast, but will almost always lift to above 700 ft above sea level (300 ft above station level) during the day.

A similar pattern is evident for the easterly regime (Fig. 8(b)). At Coltishall (15 km from the Norfolk coast) the frequency is reduced to about a third of the peak value by midday but begins to increase thereafter, again showing the effects of sea-breeze type circulations. Further inland at Marham and Bedford (65 and 165 km from the east coast respectively) the peak frequency is maintained showing that on most nights stratus will penetrate this far inland, but 260 km from the east coast at Brize Norton the maximum frequency has fallen by 50%. (The higher maximum frequency at Bedford is probably due to the inclusion of fog with sky obscured in the analysis.) Solar heating causes the base to lift at a similar time at all four stations but it returns at a later time with increasing distance from the coast suggesting advection is the dominant mechanism here.

In the winter regime there is again a marked diurnal variation inland as shown in Fig. 8(c) but there is very little variation close to the coast. The weak minimum at 20 GMT at Herstmonceux, 8 km from the south coast, may be the effect of diurnal heating over France. The increased frequency inland, both day and night, suggests formation by radiative cooling and by contact with a cold surface.

Graphs such as those in Fig. 8(b), where the diurnal variation is well defined, can be used to estimate typical clearance and formation times which can then be plotted to give the spatial variation. In this case the clearance time would not vary much, but if the time by which the frequency has risen to 50% of its peak value is plotted there appears a very coherent and physically sensible pattern over much of England which can be interpreted as an estimate of relative formation/advection times (Fig. 9). In the early evening as the insolation begins to decrease rapidly, stratus can be expected to begin to affect the Norfolk coast and then to spread steadily inland. Several sensible effects can be discerned such as the

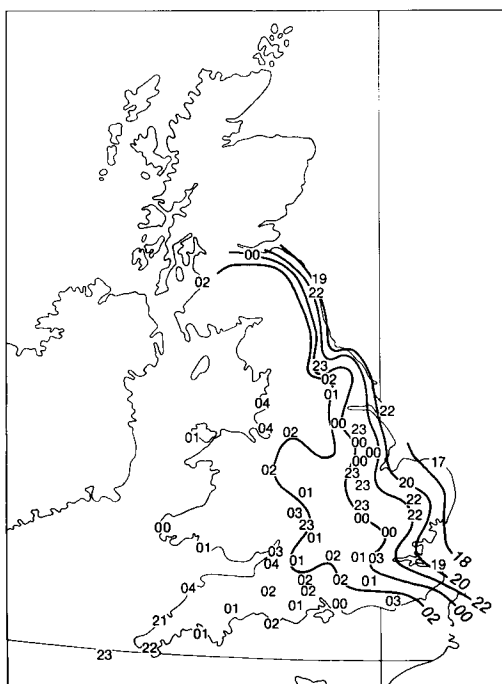


Figure 9. Distribution of typical times (GMT) of formation or arrival of stratus below 700 ft above sea level for anticyclonic northerly, north-easterly, anticyclonic north-easterly, easterly and anticyclonic easterly types in summer. See text for details.

sheltering of the Vale of York (south of Leeming) by the North York Moors, and more rapid penetration downstream of The Wash and through the gap between the Cotswold and Chiltern Hills towards Brize Norton. Bristol and the Severn Valley are well protected by the Cotswolds, and Herstmonceux near the Sussex coast is protected by the North and South Downs. Further west, local cooling of moist air advected inland by sea breeze circulations is probably responsible for the earlier formation times. In the extreme west, advection off the sea to the north is important. The effect of the London heat-island is indicated by the late arrival of stratus at the London Weather Centre.

6. Discussion

The stratus in the first two (summer) regimes is mostly advected over the United Kingdom from the sea. The forecast problem is then partly that of identifying and tracking areas of fog or low stratus. The development of techniques to detect fog and very low cloud on night-time satellite pictures using different infra-red channels will bring considerable improvements in this area. During the day there is still the effect of local circulations such as sea-breezes to consider and also the time at which stratus, advected inland overnight, will clear during the morning. For accurate assessment of the latter it is necessary to know the depth of the cloud layer and whether there are further cloud decks above. Again the advancement of satellite techniques will help. The Meteorological Office is also setting up a system of minisonde ascents to be made from key stations as the situation demands. This will enable the boundary-layer structure to be ascertained in regions remote from the regular radiosonde stations and at the time required rather than at set intervals. This will clearly help with prediction of both the formation and dispersal of stratus and fog. The problem of the effect of local circulations is being tackled by both modelling and observational studies. In recent years research has been carried out into the interaction

between sea fog and the local circulation of northern Scotland using radiosonde and aircraft data (Findlater 1985, Findlater *et al.* 1988). Experiments with the Meteorological Office mesoscale model (Taylor 1987) have demonstrated its ability to reproduce the local circulations crucial to the correct forecasting of low cloud and fog in this area.

The forecast problem in the winter regime appears to be more difficult in that there appears to be a mix of cooling, probably by surface contact and by radiation, causing formation *in situ*, and advection of pre-existing stratus from over the sea. However, the air mass can probably be traced back to the Continent where its initial conditions can be reasonably well defined. It therefore seems that this situation may best be tackled using a Lagrangian boundary-layer model with the boundary conditions supplied by larger-scale forecast models. However, the modelling of the stable boundary layer, which is likely to exist most of the time in this situation, is notoriously difficult. As part of a continuation of the studies of sea fog mentioned above it is planned to carry out flights this summer using the Hercules aircraft of the Meteorological Research Flight to investigate the development of sea fog and low stratus off south-west England by flying a low-level saw-tooth pattern into the low-level wind. As well as providing more direct guidance to forecasters on the structure of fog and stratus in its formative stages, this will provide an ideal data set against which to test any model of stratus development.

In the shorter term it is to be hoped that the dissemination of some of the statistical data discussed here will give forecasters a clearer idea of the behaviour of stratus over the country as a whole as well as at their own location.

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An introduction to radio ducting

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Summary

Anomalous propagation of radio waves in the atmosphere has been recognized as a problem with radar and radio communications for many years. The propagation characteristics of radio waves depend upon the meteorological conditions, and several different propagation regimes can occur. In particular, radio ducting is a condition where detection and reception ranges are severely modified by atmospheric conditions. This paper summarizes the relevant aspects of radio propagation theory, the meteorological conditions that lead to ducting, and discusses the various techniques that can be used to predict ducting.

1. Introduction

The occurrence of anomalous propagation of radio waves has been recognized since the early days of radar during World War II. The term ‘anaprop’ is now normally used to describe conditions when radar detection distances are significantly greater than usual. Such conditions occur fairly frequently.

The phenomenon known as 'ducting' is an extreme form of anaprop, and describes those occasions when radio waves become trapped in a shallow quasi-horizontal layer. In such conditions, greatly enhanced radar-detection ranges occur, owing to the concentration of energy within the duct. However, since energy is concentrated within the duct, this results in a reduction in the amount of energy reaching the region immediately above or below the duct and can lead to what is termed a radio or radar 'hole'. The presence of radar ducts and holes is of great importance to military operations, and there is a need to be able to forecast them so that their effects can be exploited or avoided.

The effects of anaprop are also important to the Meteorological Office Weather Radar Network, as illustrated in the example shown in Fig. 1. On this occasion, although most of Britain had a dry night, the radar display showed many returns across central England, and also from the Isle of Man; these were not caused by precipitation, but were due to anomalous propagation. Such spurious echoes, which have to be removed before rainfall intensities can be estimated, are a common problem with the weather radars (Smith 1981).

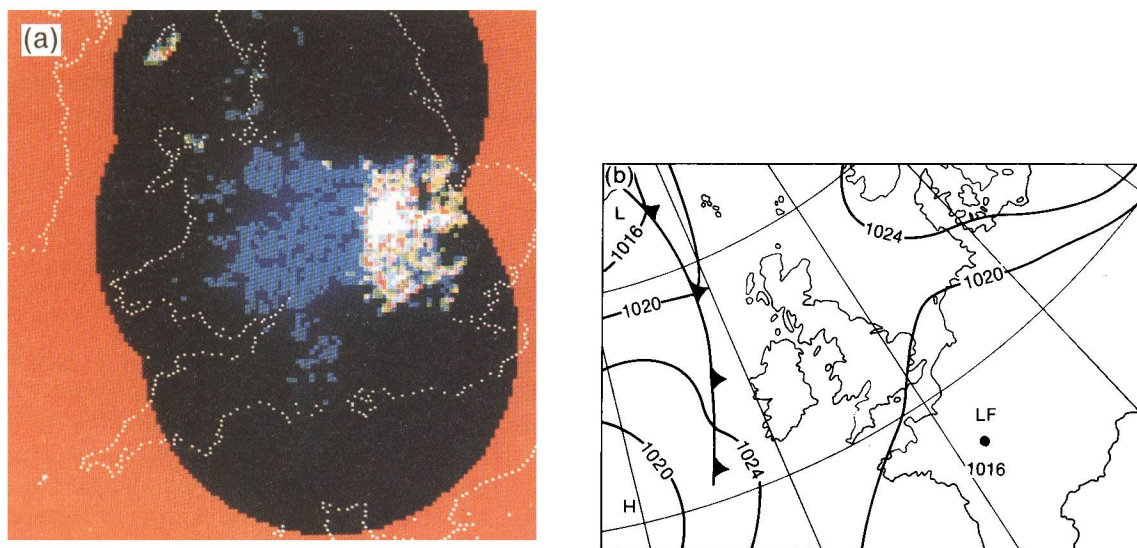


Figure 1. (a) An example of spurious returns due to anomalous propagation as seen by the Meteorological Office Weather Radar Network at 2200 GMT on 21 June 1983, and (b) synoptic chart for 0000 GMT on 22 June 1983.

2. Theory of radio propagation

2.1 Propagation characteristics

When radio waves, which are a form of electromagnetic radiation, travel through the atmosphere, they follow curved rather than straight paths. This occurs because the refractive index of the atmosphere varies with height, and so the rays are refracted. The curvature of a ray depends upon the rate of change of the refractive index of the air with height. The refractive index, n , is a function of the air pressure, p , temperature, T , and vapour pressure, e . At sea level in mid-latitudes a typical value of n is 1.00035 and so it is usually more convenient to define the refractivity, N , where

$$N = (n - 1) \times 10^6.$$

When n is 1.00035 the corresponding value of N is 350 (in N units). The refractivity is given (Bean and Dutton 1966) by

$$N = (77.6/T)(p + 4810e/T) \quad \dots \quad (1)$$

where p and e are in millibars and T is in degrees Kelvin. The vapour pressure can be determined from the dew-point temperature, T_d , using Tetens' equation

$$e = \exp \left(1.8099 + \frac{17.27 T_d}{T_d + 237.3} \right)$$

where T_d is in degrees Celsius.

The refractive index of the atmosphere normally decreases with height, which results in a downward bending of the wave path. To a high degree of approximation the curvature, K_0 (i.e. the reciprocal of the radius), of a near horizontally propagating radio wave is given by $K_0 = -dn/dz$ (Director of Naval Oceanography and Meteorology 1984) where K_0 is in km^{-1} and z is the height (km) above the earth's surface. In a well-mixed atmosphere, the value of dn/dz is such that a near horizontal ray is bent downwards with a curvature roughly equal to one quarter that of the earth's surface. This enables the radar to see 'over the horizon' as illustrated in Fig. 2. (Note that the ray path shown here is for an initial elevation which is below the horizontal.)

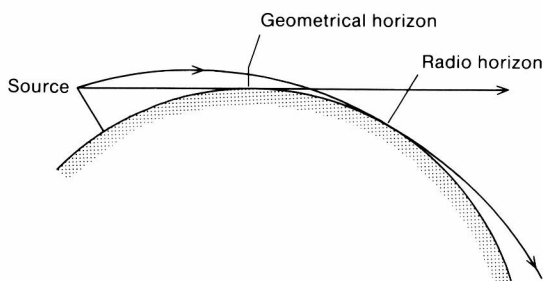


Figure 2. Schematic diagram illustrating the bending of a radio wave beyond the geometric horizon due to atmospheric refraction (vertical scale greatly exaggerated).

Fig. 3 illustrates the various refraction propagation categories. Standard refraction conditions refer to those that occur when the atmospheric state is close to that of a well-mixed atmosphere, for which the refractivity gradient $dN/dz = dn/dz \times 10^6$ is about -40 (N units km^{-1}). Standard conditions, where dN/dz is in the range from 0 to -79 N units km^{-1} , are representative of the mean state of the atmosphere.

If the decrease of refractivity with height is greater than that for standard conditions, then the curvature of the wave path is increased, and in extreme conditions can become comparable with the curvature of the earth $K_E = 1/R$, where R is the radius of the earth ($= 6371$ km), and therefore $K_E = 157 \times 10^{-6} \text{ km}^{-1}$ ($dN/dz = -157$ N units km^{-1}). If the curvature of the ray becomes greater than that of the earth, i.e. when $dN/dz < -157$, then the ray is bent to such an extent that it intersects the ground and the propagation characteristics become very different. This process is referred to as 'trapping', and the layer in which the ray is bent back downwards is called the trapping layer. The 'duct' is that region below the top of the trapping layer in which the radio wave is propagated. (Some examples of trapping layers and ducts will be considered in section 2.2.)

If the refractivity gradient lies between -79 and -157 N units km^{-1} (i.e. the curvature exceeds the standard value), but the ray is not brought back to the surface, the conditions are described as

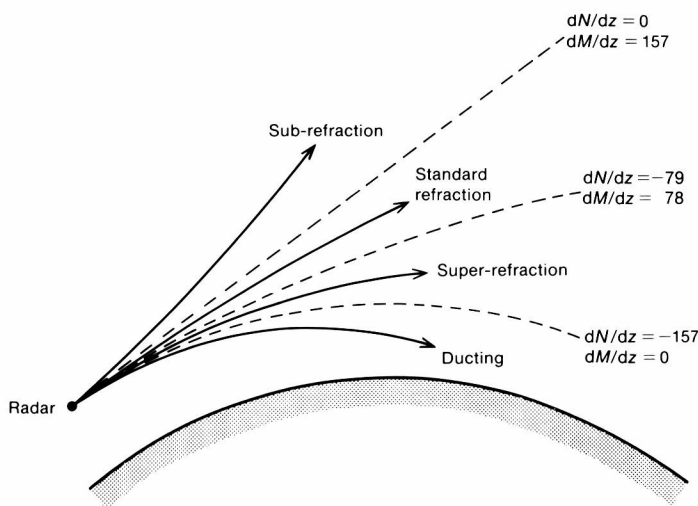


Figure 3. Refractive propagation categories. Note that the ray-paths all result from an initially horizontal ray. For explanation of lettering see text.

'super-refracting'. An initially horizontal ray is bent down with an increased curvature, and there is an increase in detection range.

Under some circumstances the refractivity may increase with height, and the wave is then bent upwards as shown in Fig. 3. Such conditions are described as 'sub-refracting' and detection ranges are then less than the standard values.

Because of the marked change in the propagation characteristics of radio waves, when their curvature exceeds that of the earth's surface, it is useful to consider the difference ($K_o - K_E$), given by

$$K_o - K_E = - (dn/dz + 1/R) = -dm/dz,$$

where m is the modified refractive index, $m = n + z/R$, and the propagation characteristics depend upon the sign and magnitude of the vertical gradient of m . It is convenient to define a modified refractivity M as

$$M = (N + z/R) = N + 157z,$$

where z is in km. Then $dM/dz = dN/dz + 157$ and the gradient of M is zero when the curvature of the ray is equal to that of the earth, i.e. $dM/dz < 0$ for ducting conditions. M is therefore a useful index for diagnosing ducting.

The various classes of propagation, as discussed above, can be defined in terms of dN/dz and dM/dz , and are summarized in Fig. 3.

2.2 Types of duct

As noted above, ducts can be identified from examination of the vertical profile of modified refractivity. Fig. 4 shows the three basic forms of the M profile under ducting conditions and illustrates how the duct depth is determined. In Fig. 4(a) the duct exists from the local minimum to the surface, and the trapping layer, where $dM/dz < 0$, extends throughout the duct. In Fig. 4(b) the duct again extends to the surface, in spite of the fact that the trapping layer does not, as dM/dz is positive close to the surface.

This is because the value of M at the surface is greater than the value at the top of the duct (i.e. at the local minimum), hence the average value of dM/dz below this level is less than zero. Fig. 4(c) shows the structure associated with an elevated duct. Here the value of M at the surface is less than the value at the top of the duct, and so the duct cannot extend down to the surface. Its depth extends from the local minimum to the height at which the M value equals that at the top of the duct.

Fig. 5 illustrates the type of propagation paths that occur in the three different types of duct described above. Not all rays are trapped in a duct. In practice only those rays entering the duct at a very shallow angle to the local horizon (typically less than 1°) are trapped. In each case the presence of a radio/radar hole above the duct is indicated (i.e. where there is little penetration of the radio/radar beam as a result of the duct). In reality, all ducts are 'leaky' and some energy will escape through the top of the duct into the region above. Thus it is possible to detect targets within a radar hole, although detection ranges will

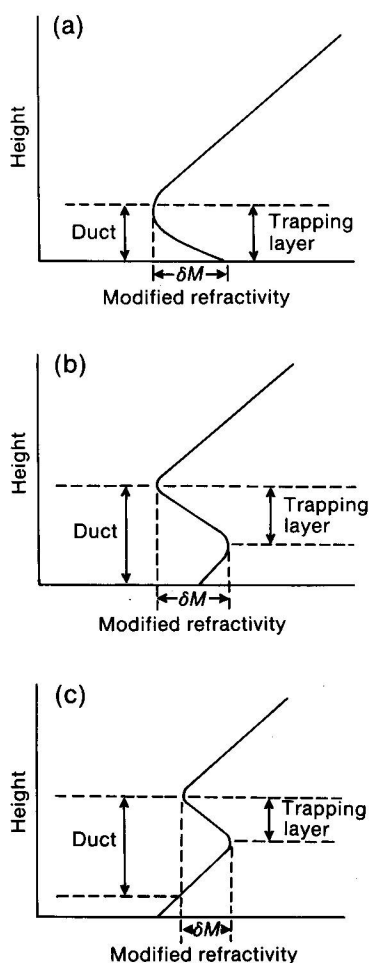


Figure 4. Typical modified refractivity (M) profiles for (a) simple surface duct, (b) surface S-shaped duct, and (c) elevated duct. The depth of the ducts and the trapping layers are indicated.

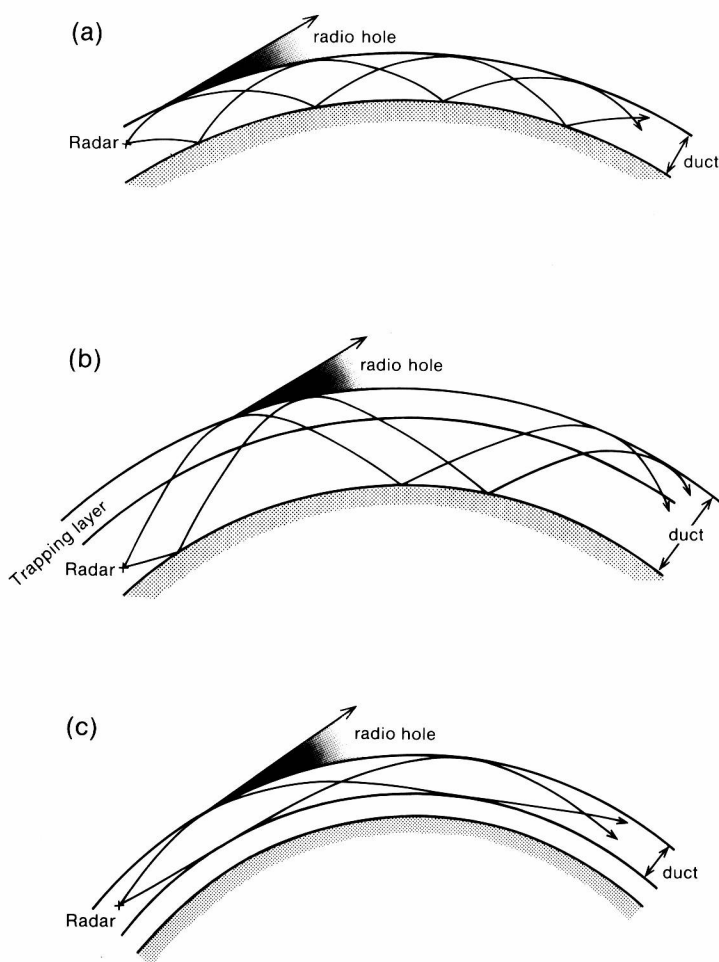


Figure 5. Typical radio propagation paths that occur in the presence of a (a) simple surface duct, (b) surface S-shaped duct, and (c) elevated duct.

be greatly reduced when there is little energy propagated into the region. Consequently the ability to forecast ducts and holes is of great importance to a wide variety of military operations.

2.3 Intensity of duct

The intensity, or strength, of a duct is given in terms of the maximum wavelength which is trapped by the duct. Using a simplified mode theory (Kerr 1951) gives the following expression for estimating the duct intensity:

$$\lambda_{\text{MAX}} = C \int_{z_L}^{z_U} (M(z) - M_U)^{1/2} dz \quad \dots \dots \dots (2)$$

when λ_{MAX} is the maximum wavelength (m) trapped by the duct, and z_U and z_L are the upper and lower limits of the duct; $C = 3.77 \times 10^{-3}$ for a surface-based duct and $C = 5.66 \times 10^{-3}$ for an elevated duct. This leads to the following expression for the duct intensity, assuming linear refractivity profiles in the trapping layer and for the layer beneath:

$$\lambda_{\text{MAX}} = (2C/3)[\delta M^{1/2}t + \{(\delta M^{3/2} - (M_L - M_U)^{3/2})(d-t)/(\delta M + M_U - M_L)\}]$$

where δM is the modified refractivity difference through the trapping layer ($\delta M = M_B - M_U$, where M_B is the modified refractivity at the base of the trapping layer), d is the depth of the duct (m) and t is the depth of the trapping layer (m). For both a simple surface duct and an elevated duct this expression simplifies to give

$$\lambda_{\text{MAX}} = 2Cd \delta M^{1/2}/3$$

as given by Hall (1979). Note the different values of C for surface-based and elevated ducts. For a simple surface duct and an elevated duct the intensity of the duct depends upon the change in refractivity through the trapping layer and the thickness of the duct.

Table I shows the maximum wavelength propagated for elevated ducts with various characteristics. A large value of λ_{MAX} means that the duct is strong because all shorter wavelengths are trapped.

Table I. The maximum wavelength λ_{MAX} in metres propagated by an elevated duct for given duct characteristics

Duct thickness d (m)	Values of δM (M units)			
	5	10	20	50
5	0.04	0.06	0.08	0.13
10	0.08	0.12	0.17	0.27
20	0.17	0.24	0.34	0.53
50	0.42	0.60	0.84	1.33
100	0.84	1.19	1.69	2.67

It should be noted that atmospheric ducts do not have a sharp cut-off wavelength above which waves will not propagate, but that the effects of ducting fall off gradually such that wavelengths longer than λ_{MAX} will still be affected by the duct to some extent.

In practice radio waves are often referred to in terms of their frequency f . The minimum frequency f_{MIN} (in Hz) which is trapped by a duct is given by

$$f_{\text{MIN}} = c/\lambda_{\text{MAX}},$$

where c is the propagation speed of the radio wave ($c = 3 \times 10^8 \text{ m s}^{-1}$).

3. Meteorological aspects of duct formation

It can be seen from equation (1) that the refractivity is a function of pressure, temperature and vapour pressure. The sensitivity of N to changes in these parameters can be investigated by partially differentiating equation (1). It can be shown that on most occasions the change of vapour pressure is the dominant term with a smaller contribution due to the change of temperature; pressure changes are the least important.

The meteorological conditions which lead to duct formation are the existence of a strong hydrolapse, and to a lesser extent the presence of a marked temperature inversion. There are five main types of meteorological processes where such conditions occur

- (a) evaporation over the sea,
- (b) anticyclonic subsidence,
- (c) subsidence at frontal surfaces,
- (d) nocturnal radiative cooling over land, and
- (e) advection.

In addition ducting can occur as the result of more localized effects, e.g. sea breezes and thunderstorm outflows.

3.1 *Evaporation ducts*

A shallow surface-based duct is frequently observed over the oceans and results from the large hydrolapse normally present immediately above the sea surface. The evaporation duct exhibits a geographical, seasonal and diurnal variation with greater depths at lower latitudes, during summer months and during daytime. For example, the mean duct depth over the North Sea is about 5 m, but is 10–14 m in the Mediterranean. It is primarily of interest to shipping and can be critical in naval operations, but also affects coastally sited radars.

Evaporation ducts may also form over land areas as a result of evaporation over wet surfaces after rain, or over lakes when steam fog is observed. However, land-based evaporation ducts are generally short-lived features.

3.2 *Ducts associated with anticyclonic subsidence*

The most common reason for the formation of elevated ducts in mid-latitudes is subsidence associated with anticyclones, where a temperature inversion is formed by the subsiding air. Depending on the strength of the hydrolapse, elevated ducts may form in association with the anticyclonic inversion. Usually such ducts form up to a height of about 3 km above the surface. In particular, when stratocumulus cloud forms in the boundary layer beneath an anticyclonic inversion it is usually characterized by a strong capping inversion and hydrolapse, and ducting might well be expected to result. Stratocumulus sheets are a very common feature around the British Isles and western Europe and the potential ducting could be important to low-level flying operations undertaken by the RAF. Semi-permanent areas of stratocumulus also occur in the subtropics, which could result in semi-permanent regions of ducting.

3.3 *Ducts associated with frontal systems*

The temperature inversion through a frontal zone is not usually associated with a marked change of refractivity as the moisture content of the air is higher in the warmer air above. However, layers of subsided air are often found beneath a frontal zone (especially in warm fronts), and can lead to the formation of elevated ducts which are generally found ahead of the rain belt in a warm front and behind it in a cold front. Such ducts are relatively transitory features.

3.4 *Ducts associated with nocturnal cooling over land*

Night-time radiative cooling of a land surface under clear skies leads to the formation of a temperature inversion, whilst dew deposition leads to an increase of humidity with height. Whether a duct forms will depend on whether the wind is sufficiently light to reduce the deposition of dew. Such conditions are often associated with the formation of radiation fog, and a duct may form during the early stages of the fog. However, as the fog thickens, the temperature inversion migrates to the fog top, where a negative hydrolapse may develop, thus weakening the duct.

3.5 *Advection ducts*

Advection ducts may form when warm, dry continental air passes over a cooler sea, thus cooling and moistening the lowest layers. This effect can reinforce a pre-existing evaporation duct and so increase its depth. Advection ducts are usually confined to within 100 km downwind of a lee shore. Such ducts are particularly important for coastally sited radars and to low-level coastal operations. Advection ducts are also sometimes observed when warm moist air is advected over a cooler sea, resulting in the formation of sea fog with a duct near the top of the fog.

4. Forecasting techniques

Forecasting the existence of ducts depends upon being able to predict the vertical profiles of temperature and humidity in the region of interest. This is achieved by a combination of conventional manual and modelling techniques.

4.1 *Conventional forecasting*

It is relatively straightforward to determine the refractivity profile from a tephigram. The main problem is in constructing a tephigram for the time and place of interest, and to assess the representativeness of the profile. N and M may be calculated from a tephigram either by using standard overlays or by using a simple program on a desk-top computer.

Fig. 6(a) shows part of a tephigram for the radiosonde ascent at Crawley at 0000 GMT on 13 August 1987. The modified refractivity (M) profile has been calculated from this ascent and is shown in Fig. 6(b). In this example a duct is found to exist from 889 mb down to 919 mb. At 900 mb a moist spike in the humidity profile due to the lag of the sensor is apparent. However, this feature makes no difference to the depth determined for the duct, although it should be accounted for in calculating the intensity (equation 2).

On occasions when the radiosonde data suggests the existence of a surface-based duct, this should be interpreted carefully as the low-level humidity measurements from the sonde are sometimes unreliable. Also there may be a mismatch between the surface observations and the sonde measurements near the surface. Consequently radiosonde data should be used with caution to infer the presence of surface-based ducts. In addition, when a sonde emerges from cloud, the lag in the humidity element means that the sharpness of the hydrolapse may be misrepresented. Also the temperature element may be subject to evaporative cooling. These effects should be taken into account when assessing ducting from radiosonde data.

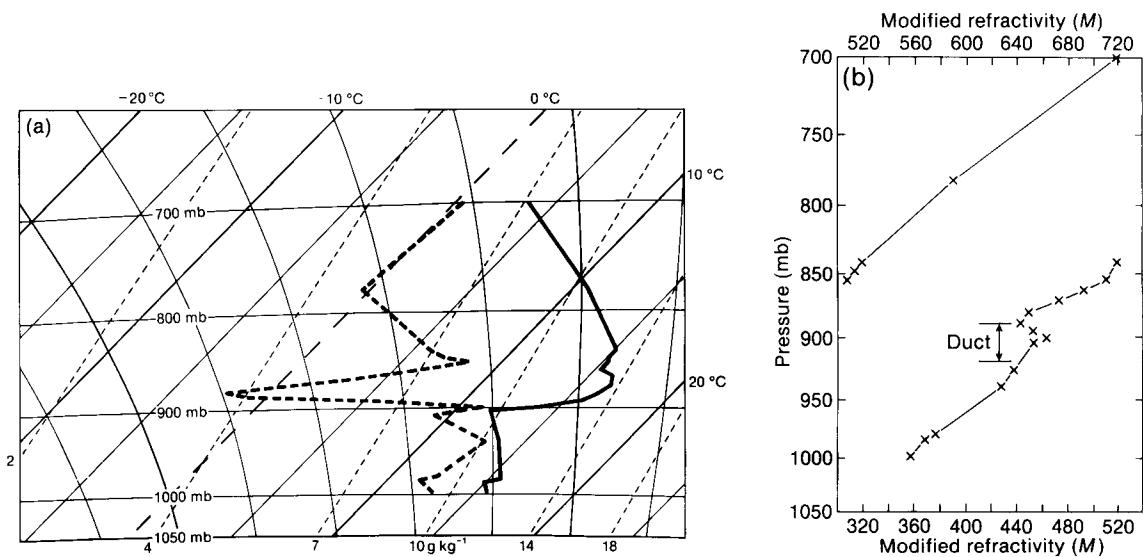


Figure 6. (a) Tephigram for the radiosonde ascent for Crawley at 0000 GMT on 13 August 1987, and (b) the modified refractivity (M) profile determined from the ascent.

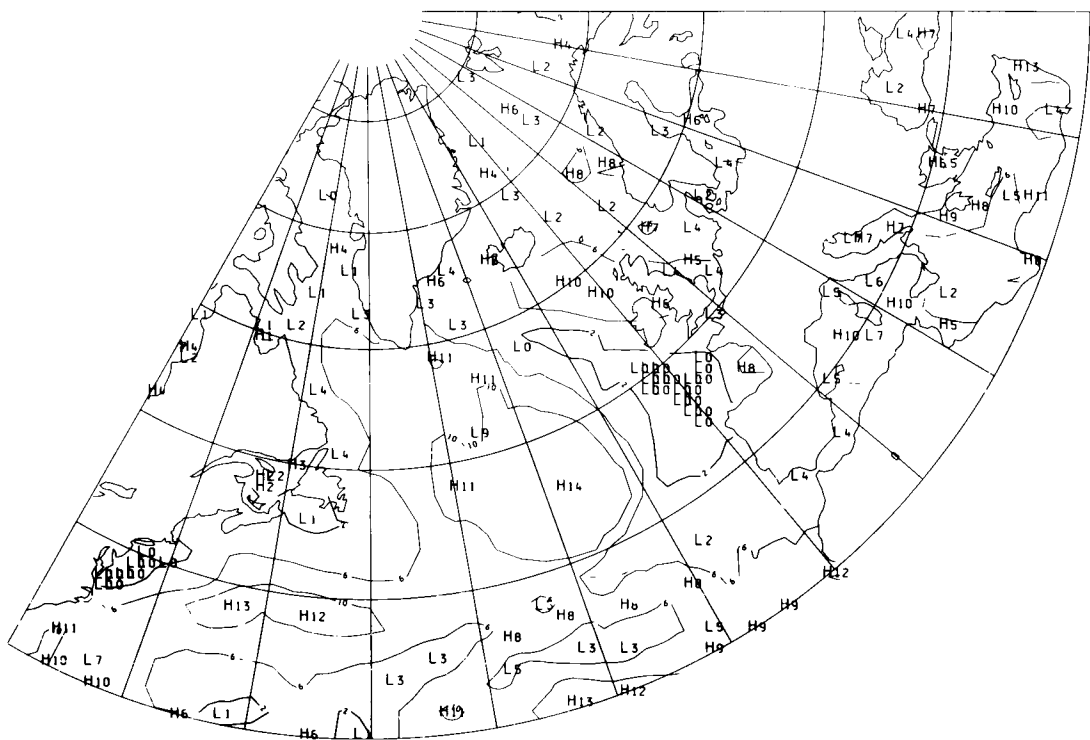


Figure 7. A fine-mesh model 24-hour forecast from 1200 GMT on 21 November 1986 of the evaporation-duct depth (m) over the North Atlantic.

4.2 *Modelling techniques*

Although numerical models can help identify the relevant air mass and give good guidance to the general synoptic development, they cannot provide vertical profiles of temperature and humidity to the accuracy required to predict ducts. This is due to three factors:

- (a) lack of vertical resolution,
- (b) the forecast humidity fields lack the necessary detail and accuracy, and
- (c) the boundary-layer parametrization is too simple to represent the evolution of the boundary layer with sufficient detail.

A comparison of fine-mesh model profiles with actual radiosonde data on occasions when ducts were known to be present shows that the model profiles do not represent the fine structure associated with the ducts. A possible solution to this problem is to use a method based on model output statistics. This approach is currently being investigated in the Special Investigations Branch of the Meteorological Office.

Numerical models are, however, able to provide forecasts of the evaporation duct over the sea. A simple model has been developed based on bulk aerodynamic formulae to estimate the surface fluxes of heat and water vapour, and using similarity theory to predict the low-level profiles of temperature and humidity. This model has been coupled to the fine-mesh model to produce forecasts of the evaporation duct over the sea. An example of the model output showing predicted duct depth is shown in Fig. 7. (A similar output for duct intensity, i.e. λ_{MAX} , is also produced.) The usefulness of these forecasts has been assessed by the Royal Navy, and they are to be produced routinely.

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An unusual example of freezing rain

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Summary

On 2 March 1987 a narrow band of freezing rain, probably no more than 30 km wide, occurred over northern areas of the Netherlands and the Federal Republic of Germany. At Gütersloh the freezing rain persisted for 9 hours, resulting in considerable damage to power and telephone lines, and especially to trees.

1. Synoptic situation.

A well-marked cold front, which had initially moved eastwards, returned slowly westwards through Gütersloh on 1 March. At 1800 GMT it was about 30 km south-west of Gütersloh and stationary. An active warm front was crossing Belgium from the west and by midnight there were signs that the two frontal zones were merging.

Fig. 1 shows the synoptic situation at 1200 GMT on 2 March 1987. It is no longer possible to distinguish between the two fronts at the surface over north Germany and they are shown as one warm front. Despite the ridge to the east collapsing, there was no sign of the front making any progress eastwards. Later in the day a depression moved south-eastwards over Germany, the front then moving away to the south-west.

Fig. 2 shows part of the radiosonde ascent from Fritzlar for 1100 GMT on 2 March 1987 with the warm 'nose' above a sub-freezing surface layer (the text-book conditions for freezing rain). Fritzlar is about 100 km south-east of Gütersloh and although colder at the surface it can be considered a representative ascent.

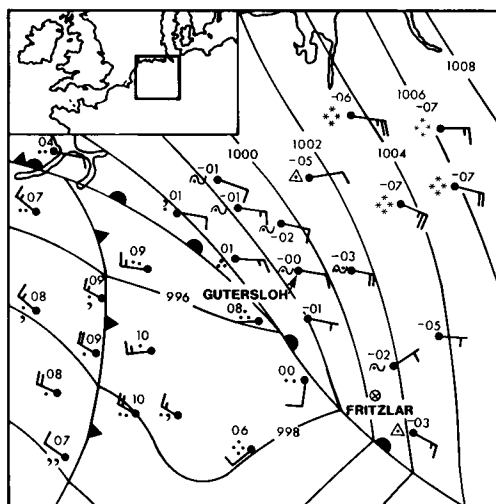
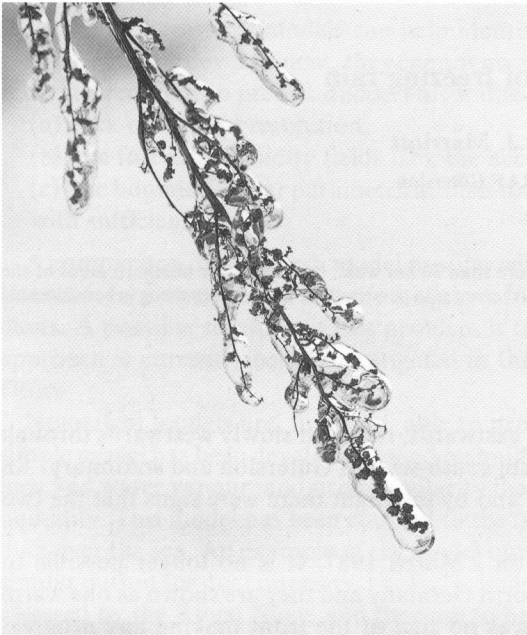


Figure 1. Synoptic situation at 1200 GMT on 2 March 1987 — the analysis from Gütersloh Meteorological Office. Observations show wind speed, temperature and present weather. Note that the observation approximately 90 km south of Gütersloh is from a high-level station, which was believed to be in the warm sector.



Some photographs showing the effects of the freezing rain at Gütersloh.

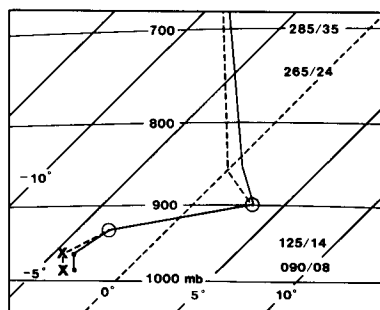


Figure 2. Part of the radiosonde ascent from Fritzlar at 1100 GMT on 2 March 1987; the location of Fritzlar is shown in Fig. 1.

2. Freezing rain and its effects.

Freezing rain is usually a transitory feature, occurring as warm air displaces a cold, continental air mass. This event is noteworthy because the freezing rain persisted for 9 hours at Gütersloh, despite the band of freezing rain being only about 30 km wide.

Rain began at Gütersloh at 2300 GMT on 1 March 1987 when the air temperature was 1.8 °C, and was continuous thereafter. Freezing rain commenced at 0600 GMT on 2 March with the air temperature hovering around zero and the grass temperature -0.2 °C. The rain was freezing on most surfaces, including the grass, but not on concrete or tarmac roads. After about 9 hours, the freezing rain gave way to snow, with the air temperature -2.2 °C. At 1800 GMT the grass temperature had fallen to -2.7 °C but solid ground surfaces were still wet. Skies cleared early on 3 March and there followed a period of cold, clear weather.

While the freezing rain caused considerable damage to telephone and power lines the main victims were the trees. Within two hours of the onset twigs and small branches were snapped off and, as the deposits grew, countless trees were brought down or damaged under the weight of ice. A local British Forces school project found that, in one example, the weight of ice on a twig was six times the weight of the twig itself. For some weeks the authorities were cutting down trees that were in a dangerous state or damaged beyond recovery. Silver birch were particularly prone to damage, bending double under the immense weight with their tops touching the ground. They then froze in this position and stayed that way even after the thaw which followed several days later.

3. Conclusion

Freezing rain, while not unknown, is rare over western Europe and is nearly always a transitory feature; this occurrence over north Germany was unusual in that it was so prolonged — local inhabitants with memories going back over 50 years could not recall having seen anything like it before.

The event illustrates vividly not only the ability of cold continental air to persist at the surface, despite the apparent encroachment of warm air, but also the marked difference between the cooling rates of grass and solid surfaces. This latter property is well known, but in this case it was surprising that after nine hours of freezing rain, with sub-zero temperatures, roads and paths were still wet, whilst most other surfaces were covered in ice.

Acknowledgements

The authors would like to express their thanks to S. Thompson of the Meteorological Office Gütersloh for his assistance with the diagrams and to the Photographic Section, RAF Gütersloh for providing the photographs.

Notes and News

Retirement of Mr D.M. Houghton

Mr D.M. Houghton, Assistant Director in charge of Marketing Services, retired from the Meteorological Office on 7 June 1988.

David Maurice Houghton joined the Office in September 1951 after studying physics at the University of Manchester, and postgraduate meteorology at Imperial College, London. He had no sooner completed the Scientific Officers Course at Stanmore than he was invited to meet his national service obligations. He elected to take a Short Service Commission in the Instructor Branch of the Royal Navy where, not surprisingly, he was given forecasting duties. During his three-year spell he opened a forecasting office at RNAS Yeovilton, where one remains in being to the present.

After a short period in the Long-range Forecasting Branch at Dunstable on his return to the Office, which resulted in a paper in this magazine on heat sources and sinks, David was promoted to Senior Scientific Officer and soon found himself in the Director-General's Office where he took part in the international work of the day as a UK delegate to the Third Congress of the World Meteorological Organization and as Secretary to the Conference of Commonwealth Meteorologists, both held in 1959. The next step was a move into forecasting, first on the upper-air bench in the Central Forecasting Office (CFO) at Dunstable and later, following the move of CFO to Bracknell, as a senior forecaster and Principal Scientific Officer. David remained in CFO until 1970 and established a reputation there for being a very sound, if sometimes adventurous, forecaster who was always on top of the situation and always up-to-speed with his work. His personal qualities fitted him particularly well for the senior forecaster post and he showed himself to be a natural leader, energetic, unshakeably good-humoured and enthusiastic. The period in CFO spanned the introduction into the forecaster's armoury of operational numerical weather-prediction products and of satellite picture analysis, and David was chosen to open discussions at the Royal Meteorological Society and in the Office on the topics of synoptic analysis and the use of satellite data.

During 1970 he was selected for the Joint Services Staff College, No. 39 Course at Latimer and later took up the post of Deputy Chief Meteorological Officer at Headquarters, Strike Command, High Wycombe, with the responsibility there of managing the Principal Forecasting Office. However, as a result of his abilities in staff management and an interest in his fellow men, he was moved again, after two years, into the Personnel Management Branch at Bracknell where he was given charge of recruiting, career management and overseas matters. At this time the Fulton concepts in management were being introduced to the Office and it fell to David to bring in the new job appraisal review system and to see through the programme of training associated with it. This called for a great deal of hard work and a degree of personal commitment to the aims of the programme which were not necessarily shared by all with whom he came into contact at the time. The system, however, came to stay and handsomely justified both itself and David's original faith in it.

The next appointment, in 1975, as Head of the London Weather Centre was tailor-made for David Houghton's talents. He was untiring in the promotion of its services. The Office was coming increasingly under pressure to recover the costs from its clients in industry of services that had acquired a high technology base and whose value in commercial terms was becoming increasingly appreciated by them. Notable were those in the offshore industry amongst whom David was personally active. The repayment income grew by leaps and bounds. His stock was high, too, at the BBC where he was seen as the harbinger of changing Office attitudes in the areas of radio and television presentation. Acceptance that the attention of the audience might best be held by more informal and less stereotyped styles was in sight!

The London Weather Centre had long been noted for its *esprit de corps* and the pride it took in its work but under David it acquired a bright professional image as well.

The promotion in 1977 to Senior Principal Scientific Officer came as no surprise, but the posting to Head of the Synoptic Climatology Branch, a research unit committed to the pioneering of long-range forecasting techniques, was a little unexpected. With typical resilience David set about the rationalization and streamlining of the experimental long-range forecasting procedures and he encouraged firms that might have the capacity to exploit somewhat slender margins of success to take a commercial interest in the results. This work was not without its rewards for him but he left it in 1981 to return to staff management work as Assistant Director in charge of the Personnel Management Branch. Again, perhaps, this would not have been a posting of his choosing but he tackled it with his customary diligence making his mark with management, unions and staff alike.

When, in response to the recommendations of the Rayner Resource Control Review, a Marketing Services Branch was set up in 1984 for the benefit of the commercial services of the Office as a whole, David Houghton was the natural choice as leader. He is a true marketing man, ever watchful for fresh commercial opportunities and enjoying the cut and thrust of negotiation with commercial contacts. In the course of his work, both at this time and previously at the London Weather Centre, he has set out to change Office attitudes, often being impeded by bureaucratic procedures. Disappointment or discouragement has never lasted long, however, and at the end of the day it is the system that has yielded. He leaves a very well found Branch that has taught the Office, amongst other things, the principles of marketing, how to use consultants in its commercial work, and how to face up to the discipline of market planning.

David's promotion of meteorology has not been confined to the Office and he has played a very full part in the work of the Royal Meteorological Society as a Member of its Council and of several of its committees. His interest in sailing led him to propose to the Society that it should include as part of its Field Study programme a course on Weather and Sailing. He organized and ran, as well as providing one of the two sets of lectures, the first very successful Field Study Courses at Falmouth in 1962 and was responsible for their repetition over the following eight years. Through these courses David's expertise became recognized by the Royal Yachting Association (RYA) and he was co-opted as instructor and adviser to successive British Olympic Yachting teams beginning in 1968. He is currently engaged in preparations for sailing races to be held in Korea. The Olympic involvement led Edward Heath, when he was Prime Minister and Captain of the British Admiral's Cup team, to seek David's services for that event, too. He has also been in demand for America's Cup preparations. He was awarded the Fitzroy Prize for Applied Meteorology by the Royal Meteorological Society in 1973.

In 1963 David joined the Editorial Board of the Royal Meteorological Society's *Weather* and when he relinquished this task in 1969 he was launched upon a career as author which has gained him increasing recognition, not least amongst the sea-going fraternity. The seeds were sown perhaps in his *New Scientist* article (with John Woods as co-author) on the Slippery Seas of Acapulco and the 50-page booklet *Weather Forecasts* written for the RYA, also in 1969. Other books have been *Weather* in the Jonathan Cape Jackdaw series (1971), *The Weathermen* in Gunn and Co's Wider Interest Series (1972), *Weather at Sea* (British version, 1986), *Wind Strategy* (Fernhurst Books, 1984) and, to be published, an American edition of *Weather at Sea* written with co-author Fred Sanders. David has also been on the Editing Committee of the Royal Meteorological Society's *Journal of Climatology* since 1980.

A further hat that David has worn has been that of Press Officer for the Meteorological Office. In his many contacts with the media over the years he has shown himself to be a consummate spokesman whether on radio or television.

One might think that amidst all this endeavour David's family life might have suffered. Not a bit. His wife, Verna, whom he married in 1955, is a practising doctor of medicine. They have four children at ages

ranging from 18 to 30. Those who have visited them over the years recall manifestations of David's skill in carpentry, plumbing, electrical installation, decorating and gardening. A few years ago Verna and David rather astutely acquired a riverside mansion at Wargrave, then in need of renovation. They plan to continue to live after David's retirement (in some style) at Wargrave Court. David has a number of irons in the fire for the future. He will leave a very empty office at Bracknell behind him but, one suspects, his family will scarcely notice the change. The armchair and slippers are a very long way off.

D.H. Johnson

Correspondence

551.553.6:003

Comments on 'Exceptionally strong winds of 16 October 1987 over the south of England'

The Advisory Services Branch's article (*Meteorol Mag*, 116, 389–390) is a very sloppy presentation. The table of wind speeds, which is the crux of the article, does not say:

- (a) Whether the mean speed is a 15-second, 10-minute or 1-hour mean. Hence valueless.
- (b) Whether the approximate return period is an all-year or October figure. Hence valueless.

The relationship between the Gatwick return periods for mean wind and gust seems to be wildly inconsistent with other return periods, although it may well be correct.

Generally, wind speeds were not out of the way. The 1952 Cranwell gust exceeded all the tabulated values and yet no damage was caused there to buildings or trees. The critical additional factors which caused the havoc in October — and not mentioned in the article — were the exceptionally wet ground (which reduced anchorage) and the fact that trees were in leaf, hence increased drag coefficient. Practically all the damage and disruption was caused by trees falling on roads, power lines. Without that damage the storm would have passed virtually unnoticed.

A. Blackham

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Reply by G.P. Northcott

Because of the need to respond quickly to the demand for publication of interesting wind data it was not made clear that the winds in question were synoptic (10-minute) winds and that the return periods were computed from annual data. This information was clear in the original preliminary report produced by the Advisory Services Branch but unfortunately was inadvertently omitted from the abridged version published in the *Meteorological Magazine*.

The present anemometer site at Gatwick (dating from 1983) is somewhat sheltered, especially from the south-east quadrant, and this is probably the reason for the anomalously low mean wind speed, although gust values were similar to those generally occurring over south-east England.

G.P. Northcott

Advisory Services Branch
Bracknell, Berkshire

Gorleston wind speeds October 1987

When wind charts were received at Bracknell after the storm of 16 October 1987 it was known that the Gorleston direction trace was defective because the vane had been vandalized about a month earlier. The speed trace was accepted as read, however, and quoted in official reports on the storm in the *Meteorological Magazine*, *Weather* and elsewhere. Subsequently it was discovered that the cups were also damaged and were bent downwards by 45 degrees.

Accordingly the anemometer head was removed and sent to the Operational Instrumentation Branch of the Meteorological Office, where tests in the wind-tunnel showed that the speed was over-registering by about 20% at most levels. The revised assessment of the highest wind speeds at Gorleston gives a mean of 54 kn (not 68 kn) and the highest gust of 85 kn (not 106 kn). These corrected values will be published in due course in the back-page corrections for Table 6 in the *Monthly Weather Report*.

G.P. Northcott

*Advisory Services Branch
Bracknell, Berkshire*

Reviews

General circulation of the ocean, edited by H.D.I. Abarbanel and W.R. Young. 170 mm × 248 mm, pp. xii + 291, *illus.* New York, Berlin, Heidelberg, London, Paris, Tokyo, Springer-Verlag, 1987. Price DM 160.00.

The collected articles in this book are based on lectures which were presented at the Scripps Institution of Oceanography in 1983, by speakers who are well-known in the fields of physical and dynamical oceanography. I found each of the five contributions enjoyable and instructive in various ways; Pedlosky, Veronis and Young concentrated on their own particular areas of research, while Niiler and Hendershott gave broad overviews. The specialized material has lost its original 'hot off the press' immediacy, but this is compensated by the careful presentation, and many of the pointers to future developments remain valid today.

As stated in the introduction, the aim is to give 'viewpoints of the essential dynamics of the general circulation', as applied to our understanding of the average, basin-scale state of the oceans. These viewpoints contain a lot of theory, with good reason; the sparseness of observations, particularly direct current measurements (especially at depth), means that dynamical theories are needed both to understand the available data and to fill in the substantial gaps in a rational way. Given hydrographic data (relatively plentiful), currents can be calculated from 'thermal wind' relative to some baseline. That elusive reference level, virtually an oceanographer's Holy Grail, is a recurrent theme in the book.

The opening lecture by Niiler is a well-illustrated development of such links between observations and dynamics. The few equations will be recognized by meteorologists, being based on the thermal wind and the β -plane. For oceanographers, this chapter is a useful reminder of basic ideas closely tied to observations.

Although Hendershott's article is the last in the book, it is logically the next to read as it offers a good summary of the development of circulation theories. It is textbook in style and content, with derivations of quasi-geostrophy etc. The classical steady theories are described in turn; the mathematics gets quite dense on some pages (and observational links correspondingly sparse), but diagrams make the results clear. Rossby waves are briefly reviewed, including a tropical mention. Ocean boundaries have crucial effects, so equations familiar to meteorologists have unfamiliar solutions!

The first of the specialist articles concentrates on an (as yet) unsolved problem; what determines the density structure of the ocean, particularly the thermocline? Pedlosky gives the reader a very useful overview and commentary on some of the main theories, old (late 1950s) and new. Due to density advection the general thermocline problem is fundamentally non-linear — even simple-seeming relations lead to daunting equations. With a layered approach (of which Pedlosky is a founder), interesting solutions are presented that are readily understandable and that offer considerable insight. New papers on this topic appear regularly; I shall be using this lecture as an excellent reminder of the basic assumptions and techniques.

The reference-level problem is directly addressed by Veronis, who describes various procedures for determining the circulation from observations, including the difficulties posed by data noise and sparseness. The pitfalls and ambiguities associated with various assumptions (and some are always needed) are made clear. Some specific, instructive, examples are provided. The mathematical load is lighter here, apart from a carefully explained excursion into matrix algebra.

The chapter on baroclinic theories is a return to idealized theories, in what amounts to a guidebook on two-layer quasi-geostrophic flow (see the contents list!). Basic equations are derived (there is considerable overlap between chapters in this regard) and a succession of examples used to illustrate the role of potential vorticity contours. In certain 'unblocked' regions inviscid flow is not uniquely determined and dissipation is needed to resolve the ambiguity — in this treatment, dissipation is related to mesoscale eddies which thus influence the large-scale circulation. Young gives, in some detail, a rationale for the hypothesis that the effect of eddies is to make potential vorticity uniform in unblocked regions: this idea is supported by some observational and numerical-model evidence. This new approach offers a way of calculating large-scale circulation with eddies taken into account.

Overall, this collection of articles, well produced and illustrated, takes the reader to the leading edge of ocean circulation theory, while keeping sight of observational facts and limitations. My chief regret is that there was no way to somehow bridge the gap between the time of the lectures and the year of publication.

I expect that meteorologists would find Niiler's contribution the most useful and the easiest to assimilate: the remainder is rather too specialized to recommend individual purchase for general reading. For the dynamical oceanographer — highly recommended.

M.K. Davey

The weather of the 1780s over Europe, by J. Kington. 212 mm × 303 mm, pp. x + 164, *illus.* Cambridge University Press, 1988. Price £35.00, \$70.00.

This very interesting volume presents daily synoptic maps of mean-sea-level pressure over Europe and the adjacent seas from 1781 to 1785. Analysis of the years 1786–90 is yet to be completed. The author begins by describing the sources of data, which are surprisingly plentiful, and gives a brief account of the development of the understanding of synoptic meteorology in recent centuries. There is next a description of the reduction and plotting of the data, and of the analysis procedures, which include considerations of synoptic continuity. The maps themselves cover 120 pages. Following these is a chapter describing the classification of the daily fields into H.H. Lamb's weather types and into the Grosswetterlagen (weather types). These classifications are used to compare the atmospheric circulation in the period from 1781 to 1785 with that in more recent times.

There are some shortcomings in the areas of quality control and subjectivity. In chapter 4 there is no discussion of the treatment of suspect values in the data from the observing stations. The author has clearly taken wise steps in the selection of the more reliable data by, for example, using observations around the middle of the day, thus avoiding frost-hollow effects and highly ageostrophic night-time winds, but there is no indication of any allowance for sea-breeze effects at near-coastal stations. Furthermore, has the author adjusted the mean-sea-level pressure data to standard (45° N) gravity? This adjustment would be about +1 mb at 60° N.

The attractively produced maps could have been interpreted more readily if the locations of pressure and wind data had been marked, preferably with separate symbols, though it would have been impracticable to have plotted the data themselves. As the maps stand at present, the reader cannot be sure how well founded they are, especially over the ocean and near the edges of the analysed area, though the use of continuity from chart to chart is good. For future work, an objective analysis scheme could also be considered, and applied not only to some of the fields of data for the 1780s but also to data for recent times, limited to a station network corresponding to that available for the 1780s. The latter analyses can then be compared with maps based on the full modern network; this comparison can then be used to assess the reliability of the objective analyses for the 1780s and, to some extent, the reliability of the subjective analyses published in this book.

Subjectivity is an inherent feature of the Lamb and Grosswetterlagen classifications, and the book would have benefited from inclusion of objective classifications, based on values at particular locations or grid points, both for the 1780s and for modern times, so as to confirm any differences in atmospheric circulation characteristics. The author should have discussed the apparent divergence between the indications of the Lamb classifications and the Grosswetterlagen classifications for 1781–85. The former, according to his results, suggest more frequent blocking or non-progressive situations in comparison with more recent times. The latter (Table 6.20) are ambiguous in this respect. Furthermore, this reviewer examined the charts classified as Lamb's 'north-westerly' and considers that 7 (5%) of them are better classed as 'westerly'. This difference would not significantly affect the overall results in Table 6.13 and 6.14 but suggests that the subjective classifications, which are useful in that they relate to well-known published schemes, should be replicated by several independent analysts.

The author could have indicated how the 1781–85 curve in Fig. 6.2 compares with individual 5-year periods from 1861 onwards, e.g. did any of these have maxima of blocking in March and December? Both Figs 6.1 and 6.2 could usefully be updated in the forthcoming volume.

Better omitted could have been the section on sunspot-blocking relationships — the record may be too short to establish these properly. The author does not indicate whether the apparent relationship has applied since 1950. A further point, incidental to the volume, is that though (page 2) man-made warming is likely to result from increasing concentrations of carbon dioxide and other 'greenhouse' gases in the atmosphere, industrially produced heat is expected to have a much smaller effect on the globe as a whole.

The volume is well presented and will be of interest to local as well as national and international historians. It is also a useful contribution to research into climatic variations and the causes and characteristics of the 'Little Ice Age', though its usefulness in this area is somewhat limited by the lack of objective tests of the analyses and classifications, and by the incomplete presentation of the quality controls carried out. The book makes enjoyable, fascinating reading. The publication of the charts for 1786–90 is awaited with interest — in that volume the author could usefully make his treatment more complete.

D.E. Parker

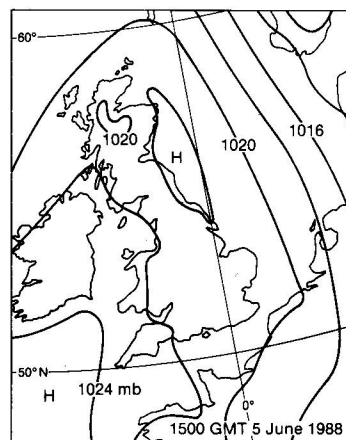
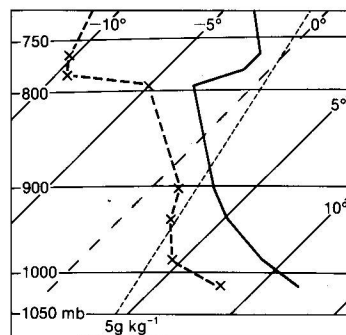
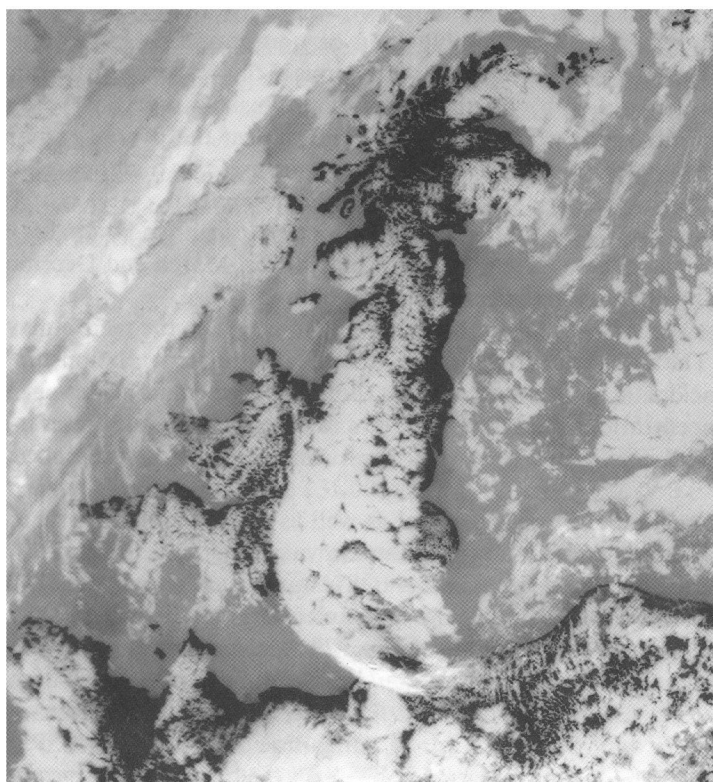
Satellite photograph — 5 June 1988 at 1427 GMT

This infra-red image was taken when the British Isles lay within a shallow ridge of high pressure at the end of a cold, unstable spell of weather. By 5 June some subsidence had occurred, resulting in the convection top being constrained by an inversion. The midday Aughton (near Liverpool) radiosonde ascent, representative of the air over England and Wales, suggests the cloud top to be within a layer of sub-freezing temperatures at about 2000 m above sea level.

The convective cloud, seen mostly over the land, has generally spread out into areas of stratocumulus, especially over Ireland and south-east Britain. Convective cloud which developed over Scotland the previous day drifted southwards overnight, partially dissipating. Renewed convection due to surface heating on the day of the photograph enhanced this pre-existing cloud area now located over south-east Britain on the picture. The sharp western boundary lay along the west coast of Scotland the previous day.

Over England and Wales, a northerly airflow is suggested by the imagery since north facing coasts are generally cloud free (the air being stable to the sea temperature), and where the cloud remains broken, it is organized into north-south bands. Over Ireland, where winds were very light, cloud terminates close to the coast, and even Lough Neagh is cloud free (best seen in visible image — not shown). The more general cloud over western Ireland is ahead of an advancing warm front.

Dry air over the Highlands of Scotland (relative humidity as low as 40%) probably inhibited general cloud formation.



Photograph by courtesy of University of Dundee.

Meteorological Magazine

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Content

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

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Spelling should conform to the preferred spelling in the *Concise Oxford Dictionary*.

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 referred to 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.

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