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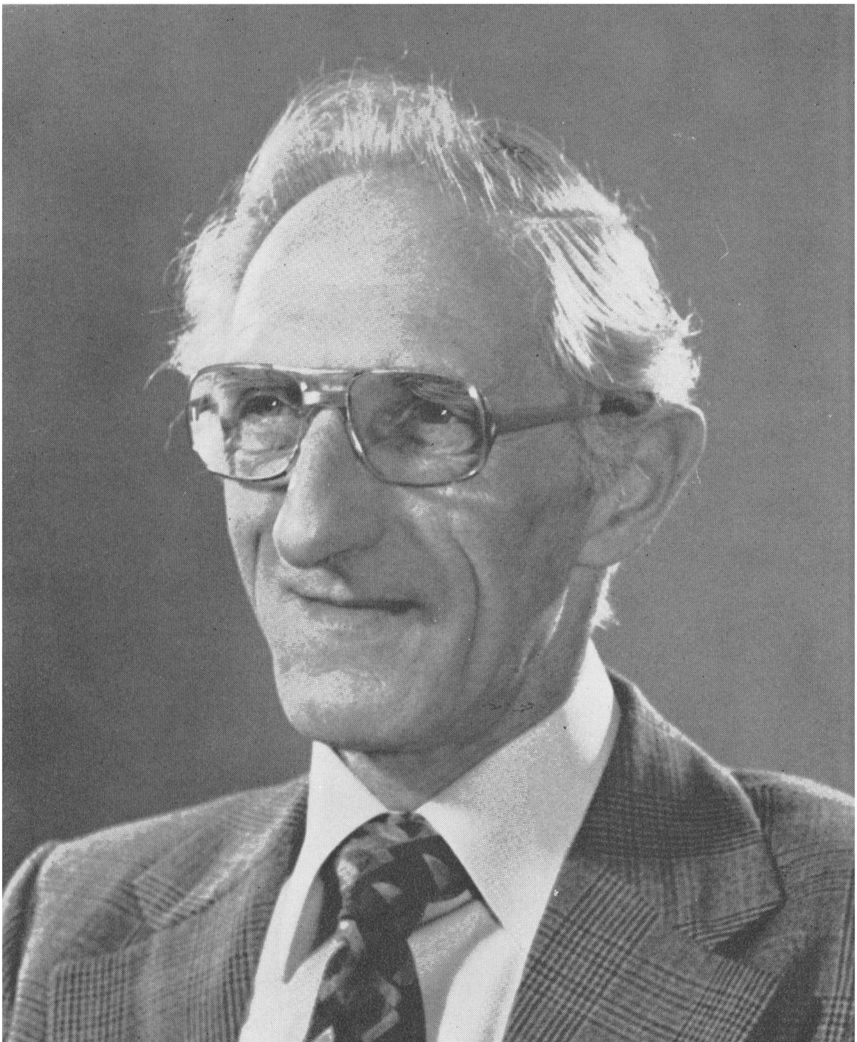

Photograph by G. A. Corby

MR G. A. CORBY

METEOROLOGICAL OFFICE Met.O.915

THE METEOROLOGICAL MAGAZINE

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RETIREMENT OF MR G. A. CORBY

On the retirement of Mr G. A. Corby as Director of Services on 30 April 1978, the Meteorological Office lost one of the most able, versatile, popular and respected figures of the post-war era. In an outstanding career spanning 37 years, during which he achieved a high reputation as a forecaster, research scientist and senior administrator, he brought a high degree of dedication, professional ability, excellent judgement and a sense of style to every task. His contribution and influence have been immense.

Educated at St Marylebone Grammar School and London University, he graduated with first class honours in mathematics in 1941 and entered the Office in September of the same year. After joining the RAFVR Meteorological Branch in April 1943, he served in India, Ceylon and Singapore until the end of the war. After demobilization in July 1946, he spent a short time at London Airport as a forecaster and then took charge of the office at Northolt where he was promoted to Principal Scientific Officer in 1949. In October 1953 he joined the newly formed Forecasting Research Branch at Dunstable where he made his mark as a research scientist in a series of important papers on the airflow over mountains and atmospheric waves and carried out one of the first experiments in three-dimensional objective analysis. These contributions were recognized by the award of the L. G. Groves Memorial Prize in 1954.

In 1963 he was promoted to Assistant Director to establish a new research branch in Dynamical Climatology where he was the architect of the very successful 5-level global circulation model and led the team which developed the powerful 13-level model that produced a very realistic sudden stratospheric warming on its first long-period integration. It was during this period that George Corby demonstrated his scientific leadership and his talents as a mathematician with a deep knowledge and understanding of dynamical meteorology. One cannot but wish that he could have started his research career much earlier and received greater recognition of his own scientific talents.

However, his abilities were well appreciated within the Office where he was promoted to Deputy Director in charge of computing and telecommunication services in 1973 in preparation for his final promotion to Director of Services and deputy to the Director-General, with the rank of Assistant Under Secretary, in 1976.

In this demanding role he has been a tower of strength, dealing with a whole range of important issues with cool, calm and excellent judgement and with the complete co-operation and confidence of his staff.

I shall miss his wise and courteous counsel and unfailing support. I am sure that all George's friends and colleagues will join me in wishing him and Mrs Corby a long and happy retirement with more time for his other interests of music, photography and cabinet-making to which he brings the same degree of skill and professionalism that has characterized his work in meteorology.

B. J. MASON

METEOSAT

Meteosat, which is the geostationary meteorological satellite of the European meteorological community, together with the associated program of data collection and dissemination, will form one of the most important European contributions to the First GARP Global Experiment (FGGE). Meteosat, which was developed by the European Space Agency, was successfully launched on 23 November 1977 from Eastern Test Range, Florida by NASA, using a Delta 2914 vehicle. Test transmissions producing excellent pictures began shortly afterwards.

Meteosat is a geostationary satellite, that is to say it travels round the centre of the earth in a circular orbit in the equatorial plane with the same angular velocity as the earth, so that it remains stationary relative to points on the earth's surface; it lies at a height of about 36 000 km over the Greenwich meridian. When it becomes fully operational it is hoped that it will produce images every 30 minutes in one band of the visible spectrum (0·4–1·1 μm), and two bands of the infra-red spectrum (5·7–7·1 μm for water vapour and 10·5–12·5 μm for thermal emissions). The resolution at the subsatellite point is 2·5 km for the visible image and 5 km for the infra-red. Meteosat spins about its axis at 100 r/min and this spin is made use of in the optical arrangements for systematically scanning the earth's surface. The focused visible and infra-red signals are converted into analogue electrical signals by various detectors, processed, and transmitted to the central ground station near Darmstadt (Federal Republic of Germany). Following certain further processing of the data received at Darmstadt, images are disseminated via the spacecraft to user stations operated by various meteorological services (for example Lasham in Hampshire for the Meteorological Office) and eventually quantitative products (e.g. winds) will be distributed over the normal meteorological telecommunication channels.

(See Plates I–III.)

551.507.362.2

THE SIGNIFICANCE OF METEOSAT FOR METEOROLOGY*

By K. H. STEWART

(Director of Research, Meteorological Office, Bracknell)

The paper that follows was written in response to a request from the European Space Agency for an article for a special issue of their *Bulletin* designed to celebrate the launch of Meteosat. It seemed appropriate to deal with the meteorology in a simple way and to put emphasis on the benefits to be expected from Meteosat; I hope readers of the *Meteorological Magazine* will not feel I have simplified things too much or taken an unreasonably optimistic view.

Meteorology is both a pure and an applied science. As pure scientists meteorologists try to understand and explain the phenomena of weather and climate. As applied scientists they use their knowledge to give advice on the effects of weather on agriculture, industry, transport and daily life. The main practical demand is for forecasts of what the weather will be like in the future—from a few hours ahead to many centuries ahead—but information on past and present weather and its effects can be very important too. Observations provide the essential foundation for both the understanding and the prediction of weather, and the appetite of meteorologists for observations is almost insatiable. Ideally, the observations should measure the state of the atmosphere—its composition, temperature, pressure and velocity—at all heights all over the globe. The space and time resolution required depend on the phenomenon being studied and are closely linked together, because small-scale phenomena tend to have short life-cycles, and large ones long ones. Local weather forecasts for a few hours ahead require a resolution of a few kilometres in the horizontal and less than an hour in time. Forecasts for a few days ahead require a horizontal resolution of a few hundred kilometres and time-resolution better than a day. For purposes of pure science it might be enough to collect such observations for a limited period only, long enough to obtain a sample of all the important phenomena of meteorology. For the applied science of forecasting, however, there is no limit to the time for which observations are required. This is because we are trying to predict the behaviour of an inherently unstable system. However well we can predict the future development of the flow patterns existing at one time, there will always be new disturbances to the pattern which grow from below the threshold of detectability and have to be taken into account in making later predictions.

Although meteorologists have always been hungry for observations it is only in the last decade or two, with the development of large computers, that they have had the capacity to digest them in the large quantities they know to be necessary. In the last few years the capacity of computers to model the behaviour of the atmosphere, both globally and on more local scales, has far outstripped the capacity of conventional observing systems to provide data for testing, developing and using the numerical models. The problem is not that conventional methods are in principle incapable of providing the data required; it is simply that the cost of operating the thousands of stations needed (mostly

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* Reprinted from the *ESA Bulletin* No. 11, December 1977.

in the oceans) would be quite prohibitive. It is no wonder, then, that meteorologists are eager to exploit to the full the possibilities of satellites in providing a world-wide observing system at reasonable cost.

Satellites have been used in meteorology for over 15 years. The first glamour and excitement has faded, leaving the conviction that satellites can make an enormous contribution to meteorology but also the realization that it is not a simple matter to make full use of their potential contribution. Satellites do not observe directly the quantities meteorologists most need to know and much ingenuity and effort have to be expended to plan the satellite system to best advantage and to extract the maximum of useful information from its data. The first and strongest reason European meteorologists have for welcoming Meteosat is that it enables them to play a really active part in exploring and extending the ways of using satellites in their science; of course, much work has already been done using data from American satellites, but the full understanding of the limitations and possibilities of satellite techniques that is needed to exploit them fully comes only from working in close and interactive contact with the system and its data. During the development of Meteosat only a rather small circle of meteorologists has benefited from this contact, but the circle has widened as the day of launch approaches and once the data begin to flow in, the challenge and the opportunity will be open to the whole community of European meteorologists.

Meteosat has been planned to complement rather than duplicate existing weather satellites. For many years the USA has provided satellites in fairly low near-polar orbits which give coverage of the whole earth once or twice per day. The observations from these satellites have improved gradually over the years and will take a big step forward in 1978 when the TIROS N series is introduced. The satellites provide images at several different visible and infrared wavelengths and 'soundings' of the vertical distribution of temperature and humidity. The images give valuable data on conditions at the earth's surface—the distribution of snow and ice and of sea-surface temperature—as well as showing the cloud patterns and thus determining in a qualitative way the main features of the weather systems. The sounding data, in principle, give comprehensive quantitative information about the state of the atmosphere. Although it is only the temperature and humidity that are measured, the pressure can be inferred at all levels (provided it is known at one reference level, such as the earth's surface) through the hydrostatic relation and the wind can be inferred through its relationship to pressure gradient. In practice, there are still serious limitations to the accuracy and vertical resolution of the sounding data. Apart from this technical and, we hope, temporary difficulty, the polar satellites fall short of providing comprehensive data in two important respects. The first is that their coverage is only intermittent—twice per day for most places. This means that the satellites do not provide a satisfactory sample of weather observations for long-term studies, because weather in the afternoons, for example, may be systematically different from that in the mornings. It also means that they do not provide adequate data for short-term forecasts; if we are to predict the development and movement of the small-scale phenomena, such as thunderstorms, which often give weather its most dramatic impact, we must have observations at least once an hour. The second, more technical, inadequacy is that the familiar relationship between pressure gradient and wind is too weak near the equator to allow us to infer wind from the temperature-sounding data. Air movements within the tropics play a vital part in the evolution of global weather and we therefore need some other method of measuring wind there.

These two deficiencies of the polar satellite system can largely be made good by the use of geostationary satellites. These can provide quasi-continuous coverage of the whole area within their field of view, which is what is needed for short-range forecasts, and the wind measuring problem can then also be solved by tracking the motion of clouds over an hour or two and assuming that they move with the wind. The method only works, of course, where clouds are present, and care has to be taken to avoid clouds of types which might not move with the wind, but experience has shown that reasonably adequate sets of data can be obtained. Four or five geostationary satellites are needed to cover all longitudes and these are being provided by a natural geographical division of responsibility, with the European Meteosat located at 0° longitude.

Although the system of polar and geostationary satellites can cover the whole earth adequately, there are several important quantities which cannot yet be measured properly by remote sensors on satellites, atmospheric pressure at the surface, rainfall amounts and river flow being the notable examples. It is not very difficult to devise automatic stations to measure these quantities in remote or inaccessible areas, but the transmission of data from them is often difficult or costly and the satellites can play a very useful role as a data link.

As a geostationary satellite in the African–European sector, then, the role of Meteosat is not to supersede other satellites or the existing network of meteorological stations but to complement them so that, if all systems play their part, the Global Observing System will for the first time give to meteorologists a truly world-wide set of the data they need. The contributions of Meteosat may be discussed more specifically under the four headings: short-range local forecasting, global forecasting, climatological studies and research.

Local forecasting

As already stated, the unique contribution of Meteosat to local forecasting is the quasi-continuous coverage it provides. Images of the clouds will be available every half hour. Images by visible light will only be available in daylight hours, of course, but those at infra-red wavelengths (10–12 μm) will be available day and night and are valuable because they indicate the temperature of the cloud tops (or of the sea surface, in clear conditions) as well as showing the distribution of clouds. The vast amount of detail in these images is beyond the power of any central station to analyse in relation to local conditions, so use will be made of Meteosat's capacity to relay information to broadcast the images to local forecasting stations; before doing so the images are put into a readily usable form at the central station by adding latitude–longitude grids and other information. On receipt, the images will be examined by the forecasters; they will look first to see how well the latest images confirm the ideas they have already formed about the development of the weather from other evidence, then for signs of any new or unexpected developments, particularly in areas not well covered by ordinary observations, then in more detail at features of special interest to their own locality—the spread of fog from the sea to land, for example, or the movement of shower clouds. It is in the field of local forecasting that there is probably most to learn, most room for ingenuity and most likelihood of surprises. We know that in some conditions the new information will be of great value; in other conditions it is not yet obvious how the information can be used but we can hope that experience will teach us. One of the most important uses will certainly be in giving warnings of dangerous conditions such as heavy rainfall or floods. Meteosat can help here not only by its images but also by its capacity to act as a data relay for warning messages from ground stations. One powerful technique whose use is being planned in several countries is that of making a succession of images into a motion-picture of the cloud development; this can give an immediate apprehension of features which may not be obvious from a sequence of still pictures. Another technique that will be used is to combine Meteosat images with those obtained from ground-based radars; these will show the actively raining parts of clouds within the general cloud structure.

Global forecasting

The unique contribution of Meteosat to global forecasting (and it must be remembered that if we are to forecast for any one region for more than a few days ahead, the forecast must necessarily consider the globe as a whole) is the provision of information on winds in the tropical belt. This is one of the most exacting applications of satellite data, demanding great precision in finding the position of the clouds (and therefore in finding the position and orientation of the satellite) and following the motion from one image to the next. The necessary data processing will be done at the central station and the results disseminated by the usual meteorological channels. Other important contributions to large-scale forecasting will be the use of the cloud patterns to delineate weather features and the use of the infra-red image channel to give data on sea-surface temperature. In addition to providing images in the visible and infra-red 'windows' at wavelengths of about 0·7 and 11 μm, Meteosat will give images at about 6·3 μm, a region of emission and absorption by water vapour. This is a new feature, not included in the geostationary satellites of the USA. The 'water vapour' images should give valuable information on the distribution of water vapour in the upper troposphere (6–8 km above the earth) and may also allow winds to be estimated even when no clouds are visible, by tracking invisible clouds of vapour. The analysis of the images to produce simplified maps of the distribution of cloud, water vapour and sea-surface temperature will be carried out at the central station, and the products will be distributed both by land-line and via the satellite itself. The data-relay powers of Meteosat will be brought into play in two ways in the large-scale forecasting field, first by relaying weather information from remote automatic stations (DCPs), for example in Greenland or on ships at sea, secondly by relaying images obtained from the American geostationary satellite GOES 1 and showing conditions in the west Atlantic and Caribbean otherwise invisible from Meteosat.

These contributions from Meteosat will be vital to the sucess of the important international project known as the First GARP Global Experiment. This project has been planned to obtain the maximum possible global coverage of meteorological data during 1979 and to use the data in numerical experiments designed to explore future possibilities and requirements for the prediction of weather. The Experiment leans heavily on satellite data as well as the conventional observing network, but various supplementary 'special observing systems' will be used too.

Climatology

The role of Meteosat in climatological studies will be primarily to provide statistics on cloud coverage within its field of view; most importance is attached to ocean areas where data are scarce. Climate is determined chiefly by the balance between the radiation received from the sun and that re-radiated by the earth. Clouds have a considerable effect on this re-radiated energy and a comprehensive picture of their distribution and its changes will greatly help our understanding of climate. Although much information has already been obtained from polar-orbiting satellites, it is seriously incomplete because the observations are made only at a few, more or less fixed, times a day. The continuous coverage of the geostationary satellite will allow much more satisfactory estimates of true daily averages to be obtained. As well as giving data on the presence or absence of cloud, the central station will process the data to give estimates of the net 'radiation balance' for each area seen from Meteosat. Other climatological uses of Meteosat may well appear in the future; its use to measure snow cover and to estimate aerosol content are possible examples.

Research

The boundary between research and applications in meteorology is not a distinct one; a forecaster may be described as a researcher who is never allowed the time to complete his research. All of the applications of Meteosat data just described have their research aspects too. The most important is probably the contribution Meteosat will make to the data set of the First GARP Global Experiment. The possession, for the first time, of a truly comprehensive set of data on the world's weather will make possible a great variety of research projects on large-scale atmospheric processes, particularly the fundamental processes that transfer energy from low to high latitudes. On a more local scale, Meteosat will be used to clarify the factors governing African weather—those controlling rain in semi-arid regions being particularly important—to study the local storms that affect the Mediterranean region and to investigate the effects of hills and coastlines on cloud development, to name but a few of the possible projects.

No doubt many small research projects will be carried out by using the images received at local forecasting stations, but the major projects will require access to larger amounts of data and it is here that the comprehensive archiving and data processing facilities provided at the central station will be of great value. Most research will probably be done by requesting the appropriate data sets from the archives but for projects requiring access to and manipulation of really large amounts of data it may be possible for the researcher actually to work at the central station, using its computers during the off-peak period.

This article has tried to show how Meteosat fits into the general scheme of observations for meteorology and what the significance of its contribution in various specific fields will be. In the long run, the Meteosat project may be even more important as a prototype of the techniques and organization that will be needed if meteorology is to make full use of modern technology in the future. Meteorology inevitably uses vast amounts of data, and the problems of collecting the data, processing them to reduce their bulk without destroying their value and then distributing them to the point of use are formidable—particularly when it is remembered that they have to be dealt with continuously and in real-time. The Meteosat satellite provides an advanced means of acquiring data but it was early realized that it would lose much of its value unless supported by adequate data-handling facilities. These have been provided and the basic scheme for their use worked out, but the total system—the satellite as an observing platform, the computers on the ground and the satellite as a data relay station—has enormous flexibility and possibilities of development and adaptation to meet new needs or take advantage of unforeseen opportunities. It will be the task of those who use Meteosat to develop its possibilities to the full and to learn from it the lessons that will lead to a still better system in the future. To end on a personal note, the experience I have been privileged to have of the far-sightedness of the original French designers of Meteosat, the skill and professionalism of the European teams that have carried the project forward and the co-operativeness and enthusiasm of the meteorologists who have planned how to use the satellite leave no doubt that the task will be done well.

551.553.8:551.466.3

WINDFIELDS DURING GALES IN THE NORTH SEA AND THE GALES OF 3 JANUARY 1976

By J. HARDING (Bracknell) and A. A. BINDING (Maidenhead)*

SUMMARY

A project is described in which surface wind and atmospheric pressure fields associated with 42 gales in the North Sea were prepared and wind and pressure tabulated for a network of gridpoints. The severe gale of 3 January 1976 is described in detail and reference is made to that of 31 January/1 February, 1953.

INTRODUCTION

This article will describe a project which was undertaken primarily to provide data for use with a numerical North Sea Wave Model (NORSWAM), and it is therefore of interest to give some background information to the NORSWAM study.

Operators engaged in fossil fuel extraction from the sea-bed of the United Kingdom continental shelf, and in particular of the North Sea, need wave information which is broadly speaking of two types:

(1) Accurate wave forecasts so that they can conduct their day-to-day operations as efficiently and safely as possible.
(2) Statistical information on waves for planning purposes and for use in the engineering design of offshore installations.

The situation with regard to both types of information was unsatisfactory: for operational forecasts, the methods which have been used for calculating the wave field from a given windfield do not use the considerable recent advances in this subject, while for extreme wave heights it is impracticable to obtain data of adequate geographic coverage, or of the duration which is desirable for reliable statistics.

The North Sea Numerical Wave Model which was formulated by the NORSWAM group of European scientists and is supported by a consortium

* The work described in this paper was carried out by the authors while in the employment of the Institute of Oceanographic Sciences.

of oil companies and the Departments of Industry and Energy, is being developed in response to these problems, to which it gives at least a partial solution.

It is clear that a numerical wave model which uses the knowledge gained in recent theoretical and empirical studies can make important contributions to operational forecasting if the other outstanding problem, that of providing accurate wind forecasts, can be overcome. It is perhaps less obvious that the model can also be used to provide better data on which to base estimates of long-term extremes. This is done by using it as a 'hindcast' model, as is now described:

The best estimates of the wind fields which occurred during a past storm event are fed into the model, and the corresponding wave fields are calculated. If the worst storms over a number of years are selected according to a suitable criterion, then the wave data which the model calculates can be used to make an estimate of the distribution of extreme waves over the same period, and this can be extrapolated to the longer periods for which extreme wave predictions are required.

The central advantage of the method is that it allows one to produce a wave data set whose extent in terms of both time and space is much greater than can be produced by instrumental measurement.

In the development of the model, it is logical that it should be first used in the hindcast mode. The most important reasons for this are:

(1) The possibility of providing accurately specified wind fields for the storms of interest.
(2) The availability of wave data at selected positions in a form suited to analysis and comparison with the output of the model.
(3) The considerable amount of work which is required on the specification of forecast windfields before progress can be made in the real-time use of the model.

In view of these it is clear that the model must be used in the hindcast mode during the proving and verification stages.

The project herein described was addressed to the specification of wind and pressure fields during past storms and used 'subjective' rather than 'objective' methods. That is, it relied on the hand analysis and reanalysis of synoptic weather charts, rather than the use of computer methods. It was considered that by reanalysing the relevant charts, using all the available data and paying due attention to temporal continuity an estimate of the wind fields could be made which was superior to currently available objective methods.

The resulting data have applications to other numerical models besides the wave model, in particular those which predict storm surges and the non-tidal current circulations which accompany them. In view of this, efforts have been made to ensure that the results are as widely applicable as possible.

One of the storms selected for analysis was the severe gale of 3 January 1976 and this will be described in detail in the belief that it is of wide interest to meteorologists.

The work was carried out by meteorologists employed by the Institute of Oceanographic Sciences, but who used accommodation and facilities provided by the Meteorological Office at Bracknell.

A full report on the analysis is available in the *Institute of Oceanographic Sciences Report* series, No. 55, by Harding and Binding (1978).

THE SPECIFICATION OF THE WINDFIELDS

Initially the decade 1965–74 was chosen as the period to be investigated, but latterly 1965 was dropped and some events from 1975 and 1976 were included.

An examination of the *Daily Weather Reports* of the Meteorological Office for the period 1965–74 produced a list of more than 200 occurrences of gales in the North Sea. It was recognized that the gales should be classified according to the prevailing weather patterns. This had significance from the point of view of fetch and therefore for the choice of area for wind analysis. Moreover, it facilitated the choice of a reasonable representation of the various weather patterns in the list of gales chosen for analysis.

Seven classes of depression were identified and the principles governing the classification are given below.

Class A—Depressions from the north-west and north

Sub-class a—Depressions which moved from Iceland to south Norway and the south Baltic.

Sub-class b—Depressions which moved from Iceland to the Shetland area and Denmark.

Sub-class c—Depressions which moved south along the Norwegian coast to south Norway and Denmark.

Sub-class d—Depressions which moved south-south-east or south-east from the vicinity of Ocean Station M (66°N, 2°E).

In general, associated gales in the North Sea were between west and north. There were occasional south to south-west gales, usually associated with depressions on the more westerly tracks.

Class B—Depressions which moved east to the south of Iceland

Sub-class a—Depressions and waves which moved east to the south of Iceland but north of the British mainland.

Sub-class b—Depressions which moved east from Iceland to Norway.

Sub-class c—Polar depressions which moved east or east-south-east from north of Iceland to Norway.

Gales were predominantly west to north-west. Wind directions sometimes veered as far round as north; whether or not this happened often depended on the history of the depression after reaching the Norwegian coast, for example, some might develop south-eastwards or even southwards rather than eastwards, with north-west to north gales in the North Sea. Sometimes a polar depression developed behind the main depression and moved south along the Norwegian coast. From time to time a development of this type produced a major gale in the North Sea.

Class C—North-eastward-moving depression in the North Atlantic

Gales in the North Sea were most frequently produced by this type. Broadly speaking they were north-eastward-moving depressions or waves over the North Atlantic, moving between Iceland and Scotland, but some which moved north-east through the Denmark Strait also led to gales in the North Sea.

A few of these depressions turned east while still to the west of Britain, while others did not turn east until they reached a point to the north. A few swung south-eastwards into the North Sea and across Denmark or south-eastwards across south Norway. Some became quasi-stationary near Iceland.

Gales in the North Sea associated with these depressions predominantly followed the direction sequence south-south-east to south-west to west to north-west. Depressions swinging south-eastwards into the North Sea might result in gales as far round as north.

Class D—Depressions or waves over or west of Britain which moved north or north-north-east

Usually there was an anticyclone over the continent, either with depressions west of Britain moving north, or deep depressions from the south-west turning north towards Iceland. Waves moving north over Britain between a continental anticyclone and an Atlantic depression would on occasions tighten the North Sea gradients sufficiently to produce gales.

Associated gales were mainly south to south-east and included some prolonged periods of gales or near gales, for example on 3–13 January 1974.

Class E—Ridge of high pressure to the north, and depressions to the south

Associated gales were mainly between east and north-east.

Class F—Depressions which crossed the North Sea, but excluding Class A and Class C depressions

Class F gales were a good second to Class C gales in frequency. They may be roughly sub-classified as follows:

Sub-class a—Depressions from Scotland and north-east England.

Those which moved north or north-north-east were mainly associated with gales between south and west.

Those which moved north-east were mainly associated with gales having a south-west to west and north-west sequence of directions.

Those which moved in directions between east-north-east and east-south-east were mainly associated with gales having a south to west to north sequence.

Only 2 out of 34 depressions in this sub-class moved south-east or south-south-east, one with west veering north-west gales and the other with north-west and north-east to east gales.

Sub-class b—Depressions from east and south-east England.

These depressions moved in directions between east and north-east. Gale directions were predominantly south-east backing east backing north-east, and south-west veering west veering north.

Sub-class c—Others.

One depression moved northwards from the continent, with gales between north-east and north.

Two moved south-west and then south from Denmark, with northerly gales.

Class G—Depression over Germany

There was one occasion of northerly gales over the central and southern North Sea associated with a depression over Germany. This depression had come from the south-east, deepening. It then moved away eastwards, filling.

SELECTION OF GALES FOR ANALYSIS

In all 215 North Sea gales were identified in the 10 year period 1965–74, and from these a sub-set had to be selected which adequately represented the main features of the most severe gales in that period.

It was realized that for reasons of cost and time the number of gales which could be analysed by a subjective method would be limited to about 50, and with such a comparatively small sample the task of selection would need to be approached with great care.

As a first step the original total was reduced by about 50 per cent by deleting the less noteworthy gales. This left 113 gales which again required reduction by more than half.

TABLE I—STORMS SELECTED FOR ANALYSIS

Year	Month	Class	Analysis Period (DDHH)	Analysis Area
1966	May	F	2200–2506	NN
	Nov/Dec	A	2818–0206	NN
	Dec	C	0700–0918	N
1967	Feb/Mar	C	2612–0215	NNA
	Dec	C	0206–0506	NNA
1968	Mar	B	1512–1912	NNA
1969	Mar	E	1206–1918	N
	Nov	A	2612–3012	NN
	Dec	D	1812–2300	N
1970	Jan/Feb	C	3112–0418	N
	Feb	F	1818–2200	N
	Oct	B	1612–2200	NNA
1971	Oct	C	2100–2400	NN
	Nov	B	1500–1818	NNA
	Nov	F	2000–2321	N
1972	Jan	F	2600–2906	NN
	Mar	D	0206–0506	N
	Nov	C	0806–1212	NNA
	Nov	F	1200–1412	NN
	Nov	C	1718–2106	N
1973	Feb	C	1012–1306	NNA
	Apr	F	0106–0406	NN
	Nov	B	1106–1418	NNA
	Nov	C	1706–2106	NN
	Dec	A	1118–1518	NNA
1974	Jan	D	0318–0621	NN
	Jan	D	1100–1403	NN
	Jan	F	1518–1812	NNA
	Jan	D	2700–3006	NN
	Feb	C	0912–1306	N
	Sept	F	0606–0921	NN
	Oct	G	2112–2412	N
	Oct	A	2612–3018	NNA
	Nov	C	1000–1312	N
	Nov	F	2318–2706	N
	Dec	C	1612–1918	NN
1975	Jan	B	0406–0718	NNA
	Jan	B	2106–2512	NNA
	Nov	F	2606–2906	NN
	Nov/Dec	F	3012–0412	NN
1976	Jan	F	0112–0500	NN
	Jan	B	1815–2306	NNA

DD = Day of month. HH = Hour of synoptic chart.
Analysis periods refer to the North Sea and, when analysed, to the northward extension to 70°N. Periods of Atlantic analysis usually differ from those of the North Sea.

N = North Sea.
NN = North Sea and northward extension to 70°N.
NNA = North Sea and northward extension to 70°N plus a selected area of the North Atlantic.

A. F. Jenkinson of the Meteorological Office has made an objective classification of weather types around the British Isles and has allocated an index of severity to gales in the area since 1881 (Jenkinson and Collison, 1977). Using this catalogue he selected a set of 56 periods for analysis. In carrying out the selection care was taken to preserve the distribution of gales when classified by type, monthly occurrence and annual frequency. At a later date the year 1965 was deleted from the investigational period and 1975 added, and again using Jenkinson's gale catalogue a selection of less vigorous gales was deleted. Furthermore, two gales from January 1976 with high severity indices were included. The final list of gales is shown in Table I together with the period and area of analysis.

The distributions of gales by year and by class in the final selection are shown below.

TABLE II(a)—DISTRIBUTION OF GALES BY YEAR IN THE FINAL SELECTION

1966	67	68	69	70	71	72	73	74	75	76 (Jan.)	Total
3	2	1	3	3	3	5	5	11	4	2	42

TABLE II(b)—DISTRIBUTION OF GALES BY CLASS IN THE FINAL SELECTION

A	B	C	D	E	F	G	Total
4	7	12	5	1	12	1	42

The distribution of gale classes by month is shown below.

TABLE III—DISTRIBUTION OF GALE CLASSES BY MONTH IN THE FINAL SELECTION

January	BBB	DDD	FFF		9
February	CCCC	F			5
March	B	D	E		3
April	F				1
May	F				1
June					
July					
August					
September	F				1
October	A	B	C	G	4
November	AA	BB	CCCC	FFFF	12
December	A	CCC	D	F	6

SPECIFICATION OF ANALYSIS AREAS

The windfields for the selected gales were specified at 3-hourly intervals, using the grid used in numerical forecasting by the Meteorological Office (Burridge and Gadd, 1977). Because of the importance of fetch the choice of analysis areas was varied from storm to storm. The areas are described below.

TABLE IV—DESIGNATION OF ANALYSIS AREAS

N—The North Sea.
NN—The North Sea and northward extension to 70°N.
NNA—The North Sea and northward extension to 70°N, plus a selected area of the North Atlantic.

It should be noted that area NNA varied from storm to storm. The 100 km grid was used in the North Sea and the 300 km grid elsewhere.

METHOD OF ANALYSIS WITH PARTICULAR REFERENCE TO THE DETERMINATION OF THE WINDFIELD

Synoptic weather charts as produced routinely within the Meteorological Office were used in the analysis work.

For the North Sea analysis the $1:3 \times 10^6$ British Isles series was used, and the relevant charts were borrowed from the London Weather Centre archive. The scale proved to be ideally suited to wind analysis and a 100 km grid.

For the analyses of areas outside the North Sea and for periods up to mid-1971 the $1:15 \times 10^6$ North Atlantic charts held in Meteorological Office archives were used. In mid-1971 these charts were replaced by charts with a scale of $1:20 \times 10^6$ and this scale was found to be inadequate for ease of isotach analysis. It was decided, therefore, to replot the observations on charts with scale $1:7{\cdot}5 \times 10^6$. Towards the end of the 10 year period this need for the preparation of new charts disappeared as similar charts were available from the Meteorological Office at London/Heathrow Airport.

Wind and pressure fields were specified every three hours throughout an analysis period. The surface windfield was derived primarily from a consideration of the surface pressure field, although reported winds provided essential additional information in all but the simplest pressure fields. The geostrophic winds were read from the charts by using the conventional transparent scale and it was then necessary to convert these geostrophic winds to surface winds. In order to simplify this task a table was prepared based on the work of Findlater *et alii* (1966). This is reproduced as Table V. Essentially it shows the amount by which a given geostrophic wind must be reduced and by how much it must be backed in direction under various conditions of flow, stability, and curvature in order to give the best estimate of the surface wind.

Isotachs were extensively used, and the tracking of isotach features proved to be a powerful method of analysis.

The values of wind speed and direction and pressure were read from the chart for each gridpoint and written on to specially prepared forms for subsequent transference to punched cards and ultimately to magnetic tape.

Accuracy of the wind and pressure fields

It has proved to be very difficult to make a quantitative assessment of the accuracy obtained in the specification of wind and pressure fields. What can be done is to consider the factors which affected the analysis and make subjective estimates of accuracy in different situations.

On this basis it is probably fair to say that many derived wind speeds are accurate to within ± 10 per cent or ± 3 knots whichever is the greater.

However, higher errors must be expected at some gridpoints at times, for example when winds were strong and isotach gradients steep. Wind directions were often correct to within 10°, but greater errors must be expected locally when there were vigorous changes in the pressure field. The smallest errors were probably attained in strong straight flow in unstable air.

The gales of early January 1976

The gales of early January 1976 were amongst the most severe to affect the British Isles and North Sea this century. Shaw *et alii* (1976) have written in considerable detail about the gales over the United Kingdom itself, where damage was widespread. A study of the detail of developments over the North Sea was possible only after the plotting of additional reports from various sources using knowledge of the reliability and systematic errors of wind and pressure measurements and using tracking techniques to determine the most probable intermediate situations between those that had been adequately

TABLE V—REDUCTION OF GEOSTROPHIC WINDS TO SURFACE WINDS

	Geostrophic Wind (kn)																									
Cyclonic flow	10		15		20		25		30		40		50		60		≥70									
Straight flow	10		15		20		25		30		35		40		50		60		70		80		90		100	
	Surface windspeed V_s and angle of backing β from geostrophic wind direction																									
Lapse rate (K/300 m)	V_s	β	V_s	β	V_s	β	V_s	β	V_s	β	V_s	β	V_s	β	V_s	β	V_s	β	V_s	β	V_s	β	V_s	β	V_s	β
≥3·1	10	0	15	0	18	0	23	0	25	0	30	0	32	0	36	0	40/43*	0	45/50	0	50/55	0	55/60	0	60/67	0
3·0–2·2	9	5	13	5	17	5	20	5	25	5	28	5	30	5	34	5	37/40	5	43/47	5	47/52	5	52/57	5	57/64	5
2·1–1·4	9	10	13	10	15	12	20	12	20	15	25	15	27	12	30	10	32/35	10	37/41	10	41/45	10	45/49	10	49/55	10
1·3–0·6	8	17	12	17	15	20	18	20	20	20	23	20	25	22	27	20	30/33	20	34/38	20	38/41	20	41/45	20	45/51	20
0·5–0·3	7	15	11	15	13	18	17	18	20	20	22	20	25	20	26	25	27/30	25	31/35	25	35/38	25	38/42	25	42/46	25

* The notation '40/43' means that the surface wind speed varies linearly with latitude from 40 kn at 50°N to 43 kn at 70°N.

documented. The eight synoptic charts for 3 January are illustrated in Figures 1–8 and the tracks of the parent and secondary depressions are at Figure 9. Developments in the windfield are readily followed by reference to the isotachs on the synoptic charts.

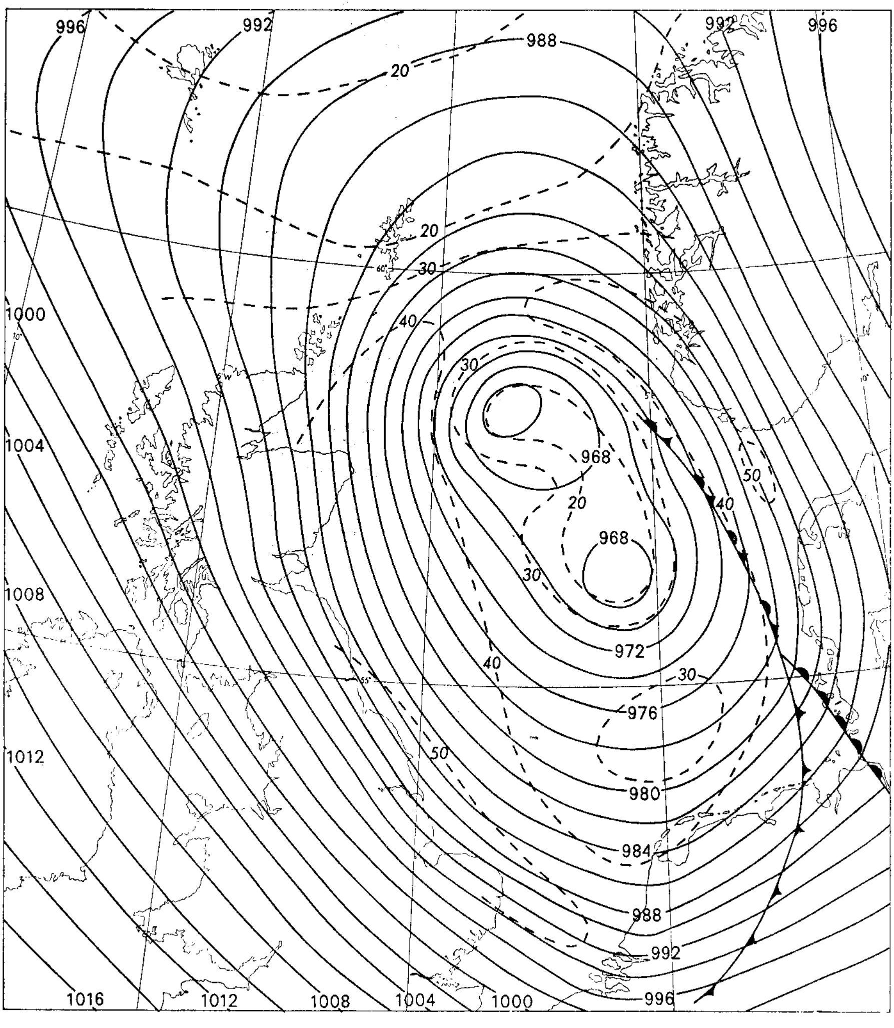


FIGURE 1—SYNOPTIC CHART FOR 00 GMT 3 JANUARY 1976
——— isobar (mb) – – – isotach (kn)

Having moved east-north-east from the Atlantic to a position over the western Highlands of Scotland by 1800 on 2 January, a small but vigorous and deepening frontal depression continued on the same track for another three hours, then turned east and later south-east. The centre deepened to its lowest pressure, estimated at 963 mb at 0300 on the 3rd, and slowly filled thereafter.

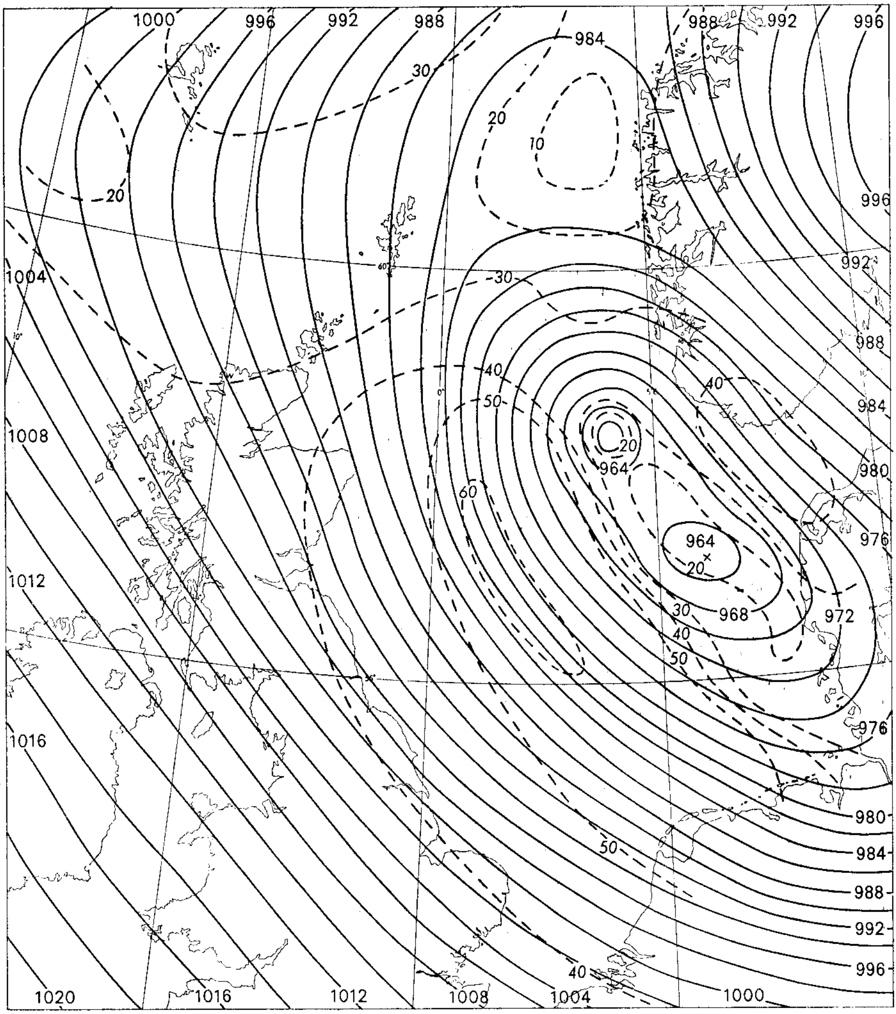


FIGURE 2—SYNOPTIC CHART FOR 03 GMT 3 JANUARY 1976
——— isobar (mb) - - - isotach (kn)

By 1800 on the 2nd the northerlies behind the deepening low had gained strength and fetch, causing severe troughing southwards from the centre, and as this process intensified a new depression centre formed in the trough soon after it crossed the east coast of Scotland, becoming evident by 2100. This centre moved almost due east, deepening to a minimum central pressure of 964 mb also at 0300 on the 3rd. Turning north-east after 0600, by 0900 it had coalesced over north-west Denmark with the original centre, and the combined centre then continued in a south-easterly direction with the same central pressure of 967 mb and later turned east-south-east, filling slowly.

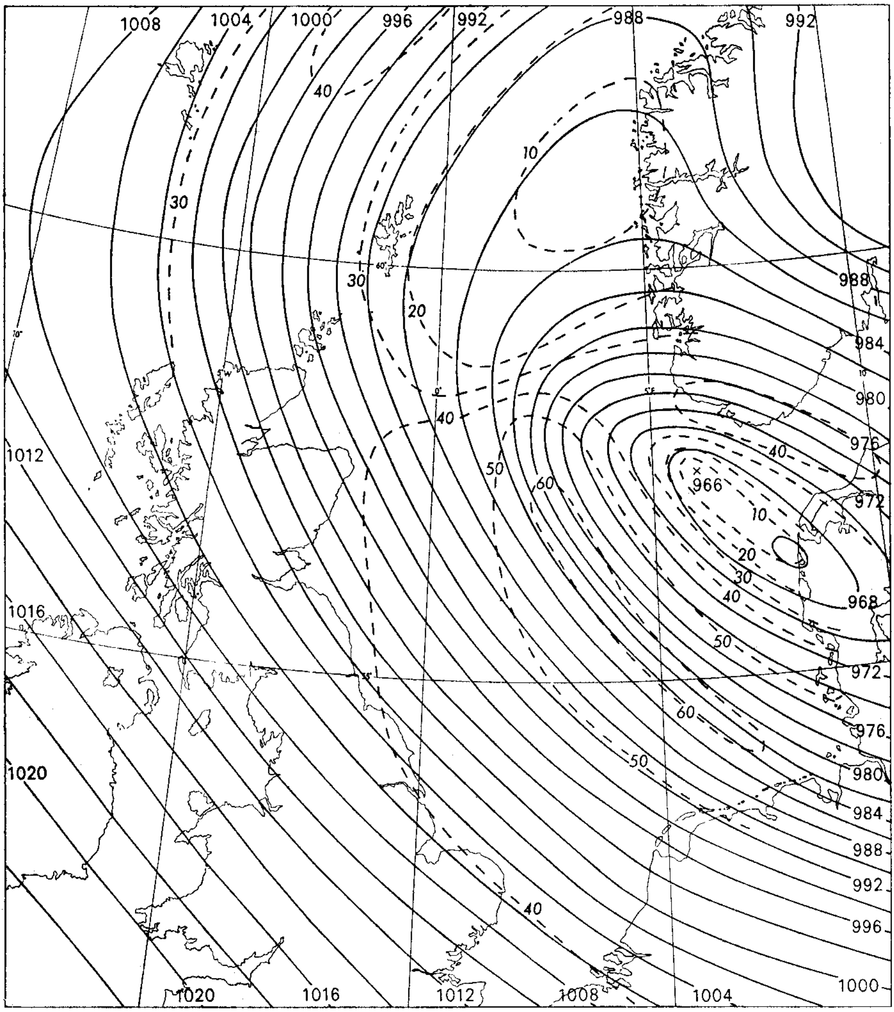
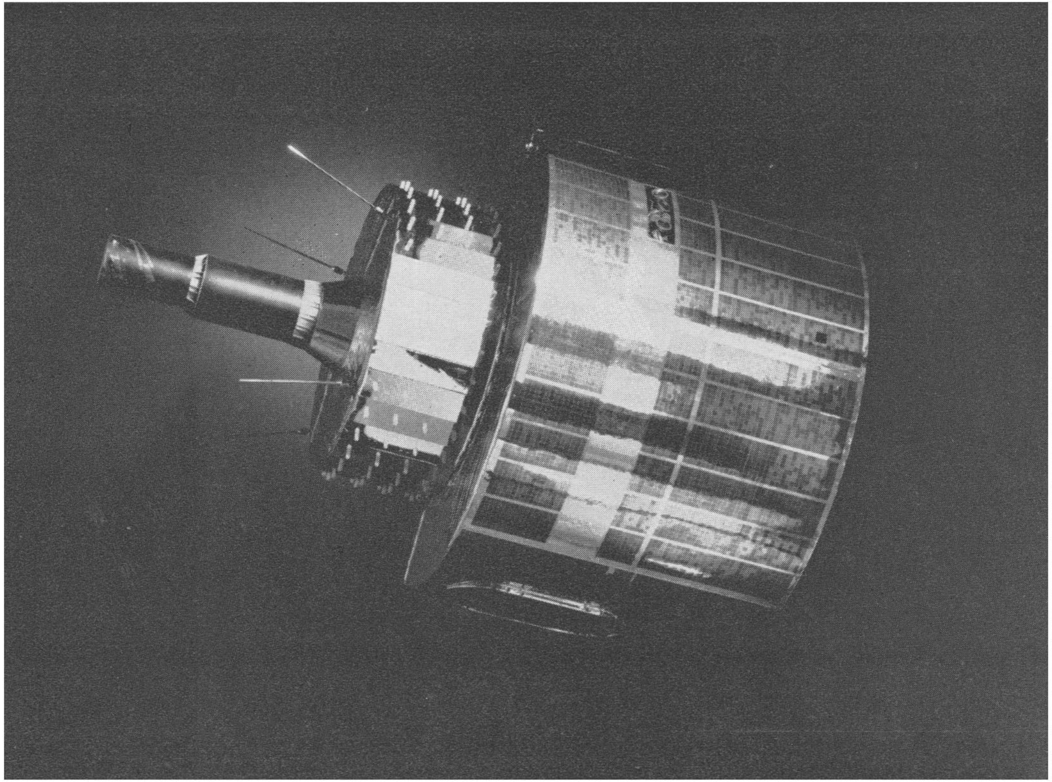


FIGURE 3—SYNOPTIC CHART FOR 06 GMT 3 JANUARY 1976
——— isobar (mb) - - - isotach (kn)

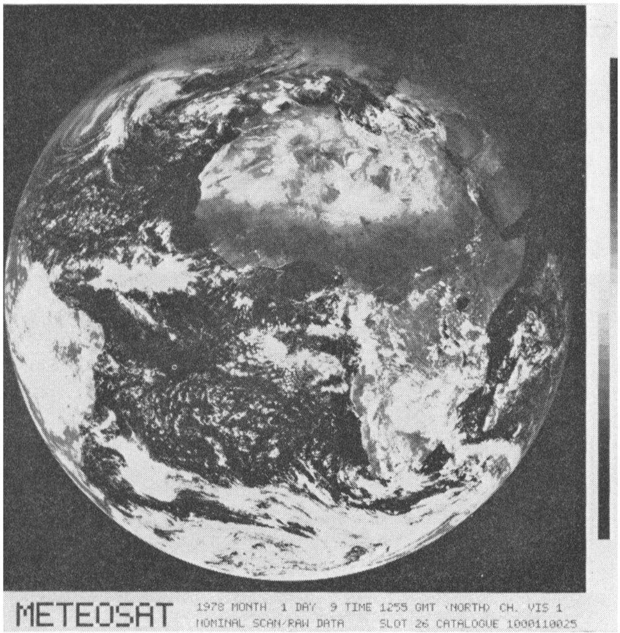
The north-westerly gales associated with the depressions had already reached the western North Sea by 0001 on the 3rd with a maximum mean wind exceeding 50 kn along the east coast of England. This increased to more than 60 kn as it moved very quickly east, broadly retaining its position relative to the centres of the depressions, then between 0300 and 0600 extended downward towards north-west Germany. Notable gusts at heights somewhat above 30 m reported from North Sea installations include 90 kn near 56¼°N 2½°E at 0500 and 95 kn near 57°N 2°E at 0600. The maximum wind then transferred downwind as pressure rose strongly behind the centre, weakening the pressure gradient there, and between 1200 and 1500 passed into north-west Germany and the Danish border, where coastal gusts of 85 and 88 kn were recorded (Loader, 1976).

To face page 174

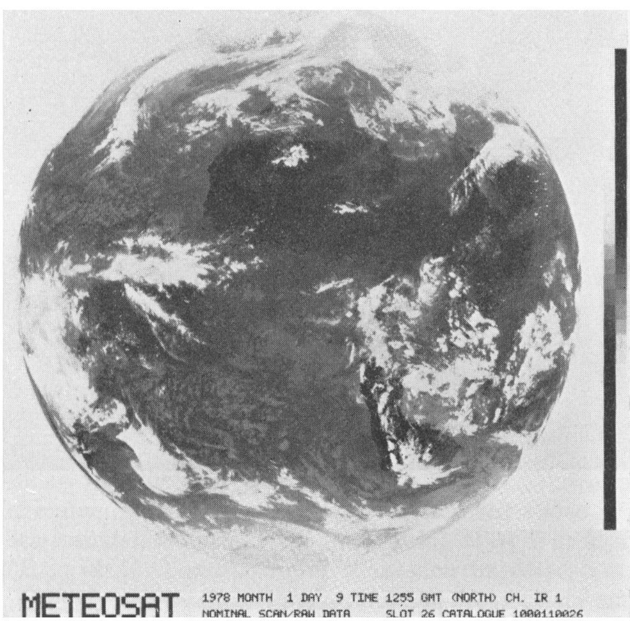


Photograph by Paul Genest for European Space Agency

PLATE I—FULL-SIZE MODEL OF METEOSAT, THE EUROPEAN GEOSTATIONARY SATELLITE
(See page 158.)


METEOSAT
1978 MONTH 1 DAY 9 TIME 1255 GMT (NORTH) CH. VIS 1
NOMINAL SCAN/RAW DATA SLOT 26 CATALOGUE 1000110025

(a)


METEOSAT
1978 MONTH 1 DAY 9 TIME 1255 GMT (NORTH) CH. IR 1
NOMINAL SCAN/RAW DATA SLOT 26 CATALOGUE 1000110026

(b)

(c)

PLATE II—METEOSAT IMAGES

(a) This 'visible channel' image was produced by the Meteosat radiometer between 1230 and 1255 GMT on 9 January 1978. The image is made up of 5000 scan-lines, each containing 5000 brightness values. The spatial resolution at the centre of the image is about 2·5 × 2·5 km.

(b) This is the corresponding image from the infra-red channel, with passband at around 11 μm. At this wavelength the atmosphere is almost transparent (hence the term 'window'). The image comprises 2500 lines, each of 2500 points, resolution 5 km. The hot land appears black; warm sea is dark grey; low cloud appears light grey; high and thick cloud is white. Note how, in conjunction with the visible image, one can interpret the cloud field in terms of its various layers.

(c) This is the image, also produced simultaneously, in a spectral band around 6·3 μm, where water vapour is strongly absorbing. One is seeing the upper troposphere; dry areas appear dark; moist areas appear light grey. Very high clouds show through as white. Meteosat is the first geostationary satellite to have a 'water-vapour' channel.
(See page 158.)

PLATE III—THE FIRST VISIBLE IMAGE RECEIVED FROM METEOSAT ON 9 DECEMBER 1977

(See page 158).

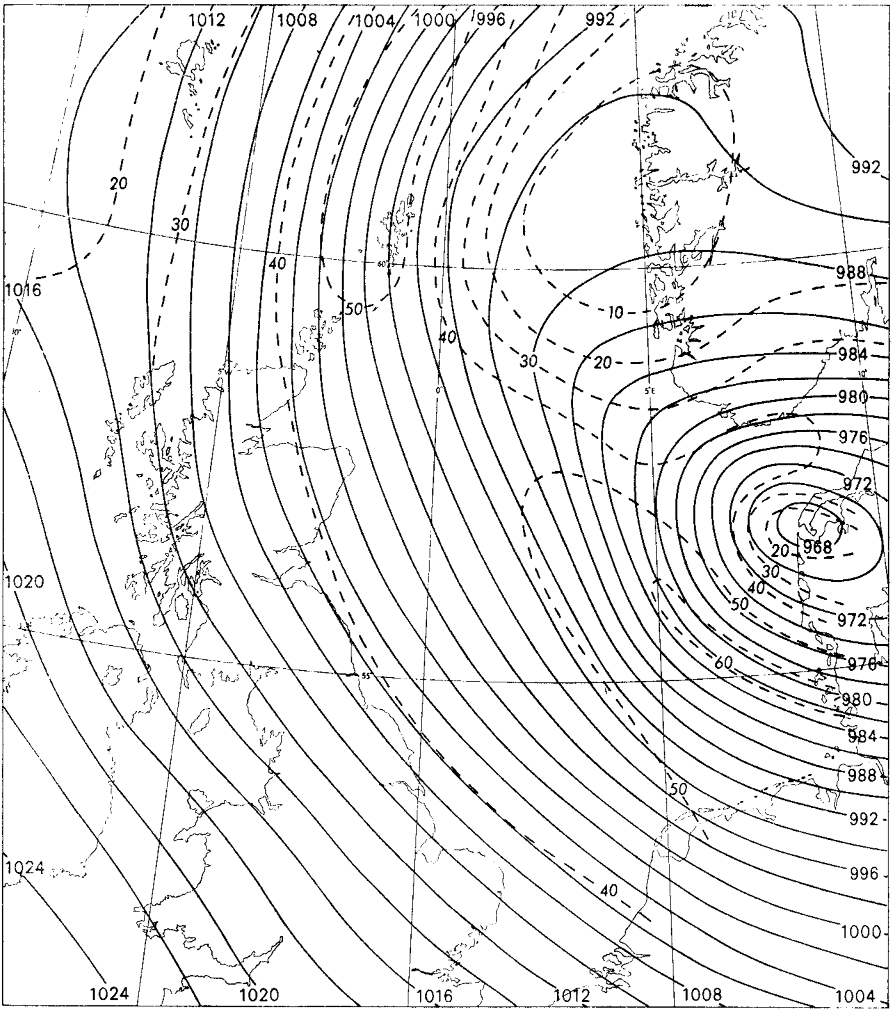


FIGURE 4—SYNOPTIC CHART FOR 09 GMT 3 JANUARY 1976
——— isobar (mb) – – – isotach (kn)

Meanwhile between 0000 and 0300 on the 3rd a well-marked trough developed off the Norwegian coast between about 60° and 65°N owing at least in part to orographic influence in the easterlies north of the depression, while a ridge of high pressure was moving east over the eastern North Atlantic. Pressure rose gradually in the trough which moved little during the next 12 hours, but as the ridge continued its eastward movement towards the British Isles pressure began to rise more strongly between 0300 and 0600 to the north-north-west of Scotland, increasing the pressure gradient between 0° and 5°W north of 60°N, and this process continued as the ridge continued to approach the almost stationary trough off Norway. The pressure gradient continued to increase and its maximum moved south and developed gradually eastwards, giving rise by 1200 to a

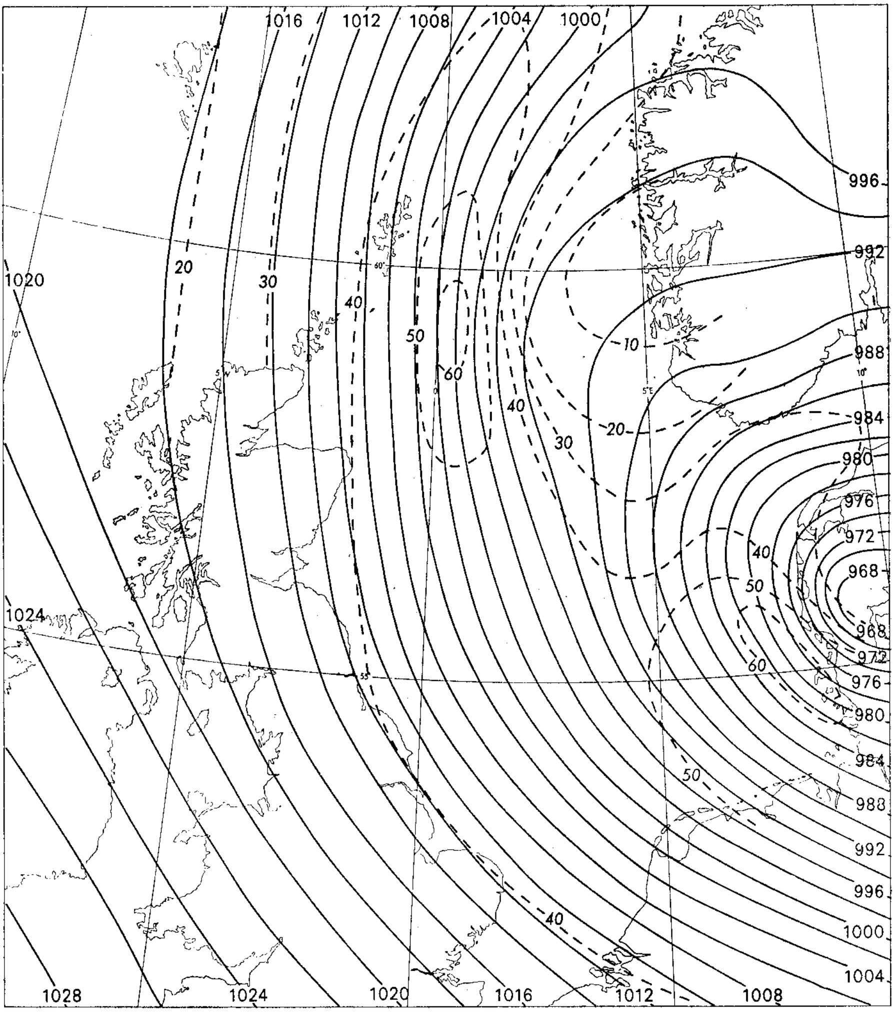


FIGURE 5—SYNOPTIC CHART FOR 12 GMT 3 JANUARY 1976
——— isobar (mb) - - - isotach (kn)

belt of northerly winds with a maximum of over 60 kn just east of the Greenwich meridian between 59° and 60°N. This maximum wind belt moved slightly east of downwind with little change in intensity until 1800. It then decreased while progressing south-south-east, the ridge approaching from the west having collapsed over the British Isles and the trough off south-west Norway having quickly moved south and filled. This rapid filling of the trough occurred as the easterlies over southern Norway died away, the causal depression having continued to fill and to move away east-south-eastwards. Notable gusts in this second burst of storm-force winds from the north were 90 kn at 0900 and 82 kn at 1200 in the extreme north of the Shetland Isles, 88 kn near $61\frac{1}{4}$°N $1\frac{1}{4}$°E

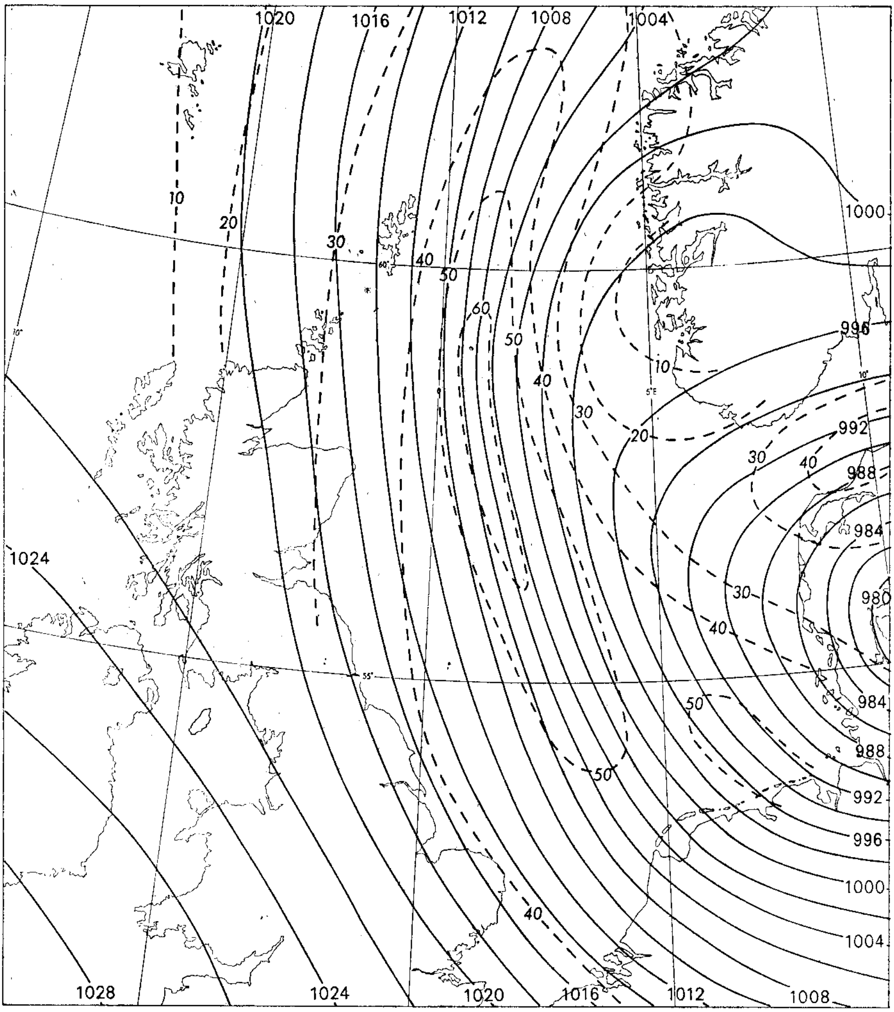


FIGURE 6—SYNOPTIC CHART FOR 15 GMT 3 JANUARY 1976
——— isobar (mb) - - - isotach (kn)

at 1200, 85 kn near 57°N 2°E at 1800 and 84 kn near 59½°N 1½°E at 1500, the last three quoted being from North Sea installations at heights above 30 m. It is also interesting that at an installation near 61°N 2°E the wind speed increased from 16 kn to 60 kn in the 10 minutes preceding 0900, not unexpectedly at a time and place where a very steep isotach gradient existed.

It has been a natural reaction in any study of this gale to recall that of 31 January/1 February 1953 over the United Kingdom and North Sea. Douglas (1953) reported on the latter. Shaw *et alii* (1976) refer to it when comparing the associated tidal surges in the North Sea on the two occasions.

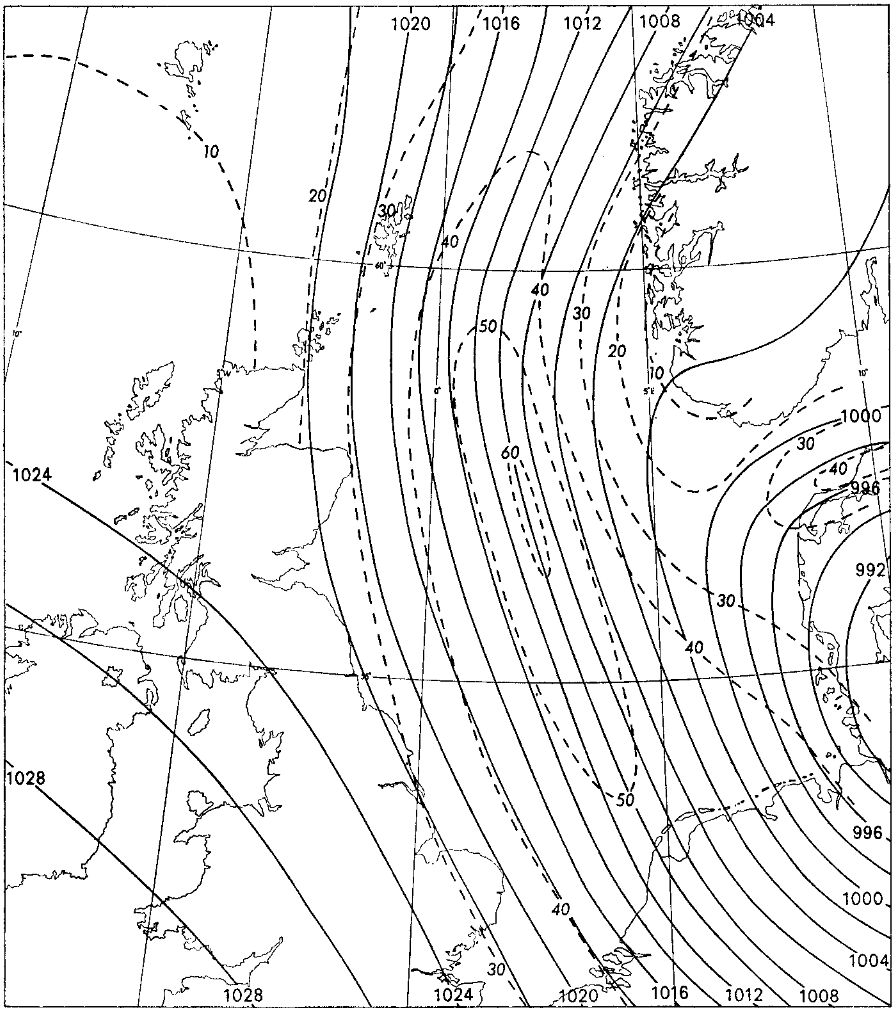


FIGURE 7—SYNOPTIC CHART FOR 18 GMT 3 JANUARY 1976
——— isobar (mb) - - - isotach (kn)

Loader (1976) draws comparisons between them both synoptically and in respect of tidal surges in the North Sea. Inspection of the 1953 charts reveals an almost complete absence of observations over the North Sea with the exception of light-vessel reports near coasts. It would be impossible to carry out a wind analysis with the same confidence as for that of the period from 1966. However, conclusions can be drawn from the charts from which comparisons can be made with the 1976 gales.

The 1953 depression originated on the warm front of a depression which was moving towards the Azores from the north-west. It moved north-eastwards

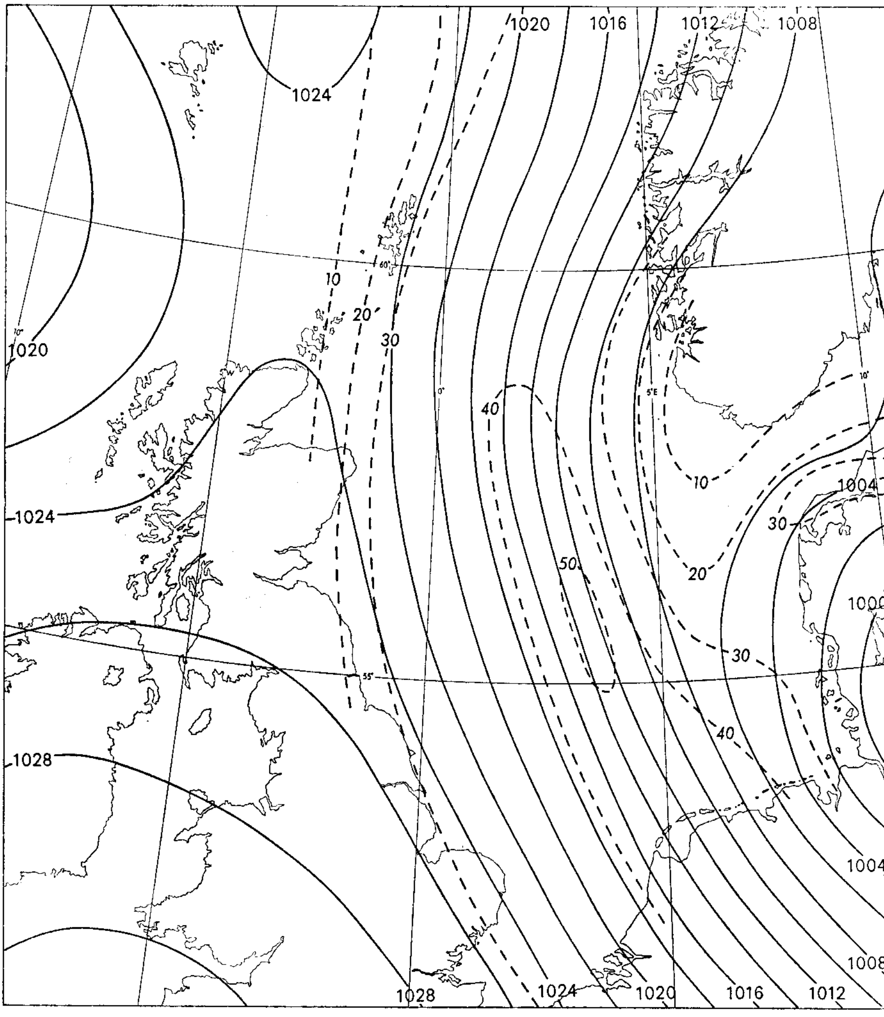


FIGURE 8—SYNOPTIC CHART FOR 21 GMT 3 JANUARY 1976
——— isobar (mb) – – – isotach (kn)

and then eastwards to a position between Scotland and Thorshavn and then south-eastwards between Scotland and the Shetlands and across the North Sea and Helgoland Bight. An outstanding feature of this depression was the intense broad northerly flow over Scotland behind the depression. Douglas (1953) estimated that the geostrophic wind reached 150 kn in a belt over 100 miles wide and that there was a long belt with a geostrophic wind averaging about 120 kn over the whole of the western and central parts of the North Sea as the depression moved south-east towards the Helgoland Bight.

The 1976 depression had a somewhat similar origin, breaking away from an area of low pressure to the west of the Azores and moving north-eastwards to Scotland. It subsequently moved east and south-east across the North Sea and Denmark—see Figure 9 below. Shaw *et alii* (1976) studied in detail the low-level winds over the United Kingdom. They found evidence of geostrophic winds of 150 to 160 kn over Lancashire and the Sheffield area.

The tracks of the two depressions were significantly different, with corresponding major differences in the distribution, fetch and direction of the gales in the North Sea. There were also significant differences in the development of the two depressions. As described earlier in this section a secondary depression

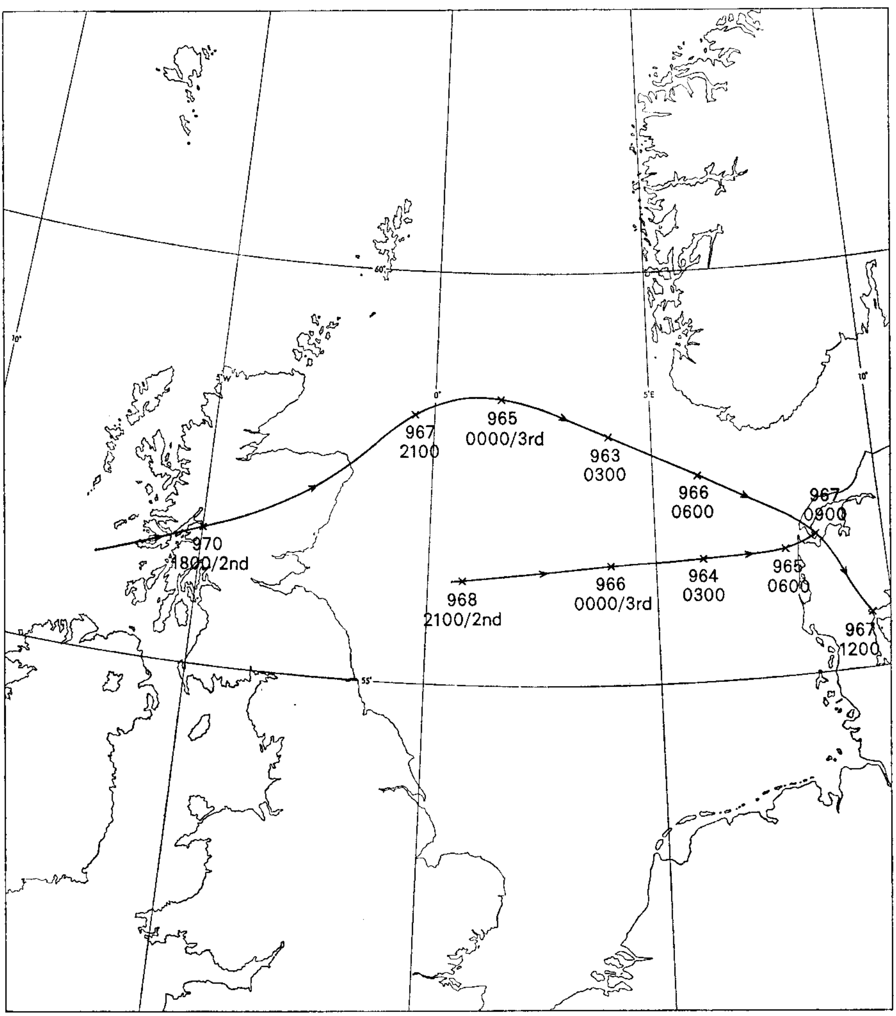


FIGURE 9—TRACKS OF DEPRESSIONS WITH CENTRAL PRESSURES AND TIMES

formed in the severe troughing behind the 1976 depression and the two depressions coalesced over Denmark as illustrated in Figure 9. There was well-defined troughing behind the cold front of the 1953 depression but there is no evidence to suggest that a secondary depression existed at any time in this trough. Any secondary developments were weak and associated with the frontal system to the east of the depression. This is also the interpretation of Mr J. Sanders of the Koninklijk Nederlands Meteorologisch Instituut, who kindly supplied his synoptic reconstruction of the 1953 gales. The isotach maximum moved south-eastwards from North Scotland to the Netherlands more or less parallel to the track of the depression. Herein lie the major differences between the 1953 and 1976 gales. The synoptic charts at Figures 1–8 clearly illustrate the existence of two isotach maxima both of which exceeded 60 kn at peak development. The first was closely associated with the depression itself and its secondary whilst the second and more unusual maximum was associated with the interplay between the advancing Atlantic high-pressure ridge and the trough off the Norwegian coast. It is this secondary maximum that has made the 1976 gales of especial meteorological interest.

AVAILABILITY OF REPORT AND DATA

A detailed account of the work appears in the *Institute of Oceanographic Sciences Report*, No. 55, 'The specification of wind and pressure fields over the North Sea and some areas of the North Atlantic during 42 gales from the period 1966 to 1976' (1978) by J. Harding and A. A. Binding. Copies of the wind and pressure data for the 42 gales are available from the Marine Information and Advisory Service, Institute of Oceanographic Sciences, Wormley, Godalming, Surrey GU8 5UB.

ACKNOWLEDGEMENTS

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NOCTILUCENT CLOUDS OVER WESTERN EUROPE AND THE ATLANTIC DURING 1977

By D. H. McINTOSH and MARY HALLISSEY

(Department of Meteorology, University of Edinburgh)

Table I summarizes the observations of noctilucent clouds (NLC) made over western Europe and the Atlantic during 1977 and reported to the Department of Meteorology, Edinburgh University. A grant from the Meteorological Office finances the collection, collation and publication of these data.

Observers' reports, positive or otherwise, were requested for the months May to August, and as in previous years the period mid-May to mid-August encompasses the main observing season—only a possible sighting from Norway in early September is entered in the list outside these dates. The times in the second column of the Table are not necessarily the total duration of the display. Voluntary observers are obviously unable at times to record a display to the point of disappearance, and tropospheric cloud interference may be such as to allow only short periods of observation; nor can professional observers, whose routine observations are made once per hour, always be sure of the exact time of appearance or disappearance of NLC, though in many instances these have been given.

In the third column of Table I, brief notes on the displays develop slightly the facts given in figures in the remaining columns—details of the relevant station co-ordinates to the nearest half degree, the maximum elevation and limiting azimuths of the observed NLC, where known—and refer to photographs and other points of interest.

TABLE I—DISPLAYS OF NOCTILUCENT CLOUDS OVER WESTERN EUROPE AND THE ATLANTIC DURING 1977

Date— night of	Times UT	Notes	Station position*	Time UT	Max. elev. *degrees*	Limiting azimuths *degrees*
14/15 May	2300, 0200 0300	Faint bands of NLC visible.	57·5°N 03·5°W 55·5°N 01·5°W 55°N 04·5°W	0200 2300 0300	6	360, 045
15/16	2300 0200	No details.	55·5°N 01·5°W			
17/18	2305 0100	NLC partly obscured by tropospheric clouds at more northerly station, and by 0200 cloudy conditions prevailed.	57·5°N 03·5°W 55·5°N 04·5°W	0100 2305	14	020
20/21	2145 2300 2320–0110	Vertically banded area of eastern section of NLC spreading farther south than main cloud field of horizontal bands.	59°N 03°W 56·5°N 07°W 55°N 04·5°W	2330 2300 2145	25 20	340–360 270–360 330–020
21/22	0200	NLC suspected just visible above encroaching tropospheric cloud. NLC not visible in previous or later routine observations.	56·5°N 07°W	0200		025
28/29	0200	NLC veil of medium brightness.	54°N 04·5°W	0200	10	360–060
29/30	2400	Greenish-white glow partly obscured by tropospheric clouds recognized as probable NLC.	56·5°N 03°W	2400		360

* To nearest 0·5 degree.

TABLE I—*continued*

Date—night of	Times UT	Notes	Station position		Time UT	Mox. elev.	Limiting azimuths *degrees*
1/2 June	2314–2349 0100 0345	Banded NLC of moderate brightness seen low in north-west during the early observation. The observer—assuming NLC height of 82·4 km—provided details of cloud speeds and airflow direction (average measured speed 31 m s^{-1} towards 168°); display reported as 'extensive' at later time of maximum spread south.	56°N	04·5°W	2314	5	324–340
					2349	6	318–338
			55°N	04·5°W	0345	20	345–100
			54°N	04·5°W	0100	10	360–020
3/4	0100	Small patch of 'pearly-white' NLC.	56·5°N	07°W	0100	8	345
5/6	2200–2400	NLC visible through breaks in tropospheric clouds—no details of forms.	55·5°N	01·5°W			
8/9	2320–0310	Early sightings SW England and N. Ireland—formation of veil, bands (SW–NE) orientation with cross billows and 'thick' patches of brighter NLC—these latter possibly identified as whirls from two stations. From 0225 to 0245 billow formation seen from N. Ireland in ESE direction. Display generally of medium brightness.	54·5°N	06°W	0110	15	350–030
					0230	90+	090–120
			55°N	01·5°W	0100	15	330–020
			53·5°N	07·5°W	0220	17	330–070
					0240	35	310–080
					0300	12	
			52°N	02·5°W	2350	35	045
12/13	2400	Patch of bright NLC—whirl formation noted.	57°N	02°W	2400	40	345
13/14	2200–0240	Widely observed display of NLC in spite of hampering effect of mist in many areas—visible for duration to observer near Glasgow, who supplied photographs (1 second exposures 0010 to 0100) and detailed notes of geographical position, rate of movement and estimated height (average measured speed 49 m s^{-1} towards 220°). Gradual movement eastwards of the well-defined cloud area. Collectively, all forms seen. Photographs taken Malin Head at 0020 and 0042 show unusual amount of 'turbulence'. Brightness of display '4' for westerly placed stations.	56·5°N	03°W	0100	30	350–030
			56°N	04·5°W	0100	20	345–020
			55·5°N	05·5°W	2245	15	360
					2300	30	340–010
					2400	30	340–030
					0100	20	340–045
			55·5°N	07·5°W	2355	9	350–030
					0037	10	357–035
			55°N	04·5°W	2255	17	345
			55°N	03°W	2300	8	020–026
			54°N	04·5°W	2300	10	010
					2400	10	360–020
			53·5°N	07·5°W	0215	10	020
14/15	2346–2400	NLC visible at stations in same longitude in north of Ireland and western Scotland. Veil of earlier sighting soon obscured. Bright bands and billows of later sighting lost in brightness of sunrise.	57·5°N	07·5°W	0100	12	330–360
					0200	10	330–010
			55·5°N	07·5°W	2346	5	291–297
15/16	2200–0200+	NLC visible in both western and eastern Scotland. Bands, billows and whirls developed from early veil—the rippled and striated veil described as 'chaotic' on eastern edge; sketch shows the 'rippled' areas at each end of azimuthally extensive display.	57·5°N	07·5°W	2200	10	330–010
					2300	10	330–360
					2400	15	290–360
					0100	10	330–010
			57°N	02°W	0100	30	300–050
			56·5°N	07°W	2310	21	290–040
					0100	18	300–050
					0200	20	320–080
			56·5°N	03°W	2400	10	340–030
					0100	30	330–080
19/20	2400 0100	2–3 patches of NLC in NW and NNE. Sky reported clear of NLC in previous and later routine observations.	56·5°N	07°W	2400	10	300–320
						8	010
					0100	8	330–030
21/22	2330–0100	Faint band of NLC visible around midnight—most southerly station suspected the glow to be aurora, but this being clearly unlikely, the observation was recorded as a questionable NLC sighting.	55°N	04·5°W			
			54°N	04·5°W	2400	15	350–020
			53·5°N	01·5°W	2400	45	315–360
22/23	2115, 2305 0100, 0200	Faint veil of NLC.	57·5°N	07·5°W	0100 0200	10	330–360
			55°N	04·5°W			

TABLE I—*continued*

Date—night of	Times UT	Notes	Station position	Time UT	Max. elev. *degrees*	Limiting azimuths *degrees*
23/24	2120–0230	Early development of NLC as seen SW Scotland first considered suspect, but by 2230 display outstanding, spreading W–NE. Seen at this time from 52°N, where effect of haze made NLC patches featureless, though slightly farther north the bands and billows were seen as 'tangled and dense'; viewing here also soon weakened by haze. Bright whirls seen at 2300 from N. Yorks., Northumbria and S. Scotland.	57·5°N 03·5°W	2400	20	340–045
			55·5°N 01·5°W	2300	15	360
				2400	15	360–045
				0100	17	350–040
				0200	28	
			55·5°N 03°W	2200 2300		315–360
				0200		045
			55°N 04·5°W	2230		270–045
			55°N 01·5°W	2245	15	320–020
			54·5°N 01·5°W	2300	15	318–020
				2400	9	330–020
				0100	9	340–040
				0200	24	355–080
				0210	45	330
			53°N 0·5°W	2300	11	330–025
				2400	7	340–020
				0200	20	350–070
				0225	50	070
			52°N 0·5°W	2250	7	320–360
26/27	2135–0225	From Northumbria no NLC seen 2300 but at 2315 thin bands to 15° were seen in NE; before midnight NLC suspected visible from Bedford. Bright billow formation reported from N; later southerly station noted billows and whirls in E part of display.	56·5°N 03°W	0100	20	030–050
			55·5°N 01·5°W	2315	15	020–050
				0100	15	030–050
			52°N 0·5°W	2400	3	—
				0150	8	360
				0207	5	010
27/28	0215–0300+	Almost 8/8 tropospheric cloud cover broke sufficiently to reveal very bright NLC band. No further observation possible.	54·5°N 06°W	0215	15	330–020
				0300		350–040
2/3 July	2055–2225 0045–0115	Earlier display bright formation of bands and 'knots' seen from Denmark—photographed 2142 and 2144. NLC stretching into SE when 'lost' in moonlight and tropospheric cloud. From NE Scotland small rippled patch visible for half hour just E of N.	57°N 02°W	0100	12	360–010
			55°N 14·5°E	2055	20	360
				2140	15	045–090
				2225		135
3/4	2400	Faint traces of NLC partly obscured.	55·5°N 01·5°W	2400	6	360
4/5	2150	Very faint NLC in NW, billowed structure identified through binoculars. (Entire E sky and parts of N sky covered by tropospheric clouds.)	55°N 14·5°E	2150	22	315
5/6	2300–0300+	NLC first sighted from west central Scotland as very faint band at high elevation; last sighting from same station when bright whirls still visible overhead. All stations reported, and some sketched, bright and extensive display of classic forms at high elevation.	57°N 02°W	0045	29	305–350
				0125	30	325–040
				0145	50	340–040
				0205	50	340–040
			56·5°N 03°W	0200	90	330–020
			56°N 04·5°W	0110	19	345
				0200	20	340
				0220	21	340
			55·5°N 04·5°W	2300	40	360–030
				2400	30	350–010
				0200	90	320–020
				0300	90	—
			55·5°N 01·5°W	0100 0200	25	330–030
			55°N 04·5°W			
6/7	2400, 0250	Earlier sighting of faint band of NLC, W–E orientation. Later short-lived sighting of faint rippled patch.	56°N 04·5°W	0250	33	020
			55·5°N 05·5°W	2400	14	350
9/10	2330–0240	First suspected visible behind tropospheric cloud by observer in SW Scotland, then seen as amorphous veil above mist from northern Ireland. Greatest spread southwards approx. 0220. Billows and whirls noted from Benbecula.	57·5°N 07·5°W	0100	13	290–350
				0200	8	300–360
			56·5°N 07°W	2400	11	320–030
				0100	11	320–040
				0200	18	320–090
			55·5°N 07·5°W	2400	8	360–020
			55°N 04·5°W	2330		
				0200		
			54·5°N 06°W	0200	11	330–080
				0220	17	330–020
					10	040–080
			53·5°N 03°W	0200	10	010–030
				0218	15	010–030
				0225	18	010–030
				0235	16	010–030

TABLE I—*continued*

Date—night of	Times UT	Notes	Station position	Time UT	Max. elev.	Limiting azimuths *degrees*
11/12	0100–0215	Bright bands, 'strongly defined', as seen from Tiree.	56·5°N 07°W	0100	20	330–060
				0200	30	330–020
			55·5°N 07·5°W	0100 0200	5	355–010
			55°N 04·5°W	0145	7	345–045
14/15	0145	Faint NLC of large horizontal extent.	55°N 04·5°W	0145	8	020
15/16	2145–2305 0130 0210, 0300	Faint NLC seen earliest from Denmark—extensive new formations in ENE with bright bands and billows. Photographs 2205–2240. Extensive spread of NLC noted from Roden (Netherlands); multiple bands, photograph 0130. Latest report from N. Ireland: banded formation.	55·5°N 10°E	2145	—	315–020
				2230	—	060
				2305	—	—
			54·5°N 06°W	0210	10	350–040
				0300		
			53°N 06·5°E	0130		
16/17	2400, 0100	W–E banded formation, with veil stretching southwards to observer's zenith on W side of display.	57·5°N 03·5°W	0010	90	330–360
					30	340–050
17/18	0200	NLC—no details.	54·5°N 01·5°W	0200	10	360–020
19/20	2215–0130	Greatest elevation in early part of observing period—faint, striated patches. Little movement.	55·5°N 01·5°W	2215	13	360–040
				2355	6	010–020
				0100	7	010–030
20/21	2305–0038	Banded formation NLC rising from NNE: slowly increasing brightness: westward movement. When obs. ceased (not end of display) bright bands visible spreading southwards at right angles to horizon. Display photographed 2345–0050.	56°N 10°E	2305	10	020
21/22	2258, 2305	In very good observing conditions no NLC until very faintly apparent at 2258, visible through binoculars. Drifting tropospheric clouds hampered observations but NLC had become visible to naked eye by 2305.	56°N 10°E	2258	5	020
22/23	2300–0150	At 2300 NLC visible from Norway and suspected from NE Scotland. At 0130–0150 veil seen from Norway—'illuminating eastern half of sky sufficiently to light up details of countryside'—and from NE England —'now brighter and striated'.	59°N 09°E	2300 2330	50	360–045
				0130	90+	090
			57°N 02°W	2300	—	315, 360
			55·5°N 01·5°W	0100	4	—
				0150	8	010–030
25/26	0220–0245	NLC patches aligned from NNW–ENE.	55°N 04·5°W	0230	12	010
26/27	2200–2230, 0020–0125	Faint NLC visible, through binoculars above tropospheric cloud. New patches appearing later, extending westwards; fast development in E and quickly increasing brightness. Observations ended with dawn. Photographs 0100–0113.	56°N 10°E	2200	12	—
				0020	8	
				0125	18	345–090
28/29	0050–0300	Very low elevation NLC bands appearing intensely bright as seen Tiree, less bright from Malin Head and behind haze from SW Scotland.	56·5°N 07°W	0100	1	—
				0200	4	360–030
				0300	5	025–040
			55·5°N 07·5°W	0100	3	345–360
			55°N 04·5°W	0250		
30/31	0240	Probable NLC.	55°N 04·5°W	0240		
31 July/1 Aug.	0348, 0403	Aircraft captain's observation of striated veil spreading NE towards SW. Later observation noted band and billow formation and higher elevation.	54°N 28°W	0348	5	350–050
			54°N 24°W	0403	11	360–035
1/2 Aug.	2030, 2040 0145–0330	Early sighting Denmark at high elevation—moderately bright NLC bands W–E aligned. Later observations from NE and central England: bands and whirl formation to fairly high elevation taking account of lateness in observation 'season'.	55·5°N 01·5°W	0145	7	360–020
				0220	8	
				0230	10	340–070
				0235	14	
			55°N 14·5°E	2030	25	345–360
			55°N 01·5°W	0300	20	010–070
			52°N 0·5°W	0255	10	010–040
				0305	10	020
				0315	9	020
				0330	10	010

TABLE I—*continued*

Date—night of	Times UT	Notes	Station position	Time UT	Max. elev. *degrees*	Limiting azimuths *degrees*
2/3	0200, 0300	Bright bands seen Tiree; fainter by 0300 with slight recession of W edge.	56·5°N 07°W	0200 0300	4 4	340–030 350–030
6/7	2200	Isolated band of NLC, medium brightness at high elevation.	56·5°N 07°W	2200	40	340–360
9/10	0310	2 bands of NLC to high elevation, aligned NNE–SSW.	56·5°N 03°W	0310	80	020
10/11	0220	Trace of very faint NLC—simultaneous appearance of aurora.	59·5°N 01·5°W	0220	15	020
11/12	2300, 0015	Small area of NLC—'the cloud was bright enough to readily attract attention, having a pale lilac-coloration'. Small area of billows in veil. Simultaneous auroral appearance as NLC fading.	59·5°N 01·5°W	2300 0015	10	020
14/15	0215–0240	NLC visible at high altitude.	59°N 09°E	0230		060–100
15/16	2058–2135	Bright striated NLC with dense patches, WNW–ESE orientation almost in observer's zenith—obscured after 2135 by prevailing haze.	51·5°N 02°W	2050	87	—
7/8 Sept.	2015–2045	Diffuse but weak spread of NLC over much of sky.	59°N 09°E			

Positive reports of NLC were received from some 22 stations of the Meteorological Office network in Great Britain and from two stations of the Irish Meteorological Service network. Reports from many voluntary observers included those from the Fair Isle lighthousekeeper, the captain of an aircraft over the eastern Atlantic and experienced contributors to these lists observing from scattered points throughout Denmark, The Netherlands, Norway and the United Kingdom. Photographs and sketches were a helpful accompaniment whenever provided.

Routine observations for hours of darkness were received from 16 Meteorological Office stations and form an important part of the data collection, particularly where conditions are such that an observer is able to state with confidence 'No NLC'. These 'negative' reports are regarded as significant, particularly for nights during a possibly unbroken series of appearances of NLC. They are also a helpful point of reference when NLC is suspected by some observer in the vicinity. The high standard of all the reports received is greatly appreciated.

Table I records NLC sightings on 50 nights. Many of them were single-station 'definite' reports, but there is no hesitation in including such uncorroborated reports from experienced observers when sightings from neighbouring stations are prevented by lower cloud. With the high amount of tropospheric cloudiness recorded throughout the whole observing season it was fortunate that the infrequent clear periods were used to such good purpose. The displays of 13/14 and 23/24 June were the most widely observed. There were no outstanding displays, though on many occasions details of the cloud formation were clearly visible and described from different angles of view. Occurrences of the clouds were fairly evenly spread over the three two-week periods from mid-June to end-July, rather than showing concentration into a more usual 'peak' in the second half of June and/or the first half of July. It is notable, too, that no NLC appearances were reported from Denmark until early July, while, generally, the number of appearances of the clouds in August is greater than usual. This may in part be accounted for by somewhat better observing conditions, i.e. less tropospheric cloud, as well as greater awareness that the clouds may still (in principle) be observed then; observers at Lyneham would, even so, no doubt be surprised to record a sighting of NLC as late as 15/16 August.

Time-lapse photography of NLC was carried out throughout most of the observing 'season' from Edinburgh. There were, however, no 'clear' displays, camera trouble or tropospheric cloud interfering on all occasions. Displays for which photographs have been received from observers are 13/14 June (Milngavie and Malin Head), 2/3 July (Rønne, Denmark), 15/16 July (Håstrup, Denmark and Roden, The Netherlands), and 20/21 and 26/27 July (Alrø, Denmark).

The photograph of the display of 18/19 June 1976, taken by Dr D. A. R. Simmons of Milngavie, near Glasgow, was published on the cover of *Weather* (July, 1977); backed up by his account of the display, this photograph has been awarded the James Paton Memorial Prize for 1977.

TABLE II—ADDITIONAL REPORTS OF NOCTILUCENT CLOUDS OVER WESTERN EUROPE DURING 1976

Date—night of	Times UT	Notes	Station position		Time UT	Max. elev.	Limiting azimuths
						degrees	
7/8 June	2400	Colour photographs were taken showing Groningen silhouetted against the NLC.	53°N	06·5°E			
6/7 July	0030	Several concentrations of fine filament type formation NLC in NW and single patch also in NE—moving very slowly westwards.	53°N	06·5°E	0030	6	315–045

REVIEWS

Applied statistics in atmospheric science, Part A: Frequencies and curve fitting (*Developments in Atmospheric Science* 4*A*) by Oskar M. Essenwanger, 240 mm × 170 mm, pp. xiv + 402, *illus.* Elsevier Scientific Publishing Company, Amsterdam, The Netherlands, 1976. Price: $53.95, Dfl 140.00.

A new book on meteorological statistics is always something to look forward to, because there is a pressing need for texts which are more up to date in content and outlook than good old Brooks and Carruthers. Professor Essenwanger's book, which covers a good deal more ground than the title implies, does not quite live up to the promise of the early chapters. These are good, and provide clear and convincing accounts of topics which meteorologists cannot readily find elsewhere, but in the later sections, the discussion on time series analysis gives the impression that the author's extensive personal experience in the field of atmospheric turbulence has not extended to climatology. The chapter on factor analysis is not very satisfactory, but perhaps no worse than other accounts of this unsatisfactory subject. The extensive section on principal component analysis suggests that the author is out of touch with scientists at institutions such as the University of Wisconsin or the Meteorological Office, where principal component analysis is one of the tools of the trade. If these comments seem a little condescending, the author has stated his wish not to produce another text on theoretical statistics, but given this good intention, he might have done better to include only those topics in which each subject could be followed by a worked example drawn from his personal experience. The book would then have been more down to earth, and probably a good deal shorter. Still, it is good in parts, and should prove valuable to the reader who already knows how he intends to tackle his assignment, and is prepared to dip into the book for further information. With all its faults, a noteworthy addition to the literature on meteorological statistics.

J. M. CRADDOCK

The weather almanac (*second edition*), edited by J. A. Ruffner and F. E. Bair. 225 mm × 150 mm, pp. viii + 728, *illus.* Gale Research Co., Detroit, Michigan, U.S.A., 1977. Price: $25.

The first (1974) edition of this book was reviewed by P. G. F. Caton in the April 1977 issue of the *Meteorological Magazine.* For the second edition the editors have revised and updated the weather records of 108 selected cities from the United States and various other statistical tables. A chapter entitled 'Weather fundamentals' has been added, which is a fast-moving course in meteorology in no more than 40 pages including many diagrams and photographs. The section on air pollution has been largely rewritten and now includes more discussion of meteorological principles. The book continues of course to deal almost exclusively with the United States of America except for the 'Round-the-world weather' section.

R. P. W. LEWIS

OFFICIAL PUBLICATIONS

The following publications have been issued since the two series concerned were last referred to under this heading in the *Meteorological Magazine:*

Geophysical Memoirs

No. 120. Average temperatures, contour heights and winds at 30 millibars over the northern hemisphere. By R. A. Ebdon. (London, HMSO. £11.50.)

No. 121. Bumpiness in clear air and its relation to some synoptic-scale indices. By W. R. Sparks, B.Sc., S. G. Cornford, M.Sc., and J. K. Gibson, G.I.M.A. (London, HMSO. £3.75.)

Scientific Papers

No. 34. The Meteorological Office operational 10-level numerical weather prediction model (December 1975). By D. M. Burridge, Ph.D., and A. J. Gadd, Ph. D. (London, HMSO. £1.25.)

No. 35. A study of some aspects of the climate of the northern hemisphere in recent years. By D. J. Painting, B.Sc. (London, HMSO. 80p.)

No. 36. A computer-based model for design rainfall studies in the United Kingdom. By J. F. Keers, B.Sc. and P. Wescott. (London, HMSO. 85p.)

No. 37. The variability of long-duration rainfall over Great Britain. By R. C. Tabony, B.Sc. (London, HMSO. 85p.)

No. 38. The psychrometer coefficient of the wet-bulb thermometers used in the Meteorological Office Large Thermometer Screen. By C. K. Folland, B.Sc. (London, HMSO. £1.25.)

NOTES AND NEWS

Royal Meteorological Society Exhibition

The Royal Meteorological Society is mounting an exhibition in Bracknell College from 14 to 17 July 1978 inclusive which will be opened by Her Majesty the Queen. The Meteorological Office will be taking part in the exhibition together with about 80 other organizations. The exhibition will be divided into nine themes and the Office is proposing to contribute items in seven of these. Amongst the contributions from the Office will be a working automatic weather station, an operating Stratospheric Sounding Unit and a video display of the results from some experimental numerical forecasting models. The Central Forecasting Office will maintain a display of current analyses and prognoses in the entrance hall of the College.

International conference on 'Evolution of planetary atmospheres and climatology of the earth'

The Centre National d'Études Spatiales (CNES) is organizing an international conference on 'Evolution of planetary atmospheres and climatology of the earth' to be held at the Palais des expositions in Nice (France) from 16 to 20 October 1978.

The main topics will be: Comparative evolution of planetary atmospheres; Evolution of the earth's climates up to the present time; Physical mechanisms of the climate and modelling; Measurement and modelling prospects.

Those who are interested in the conference should contact

Centre National d'Études Spatiales,
Département des Affaires Universitaires,
18, Avenue Édouard-Belin,
31055 TOULOUSE CEDEX,
France.

HONOUR

We note with pleasure that Dr K. A. Browning, Senior Principal Scientific Officer at the Meteorological Office Radar Research Laboratory, Malvern was elected a Fellow of the Royal Society on 16 March. Dr Browning has made exceptional use of radar techniques, especially of Doppler radar, to elucidate the structure and evolution of precipitating cloud systems. Using radar and other sounding techniques and powerful new methods of meteorological analysis, he has been able to establish, for the first time, a comprehensive, self-consistent, quantitative description of the air motion in both frontal cloud systems and thunderstorms and to relate this to the distribution and intensity of rain and hail. He has also used the powerful radar at Malvern to gain new insight into the mechanisms of clear-air turbulence and the initiation of convection. Dr Browning's work is characterized by exceptional observational skill and physical insight and an unrivalled ability to analyse and synthesize large masses of complex observational data, to extract from them quickly the essential facts and to present them clearly as unique case studies which will serve as models for many years to come.

PROFESSOR P. A. SHEPPARD

With the passing of Professor P. A. Sheppard, C.B.E., F.R.S. on 22 December 1977, British meteorology lost one of its leading figures of the post-war era. Born in 1907, he graduated with first-class honours in physics at Bristol University in 1927 and joined the Meteorological Office as a junior professional assistant in 1929. His last professional appearance was at a meeting of the Physical Sub-committee of the Meteorological Research Committee held at Bracknell on 24 October 1977, only a few weeks before his death. He was therefore associated with the Meteorological Office from the beginning to the end of his career stretching over nearly half a century.

Soon after joining Kew Observatory he began to plan for the International Polar Year, 1932–33, which he spent as a member of a small British team that included J. M. Stagg and Angus Grinsted at Fort Rae in the North-west Territories of Canada and carried out research on atmospheric electricity. On his return he was posted to the Meteorological Office group at Porton headed by O. G. Sutton which was concerned with meteorological aspects of chemical warfare and there began his researches on turbulence and diffusion in the atmospheric boundary layer which were to become his main scientific interest for the next forty years.

Sheppard resigned from the Office in April 1939 on being appointed Reader in meteorology at Imperial College under Professor (later Sir David) Brunt but returned to the Office at the outbreak of war. For the first few months he was an instructor with Brunt at the Meteorological Office Training School but, for the remainder of the war, was heavily involved in the establishment of the radiosonde network and in co-ordinating upper-air observations derived from a variety of sources and techniques.

In 1945 he returned to Imperial College where he assisted Sir David Brunt in establishing the only fully-fledged university department of meteorology in the country, recruiting a group of young men each of whom was to become a leading authority in his own field. In a remarkably short time the department became internationally famous as a postgraduate centre of research and teaching, attracting students and senior research workers from all over the world. Here Sheppard, who succeeded Brunt to the professorship in 1952, played a very important role, not so much by his leadership in research, but as the most widely read and informed meteorologist of his day, whose penetrating criticisms, scholarly review articles and lucid lectures were of great value and influence.

From about 1957 onwards he became increasingly involved in many important activities outside the department where his breadth of knowledge and incisive mind showed to great advantage. He served the Royal Meteorological Society with great ability and devotion as Secretary, Editor and as President (1957–59). He was a stimulating and provocative member of any committee and an excellent chairman. He was a member of the Meteorological Research Committee from 1947 until his death and was Chairman from 1958 to 1968, a remarkable record for which he received the C.B.E. in 1963.

As Chairman of the Science Research Council's Space Policy and Grants Committee from 1965 to 1971, and vice-chairman of the ESRO Council, he played an important role in the formative years of European space research. But, sadly, the work-load and travelling put a heavy strain on his energies and took him away a great deal from his department which, with the departure or illness of several of its leading members, lost its former eminence. This must have been a worry to Sheppard, but he never lost his optimism, or his love of, and interest in, meteorology even during a long, debilitating illness which he endured with great fortitude and humour. It was during these last few years especially that I, and probably many others, came to realize that his bark was much worse than his bite and to appreciate his warm, human qualities. This makes his passing especially sad and leaves a gap that will be hard to fill.

B. J. MASON

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ, and marked 'For Meteorological Magazine'.

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

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