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One hundred years of the Dines pressure-tube anemometer*

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Summary

A brief description is given of the development of the Dines pressure-tube anemometer which celebrates 100 years of use world-wide.

1. Introduction

One hundred years ago William Henry Dines (1855–1927) demonstrated his prototype pressure-tube anemometer (PTA) to the Wind Force Committee of the Meteorological Society. This instrument was the result of the combination of Dines's academic prowess, practical capabilities and experimental skills. PTAs are still in use today in many countries of the world and in desert conditions which cannot be coped with by modern electrically powered anemometers. In this article a brief description is given of Dines's early life which led to the development of the PTA, and its use and manufacture thereafter.

For readers unfamiliar with this instrument the basic components of the speed-measurement mechanism are shown in Figs 1 and 2. It operates using a vane to ensure that an open-ended horizontal tube always points into the wind creating a pressure in the tube (Fig. 1). A second, vertical, static tube is drilled with holes so that the air travelling past creates a suction. The two tubes lead to a sealed tank containing water in which floats an inverted 'bell' attached to a rod which actuates the recording mechanism (Fig. 2). The pressure tube leads to the space above the water in the bell, and the suction tube to the space above the water in the tank. As the wind speed increases, the combined action of the pressure increase in the pressure tube and its decrease in the suction tube causes the float to rise. Fig. 3 shows the

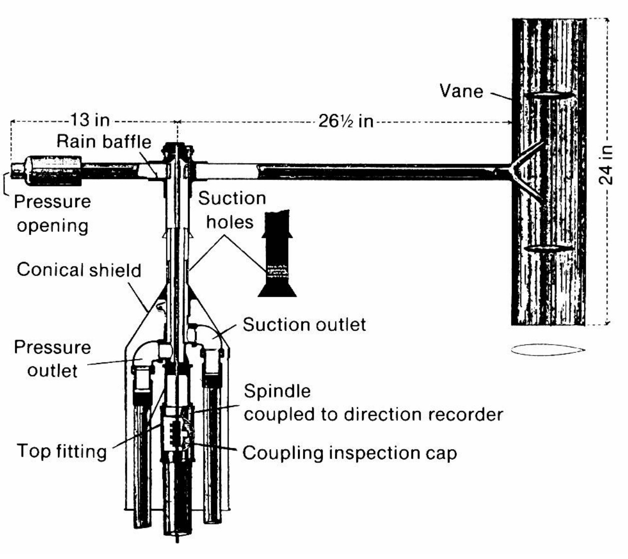


Figure 1. Head arrangement of the pressure-tube anemometer.

* This article is based on a more comprehensive article on the subject which is lodged, as a pamphlet, in the National Meteorological Library, Bracknell.

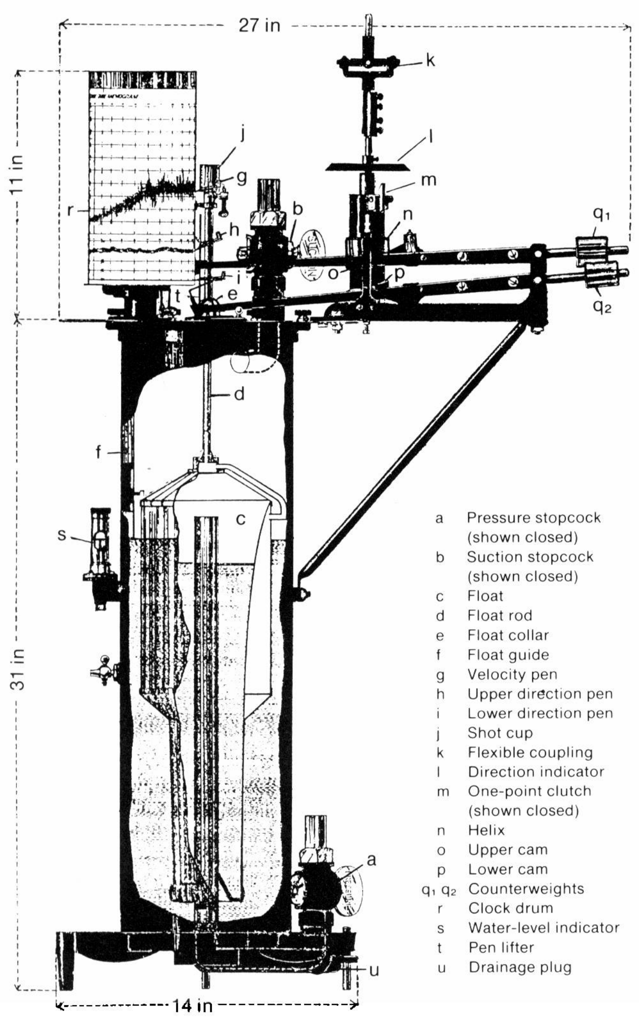
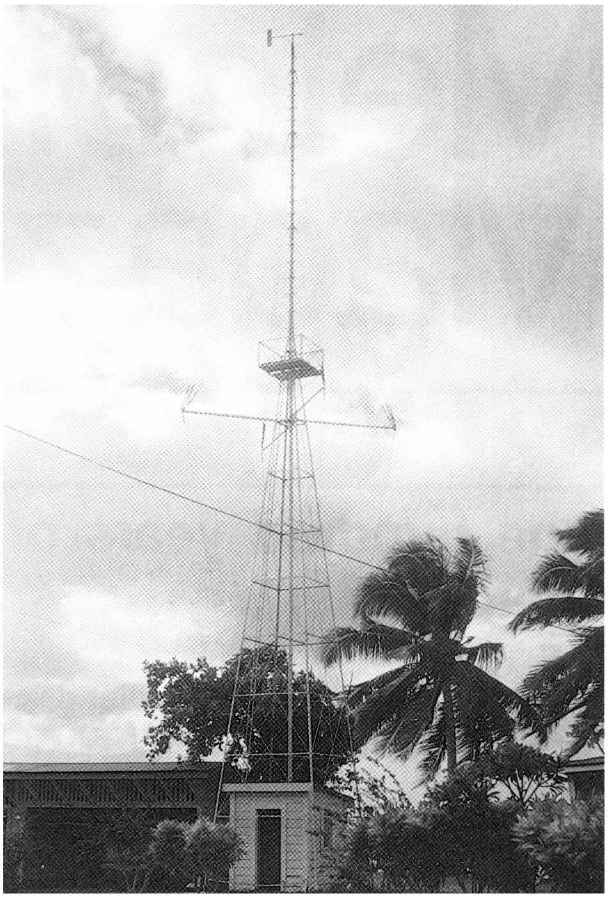


Figure 2. Recording mechanism of the pressure-tube anemometer.



Photograph by courtesy of Mr J.S. Falconer, New Zealand Meteorological Service

Figure 3. The pressure-tube anemometer mast at the Geophysical Observatory, Apia, Western Samoa.

PTA head and down-tubes installed on a lattice tower and guyed mast at Apia, Western Samoa. A Dines PTA thus exposed must rank as one of the more impressive meteorological instruments!

2. Dines's early years

Between the ages of 9 and 14 Dines attended Woodcote House School, Windlesham where he displayed an outstanding grasp of mathematics. From there he progressed to Trinity College, Eastbourne but left after a year, at the age of 16, having come into conflict with his master who disapproved of his unusual style of mathematical expression. The next four years laid the foundation of his skills in engineering and drawing during an apprenticeship at the London and South Western Railway locomotive works at Battersea. In this period his interest in wind and its measurement was awakened having observed, from the footplate, that the smoke from locomotives seldom overtook them; from which he concluded that wind velocities greater than 25–30 m.p.h. were uncommon inland. This agreed with the view of his father (G. Dines) that currently reported wind speeds were often too high such that if they were correct then buildings could not have withstood them.

At the end of 1877 Dines started his studies at the University of Cambridge, reading mathematics. During his stay, the Tay Bridge disaster occurred on 28 December 1879, which again stimulated his interest in the pressure exerted by wind on engineered structures and provided the initial motivation which led to development, 10 years later, of the prototype PTA.

At this time the Robinson cup anemometer was widely used to register wind speed but there was disagreement amongst scientists of the day about its accuracy; Dines was convinced that it under-registered gusts and over-registered mean speed because of mechanical lag associated with the cup's momentum. As a focus for discussion on wind measurement the Royal Meteorological Society formed the Wind Force Committee in 1885 to investigate and report upon 'the best mode available for... a satisfactory solution of the entire question of wind force'. Dines later became a member of this Committee. In the mid-1880s Dines started experimental work on wind speeds registered by contemporary anemometers, and air pressure exerted on plates, using a whirling test-bed installed at

Hersham. It was on this installation that Dines tested his prototype PTA head which he demonstrated to the Committee on 18 December 1889. The PTA head was found to have a large tolerance of wind direction — up to 15° — before a decrease of recorded speed occurred, so the provision of a vane to keep the open tube facing into the wind was adequate to enable high accuracy of registration even with gusts and turbulent winds.

In 1891 the Committee organized an anemometer comparison which included (along with others) the Robinson, the Kew-pattern and the PTA, the instruments being mounted on the roof of a house, designed and built to Dines's own specifications, in Oxshott. Difficulties were encountered in finding a suitable height above the roof to avoid eddies caused by the house itself; finally a height of 18 ft was used. As a result of these comparisons the PTA was recommended to the Meteorological Council and in 1892 the first production PTA was made by the Munro company (now R.W. Munro Ltd). In 1896 further comparisons were made using anemometers exposed on the training ship HMS *Worcester* at Greenhithe and on Stone Ness lighthouse about half a mile distant on the north side of the River Thames. Interesting deductions about the exposure of anemometers were made from the observations, which suggested that the influence of low hills (175 ft high) a mile away and of trees a quarter of a mile away could be detected. These results and the Oxshott findings were instrumental in defining the standard practice of measuring winds at 10 m (33 ft) height over a flat plain without obstruction, which is recommended by the Meteorological Office today.

The pitot head is only part of the complete PTA installation and several other workers contributed to the development of the very practical and reliable instrument that it has been. Munro's contribution was to redesign the float tank and recorder. A new-shape float and taller tank were provided to cope with winds up to 120 m.p.h. but the experience of even higher gusts recorded on Mauritius required a longer float which could cope with winds up to 200 m.p.h. Subsequently a gust of 174 m.p.h. was recorded on Mauritius using the 'long-float' modification — Fig. 4 depicts the winds recorded during the passage of the tropical cyclone in which this gust occurred.

In the early 1900s Baxendell designed a wind-direction finder to complement the PTA head giving rise to the Dines–Baxendell anemograph which used a common head. Initially the Baxendell direction recorder was mounted directly below the wind vane, was noisy in action and needed a separate chart drum from the PTA. Dines's son (J.S. Dines) developed a twin helix and chain combination (see Fig. 5) allowing the recording of wind speed and direction on one chart. In 1918 J.H. James, the Meteorological Office's chief mechanic, demonstrated that long levers operated the twin pens more successfully; later modifications have included the use of polythene tubing, and felt-tip pens (see Fig. 6).

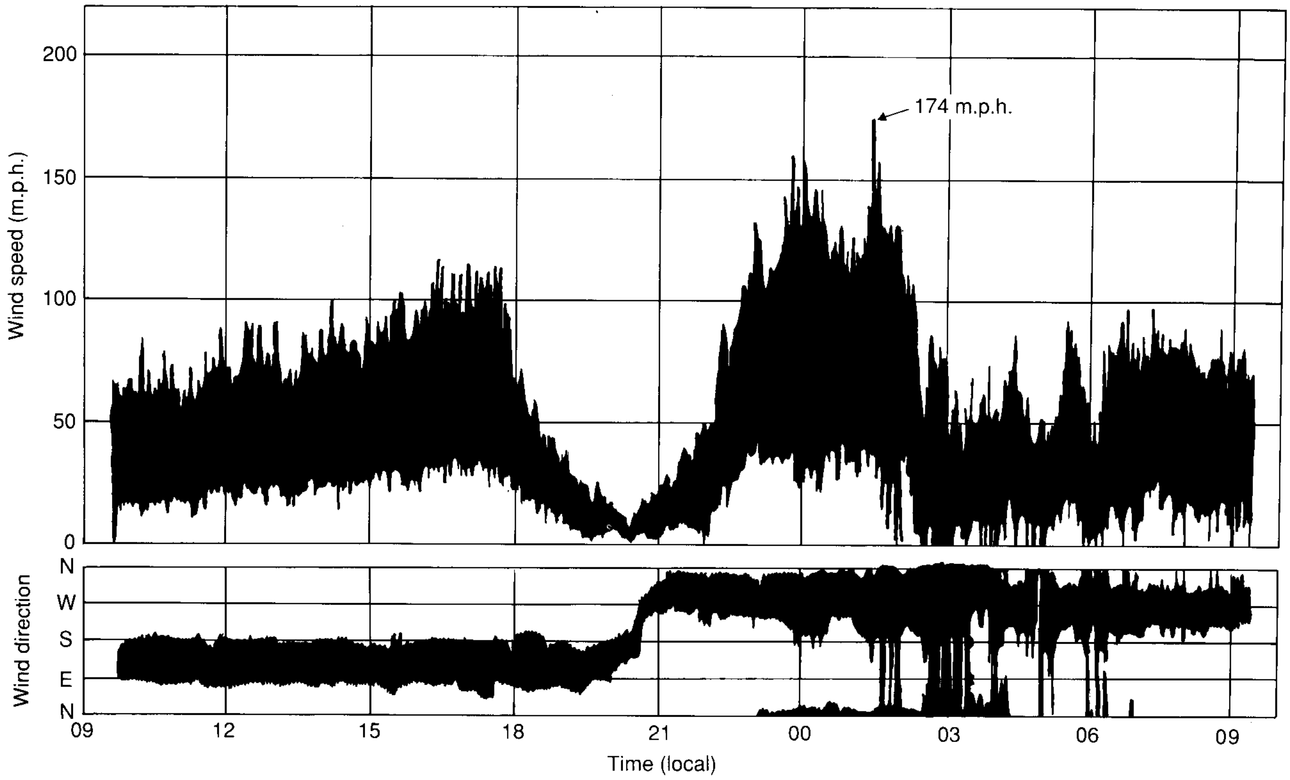
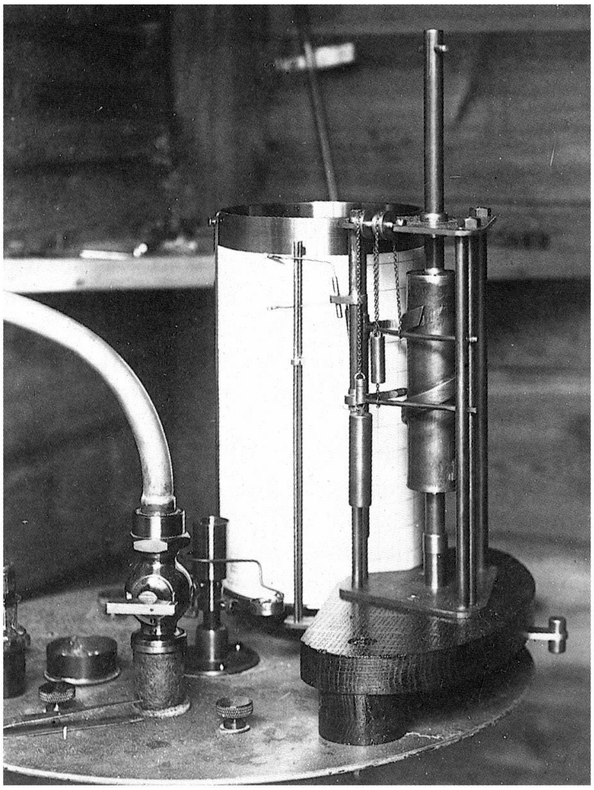
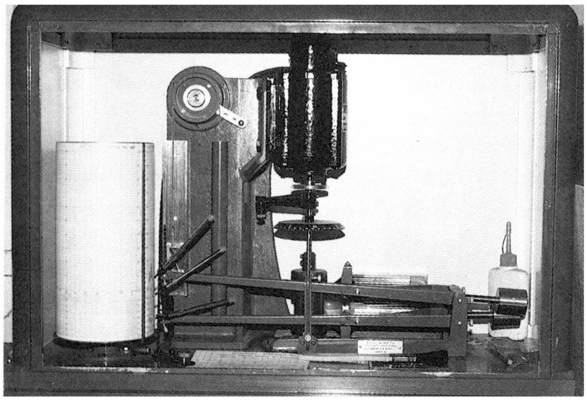


Figure 4. Pressure-tube anemometer record showing the passage of tropical cyclone Gervaise over the Mon Désert Alma Sugar Estate, Mauritius on 6/7 February 1975, during which the island's record gust of 174 m.p.h. was registered. (Reproduced from information supplied by Mr R.R. Vaghjee, Mauritius Meteorological Service.)



Photograph by courtsey of Mrs G. Poole

Figure 5. The 'chain system' for recording both wind speed and direction on one chart (*circa* 1910).



Photograph by courtesy of Mr J.S. Falconer, New Zealand Meteorological Service

Figure 6. The long-lever recording system with fine-line felt-tip pens attached.

In the 1930s some PTAs were adapted so that by electrical means their readings could be made available remotely (then known as Distant Reading Anemometers, DRAs) and this was useful particularly on airfields where the mast could now be sited some way from offices and hangars. The DRA was not popular because of the high ambient noise levels from the recorder unit's electric motors which operated continuously.

The PTA is not suited to use in cold climates because the head opening and suction holes can easily be blocked by snow, and the water in the tank could freeze, as was demonstrated by the one optimistically taken by Scott's Polar Research Expedition to Antarctica in 1910. However, in the 1940s a PTA was modified so that the exposed parts were heated electrically — requiring about 2 kW — thus enabling it to register winds up to 130 m.p.h. in temperatures down to −39° F.

3. Supply and use of the Dines PTA

In 1892 Munro began to manufacture 'speed only' instruments at a rate of five or six per year. By 1901 forty-three PTAs had been installed. Three were under test on Tower Bridge, with others equipping Kew, Holyhead, Scilly, and Southport Observatories. Exports listed by that time were: India 8, Japan 4, Mexico 3, Switzerland 2, Austria 2; also one each to Argentina, Egypt, The Netherlands, Nigeria, Norway, Spain, the US Weather Bureau and the Central Observatory, Paris. A further 21 sites had Dines PTAs installed by 1905, including Agram, Hungary; São Miguel in the Azores; Mauritius; Milan, Italy; three more in Japan; the University of Glasgow; and one on the Eiffel Tower in Paris.

Production and orders steadily increased with 54 PTAs being made during 1939, but World War II reduced this figure to 12 complete sets in 1940. With the Battle of Britain won, eventually by 1944, the 'war effort' saw Meteorological Office contracts for 165 PTAs being fulfilled at a steady rate of 8 per month.

Dines PTA production has tapered off since the instrument's 'heyday', a 25-year period, 1948–73, when export orders were being sent to Argentina, Australia, China, India, Mozambique, New Zealand and the United Arab Republic. Since the instrument does not need an electrical power supply to remain operative it was favoured in countries experiencing destructive hurricane-force winds; an order for 35 PTAs (equipped with 180 kn floats) destined for Cuba, occupied the factory over the period 1970–71. A recent peak demand saw over 40 new PTAs made and despatched during 1981–82 by Munro to various places including the Niger River Valley 7, Botswana 5, Jordan 5, Malaysia 4, and Fiji 1. In all, Munro PTAs have been despatched to 29 countries since 1982. The eight countries with the largest numbers of Munro PTAs still operating are listed in Table I. A list of stations offering researchers the possibility of a 60-year continuous record made with Munro PTAs is given in Table II.

In the United Kingdom there are only a few PTAs still continuously recording and in good repair. These are at East Malling, Fleetwood, South Shields, and at the Universities of Durham and Keele. The East Malling PTA produced an interesting record (as shown in Fig. 7) during the storm of 15/16 October 1987 at a time when there were widespread power cuts in south-east England (the break in the speed trace was caused by the pen running dry in a period of extreme gustiness; the station is not manned around the clock).

Table I. Munro's production and export figures over the past 50 years (1938–87) for Dines PTAs

Country	No. of PTAs now operating	Sets despatched directly by Munro since 1938	Sets including DRA conversions	DRAs now in service	Dines PTA first used
Australia	88	106	50	13	1927
Malaysia	32	24	3	–	1930
Sudan	23	17	–	–	1922
South Africa	18	62	37	18	1904
Syria	17	55	–	–	1959
Jordan	17*	11*	–	–	1955
Egypt	16	33	–	–	1899
Irish Republic	16	19	3	–	1924

* Uncertain figures.

Table II. Some stations where PTAs have recorded more or less continuously for over 60 years

Name and location		Duration of records	No. of years
Kew Observatory, London, United Kingdom		1896–1981	86
St. Mary's Observatory, Scilly Isles, United Kingdom		1896–1981	86
Pamplemousses, Mauritius	Royal Alfred Observatory Scientific and Industrial Institute	1903–1960 1961–present	86
Dover, United Kingdom		1907–1988	82
Fernley Observatory, Southport, United Kingdom		1896–1977	82
South Shields, United Kingdom		1909–present	81
Fleetwood, United Kingdom		1914–present	76
Coats Observatory, Paisley, United Kingdom		1914–present*	76
Den Helder, The Netherlands		1897–1972	76
Shoeburyness, United Kingdom		1902–1974	73
Anglesey, United Kingdom	Holyhead RAF Valley	1895–1952 1952–1963	69
Khartoum, Sudan		1922–present	68
Valentia Obervatory, Irish Republic		1924–present	66
One site, Yucatan State, Mexico		1925–present	65
Meteorological Office, Vacoas, Mauritius		1925–present	65
Central Institute for Meteorology and Geodynamics, Vienna, Austria		1911–1974	64
The Geophysical Observatory, Apia, Western Samoa		1927–present	63
Hobart, Tasmania		1927–present	63
Eskdalemuir Observatory, United Kingdom		1908–1967	60
Several stations, Malaysia		1930–present	60

* Last known operating Dines–Baxendell recorder.
Where records cease before the present time, the station has closed or the record been discontinued.

4. Other PTA designs

PTA designs remarkably similar to the original 'Dines' have been developed and marketed by Askania, Steffens–Hedde, and Fuess. During 1939–42 Fuess Universal instruments were installed at new bases in occupied Europe. In Belgium and Germany some Fuess PTAs are still in use today, and the Spanish Instituto Nacional de Meteorologica currently operates a network of 15 of these PTAs including one at the Base Aerea de Villanubla which has seen more or less continuous service since 1942.

5. Concluding remarks

Over the last century Dines PTAs have been found to provide robust and reliable service over long periods in many remote and sometimes hostile environments. In Zimbabwe, where a network of 13 instruments is maintained, recorders at Bulawayo and Harare still function well using their original tanks installed in 1936! Wherever it has operated, sensitivity combined with durability has been the hallmark of the 'Dines/Munro' PTA.

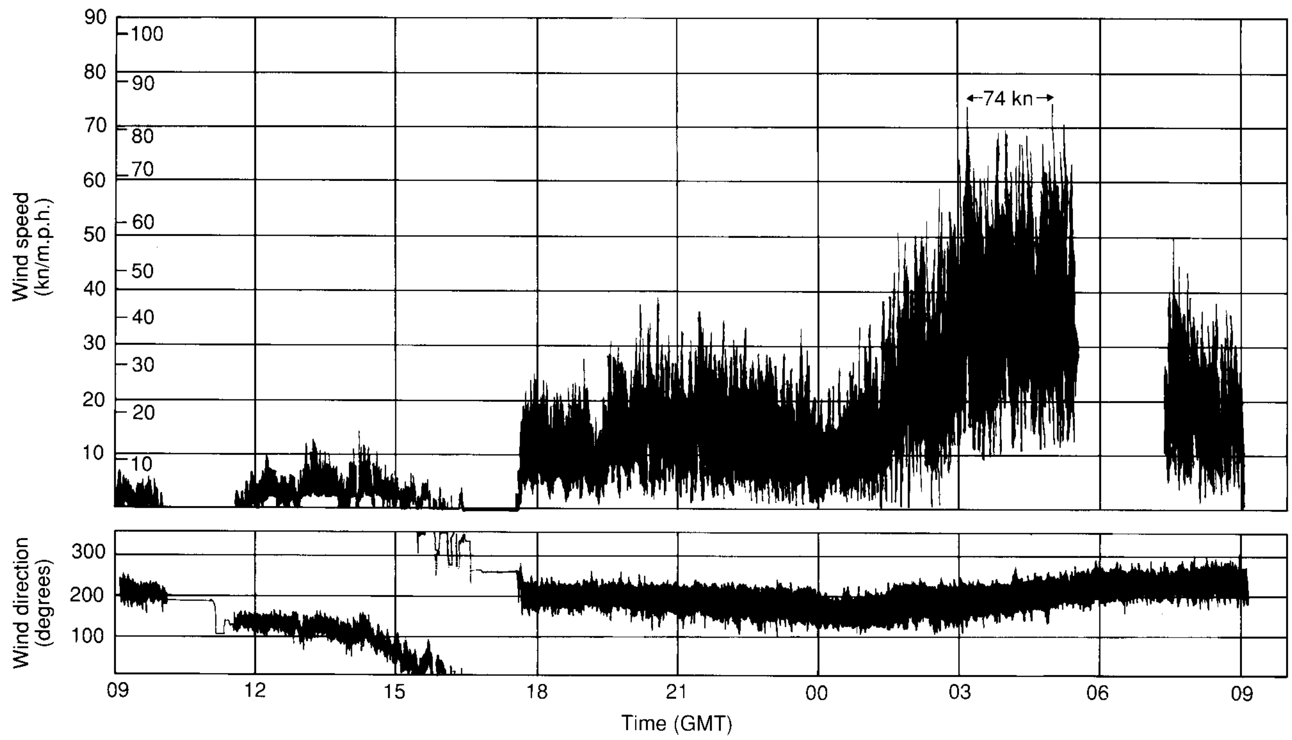


Figure 7. Pressure-tube anemograph record made at the Institute of Horticultural Research, East Malling, Kent during the 'great storm' of 15/16 October 1987 showing gusts of 74 kn at 0312 and 0501 GMT. (Reproduced from information supplied by the Institute.)

Acknowledgements

Thanks are extended to Mrs G. Poole, W.H. Dines's granddaughter, for the use of family documents to prepare this article, and to R.W. Munro Ltd, makers of the PTA, for access to their manufacturing and sales records. Thanks are also due to J.S. Falconer, New Zealand Meteorological Service and B. Bradshaw, Australian Bureau of Meteorology, for information regarding the operations of PTAs and to R.R. Vaghjee, Mauritius Meteorological Service, for supplying the anemogram of tropical cyclone Gervaise.

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Noctilucent clouds over western Europe during 1988

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Summary

Noctilucent cloud reports by voluntary and professional observers in the British Isles, Denmark, The Netherlands, Finland and Estonia suggest another year of high incidence of the phenomenon.

Table I summarizes the noctilucent cloud (NLC) reported to the Aurora Section of the British Astronomical Association (BAA) during 1988. The times (UT) are of reported sightings, not necessarily the duration of a display. 'Negative' nights (Table II) are based on the judgement of two or more experienced observers north of 54° N with clear or nearly clear sky conditions over the period of the night when NLC is likely to occur. Again, observers in British latitudes were forced to contend with bad weather and very poor skies in July, one of the worst summer months for years. Nevertheless, 38 positive sightings were made from the British Isles, Denmark and The Netherlands, 31 from Finland and Estonia.

Contributions were received from 35 voluntary observers and 9 meteorological stations in the British Isles, 5 observers in Denmark, 1 in Norway and 8 stations of the Royal Netherlands Meteorological Institute, together with a summary of the work of the excellent Finland–Estonia network. Full reports by the latter are published in the periodical *Ursa Minor* of the URSA Astronomical Association (Laivanvarustajankatu 3, SF-00140, Helsinki 14). The Canadian–USA observing network, co-ordinated at Edmonton by Mr Zalcik, is now well established but its results are not included here.

Over the last few years there has been a growing interest in NLC and mesospheric conditions with possible implications as to the state of the global environment. The intention of the BAA Aurora Section, an amateur organization with limited funding, is to provide a data bank of NLC distributions for professional workers and to maintain a continuity of observations. However, it will be apparent, from previous reports, that the 'western Europe' network is far from complete — several northern countries do not participate. The author would be interested in making contact with individuals and agencies in such lands, as it would be desirable to spread the observing network as far as possible to obtain a clearer picture of the incidence and movements of this intriguing phenomenon.

Details of individual displays and instructions for the systematic observation of NLC may be obtained from the author. All data are ultimately transferred to the Balfour Stewart Archive in the University of Aberdeen.

Thanks are due to all amateur and professional observers for their work, and to Dr M. Gadsden (Aberdeen), Mr R.J. Livesey (Director, BAA Aurora Section), Mr N. Bone (Director, Junior Astronomical Society Aurora Section), Dr B. Zwart (The Netherlands), Mr V. Mäkelä (Finland), Mr. J.Ø. Olesen (Denmark) and his colleague Mr H. Andersen whose superb photographs are regularly shown at astronomical meetings and exhibitions.

Table I. Displays of noctilucent clouds over western Europe during 1988

Date — night of	Times UT	Notes
14/15 May	2203–2240	Faint veil and bands at Milngavie near Glasgow, max. elev. 22° at 2203.
16/17	2200–0200	Faint bands at Machrihanish.
20/21	0015–0215	Suspect faint veil, bands visible only in binoculars at Morpeth. NLC at Helsinki.
23/24		Small NLC at Espoo (Finland).
25/26		Suspect NLC at Pori (Finland).
26/27		NLC to zenith at Helsinki. NLC at Tallinn.
4/5 June	2215–0045	Weak NLC to elev. 7° in NE at Milngavie.
6/7		NLC at Tallinn.
7/8	2245–0050	Billows and twisted bands to elev. 45° at Caithness, bands and whirls at Dundee, St. Andrews, Milngavie. Faint horizontal bands and complex structures photographed at Kilbirnie, Ayr, by Mr McEwan.
11/12	2110–0220	Veil, bands and billows as far south as Cambridge. NLC over ¾ sky at Caithness at 2245. Max. elev. 15° at I. of Man. Bands at Rønne. NLC at Tallinn. Bands elev. 10° at Nieuw Loosdrecht, Bussum and Rotterdam.
12/13	2130–2200	NLC at Nieuw Loosdrecht. Faint veil at Tallinn.
14/15	0100	Low bands photographed at I. of Man.
15/16	0030–0140	Faint veil, distorted bands and whirls in patchy tropospheric cloud at Kilbirnie.
16/17	2220–2305	All-sky NLC at Espoo and Jämsä (Finland). Bright billows to elev. 10° at Vildbjerg (Denmark). NLC at Tallinn.
17/18 June	2135–0215	Veil, bands and billows at Espoo, Pori, Jämsä, Helsinki. Faint veil and radiating bands to elev. 33°, horizontally widespread, at Kilbirnie. NLC at Tallinn.
18/19	2337–0200	NLC in trop. cloud gaps at Alness and Edinburgh. Bands, billows and whirls to max. elev. 28° at Morpeth and Castleford.
19/20		Faint bands and whirls, Co. Clare. Faint band at Espoo.
20/21	2145	Suspect NLC at Helsinki.
21/22	2151–0100	NLC over ⅛ sky, Orkney and N. Scotland. Veil, bands and billows in central Scotland and Netherlands. NLC in trop. cloud at Preston. Bright NLC at Espoo and Tallinn.
22/23	2120–0130	Bright display, all forms, into S. sky at Alness 2350. Max. elev. 60° at I. of Man, 25° at Cambridge; as far S. as Cardiff. Veil and bands at Rønne. Billows to elev. 15° at Rhoon, Rotterdam.
23/24	2210–0130	Faint horizontal bands, some billows, elev. 8° at Morpeth. Veil and bands at I. of Man. Bright NLC in trop. cloud in central Scotland. Veil, bands and billows, low, Co. Clare. NLC at Rhoon
24/25	2335–0118	Diffuse bands in misty sky at Milngavie. Suspect NLC in trop. cloud at Edinburgh. Veil and bands to elev. 23° at Vildbjerg.
27/28	2045–0230	Bright bands, billows, whirls in W. Scotland and I. of Man where elev. 45° at 0200. NLC extensive at Vihti, Jämsä. Bands to zenith at Helsinki. Veil and bands Jutland, Rønne, Deventer. NLC at Tallinn.

Date — night of	Times UT	Notes
28/29 June		Faint bands at Jämsä
29/30	2238–0130	Small NLC patch in trop. cloud at Alness. Faint display, all forms at Morpeth. Billows and bands in trop. cloud in central Scotland. Bands low in sky at Leeds.
1/2 July		NLC at Tallinn.
2/3	2130–0300	Extensive and bright display, all forms, seen as far south as London and Guildford. Photographed at Kilbirnie. NLC at Jutland: bright bands and billows to elev. 25° photographed at Vildbjerg. Large billows elev. 15° at Appingedam, Netherlands.
3/4	2120–0313	Moderately bright display, all forms, in Scotland and as far south as Leeds where faint veil suspected in zenith. Photographed in Skye and Kinloss where max. elev. 56°. Bright bands and billows photographed at Jutland. Billows at Appingedam. NLC throughout Finland and at Tallinn.
4/5		All-sky NLC in Finland, all forms. NLC at Tallinn.
5/6		NLC at Tallinn.
6/7	2125–0305	Veil, patches, bands and billows in central Scotland. Patches to elev. 10° in Essex. Small faint bands at Vildbjerg. Faint NLC at Jämsä.
7/8	2100–0100	Fairly bright, veil, bands and some billows in E. Scotland. Faint NLC elev. 20° at Todmorden. Bright bands and billows photographed at Jutland and Funen. NLC at Tallinn.
8/9	2145–0200	Bands and billows to elev. 30° at Alness. Bands, billows and whirls at Dundee. Small patches I. of Man. Veil, bands and billows in trop. cloud at Vildbjerg, Turku and Espoo. NLC at Tallinn.
9/10	0235–0250	Billows in NE, elev. 15° at Northolt.
10/11		Veil, bands and billows at Vammala (Finland).
11/12	2330–0125	Veil, bands and billows to elev. 25° at Alness. Patch and bands at Dundee. Moderately bright, all forms at Turku, Helsinki, Jämsä. NLC at Jutland and Tallinn.
12/13	2115–0245	Bands and billows in trop. cloud at Wick and Shetland. NLC overhead and covering ½ sky in Orkney. NLC to elev. 19°, all forms at Jutland. All-sky NLC, all forms at Espoo, Jämsä, Helsinki and Tallinn.
13/14 July	2345	Band in trop. cloud gap at Sumburgh.
15/16	0200	Veil, bands and billows at Dundee.
16/17	2055–0000	NLC in trop. cloud gap NNW, Orkney. Bright bands and billows photographed at Alrö and Vildbjerg, max. elev. 28°.
20/21	2350–0005	2 bands in trop. cloud gap at Alness.
21/22		A few bands at Espoo, Raake and Vantaa. NLC at Tallinn.
22/23	2310–2320	Thin band in NW elev. 4° at Sumburgh. Faint NLC in poor sky at Turku.
24/25	2315–0100	Bright bands and billows in N. Scotland, elev. 45° in Shetland.
25/26		NLC to elev. 10° at Turku.
26/27	2305–0305	Veil, bands and whirls in N. Scotland. NLC in trop. cloud at Edinburgh. Moderately bright veil and bands up to elev. 8° at London.
27/28	0245	Bands in trop. cloud gaps at Edinburgh. Brilliant and multicoloured 'NLC' observed at Tallinn and throughout Finland, believed to have been induced by Soviet rocket exhaust. Photographs are in the URSA journal *Tähdet Ja Avaruus*, **5/88**, 172–173.
28/29	0215	Small bands and veil NNE at Dundee.
30/31		Moderately bright veil, bands and billows at Turku, Liminka and Siuntio. NLC at Tallinn.
1/2 Aug		NLC at Tallinn.
3/4	0200–0315	Faint bands and billows to elev. 10° at Morpeth. Billows above low trop. cloud at Wallsend.
4/5		Suspect faint NLC at Helsinki. NLC at Tallinn.
5/6	2050–0328	NLC patch in trop. cloud gaps at Caithness. Very faint bands at elev. 12° at Morpeth. NLC patch photographed at Frimley, Surrey at 2050.
6/7	0000	Suspect NLC in north at Kirkwall.
7/8		Veil, bands and billows at Raake (Finland). NLC all forms to elev. 60° at Kemi.
8/9	2330–0000	Moderately bright bands and billows to elev. 20° at Kustavi. Billows at Bergen. NLC at Tallinn.

Table II. Negative nights (British Isles) north of latitude 54° N

May 5/6, 6/7, 15/16, 17/18, 18/19, 19/20, 21/22, 25/26, 27/28, 28/29, 30/31; June 3/4, 5/6, 9/10, 10/11, 13/14; July 25/26, 29/30; Aug 1/2, 7/8, 9/10, 10/11, 12/13, 14/15, 16/17.

551.5:38:65

Commercial aspects of the application of meteorology*

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Summary

The wide and developing role of meteorological services to specific users is reviewed and the need emphasized to market such services to both public and private sectors. Providers of such services are encouraged to interpret meteorological advice into industry-specific parameters so as to put the interpretation of the effects of the weather on a customer or business on to an objective rather than a subjective basis. This implies the development of close customer–contractor relationships.

1. Introduction

National Meteorological Services (NMSs) meet the needs of their countries in various ways. First and foremost they provide the primary functions of making or having observations made to the necessary standard for all meteorological purposes, secondly they provide basic weather analyses and prognoses, and thirdly they collect and validate all available meteorological data to create meteorological data archives. Thereafter NMSs differ in their modes of operation. In some countries all secondary services using the basic material of observations, analyses, prognoses and data archives are provided by, and only by, the NMS. In other countries all or most of this secondary service provision to users is carried out by independent or quasi-independent organizations for their own, usually profit-making, motives. Between these two extremes there are mixed situations, with the NMS and the independent meteorological organizations either competing directly or complementing each other in the services that they provide. In at least one World Meteorological Organization (WMO) Member State (not the United Kingdom) the NMS has indicated that it is being transformed into an independent institution outside the control of its government finance. Such a service will have to sell services sufficiently to raise all the running costs of the NMS including research and development. In a number of other countries the NMS is having to make choices between increasing revenue for services and reducing such activities as research and development.

In whichever situation exists it is vitally important that there should be sufficient funding for the NMS to provide the primary services mentioned above. This need is usually recognized by governments, and an important role of WMO is to help to ensure that governments continue to take that view. However, there has also to be sufficient funding for the provision of the secondary services to end users. Where such services are supplied by commercial organizations then the need to market and sell such services with a realistic pricing structure will be well understood. A commercial organization doing otherwise would not continue in existence. Where, however, services are mainly or entirely supplied by the NMS then, typically, an appreciation of the need to have sensible and defensible pricing structures is less likely. Similarly, the need to market or advertise services may not be understood.

2. Application of meteorology

In recent years there have been developments in the application of meteorology to many human activities. Meteorology has been perceived as being capable of providing input to day-to-day operations such as transport by sea, air or land, to energy generation and acquisition, to water supply, to agriculture, and to many manufacturing and construction projects. Meteorological advice can be used in the planning or design stages of the same operations. Meteorology is thus entering (or has already entered in many cases) previously unforeseen applications by industrial, commercial and professional organizations. These organizations may be managed either nationally or regionally by the State or can be private sector firms varying in size from multinational companies to one-man businesses.

This widening of the application of meteorological services has been occurring at a time when governments are looking more and more at their own operating costs. Decisions at all levels of government are increasingly having to be made on cost–benefit grounds. Yet this is at a time when the techniques of management have become sufficiently sophisticated so that the efficiency and effectiveness of industry, commerce and the professions can be increased by the input of the appropriate meteorological information. This somewhat paradoxical situation is heightened by the imprecise nature of meteorology as a science, particularly in the field of

* This article is based on the author's contribution to the World Meteorological Organization report, WMO-TD No.281, on 'Climate applications: on user requirements and need for development' presented to the tenth session of the Commission for Climatology, Lisbon, April 1989.

forecasting, but also in the marked variabilities that can occur in weather parameters over short distances and over small time-scales. The science of meteorology is still developing at a pace often dictated by advances in technology applied to observing systems, communications and computing. The uncertainties in weather analyses, even with the most advanced observing systems available, to say nothing about uncertainties inherent in forecasting, make it difficult to convince the lay person that benefits can accrue by means of the careful application of such an imperfect tool. This problem of persuasion is enhanced by the increasing complexity of modern-day life in developed countries and by the increasing perception by meteorologists of the many and diverse ways in which their science can be applied. In developing countries, problems are also heightened but here, more often, it is because of the greater limitations of the basic database and the difficult forecasting problems in these often tropical or subtropical areas. Countries in such areas are often those in greatest need of meteorological advice and services and yet the understanding by the potential user of what may be achievable can be even less than in more developed countries with a longer history of the systematic application of meteorology to commercial and industrial problems.

3. Educating users

The above summary indicates that there is a process of education to be undertaken. It is also common experience that it is difficult to persuade lay persons to understand and use meteorological advice provided to them in terms with which they are not familiar. Therefore, it follows that meteorologists have to be able to understand the problems of potential users of weather services and have to be able to present information in terms related to the needs of the end user. There is nothing new in this concept. For example, aviation forecasters do not normally provide airline operators with detailed forecasts of wind shear and temperature lapse rate, rather they provide forecasts of the extent and severity of clear air turbulence. In entering into discussions regarding weather services, whether to organizations in the public or private sectors of national economics, the meteorologist must extend this principle. Services must be made specific as far as possible. Agriculturists do not want to know what the temperature and humidity have been over the past few days or what they are to be over the next few days, but they do want to know whether or not they should be spraying their crops for disease or pest control purposes.

4. Financial aspects

The level of services capable of being supplied by an NMS depends upon the resources available and this, as already noted, can be dependent upon the funding of the NMS. Where services are being supplied to national or state concerns, such as those engaged in power supply and generation or to transport services, then it is important that the benefits of the meteorological services provided be recognized either by transfer of funds from the user to the NMS or, more simply, in government funding to the NMS. Such arrangements necessitate an appreciation of the cost-accounted benefits of the meteorological advice to the user and, thus, to the national economy. When private sector organizations are taking meteorological advice then the discipline imposed by the need to operate with a trading profit provides a regulator of any payment made to the NMS. In the past many NMSs, particularly in the more industrialized and developed countries, have supplied meteorological advice and information to private sector organizations at charges well below the cost of providing the service if not at zero or minimal cost. In some countries legislation does not permit the NMS to charge customers or limits the charges that can be made. Increasing costs of running NMSs and greater demand upon government funds are resulting in such subsidies of private sector enterprises being reduced and there are increasing pressures upon NMSs to recover revenue for such work.

5. Communication

A technological constraint upon services provided by meteorologists whether of the NMS or from the private sector is the problem of communication with the end users. Many meteorological services are only of value if they can be made available to the end users on time-scales appropriate to their operations. When providing services to a small number of customers then this is not usually a problem — telephone or telex messages, for example, can be sufficiently effective and speedy. When providing services to, say, many thousands of farmers then effective, efficient and rapid message-dissemination is required. Here, again, cost can enter the equation and labour-intensive distribution methods may not be cost-effective.

6. User requirements

User requirements can be categorized in various general ways as follows:

Design.
Planning.
Operations.
Post mortem.

The types of user requirement will now be considered under these four general headings.

6.1 Design

The potential user of meteorological services for design can be concerned with, for example, engineering structures, the formulation of a service or the development of an operational system.

At the design stage of a structure or building there will be a need at an early stage to define criteria to ensure that the structure is capable of withstanding an acceptable range of meteorological conditions and that the probability of failure is less than some specified value. In some cases the designer will wish to ensure that the structure is able to withstand the worst possible combination of conditions. This might be, for example, in the case of an earth dam where overtopping could be catastrophic. The spillway in such a situation has to be able to withstand the probable maximum flood. In other cases it will be acceptable to design with a finite (although small) probability of failure. Similarly, when designing a system or a service then the probability of interruption or failure has to be at an acceptably low level. An example might be a land transport system in which there is a choice of vehicles. The extra cost involved in purchasing vehicles capable of operating under very adverse weather conditions might or might not be justified by the frequency with which those conditions occur. Similar considerations can enter into the design of structures. For example, the extra cost of putting wind shields on a bridge so that vehicles can cross safely when winds exceed some given speed might, or might not, be justified depending upon the frequency with which such winds occur and the penalties incurred in not being able to use the bridge in those extreme conditions.

When working with designers the meteorologists have to be aware of the characteristics of the weather sensitivities involved. A structure may react to gust speeds of a specific duration, it may be prone to loading by snow, it may have to withstand penetration of rain, it may have to be used under certain extreme conditions of temperature or sunshine. A transport system may cease to operate during spells when there is significant visibility reduction due to blowing dust or fog. The design of such systems will depend upon how often these conditions occur, what the cost is of providing equipment to clear the snow, what are the cost penalties of over-design etc.

A particularly important aspect of the advice that can be given by meteorologists to designers is in the understanding of the meteorological data, their shortcomings and, particularly, their representativeness. Weather observing networks very rarely provide all the data that might be required for a particular application. So meteorologists must be able to decide and advise upon what data can or should be used for a particular application and how these data should be interpreted. Many designers, even those of long and wide experience, do not understand sufficiently the effects on meteorological elements, particularly on extremes, of large-scale topography, local topography or seasonality. Accordingly the meteorologists must take steps to ensure that their expertise and their roles during design phases of projects are well understood.

6.2 Planning

Planning can be in the sense of a one-off problem such as a major construction project or, perhaps, a repetitive operation likely to occur during a definable period of time. The kinds of questions that planners have to answer usually relate to the cost and resources required to undertake a task. In the case of a major structure the questions will concern the various phases of construction. At certain times of the year what will be the probability of being able to complete certain operations? What is the probability of delays due to the ground being too wet, or too frozen? What is the possibility of getting weather windows for particularly critical operations such as the towing of structures out to oil rigs? Obviously, some design questions overlap or are very similar to those used for planning purposes while other questions are unique either to the design or to the planning phase. As for design, the meteorologist has to be prepared to make the user aware of the dangers of the uninformed or incorrect use of meteorological data.

6.3 Operations

Here the role of the meteorologist is better understood by the user. The interaction of the weather forecaster with aviation and marine interests has developed sufficiently over many years and the benefits of meteorological advice are quantifiable and in some cases quantified. In the case of aviation it is reasonably straightforward to calculate the effects on fuel usage of not taking a weather forecast and, indeed, the effects of taking weather forecast services with known root-mean-square errors in wind vectors can be calculated. However, there are many activities of a weather-sensitive nature for which professional meteorological advice is not universally used. A list, by no means exhaustive, could include the following as particularly weather-sensitive operations in addition to the normal aviation and general marine forecasting services.

The weather routeing of ships either to avoid damage or to minimize time of passage. Here the user will require not only forecasts of wind, sea state and visibility but also forecasts of the effects of that weather in terms of damage to the ship and its speed. However, to be able to benefit by the advice it must be sufficiently timely to allow action to be taken to avoid damage or loss of speed.

Management of energy supply systems requires weather forecast information for short periods of an hour or so, longer-period forecasts of a day or days and, ideally, even longer-period forecasts of weeks or months. Short-period forecasts of energy requirements are needed in order to decide whether a power station can be shut down or whether others should be started up, whether energy will have to be bought from a neighbouring country, etc. Forecasts of energy requirements for the next two or three days are used for decisions concerning maintenance of power stations. Still longer-period forecasts can be used for technical planning or the movement and purchase of fuel.

Manufacturers and retailers wish to be able to predict demand for their products, customer behaviour, and effects of weather on their products during storage or transport. Correlations of various lag times exist between weather and sales of such diverse products as ice-cream, soft drinks, soup, clothing, motor cars, bottled gas, etc. The weather can greatly influence customer behaviour and determine whether or not the customers will visit the nearest shop or travel some distance to a shopping centre or a supermarket. Food quality can deteriorate rapidly in adverse weather conditions in a manner which, of course, will vary from food to food.

Firms concerned with building and construction require forecasts specific to certain operations. The weather can influence significantly the ability to concrete, to use mechanical diggers, to spread bitumen on roads, to operate tall cranes, etc.

In agriculture, current and forecast meteorological information can be used to help farmers decide what should be done on a particular day. For example, if the ground is not fit for ploughing now, then when will it be fit? Is there a need to irrigate and, if so, by how much? Are conditions right for the propagation of disease and, if so, when will be a suitable time to treat for the disease or pest? At what stage is the growth of certain plants? What yield is going to be obtained from a certain crop? Will there be a need to heat glasshouses tonight? Is produce going to deteriorate in store? Is any action needed to ensure, say, that seed potatoes in store will reach a satisfactory state of development for planting in the spring?

The increasing complexity of modern life, the greater sophistication of agriculture and the tighter profit margins under which industry and commerce have to operate all lead to the need for better and more informed decisions to be made. Good and informed meteorologically based advice may make the difference between success and failure or profit and loss. Indeed, in many operational activities the sensitivity of the work to meteorological advice may be more important than the sensitivity to the weather itself. Before trying to persuade a potential user to take a meteorological service some consideration should be given to the ability of the user to respond by taking remedial or corrective action.

6.4 Post mortem

There is often a need to know what the weather was in some historical sense. This can be for the monitoring of certain operations, for example to determine whether or not a contractor on a construction project is keeping up to schedule or whether delays occurring are avoidable or not (see Fig. 1). There may be questions of assessment of design criteria. For example, is the amount of fuel being used to heat a building in accordance with that expected given the size of the heating plant, the aspect and design of the building? Specific knowledge regarding the weather can be required to answer questions on a wide range of legal and insurance matters (see Fig. 2). Many weather consultants in the USA refer to themselves as forensic meteorologists and, while this term is not used in many other countries, it does indicate that meteorologists can have a role to play in helping to reconstruct events that have occurred.

7. Provision of services

The ways in which meteorological services, whether of data, data analyses, forecasts or other advice, are disseminated depend upon the customers, their needs, the technology available at their disposal and the technology available to the providers of the meteorological service.

In the simplest case, when reports are prepared providing some specific advice, such as a design or feasibility study requiring meteorological input, the use of hard copy is the obvious and, perhaps, only sensible choice. In many other cases, depending upon the nature of the service, the interaction of the NMS with other meteorological organizations, and the degree of operational urgency to which the service relates, there can be good reason to use some automated or semi-automated methods of dissemination and production.

Under the auspices of WMO, international meteorological telecommunications are relatively advanced technologically and NMSs generally, whether in developed or developing countries, are usually fairly near the forefront of data handling and processing. Meteorologists thus tend to think of automated data transmissions, computer-to-computer links and of the transfer of data in machinable form whether off-line or on-line. There is, however, less acceptance of such techniques among many users, and traditional methods of communication by letter, word of mouth direct or on the telephone are likely to dominate for some meteorological services to many of the customers and for many meteorological services to certain customers.

In addition to methods of information dissemination there are also considerations of the form of the information to be provided. Do the customers wish to be presented with some general or specific meteorological advice or do they want to have such advice translated into terms relevant to these needs? Do farmers wish to know what the weather conditions have been for the past few days or will be for the next in terms of meteorological parameters such as temperature, rainfall, relative humidity, sunshine, etc. or do they really want to know about the quality of their grass or the necessity to spray their potatoes for blight? Does a power-generating authority require a forecast of temperature and wind for the next few days or does it really wish to know how much power will be needed and whether or not a power station can be shut down for maintenance?

Methods of data provision are likely to be determined by what the customer or user can accept or wishes to accept. However, it must be noted that users are very often concerned with costs, and a labour-intensive method of information dissemination may be very

DAILY WEATHER SUMMARY — PAGE 1 — TEMPERATURE AND HUMIDITY

GLASGOW (ABBOTSINCH AIRPORT) — FEBRUARY 1989

STATION NAT GRID REF = 2480E 6667N HEIGHT = 5M AMSL

DATE	NUMBER OF HOURS IN PERIOD 0700-1700 GMT WITH TEMPERATURE LESS THAN (DEG C) 0	1	2	3	4	5	8	15	RELATIVE HUMIDITY OVER 90%
WED 01	0	0	0	0	0	0	5	10	0
THU 02	0	0	0	0	0	0	0	10	0
FRI 03	0	0	0	0	0	0	0	10	5
SAT 04	0	0	0	0	0	0	8	10	1
SUN 05	0	0	0	0	0	2	8	10	0
MON 06	0	0	0	0	0	0	0	10	2
TUE 07	0	0	0	0	0	0	2	10	0
WED 08	0	0	1	2	2	3	4	10	2
THU 09	0	0	0	0	0	0	3	10	0
FRI 10	0	0	2	2	2	3	8	10	3
SAT 11	0	0	0	0	0	0	10	10	2
SUN 12	0	0	0	1	4	7	10	10	1
MON 13	0	0	0	0	0	0	5	10	2
TUE 14	0	0	0	0	0	1	10	10	2
WED 15	0	0	0	0	1	5	10	10	0
THU 16	2	2	3	5	7	9	10	10	0
FRI 17	0	0	1	4	4	6	10	10	0
SAT 18	0	0	0	0	0	0	3	10	0
SUN 19	0	0	1	2	3	4	10	10	1
MON 20	0	0	0	1	5	9	10	10	0
TUE 21	0	0	0	1	2	3	10	10	1
WED 22	0	0	0	0	0	7	10	10	0
THU 23	0	0	1	2	8	10	10	10	0
FRI 24	0	0	0	2	3	5	10	10	0
SAT 25	0	7	10	10	10	10	10	10	10
SUN 26	1	2	4	4	7	10	10	10	0
MON 27	0	0	0	0	1	5	10	10	0
TUE 28	0	0	0	0	0	3	10	10	0
MON-FRI TOTAL	2	2	8	19	35	69	137	200	17
LONG TERM AVERAGE	16	22	37	57	86	110	173	200	49
MON-SAT TOTAL	2	9	18	29	45	79	168	240	30
LONG TERM AVERAGE	19	26	44	69	103	132	208	240	59

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Figure 1. A page from *Metbuild*, the Meteorological Office's monthly downtime summary used by the building and construction industry.

BASICPROOF
DAILY WEATHER SUMMARY

GLASGOW (ABBOTSINCH) **FEBRUARY 1989**

STATION NAT.GRID REF. 2480E 6667N 5 m above Mean Sea Level

	AIR TEMPERATURE High (deg C)	Low	RAINFALL (mm) 00-11 hours	12-23 hours	MAX. WIND dir	kts	hour	MAX. GUST kts	hour
Wed 01#	8.8	6.0	trace	trace	SW	17*	1600		
Thu 02	9.7	5.6	trace	16.4	SW	22*	1400	34	1400
Fri 03	10.7	9.2	4.4	2.6	SW	25*	2300	41	1500
Sat 04	10.2	3.9	8.6	8.0	W	25	2100	41	1600
Sun 05	10.7	1.9	2.2	3.4	W	24	0000	36	0100
Mon 06	11.4	10.6	1.0	4.8	SW	30*	1800	50	1800
Tue 07	11.0	6.6	2.2	trace	SW	30*	0400	46	0400
Wed 08	9.3	1.6	trace	trace	SE	11*	2300		
Thu 09	11.0	4.8	0.0	1.6	SE	15*	1400		
Fri 10	8.3	0.1	0.8	0.0	W	11	1600		
Sat 11	7.7	-0.8	5.0	9.8	S	26	1300	42	1100
Sun 12	5.4	0.8	4.0	1.8	W	24	1200	39	1200
Mon 13	9.9	3.8	8.2	4.0	W	37*	2000	64	1600
Tue 14	9.1	2.9	1.2	5.2	SW	25*	2300	39*	2300
Wed 15#	9.4	0.9	13.6	1.0	SW	30	0200	46	1600
Thu 16#	5.0	-0.8	0.0	0.0	W	17	0000		
Fri 17#	8.1	0.6	trace	4.0	S	19	2300		
Sat 18	10.8	6.2	0.2	3.8	S	25	1500	38	1600
Sun 19	7.0	1.0	5.0	0.4	SW	30	0500	55	0400
Mon 20#	5.9	1.3	1.0	5.0	SW	21	1100	35*	2300
Tue 21	7.7	2.1	6.8	3.4	S	21	2300	35	2100
Wed 22#	7.0	1.0	1.2	trace	SW	28	1500	42	2300
Thu 23#	4.1	1.8	trace	trace	SW	26*	1000	38*	0400
Fri 24	7.0	1.8	trace	0.8	S	15	0200		
Sat 25#	2.3	-0.4	0.8	trace	SW	8*	2100		
Sun 26	4.5	-2.9	0.0	0.0	NE	8	1300		
Mon 27#	6.1	-3.0	0.2	0.4	SW	13	1500		
Tue 28	7.3	2.5	1.0	0.2	SW	19	1300		

trace means <0.05mm; # missing hours; * value reached more than once.

WEATHER DIARY	DATES
STRONG WIND > 21 kts	2 3 4 5 6 7 11 12 13 14 15 18 19 20 21
RAINFALL >4mm in hour	4 15
THUNDERSTORM	
HAIL	5 15 19 20 23 25 26 27 28
SNOW	12 15 16 17 19 20 21 22 23 24 25 27
FROST < 0 deg C	11 16 25 26 27

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Figure 2. A page from *Basicproof*, a simple diary of the weather which may have a bearing on insurance claims.

expensive both in terms of costs for the meteorological service and for the customer. The use of Information Technology (IT) and the resultant long-term reduction in costs might well mean that automation can be introduced into both product generation and dissemination. IT can allow the often expensive human costs to be reduced, it can allow more services to be produced at little or no extra cost to the provider of services and it can free human effort for work where human input and judgement might be used to advantage.

In some countries, methods of service provision begin with the dissemination of basic meteorological data and forecasts from the NMS to other organizations which act as the interface with the user. These other organizations may simply pass on the NMS products as received or they may provide some added value. The ways in which the NMS is funded for such basic data provision are clearly a matter of political judgement in the country concerned. Where this use of other organizations is the way of working then the NMS, in order to keep its own costs down, will probably wish to provide either broadcast output to the separate users or, and perhaps additionally, may wish to provide access in an interactive fashion for the other organizations into the NMS databases of current data, historical data and predictive data.

8. Conclusions

From the above it can be seen that there are very few activities upon which meteorology does not have a bearing or the execution of which cannot benefit in some way by meteorological advice. What is apparent is that the variety of meteorological input is very great and unlikely to be fully understood, and often not understood at all, by non-meteorologists. This problem can be tackled in two ways. Either potential users can be educated in the application of meteorology to their problems or meteorologists can be educated to comprehend the requirements of users and their principal problems. In some cases the first approach is appropriate, for example aviators and mariners have a reasonably good appreciation of the benefits of taking meteorological advice and the penalties of not doing so. Even here there are probably some instances where operations could be undertaken more efficiently or more effectively given the application of appropriately tailored meteorological advice. In other cases, for example in the field of civil engineering, there can be considerable meteorological input particularly at the design stages of projects but often in a somewhat mechanistic way by reference to handbooks or standard formulae. There is a tendency for civil engineers working upon the design of structures to use standard meteorological input for such factors as wind loading, temperature limits, rainfall penetration, etc. In many cases this might be the best advice but there must be others where more specific advice would be of benefit. In many other walks of life the potential users have insufficient scientific background or understanding to know what informed meteorological advice could do for them or their work.

In many areas of trade or commerce the 'weather' is simply accepted as another unknown, another variable against which some money may be put as a contingency or against which there must be some slack in the system. This can be the case particularly, for example, with sales of goods and customer behaviour. Better knowledge of the weather relationships in these cases can help manufacturers, suppliers and retailers to plan their production, their distribution of goods, their tactical advertising and their sales strategy to good advantage.

In addition to the concept of weather sensitivity, some thought must also be given to the sensitivity of the customers or users to weather services. Indeed, from the point of view of the paying customers the critical question may well not be whether or not they lose money because of the weather but can they save money by using meteorological advice. The meteorologist has to give attention to this important issue and consider on a market-by-market or customer-by-customer basis just how an appropriate service can be provided to meet a specific need.

551.553.11:551.571.31:551.553.6(495)

Analysis of absolute humidity by wind speed and direction during land- and sea-breeze days at the National Observatory of Athens, Greece

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Summary

The technique of the rectangular wind-frequency isopleth diagram is used to examine the dependence of ambient air-water content on wind speed and direction on land- and sea-breeze days. The variation of absolute humidity in each direction at a monitoring site, as the wind speed varies, is shown pictorially. The absolute humidity is shown to increase when the wind blows from the sea and especially from directions between south-south-west and west-south-west. The local maxima and minima, occurring in some sectors, are discussed in detail.

1. Introduction

A data presentation technique developed by Zambakas (1982), the rectangular wind-frequency diagram, has been extended in scope. The existing technique enabled the distribution of wind by direction and speed to be analysed. However, it is possible to examine the effects of these variables acting simultaneously on other ambient air elements, as has been done previously (Zambakas 1984, Zambakas *et al.* 1985). In this study the technique is applied to the behaviour of ambient air-water content during days of nocturnal land-breezes and daytime sea-breezes. Details of the technique are discussed by Zambakas (1982, 1984).

2. Data

Sea-breeze days occur in Athens throughout the year. These days were selected from the 7-year period 1961–67 for the months of April (27 days in all), July (24 days) and October (24 days). Because of the rarity of this phenomenon during the winter period, a 30-year period, 1938–67 (26 days), had to be considered for January. Only days with pure sea-breeze conditions were selected to avoid interference by any other wind component during the period of the sea-breeze day. The nights before and after the chosen day had only a light land-breeze or were calm. Data were derived from the records of a pressure-tube anemograph situated at the National Observatory of Athens (NOA, 37° 58′N, 23° 43′E and 107 m above mean sea level) for where the land- and sea-breeze characteristics are examined here. These anemograph data were used by Zambakas (1973) to examine the times of the beginning and end of the sea-breeze at Athens (Atkinson 1981, p. 133), and hodographs were used to study the veering or backing of the wind during sea-breeze days. The NOA lies on a promontory and is about 5 km from an indented coastline. The topography of the region of the measurement site is shown in Fig. 1.

The mean hourly absolute humidities were calculated in millimetres of mercury (mm Hg) from the corresponding records of a hygrograph (Smithsonian Institution 1939, Table 81); in normal atmospheric conditions the absolute humidity measured as water vapour pressure (mm Hg) and in units of water concentration (g m^{-3}) have nearly the same numerical value.

3. Duration and speed of land- and sea-breezes

The characteristics regarding the duration and the time at which the land- and sea-breezes begin and end are shown in Fig. 2. These are known characteristics relative to the times of sunrise and sunset (Zambakas 1973). It has been assumed that diurnal variations remain reasonably constant over the month. The times of the beginning and end of the sea-breeze during July from Fig. 2 (from Zambakas (1973) and not calculated from anemograph data) are considered to be 0900 and 2300 hours local time (GMT+2 hours), respectively.

4. Variation of humidity with hourly wind speed and direction in land- and sea-breeze conditions

The ambient air absolute humidities were examined for 24 days in July, i.e. 576 hours. Results for other months have not yet been tabulated because at present these have to be calculated manually in the absence of computerized records.

Fig. 3 shows the frequency isopleth diagram of wind speed and direction. The frequency is calculated from the numbers of observations in increments of 0.2 m s^{-1} and 10°, relative to the total of 576 observations. The frequency of the calm category (wind speed < 0.2 m s^{-1}) is 20%. The pattern of isopleths in Fig. 3 suggests the wind flows in preferred directions with a range of speeds rather than with preferred speeds in a range of directions.

The nocturnal land-breeze is clearly seen in the sectors 0–140° and 270–360° with the maximum wind frequency isopleth (f) where f >4% in the direction 0°. The sector of the sea-breeze (140–270°) is also shown with the maximum wind frequency where f >8% in the direction 210–220°.

It is noteworthy that the median values are preferable to the mean in both Figs 3 and 4 because the frequency distribution is not Gaussian but highly skewed to the right. The wind speed seldom exceeds 2.5 m s^{-1} (f<0.1%) during the nocturnal land-breeze or 6.8 m s^{-1} during the sea-breeze (Fig. 3).

The isopleths of absolute humidity as a function of wind speed and direction in land- and sea-breeze conditions are plotted in Fig. 4 (values calculated in increments of 0.2 m s^{-1} and 10°, the median being taken because the values are skew). During the land-breeze the absolute humidity does not exceed 15 g m^{-3} (≈ 15 mm Hg), but during the sea-breeze it reaches about 18 g m^{-3} (at 3 m s^{-1}, 240°). In calm conditions the absolute humidity averages 12.6 g m^{-3}.

5. Comments, bioclimatic and medical discussion

It has been noted that the highest values of absolute humidity occur when the wind blows from the Gulf of Saronikos (see Fig. 1) between 200 and 270° (Fig. 4). It

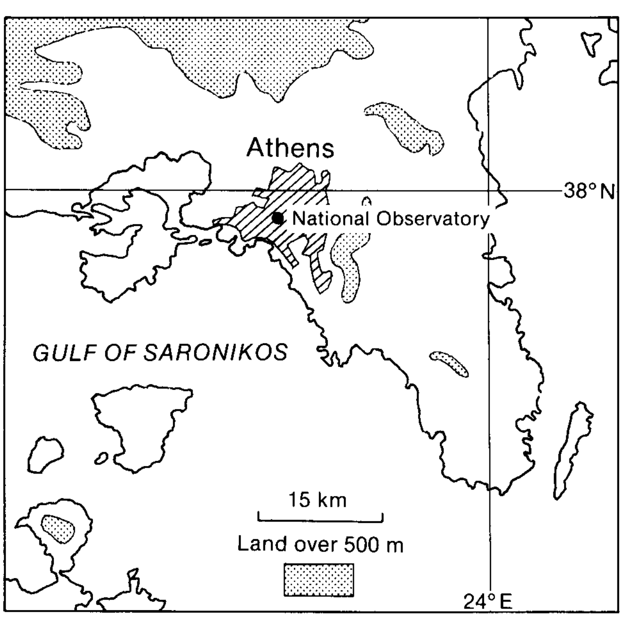

Figure 1. Location of the National Observatory of Athens, in relation to the sea and topographical features.

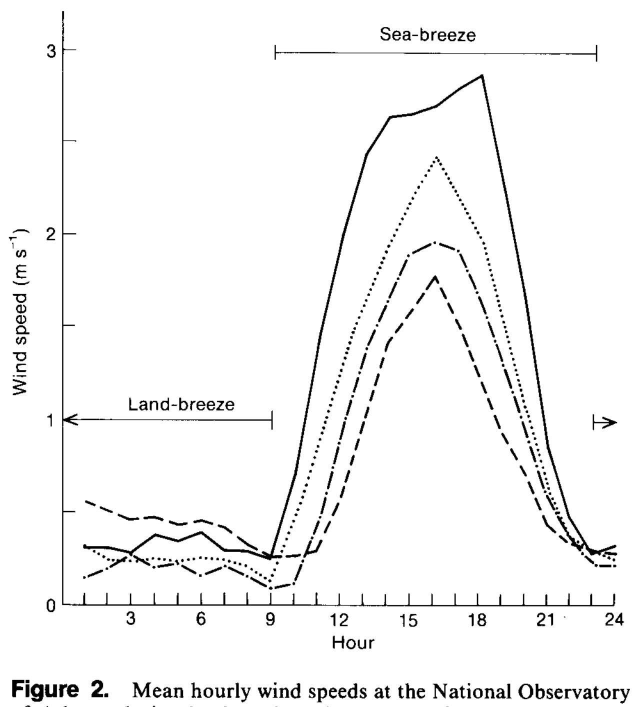

Figure 2. Mean hourly wind speeds at the National Observatory of Athens, during land- and sea-breeze days for January (dashed line), April (dotted line), July (continuous line) and October (dash-dot line).

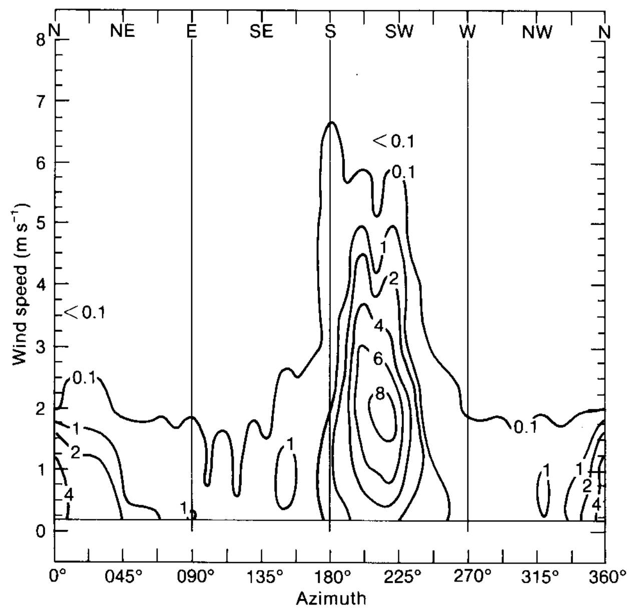

Figure 3. Frequency isopleth diagram (%) of 576 mean hourly surface wind observations at the National Observatory of Athens, during land- and sea-breeze days in July 1961–67.

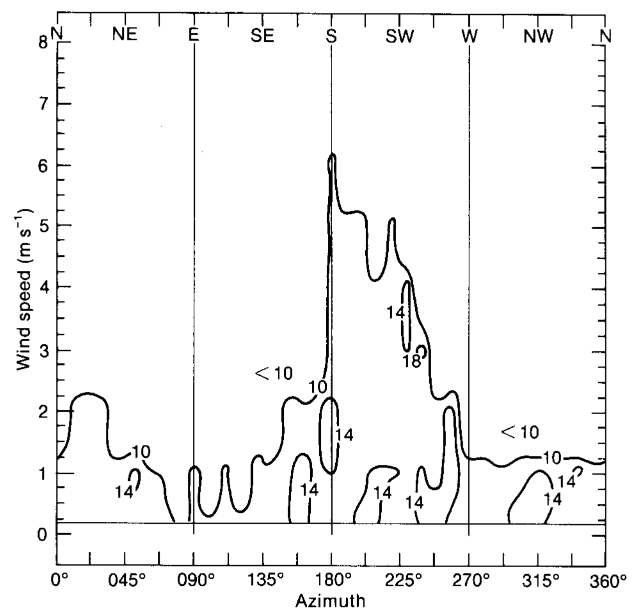

Figure 4. Rectangular isopleth diagram of 576 hourly measurements of absolute humidity (mm Hg ($\approx$ g m^{-3})) at the National Observatory, Athens, during land- and sea-breeze days in July 1961–67.

is suggested that the islands and the shallow sea facilitate greater evaporation when the sea-breeze is in this sector.

In Fig. 2 it can be seen that the sea-breeze wind speed is greatest in July, followed by April, October and January with maximum mean wind speeds of 2.9, 2.4, 2.0 and 1.8 m s^{-1}, respectively. Conversely, during the land-breeze the wind speed is greatest in January. The differences between the mean air temperature at NOA and those over the sea during July, April, October and January are 1.2, −0.8, −1.1 and −2.9 °C, respectively (Kotinis-Zambakas 1983, p. 210) — a steady increase, which corresponds to a steady decrease in wind speeds as shown in Fig. 2, although this only refers to sea-breezes.

The sea-breeze days in Athens are bioclimatically comfortable during April and October, while July is in a period favoured by tourists (Zambakas and Kotinis-Zambakas 1984). In recent decades, the Athens Basin, which is open only to the sea, has suffered from air pollution. This pollution usually prevails during sea-breeze days as the wind is light and it cannot disperse the pollutants over the mountains surrounding the Athens Basin. Previously, when the Athens Basin was not so urbanized, the sea-breeze was a refreshing light wind for the Athenians.

The alternation of sea-breeze and other weather days during the winter causes bioclimatical discomfort and consequent medical disorders; influenza and viral diseases are common. During the summer sea-breeze days, the night hours are relatively comfortable with temperatures of about 24 °C, and more so with a relative humidity of 50–60% (Fig. 5).

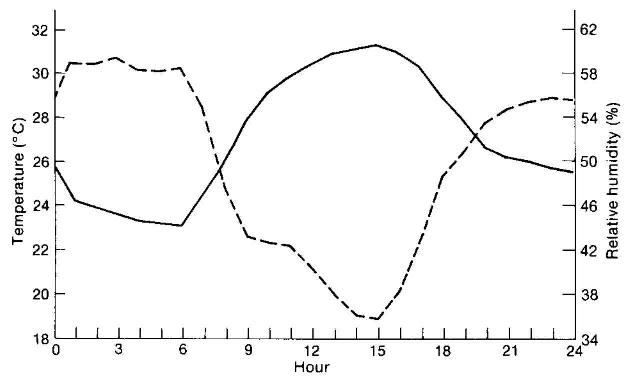

Figure 5. Mean hourly temperature (continuous line) and relative humidity (dashed line) at the National Observatory of Athens, during land- and sea-breeze days in July 1961–67.

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Workshop reports

Workshop on Artificial Intelligence Research In the Environmental Sciences (AIRIES-89), Washington DC, 2–4 May 1989

This was the third AIRIES meeting, the previous two having been held in Boulder, Colorado. It brought together upwards of 100 scientists, mainly from the USA and Canada where most of the activity in this field is centred. Meteorology was the discipline most strongly represented but with others such as forestry and pollution control well in evidence.

The first session was entitled 'Example applications' and set the tone for the meeting, which throughout was firmly anchored to the practicalities of putting Artificial Intelligence (AI) to work in real applications. Two talks were of particular interest to meteorologists. John Bullas (Atmospheric Environment Service, Canada) discussed the 'SWIFT' severe-storm forecasting system, one of the largest and most mature of the meteorological expert systems in existence, which uses local knowledge about the behaviour of weather systems, and the ability to interpret worded observations, to modify and refine predictions based on convection indices derived from numerical weather prediction (NWP) models. Encouraging results had emerged from limited operational trials in Alberta. Peter Zwack (Université du Québec) talked about 'OASIS', a system for producing forecasts of low cloud. He stressed the importance of building 'deep knowledge' into the system. Deep knowledge is a description of underlying governing processes (ultimately the physical laws) whereas 'shallow knowledge' consists of empirical rules about observed behaviour, without any attempt to relate them to mechanisms or principles. Systems incorporating deep knowledge are more difficult to build but are more likely to be transportable geographically and should be able to cope better with unforeseen events. However, shallow knowledge may still have a role in adding site-specific rules, to tune the system for a particular location.

The next session was on 'Tools and techniques'. This provided an opportunity for discussion of the traditionally troublesome process of knowledge acquisition — how to collect the important knowledge about a subject and then get it into an AI system. Robert Hoffman (Adelphi University, New York) discussed the psychology of eliciting knowledge from human experts. He discounted the value of trying to automate the process as this would force the experts to think in unnatural ways, with the result that much of their true expertise would not get transferred. Interest continues to be shown, however, in ways of enabling machines to learn directly from examples, without the need for a human being to understand the problem and to formulate rules and principles. One approach, exemplified in a ground-water contamination predictor described by David Jensen (Washington State University), is to induce explicit rules automatically from collections of examples and then to apply these rules in an expert system. Care is required in choosing the factors to be presented in the examples, but the working of the resulting expert system can be followed and additional rules can be formulated and added by the system designer. A machine-learning technique which is attracting growing attention is the use of a neural network to determine the association between a given set of input and output patterns. The network is presented with a series of input patterns from the set, for example profiles from sonde ascents together with, in each case, the corresponding 'correct' output pattern, such as an indication of thunderstorm likelihood. Having been shown the appropriate input/output examples, the network programs itself to compute the function which relates the input to the output. Paul Lampru (Consultant's Choice Incorporated) claimed high skill scores had been achieved using a neural network in a precipitation forecasting application, and in another session Vernon Derr (National Oceanic and Atmospheric Administration/ Environmental Research Laboratories (ERL), Boulder) reported that two neural networks were among seventeen AI projects being undertaken at ERL. Neural networks appear to hold promise, but are viewed with suspicion by many because they are 'black boxes', lacking the comforting understandability of rule-based systems.

Molly Stock (University of Idaho) chaired a session on 'Issues and perspectives' and presented the first paper, in which she described a task analysis on forestry management. The analysis had taken more than a year and sought to discover exactly where and how expert systems could be applied to maximum effect, while still leaving human beings with genuinely satisfying jobs. The design of the expert systems themselves had yet to commence. The thoroughness with which this study had been carried out was an example to us all, and will probably pay off in the end, but one wonders whether in practice many organizations would have the patience to undertake such a large and not obviously productive preparatory exercise.

Bryan Conway (Meteorological Office) described plans to apply expert system techniques to short-period thunderstorm forecasting in the United Kingdom, concentrating on the different problems to be overcome, including the optimum combination of many flawed data sources, the interaction between the system and the user and the automation of pattern-recognition tasks.

The final session of oral presentations was on 'Integrated systems' — combining AI with conventional techniques. Work recently begun at the Meteorological Office to automate very-short-period precipitation forecasts by combining radar and satellite observations with NWP model output is a good example of this and was described by Gill Sutton. Various numerical techniques can be used to generate forecast fields of precipitation but an intelligent process is needed to choose the most appropriate technique in the light of an understanding of the meteorological situation.

The meeting included two poster sessions showing a range of applications and techniques. These sessions included some demonstrations of small expert systems running on microcomputers. Though interesting, these were limited by their reliance on dialogue with the user — a severe bottle-neck for many meteorological applications. One very good thing was the absence of parallel sessions, which now seem to be a regular feature of larger meetings, so that it was possible to see the posters without missing something else.

'Shootout-89' was a panel session devoted to an experiment of that name held from May to August this year at Boulder, where several systems developed by different groups and in different places, ranging from simple statistical predictors to large systems like SWIFT, were competing to forecast severe storms in four regions of north-east Colorado.

This was a very useful meeting, uniquely focused on the intersection of two large subject areas — AI and environmental science. There was a refreshing openness of discussion — for the most part we have not reached the stage of people defending entrenched positions at all costs, though there was lively debate about many of the issues raised. The meeting showed what is being achieved in this field and what the current preoccupations are in a way that does not fully emerge from studying published papers. Some participants thought that papers should be submitted and proceedings published (this has not been the case with AIRIES so far), but others felt that it was more important to keep the cost down, the meetings informal, and let people present their latest work. There was general agreement that the meeting was well organized and run — perhaps its relatively small size helped here.

There was strong support for AIRIES continuing as an independent event, although the American Meteorological Society (AMS) has now established an AI committee and the subject should start appearing more strongly at AMS-sponsored meetings. Further AIRIES workshops are envisaged at intervals of about 18 months.

B.J. Conway and G. Sutton

International Workshop on Satellite and Radar Imagery Interpretation, Shinfield Park, Reading, 24–28 July 1989

An International Workshop on Satellite and Radar Imagery Interpretation was held at the Meteorological Office College, Shinfield Park, Reading, England, from 24 to 28 July 1989. It was organized by the Meteorological Office as a follow-up to an international workshop on this subject at the same venue in 1987*. At this earlier meeting it had been agreed to reconvene in 1989 under the joint chairmanship of Dr Greg Forbes (Pennsylvania State University, USA) and Mike Bader (Meteorological Office), with a view to providing material which could be used directly in the production of a reference manual on satellite and radar imagery, explaining the use of conceptual models and other interpretation methods for forecasters working principally in middle latitudes.

The workshop was opened on 24 July by Dr Keith Browning, Director of Research, Meteorological Office, who welcomed delegates from the fields of research and operational forecasting in Austria, Canada, Denmark, the Federal Republic of Germany, France, Switzerland, the United States of America and the United Kingdom. EUMETSAT, the main sponsor, was represented; the World Meteorological Organization are also supporting the project. Dr Browning thanked the sponsors for their support and reminded delegates that the manual was to meet an operational as well as a training need. A large amount of material had been submitted for discussion and consideration at the workshop. Dr Browning acknowledged the work done by all authors (including those not present) and by those who reviewed the contributions prior to the workshop, and reminded participants that there was a lot of material now available which needed to be reviewed for the planned reference manual. He said that the consolidated result would provide forecasters from many nations with some very effective guidance especially where forecasting rules were clearly identifiable.

After the opening plenary session, the workshop broke up into four specialized working groups. In addition, an Editing Committee group, with the task of integrating the selected material, met daily with the chairmen of the specialist groups to review progress and identify areas of common concern between the groups. The specialist groups were as follows:

(a) Working Group A, chaired by Peter Wickham (United Kingdom), dealt with the introduction and general characteristics of satellite and radar imagery. The group of papers in this area, which will form the first two chapters of the manual, covered the principles of remote sensing by satellite, information about satellite orbits and the characteristics of sensing channels. Basic principles of interpretation, cloud types and topographical features detectable were identified and agreed upon. An overview of how satellite pictures can provide an invaluable source of information to forecasters and how it could be applied was agreed. The basic principles of weather radar and radar types were also noted. Problems in interpretation brought about by, for example, anomalous propagation, occultation and the bright band were covered well by submitted material. This material would enable the uninitiated forecaster to be better prepared to handle the common, and not so common, precipitation patterns included in the manual.

(b) Working Group B, chaired by Martin Morris (Assistant Director (Central Forecasting) Meteor-

* Preprints of the 1987 workshop are still available from EUMETSAT headquarters.

ological Office), was concerned with three chapters dealing with the weighty subjects of using imagery in synoptic-scale analysis and identifying the principal air flows within waves, warm and cold fronts, occlusions, and ex-tropical storms reacting with the polar front. The group comprised experts from six nations, and not surprisingly there was intense debate, at times with cherished ideas being challenged and tested, in this forum. Nevertheless the group managed to identify and agree on the key issues of highlighting and interpreting the signatures commonly seen on satellite pictures, and where appropriate on radar images too, together with appropriate diagnostics so that the resultant weather can be better understood and predicted by the forecasters.

(c) Working Group C, chaired by Dr Jim Purdom (USA), dealt with papers submitted for inclusion on the section concerning convection. The group recognized the need to cover the whole range of convection from sea-breeze/land-breeze systems, mesoscale convection and circular systems through to supercells both in Europe and North America, together with the associated weather. The nature of the forcing mechanisms and instability was agreed as crucial for identifying different convective systems that challenge regional forecasters. The case-studies used have clearly demonstrated the different signatures from satellite and radar imagery commonly observed, so that forecasters should find this area of guidance most valuable.

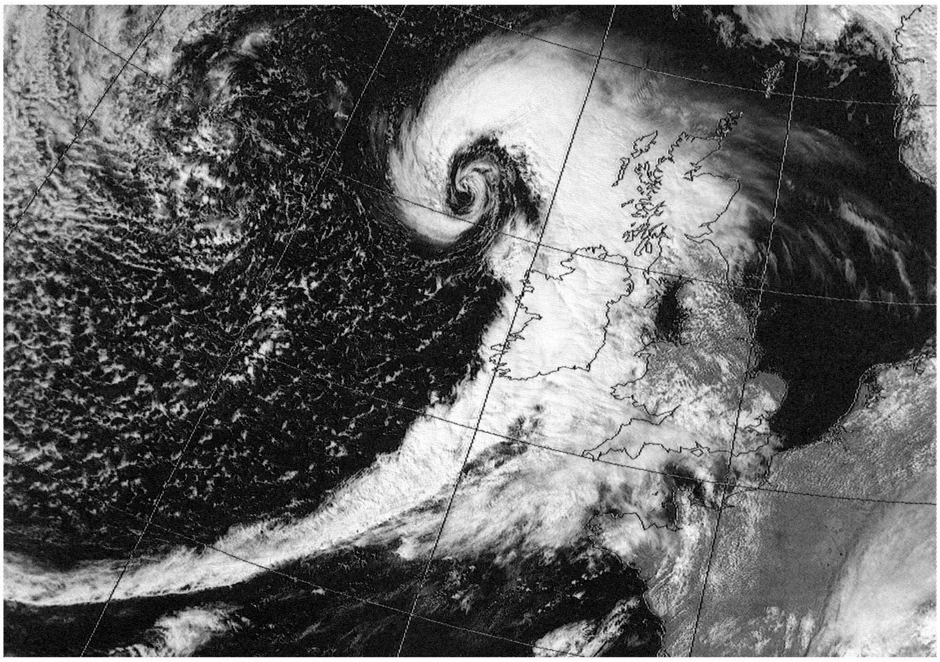
(d) Working Group D, chaired by Dr Jim Gurka (USA), determined the most suitable material for the last two chapters of the manual. These chapters concern the problem areas of forecasting fog and low cloud, topographical effects and polar phenomena. Members identified some very useful material to illustrate clues for the forecaster wrestling with the problems of fog and the ever-difficult stratus and stratocumulus. Topographical effects such as lee waves, föhn and rain-shadow events were included and material agreed for publication. Polar phenomena, and not only the polar low, are of concern to many forecasters working in middle latitudes, and a substantial amount of excellent guidance has been identified including how to use the 3.7 μm channel in addition to the more familiar ones.

Participants have returned to their respective organizations to fine-tune some of the material to be included for the publication. The Editing Committee has a lot of work to do to put it together but it is hoped to publish the manual next year. In addition the Office plans to produce, on the same time-scale, a pocket edition of the reference manual. The organizing committee, headed by Mike Bader and Tony Waters (Meteorological Office) are to be congratulated on such a productive week, and also the Meteorological Office College for ensuring the hosting arrangements worked well and thus allowed the week to pass so smoothly.

Finally, despite the hard work indoors, time was made available for the USA to take on the rest of the world in a serious cricket match one evening. The scores did not matter but teamwork of the highest order prevailed on the field!

P.R.S. Salter

Satellite photograph — 14 August 1989 at 1342 GMT



Photograph by courtesy of University of Dundee

Figure 1. NOAA-11 visible image for 1342 GMT on 14 August 1989.

The NOAA-11 visible image shown here (Fig. 1) illustrates the cloud pattern associated with an intense surface low at the end of a period of explosive deepening. A well marked cold frontal cloud band terminates within the cloud spiral near the centre of the low. There is little evidence either in the image or from surface observations of a distinct warm front (Fig. 2). Right at the leading edge of the frontal cloud band, a narrow 'rope cloud' can be seen. Images from the radar at Shannon (western Ireland) near the time of the picture confirmed that near the south coast of Ireland this rope cloud was coincident with a narrow band of heavy rain (exceeding 60 mm h^{-1}) caused by line convection. As the band continued eastwards, several thunderstorms were reported and gusts of wind exceeded 50 kn in places. Near Pwllheli in North Wales a tornado caused considerable property damage at a holiday camp.

The occurrence of a rope cloud and / or line convection together with strong gusts (occasionally tornadoes) and thunderstorms at strong cold fronts is not unknown. Indeed, analysis of radar data on occasions of tornado reports at cold fronts over the United Kingdom* suggests that intense line convection is a common feature. When thunderstorms also occur they are often characterized by relatively warm cloud tops, in this case typically −20 to −30 °C.

G.A. Monk

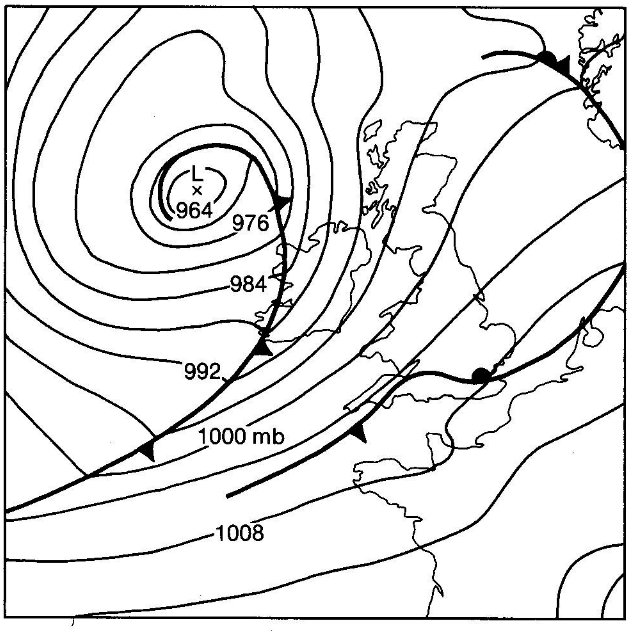


Figure 2. Surface analysis at 1200 GMT on 14 August 1989.

* Information on tornado outbreaks from: Meaden, G.T.; The classification of whirlwind types and a discussion of their physical origins, *J Meteorol UK*, **10**, 194–202.

GUIDE TO AUTHORS

Content

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

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

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

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

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

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