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Meteorological services for Defence

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Summary

Meteorological services for Defence form the largest single area of activity within the Meteorological Office and currently absorb about 25% of the total staff of the Office at 60 Defence locations outside Bracknell. The cost of services for Defence represents about 36% of the gross cost or 52% of the net cost of the Office as a whole. Apart from providing support day-by-day for Defence the Meteorological Office is concerned with maintaining a cost-effective response to Defence needs. In particular, the needs of the Royal Air Force, which remains the largest single user of Meteorological Office services, have been thoroughly reviewed in close consultation with the Air Staff to ensure that reduced manpower resources are used to the best effect. In providing meteorological services for Defence there is an essential need for an understanding of the military requirements but, if that support is to be fully effective, it is equally essential that there is a corresponding awareness on the part of military commanders of the effect of weather on military operations.

Introduction

The first recorded use of meteorological knowledge in the defence of a nation was in 480 BC when the Athenian admiral Themistocles timed his engagement of a large invading force of Persian ships under Xerxes to coincide with the onset of the afternoon sea-breeze between the island of Salamis and the mainland coast at Piraeus. The Persian fleet of 1200 large and unwieldy ships was preoccupied with keeping off the lee shore in rough water with little sea-room and was destroyed by the small but highly manoeuvrable Athenian fleet of only 380 ships, forcing Xerxes to abandon his plans for extending the Persian empire westwards over the Mediterranean.

Thereafter history frequently records the unplanned and random effect of weather on the outcome of war, but the occasions when a knowledge of the weather was used in central military planning were rare, although a notable exception was the work of the Meteorological Section of the Royal Engineers in France during the First World War. There were many occasions in the Second World War when military actions were successfully based on meteorological advice, but the one occasion when the outcome of the war could be said to have been decisively determined came in June 1944 with the commitment of the Allied Forces to the invasion of Europe. The invasion was launched on a forecast of the essential short spell of quiet weather in the English Channel. The weather of June 1944 was unusually disturbed but the required spell of quiet weather was accurately forecast at a time when the German High Command had relaxed its vigilance on advice that the weather would be against the launching of the invasion.

Following the end of the Second World War the trained manpower providing meteorological services for the Armed Forces was largely dispersed. The requirements of the Royal Air Force and the Army for meteorological services were once again met from within the civilian resources of the Meteorological Office, although the needs of the Royal Navy continued to be met from within Navy resources, as before the war, by the Naval Weather Service (now the Directorate of Naval Oceanography and Meteorology).

The need to co-ordinate afresh the activities of the Meteorological Office in support of Defence was recognised in 1966 when meteorological services for the Royal Air Force, the Army and the Procurement Executive and the national response to the meteorological needs of NATO were concentrated into one Services Directorate Branch under the title of Defence Services. The concentration within one Branch of almost the entire organizational effort of the Meteorological Office for Defence showed that the response to Defence needs represented the largest single group of activities within the Meteorological Office. Defence has since remained the largest single user of Meteorological Office services, requiring the direct involvement of a quarter of the total staff at Defence locations in the United Kingdom, Germany and the Mediterranean, and absorbing rather more than 50% of the net cost of the Meteorological Office.

The scale and diversity of meteorological services for Defence is summarized in Table I. By the end of the financial year 1981/82 a total of 687 staff was employed in direct support of Defence in 60 Defence Services Branch outstation meteorological offices located with the Royal Air Force (51), the Army (4) and the Procurement Executive (5); 49 of the offices are at outstations in the United Kingdom, 7 in Germany and 4 in the Mediterranean. The headquarters of the Defence Services Branch is located in the Meteorological Office Headquarters at Bracknell with 12 staff.

Table I. *Summary of Defence Services offices and staff complements — 1 April 1982*

	UK		Germany		Mediterranean		Total	
	Offices	Staff	Offices	Staff	Offices	Staff	Offices	Staff
Defence Services Branch HQ	1	12					1	12
C Met O HQSTC	1	4					1	4
C Met O HQ RAF Germany			1	7			1	7
Principal Forecasting Office	1	59					1	59
Main Meteorological Offices	5	125			2	43	7	168
Subsidiary Forecasting Offices:								
RAF stations	28	262	4	50			32	312
RAF units at PE establishments	3	22					3	22
Army Aviation stations	2	11	1	8			3	19
HQ 1(BR)Corps			1	(1)[a]			1	(1)
PE Army trials establishments	4	41					4	41
NATO Allied Meteorological Office:								
UK staff at AMO Maastricht			(1)[b]	3			(1)	3
Observing offices:								
RAF stations	4	19			1	5	5	24
PE/Army trials establishments	1	1					1	1
Radiosonde units:								
RAF stations					1	15	1	15
PE/Army trials establishments	(4	– –)[c]					(4	)
Total serving RAF	42	491	5	60	4	63	51	614
Total serving Defence	50	556	7	68	4	63	61	687

Notes:

a. Post held by S Met O Detmold.

b. Office outside Meteorological Office but staff remain on the Meteorological Office complement.

c. Function integrated with subsidiary forecasting offices at PE establishments.

Meteorology in military operations

A decisive factor in modern warfare is the speed and flexibility with which air power can be deployed to its full effect, to the extent that the primary aim of strategy is to achieve supremacy in the air and the primary tactical objective is air superiority. Rather than making weather redundant as a factor in the effective use of air power, increasing sophistication in aircraft design and in the technology of weapons systems is having the effect of lowering the minimum weather conditions in which air power can be effectively used. Success in air operations is more likely to go to the air commander who has the training, experience and meteorological advice which he can apply in assessing the effects of weather on operations under his control, allowing aircraft and weapons systems to be used right down to the minimum weather limits.

The area of interest to the Royal Air Force as a component of the Second Allied Tactical Air Force in the North Atlantic Treaty Organization (NATO) defence of western Europe extends from the North Sea through the Low Countries and the northern half of West Germany eastwards across the north European plain. The climatology of the region falls conveniently into three areas bounded by the longer northward-flowing rivers: between the Rhine and the Weser, the Weser and the Oder, and the Oder and the Vistula. Apart from the ridges of high ground extending northwards on either side of the Weser from the Harz mountains, the area has a low relief mostly below 150 metres. The meteorological data for most airfields in the three areas can therefore be regarded as representative of conditions over wider areas surrounding each airfield.

The analysis in Fig. 1, based on published data from airfields representative of each area, shows the average percentage frequency by months of cloud base below 300 feet and/or horizontal visibility less than 1 nautical mile, taking all hours of observation together.

The assessment of the level at which weather becomes a significant factor in military operations is a matter for military decision but the analysis in Fig. 1 shows that if a cloud base below 300 feet and/or a horizontal visibility less than 1 nautical mile restrict air operations, then the chance of failure in the effective use of air power at low level owing to poor weather, taking the day as a whole, will lie between 15 and 20% during November–February in the area between the Rhine and the Weser, and in the same range in December between the Weser and the Oder. Between the Oder and the Vistula the incidence of poor weather likely to inhibit low-level operations is less than 10% through the year. Between the Rhine and the Oder the incidence of poor weather falls below 10% from April to September, although between the Weser and the Oder the incidence falls to less than 10% in March, a month earlier.

The diurnal variation of conditions during winter when the cloud base is less than 300 feet and/or visibility is less than 1 nautical mile shows that there is little significant difference between the average incidence of the conditions during the hours of darkness and the hours of daylight. Assuming that close air support is not possible during the hours of darkness, the time during which close air support can be exercised effectively during the four winter months from November to February is limited to about 7 hours per day between the Rhine and the Weser, 7½ hours per day between the Weser and the Oder, and 8 hours per day between the Oder and the Vistula.

The percentage frequency of occasions when the cloud base will be above 1000 feet and the horizontal visibility better than 3 nautical miles, when the weather is likely to have little or no effect on low-level operations, is shown in Fig. 2. Between the Rhine and the Weser such favourable conditions will apply for over 50% of the time from March to October but only between 40 and 50% of the time from November to February. East of the Weser the incidence of such conditions is higher, averaging over 70% from March to October and between 55 and 70% from November to February.

Success or failure in a military operation may depend on exploiting the marginal differences that could tip the balance decisively one way or the other. The commander who assumes that the effects of

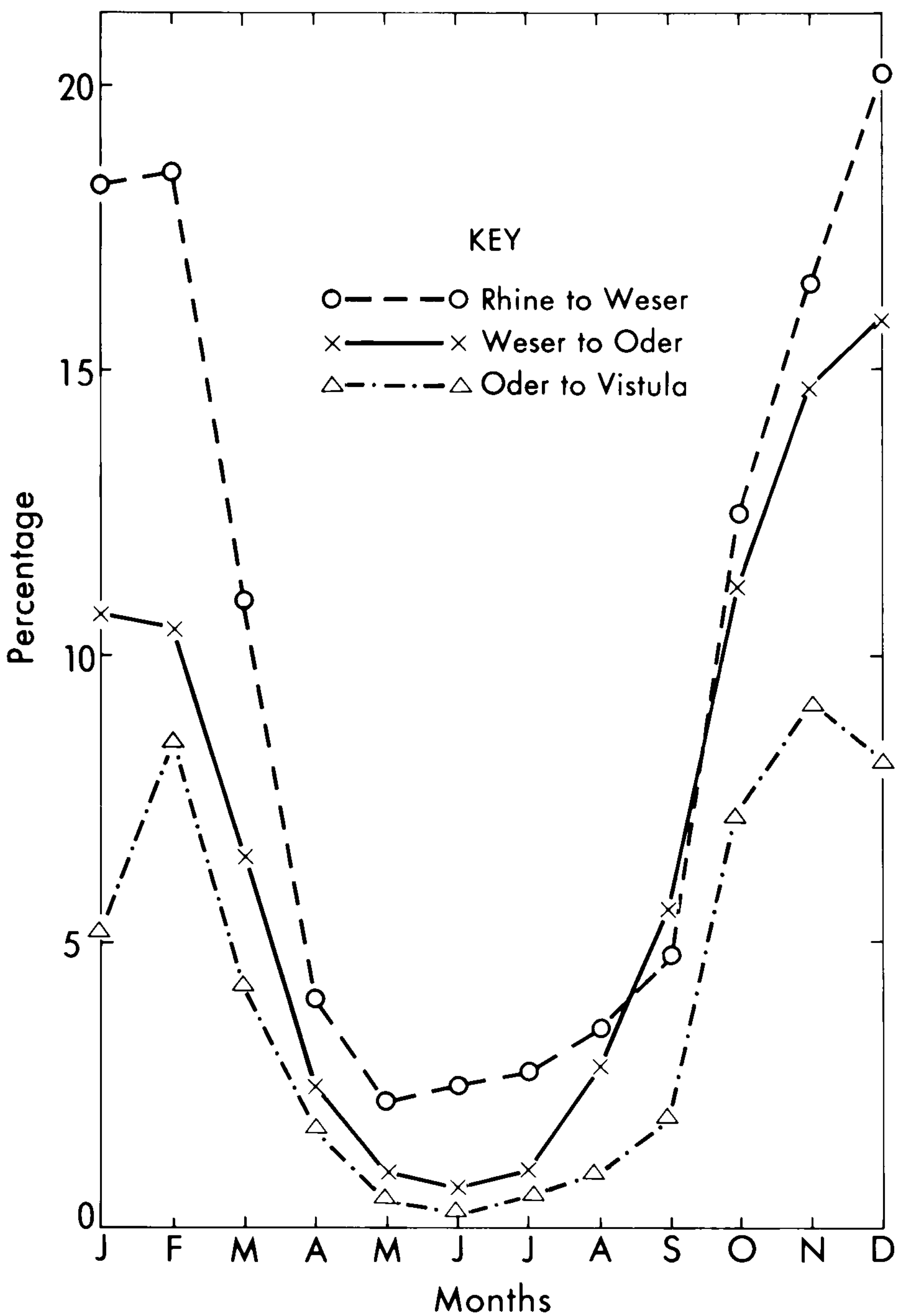

Figure 1. North European plain: monthly average percentage frequency (all hours) of cloud base less than 300 feet and/or visibility less than 1 nautical mile.

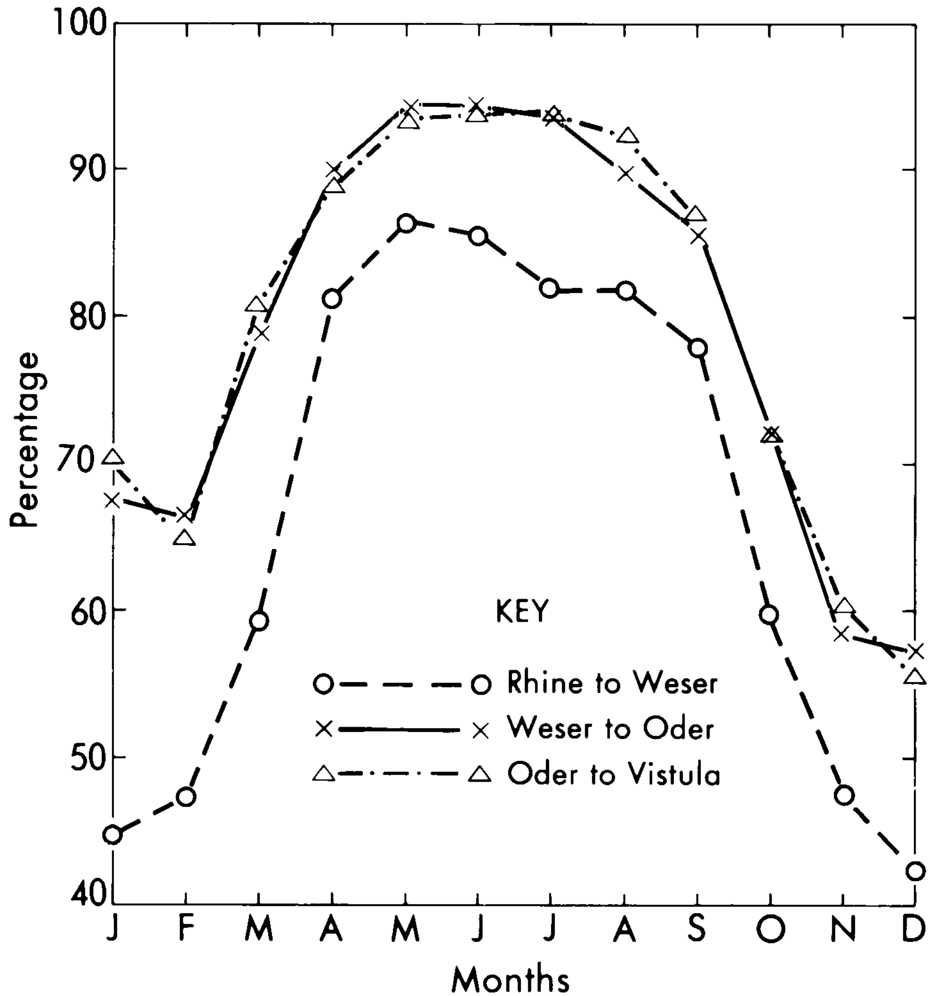

Figure 2. North European plain: monthly average percentage frequency (all hours) of cloud base higher than 1000 feet and visibility more than 3 nautical miles.

weather on his operations are the luck of the draw may fail to recognize an opportunity to load the balance in his favour. The commander who is sensitive to the effects of weather on his own and on the opposing forces will be in a position to exploit adverse weather rather than suffer it. The effective use of air power is likely to remain sensitive to weather in western and central Europe because of the high incidence of weather that is sufficiently adverse to affect operations, particularly in winter, even with increasingly sophisticated aircraft. The role of meteorologists in the defence of western Europe is to provide commanders with the advice and services that will allow the opportunities for marginal advantages to be recognized and exploited. For that to be effectively done there is a need for an understanding of the effects of weather on the exercise of air power at all levels of command, and a need for meteorological support to be given with an understanding of the relevance of weather to military operations.

The Meteorological Office response to Defence needs

(a) *Organization of meteorological services for the Royal Air Force.* The close historical relationship between the Meteorological Office and the Royal Air Force goes back to 1918 when the Royal Air Force was formed from the Royal Flying Corps and at the same time the Meteorological Office was brought under the control of the new Air Ministry. The close relationship remains and is reflected in the staff of 614, out of the total of 687 in the Defence Services Branch, who were employed on 1 April 1982 in 51 meteorological offices in direct support of the Royal Air Force, mostly at operational airfields and at Group and Command Headquarters.

After the Second World War the organization of meteorological services for the Royal Air Force continued to reflect the wartime chain of command down to the operational squadrons in the maintenance of Main Meteorological Offices (MMOs) at the various Group Headquarters. By 1965 the meteorological office at Headquarters Bomber Command at High Wycombe had begun to provide centralized advice directly to a number of airfield meteorological offices and had been designated as a Principal Forecasting Office (PFO), although some services to the airfield meteorological offices continued to be provided from the MMOs. By 1968, with the amalgamation of Bomber, Fighter and Coastal Commands into a new Strike Command, the PFO was working directly to the requirements of most of the meteorological offices at the operational airfields. Meteorological offices at some of the training airfields also received direct technical support from the PFO. With the incorporation of Air Support Command into Strike Command in 1972 there was a further extension of the direct technical parentage exercised by the PFO. The growing trend towards centralization in meteorological services for the Royal Air Force was a direct reflection of the command and control of the operational squadrons exercised from Headquarters Strike Command (HQSTC).

Under a long-standing arrangement between the Meteorological Office and the Royal Air Force, meteorological offices serving Royal Air Force needs, with the exception of the PFO, operate as multi-functional offices. Services for the general public are available from meteorological offices at Royal Air Force stations to the limits set by the staff complements established for the Royal Air Force need alone, and subject always to the priority of the Royal Air Force work. Similar services are also available from the MMOs at Group Headquarters.

In 1977 a requirement for meteorological services was prepared by the Air Staff and endorsed by the Vice-Chief of the Air Staff. The statement of requirement made it possible for the Meteorological Office to develop long-term plans for support for the Royal Air Force on authoritative forward-looking assumptions which took full account of the introduction of a new generation of aircraft into the Royal Air Force. The statement emphasized the importance of meteorological support to the efficient conduct of day-to-day flying training and to the effectiveness of air operations. Particular importance was attached to the forecasting of weather at low level for short periods ahead. The Air Staff also emphasized the importance of the direct relationship between forecasters and aircrew at the airfield level, recognizing that the requirement for details of the physical behaviour of the atmosphere in terms of cloud base, visibility, low-level turbulence and precipitation over a period only up to about six hours ahead is not susceptible to centralized automated methods of analysis and forecasting but is likely to remain, for the foreseeable future, as an area where subjective skills and expertise and local knowledge have a real contribution to make. It was also recognized that there is a need for forecasters in direct contact with operations staffs and aircrew to have a clear understanding of the operational roles for which they are providing meteorological support.

For a number of years the trend towards the centralization of meteorological support had made the outstation forecaster seem less important. The concentration of computer facilities and experienced forecasters in centralized offices was appropriate to the support of aviation conducted at medium and high levels and requiring forecasts well beyond six hours ahead. The Air Staff requirement, however, foresaw the introduction of new aircraft into the Royal Air Force inventory which would change the emphasis towards low-level high-speed operations, generating an increasing demand for forecasts of the physical behaviour of the lowest levels of the atmosphere for only short periods ahead. Support for medium- and high-level operations would still be required but would no longer generate the main demand from the Royal Air Force for meteorological support.

The only effective way in which the Royal Air Force needs can be met, as confirmed by the Air Staff, is to maintain the forecaster in direct contact with operations staff and aircrew and to provide him with the support he requires to deploy his professional skills. It would run counter to the stated Royal Air Force requirement if he were to be required to act solely as an agent for a centralized organization rather than as a professional adviser in his own right.

The statement of requirement for meteorological services for the Royal Air Force was timely. The steady trend towards the direct parentage of airfield meteorological offices from the PFO had resulted in the development of a centralized organization but the stage had not been reached when the work of the airfield forecaster could be adequately performed from the centre. Now that the requirement for retaining the forecaster in direct contact with the operators has been clearly established, the centralized organization can be developed as a system which will allow the forecaster to react faster, more effectively, and directly to operational demands.

Traditional methods of providing meteorological data to the forecaster by analogue facsimile and slow-speed teleprinter limit the speed and the effectiveness of the response to the operational needs of the Royal Air Force. A computer system has been introduced into the PFO at HQSTC which is designed to support the airfield forecaster in his main task of short-period forecasting for low-level operations. It is planned to install remote computer terminals in airfield meteorological offices, allowing the centralized system supporting the needs of the Royal Air Force to function as a demand system on the initiative of the airfield forecaster rather than as a broadcast system with a content determined at the centre. The system will be tested in pilot projects at RAF Lyneham and RAF Honington during 1982/83 and, if the pilot projects are successful, it is planned to extend the system to the meteorological offices at all Royal Air Force operational airfields over the following two or three years. It should also be possible to process radar and satellite data in the central computer in the PFO at HQSTC into a format which can be called up on the airfield computer terminals at the initiative of the forecaster. The introduction of a computer system in support of services to the Royal Air Force should result in a significant improvement in the standard of service. The ability to provide centrally a constantly updated data bank on which the airfield forecaster can draw as required will provide better technical support than is possible with the present system of fixed-time broadcasts with unavoidable delays in making available the latest data.

Flight-planning for many civil airline operations is a centralized computer-based function which leaves few decisions to be made by the aircraft captain as the result of a personal weather briefing. In military aviation, operations staff and aircrew retain some responsibility for decision-making in the detailed conduct of assigned tasks. Weather information imparted at a personal briefing using the latest available data is always relevant to mission planning and sometimes decisive. A comparison of the trends in the number of personal briefings year by year from 1974 to 1981 illustrates this significant difference between civil and military aviation in the use of meteorological support (Fig. 3). The total number of personal briefings for civil aviation shows a slight decrease over the eight-year period while personal briefings for military aviation show a marked upward trend over the same period. Further evidence of the increasing use of meteorology in military aviation is shown by the trend in the average annual number of personal briefings for each squadron in service. In 1974 there were 3232 personal

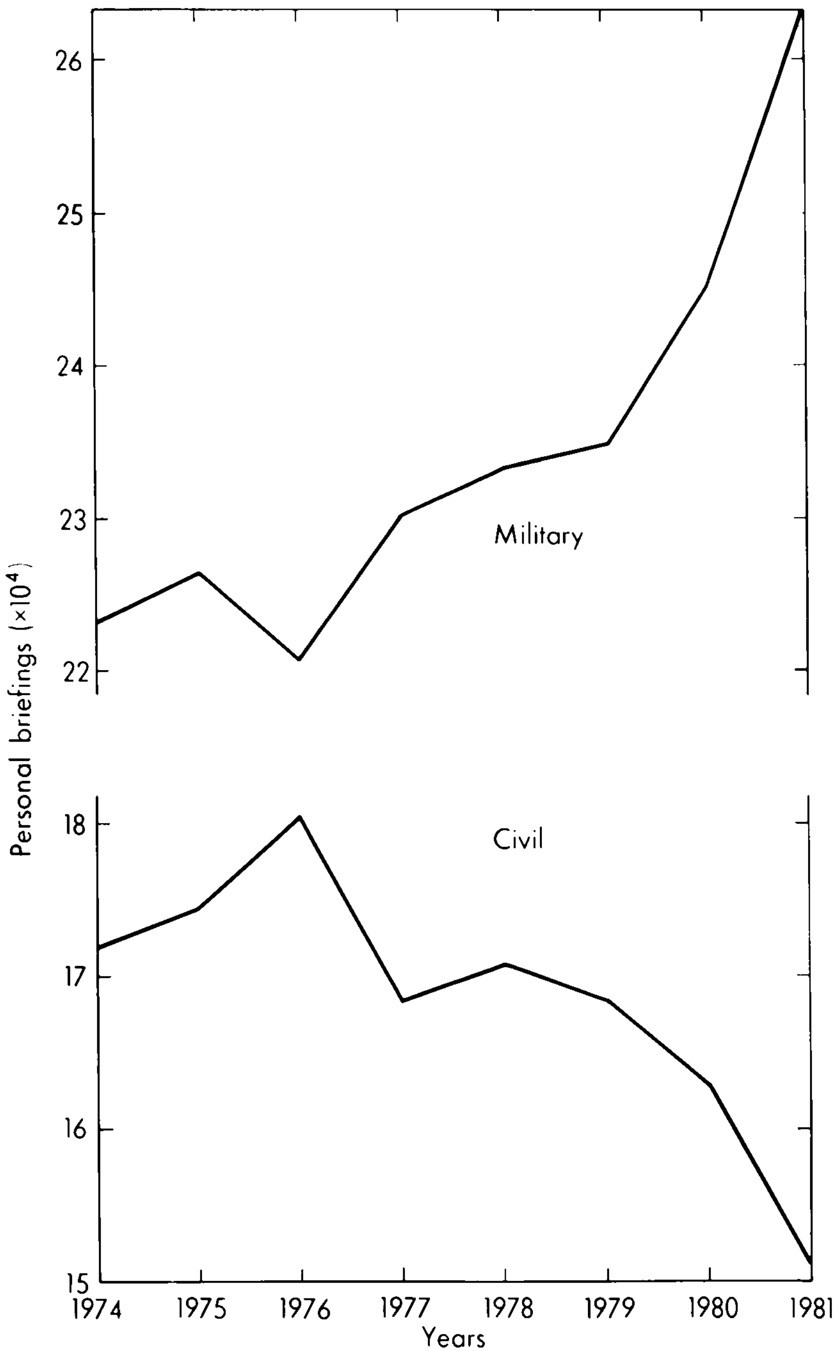

Figure 3. Personal briefings for civil and military aviation.

briefings per squadron but by 1981 the number of briefings had increased to 4461, an increase of 38%. The upward trend in the annual number of personal briefings confirms the 1977 Royal Air Force requirement for the maintenance of direct contact between forecasters, operations staff, and aircrew and reflects an increased commitment to weather-sensitive low-level operations and an increased sensitivity to the importance of weather in mission planning.

A measure of the productivity of Meteorological Office staff in response to the needs of military aviation is provided by relating the number of written forecasts and personal briefings for military aviation to the number of forecasters in the Defence Services Branch. In 1974, with 317 forecasters meeting the needs of military aviation, the average number of written forecasts issued by each forecaster was 2907. By 1 April 1982 the number of forecasters had fallen to 236 but the average number of written forecasts issued by each forecaster had increased to 3779, that is by 23%. The average number of personal briefings given by each forecaster in 1974 was 704, but by 1982 the average number had increased to 1115 or by 58%.

A significant feature of the role of the civilian Meteorological Office forecasters at operational airfields is that they function as an integral part of the operations staffs and are fully involved in national and NATO exercises, working in protective clothing and respirators in the Combat Operations Centres as and when required and often at short notice. The Meteorological Office is also responsible for the manning of the Mobile Meteorological Units of the Royal Air Force Tactical Communications Wing, operating with other assigned Royal Air Force squadrons as part of the Mobile Force of the NATO Allied Command in Europe. The Units are manned by a small complement of forecasters and observers, all of whom hold Class CC commissions in the Royal Air Force and operate in the field in uniform. The cadre of staff concerned are all volunteers and receive training in basic military skills.

(b) *Organization of meteorological services for the Army*. The Army Air Corps is faced with problems similar to the Royal Air Force in operating helicopters and light aircraft, and a close association has developed over the past decade with the Directorate of the Army Air Corps. The scale of effort is very much less than for the Royal Air Force, with only 19 staff employed in three meteorological offices at the Army Air Corps airfields at Netheravon and Middle Wallop and at Detmold in Germany. The services which are provided relate mainly to flight safety in the operation of helicopters and light aircraft, often at very low levels, although there is an increasing awareness on the part of the Army Air Corps of the relevance of meteorological advice to the effective conduct of Army Air Corps support in land-force operations. A routine part of the service to the Army Air Corps is the provision of forecast data related to the natural illumination of ground targets at night resulting from a combination of moonlight and cloud cover. The organization of services for the Army Air Corps is similar to the organization of services for the Royal Air Force. As there are only two meteorological offices serving the Army Air Corps in the United Kingdom and only one in Germany, the offices are integrated into the organization designed to meet Royal Air Force requirements although they react to the needs of the Army.

The wider interest of the Army in environmental support services is not well defined, partly because of a lesser sensitivity of Army operations to weather and partly because the effect of weather on land-force operations is not as natural a part of the training of the field officer as it is in the training of aircrew. Useful experience in the importance of weather in land operations was, however, gained by the Army in the major British Army of the Rhine exercise CRUSADER 80 held in the I (BR) Corps area in September 1980. The Senior Meteorological Officer (S Met O) in the meteorological office at Detmold also holds the post of S Met O at the Headquarters of I(BR) Corps. He was fully involved in CRUSADER 80 at the field headquarters of the Corps and was able to demonstrate the capability of the Meteorological Office in providing meteorological inputs to land-force command and control decisions.

By making use of the central resources of the Office he was also able to provide advice to the Commander which proved useful in decisions related to minimizing the damage to farmland caused by tracked vehicles.

(c) *Organization of meteorological services for the Procurement Executive.* Meteorological advice for the artillery ranges and the research and development establishments of the Procurement Executive (PE) is considered by the users as essential to the effective conduct of trials, in terms both of acquiring data for subsequent trials analyses and for range safety. A total of 42 staff in five meteorological offices is deployed in direct support of the Procurement Executive on the ranges at Aberporth, Eskmeals, Larkhill, Pendine and Shoeburyness. A full radiosonde capability is maintained at each of the ranges, with the exception of Pendine, and is used to provide upper-air data in support of specific trials. The Mk 3 radiosonde system has been specially modified at all four locations to provide detailed upper-air data in near-real time and computer-tape records for use in trials analyses. The meteorological office at Shoeburyness provides services for the Atomic Weapons Research Establishment explosives testing ground at Foulness. The meteorological office at Larkhill, as well as providing services for the Royal School of Artillery, provides services for the Chemical Defence Establishment at Porton and the Royal Aircraft Establishment range on Salisbury Plain.

An important part of the service provided from the meteorological offices on the Procurement Executive ranges is the forecasting of noise propagation which allows explosives and ordnance trials to be conducted with the minimum of inconvenience to the general public. Much of the development work associated with improving the forecasting of noise propagation is carried out at the meteorological office at the Royal School of Artillery in close co-operation with the range authorities. A method for producing noise-propagation forecasts using numerical techniques was developed in the Meteorological Office in 1978 and has since been tested and improved at Larkhill, using the small desk-top computer which forms part of the Mk 3 radiosonde system adapted for use on the ranges. The accuracy of forecasts of noise propagation has been considerably enhanced, giving over-pressure forecasts which verify to within 5 decibels. The application of the technique to acoustic forecasting for artillery trials at Larkhill has minimized periods when firing is restricted because of the likelihood of blast damage. Taped programs have been compiled for use in the other range offices equipped with the Mk 3 radiosonde system.

(d) *Meteorological support for the Home Office.* The Home Office United Kingdom Warning and Monitoring Organization (UKWMO) exists to provide warnings of air attack and to monitor and predict nuclear fallout for both national and NATO civilian and military purposes. Although no Meteorological Office staff are permanently employed in direct support of the Home Office UKWMO, there is a cadre of 15 volunteer staff who man the meteorological cells in the five UKWMO Sector Controls when required. The volunteer staff are normally fully employed elsewhere in the Meteorological Office as forecasters. Their function in the Sector Controls is to provide the meteorological data essential to the calculation of fallout trajectories. The data are obtained through links with the Central Forecasting Office (CFO) at Bracknell and there are also direct links with the eight radiosonde stations in the United Kingdom.

(e) *Meteorological support for the Royal Navy.* Meteorological services for the Royal Navy are provided by the Directorate of Naval Oceanography and Meteorology (DNOM). The Meteorological Office is responsible for making available to DNOM observational data which are not available from Naval sources and also provides, for guidance, analyses and forecasts prepared by CFO at Bracknell. Very close co-operation is maintained between the Defence Services Branch and DNOM, both at the working level between the PFO at High Wycombe and the Fleet Weather and Oceanographic Centre at

Northwood and between the Defence Services Branch headquarters and the headquarters of DNOM in Whitehall. A Naval Liaison Officer on the staff of DNOM is located at the Defence Services Branch headquarters in Bracknell. The close co-operation ensures that meteorological support from both the Meteorological Office and the Royal Navy is co-ordinated nationally and within NATO across the whole range of Defence requirements.

(f) *Meteorological Office NATO responsibilities and relations with other national military meteorological services.* National representation for the United Kingdom in the NATO Military Committee Meteorological Group and other NATO agencies concerned with meteorology is provided by staff from the headquarters of the Defence Services and the Telecommunication Branches, supported and advised in Naval matters by staff from DNOM.

National support from the United Kingdom for the small meteorological organization in Europe under direct NATO control is provided through the allocation of a forecaster and two assistants from the Meteorological Office to the Allied Meteorological Office (AMO) at Maastricht in Holland. A Principal Scientific Officer fills the uniformed post, with a Class CC commission in the rank of Group Captain, of Chief Meteorological Officer (C Met O) to the NATO Supreme Allied Commander in Europe at the Supreme Headquarters Allied Powers in Europe (SHAPE) at Mons in Belgium.

An important aspect of the international work of the Defence Services Branch is the maintenance of a close working relationship, outside the NATO agencies, with the Air Weather Service of the United States Air Force and the German Military Geophysical Office. The Meteorological Office presence in Germany in support of the Royal Air Force and the Air Weather Service presence in the United Kingdom in support of the United States Air Force result in areas of common concern to all three national meteorological organizations serving military needs. NATO Military Committee policy for meteorological support is based on the various national facilities which can be made available in a time of tension, crisis or war, and increasing use is being made of the meteorological resources of the host nations in support of national and NATO activities. The United Kingdom, through the meteorological Office representatives in the various NATO bodies, is taking the initiative in improving the NATO-wide co-ordination of national meteorological resources for military purposes. Closer co-operation with the United States Air Weather Service and the German Military Geophysical Office is developing from that initiative.

(g) *Contingency planning.* Most of the meteorological services for Defence are provided through the 60 meteorological offices located with the Royal Air Force, the Army and the Procurement Executive users, but there is a range of activities related to Defence, other than the management of the Defence Services Branch, which is organized by the small headquarters unit of 12 staff located in the Meteorological Office Headquarters at Bracknell. Contingency planning for emergencies both within the Meteorological Office and, in co-operation with all three Services, for the wider requirements for meteorological support in a national emergency is an important feature of the work in the headquarters of the Defence Services branch, working closely with the Directorate of Naval Oceanography and Meteorology. Particular attention is also paid to emergency plans for providing meteorological advice from the nearest MMO, including computed fallout trajectories, to the various nuclear establishments in the event of the accidental release of nuclear material either from a fixed location or in transit.

Support from the central resources of the Meteorological Office

The extensive central resources of the Meteorological Office at Bracknell provide major support for the meteorological offices meeting Defence needs. The central planning teams responsible for the development of computer-based systems are directly concerned with the extension of automated support to the Defence Services outstation forecasters; the communications needs of the Defence Services organization, in particular the development of automated communication systems, are integrated into Meteorological Office communication planning as a whole and the considerable research capability of the Meteorological Office takes account of Defence needs for meteorological research, previously through the Defence representatives in the Meteorological Research Committee and now through the representation of Service interests in the expanded Meteorological Committee.

With the introduction of a new cost-accounting system in 1978 it became possible to present financial information in detail and to analyse the allocation of expenditure over the whole range of Meteorological Office activities, including the provision of central meteorological support and advice for Defence. The cost-accounting analysis for 1980/81 showed that more than 50% of the net cost of the Meteorological Office was allocated to activities directly concerned with Defence. The value of providing services for Defence from within one organization meeting almost all the meteorological needs of the nation is demonstrated by the channelling to Defence of over 50% of the net expenditure of the Meteorological Office through only 25% of the total staff. The situation is unique amongst meteorological services meeting military needs and explains why the Meteorological Office is able to maintain the highest standards in its service to Defence, through the capability for drawing on central support such as numerical forecasting, computer-based systems and communications developments and Defence-related research. There is an additional advantage to the manning of Defence Services Branch posts in that the 25% of the total Meteorological Office staff who are required to work in the military environment can be selected from the total complement.

The Meteorological Office, apart from providing the meteorological support required day-by-day for Defence activities, is concerned with developing the organization which meets those needs so that it will remain relevant into the foreseeable future. An important aspect of that task is the maintenance of an understanding of the military needs for environmental support in the Meteorological Office response to the needs for Defence. If meteorological support for Defence activities is to be fully effective it is equally essential that there is a corresponding awareness on the part of military commanders of the effect of weather on military operations.

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Low-level flow through the Strait of Gibraltar

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Summary

On 25 August 1981 an unusual and fortunate set of circumstances allowed the NOAA-6 satellite to give a picture of the winds through the Strait of Gibraltar thereby enabling the wind flow to be related to the surface pressure pattern.

1. Introduction

Although the flow of air into and out of the Mediterranean Basin is largely in response to synoptic scale developments, the low-level winds are more or less controlled by the topography, especially when they are constrained to move horizontally by the presence of an inversion below the level of the adjacent high ground. Of course, the movement of the air will approach the geostrophic balance wherever and whenever possible, but owing to orographic influences the isobaric pattern is often forced to undergo some large local changes and the associated winds such as the Mistral and the Bora are well known features of the Mediterranean weather patterns.

2. Topographical aspects near Gibraltar

In the area surrounding the Strait of Gibraltar—a natural gorge and the main gap into the Mediterranean in the west—the local pressure changes usually take the form of a centre of high pressure upwind of the Strait and a downwind area of low pressure. This leads to the air being accelerated down the pressure gradient, through the Strait, with the wind direction normal to the isobars. In westerly situations, that is when the general low-level flow has a component from the west, this effect is usually not well pronounced as the air can escape southwards.

When the air is trying to get out of the Mediterranean it is trapped in the Alboran Basin and the easterly wind—the Levanter—which develops often accelerates from comparatively light airs in the Basin to near gale force at the other end of the Strait. Such winds produce some dangerous seas, especially when they are blowing against the tide and current, and the observational network is such that they would go largely unnoticed in the absence of ship reports. Even with ship reports it is not easy to build up a comprehensive picture of the wind field, and the descriptions that emerge are more of a mosaic of isolated reports made over periods of time.

3. Interpretation of the satellite pictures

Normally satellite pictures are not of any great assistance in this respect; however, on 25 August 1981 the NOAA-6 satellite provided a graphic illustration of not only the flow through the Strait but also the shape and extent of the Levanter well out towards the Atlantic.

During 24 and 25 August an anticyclone moved slowly into the area of the British Isles with a subsequent pressure rise over the western Mediterranean. Some of the surface air forced out of the latter area of high pressure was pushed westwards into the Alboran Basin, and as the sea was essentially cooler than the surface air over the anticyclone a low-level inversion formed, the height of which was about 1200 feet in the Gibraltar area. Consequently, most of this westerly flowing air below the inversion level had to be forced through the Strait. Fig. 1 shows how the pressure pattern had changed from a weak anticyclonic flow over the western end of the Mediterranean and the surrounding land masses to accommodate the effects of the topography. Normally, and particularly during the summer months, this sort of situation also produces stratus cloud, below the inversion, obscuring the sea surface from satellite scanners. Fortunately, on the 25th, not only was the air too dry for the formation of any cloud, but the position of the sun was such that sun glint would occur off reflecting surfaces, such as a smooth sea, in the Gibraltar area on pictures transmitted by the morning pass of the satellite. Fig. 2 is a satellite photograph in visible light from the NOAA-6 satellite showing Spain and part of north-west Africa. The two land masses are comparatively dark with the sea between them a much lighter shade. This is in marked contrast to that from the Atlantic where sun glint could not occur. On the right hand side, the easterly winds were strong enough to disturb the sea surface which shows as grey; further in towards the Strait they had slowed to the point where they were not strong enough to form sizeable ripples and the image is quite bright. Through the Strait and out towards the Atlantic there is a plume where the picture is nearly as dark as that from the land indicating quite clearly that the air is suddenly accelerated into a wind strong enough to destroy completely the smooth surface of the sea. The plume continues for some 100 km as a well defined, slightly widening, belt of strong winds.

Fig. 3 is the corresponding infra-red image, and it should be noted that here the sun glint has disappeared and the surface of the sea shows up as uniformly dark thereby confirming the interpretation of the visual image given above.

4. The surface pressure fields

At Gibraltar, the strength and direction of the surface wind are monitored by plotting the algebraic difference between the pressure at Alicante, on the east coast of Spain, and that reported at Casablanca, in Morocco. The direction of the wind—east or west—is given by the sign of the difference and an empirical relationship based on the magnitude is used to give the strength. Of course, such a relationship has to be used with circumspection as there are some situations that automatically preclude it as either a forecasting or an analytical tool, particularly when large isallobaric components are involved. Fortunately these situations tend to be the exception rather than the rule and for much of the year the pressure difference between stations referred to above can be used to calculate the wind, not only at Gibraltar, but in the Strait, where observations are few and far between. Indeed, it is the only way in which the winds may be forecast or estimated since there is no practical way of calculating them when the forces are markedly unbalanced.

On 25 August this pressure difference had risen to about 5 or 6 mb which can be translated into an easterly wind of about Force 4 at Gibraltar and Force 6 or thereabouts at the western end of the Strait. Although the satellite imagery cannot be used to give the strength and direction of the surface wind, it does illustrate quite clearly the pattern of the winds in the Gibraltar area when they occur with the sort of pressure field shown in Fig. 1. Since this sort of pressure distribution is quite common at any time of the year when air is trying to get out of the Mediterranean, the pictorial evidence of the winds provided by the satellite is quite valuable.

It is interesting to note that although the geostrophic force has little effect on the winds in the Strait, inasmuch as it is probably counteracted by minor changes, it is probably responsible, together with the pressure gradient force downwind of the Strait, for the maintenance of the winds generated in the Strait as a discrete area of strong winds well out towards the Atlantic until they are finally destroyed by frictional forces and a certain amount of lateral mixing with air of much lower momentum.

5. Conclusion

The fact that the wind can blow in a direction normal to the isobars for long periods of time is not as widely appreciated as it might be, especially in the small-ship community. This illustration, apart from showing the value of satellite imagery, may help with the understanding and interpretation of weather charts received by radio facsimile in the areas of the Mediterranean where the low-level flow is strongly influenced by the topography.

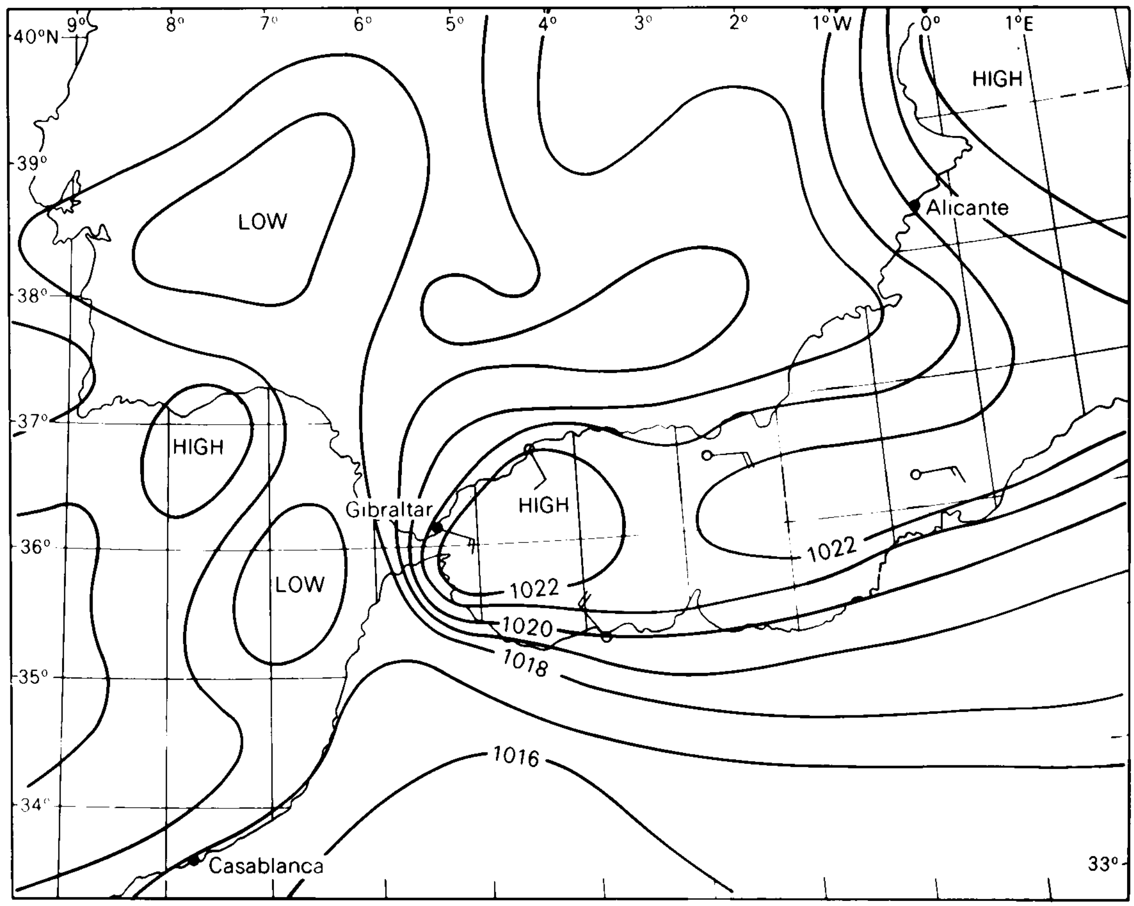
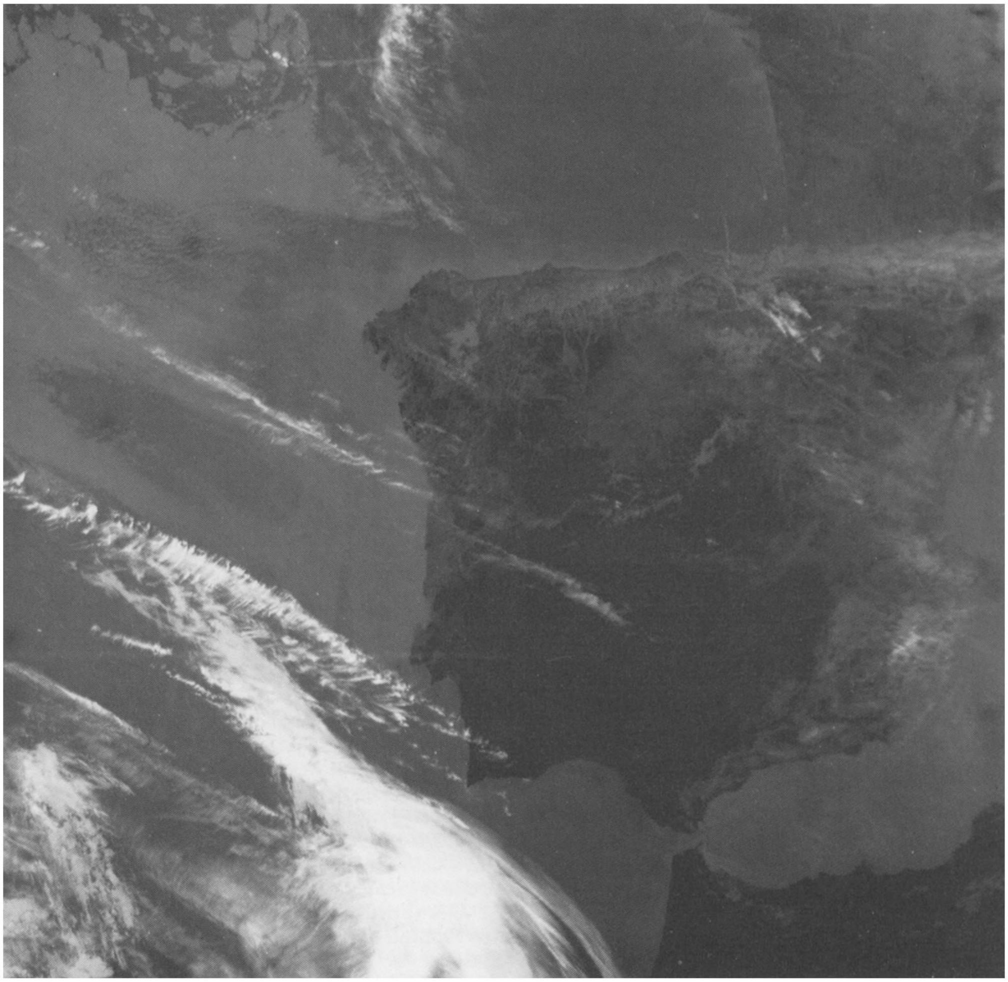


Figure 1. Mean-sea-level pressure pattern at 12 GMT on 25 August 1981.

Photograph by courtesy of Dundee University

Figure 2. Visual image received from NOAA-6 at 0858 GMT, 25 August 1981.



Photograph by courtesy of Dundee University.

Figure 3. Infra-red image from NOAA-6 for the same time as the visual image shown as Figure 2.

100 years ago

The following extract is taken from *Symons's Monthly Meteorological Magazine*, June 1882, **17**, 65.

GALE OF APRIL 29TH, AND SEA SPRAY IN LONDON.

We remember reading, but, until Mr. Ramsay's *Scientific Roll* comes to the rescue, we cannot tell where, that in one great gale all the windows in Leeds which faced W, were covered with a thin film of sea salt. From Leeds to the sea is, in that direction, about 54 miles, and between the two runs the Pennine range of hills with an average height of quite 1500 feet.

On April 29th, 1882, a very violent gale swept over the South of England—at some stations a stronger gale than on either October 13th or November 26th, 1881—and it proved seriously injurious to the young foliage of many trees, notably horse chestnuts. The precise *cause* of this injury is disputed, and as we think the matter worthy of attention, we reprint *in extenso*, or in abstract, all the notices that we have received or seen respecting it. Some persons hold that the damage was solely mechanical, and was due to the bruising of tender foliage by the violent wind, others contend, and bring evidence in support of their contention, that it was largely due to the atmosphere being charged with salt. We regret being unable to contribute anything worthy of consideration as scientific evidence to the question; for although we noticed that our windows were more obscured than usual, even after a dirty London rain, and that they looked slightly milky or frosty, it did not occur to us to examine them before they were cleaned.

We proceed with the notices upon the subject, taking them as nearly as possible in chronological order.

SATURDAY'S GALE

To the Editor of the Standard.

SIR—May I draw your attention to the unusual fact that the wind during the gale on Saturday last was, to the distance of at least thirty miles inland from the South Coast, largely impregnated with sea-salt? The effect of this on the vegetation is very marked. The foliage of this part of the country, which two days ago was dressed in its freshest Spring garb, is now, after some twelve hours of wind, reduced in many cases to a state as black, shrivelled, and scorched as it was before bright and beautiful.

Few people, I imagine, will, at first sight, suspect the true cause of this blighted state of the blossoms and foliage, some no doubt ascribing it to the extreme boisterousness of the wind, which, by knocking the leaves one against the other, beat them to their shrivelled black condition, whilst others will put it down to the peculiar sharpness of the wind. But the actual cause is easily ascertained by applying the tongue to the surface of a large broad leaf which has been plucked from some tree or shrub that has stood in the face of the wind. On some of the leaves which I examined the salt was actually visible, showing how heavily the air must have been laden with it. I had no instrument for determining the extreme velocity of the wind on Saturday, but it must, judging from the effects, have exceeded anything of the kind in this part of the country for the last seven years; probably the pressure per square foot was not far short of forty-five pounds.

I am not aware how far the wind has been known to carry the sea-brine—probably to a distance greatly exceeding thirty miles. What eventual effect this highly salinous top-dressing will produce on the fruit trees of this country remains to be seen, very probably it will manifest itself in a reduction of the crop by one-half.

I am, Sir, your obedient servant,

E.L.D.S.

Tonbridge, May 1st.

To the Editor of the Standard.

SIR—Saturday's gale produced a similar effect on the trees in the Old Deer Park, in which this Observatory is situated, to that observed by your correspondent at Tonbridge, shrivelling up and blackening the leaves not only of the horse chestnuts, but also of the oaks and elms.

Seeing his letter in this morning's paper, I have examined some of the leaves. These not only give strong evidence of the presence of salt, when water in which they have been soaked is treated with silver nitrate, but on examining their surfaces, crystals may easily be seen, which, when viewed microscopically, are readily identified as salt, by their well-known cubical form.

As this observatory is over fifty miles from the sea, in the direction of south-south-east, in which the wind was blowing during the gale, the evidence of transport of salt to such a distance is interesting.

As to the velocity of the wind in the storm, although our greatest hourly run here was fifty miles, yet I timed several gusts between three and four p.m., when for two or three seconds the rate was from seventy to eighty miles per hour.

The meteorological observations at this observatory have now been made for about forty years, and I do not recollect ever seeing an entry of such an occurrence as that of last Saturday.

I remain, Sir, your obedient servant,

G. M. WHIPPLE, Superintendent.

Kew Observatory, Richmond, Surrey, May 2nd.

To the Editor of the Standard.

SIR—Your correspondent "E.L.D.S." says that he is not aware how far the wind has been known to carry the sea-brine. I can inform him that it has been credited with conveying it a much greater distance than thirty miles. I remember a storm which occurred on a Sunday, about twenty years ago, when I was residing at Burton-on-Trent (from which place the sea at its nearest point must be about ninety miles distant), on which occasion the *savants* of the neighbourhood declared that they discovered the presence of sea-spray in the air. For the accuracy of their researches I cannot vouch, but I can attest the fact that throughout that memorable afternoon a seagull was circling over the waters of the Trent, which were lashed by the wind into the miniature resemblance of a storm-tossed ocean.

I am, Sir, your obedient servant,

J.R.

London, May 2nd

To the Editor of The Times.

SIR—The gale of Saturday last has entirely changed the appearance of the country in these parts, and has besides effected considerable damage on the fruit trees, especially in exposed situations.

The leaves of the elms and oaks on the south-west sides of the trees might convey the impression that they had been scorched by fire, while the more tender foliage of the lime, maple, and poplar appear to be well-nigh destroyed, and several weeks must elapse before the injuries received can be repaired by fresh growth; though it may be doubted whether these trees will wholly recover throughout the summer, as the young shoots are in many instances entirely destroyed. Pears have suffered much, as far as the leaf is concerned, although the fruit itself, which is now mostly set, does not appear to be greatly injured; still, as every one who has any acquaintance with gardening is aware, fruit cannot grow on trees that are denuded of leaves. The plum trees, though perhaps to a less degree, are a good deal cut about, while the leaves of the apple are blackened and the blossoms crippled. Black-currants are also sufferers, whole branches being torn off from bushes growing in open places, and the remainder appearing as though frosted.

I have never recorded so severe a gale from the south-west during the month of April, nor does the recollection of a similar one occur to the memory of that proverbial individual, "the oldest inhabitant". At this season of the year, if gales take place, they blow almost without exception from the east, or north-east, but this year these winds have been confined to the first ten days in April.

With this fact in view, and considering at the same time the unusual force of wind just experienced from south-west, I have little doubt that this will be the prevalent wind for some weeks to come and, though forecasting for any length of time beforehand is always dangerous, that the early summer, at least, will be more or less wet.

I am, Sir, your obedient servant,

WILLIAM R. C. ADAMSON.

The Rectory, Ashtead, Surrey, May 2nd

To the Editor of the Standard.

SIR—That the interesting observation of "E.L.D.S." that a deposit containing salt was left after last Saturday's (April 29th) gale was correct, I have been at some pains to verify.

Today, by washing a third-storey window, in an exposed situation, with distilled water and a piece of cotton wool (previously tested as to absence of chlorides, and not held in my fingers), I obtained a solution which markedly contains chlorides (with nitrate of silver test) and its evaporated residue crystals of salt. Its taste is decidedly saline.

Yesterday (2nd) I failed to obtain satisfactory proof by testing damaged foliage, for some showed its presence decidedly, whilst on others it was absent, the reason probably being that a later rain had removed it. I was, therefore, unable, without extensive experiments, to say for certain whether the foliage in itself did or did not contain salt.

As to the destructive effect of this salt on the foliage, I cannot but disagree with "E.L.D.S." until I have made further experiments, for frequently only the side of the damaged tree exposed to the blast is the injured side. Surely the other side must have had salt on its young and tender leaves, for they are not yet developed enough to screen one side completely from the other. Then again, each leaf has frequently only its outer edge damaged. Also I have noticed here and there a tender stem blackened in only one spot, where it has bent or been struck. I should imagine that had the destruction been due to salt in the air it would have been more universal, and not confined to those parts exposed in the teeth of the blast. Surely, battering of the leaves and branches can explain it. If due to salt, perhaps those living near the sea can say whether saline air only destroys young foliage.

I am, Sir, your obedient servant,

A.C.H.

Tonbridge, May 3rd.

BUSHEY PARK.—Probably nowhere near London was such destruction caused by Saturday's gale as in the magnificent avenue of chestnut trees in Bushey Park, which the public are informed by the usual notices are "now in full bloom". From Teddington at one end, to Hampton at the other, the scene may be described as one of wreckage. Many large trees were uprooted, while some hundreds of others have suffered severely.

SIR,—The gale of April 29th has here, as elsewhere, done much harm; no one seems to recollect such a gale at this time of the year. It was much worse, in its effect, than that of the 25th, lasting longer, too, though with less rain. The oak trees are blackened, as if by frost; in the less exposed situations, however, one side of the trees remain green. Birches, which last week were in full leaf, now look as bare as in winter. Pear trees have suffered severely, the fresh young leaves being black and scorched. The white cherry-blossom has been suddenly turned brown; in some gardens the currant bushes and young peas are much cut up, and I have seen even rhubarb all bruised and spoilt. The hop-bines in places are so injured as to be useless for tying up, and poles will have to wait for fresh shoots to be properly furnished. So that, altogether, we have a sad interruption to the prospects of a fruitful season.—Yours truly,

J. ELLIS MACE.

Tenterden, May 3rd, 1882

The terrible wind and rain storm of the 29th ult. is worthy of, and will doubtless meet with, notice in your columns. I do not remember ever seeing such devastation wrought amongst vegetation. In this district of Mid-Surrey no great damage has been done, and not many trees were blown down, but the aspect of vegetation on the side from which the storm came is forlorn in the extreme. The chestnut trees have suffered especially; so blackened and withered are the leaves and flowers on the storm side in all unsheltered places that it seems doubtful whether they can ever revive through the summer. The contrast between the storm-beaten and other side of trees is most remarkable. Even the bushes of currant and gooseberry bear considerable traces of damage, the very weeds and nettles by the wayside are blackened. Some of the daily papers have spoken of severe frost coming after the storm. I observed nothing of the kind here; my lowest reading at the time being 35° and 36°, and I am inclined to attribute all to the strange bitterness of the gale, and the cutting blast of hail during one portion of it.—A.C., *Journal of Horticulture, May 11th,* 1882.

ROYAL HORTICULTURAL SOCIETY.—SCIENTIFIC COMMITTEE—May 23rd, 1882.

Sir J. D. Hooker, F.R.S., in the chair.

Foliage injured by Salt in the late Gale.—Dr. Church described experiments he had made at Cirencester during the last fifteen years to ascertain the amount of salt brought by autumnal gales, especially from S.W. He found from 5 to 7 grs. per gallon, while the ordinary amount was only 0.5 grs. The average winter amount was but little more than that of summer. He noticed that in Oakley Park one side of the trees was severely injured, and that if no rain followed for a few days after the gale, the salt sparkled on the trees even at a distance of 35 miles from the British Channel. The salt abstracted the moisture from the cells and formed a condensed solution, so that the leaf became completely dried up and perished.

Mr. McLachlan added that salt had been observed on windows at Lewisham and at Croydon and elsewhere.

Sir J. D. Hooker remarked that Dalton first noticed it at the beginning of this century. With regard to beeches withstanding the gale better than oaks, as mentioned at the last meeting, it was stated that they were unhurt at Kew and Valewood, Haslemere; but at Cirencester, in Dorsetshire, and in Cornwall, they suffered severely.

Mr. Blackmore exhibited foliage of pears, &c., from Teddington; some were quite unhurt; of other trees growing adjacent to them the leaves were severely cut. Vines and peaches showed similar differences. He suggested that it could not be salt in this case.

The opinion generally entertained was, that such discrimination was due to the trees being relatively hardy and less hardy kinds.

SIR, My house here stands on a hill-side exposed to the S.W. I look across a valley, and on the opposite horizon see Leith Hill Tower, 5 miles distant, from which the sea is visible. Of course we felt the full violence of the gale last Saturday (29th); a torrent of rain fell and streamed down my windows for hours together. The next day (Sunday) was very dry and sunny, and I was surprised at 9 a.m. to find my window panes covered with what looked like a finely-crystallized deposit. Examining this with a lens, I detected regularly formed crystals, and on wiping them up with my finger, and tasting them, I found them to be *salt*. I did not chemically analyse it, but its taste was that of common table salt.

The gale was from the S.W., and the nearest sea-coast in that direction, in a direct line, is about 35 miles off.

When I read in the *Times* of Thursday the week's weather report from Kew, I was astonished to find that salt had been found *there* on the leaves, so many miles further from the sea than Dorking.—Yours faithfully,

JAMES DIXON.

Harrow Lands, Dorking, May 5th, 1882.

SIR,—We are thirty miles, at least, from the sea, but on the previous Saturday, our windows were thickly coated with salt, and our foliage is ruined for the year, mainly, I think, by the force of the wind, certainly *not* by insects, though they now abound.—Sincerely yours,

E. S. ROWCLIFFE.

Hall Place, Cranleigh, Guildford, 5th June, 1882.

Our readers have now before them all the evidence which we have been able to collect. We shall be glad to see the subject further discussed.

⁂ This great gale was referred to by the Revd T. A. Preston in his "Report on the Phenological Observations for the Year 1882" (*Q J Meteorol Soc,* **9**, pp 47-60 (1883)) made to the Meteorological Society. In the discussion of the Report which took place on 20 Dec. 1882 Mr. Edward Mawley (later to become President) commented as follows:

On the 29th of April, however, there occurred a gale, which as regarded the wholesale destruction of leaves and blossoms of trees, and indeed of all vegetation exposed to its direct influence, was in his experience unprecedented. For some time afterwards the windward side of those trees, the foliage of which was sufficiently advanced to be affected, appeared as if blackened by fire, whilst the sheltered side was unscathed. Later on all this was changed, so that only the usual dull green leaves of mid-summer were to be seen on the north side, while the south or injured side bore the fresh green foliage of spring. In many cases these new leaves were slow in appearing, owing to the severe shock the trees had themselves sustained through their untimely defoliation; and the effect of this was to leave them greatly open to the attacks of blight, caterpillars, and other insect pests. Only a few weeks ago a third result of this gale was apparent, for while the injured trees, and particularly oaks, had scarcely a leaf left upon them, those few which had escaped the storm continued in such active growth, owing to the cool summer and wet autumn, as to retain nearly the whole of their foliage, the dead leaves clinging to the still unripened wood. It would be, as remarked in one of the horticultural papers at the time, interesting in years to come to trace in felled timber the influence of this storm upon the thickness of the layer or layers of wood which had been formed during the current year. Mr. Mawlay was pleased to find that Mr. Preston in no way attributed the damage to trees either to the deposit of salt spray upon their young foliage, or to the action of frost, but had happily described the leaves as simply "beaten to death" by the wind. It had been popularly supposed that the salt which fell during this gale occasioned much of the mischief, and even so keen an observer of nature as the Poet Laureate appeared to have held this opinion, for in his new drama of "The Promise of May" he spoke of a "salt wind" which "burnt the blossoming trees." Whereas the long-continued violence of the wind was in itself sufficient to account for all the damage done to the tender young leaves. At Addiscombe a velocity of thirty-six miles an hour was on this occasion maintained for six consecutive hours, and at Kew some of the individual gusts were stated to have attained a rate of between seventy and eighty miles an hour. In fact, Mr. Eaton had noticed that much injury had been done to the foliage of several chestnut and pear trees in Croydon before any salt had been deposited, and some time before the storm had reached its height. In another part of Mr. Preston's report an instance had been given of even the comparatively tough leafage of autumn having been killed by the violence of the wind during the severe storm of October 1881.

However, Brazell in *A Century of London Weather* (HMSO, 1968, p. 75) says that 'It is probable that the sea salt carried inland by the wind was mainly responsible for the damage.'

Notes and news

Heaviest daily rainfall in Scotland

Recent correspondence with Mr G. Reynolds of the North of Scotland Hydro-Electric Board has drawn to our attention the fact that the daily rainfall total for the 24 hours commencing 9 a.m. on 17 January 1974 at Sloy Main Adit, amounting to 238.4 mm, broke the previous daily total officially recorded for any site in Scotland. The location of the Sloy rain-gauge, by grid reference, is NN (27) 293104 and at 204 metres above sea level.

The previous record was apparently held by Loch Quoich, Kinlochquoich, when 208.3 mm was recorded for the rainfall-day of 11 October 1916. The now third-highest total in Scotland seems to be the 199.1 mm at Dalness (Glen Etive), on 17 December 1966.

The highest daily fall in the United Kingdom remains the 279.4 mm at Martinstown on 18 July 1955, whilst the highest fall on record in Wales is 211.1 mm on 11 November 1929 at Rhondda, Lluest Wen, and on record in Northern Ireland is the 152.4 mm at Coleraine, The Cutts, on 15 December 1928.

Correspondence

Comment on 'Computation of vapour pressure, dew-point, and relative humidity from dry-and wet-bulb temperatures'

Sargent (1980) discussed a number of equations for evaluating saturation vapour pressure and compared their results with those given by the Goff-Gratch formula.

The well-known 'Tetens' expression (e.g. Lowe 1977, Murray 1967, Stackpole 1967) was not included although it is particularly suitable for use in small programmable calculators. It gives results acceptable for most meteorological purposes and is readily solved to give an expression for calculating dew-point temperature from vapour pressure.

As given by Stackpole,

$$e_s = 6.11 \times 10^{7.5/(T + 273.3)}$$

where e is the saturation vapour pressure over water in millibars (mb) and T is temperature (°C).

From this is obtained

$$T_d = \{237.3 \log(e/6.11)\}/\{7.5 - \log(e/6.11)\},$$

where T_d is the dew-point temperature corresponding to a vapour pressure e.

Slightly better agreement with results from the accepted standard formulae is obtained by using more figures for the constant 6.11. (6.107 if the formula recommended by the World Meteorological Organization (WMO) (1979) is taken as the standard; 6.1078 if, following Sargent, the Goff-Gratch formula is taken as the standard.)

The differences in saturation vapour pressure calculated with this formula and that given by WMO, are less than 0.02 mb between −50 °C and +50 °C (Table I). If the Goff-Gratch values are used as reference, or if the more exact values for the constant are used, the differences are still smaller.

In calculating dew-point the deviations are smaller than 0.05 °C from about −15 °C to +60 °C.

Table I. *Saturation vapour pressure calculated from WMO and Tetens formulae.*

Temperature *degrees Celsius*	Saturation vapour pressure *millibars*		
	WMO (W)	Tetens (T)	$W-T$
−50	0.064	0.061	0.003
−20	1.254	1.247	0.007
0	6.107	6.110	0.003
10	12.271	12.283	0.012
20	23.371	23.389	0.018
30	42.427	42.442	0.015
50	123.390	123.395	0.005

A routine for calculating the saturation vapour pressures, relative humidity, and dew-point from wet- and dry-bulb temperatures, using these formulae, requires only 59 program steps in a Hewlett-Packard 97 programmable calculator.

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J. D. Coulter & S. K. Sharma

Fiji Meteorological Service

The author replies:

Coulter and Sharma quote (or rather misquote!) the 'Tetens' formula for evaluating saturation vapour pressures and imply that it should have been included in my original paper. The same could be claimed for other formulae (e.g. Tabata, Bogel, Rasmussen, etc.) but it was never suggested that the paper was exhaustive and only a selection of formulae and procedures was included.

The Tetens formula is quite useful and in order that intending users should not be misled it is appropriate that it be quoted correctly, viz:

$$e_s = 6.11 \times 10^{(7.5T)/(T+237.3)}.$$

Although the differences are small enough to be ignored for most practical meteorological purposes, I found the values given by the WMO recommended formula to be as in Table I. The differences are shown as relative differences which give a better idea of the accuracy of the evaluations.

Table I. *Saturation vapour pressure calculated from WMO, Goff-Gratch and Tetens formulae.*

Temperature *degrees Celsius*	Saturation vapour pressure *millibars*			Relative difference *millibars*	
	WMO (*W*)	Goff-Gratch (*G*)	Tetens (*T*)	*W-T*	*G-T*
-50	0.064	0.064	0.061	0.046	0.044
-40	0.189	0.189	0.184	0.027	0.026
-30	0.509	0.509	0.502	0.014	0.014
-20	1.255	1.255	1.247	0.007	0.006
-10	2.865	2.864	2.858	0.002	0.002
0	6.111	6.111	6.110	0.000	0.000
10	12.279	12.279	12.283	0.000	0.000
20	23.385	23.384	23.389	0.000	0.000
30	42.452	42.450	42.442	0.000	0.000
40	73.813	73.811	73.774	0.001	0.001
50	123.451	123.449	123.395	0.000	0.000

G. P. Sargent

Meteorological Office,
Bracknell.

THE METEOROLOGICAL MAGAZINE

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NOTICES

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