The Meteorological Magazine

November 1992

History of MRF
PAMPA flights
Teaching dynamic meteorology
Autumn of 1991

HMSO

Met.O.1004 Vol. 121 No. 1444

First published 1992

HMSO

HMSO publications are availa

HMSO Publications Centre
(Mail, fax and telephone orde
PO Box 276, London, SW8 5I
Telephone orders 071-873 909(
General enquiries 071-873 001
(queuing system in operation f
Fax orders 071-873 8200

HMSO Bookshops
49 High Holborn, London, W
(counter service only)
071-873 0011 Fax 071-873 820(
258 Broad Street, Birminghan
021-643 3740 Fax 021-643 651(
Southey House, 33 Wine Stre
0272 264306 Fax 0272 294515
9-21 Princess Street, Manches
061-834 7201 Fax 061-833 063
16 Arthur Street, Belfast, BT1
0232 238451 Fax 0232 235401
71 Lothian Road, Edinburgh I
031-228 4181 Fax 031-229 273

HMSO's Accredited Agents
(see Yellow Pages)

and through good bookseller

The
Meteorological
Magazine

November 1992
Vol. 121 No. 1444

551.5(09):551.507.352

A short history of the Meteorological Research Flight (MRF) 1942–92

W.T. Roach
AD Met O(MRF) 1985–88

Summary

A brief history of meteorological observations in the free atmosphere from the 17th century to the beginning of World War II is followed by an account of the events leading to the formation of MRF. Then follows the main part of the paper which consists of an account of the work (scientific, observational and airborne meteorological sensor development) of MRF during the period 1942–92, how this work was integrated with the research programme of the Meteorological Office, and of national and international collaboration with universities and other research institutions in major field experiments.

1. Before MRF

Reports of the sporadic use of kites and balloons to make meteorological measurements in the free atmosphere appear in the literature back to the mid-eighteenth century. From then until the birth of aviation in the first decade of this century, highlights were:

(a) The first manned balloon flight to measure temperature, humidity and pressure was made by an English gentleman called Jeffries in 1784, who reached an altitude of about 3 km.

(b) About 1862, Glaisher and Coxwell made similar measurements from an open gondola on several balloon flights, once attaining nearly 9 km, and nearly losing their lives in the process.

(c) During the period 1898–1904, the French investigator, Teisserenc de Bort, made nearly 600 unmanned balloon ascents to measure temperature up to 14 km. His painstaking analysis of his measurements led to the discovery of the stratosphere. These flights were the first serious meteorological research, rather than reconnaissance, flights.

As early as 1913, Shaw (then Director of the Meteorological Office) realized the potential of the aircraft as a platform for meteorological measurements and research, and suggested mounting vanes on aircraft to measure vertical air motion, and an accelerometer to measure 'bumpiness', as well as 'other meteorological measurements' including atmospheric electricity. The technology, funds and resources were not available then, or for some time afterwards, to give Shaw's proposals practical effect. Between the wars, limited attempts to fit some basic instruments to a few aircraft were made and, in 1927, a meteorological reconnaissance flight was established at Duxford, but little of meteorological value came from these initiatives.

However, the weather dependence of aviation had, from the beginning, created a demand for meteorological reporting and forecasting services, and resulted in 1920 in the absorption by the Air Ministry of the Meteorological Office. In addition, the rapid technical development of aircraft, forced by the operational demands of two world wars, had soon revealed further weather-related hazards (e.g. airframe icing, visibility of aircraft contrails to enemy aircraft, fog) which created a requirement for applied meteorological research.

During the first two years of World War II, it soon became apparent that the (still) rudimentary state of forecasting science, exacerbated by the lack of observations from the Atlantic Ocean — the source of most of our weather — was inadequate for aircraft operations in war. The need to mitigate this situation led to two initiatives:

(a) The formation of duty meteorological reconnaissance flights at RAF stations all over the United Kingdom. By about 1942, one, two, or three flights were being made daily from up to 40 stations to observe temperature, humidity, winds, cloud amount, base and top height, to heights of up to 6 km. These observations formed an essential supplement to the standard synoptic observation network. Some 20 000 flights were made in all. Recently, this data was put into computer-compatible form and used to assist the helicopter icing problem.

(b) The formation of the Meteorological Research Committee (MRC) in November 1941 with an urgent brief to foster and oversee investigation and research into meteorological science.

One of the first initiatives of the MRC was to arrange (through the Air Ministry) for the deployment of meteorologists, led by Dr A.W. Brewer, to the High Altitude Flight (HAF) at Boscombe Down in August 1942 to investigate the atmospheric conditions favouring the formation of aircraft contrails.

2. Boscombe Down (1942–46)

At Boscombe Down, Brewer's group were initially allocated two Boston and one Spitfire aircraft on which to install their instrumentation. Soon afterwards, Fortress, Mosquito and Hudson aircraft were added. (At that time, aircraft were easier to obtain than staff!) Flying in these early aircraft, often without cabin pressurization or heating, was arduous and tiring. However, the Mosquito was better liked; pilot and meteorological observer sat cosily side-by-side in the aircraft cabin and cooperated very effectively.

The first task was to develop and install aircraft instrumentation for measuring temperature and humidity:

Temperature. A remote reading resistance thermometer was developed for temperature measurements from a Spitfire aircraft. Radiation shielding of the thermometer element, and calibrations to determine the correction required for kinetic heating of the element when exposed to airflows of up to 200 m s^{-1} enabled an accuracy of better than ± 1 °C to be attained. These thermometers were later installed on all MRF aircraft.

Humidity. The frost-point hygrometer for humidity measurements depended on noting the temperature at which frost could first be seen (by a met. observer) forming on a 'thimble' of black glass cooled by liquid nitrogen while exposed to the external airflow. This device was developed by Brewer's group and first flown successfully in a Fortress aircraft late in 1943.

With these basic instruments, it was found that the upper troposphere was quite often supersaturated with respect to ice — conditions which favoured the formation of dense, persistent contrails — and that the stratosphere was extremely dry. These results led to a practical aircraft-contrail forecasting method, but was also a scientific discovery of major importance to studies of the atmospheric general circulation and the related distribution of water vapour as a tracer of atmospheric motion.

3. MRF — The early period (1946–62)

3.1 Move to Farnborough

Following the end of World War II, the practical and scientific success of the meteorological section of the HAF at Boscombe Down led to the establishment in 1946 of the Meteorological Research Flight at the Royal Aircraft Establishment (RAE), Farnborough with the main task of advancing meteorological science, but continuing to provide advice as required on weather-related problems of aircraft design and operation. Although MRF was not so called until 1946, its work was a continuation of HAF work, and so MRF is generally considered to have begun its work in 1942.

MRF commenced with establishment for a larger scientific staff, two Mosquito and two Halifax aircraft and RAF aircrew. Fairly early in the period, these aircraft were replaced by Hastings, Varsity and (in 1952) Canberra aircraft. The Canberra could be 'nursed' to 15 km under favourable conditions, and complemented the lower-level work of the other aircraft. MRF staff and aircrew were accommodated in 'temporary' prefabricated huts near the RAE control tower until 1961, when they moved into a purpose-built brick building on the other side of the airfield.

The aircraft were serviced by the RAE, who also designed the installation of meteorological instrumentation on aircraft to ensure that military safety standards were met, and provided (from various departments) invaluable technical advice on a wide variety of topics. The crucial role played by the RAF aircrew during the whole life of MRF cannot be overstated. A posting to MRF from a 'standard' RAF station was a 'cultural shock' to some aircrew, but they soon entered into the work, and educated the scientists into what flight plans were possible under the increasingly severe navigational constraints imposed by outside military and civil aviation interests.

The daily operational schedule began (subject to aircraft availability) with a briefing meeting at 0830 UTC (often earlier) at which final flight plans for the day were decided on the basis of the meteorological situation provided by the forecasting office based (until recently) at RAE. A flight-liaison officer liaised between scientific users, MRF technical staff, RAF aircrews and several departments of the RAE in relation to flight planning and briefing, and installation and removal of scientific equipment from the aircraft. Finally, he coordinated overseas detachments, where effective liaison with a host airfield staff unfamiliar with the special demands of MRF was essential for the success of a detachment.

This organizational set-up has remained unchanged in fundamentals to this day, though naturally there has been a great increase since 1946 in the sophistication of scientific equipment and data-processing, and also in the lead time required to design and install new equipment on aircraft.

Although aircraft have been used for meteorological research in other countries (particularly in America) since the end of World War II, the MRF facility is unique — as far as the author is aware — in having an aircraft and aircrew dedicated to it full-time.

3.2 Scientific work

The emphasis of 'in house' MRF research was (and still is) on physical rather than dynamical meteorology — i.e. with the structure and behaviour of weather on a fairly local scale, rather than the large-scale atmospheric circulation which carries, and, to some extent creates, weather. Under the active direction of Dr Murgatroyd, three main topics characterized the work of this period: aerosol and cloud physics, radiative transfer and atmospheric tracers.

3.2.1 Aerosol and cloud physics

This was a period of active development of sensors (with considerable assistance from the RAE) to measure the physical properties of clouds — e.g. the distribution of liquid water content, cloud- and rain-drop sizes, and ice particles — and of associated cloud condensation nuclei.

Sensors used then were: impaction on aluminium foil to detect ice particles and drizzle droplets, oiled slides to collect cloud droplets, hot-wire devices to measure cloud water content and a (Pollak) total aerosol counter. Data had to be manually processed which was very slow and time-consuming, but nevertheless produced some valuable studies. The emphasis was on rain-producing clouds, particularly cumulus in various stages of development, but some studies of clouds associated with atmospheric fronts, and also layer clouds were made. This work was to some extent complementary to laboratory studies of cloud microphysics being made at that time under B.J. Mason at Imperial College, and all contributed to a better understanding of the generation of precipitation, and the role of ice particles in this.

3.2.2 Radiative Transfer

Brewer and Houghton (University of Oxford) flew an infrared radiometer from the MRF Mosquito aircraft in 1954 to make some of the earliest measurements of long-wave radiative fluxes and heating rates through the troposphere. So began a long tradition of the use of MRF facilities by Oxford to fly radiometers developed in the Clarendon Laboratory. Later, the installation of photometers and solarimeters on MRF aircraft were used to measure upward and downward solar fluxes in cloud and clear air. The infrared absorption properties of liquid water and water vapour were already known, but MRF flights gave some of the earliest indications of significant additional absorption of solar radiation in clouds and clear air, attributed to the presence of aerosol, particularly downstream of urban areas.

3.2.3 Atmospheric Tracers

During the period covered by this section, first under Dr R. Frith, and then under Dr R.J. Murgatroyd, much further use was made of the frost-point hygrometer and, late in the period, of an ozone detector (also developed by Brewer in the Clarendon Laboratory, University of Oxford) to study the distribution of water vapour and ozone in the upper troposphere and lower stratosphere, particularly through jet streams, and also through a range of latitudes from 10° S to 75° N. A related study was of the incidence of cirrus cloud at high levels, particularly in the easterly jet stream outflow from the Indian monsoon spreading over equatorial Africa during summer.

This topic departed from the mainstream of MRF research in that it was relevant to studies of the stratospheric–tropospheric interchange of air associated with large-scale vertical circulations in temperate and subtropical jet streams in relation to the movement of radioactive products of nuclear tests during the period. The relatively quiescent mid stratosphere was identified as a 'storage tank' for these products.

3.3 Collaborative projects

While the research outlined above was carried out largely 'in-house', it was realized that the exploitation of the data-gathering potential of the aircraft required continued development of airborne sensors and of associated data-processing; of more staff to handle this development; and (perhaps most importantly) the involvement of other research groups. Consequently, collaborative projects became an increasingly important feature of MRF work during this (early) period. Examples were: Observations of the structure of jet streams and fronts in collaboration with the Meteorological Office Forecasting Research Dept., discharge of smoke puffs and radar-reflecting foil for short-period wind investigations at the Meteorological Office radar station, sampling particle plumes for medium-range dispersion studies at the Meteorological Office research outstation at Porton Down in collaboration with the Chemical Defence Experimental Establishment there, carrying radioactive particle samplers, providing solar radiation observations for Kew Observatory, and obtaining samples of airborne pollen for Rothamsted Experimental Station. In addition, links with university research groups were strengthened and many smaller projects undertaken.

The high-altitude work of MRF was interrupted in February 1962 by the loss of the Canberra aircraft (but, miraculously, none of its aircrew) in the sea when approaching to land at Leuchars, Scotland after a long flight to measure water vapour and ozone distribution in the lower Arctic stratosphere. This work was recommenced in the following year with a replacement Canberra with improved instrumentation.

4. The Middle Period (1962–81)

This period marked a transition from the early period with several aircraft, few staff and limited resources to the modern period with advanced technological support and a much larger staff. The work was more integrated within broader research projects.

The rapid advances in microchip and computer technology in this period greatly increased the potential for instrument development on one hand, and for the modelling of atmospheric physical and dynamical processes on the other hand. In particular, the increasing speed and capacity of computers enabled the incorporation of (usually parametrized) physical processes into numerical forecasting and general circulation models, and towards the end of the period, into climate models. MRF therefore had an increasingly significant role to play in providing basic physical data for improving and validating the parametrization of physical processes in models.

In any case, a natural break in MRF work in 1962 was occasioned by the move of MRF to its new building, the loss of the Canberra aircraft and the departure of Dr Murgatroyd. After brief tenures by Mr Zobel and Mr Aanenson, Dr D.G. James became Head of MRF from 1971 to 1982.

External factors shaping the development of the MRF programme during this period were:

(a) Prof B.J. Mason was appointed Director-General of the Meteorological Office in 1965 and, soon afterwards, transferred his Cloud Physics Department at Imperial College with some of its staff to the Meteorological Office under Mr P. Goldsmith. This department has been the principal user of MRF facilities since then.

(b) The Meteorological Research Unit located at the Telecommunications and Radar Research Station, Malvern led (after 1966) by Dr K.A. Browning. This unit was responsible for pioneering the national weather radar network we now have, and its common areas of interest with MRF were frontal dynamics and clear air turbulence.

(c) The Meteorological Research Unit at Cardington, Bedford used the tethered balloon facility there to make measurements of the structure of the atmospheric boundary layer. This unit has collaborated with MRF in studies of boundary-layer flow and turbulence in the vicinity of hills.

(d) Growing concern with atmospheric pollution in general and the acid rain problem in particular during the 1970s led to collaboration with the Central Electricity Research Laboratories (CERL), Leatherhead and the beginning of atmospheric chemistry studies at MRF.

The Hastings and Varsity aircraft were withdrawn from MRF at the end of their design lives during the late 1960s, and replaced by another Varsity and (not until 1974) by the C-130 Hercules aircraft (XV208), or 'Snoopy' as it became known after the installation of its nose probe (Fig. 1).

The case for acquiring the C-130 rested heavily on the invitation for it to participate in the international Global Atlantic Tropical Experiment (GATE) in 1975. This was the first of about a dozen international cooperative experiments (see Annex B) in which the Hercules has participated up to now.

4.1 Instrumental development

Important developments during this middle period were:

On-board data-processing system. At the beginning of this period, aircraft data was recorded manually by observers, or on charts, and the subsequent processing was also largely manual. It had been realized for some time that a radical improvement in aircraft data-process-

Figure 1. A view of the C-130 in flight. Its capacity and endurance make it ideal for atmospheric research.

ing facilities was essential if further scientific progress was to be made. The main concept was to install an on-board computer to record data from meteorological sensors on tape to be processed after the flight by ground-based computer. This computer was installed in an observer's cabin (or van) in the Hercules. This cabin protected observers in it from aircraft noise, provided real-time displays in the van and to the aircraft scientist on the flight deck, while the van itself could be removed bodily from the aircraft during periods of major servicing.

The implementation of this system was given urgency by the planned participation of the Hercules in GATE. Aircraft data had to be transferred to magnetic tape in a prescribed format for transmission to other scientific institutions involved in GATE.

A parallel development was a move away from dependence on the RAE for ground-based computer processing of data with the installation of computer systems in MRF, and virtually complete independence from RAE computing facilities was achieved by about 1980.

Inertial navigation. The installation, first on the Canberra and later on the C-130, of nose probes carrying rapid-response wind vanes linked to inertial platforms centred near the aircraft centre of gravity, made it possible to extract the aircraft position at any time, and also wind and turbulence data from which aircraft motions had been automatically removed. This development was foreseen by Shaw 60 years before.

Dropsondes. One of the first tasks undertaken by the Cloud Physics Department after its move to the Meteorologcal Office was to develop a radiosonde to be released from the Hastings aircraft. The transmitted data would then be received and stored by an on-board computer. This system was used on the Varsity aircraft in Project SCILLONIA (see below) in 1969–70. A radically improved system was then developed for installation on the C-130, and eventually used in a major project in 1987.

Cloud-physics probes. During the first decade of this period, it became possible to collect and process large amounts of cloud microphysical data in a reasonable time using advanced optical-sensing techniques developed in particular by Knollenberg, an American electronics engineer. Some of his optical probes were purchased by the Cloud Physics Dept. and installed on the C-130. They depended mainly on detecting and measuring the intensity of pulses of light scattered from cloud droplets (and later precipitation and ice particles) passing through a sensitive volume exposed to the airflow. An example of the data obtained using these probes is shown in Fig. 2.

A holographic camera was also installed to give the 'instantaneous' location and size of particles in a 0.5 litre air sample 'caught' by a laser pulse a few nanoseconds in duration. Liquid water content was measured by an advanced hot-wire device and compared with liquid water contents derived by summing over drop-size distributions obtained with the Knollenberg probes. There remained, however, considerable difficulties in assessing how representative the measurements were of the structure of cloud volumes large compared with the (very small) sampling volume of the probes.

Chemical sampling. A range of chemical sampling equipment was installed on the C-130 for use by CERL. These enabled both *in situ* measurements to be made,

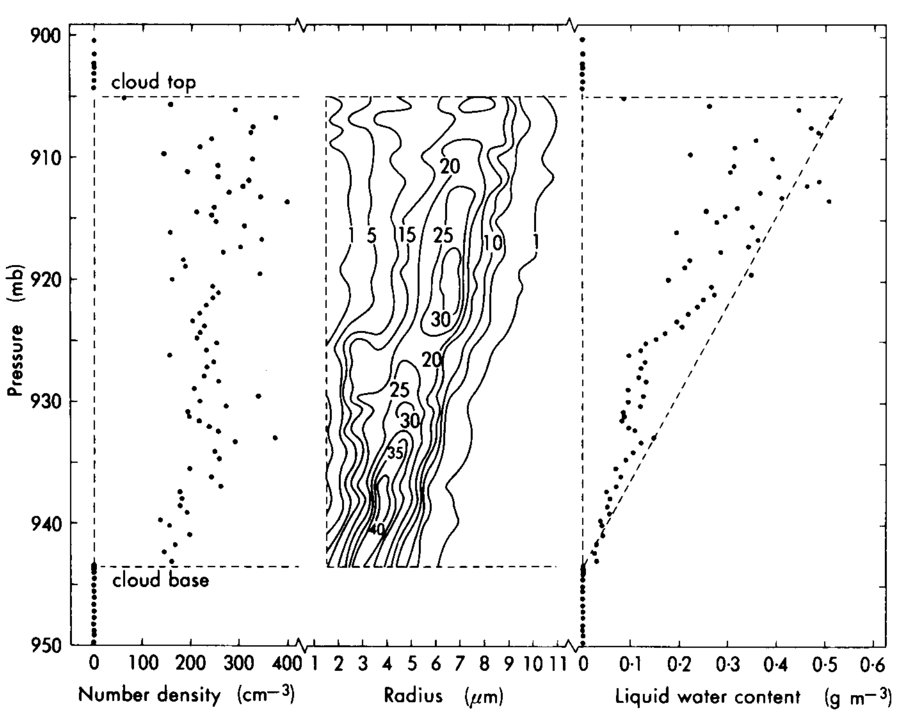

Figure 2. Profiles of the concentration and spectra of cloud droplets, and of the liquid water content through a layer of stratocumulus cloud on 19 November 1976 using an optical probe.

and samples collected for later analysis of several chemical species, particularly nitrogen and sulphur species and ozone.

4.2 Scientific work

Cloud Physics. Early in this period, the main thrust of research in cloud physics was moving away from laboratory studies and towards the interaction of the cloud microphysics with cloud dynamics. This study could only be advanced by the use of research aircraft.

The first major project SCILLONIA (based from the Scilly Isles) used dropsondes released at 5 km from the Varsity aircraft to obtain the mesoscale structure of wind, temperature and humidity within active warm-frontal zones approaching the British Isles from the Atlantic, where the system was (as yet) undisturbed by topography. A major finding of this study was the existence of organized bands of vertical ascent and descent spaced apart by about 100 km and correlated with bands of precipitation. This led to the development of a new dynamical theory of 'conditional symmetric instability' depending for its initiation upon the release of latent heat in air ascending the frontal slope.

Atmospheric turbulence. The installation of the inertial platform on the Canberra and C-130 made possible some important studies of turbulence in various meteorological contexts:

(a) Studies of the structure of the marine boundary were made to check existing marine boundary layer similarity theory and bulk aerodynamic transfer coefficients. As part of this study, the C-130 participated in the Joint Air–Sea Interaction (JASIN) experiment off north-west Scotland in 1978.

(b) In collaboration with MRU Cardington, measurements were made from the C-130 of the flow and turbulence structure around Ailsa Craig, a steep, symmetrically shaped island off south-west Scotland. Measurements were also made with a tethered balloon deployed to Ailsa Craig. This study was used to validate a numerical model of the airflow in order to tackle the very difficult problem of airflow over hilly or mountainous terrain needed urgently to improve parametrization of frictional drag of the earth in forecasting models.

(c) Studies of the structure of high-level clear air turbulence and mountain waves were made using the Canberra aircraft with the objective of improving understanding of the role of internal friction (as distinct from friction with the ground) in modifying the atmospheric circulation. Some clear air turbulence studies were made in collaboration with MRU Malvern, with the aircraft flying over a high-power Doppler radar able to detect clear air turbulence. A detachment of the Canberra aircraft was made to the Colorado mountains in 1973 to measure the vertical transfer of momentum flux by high-level standing gravity waves. This is internal drag due to the 'cog-wheel' effect of distortions of the wave shape.

Atmospheric Chemistry. A series of flights were made over the North Sea in downwind plumes emitted by a major power station to study the dispersion and chemical evolution of plume pollutants. The rate of oxidation of sulphur dioxide to sulphate was found to depend critically on the presence of cloud.

Radiative Transfer. Work in this area was relatively low-key during this period. However, the prototype flight model of the Selective Chopper Radiometer flown on the NASA NIMBUS 5 satellite was installed on the Canberra aircraft, and a study made by the University of Oxford group of the background (continuum) absorption (attributed to water vapour) across the 10–12 micron 'window' in the atmospheric infrared spectrum. The emission associated with this absorption is a significant contributor to the greenhouse effect, but has not had the 'publicity' of carbon dioxide in this regard.

During the late 1970s, the evolution of layer clouds, and particularly their interaction with radiative transfer had begun to attract attention. Fluxes of solar and terrestrial (long-wave infrared) radiation through marine stratocumulus were observed during JASIN with radiometers mounted on the Hercules and other aircraft. In this case, the fluxes observed agreed well with those generated by radiative transfer schemes.

By the end of this middle period, MRF had an international reputation, and the C-130 was in regular demand to participate in international projects.

The Canberra aircraft (WE173) was removed as part of the cuts in Government expenditure in 1981. The ability of the Canberra aircraft to provide observations in the lower stratosphere was limited to the aircraft ceiling of about 15 km. While this had been an advance on the Mosquito aircraft ceiling of about 12 km, 15 km was not adequate for comprehensive observations within most of the ozone layer — probably the most important requirement in modern environmental studies of the stratosphere. Unfortunately, there was no opportunity in 1981 of obtaining a replacement aircraft with a sufficiently high ceiling to make worthwhile advances in many investigations of the stratosphere. Accordingly, the thrust of MRF's work became concentrated on tropospheric studies during the modern period.

5. The modern period (1981–92)

With the withdrawal of the Canberra aircraft in 1981 and the retirement of Dr James in 1982, MRF entered a slightly unsettled period in that Dr Jenkins, the present Head of MRF, became (in 1991) the seventh incumbent of that post since James departed in 1982. Nevertheless, the momentum of MRF progress was not seriously interrupted. The main initiatives taken during this period (in roughly chronological order) were:

(a) By 1981, climate research was increasing in importance. When Dr Readings took over from Dr James in 1982, he was directed to upgrade radiative transfer research at MRF in view of the significance of cloud-radiation interaction to climate research.

(b) The ground-based computer at MRF was becoming obsolescent and had to be replaced to cope with the increasing data-processing, analysis and numerical modelling work being undertaken in MRF. In addition, the capacity of recently established links with the main Meteorological Office computer system at Bracknell needed expanding. The development was successfully completed by 1988.

(c) Upgrading of the airborne data-processing system and the transcription of aircraft data tapes to the ground system had again become necessary. This had achieved an acceptable level of performance by 1989.

(d) Installation of additional sensors on the C-130 continued throughout the period in response to the research requirements detailed below. The aircraft now probably carries a larger range of meteorological sensors (Figs 3 and 4) than any other meteorological research aircraft.

(e) As part of a reorganization of the structure of the Physical Research Directorate of the Meteorological

Figure 3. The operation of the meteorological sensors is coordinated by the Aircraft Scientist from the flight deck where he has a clear view through the aircraft window and can call up a graphical display of the real-time output of any sensor as required.

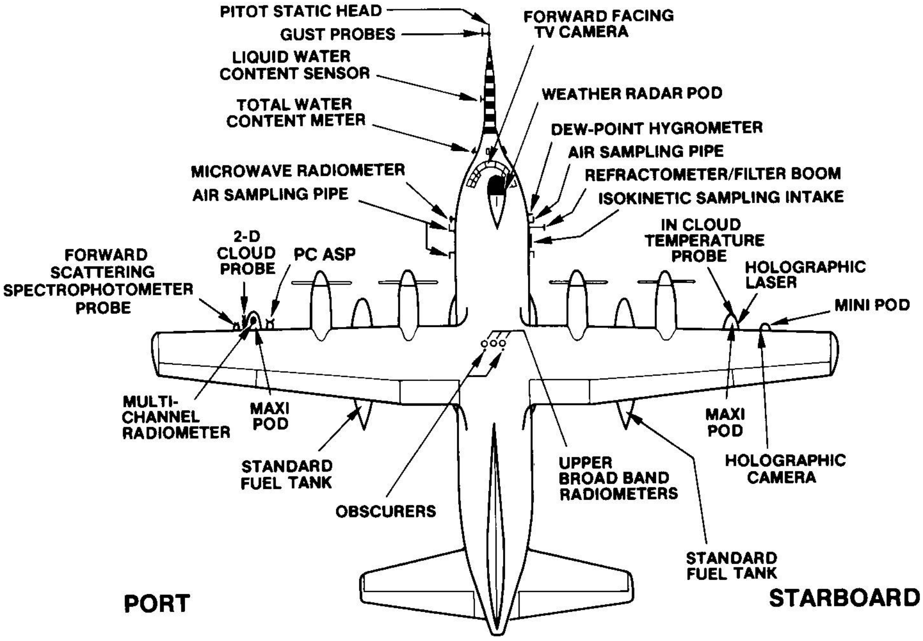

Figure 4. Plan view of the C-130, showing the location of the main meteorological sensors.

Office, the Cloud Physics Department was disbanded, but its two sections using MRF (cloud microphysics and atmospheric chemistry) were brought into the branch, but it was not until 1991 that the latter section moved to Farnborough. In addition, the advanced satellite instrumentation section of the old High Altitude Research Branch was moved to a separate unit located next to MRF, to be known as the Remote Sensing Instrumentation Branch. At the end of these moves the Meteorological Office presence at RAE had expanded from about 25 to about 75. By that time, RAE had become part of the Defence Research Agency (DRA).

Most of the work on the research topics pursued during the middle period (section 4) has continued to the present day, but with some changes of emphasis.

Radiative Transfer. Of central importance to all general circulation and climate modelling is an accurate evaluation of the contribution of radiative transfer to the distribution of heating and cooling in the atmosphere. Accordingly, the principal research objective at MRF was to obtain simultaneous measurements of the optical and physical properties of clouds and aerosol and their environment in order to improve the basis of radiative transfer schemes used in general circulation and climate models. To this end, the first few years of this period were devoted to upgrading the radiometer installations on the C-130 in the following respects:

(a) An updated version of the Oxford Selective Chopper Radiometer (SCR) — previously installed on the Canberra — was installed on the starboard wing of the C-130. This radiometer was designed to sense radiation in 16 channels distributed mainly in the atmospheric window region (10–12 microns) and the near solar infrared spectrum.

(b) Upward- and downward-facing total solar (pyranometers) and terrestrial (pyrgeometers) radiative-flux sensors and their associated data-processing were upgraded.

This equipment was operational by 1987, and the following studies made:

(a) There is a balance of evidence that the observed absorption of solar radiation in layer clouds is generally higher (particularly in the near infrared), and the albedo (reflectivity) of cloud is less than model predictions. In addition, the rate of increase of albedo with fractional cloud cover of broken cloud fields is slower than model predictions. Several theories have been advanced to account for these discrepancies, which remain unresolved. However, the observational base for this study is still inadequate. In this regard, participation of MRF in FIRE (the First International Satellite Cloud and Climatology Regional Experiment) in California in 1987 was an important step.

(b) A long-standing area of uncertainty is the cause and amount of background (continuum) absorption and emission of infrared radiation stretching across the 8–13 micron window, and is attributed to water vapour. This is about 10% in temperate latitudes, but is about 50% in tropical latitudes and is a significant contributor to the greenhouse effect. The SCR was used in a detachment to Dakar, Africa to obtain much-needed observations of the tropical continuum absorption, found to be about 30% higher than existing theoretical models. Further flights have been made around the United Kingdom and over the Mediterranean, and are being analysed.

(c) A start was made on the difficult study of cirrus cloud, limited (at MRF) by the inaccessibility of the higher cirrus cloud by the C-130. MRF participated in a European International Cirrus Experiment in 1989 in parallel with other aircraft with higher ceilings. While some rudimentary knowledge of the gross optical properties of cirrus cloud are beginning to emerge, problems of methods of measurement and their interpretation have still to be resolved, and are likely to absorb most effort in this area for some time to come.

Mesoscale Frontal Dynamics. A major collaborative field study — FRONTS 87 — with French research groups, using ground radar and aircraft deploying dropsondes (Fig. 5) was based at Brest.

The main objective was to obtain an improved dynamical understanding of synoptic — (100–1000 km), mesoscale — (30–100 km) and smaller-scale interactions within systems containing cold fronts. Some principal findings were:

(a) Thermal wind balance along a front is roughly maintained on scales greater than 50 km, but instabilities occur on smaller scales.

(b) Direct evidence of conditional symmetric instability, first thought to be associated with rain bands in warm fronts observed in SCILLONIA.

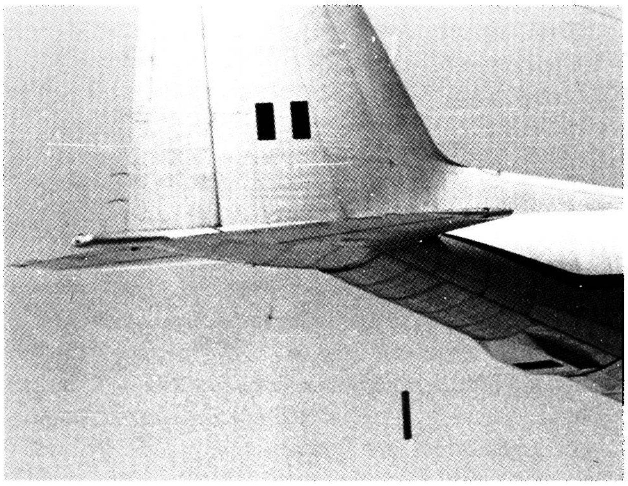

Figure 5. A dropsonde immediately after ejection from the horizontal slot to the right of the sonde. A small parachute is deployed from the sonde a few seconds after release

(c) Frontal development is significantly influenced by regions of condensation and evaporation — particularly of snow and ice particles.

(d) The importance of the role of some conservative dynamic variables (particularly potential vorticity) was clarified.

The data collected during FRONTS 87 (e.g. Fig. 6) has given a fresh impetus to the difficult study of factors controlling the mesoscale structure of fronts, and a successful follow-on study (FRONTS 92) promises to be equally rewarding.

Cloud Physics. Observations and numerical modelling of the water and heat balance of marine stratocumulus was the main theme of this period. Aspects receiving particular attention were: entrainment of dry, relatively warm air into the cloud at cloud top; interaction of the cloud evolution with radiative transfer; and the formation and precipitation of drizzle formed in thicker cloud layers. Successful field-studies were made as contributions to the programmes of FIRE and (recently) ASTEX (Atlantic Stratocumulus Transition Experiment).

A related study of nocturnal stratocumulus was also made from a tethered balloon at Cardington using some of the cloud physics probes normally operated from the C-130. Finally, some case-studies of sea fog forming in early summer off the north-east coast of Scotland were made using the C-130, and the results interpreted as an extension of a numerical model of stratocumulus cloud with its base on the sea surface. Insight into the fog as a self-maintaining, persistent system was gained.

A study was made of the microstructure of ice particles in light precipitating cloud. This involved collaboration of the C-130 with the Rutherford Appleton Laboratory using their dual polarization radar at Chilbolton Observatory. The ratio of horizontally and vertically polarization reflectivity of the cloud observed by radar was related (with some success) to the physical properties of the ice crystals observed from the C-130.

Atmospheric Turbulence. Further projects to investigate the effect of hills on airflow were made over the hills of South Wales using the C-130, tethered balloon and other surface observations. Other international projects were joined to measure the structure of organized convection over the North Sea (KONTUR) and humidity exchange over the sea.

Satellite Meteorology. MRF's involvement in aspects of satellite meteorology have expanded in two main areas; the evaluation of sensors to be installed on satellites, and the provision of ground truth measurements from the aircraft for comparison with satellite measurements at the same time in the same area (known as calibration–validation or 'cal–val' activities).

In the first area, an evaluation has been made of the microwave radiometer (AMSU-B) mounted on the C-130 to measure water-vapour emission in two wavelengths. This radiometer is due to be installed on a NOAA satellite in 1994. The MCR was used during the detachment of the C-130 to Dakar in 1987 to test the principles of the Along Track Scanning Radiometer (ATSR) developed for the ERS-1 satellite.

Cal–val activities have concentrated on the European Space Agency ERS-1 satellite launched in 1991. In September 1991, wind measurements over the sea off the west coast of Norway were made to validate wind algorithms derived from ERS-1 scatterometer data (Fig. 7).

Shortly afterwards, measurements of sea surface temperature (SST) were made from the C-130 in the South Atlantic for comparison with ATSR. (This detachment also provided measurements of the effect of diffuse and direct solar radiation on the dust veil from Mt Pinatubo.)

Atmospheric Chemistry. Although work on 'acid rain' is no longer a major topic (however, sulphur dioxide plumes are still tracked to compare against the

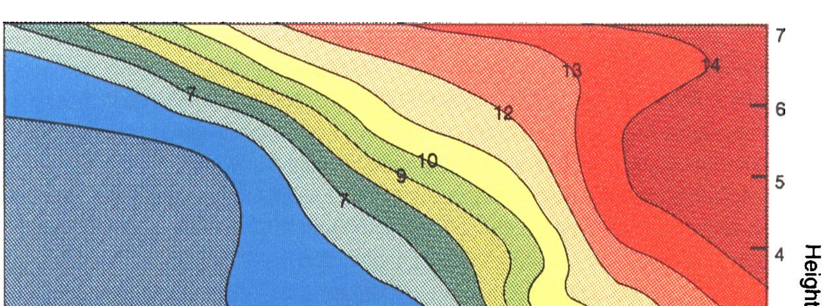

Figure 6. A cross-section of a cold front from FRONTS 87 revealing the fine details of humidity (as wet-bulb potential temperature in °C).

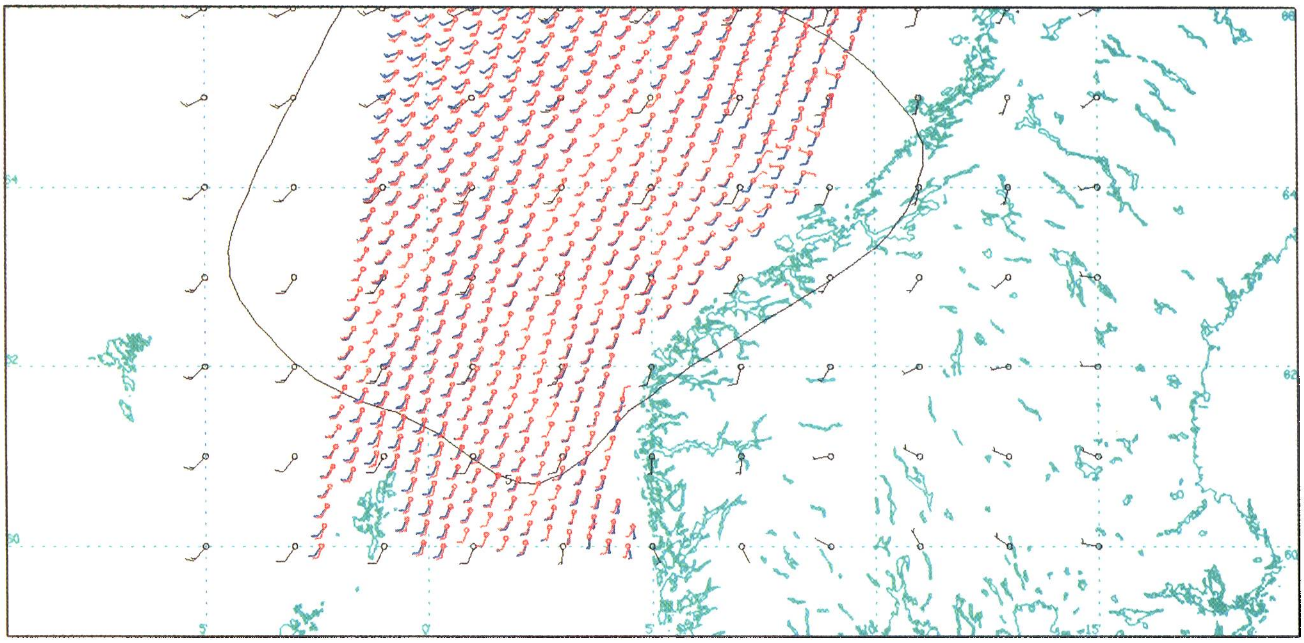

Figure 7. Low-level winds (black vectors) measured from the C-130 off the Norwegian coast are compared with those (red vectors) derived from the scatterometer on the ERS-1 satellite.

predictions of the Met. Office's Nuclear Accident Model), other areas of atmospheric chemistry have expanded. The increasing concentration of ozone in the troposphere, and the realization of its importance as a 'greenhouse' gas has highlighted the need to understand its generation from pollutants such as nitrogen oxides, hydrocarbons and carbon monoxide. The contribution from the stratosphere is also not well known. By 1990, a wide range of chemical samplers had been installed on the C-130 in conjunction with the University of East Anglia and KFA Julich in Germany to tackle this problem.

The chemical instrumentation was brought into use in an unexpected way in March 1991 after the Gulf War had left several hundred oil wells alight in Kuwait. Model calculations that the environmental impact would be locally severe but regionally and globally insignificant were supported by the first airborne measurements made by MRF of chemical and radiative properties of the smoke plume a few weeks after the end of the war. US and German aircraft followed shortly after.

6. The future

Following a major service in 1992, the C-130 has a very full diary for the following two years, with involvement in international programmes in air–sea interaction (TOGA-COARE), atmospheric chemistry (OCTA and NARE) and clouds and radiation (EUCREX). NERC has established a post of Aircraft Officer at MRF in order to enhance the use of the C-130 by the university community in collaborative research programmes with MRF.

There is little doubt that the requirement for a platform for *in situ* measurements of atmospheric processes will continue for the foreseeable future, although the particular emphasis will change. Although weather forecasting and climate prediction models can be improved by greater time and space resolution, this must be accompanied by a better representation of physical processes, many of which are still poorly understood. The main task of MRF continues to be the execution of basic research of atmospheric processes and publication of the results, but with increasing emphasis on the timely incorporation of the results into atmospheric models. In addition, the need for satellite instrumentation development, with the subsequent validation of space-borne measurements, is likely to expand as a greater proportion of global data comes from satellites.

Finally, following the announcement in 1991 that routine military flying will cease from the Farnborough airfield in 1995, hard decisions will have to be made about the future location of MRF. A return to the MRF birthplace at Boscombe Down is one possibility.

Acknowledgements

The author is indebted to Dr G.J. Jenkins, Head of Meteorological Research Flight, for his cooperation, and for contributing sections 5 and 6, photographs and Annexes of this paper. The author also thanks Dr A.W. Brewer and Dr R.J. Murgatroyd for their comments on, and suggested additions to, a draft of this paper.

ANNEX A

Aircraft of the Meteorological Research Flight

2 x Spitfire + Boston (original establishment)	
Hudson	
Flying Fortress	
Mosquito	
Mosquito	VL621
Mosquito	RG248
Halifax	ST817
Halifax	ST796
Hastings	TG618
Hastings	TG619
Canberra B2	WJ582
Varsity	WJ906
Canberra PR7	WE173
Varsity	WF425
Hercules	XV208

Assistant Directors Meteorological Office (Meteorological Research Flight)

1942	Dr A.W. Brewer
1946	Dr R. Erith
1951	Mr H.C. Shelland*
1951	Dr R.J. Murgatroyd
1962	Mr R.F. Zobel
1967	Mr C.J.M. Aanensen
1971	Dr D.G. James
1982	Dr C.J. Readings
1984	Dr R. Pettifer
1985	Dr W.T. Roach
1988	Dr P. Jonas
1989	Dr S. Mattingly
1990	Mr W.D.N. Jackson*
1991	Dr G.J. Jenkins

* Acting Heads between main appointments

Officers Commanding Meteorological Research Flight

1948	Flt Lt Tomlinson
1952	Flt Lt N.C. Thorne
1953	Flt Lt H. Baker
1955	Flt Lt S.F. Thomas
1958	Flt Lt D.A. Cree
1962	Flt Lt A. Abczynski
1966	Flt Lt G.F. Holbrook
1969	Sqn Ldr G.F. Holbrook
1970	Sqn Ldr N. Lamb
1977	Sqn Ldr M.J. Bibby
1980	Sqn Ldr M.K. Allport
1983	Sqn Ldr M.J. Stokes
1985	Sqn Ldr D. Curteis
1988	Sqn Ldr S.R. Roberson
1991	Sqn Ldr M. Lampitt
1992	Sqn Ldr H. Burgoyne

ANNEX B

Aircraft campaigns and detachments

Year	Aircraft	Base	Projects
1952	Canberra	Khartoum	Humidity
1957		Malta	Latitudinal
		Nairobi	variations of temperature
1960		Nairobi	and humidity
1961		Malta	at high levels
1962		Bodø	Ozone also measured after 1959
1965	Canberra	Singapore	Vertical extent of Cb
1970	Canberra	Malta	Sea surface temperture
1970	Varsity	St Mawgan	SCILLONIA: warm fronts
1973	Canberra	Denver	WAMFLEX: mountain waves
1974	Hercules	Dakar	GATE: tropical convection
1975	Canberra	Dakar	Tropical radiation
1978	Hercules	Gibraltar	measurements for satellites
1979		Dakar	and air sampling
1977–80	Canberra	Lossiemouth	Lat/Seasonal humidity cross-sections
1978	Hercules	Machrihanish	JASIN: air–sea interaction
1978		Gibraltar	Meteosat
1979		Dakar	Meteosat
1980		Gibraltar	Mount St Helens volcanic dust sampling
1981		Europe	KONTUR: turbulence over the sea
1983		Bermuda	CAMEX: microwave sounding trials
1983		Machrihanish	NARTHEX: frontal structure
1985		Bodø	PLEXUS: polar lows
1987		Farnborough	HEXOS: humidity over the sea
1987		San Diego	FIRE: marine stratocumulus
1987		Farnborough	FRONTS87: frontal dynamics
1988		Dakar	WATER: water vapour continuum
1989		Farnborough	ICE89: International Cirrus Experiment
1990		Trondheim	ERS-1 instrument development
1990		Oulu	SAAMEX: microwave
1990		Crete	MASTEX: water vapour continuum
1991		Farnborough	TOASTE: strat–trop exchange
1991		Bahrain	GULFEX: Kuwait oil smoke plume
1991		Farnborough	CHEMEX: atmospheric chemistry
1991		Trondheim	RENE1: ERS-1 winds comparison
1991		Ascension Is	FATE: ERS-1 SST comparison
1991		Trondheim	RENE2: ERS-1 winds comparison
1992		Farnborough	FRONTS92: cold front waves
1992		Azores	ASTEX: marine stratocumulus

551.507.352:358.4:77

The PAMPA flights

R.J. Ogden
Silverwood Drive, Camberley

Summary

To mark the 50th Anniversary of the wartime weather reconnaissance missions flown with Mosquito aircraft, these operations and the background to them are described.

1. Introduction

With the aim of improving the standard of weather forecasting, meteorological reconnaissance flights were made regularly during the 1940s to obtain observations from the data-sparse areas of the North Sea and eastern Atlantic. Tracks, schedules and operating procedures for these flights were all standardized and many details have been published (e.g. Air Ministry (AHB) 1954, Kraus 1985, Ogden 1985, Yates 1986, Rackliff 1987). But only passing references (Rackliff 1987, Ratcliffe 1987) have appeared in meteorological publications about a quite different type of weather reconnaissance; this was that made over enemy territory primarily for operational rather than synoptic reasons. Those missions were known as PAMPA (Photographic and Meteorological Photography Aircraft) flights*.

2. The formation of 1409 (Met) Flight in RAF Bomber Command

1401 (Met) Flight based at Mildenhall was responsible for obtaining vertical profiles of temperature and humidity; by mid 1941 it was equipped with Gladiators for the famous THUM (Temperature and HUMidity) flights and with Spitfires for the complementary PRATA (PRessure And Temperature Ascent) flights. During August of that year two additional Spitfires were allocated to the Flight specifically to undertake 'long-range reconnaissance over enemy and enemy-occupied territory. Tracks laid on as required'. (Meteorological Office Archives); this was the new PAMPA role. In late October the Flight moved to Bircham Newton where 1403 (Met) Flight was based to operate the RHOMBUS flights over the North Sea; in January 1942 the two Flights were amalgamated and all the operations were then moved to the satellite airfield at Docking (Bowyer 1979). The PAMPA Spitfires were replaced during the following month by two Mosquito IV aircraft which carried crews of two and had an endurance of about 4.5 hours (Meteorological Office Archives). Operational PAMPA sorties using the Mosquitos probably started in May 1942 (Rackliff 1987). With Gladiators, Spitfires, Hudsons and Mosquitos for the THUM, PRATA, RHOMBUS and PAMPA flights respectively, 1401 (Met) Flight by then had very wide responsibilities and not surprisingly on 1 August 1942 it was upgraded to become 521 (Met) Squadron (Bowyer 1979).

To meet the need for more operational weather reconnaissance as the RAF Bomber Command offensive gathered momentum, at the end of September the number of Mosquitos in the Squadron was increased from two to eight (Meteorological Office Archives). Not long before this, the new Pathfinder Force (PFF) had been formed in Bomber Command under Gp Capt (later Air Vice-Marshall) Donald Bennett. He had strong views about the importance of operational weather reconnaissance, especially in relation to PFF tasks, and gently tried to bring the PAMPA Flight under his command (Bennett 1958). That did not formally come about until 1 April 1943 when the eight Mosquitos of 521 (Met) Squadron were hived off to form a new 1409 (Met) Flight based at one of the original PFF airfields of Oakington, near Cambridge (see Fig. 1). After converting to Mosquito IXs, the Flight moved to Wyton in January 1944 and remained there for the rest of the War (Bowyer 1979); one Mk. IX aircraft was retained for low-level sorties, but the others were subsequently exchanged for six Mosquito XVIs, painted in PR (photo-recce) blue and equipped with pressurized cabins. All these later aircraft were fitted with extra fuel tanks, both internally and as drop tanks under each wing; this increased the endurance to nearly 6 hours and the extreme range to 2000 miles or so. But it should never be forgotten that the PAMPA Mosquitos carried no bombs and had no defensive weaponry (Currie 1983).

3. Crew selection

Despite their lack of guns for self-protection, the PAMPA crews were often ordered to penetrate deep into Germany, even in broad daylight with no cloud cover. To minimize the chances of fighter interception they naturally flew high (e.g. 30 000 ft or more) and fast whenever possible, but the Me 262 jet fighter which the Luftwaffe brought into service late in the War could outpace the Mosquito, and only the superior manoeuvrability of the latter, allied to a high degree of pilot skill, could then keep them out of trouble (Bennett 1959).

The role of the navigator was equally vital. He had personally to plan the route (see below), then with the aid of Gee and radar monitor the aircraft's progress, advising the pilot of course changes and computing winds *en*

*A new series of so-called PAMPA flights was operated from Waddington between 1946 and 1949 by 61 Squadron, Bomber Command, using Lincoln aircraft; these were not comparable with the wartime missions and are not covered in this article.

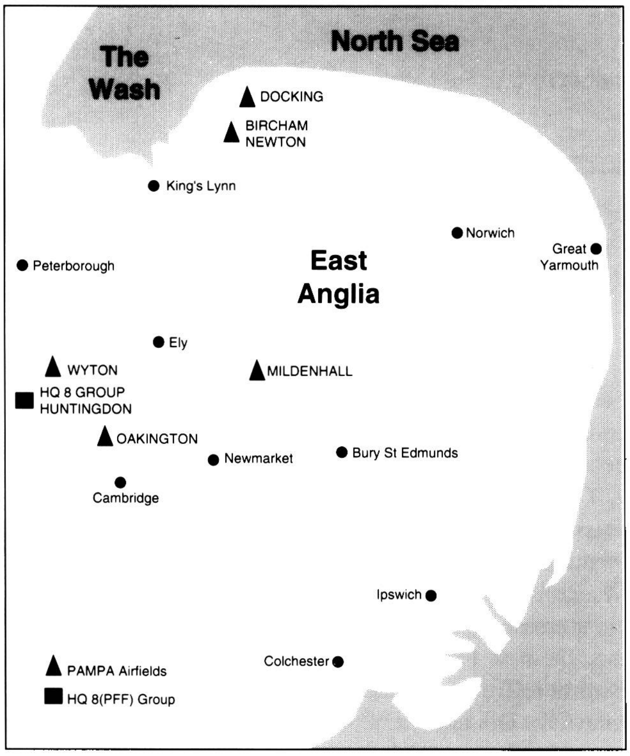

Figure 1. East Anglian locations mentioned in the text.

route; he was also responsible for making the weather observations, a task for which he was specially trained. In these circumstances, it is not surprising that the PAMPA crews were chosen with great care. All the crews in PFF were selected from volunteers, but for 1409 (Met) Flight there were additional constraints; only those who were both commissioned and had been awarded above average ratings at the Mosquito OTUs were considered (Currie 1983).

4. Organization of PAMPA sorties

Having decided on a probable target, and in the light of discussions with his Chief Meteorological Officer (M.T. Spence), the C-in-C of Bomber Command might elect to order a PAMPA flight as an essential preliminary before tactics for PFF and the main force were finalized. In total contrast to the procedures for the regular scheduled meteorological reconnaissance flights, PAMPA sorties might be dispatched at short notice anywhere, at any time, and had to be completed without delay. The required task was detailed to 8 (PFF) Group for action by 1409 (Met) Flight. The navigator of the duty crew then had to prepare his own flight plan to cover the given objectives, avoiding well-defended areas whenever possible and also incorporating sundry changes of course both to mask the specific area of interest and to make it more difficult for fighters to intercept the aircraft. On occasions, the AOC of 8 Group also aranged PAMPA flights to meet specific requests from other Commands or from other services such as the USAAF. On a particular day a single flight might suffice, but as many as four or even more sorties were sometimes mounted within a 24-hour period (Bennett 1958). At full strength 1409 (Met) Flight had 10 crews, and unless formally stood down duty crews had to be ready to carry out any assigned task immediately; moreover, stand-by crews and aircraft were always available so that if an aircraft became unserviceable before or shortly after take-off, a replacement could be airborne very quickly, using the flight plan prepared by the original crew (Currie 1983).

The detailing of the task was strongly influenced by the meteorological input at Bomber Command. Sometimes the objective was to provide a general survey of a broad area which included the target. More usually however, the PAMPA mission was to make detailed appraisals of particular significance for the raid being planned; the emphasis was then primarily on cloud conditions. For example, the zone just behind a cold front is often a very suitable location for clear identification of a target, but it is essential to know whether the front concerned is indeed immediately followed by a significant cloud clearance and if so exactly where the front is, whether it has any waves on it and how steadily it is moving (Ratcliffe 1987).

From late 1943 onwards, the operations of 1409 (Met) Flight and indeed other PFF formations were greatly assisted by the availability of FIDO, the first installation of which was at Graveley, another of the original four PFF airfields. The first landing in fog using FIDO was made there by Bennett himself in July 1943, and other nearby airfields were equipped with FIDO later that year, including Downham Market which became an 8 Group station in March 1944 (Ogden 1988). Knowing that aircraft could be landed safely in fog meant that PAMPA sorties could be dispatched when, without FIDO, they would have been grounded.

5. Meteorological procedures

Having fought hard to bring the PAMPA Flight under his command, AVM Bennett naturally took a keen interest in its work, and he maintained a close liaison with M.J. Thomas, his Group Meteorological Officer. Each sortie was given detailed objectives not only on where to go but also on what to look out for. The making of comprehensive cloud observations was paramount — types, amounts, height of tops and often of bases as well. To assist the navigator he was provided with a hand-held camera which could be used looking forward through the windscreen to photograph interesting cloud features such as cumulonimbus. The aircraft might then deliberately fly into Cb clouds at various levels to determine the degrees of turbulence and airframe icing which might be highly relevant for the forthcoming operation. Although it is normally safer when flying at higher altitudes, the aircraft often made descents in key areas to measure the heights of cloud tops and bases and to obtain vertical temperature profiles (Currie 1983). The computation of winds was a routine procedure and accuracy here clearly depended on the efficiency of the navigation.

Photograph by courtesy of the Royal Air Force Museum

Figure 2. De Havilland Mosquito P.R. XVI

On return to Oakington or Wyton, the navigator reported immediately on a scrambler telephone to the 8 Group Met. Office at Huntingdon who passed on the information to HQ Bomber Command and also prepared a summary report for transmission to ETA (the Met. Comms Centre at Dunstable); this latter text was subsequently disseminated on the meteorological teleprinter broadcast to all the Bomber Command outstations.

Although the majority of PAMPA operations were pre-attack sorties that reported to base before the main force took off, sometime after PFF introduced the procedure whereby a Master Bomber controlled the attack over the target (a practice that started late in 1943). 1409 (Met) Flight also flew additional missions some 30 minutes ahead of the PFF target markers; the PAMPA pilot then gave an up-to-date weather report for the target area directly by radio to the Master Bomber or his Deputy (Currie 1983).

6. Postscript

To forecasters at Bomber Command outstations between 1942 and 1945, the PAMPA.reports on the teleprinter broadcast provided most welcome factual information to clothe the bare bones of the operational forecasts we received and on the basis of which we had to brief the main-force crews. But their primary contribution was at the heart of the operational planning at Group and Command level. The last words should be left to AVM Bennett: '1409 (Met) Flight never hesitated and never failed to do their job with absolute reliability and constancy. The danger was extreme and it was a most nerve-wracking job for the crews, (yet) in the final analysis their losses were extremely low, although not quite as low as in the rest of PFF.'

References

Air Ministry (Air Historical Branch), 1954: The Second World War 1939–1945: Meteorology. (Unpublished copy available in National Meterological Library, Bracknell.)

Bennett, D.C.T., 1958: Pathfinder. Frederick Muller

Bowyer, M.J.F., 1979: Action Stations. Vol. I, Wartime military airfields of East Anglia 1939–1945. Cambridge, Patrick Stephens.

Currie, J., 1983: Mosquito Victory. Goodall Publications.

Kraus, E.B., 1985: How the meteorological reconnaissance flights began. *Meteorol Mag*, **114**, 24–30.

Meteorological Office Archives, ...: History of Meteorological Reconnaissance Flights. (Unpublished, undated papers probably written in the late 1940s.)

Ogden, R.J., 1985: Meteorological Reconnaissance Flights. *Meteorol Mag*, **114**, 108–113.

—,1988: Fog dispersal at airfields, Parts 1 & 2. *Weather*, **43**, 20–25 and 34–38.

Rackliff, P.G., 1987: Meteorological Reconnaissance Flights. Meteorology and World War II, Vol. I, pp. 1–13. Royal Meteorological Society.

Ratcliffe, R.A.S., 1987: Bomber Command Upper Air Unit. Meteorology and World War II, Vol. I, pp. 46–57. Royal Meteorological Society.

Yates, J.B., 1986: Wartime long range meteorological flights. *Weather*, **41**, 61–62.

551.511.3:37

A modern tool for teaching dynamic meteorology

M.J.M. Saraber, T.H. The* and L.J.M. Kroon
Wageningen Agricultural University, The Netherlands

Summary

A problem in teaching dynamic meteorology is that solutions to the dynamic equations of atmospheric motion are not simply obtained. A user-friendly software package has been developed, which makes it possible to construct approximate solutions to the equations in a step-by-step way, which then can be studied and understood. The package runs on Apple Macintosh personal computers.

1. Introduction

One of the fundamentals of modern meteorology and weather forecasting in particular is the understanding of synoptic-scale dynamics of the atmosphere. This understanding is based on the combination of theoretical knowledge and its application to real weather situations. From the educational point of view this can be achieved by constructing solutions of the relevant equations for real weather situations, which then can be studied and understood. It is the construction of realistic solutions which is such a difficult problem. The reason for this lies mainly in the highly complicated nature of atmospheric dynamics. Solving the dynamical equations for a fluid in motion on a rotating sphere is a very difficult task indeed.

There are several ways of approaching the problem. One way is to try and find analytic solutions, which are rather easy to understand. To obtain such solutions, however, one has to simplify the equations rigorously. This results in the so-called textbook solutions, which have almost no link with real weather situations. This approach, therefore, is only useful to a very limited degree.

A different way is to try to construct more-realistic solutions by computational methods and to study these. This is done nowadays and the equations are solved numerically. This has led to the advanced, but complicated, numerical models of the atmosphere, which run on supercomputers every day. The problem is that these models are mathematically complicated and distract the attention from the dynamical (i.e. meteorological) problem towards the numerical (i.e. mathematical) problems one has to solve. Also, from the point of view of the physics of the atmosphere, these models are very complex. They tend to generate only final results of all the complex atmospheric processes together, making it almost impossible to study certain isolated dynamical problems. These models, even the more simple ones of the early days of numerical weather prediction, tend to obscure rather than to increase the understanding of synoptic-scale atmospheric dynamics and therefore are of almost no use for educational purposes. To this must be added the fact that most of these numerical models need large computers to run and are difficult to handle in practice. Therefore it is understandable that using these models as tools in education, mostly results in frustration both with students and teachers.

Particularly in the 1940–60s, however, when almost no computing capacity was available, many manual methods were developed, resulting in approximate but rather realistic solutions of the equations. Even today these methods are of great value for the understanding of synoptic-scale atmospheric dynamics, because the solutions are constructed in a step-by-step way and can be studied and understood quite well. The drawback of these methods, however, still is the amount of work needed to produce practical results. This not only distracts the attention from the meteorological problem, but it makes it almost impossible to obtain these results in a reasonably short time. For these reasons, they are not directly suitable for educational purposes.

2. Looking for a remedy

From the educational point of view the situation sketched above is rather unsatisfying. There is a need for new educational tools, which can help to bridge the gap between teaching theory and application of the theory in real weather situations.

What is needed, is a combination of theory and a transparent step-by-step method to do the necessary calculations, which can be understood and easily handled by the students. If one also could present the results of the calculations graphically and apply the method to real weather situations, one could expect to have made a major step forward in explaining and understanding the dynamics of the atmosphere.

It is at this point that personal computers come into view. These machines nowadays combine calculating power with the possibilities of graphical (and alphanumerical) presentation, both on screen and printer. Add to this the fact that these machines are rather cheap and easy to handle, and it is clear that personal computers have the potential to serve as a tool to close the gap between theory and practice.

* Present affiliation: Royal Netherlands Meteorological Institute (KNMI), de Bilt, The Netherlands.

3. A new tool

For the purpose of teaching dynamic meteorology, a user-friendly software-package has been developed at the Department of Meteorology of Wageningen Agricultural University. At the time the package took approximately a year to develop and runs on Apple Macintosh personal computers, but would probably take less time now. 'User-friendly' means that students do not have to do any programming themselves and that they do not have to bother about computational problems.

The one thing students do have to bother about is how to solve the dynamical (i.e. meteorological) problem in a step-by-step way. In practice they have to work out for themselves which equations should be solved and in what order. The computer then does the calculating work.

The package is mouse-menu driven and the essential part of it is a formula parser, which can be accessed by means of a worksheet, in which the formula one wants to calculate has to be typed in. Essential for solving synoptic-scale dynamical problems of the atmosphere, is the necessity to solve the equations for a large number of points, that is, one needs to calculate fields rather than point values. Besides, one needs to calculate derivatives in space, for which we need values at several locations.

Calculations, therefore, are automatically performed on a grid and the values at the grid-points together represent the field which is required. The grid is polar stereographic, covering Europe and a large part of the North Atlantic Ocean. It contains 30 × 18 grid-points and the grid-point distance is 300 kilometres.

The calculation of derivatives in space is preprogrammed in the package and can be performed easily by using the relevant mathematical symbols, which can be accessed by typing a certain key-combination. To link the calculations to real weather situations, basic fields, such as height of pressure levels, temperature at pressure levels, etc. from the ECMWF atmospheric model are used, but basic fields from other sources could be used instead.

Fig. 1 shows the worksheet, in which the equations one wants to evaluate, can be typed in as algebraic formulas. This done in the 'Equation-window'. Capital letters are used to indicate variables (i.e. fields). Derivatives are indicated by means of their mathematical symbols. These are shown in the left area of the worksheet, together with some much-used symbols in meteorology (u_g and v_g stand for the geostrophic wind components, ζ for vorticity, Φ for geopotential height, f^{-1} for the inverse of the Coriolis parameter and ω is the vertical velocity in pressure coordinates). They can be accessed by simple key-combinations. Some basic variables (like the Coriolis parameter f and the mapfactor m) and constants (like the acceleration of gravity g) are available too.

The equations which are evaluated are also shown in the larger window in the middle of the worksheet. This makes it possible to check on errors in the formulas, made by the students. In the educational process this is an important feature of the program.

In the window in the upper right corner of the worksheet, one has to type in the pressure level at which the calculations have to be performed. One can choose from a number of (standard) pressure levels. The date and time (UTC) of the weather situation which is studied have to be chosen too. By typing in this date and time, ECMWF data for this time become available.

In the bar at the top of the worksheet main-menue options are shown. These options give access to presentation, file-handling, etc.

4. Example

Figs 1–4 show a typical example of how the package can be used. Suppose one is interested in the development of mid-latitude cyclones. From theory it follows that temperature advection and vorticity advection play a dominant part in this process. Thus one is interested in calculating these quantities in a particular situation. For the example the storm of 25 January 1990 was chosen. First of all, and this is essential in the process of teaching and learning, students have to work out, step by step, how these quantities can be calculated from the basic ECMWF fields, in this case from the height of pressure levels. Thus, the problem first has to be analyzed and the relevant equations written down in the correct order.

In the example one starts with calculating the geostrophic wind components (u_g and v_g) from the height of the relevant pressure levels, in this case 500 hPa. This height-field is indicated by the letter 'Z' and linked to the file ZZ0500_900125_12, which contains the ECMWF data. The formulas are typed in and calculated. Next the temperature field is constructed by subtracting the heights of two pressure level, resulting in the thickness of the atmospheric layer, which is proportional to the mean temperature of the layer (this is all basic theory). In this case the thickness of the layer between 500 hPa and 1000 hPa is calculated, indicated by 'T'. The height of the 1000 hPa level is given by the field 'H'. This field is linked to the file ZZ1000_900125_12, containing the ECMWF data. Now thickness (temperature) advection is the internal product of the wind vector and the gradient of the temperature. The thickness-advection, indicated by 'A', can now be calculated.

Similar to the calculation of the temperature and temperature-advection, vorticity and vorticity-advection are calculated.

The calculated equations are visible in the large window, and the formula which has been calculated last is also visible in the 'Equation-window'. The calculated fields can be presented on the screen and then printed. It is possible to present (and print) different fields together. Fig. 2 shows the 500 hPa height-field together with the calculated geostrophic wind vectors. Fig. 3 shows the 1000–500 hPa thickness field together with the calculated thickness (temperature) advection. Fig. 4 finally shows the 500 hPa field, vorticity contours and regions with positive vorticity-advection (these regions are shaded). In principle the whole operation can be done in a rather

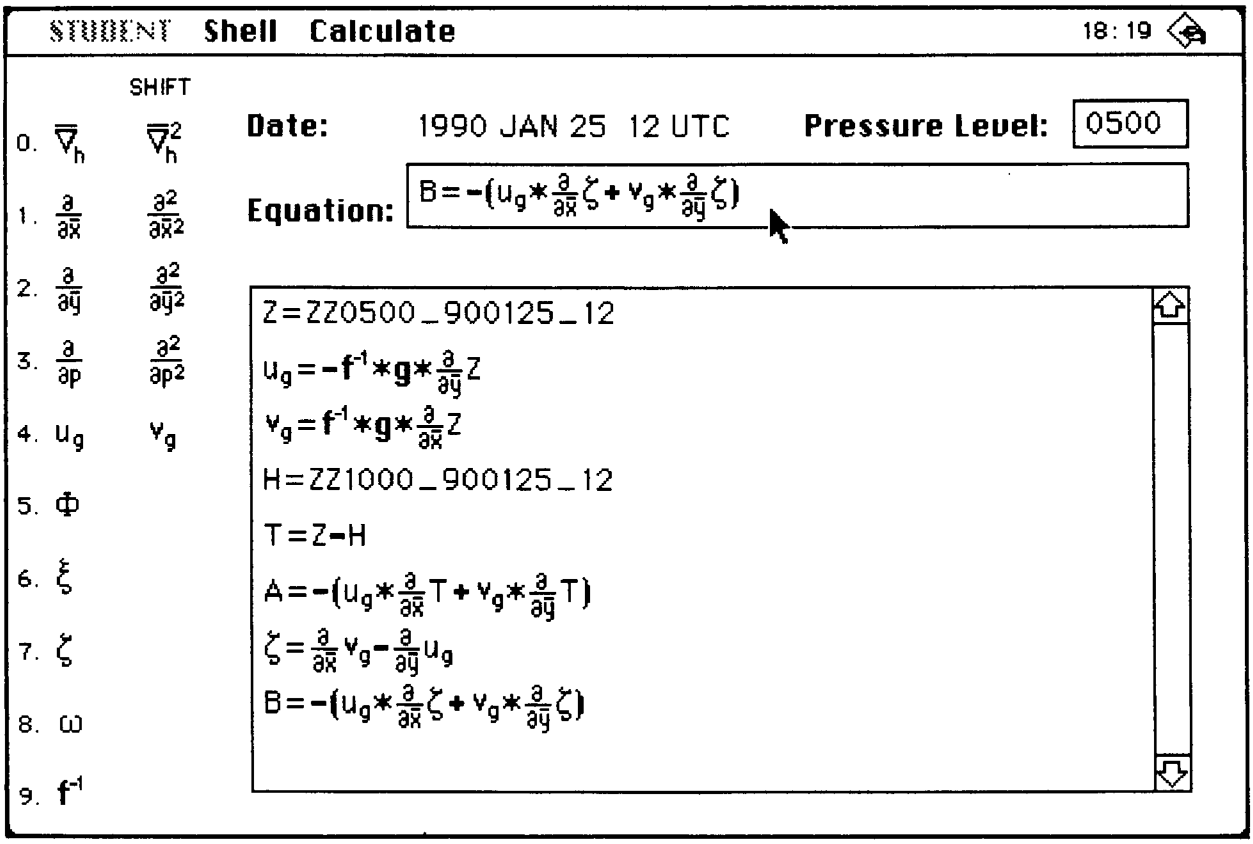

Figure 1. Worksheet, showing the windows for the equations, the pressure level and the large window with the calculated formulas. The mathematical symbols which can be used in the formulas are shown in the left-hand area of the worksheet. In the bar at the top of the sheet, options of the main menu are shown. The equations which had to be calculated to solve the problem of the example are shown in the large window. The last equation which was calculated, is also shown in the 'equation-window'.

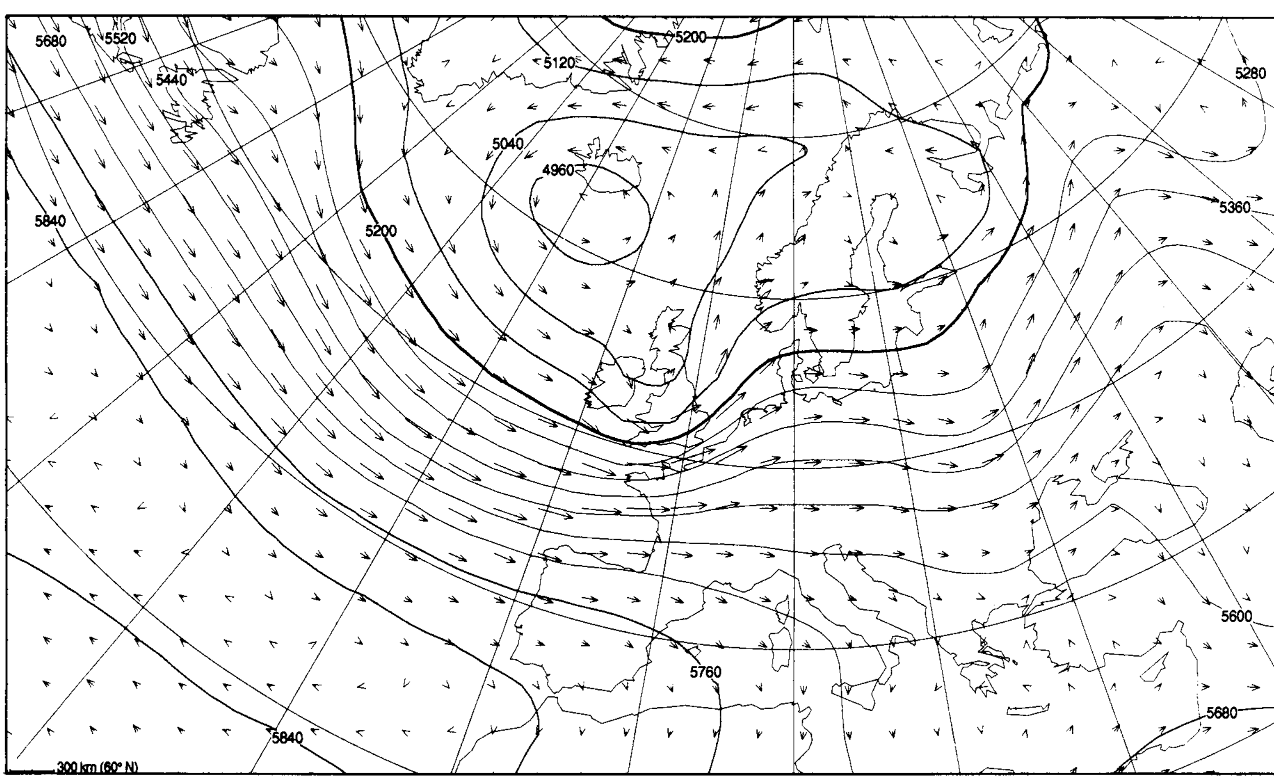

Figure 2. Results of the example, showing the heights (m) of the 500 hPa level together with the geostrophic wind field (arrows). This figure also shows the area covered by the grid.

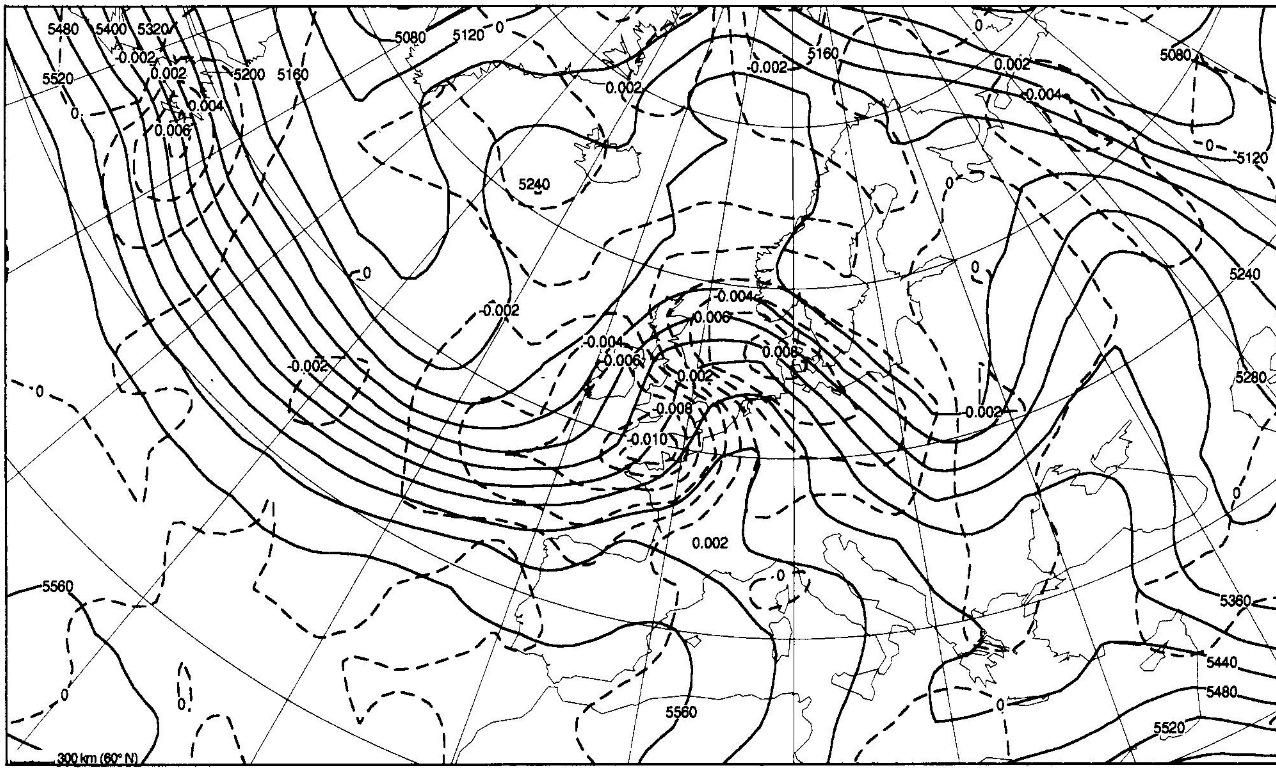

Figure 3. Results of the example, showing the 1000–500 hPa thickness field, together with thickness-advection ($m\ s^{-1}$) dashed lines.

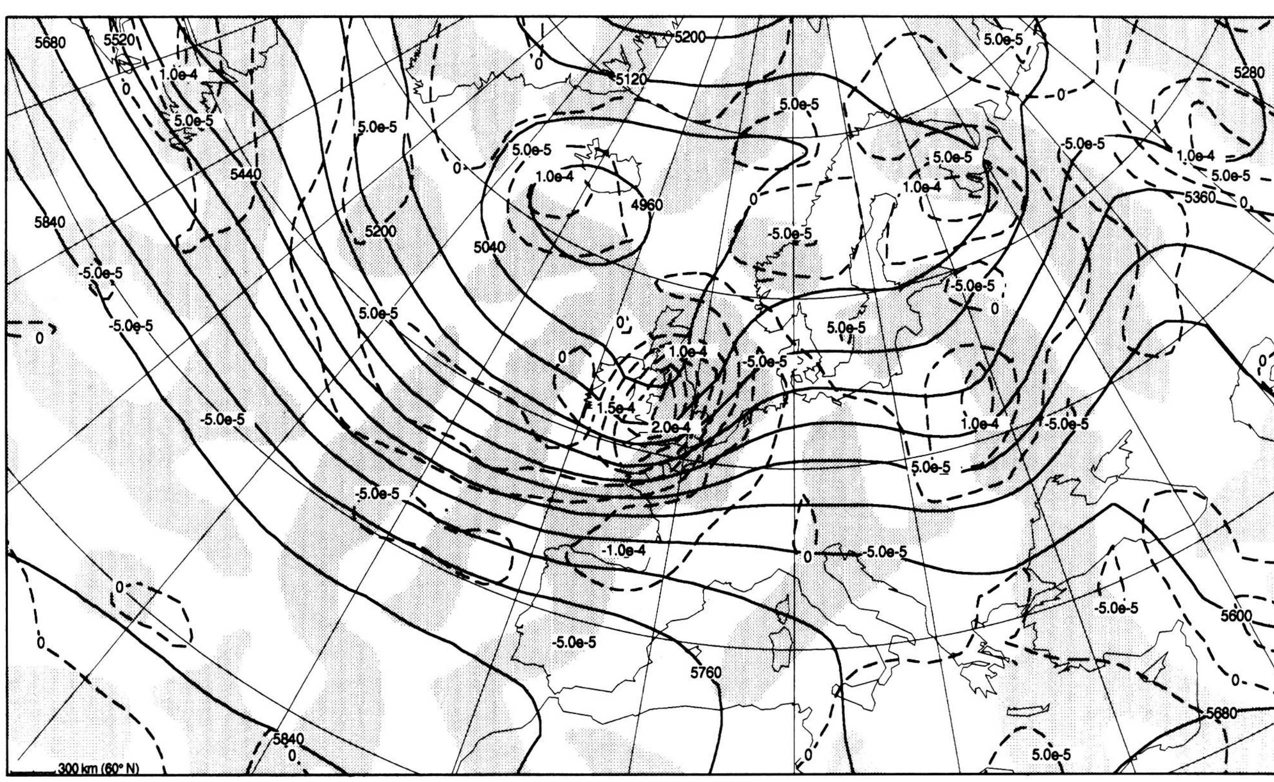

Figure 4. Results of the example, showing the 500 hPa height field (m), together with relative vorticity (s^{-1}) dashed lines and vorticity advection (shaded areas indicate positive vorticity-advection).

short time (calculation of a particular field and preparing the graphical presentation on the screen takes only a few minutes), but depends of course on the skills of the student who has to solve the dynamical problem.

5. Final remarks

Though the above example may be simple, it shows some essential points, namely:

(a) Students can concentrate on solving the dynamical (i.e. meteorological) problem and on the interpretation of the results of the calculations. Students have to think and work out for themselves how to solve the problem.

(b) The computer is a helpful tool — it carries out the laborious calculations and it generates no precooked solutions.

(c) End results and in-between results of the calculations can easily be presented, both on screen and printer.

(d) Students do not have to bother about numerical problems, e.g. how to calculate derivatives on a grid. This is preprogrammed in the package.

At the moment experience has been gathered in the use of the package, but the full potential of it still has to be exploited much further. A further paper is planned to describe the experience of and developments in the system. Developments being considered are a real-time datalink and the writing of a manual for general release. A thorough technical description of the package is required in the first instance.

Although there never are perfect solutions to educational problems, in the opinion of the authors this software package is a major step forward in the way dynamic meteorology can be taught by combining theory and practice.

References

Holton, J.R., 1979: An introduction to dynamic meteorology (Second edition). New York, Academic Press.

Saraber, M.J.M., The, T.H., and Kroon, L.J.M., 'Integrating Theory and practice in teaching Dynamic Meteorology'. Paper presented at the WMO Symposium on Methods of Meteorological Education and Training including the use of new relevant techniques, Toronto, Canada, 19–23 August 1991.

551.506.1(41-4)

The autumn of 1991 in the United Kingdom

G.P. Northcott
Meteorological Office, Bracknell

Summary

Temperatures remained about average over the autumn period generally; the autumn was wet over most of Scotland and north-west England, but generally dry elsewhere, and sunny everywhere excepting north-west Scotland.

1. The autumn as a whole

Seasonal temperatures were near or below normal over much of Scotland and Northern Ireland, but mainly above normal over England and Wales, ranging from 0.9 °C above normal at Penkridge, Staffordshire and Poole, Dorset to 0.4 °C below normal at Glenlee, Dumfries and Galloway. Rainfall amounts were above average over north-west England, part of North Wales, the Bristol Channel area, part of the Midlands and the Norwich area of Norfolk and most of Scotland except for the south-east, and below or near average elsewhere. Values ranged from 141% of normal at Cheltenham, Gloucestershire to 55% of normal at Cawood, North Yorkshire. Sunshine amounts were above average in most parts of the United Kingdom apart from north-west Scotland where it remained dull, and parts of southern and central England where amounts were near average, ranging from 137% of average at Buxton, Derbyshire to only 81% of average at Hadlow College, Kent.

Information about the temperature, rainfall and sunshine during the period from September to November 1991 is given in Fig. 1 and Table I.

2. The individual months

September. Mean monthly temperatures were above normal over England, Wales and Northern Ireland, but below normal generally over Scotland, ranging from 1.9 °C above normal at Penkridge, Staffordshire and Malvern, Hereford and Worcester to 0.4 °C below normal at Camps Reservoir, Strathclyde Region. The highest temperatures occurred during the first week, and it was the warmest September in some places for 30 years. Monthly rainfall totals were generally below normal except in north-western parts of Scotland and parts of southern and eastern England where they were about or above normal, and ranged from 168% at Woburn, Bedfordshire to as little as 26% at Edinburgh,

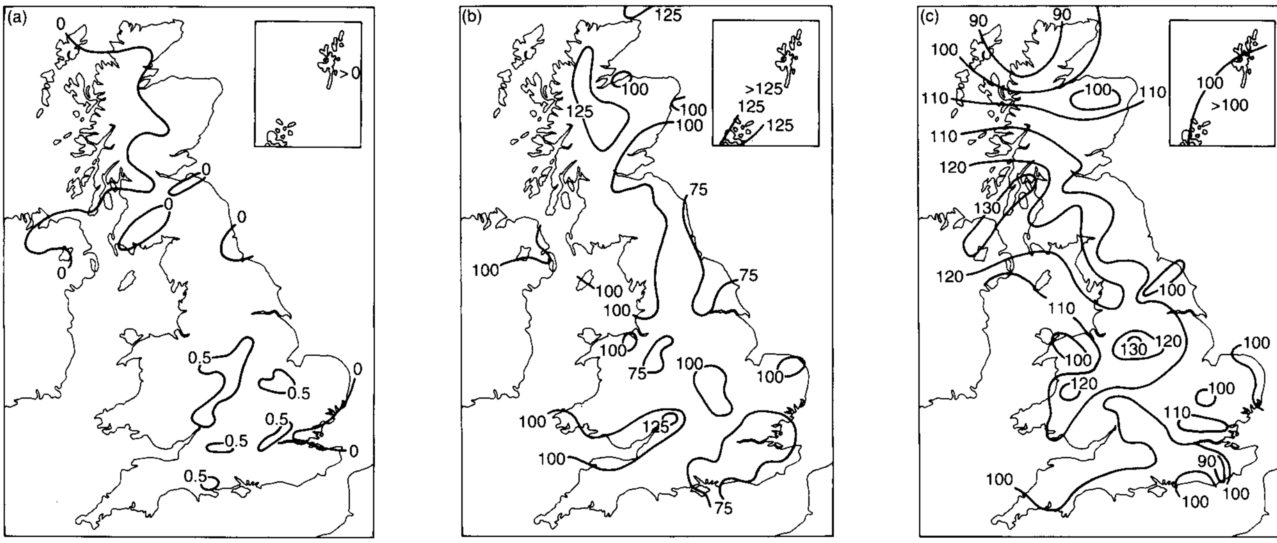

Figure 1. Values of (a) mean temperature difference (°C), (b) rainfall percentage and (c) sunshine percentage for autumn, 1991 (September–November) relative to 1951–80 averages.

Table I. District values for the period September–November 1991, relative to 1951–80 averages

District	Mean temperature (°C)	Rain-days	Rainfall	Sunshine
	Difference from average		Percentage of average	
Northern Scotland	–0.1	+1	127	89
Eastern Scotland	+0.1	0	110	102
Eastern and north-east England	+0.2	–1	91	104
East Anglia	+0.2	–1	83	98
Midland counties	+0.5	–1	86	100
South-east and central southern England	+0.3	–1	75	96
Western Scotland	0.0	0	116	111
North-west England and North Wales	+0.3	0	97	102
South-west England and South Wales	+0.3	0	97	98
Northern Ireland	+0.1	+1	100	118
Scotland	0.0	0	121	101
England and Wales	+0.3	–1	91	100

Highest maximum: 29.7 °C in south-eastern and central southern England in September.
Lowest minimum: –8.4 °C in northern Scotland in November.

Royal Observatory. The rainfall on the 14th was the first rain for 32 days at Charing, Kent. Monthly sunshine totals were above normal nearly everywhere except for one or two places on the coasts of southern and eastern England and ranged from 168% at Camps Reservoir, Strathclyde Region to 98% at Mayflower Park, Southampton.

September was warm, especially in the south, and generally dry, but during the second half of the month it became less settled and cooler, with some areas of heavy rainfall, although southern areas remained warm until the last week. There were thundery outbreaks over eastern Scotland from Aberdeen to Berwick on the 16th. Showers were of sleet at Fair Isle, Shetland on the 22nd and 23rd. Thunder was reported over Somerset and Dorset later on the 25th, and thundery showers, some accompanied by hail, became widespread over central southern and eastern England on the 26th, bringing the first heavy rain of the month to many parts of England, with outbreaks over Lincolnshire and Norfolk, South Wales and across southern England from Cornwall to Kent. On the 26th waterspouts were observed, 26 km south-west of Llanbedr, Gwynedd and off Pendine, Dyfed. Scattered thunderstorms on the 27th gave some prolonged spells of rain, some of it heavy. Thunderstorms occurred over central southern England later on the 28th and into the 29th, and later that day over parts of south-east England and East Anglia.

October. Mean monthly temperatures were below normal nearly everywhere and ranged from 0.4 °C above normal at Penkridge, Staffordshire to 1.6 °C below normal at Castle Archdale, Co. Fermanagh. On the morning of the 21st Bedford recorded its lowest October temperature since its records began in 1957. Monthly rainfall amounts were above normal in the west and north-east, but below normal in central Scotland and central and eastern England, ranging from 166% at Braemar, Grampian Region to as little as 30% at Greenwich, Greater London. Monthly sunshine amounts were below average nearly everywhere except for eastern Kent and parts of the Midlands where sunshine was just above average, and ranged from 106% of average at Keele, Staffordshire to less than 50% at Kinlochewe, Highland Region.

During the afternoon of the 1st a thunderstorm was reported over Manchester. On the 3rd there were reports of hail at Cape Wrath in the Highland Region. On the 4th Orkney and Shetland reported thundery outbreaks. Thundery activity was reported over east Devon on the 8th, 9th and 11th. Hail was reported widely between the 16th and 19th, and thunder in the south-west on the 18th. After a settled period from the 20th to 29th, the weather was unsettled during the last two days, producing the most significant rainfall of the month at some places in south-east England. On the 31st many areas had a wet and windy 24 hours: Winterbourne, West Midlands reported serious local flooding on roads in Birmingham City Centre and Bidston, Merseyside reported torrential rain with flooding on roads. On the 18th Guernsey Airport received an aircraft report of a waterspout at 1658 UTC, 020° 12 miles from Alderney; the cloud base was 2000 ft (600 m) and the weather showery, the showers heavy at times.

November. Mean monthly temperatures were normal over Northern Ireland and above normal over most of the remaining parts of the United Kingdom, ranging from about 1 °C above normal in parts of northern Scotland to 0.5 °C below normal at Lowestoft, Suffolk. Monthly rainfall amounts were generally above normal north of a line from Preston, Lancashire to Scarborough, North Yorkshire, apart from some places around the Firth of Forth, the Firth of Tay, and Tyneside, Tyne and Wear, where rainfall was below normal. South of the line most places except South Wales, the south Midlands, and parts of East Anglia and Kent were generally dry. Amounts ranged from 198% of normal at Prestwick, Strathclyde Region to 56% of normal at Sparsholt, Hampshire. Monthly sunshine amounts were below average nearly everywhere apart from a few locations in southern and eastern Scotland and northern England and ranged from 124% at Dumfries, Dumfries and Galloway and Buxton, Derbyshire to only 50% at Aberporth, Dyfed.

During the first fortnight it was generally unsettled with bands of rain affecting most areas, especially the north. The last two weeks of the month were generally quieter, except for the 19th, with some overnight fog. On the 12th gusts exceeded 60 kn in many places; during the passage of a squally cold front gusts reached 81 kn at Aberporth, Dyfed, 79 kn at Ronaldsway, Isle of Man and 77 kn at Gwennap Head, Cornwall; Botwnnog School, Gwynedd reported extensive structural damage caused by the 'ferocity of the gale'. During the evening of the same day a tornado was reported at Dullingham, Cambridgeshire. Thunder occurred locally on the 1st and was widespread on the 3rd over England and Wales. Thunder was reported over western Scotland on the 11th, and was widespread over Wales and northern and eastern England between the 11th and 14th. Overnight on the 12th/13th violent thunderstorms were reported over Cumbria.

Note from the Editor

In the October 1992 issue, a preamble was accidentally omitted from the start of Mr Collier's article entitled 'International radar networking'. Most readers will have correctly assumed that the article is in fact an edited transcript of a talk. This was given earlier this year to a rapt audience at the Meteorological Office. It has been reproduced in this form because it saved Mr Collier from having to rewrite the whole; more importantly, the form associated with the use of the first person (grammatically) makes for a much easier read. If you would like to comment on this milestone in scientific publishing please write to me.

We much regret that production difficulties in the Meteorological Office have caused this issue to be published very late. The December issue will, we hope, follow this issue quickly. We cannot yet be sure of the January publication date because Christmas complicates matters: but by February everything should be back to normal.

R.M. Blackall

Reviews

Asymptotic modelling of atmospheric flows, by R. Zeytounian. 157 mm × 240 mm, pp. xii+396, *illus.* Berlin, Heidelberg, New York, Springer-Verlag, 1990. Price DM 170.00. ISBN 3 540 19404 5.

This book is based on a series of graduate courses given by the author, however it is very different from the popular texts such as Gill, *Atmosphere Ocean Dynamics* or Holton, *An Introduction to Dynamic Meteorology*. The author treats meteorology as a fluid-mechanics discipline and, in doing so, presents the material in a formal and mathematically detailed manner. However this style is not inappropriate for the subject matter. The main aim of the book is to derive a number of consistent approximations to the Navier–Stokes equations, that are of particular interest to the meteorologist, using expansions in the dimensionless numbers that describe properties of the atmospheric flow. Using jargon from numerical weather prediction, filtered models are obtained as limiting flows when the dimensionless numbers are assumed to be small or large compared to unity. There is an absence of extensive discussion of the dynamics of the solutions, however the presentation is clear and in a logical order. The book achieves its aim.

Following the introduction where about nine dimensionless parameters are mentioned, some of which are not often seen in English literature, the next three chapters are devoted to an overview of material that is familiar to most. In these chapters the term 'filtering' is used in place of the more common expression 'approximation'. The author uses the term filtering when discussing the *model* obtained by approximating the Navier–Stokes equations. The term 'approximation' is reserved for the study of the limiting process using asymptotic methods. In chapter two, the f-plane (in the book the Coriolis parameter is denoted by l) and, β-plane approximations, the Euler equations and the Primitive equations are discussed. Chapter three deals with internal waves and filtering, in particular quasi-static filtering, Boussinesq filtering and Anelastic (referred to as Deep Convection) filtering. Chapter four is devoted to the topic of Rossby waves. This material is followed by a discussion of asymptotic methods: The Matched Asymptotic Expansions Method and Multiple-Scale Method. Chapters six–ten examine in detail the various approximations used in the models discussed in chapter three, by use of asymptotic expansions. Chapters eleven–thirteen are devoted to the quasi-geostrophic and ageostrophic models, the low Mach number models and models for mesoscale flows. An appendix discusses a consistent treatment of the hydrostatic equations and points out that the equations most commonly used in meteorology and numerical weather prediction do not appear to be asymptotically consistent from the point of view adopted in this book.

The author includes 29 references to his own work, covering a period of over 22 years. The majority were published in French or Russian with only about a quarter appearing in English. There is currently much interest in the generation of consistent rather than *ad-hoc* approximations to the Navier–Stokes equations using techniques such as variational principles. The appearance of this self-contained account is timely and complements alternative approaches to the subject .

I would recommend this book to researchers in atmospheric dynamics and numerical weather prediction. I feel that few people will consider it suitable as a textbook for a course in dynamical meteorology, as it employs specialized mathematical techniques and lacks a discussion of the more physical aspects of the results. However, it is worth emphasizing that it deals with issues that are central to an understanding of many problems in numerical weather prediction. To quote from the Preface, 'Much of knowledge, however, is based on simple truths which are exceedingly difficult to put into words.'; therefore, what better language than that of mathematics.

I. Roulstone

The year without a summer?: World climate in 1816, edited by C.R. Harington. 217 mm × 279 mm, pp. iv+576, *illus.* Ottawa, Canadian Museum of Nature, 1992. Price C$42.80. ISBN 0 660 13063 7.

This volume collects together the 39 conference papers given by climatologists, vulcanologists, glaciologists, dendrologists, geographers and historians at an international meeting held at Ottawa during 25–28 June 1988. It can, therefore, be described as a large volume of conference proceedings; with an introduction (by Harington), a summary (by Cynthia Wilson), and a very thoroughly compiled 18-page index, all added at a later date.

Perhaps it is the diversions and 'dead ends' which make this historical investigation so enjoyable to read! No sooner do we establish how very cold 1816 was around the Hudson Bay, when a study of tree-ring growth from the Canadian Rockies points to both 1799 and 1824 as being apparently much colder there (see pp. 275–276 of Luckman & Colenut, an article containing the book's five black and white photographs). In the north-eastern USA, Baron (pp. 124–144) mentions that 1812, 1817 and 1836 had equally low or lower summer temperatures, but that the combination of killing frosts and drought affecting the growing season caused 1816 to gain notoriety as 'eighteen-hundred-and-froze-to-death' in local 'folklore'.

We are looking at a 'milestone volume' rather than a finished production because much of its contents are concerned with 'historial comparison' which will go some way towards enabling the continuing (and more difficult) work of synoptic reconstruction to be done. In this respect, early records of the Hudson's Bay Company have been particularly helpful to researchers Wilson &

Ball. Nearly 200 pages of this volume are devoted to the climate and weather of the period in Canada.

Probably too early in the book, Harington mentions (on p. 7 of the introduction) that "Certainly 'the year without a summer' in 1816 was a regional phenomenon... parts of Western North America, Eastern Europe and Japan seem to have had average or above-average temperatures as opposed to the remarkable cold that characterized much of Eastern North America, Western Europe and China. Incursion of freezing arctic air southward in one region was offset by poleward flow of tropical air in another. " Wilson's conclusion also points to persistent meridional airflows around strongly developed atmospheric 'blocking patterns' as being primarily responsible for these regional climatological anomalies, rather than to effects of the volcanic eruption of Tambora in Indonesia during April 1815 which seems, at most, a possible contributory effect and at least, a complete 'red herring'.

On this basis, it was probably unnecessary to include so much of the 'General' material on volcanism, and the particular concentration on Tambora, which make up much of pp. 12–92; and a future revision might include more synoptic meteorological charts (the reconstruction for 5 June 1816, is not only repeated on p. 179 and p. 192, but is also to be found prepublished in *Weather*, **40**, p. 137...meaning that it is probably 1984 vintage). As yet there appear to be no reconstructions planned for charts covering 18–22 August 1816, which was a particularly cold period in eastern North America. Also, the general notion of severe unseasonal frosts does not live happily with that of a persistent volcanic 'pall', darkening the sky by day, but probably also reducing night-time radiation.

There does not seem to be much pictorial evidence from 1816 that skies (particularly at sunrise or sunset) were unusually coloured, and if there had been, one suspects that Ball (who makes a brief passing reference to paintings on p. 202) would have mentioned this. In the United Kingdom, Constable painted unsettled, showery, cyclonic weather that year (particuarly on his honeymoon in Dorset during October–December. The various versions of'Weymouth Bay', one of which appears on the front cover of *Weather* magazine in September 1968, date from his 'oil sketches', made from nature during this period). In Canada, the cold weather was probably at least partly responsible for the portrait painter, Robert Field, emigrating from Halifax, Nova Scotia, to Kingston, Jamaica, at the end of summer 1816. Such 'artistic clues' to the prevailing weather could have usefully illustrated this work, which otherwise only has a reproduced poem ('Darkness', written by Lord Byron in Geneva, which is, arguably, the biggest 'red herring' ever reproduced as the 'frontispiece' of a scientific volume of literature!?) and a photographed medallion (front cover) which was struck in southern Germany 'in memory of the great famine of 1816–17'. Also, an art historian could have been employed to discuss some of the more-worthy paintings dating from 1816.

Nevertheless, this collection of so many climatological articles from both northern and southern hemispheres make this wide-ranging volume well worth the £20 asking price (current exchange rate approximately C$2. 15 = £1) to those fascinated by historical detective work in progress. The conclusion has not been firmly arrived at as yet, which is probably why the editor decided that a 'question mark' should still appear in the title?

W.S. Pike

Correspondence

Hoar-frost deposition

With reference to the letter of R. Mansell (*Meteorol Mag*, **121**, 241), the purpose of the paper was to elucidate the *meteorological factors* evident in the formation of *hoar-frost* alone. This treatment necessarily excluded ice formation by other means along with the effects of salt concentration, traffic density, road surface type, etc.

We agree that a wet, salty road is more slippery than a dry one, and that the number of hours in a wet, salty state is highly likely to exceed the number of hours in an ice covered state.

Motorists are expected to adjust their driving speed according to ambient conditions. Wet, salty roads are usually extensive due to the nature of salt application and the spreading effect of traffic. The more localized nature of hoar-frost and other forms of ice makes them less obvious, thereby increasing the accident risk. This must be borne in mind when a decision on salting has to be made.

From any viewpoint, a better understanding of hoar-frost deposition and other ice forming processes can lead to nothing but improved road safety *and* fewer wasted saltings.

N. Gait and T. Hewson

GUIDE TO AUTHORS

Content

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

Preparation and submission of articles

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

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

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

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

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

Illustrations

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

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

Copyright

Authors should identify the holder of the copyright for their work when they first submit contributions.

Free copies

Three free copies of the magazine (one for a book review) are provided for authors of articles published in it. Separate offprints for each article are not provided.

Contributions: It is requested that all communications to the Editor and books for review be addressed to the Chief Executive, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ, and marked 'For *Meteorological Magazine*'. Contributors are asked to comply with the guidelines given in the *Guide to authors* (above). The responsibility for facts and opinions expressed in the signed articles and letters published in *Meteorological Magazine* rests with their respective authors.

Subscriptions: Annual subscription £36.00 including postage; individual copies £3.25 including postage. Applications for postal subscriptions should be made to HMSO, PO Box 276, London SW8 5DT; subscription enquiries 071–873 8499.

Back numbers: Full-size reprints of Vols 1–75 (1866–1940) are available from Johnson Reprint Co. Ltd, 24–28 Oval Road, London NW1 7DX. Complete volumes of *Meteorological Magazine* commencing with volume 54 are available on microfilm from University Microfilms International, 18 Bedford Row, London WC1R 4EJ. Information on microfiche issues is available from Kraus Microfiche, Rte 100, Milwood, NY 10546, USA.

November 1992

Edited by R.M. Blackall
Vol. 121
No. 1444

Contents

ISSN 0026—1 149

ISBN 0-11-728989-2

9 780117 289895

Printed in the United Kingdom for HMSO Dd 291241, 1/93, C13, 543, 24503