



# THE MET EOROLOGICAL MAGAZINE

HER MAJESTY'S  
STATIONERY  
OFFICE

Outstation display systems  
Measurement of geopotential height  
Improving precipitation forecasts  
Naval Meteorological Branch  
Satellite and radar imagery

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## **Meteorological Office Outstation Display System: from concept to reality**

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### **Summary**

The development of the concept of an Outstation Display System (ODS) is described. ODS is intended to support forecasters by the reception, storage, processing and display of data as well as providing facilities for the generation of products. The present configuration of an ODS is described in terms of its hardware and software. Plans for the remainder of the development and installation programme for ODS are outlined.

### **1. Introduction**

The Systems Development Branch of the Meteorological Office (Met O 22) has, for the last 10 years, been working to spread the benefits of automation to the outstations of the Meteorological Office. In the late 1970s, much attention was given to how best to provide an automated facility for the plotting of charts at the major forecasting outstations, at which this was a manually intensive function. The Outstation Automation System (OASYS) was developed and deployed at London (Heathrow) Airport, Headquarters RAF Strike Command (HQSTC) and London Weather Centre, in 1980, 1981 and 1983 respectively. OASYS was a relatively expensive system, originally costing about £300 000 each. It consists of two minicomputers supporting a variety of peripheral equipment which includes two pen plotters capable of plotting charts up to A0 size.

When the feasibility of OASYS was being considered, major issues that arose were where the observational data base should be located and where the computations to generate the graphical plots should be performed. In the end, it was decided to transmit the raw observations from Bracknell to each site, store the data in a local data base, and generate graphical output locally from the information held in the local data base. One important consequence of this approach was that it gave the users at each outstation the ability to decide when a particular product should be generated. After one false start on the method of data acquisition, it was arranged for data to be broadcast to each OASYS from the Meteorological Telecommunications Centre at Bracknell according to a fixed routeing list. This ensures that all the required data are broadcast to the outstation as soon as they are available. On receipt, all data are stored automatically without operator intervention.

During the planning of OASYS for HQSTC, a requirement was stated for automated support for the front line RAF stations. Much emphasis was placed on the requirement for rapid retrieval of data on demand, e.g. airfield observations and forecasts (METARs and TAFs). To meet this requirement, Met O 22 considered the possibility of supporting terminals at each RAF station connected to OASYS at HQSTC to provide access to the OASYS data base. It was clear that a major expansion in computing power would be required to support such a large terminal network.

The next step in the development of these ideas was the instigation of a pilot project which would not necessitate the enhancement of OASYS. The objective was twofold: firstly, it was to demonstrate that the claimed benefits of automated support were real, and secondly, to determine the best technical design for an operational system. Equipment was purchased and installed at two stations, RAF Lyneham and RAF Honington, and came to be known as ROAST (Remote Outstation Automation System Terminal). It consisted of simple components — a monochrome Visual Display Unit (VDU) (including storage for seven screens-full of data but with no internal processing power) and a dot matrix printer. Each ROAST was connected (using special communications protocol converters) by a 4800 bits-per-second circuit to OASYS at HQSTC. Fig. 1 shows the arrangement. The pilot project ran for the period from October 1983 to March 1984.

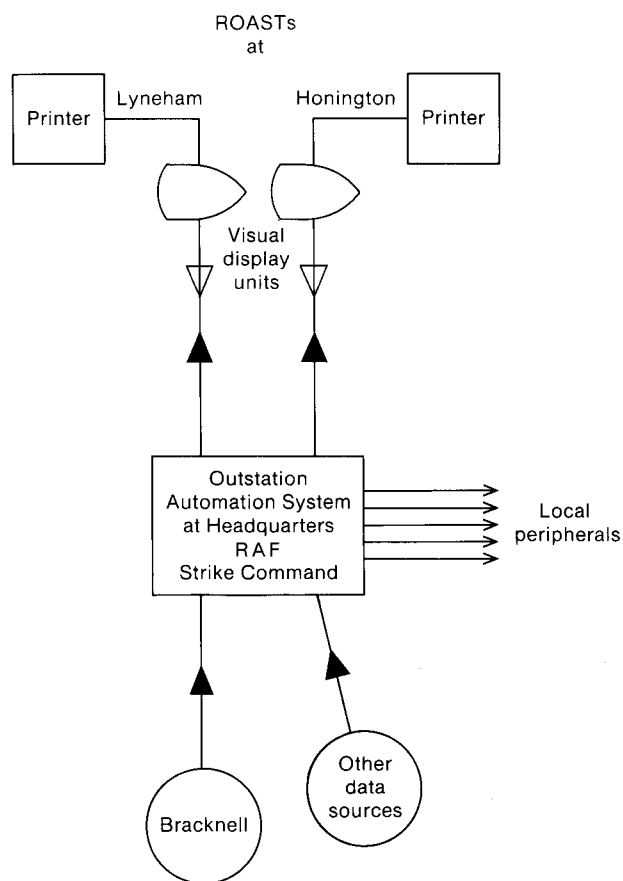


Figure 1. The ROAST (Remote Outstation Automation System Terminal) pilot project.

The ROAST pilot project enabled a number of valuable conclusions to be drawn. Firstly, it was clearly demonstrated that the provision, on demand, of observational data was a major advance over the current method of receiving such data according to a strict, inflexible schedule via slow telegraph circuits. Secondly, the displays of data, both soft and hard copy, were useful not only for direct use by the forecaster but also as an aid in briefing aircrew and other RAF personnel. Thirdly, it was felt that further advantages would accrue if it were possible for the data to be displayed in graphical formats, as these can be assimilated more quickly (note that the limited experimental graphics which were provided on the printer took too long to draw to be of much benefit). Finally, shortcomings were recognized in the responsiveness of the system — at peak times, when OASYS at HQSTC was heavily loaded, response times were often several minutes and, in addition, the ROASTs were affected by even partial outages of OASYS itself.

## **2. Development of the concept of the Outstation Display System**

In order to design an operational version of ROAST, it was necessary to take into account a number of factors:

- (a) The conclusions drawn from the pilot project.
- (b) The need, eventually, to support at least 40 ROASTs.
- (c) The requirement that ROASTs should be compatible with, or indeed become part of, a general modernization of the means of distributing data to the outstations and the methods of display and use of these data by outstation staff.

During 1983/84, staff of the Telecommunications and Systems Development Branches worked together to produce an outline strategy for a new Weather Information System (WIS). WIS was designed to replace the existing telecommunications support for outstations, both military and civil, with a new, integrated digital network. The existing teleprinter, facsimile and radar rainfall and satellite data networks would be phased out and all data would be carried reliably over the new network which would have a much greater capacity. The data would be delivered to each outstation in a digital format and permit the use of digital storage and processing techniques in a general-purpose display system. This display equipment, known as the Outstation Display System (ODS), would carry out a large range of functions, including data storage, processing and display. The necessary telecommunications infrastructure, which would provide the facilities described above, became known as the Weather Information Network (WIN), and it included the provision of a dedicated communications node at each outstation, the Outstation Communications Processor (OCP), thereby separating communications functions from the data-processing functions of ODS. The WIS concept was accepted by the Directorate of the Meteorological Office in 1984.

Within the design for WIS, ROAST became part of the modular, microcomputer-based ODS capable of being enhanced to provide all of the required functions under the plan for WIS. All data required by ODS would be broadcast from central sources, mainly Bracknell and HQSTC via the WIN, and then stored locally on magnetic disc storage which would be supported by the ODS microcomputer. This would ensure that the requirement for guaranteed response times would be met because the possibility of contention between requests for similar data by staff at different stations would not arise. To restate this, each ODS would have a local data-base, entirely analogous to that on OASYS. Other advantages of adopting this distributed-processing and data-base approach were that it provided much more resilience against hardware failure and it avoided the problems and expense of supporting a large terminal network, from which many requests for similar data would be received simultaneously at a central computer.

Fig. 2 illustrates the conceptual model of ODS which evolved. It was conceptual as the links shown between the various items of equipment were meant to represent logical connections and would not necessarily have a direct equivalent in practice. ODS would be based on one or more general-purpose microcomputers with peripheral devices, the range and type of which would differ from station to station, depending on requirements. All transfers of data, both into and out of the ODS, would be via the OCP. This was an important feature, as it off-loaded the overheads of dealing with multiple communication protocols from ODS and would facilitate the upgrading of communications facilities independently of ODS. Magnetic disc storage would hold the data base of incoming data, and support the processing of data and the generation of products. At least two VDUs were provided to enable forecasters and supporting staff to access ODS. At least one of these VDUs needed to be able to display graphical and image data in addition to accepting graphical input so that forecast products (e.g. significant weather charts) could be prepared. Printer(s) were provided to enable hard copy to be produced. It was not intended to provide the facility to print out imagery, either satellite or radar rainfall, unless the expense of so doing could be separately justified.

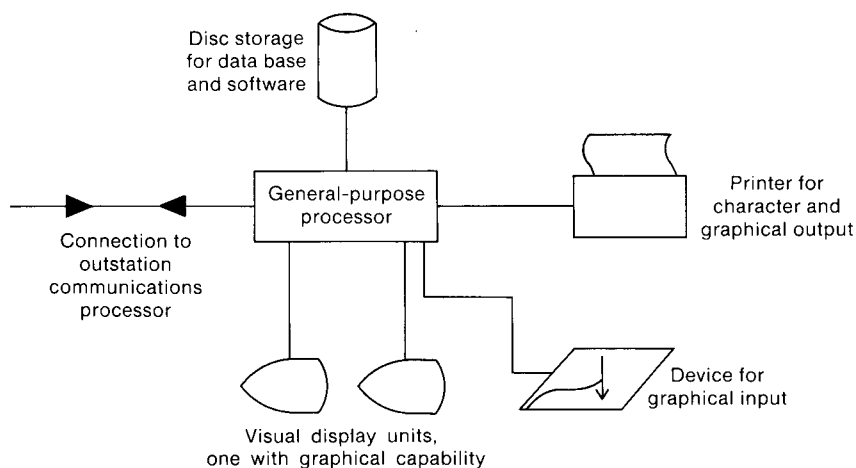


Figure 2. A conceptual model of ODS (Outstation Display System).

### 3. Prototype ODS and the development of the User Requirement

During the latter half of 1984, work was undertaken to build a functional prototype of ODS. There were several objectives in acquiring such a prototype:

- (a) To enable experience to be gained with the relevant microcomputer technology and to demonstrate that this technology could support the required ODS functions.
- (b) To allow more precise specifications to be made in the Operational Requirement which would be the basis for the competitive procurement of the operational hardware.
- (c) To enable experimental work to be carried out, particularly on the user interface.

It should be stressed that the system was not intended as an engineering prototype but as a functional prototype, the aim being to demonstrate the various ODS functions rather than to implement these functions in a form close to the future operational configuration.

The prototype ODS was constructed from components which would allow the objectives to be met and which would entail the minimum of new software being written. Equipment which was software compatible with OASYS was therefore selected and the system is shown schematically in Fig. 3. As soon

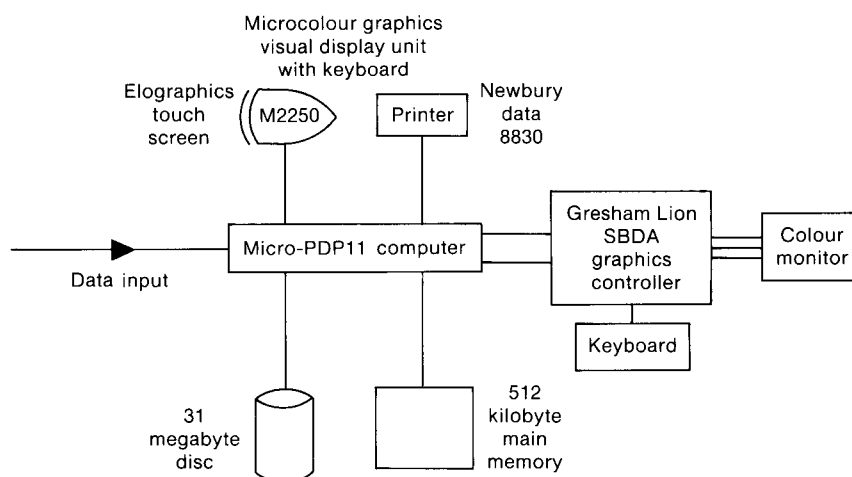


Figure 3. The prototype ODS (Outstation Display System).

as the hardware was available, software was transferred from OASYS, modified as necessary, and by January 1985 a demonstrable prototype was available. During 1985 and the first half of 1986, the prototype system was extensively used for experimental work, developing ideas regarding the user interface and other important parts of the ODS software. The acquisition of the functional prototype proved to be a very valuable investment:

- (a) It helped to demonstrate and develop the ODS concept.
- (b) It allowed forecasters to be more closely involved with the development of the user interface.
- (c) It enabled the design of major components of the operational software to be developed before a contract for the operational equipment had been awarded.

(As an aside, it is becoming increasingly accepted in the software industry that prototyping is a powerful technique for refining user requirements and designing the user interface.)

A detailed User Requirement for ODS was developed in 1985 and considered the three major functions, namely:

- (a) The acquisition, storage and display of various types of data — coded observations and text, coded numerical forecast data, pictorial data, radar rainfall imagery and satellite imagery.
- (b) The processing of data — local forecasting algorithms, climatological processing and data archiving.
- (c) The generation of textual and graphical products (including coded surface observations).

The User Requirement attempted, where possible, to quantify these various requirements and to assign priorities to them. Ergonomic factors, configuration and availability of the required facilities were also considered.

#### 4. Initial procurement and installation of ODS hardware

During 1985 proposals were prepared for the purchase of an initial batch of ODS, consisting of 15 systems, for installation at eight RAF stations (Lyneham, Honington, Coningsby, Leuchars, Marham, Wattisham, Lossiemouth and Brize Norton). Six of the stations were to be provided with two systems, and one system would be deployed at Bracknell to support development of the software. It was decided that the initial systems should provide ROAST-type facilities but with the additional benefit of graphical displays. As WIN would not be available in time to support the initial systems, it was decided

to provide an interim scheme for the communications. This would provide a data broadcast from Bracknell and would operate asynchronously at a speed of 4800 bits per second. As a consequence of the complexity of transmitting binary data asynchronously, character data only are sent. The limitation to character data and the relatively low speed of the circuits would restrict the classes and quantities of data which could be carried. It would therefore not be possible to transmit imagery or pictorial data, i.e. charts, until the full network, WIN, was installed. Consequently there was little point in providing ODS with the capacity to handle and display data which could not be received for at least 2 years, and the initial configuration of ODS was conceived as being limited to meeting only a subset of the total requirement. However, it was important to ensure that any equipment purchased could be expanded and enhanced, at the appropriate time, to meet the full requirement.

After a full, competitive procurement, the contract was awarded to Digital Equipment Corporation Ltd (DEC). The hardware configuration of each system is illustrated in Fig. 4.

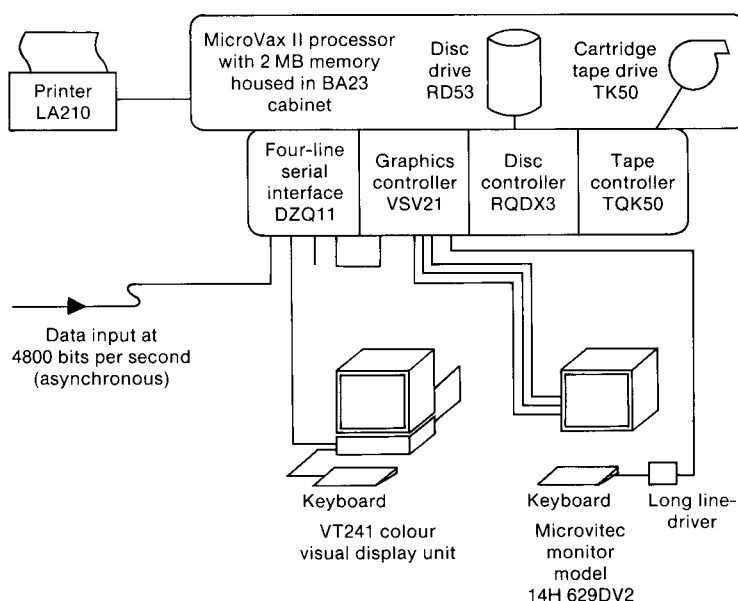


Figure 4. The initial configuration of ODS (Outstation Display System).

Each system is based on a MicroVax II processor. This is a very powerful microcomputer which is software compatible with DEC's range of larger VAX processors and is capable of being enhanced in a variety of ways. The systems were installed with two megabytes of main memory, and with 71-megabyte discs which hold the software and the data base. A cartridge tape drive enables the reloading of software, software updating, and the backing up of user-created files. Two VDUs are provided. One is a medium-resolution graphics device which is capable of producing graphical displays with a resolution on the screen of either  $512 \times 512$  pixels or  $640 \times 480$  pixels (picture elements) in up to 16 colours (these colours being selected from a palette of 4096 colours). This display, which is used in support of the forecaster, provides high-performance drawing of pictorial information and has the capability to display images. The second VDU is mainly for use by a supporting member of staff and at present provides an alphanumeric function. However, it does have a limited, if relatively slow, graphics capability which may be exploited later in the development programme. This VDU also has a colour



capability, enabling the simultaneous display of up to 4 colours, selectable from a palette of 64. The printer uses high-speed matrix technology, allowing printing at 240 characters per second, and can also provide limited graphical capability with a resolution of about 70 dots per inch.

The first two systems were delivered to Bracknell in July 1986 and the installations at the eight outstations were phased over the period October 1986 to January 1987. By February 1987, all of these systems were successfully installed and accepted. Each installation was planned individually, within the overall guidance that the processor should be installed in the communications room; the noise generated by the cooling fans in this equipment making it unsuitable for installation in a small forecast office. The remainder of the equipment was installed in the forecast office, the printer being supplied with an acoustic cover to reduce the noise level. Fig. 5 shows the equipment installed in the Meteorological Office at RAF Lyneham.

## **5. Software design**

### *5.1 General considerations*

Although the experience gained with the design and implementation of OASYS and ROAST was heavily drawn upon and many of the ideas used in the design of these systems were reused or modified, the software development team started the ODS design afresh. This was for a number of reasons. Firstly, ODS was conceived as an interactive system to support outstation forecasters, whereas OASYS had been designed principally to provide an automatic plotting function, even though graphics VDUs for forecasters' use had been added later. Interactive working demands response times which are short, preferably sub-second. In addition, the system must be easy to operate without becoming tedious for the experienced user.

Secondly, OASYS has dedicated operators whereas ODS is not intended to have operators as such, just users of the system. This implies that, wherever possible, all routine functions should be carried out automatically, without user intervention, or in some cases without the presence of any staff at all. It has therefore been necessary to build resilience into the software and care has been taken so that error conditions are handled without recourse to operator intervention.

Thirdly, with the advance of computer technology, the performance constraints lie in different aspects of the machines. OASYS is based on DEC PDP11/60 processors which are limited, by their architecture, to a maximum memory of 256 kilobytes. The MicroVax processors used in ODS have much larger main memory (2 megabytes is presently installed, but this is expandable to 16 megabytes). The computing speed is comparable, if not slightly faster than the PDP11/60, but the average disc access time is similar to that on OASYS. It therefore becomes feasible and worthwhile to try to use the increased memory available to reduce the number of disc accesses and hence increase the speed of certain operations. In the most active parts of the system, input and output operations are often minimized in the ODS design at the expense of increased use of memory.

The final general consideration in the design was the ease of maintenance of the software and its robustness and flexibility. Although these factors were also important with OASYS, they became more so with the ODS project because of the following factors:

- (a) The long-term nature of the project.
- (b) The large number of ODS which it is intended to install eventually (in excess of 60).
- (c) The remoteness of most of the sites from Bracknell where the staff tasked with supporting the software are based.

The software design is modular so that one area can be changed without impacting on others. The bulk of the software is written in FORTRAN 77 as it is suitable for this application; the FORTRAN



Figure 5. Photographs of the initial ODS (Outstation Display System) hardware installed in the Meteorological Office at RAF Lyneham: (a) the processor installed in the communications room (to the right of the table), (b) the graphics VDU (Visual Display Unit) installed for use by the forecaster, (c) the second VDU installed for use by support staff and (d) the printer with its acoustic cover.

compiler produces very fast code on the MicroVax, and FORTRAN is the standard language used within the Headquarters building at Bracknell.

The software divides up naturally into a number of functional areas, but for brevity this article will only describe the design of three fundamental aspects: communications, data base and user interface.

## 5.2 *Communications and data bases (see Fig. 6)*

The reception and storage of data are controlled by three processes running continuously and independently of any user interaction. These are data acquisition, pre-storage and storage, and are described in turn.

(i) *Data acquisition.* The first process takes data from the input port at 4800 bits per second and writes it to a 'raw-data' memory buffer. This buffer is arranged as a circular list of 8 kilobytes (see Knuth (1973)\* section 2.2.2). This process is the most time-critical task in ODS and is consequently given the highest level of processing priority. If no data are received for 15 minutes at a stretch, a warning message is printed out to alert the user to a possible communications failure.

(ii) *Pre-storage.* This process takes data from the 'raw-data' buffer and determines the start, end and type of each bulletin and copies each report within the bulletin to a second circular buffer (the 'report' buffer) prefixed by a header containing an indication of the data type and length of the report.

(iii) *Storage.* The third process takes each report from this second buffer and deals with it according to its type. SYNOPs and METARs are decoded into binary representations for each weather element and this decoded form and the original report are stored in a common specialized data base. This enables the very rapid retrieval of, say, all observations of temperature for the United Kingdom. The original report is stored as received, as a matter of policy, so that it is available for scrutiny. This can be particularly valuable in the event of data being received in a corrupted form. Ship reports, TAFs, and upper-air reports are each stored in their individual data bases, and all other reports are placed in a 'catch-all' data base.

## 5.3 *Data-base organization*

All the data bases have two components:

- (a) A disc file to hold the data.
- (b) An index of pointers into the data file to allow the retrieval software to find quickly the data which the user has requested.

For performance reasons the index to the SYNOP/METAR data base is held permanently in memory, and is shared by all the storage and display programs needing it. In contrast, the other data bases have disc-based indexes in the form of indexed-sequential files.

The data themselves are all held in direct-access files but the file for SYNOPs and METARs is arranged differently from the others. Each possible SYNOP or METAR from each station at each hour of the day is allocated its own dedicated record in the file. The other data files are simply written to in a sequential fashion until the end is reached whereupon writing recommences at the beginning. The size of each of these files is chosen so that this 'wrapping around' never occurs at intervals of less than 24 hours.

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\* Knuth, D. E.; *The art of computer programming (second edition) Vol. 1: Fundamental algorithms*. Reading, Massachusetts, Addison-Wesley, 1973.

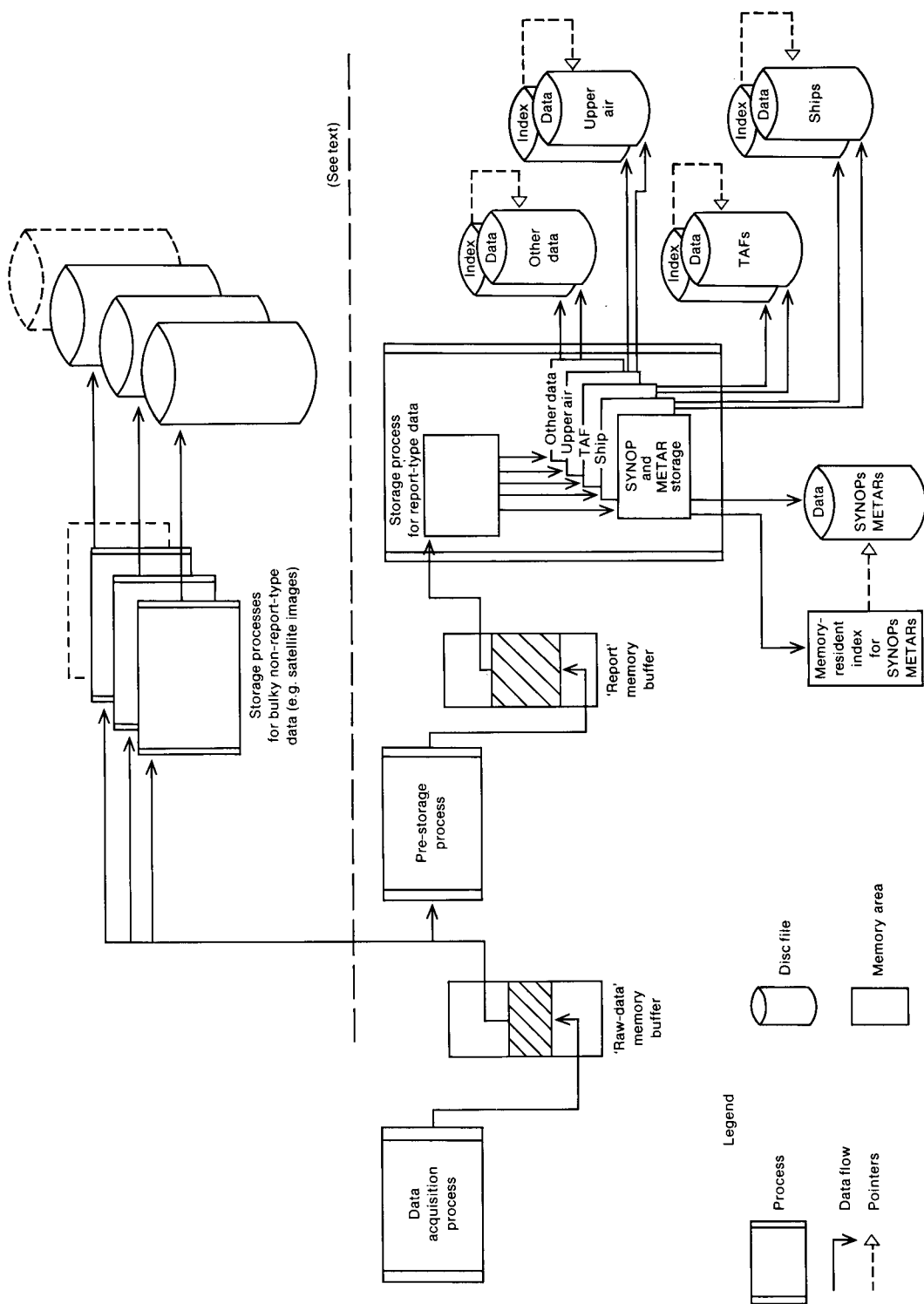


Figure 6. Data acquisition and storage processes used by ODS (Outstation Display System).

#### 5.4 *User interface*

The method which the user employs to obtain information from ODS is designed to be as self-explanatory as possible for the beginner and yet allow short-cuts for the expert. It consists of a menu system with full screen 'pages' of options displayed and, when a selection is made, this leads to further pages until at some point the user is asked to enter information such as a station number or a geographical location for which data are required. At all times, relevant helpful hints are available at the touch of a key. The top level, or master, menu is illustrated in Fig. 7.



Figure 7. The master menu displayed on ODS (Outstation Display System).

#### 5.5 *Software implementation*

Excellent progress has been made with the production of the necessary software. An early version of the software was installed at Lyneham at the end of October 1986, with the first full release of software being provided to all other stations as their equipment was installed. Additions to the software have been made subsequently. These software updates are provided to outstations on magnetic tape cartridges and the updates are installed by the outstations' own staff.

At the time of writing, ODS is able to receive and to store all character data which are transmitted to it. The menu system allows users to retrieve data on demand in a variety of formats. Hard copy facilities are provided. One graphical display has been provided so far (the plotting of a sequence of hourly observations for a selected station) and others, such as plotted tephigrams, are in the pipeline.

## **6. Future programme for ODS**

Approval was given for the continuation of the ODS programme during 1987 with installations at the following sites: Coltishall, Cottesmore, Cranwell, Finningley, Kinloss, Leeming, St Mawgan, Wyton, Manchester, Meteorological Office College and HQSTC. Equipment similar to that provided for the first batch of stations will be installed. The interim scheme for communications to the first eight stations will be extended to supply data to these stations as well.

The installation of equipment at additional stations cannot be continued much beyond that planned for 1987 until WIN has been installed. It is therefore planned in 1988 to concentrate the available resources on upgrading the first two batches of systems with additional equipment, in readiness for the additional quantities and types of data that will become available across WIN. Several parts of ODS will need to be upgraded. Main memory will be added to increase the overall system throughput. Extra disc storage will be added to provide adequate space for the additional products, in particular satellite imagery which is very bulky. Furthermore, there will be advantages of resilience in having more than one disc drive. An additional communications interface will be added which will provide the high-speed connection to the OCP. A graphics printer will be provided to enable high-resolution copies of charts and other graphics output to be produced. Finally, it is intended to provide a new generation of higher performance graphics displays. These will have a higher resolution than the existing ones and will also enable more colours to be displayed at one time. A means of providing input to the screen, to enable a forecaster to generate charts, will also be provided. It is expected that a full configuration ODS to support a single forecaster will cost about £45 000.

The installation programme is expected to continue until 1992, by which time all forecasting offices will have been equipped with ODS, providing an interactive graphical display unit for each forecasting work position. Temporary installations of ODS, to run alongside OASYS, will be provided for the London Weather Centre and HQSTC pending the eventual replacement of OASYS by the next generation of systems at these larger forecasting units.

Much software has still to be written, including the provision of an expanding range of graphical displays. However, the biggest change anticipated in the way ODS will work in the future will be to allow the reception and storage of large volumes of data, such as satellite images and charts, encoded in binary formats. The quantity of data involved is such that it will be important for these data to be stored on disc with the minimum of processing. Consequently, it is planned that such data will be taken directly from the 'raw-data' buffer and written to disc, by-passing the pre-storage step. This is illustrated in Fig. 6 above the dashed line. Another major enhancement in the facilities will be the provision of the means for forecasters to generate products, both textual and pictorial. A major software development effort will continue to be required to provide these functions and the other facilities which are specified in the User Requirement.

# The direct measurement of geopotential height from orbiting platforms

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## Summary

The horizontal gradient of geopotential height is an important element in determining the field of atmospheric motion by numerical means. Orbiting platforms can provide consistent measurements over otherwise data-sparse areas, thereby complementing the conventional network of observations. To date, geopotential height has been determined from orbiting platforms via retrieved profiles of temperature and an additional external measurement of surface pressure. We describe here a method of determining geopotential height directly by combining satellite measurements of pressure, temperature and geometric altitude.

## 1. Introduction

Routine observations from both geostationary and polar orbiting satellites contribute substantially to the global observing system for operational meteorology. In addition to information about weather systems which can be derived from visible and infra-red images of clouds and the earth's surface, a range of variables, including temperature, humidity and wind (from tracking clouds) is available for direct incorporation into numerical global forecasting models (see, for instance, Houghton *et al.* (1984)). The main advantages of observations from polar orbiting satellites are that global coverage is available twice per day and that, because a single instrument is involved for all the measurements, a high degree of consistency in the measurements is achieved. A further characteristic of satellite observations is that, although the vertical resolution for some measurements (e.g. temperature and humidity) is poor, the horizontal resolution of these measurements is high — considerably higher than is available from conventional observations, even in data-rich areas. It is, therefore, valuable to investigate whether it is possible to increase the range of observations which can be made from satellite vehicles.

## 2. Requirements of numerical models

Numerical models for weather prediction require an analysed field of the distribution of mass (i.e. the density field) throughout the atmosphere as a starting point for the integration of the equations of motion (see, for example, Gadd (1985)). In the operational model currently employed in the Meteorological Office, the density field is described in terms of the distribution of geopotential height on surfaces of constant pressure. The geopotential height,  $h$ , is defined by the relation

$$h = \Phi / g^* \quad \dots \dots \dots (1)$$

where  $g^* = 9.8 \text{ m s}^{-2}$  is an average value of the acceleration due to gravity and the geopotential,  $\Phi$ , of a body at a particular place above the earth's surface is its potential energy per unit mass, that is

$$\Phi = \int_0^z g'(z, \phi) dz \quad \dots \dots \dots (2)$$

where  $g'(z, \phi)$  is the apparent acceleration due to gravity which is a function of the altitude,  $z$ , and the latitude,  $\phi$ .

Applying the hydrostatic relation to equation (2) yields the difference in geopotential between two different levels denoted by the subscripts 1 and 2.

$$\Phi_2 - \Phi_1 = -R \int_1^2 (T/p) dp \quad \dots \dots \dots (3)$$

where  $R$  is the gas constant for air and  $T$  is the temperature at a level where the pressure is  $p$ .

From equation (3) it will be clear that to obtain a complete field of geopotential, knowledge is required of the distribution of temperature throughout the atmosphere together with the distribution of geopotential on one surface of constant pressure. This latter information is provided at the moment from measurements of surface pressure which can easily be turned into values of geopotential on the 1000 mb surface.

This paper describes a method of measuring, directly from an orbiting platform, the geopotential height well away from the surface.

### 3. The principle of the measurement

The principle of the proposed measurement is to determine simultaneously the pressure at a suitable altitude above the earth's surface by a direct observation of the radiance emitted from the atmosphere, and the geometric height of the region at which the pressure is measured (see Fig. 1). The radiance is measured when viewing along a path that does not intercept the surface of the earth, a so-called 'limb' path. This permits a much finer vertical resolution than can otherwise be achieved, and prevents

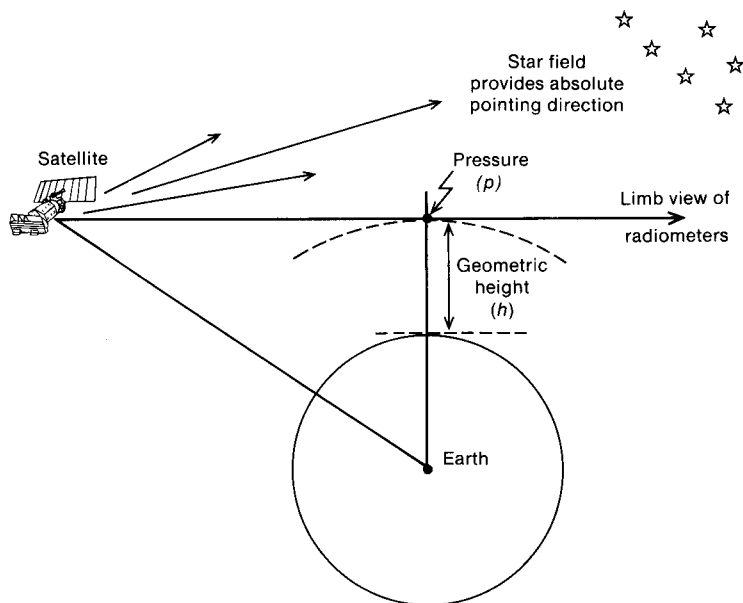


Figure 1. The geometry of the proposed measurement. The satellite measures simultaneously the pressure at the tangent to the earth,  $p$ , and the geometric height of the tangent,  $h$ .



contamination of the measurement by radiance from the earth itself. The geopotential height corresponding to the geometric height can be calculated from an explicit form of equation (2), given that the latitude of the point on the surface below this region is known.

To determine the pressure accurately from a radiance measurement, the emission observed must be from a gas which is substantially uniformly mixed at an altitude high enough to avoid contamination by clouds. Emission from carbon dioxide ( $\text{CO}_2$ ) in its  $4.3\ \mu\text{m}$  or  $15\ \mu\text{m}$  bands from a region well above the tropopause is suitable. The altitude of measurement should not be too high; it should be sufficiently low to be easily useful in operational meteorology. The compromise altitude adopted for this study was about 25 km, corresponding to a pressure of 25 mb.

#### 4. Required accuracy

It is convenient to consider the 500 mb level which, being in the middle of the atmosphere, is one of the most relevant from the forecasting point of view. The accuracy of measurement of the geopotential height of the 500 mb surface will depend upon the accuracy of measurement of both the 25 mb geopotential height and the intervening temperature field.

A computer simulation was performed in which random errors with specified statistical characteristics were applied to the temperature profile and to the height of the 25 mb surface. Repeated application of the technique produced the curves in Fig. 2. As would be expected, only with perfectly known temperatures can the errors at 500 mb be kept down to those at 25 mb. Existing methods of determining the 500 mb height, using remotely sensed temperature profiles coupled with surface-pressure measurements, show errors of about 30 m in the northern hemisphere and 45 m in the southern hemisphere where observations are much more sparse (see, for example, Allam (1987)). To be of value, a new system must be capable of significant improvement on these figures; a baseline value for the purposes of this investigation was taken to be 25 m. Fig. 2 indicates that with a root-mean-square (r.m.s.) error in the temperature of 0.7 K specified at each level, the requirement for the maximum r.m.s. error in the height of the 25 mb surface is about 15 m. For the number of levels used in the simulation, an r.m.s. temperature error of 0.7 K at each level is equivalent to the r.m.s. error of 0.2 K in the mean temperature of the whole layer.

With the temperature sounding instruments which will be carried on board polar orbiting satellites in the late 1980s, namely the High-resolution Infra-Red Sounder (HIRS) and the Advanced Microwave Sounding Unit (AMSU), it is not unreasonable to assume that the mean temperature between 500 mb and 25 mb will be determined to 0.2 K. The rest of this article therefore addresses the problem of the possibility of the measurement of geopotential height at 25 mb to within 15 m.

#### 5. Determination of geometric height

The proposed measurement is of the geometric altitude of the 25 mb surface. It is not feasible to determine this quantity from a single observation: instead, observations will be made at a number of appropriate pressures and the value at 25 mb determined by interpolation. These observations will be made by using a vertical array of detectors to receive radiation from the atmosphere's limb (Fig. 1), positioned such that their fields of view scan across the 25 mb surface. For each detector, the pressure at the tangent point of the path from which the radiation originates will be measured; details of this measurement will be given in the next section. The geometric height of the tangent points for each of the fields of view will also be calculated.

The determination of the geometric altitude (Fig. 3) relies upon simultaneous measurements of the satellite ground-track, satellite altitude and the direction of the line of sight of the radiometer. To

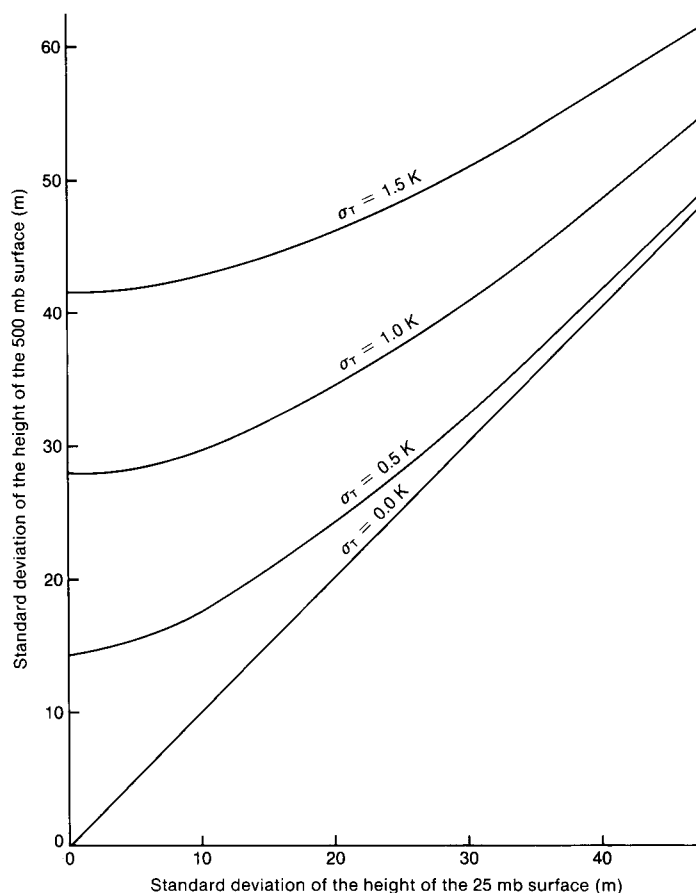


Figure 2. Standard deviation of the height of the 500 mb surface as a function of that of the 25 mb surface for different values of the standard deviation of temperature,  $\sigma_T$ , specified at standard levels within a profile. The nominal height of the 25 mb surface was 25 000 m and that of the 500 mb surface was 5537.5 m. The results were determined by Monte Carlo simulation.

determine the direction of the radiometer's line of sight, a star mapper will be required. This instrument observes the apparent positions of suitable stars to derive its pointing direction relative to some universal set of coordinates. Coupling this knowledge with the angle between the lines of sight of the star mapper and the radiometer enables the pointing direction of the radiometer to be determined. The angle between the two lines of sight can be measured accurately before launch, but the stresses of launch and the changes in the gravitational environment could cause significant relative shifts. A calibration of the angle in flight would be required.

Errors in the determination of these quantities would all have an impact on the final measurement of the tangent height. These errors are dealt with more fully in an expanded version of this paper (Allam 1987) to which the reader is referred.

Summarized below are the precisions in the various parameters needed to measure the height of the 25 mb pressure surface to better than 15 m.

- (a) The altitude of the satellite has to be known to better than 17 m.
- (b) The direction of the line of sight of the radiometer must be known to about 1 arc second in the vertical, but less accurately horizontally. The angle between the line of sight of the star mapper and

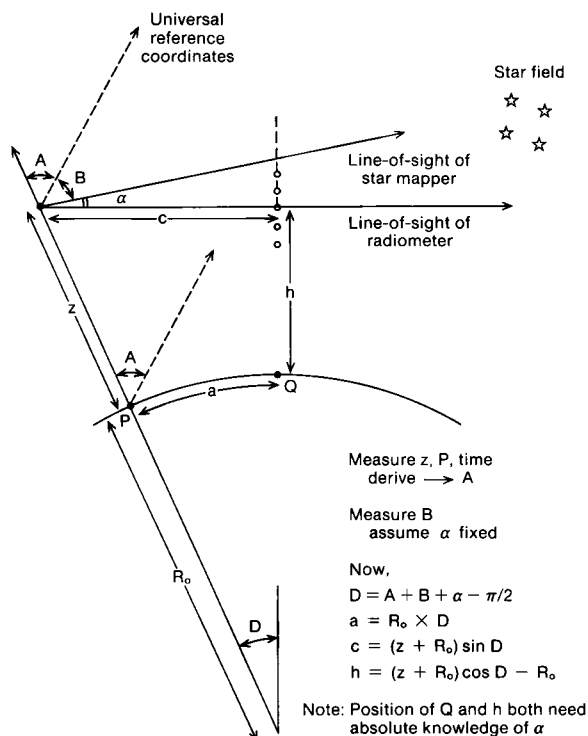


Figure 3. Method showing how the tangent height can be determined from observed quantities. The dots near the tangent point indicate schematically the altitudes of the measurements of pressure from the vertical array of detectors referred to in section 5.

that of the radiometer should also be known to about 1 arc second. The short-term variability of the pointing direction should be less than about 0.1 arc seconds in 2 seconds.

(c) Differential heating of opposite sides of the instrument mounting leading to a temperature differential of 1 K could cause significant distortion. This should either be prevented or measured independently, thereby allowing a correction to be made.

(d) A determination of the apparent ground-track of the satellite would be required to about 30 m, which is equivalent to knowing its equator-crossing time to within about 4 ms. An orbital model capable of predicting the satellite's position relative to the earth to this accuracy would also be required.

The values for the errors given above are those which would apply if each error only applied in isolation. Because in practice several sources of error will be compounded, the aim should be to achieve precisions of measurement no greater than, say, two-thirds of those quoted above.

Of the above parameters, the position parameters (a) and (d) do not present too much difficulty. Techniques are available (for instance, radar altimetry) with which the altitude and position of satellites can be determined to considerably better than what is required. Limiting structural distortion as mentioned in (c) or allowing for it should also be achievable with careful design. The more difficult measurement is that of the angle of the line of sight (b).

Because of the availability of Charge-Coupled Device (CCD) arrays with large numbers of elements (for example, several thousand squared) and high sensitivity, substantial developments in the technology of star mappers have recently become possible. For instance, one being built for the

Roentgen Satellite (ROSAT) mission for X-ray astronomy can detect stars down to 6.5 magnitude over a field of view of  $2^\circ \times 10^\circ$  or can make an attitude measurement to between 3 and 5 arc seconds in a 1 second integration time. It is a relatively small instrument (about 50 mm in each linear dimension) and very substantially less complicated than that being built for the Space Infra-Red Telescope Facility (SIRTF), which will have a precision of 0.1 arc seconds. For our purposes, a star mapper will be required with rather higher performance than the ROSAT model, but less sophisticated than those designed for the larger space telescopes.

## 6. The determination of pressure

The radiation received by a detector on the spacecraft which is observing the atmospheric limb is dependent on the amount of emitting gas, its pressure  $p$  and its temperature  $T$  within the field of view of the radiometer. An advantage of the limb view at the levels that are being considered is that cold space from which no radiation originates is behind the atmosphere, and no clouds are present to interfere with the radiation stream.

The intensity of radiation,  $I$ , (or the radiance) measured by the satellite radiometer is

$$I = \int B(x, T) d\tau(x) \quad \dots \dots \dots (4)$$

where  $B(x, T)$  is the Planck black-body function at the temperature  $T$  which exists at a point  $x$  on the limb path. The transmissivity,  $\tau$ , from the point  $x$  to the satellite for radiation over the range of wavelengths observed by the radiometer and the integration is over the whole path viewed by the radiometer. It is useful to employ  $-\ln p$  as a variable instead of  $x$ , in which case

$$I = \int B(-\ln p, T) \left\{ \frac{d\tau}{d(-\ln p)} \right\} d(-\ln p). \quad \dots \dots \dots (5)$$

The second term under the integral is known as the 'weighting function' since it determines the relative contribution from different pressure levels to the total received radiation. Eyre and Jerrett (1982) give a complementary and more physical explanation of these principles of radiative transfer.

Fig. 4 shows a set of weighting functions for a radiometer viewing a limb path with a tangent pressure of 25 mb at various spectral intervals within the  $15 \mu\text{m}$   $\text{CO}_2$  band. The reasons for selecting this tangent pressure were outlined in section 3. For curves 1 to 4 of Fig. 4, a large proportion of the radiance would be characteristic of a layer within a few kilometres of the tangent pressure. Curve 5 is for a highly absorbing part of the spectrum for which most of the radiance comes from points much closer to the satellite, and therefore higher in the atmosphere, than the tangent point. Such regions of the spectrum would need to be avoided.

With the simplifying assumption of an isothermal atmosphere, the intensity that would be measured at the satellite can be related to the tangent height of the path being observed using equation (5). Fig. 5 shows this relationship and indicates that a wave-number interval can be selected such that the intensity varies strongly with the logarithm of the tangent pressure between about 10 mb and 50 mb. At low levels (below about 100 mb) the atmospheric limb becomes completely opaque for both upper and lower limits of the intervals. Above about 10 mb, the intensities vary more slowly with the logarithm of the tangent pressure and are in any case rather small. Curves similar in shape to those in Fig. 5, but displaced in the vertical, would apply to other spectral intervals in the  $15 \mu\text{m}$   $\text{CO}_2$  band. Thus, a measurement of intensity made using a suitable wave-number interval could provide a sensitive determination of the tangent pressure.

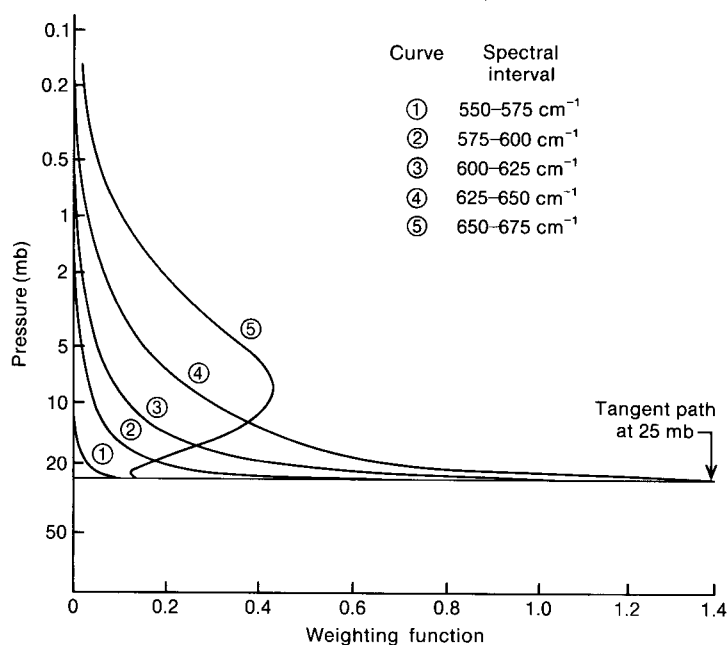


Figure 4. Total weighting functions for tangent path at 25 mb for different spectral intervals in the 15  $\mu\text{m}$  carbon dioxide band.

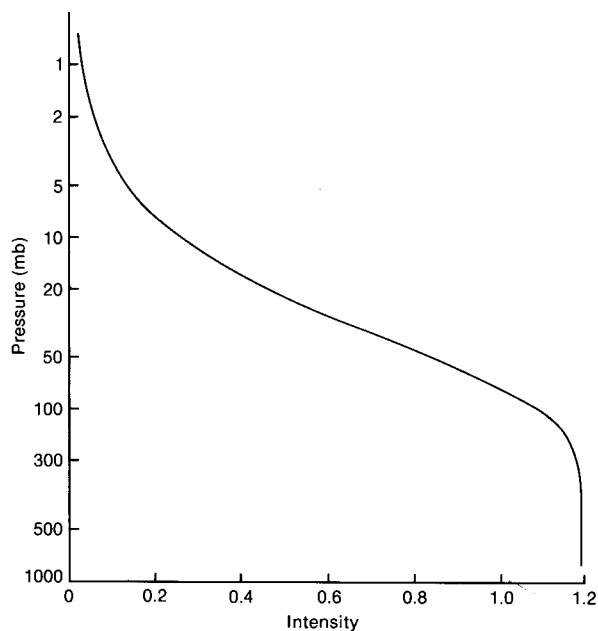


Figure 5. The relationship between the atmospheric pressure at the tangent point and the intensity that would be measured within a wave-number interval of 600–625  $\text{cm}^{-1}$ , computed using equation (5).

Given that good information is available about the properties of the transmissivity for the CO<sub>2</sub> absorption bands being used, two quantities in equation (5) need to be determined, namely  $T$  and  $p$ . Drummond *et al.* (1980) pointed out that both can be retrieved for a limb path from measurements at two spectral intervals. A practical instrument would employ radiometers observing in two or more spectral intervals so that both temperature and pressure could be retrieved simultaneously. This retrieval process would also use information which would be available from other sources regarding the atmospheric temperature field (see, for example, Eyre (1987)).

The purposes of this study require an estimate of the accuracy with which the radiances would need to be measured in order to achieve an error in pressure equivalent to an error of 15 m in geopotential height. To simplify the calculation, the assumption has been made that the temperature field is known together with appropriate estimates of the errors in that field.

A computer simulation of the effect of random errors in the measurement of intensity from five detectors, with fields of view separated by 2500 m, upon the error in the determination of the height of the 25 mb surface was performed using a curve similar to that shown in Fig. 4; the details are given in Allam (1987). The results showed that in order to determine the height of the pressure surface to 15 m, the random errors in intensity should be less than 0.1% of the black-body intensity. With care, this is achievable.

## 7. Synthesis of the two measurements

The fields of view of the five radiometers would be directed to span the 25 mb level. Values of the pressure viewed by each radiometer would be obtained. The geometric heights of their fields of view could be computed from observations of the star field and from knowledge of the position of the platform as indicated in a previous section. Interpolation could then be used to give the geometric height of the 25 mb pressure surface. The geopotential height corresponding to this geometric height can be computed through the use of an explicit form of equation (1).

Since measurements of geopotential height in the atmosphere are available by conventional means (for example, from surface pressure and radiosonde temperatures) over much of the land surface of the globe, it is not necessary for the satellite measurements of geopotential height to be absolute. What is needed is the ability to interpolate between places where there are good conventional measurements.

## 8. Conclusions

A system has been proposed which uses five measurements of the intensity of infra-red radiation emitted from the limb of the atmosphere together with simultaneous observations of the position of the star field to derive the geopotential height of the 25 mb surface. It was shown that, to be useful to operational meteorologists, this surface should be known to about 15 m.

The precisions of various parameters to achieve this goal have been calculated and are summarized below.

- (a) Altitude of satellite — 17 m.
- (b) Ground track of satellite — 20 m or 3 ms.
- (c) Pointing direction of radiometers.
  - Accuracy — 0.7 arc seconds
  - Stability — 0.1 arc seconds/3 seconds
- (d) Random noise in detectors — 0.1% of black-body intensity.

Realizing that what are required are relative measurements to provide adequate interpolation between places where the geopotential height can be determined by conventional means, the precision required of all the measurements seems to be within the state of the art.

## Acknowledgements

Dr J. Barnett of Oxford University and Dr R. Holdaway of the Rutherford-Appleton Laboratory have provided useful information and helpful advice.

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551.509.542:551.573

# Improving precipitation forecasts from the Meteorological Office fine-mesh model by using a modified evaporation scheme

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## Summary

A new treatment of the evaporation of precipitation in the fine-mesh model is described. The improved forecasts of precipitation, especially of showers, are illustrated by the results of one case study.

## 1. Introduction

During the last 3 years a significant number of fine-mesh model forecasts have underestimated the extent of showers over the United Kingdom, especially in northerly and north-westerly airstreams. It was felt that this behaviour may have been due to excessive evaporation of convectively produced rain. Therefore, a series of experiments was carried out to see if the precipitation forecasts could be improved by modifying the evaporation scheme which was being used in the operational model.

## 2. The parametrization schemes

### 2.1 The operational evaporation scheme (prior to 22 July 1987)

The operational precipitation scheme has been described in detail by Bell and Dickinson (1987). The model produces large-scale (dynamic) precipitation when air at a model grid point becomes supersaturated as a result of ascent or radiative cooling. The excess water vapour is then condensed and allowed to fall as precipitation (either rain or snow depending upon the temperature). As the precipitation falls the melting of snow is taken into account and both types of precipitation are assumed

to evaporate at a rate,  $E$ , which depends upon the difference between the saturation specific humidity,  $q_s$ , and the specific humidity,  $q$ , of the surrounding air:

$$E = \beta(q_s - q).$$

The value of  $\beta$  chosen for dynamic precipitation was  $2 \times 10^{-5} \text{ s}^{-1}$  (where  $q$  and  $q_s$  are in units of  $\text{kg kg}^{-1}$ ) irrespective of the intensity of precipitation. Kessler (1969) proposed that  $\beta$  should depend upon the density of rain (per volume of air), which in turn is related to the rainfall rate. A precipitation rate of  $0.1 \text{ mm h}^{-1}$  would give an evaporation rate, for air near the ground, similar to that obtained from using  $\beta = 2 \times 10^{-5} \text{ s}^{-1}$ . However, at higher rainfall rates the use of this value slightly underestimates the evaporation compared to that given by Kessler's expression for  $\beta$ .

The deep convection parametrization scheme used in the model is based on parcel theory modified by entrainment. The scheme assumes that in each grid box there is an ensemble of buoyant convective plumes which entrain air from the surroundings and ascend until they are no longer buoyant. If the cloud depth is greater than a certain critical value and the cloud-water mixing ratio exceeds a specified threshold value (whichever is the smaller of the local saturation specific humidity and  $1 \text{ g kg}^{-1}$ ), the cloud water in excess of the threshold is assumed to fall as precipitation. As the precipitation falls through the air beneath the cloud, which is assumed to cover 10% of the grid box, the effects of evaporation of rain and melting of snow are taken into account. The expression used to calculate the evaporation rate of convective rain is the same as that used for dynamic rain except that  $\beta$  has a value of  $10^{-3} \text{ s}^{-1}$  which corresponds to a rainfall rate of  $50 \text{ mm h}^{-1}$  near the ground. Clearly this value of  $\beta$  is only really applicable for intense thunderstorms.

## 2.2 The modified evaporation scheme

Rowntree (personal communication) has suggested that the representation of evaporating precipitation in the fine-mesh model would be improved if  $\beta$  depended upon the precipitation rate. Therefore, following Kessler (1969),  $\beta$  for dynamic precipitation was assumed to be given by

$$\beta = 1.34 \times 10^{-2} R^{0.6} \text{ s}^{-1}$$

where  $R$  is the precipitation rate in  $\text{kg m}^{-2} \text{ s}^{-1}$  ( $\text{mm s}^{-1}$ ). For example, a precipitation rate of  $1 \text{ mm h}^{-1}$  would give a value of  $\beta = 9.8 \times 10^{-5} \text{ s}^{-1}$  whereas a rainfall rate ten times larger would give  $\beta = 3.9 \times 10^{-4} \text{ s}^{-1}$ . For simplicity this expression for  $\beta$  is used for both rain and snow.

For convective rain, the evaporation depends upon the fractional area of precipitating cloud,  $A$ , and the local rainfall rate over that area,  $R_1$ , so

$$\beta \propto A R_1^{0.6}.$$

To use this expression  $A$  and  $R_1$  must be expressed in terms of the grid-box average precipitation rate,  $R_1$ , predicted by the model. By definition  $R_1 = R/A$  and, from a study of ship and radar data collected during the GARP Atlantic Tropical Experiment (GATE),  $A \propto R^{0.5}$ . Substituting these into the expression for  $\beta$  gives

$$\beta = 4.37 \times 10^{-2} R^{0.8} \text{ s}^{-1}$$

where  $R$  is expressed in terms of  $\text{kg m}^{-2} \text{ s}^{-1}$ . A rate of  $1 \text{ mm h}^{-1}$  corresponds to  $\beta = 6.2 \times 10^{-5} \text{ s}^{-1}$ , whilst a



rate of  $10 \text{ mm h}^{-1}$  corresponds to  $\beta = 3.9 \times 10^{-4} \text{ s}^{-1}$ . As the grid-box rainfall rate grows,  $\beta$  increases more for convective rain than for dynamic precipitation because the fractional area of precipitation also increases.

At the same time that  $\beta$  was changed, the threshold liquid-water content in convective cloud for which precipitation forms was changed from  $1 \text{ g kg}^{-1}$  to  $0.1 \text{ g kg}^{-1}$ . This reduces the moistening and cooling when final detrainment occurs and the remaining cloud liquid water is re-evaporated.

### 3. The trial

In order to assess the impact of the modified scheme upon the fine-mesh precipitation forecasts, 11 pairs of trial and control forecasts were compared using:

- (a) The June 1987 version of the fine-mesh model to provide an up-to-date control forecast.
- (b) The trial version containing the modified evaporation scheme.

The 11 cases were selected from the previous 12 months in order to cover a wide range of synoptic situations over the United Kingdom; the data times of the cases and the reason they were chosen are as follows.

00 GMT 19/5/86	development of a mesoscale convective system
00 GMT 10/6/86	cool, wet, cyclonic weather
12 GMT 16/6/86	hot, humid weather with the risk of thunderstorms developing
12 GMT 22/7/86	original operational model gave a poor forecast of showers over south-east England for the Royal Wedding day on 23 July
00 GMT 23/7/86	original operational model gave a poor forecast of showers over south-east England for the Royal Wedding day on 23 July
12 GMT 27/8/86	depression in the North Sea moved slowly north-east and showers developed in the cool strong northerly airstream over much of the United Kingdom
00 GMT 29/9/86	large anticyclone controlling the weather over most of Europe
00 GMT 11/1/87	coldest period of the winter when strong easterly winds brought extremely cold weather from Siberia across the United Kingdom
12 GMT 11/2/87	slack low pressure area persisted over the United Kingdom
00 GMT 28/3/87	deep depression moved slowly northwards over Norway and a strong northerly airstream covered the United Kingdom
00 GMT 13/6/87	operational model failed to predict the heavy showers which occurred

The results from all the cases studied are given in Hammon and Wilson (1987); only one case will be considered in detail here.

### 4. The case of 00 GMT on 19 May 1986

The synoptic situation and the original fine-mesh forecast for this time have been described in detail by Morris (1986). The control forecast described here differs slightly from the original forecast since a more up-to-date version of the model was used.

During 19 May, an upper trough in the Atlantic was moving slowly eastwards towards Biscay, maintaining a south-westerly upper flow over the United Kingdom. Thunderstorms developed in the warm, humid air mass over Spain and western France ahead of an approaching cold front and started to move northwards towards the United Kingdom. During daylight hours, southern England remained dry, warm and mainly sunny. However, during the late evening, cloud increased over south-west England, Wales and the west Midlands and sporadic outbreaks of rain and isolated thunderstorms were reported from the unstable medium cloud. During the night, thunderstorms and outbreaks of heavy rain

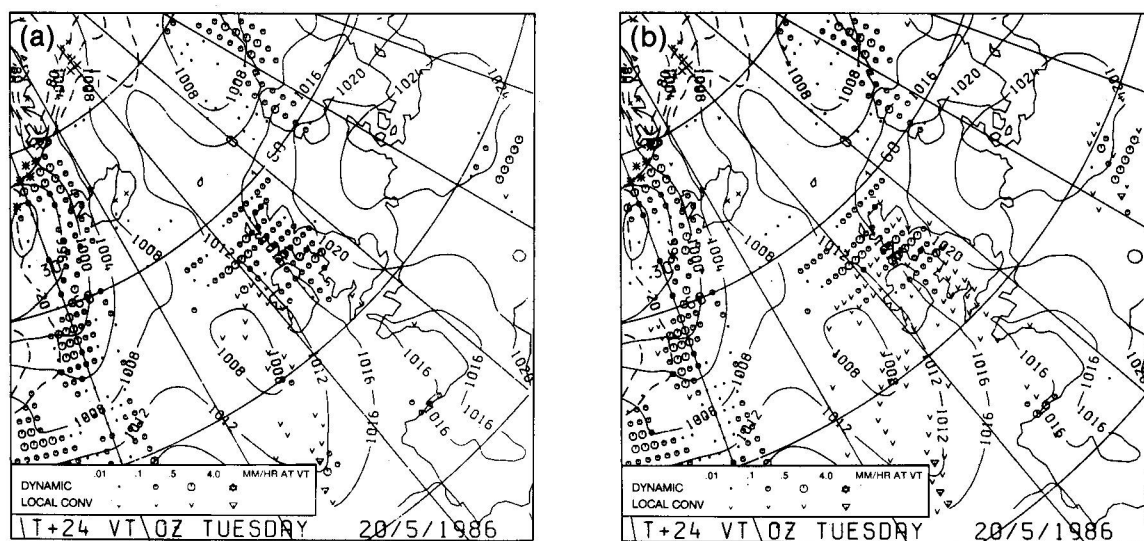


Figure 1. Fine-mesh numerical forecasts of mean-sea-level pressure (mb) and rainfall rates for T+24, verification time 00 GMT on 20 May 1986, from (a) the operational version and (b) the trial version of the model.

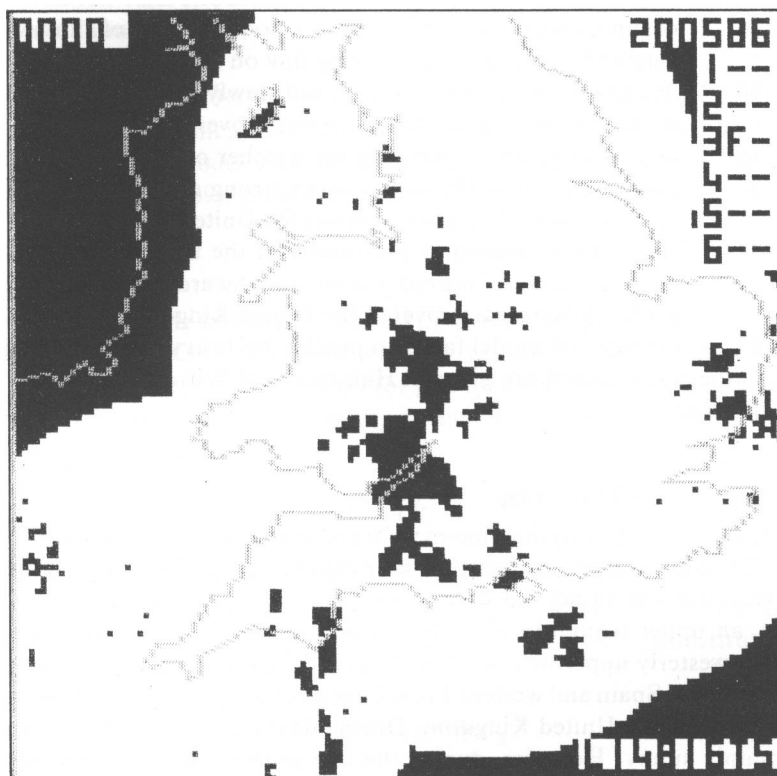


Figure 2. Radar picture showing the distribution of rain for rates above  $0.1 \text{ mm h}^{-1}$  at 00 GMT on 20 May 1986.

became more widespread, spreading northwards and eastwards over the rest of England, but Cornwall and west Wales stayed dry.

The main difference between the trial and control forecasts was noticed at T+24, verification time 00 GMT on 20 May (see Fig 1); in Fig. 2, the radar picture shows the rain area at 00 GMT. Both versions of the fine-mesh model produced very similar forecasts for the convective cloud tops and depths (i.e. tops 20 000–27 000 ft and depths 10 000–14 000 ft). However, whereas the control version forecast only had isolated showers at two grid points in south-west England from this cloud (see Fig. 1(a)), the trial version forecast widespread showers over Wales and south-west England (see Fig. 1(b)). These extra showers forecast by the trial version gave 6-hour rainfall accumulations of 0.1–1.0 mm. Although the trial forecast has predicted showers too far west, it gives a better indication of the northwards spread of the thundery rain. At T+36, verification time 12 GMT on 20 May, the forecasts were very similar.

## 5. Conclusions

The main conclusions from the complete set of cases are listed below:

- (a) Forecast mean-sea-level pressure is the same with both schemes.
- (b) The modified scheme produces a significant increase in the number of light showers forecast over the sea (between 0.1 mm and 1.0 mm added to the 6-hour accumulations of rain). However, there are indications that showers over the sea may be too widespread with the modified version.
- (c) There is a slight increase in the number of light showers forecast over land with the modified scheme — of the eight cases in which the forecast of showers over land is important, the forecast distribution of showers is improved in six cases by using the modified scheme.
- (d) There is a slight decrease in forecast amounts of low and medium cloud with the modified scheme. For low clouds the decrease was very small, but the decreases are more noticeable for medium clouds (mainly confined to unstable airstreams and the outer edges of depressions). Frontal clouds are mainly unaffected.
- (e) The indications are that there is a switch from dynamic to convective rain with the modified scheme.
- (f) When the model ascents from the two versions differ, those from the modified scheme are very slightly warmer and drier. In most cases the increase in temperature is only 0.1–0.2 °C.

Because the modified scheme tends to improve the forecasts of convective rain, it was incorporated into the operational model on 22 July 1987.

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## Golden anniversary of the Naval Meteorological Branch

**Commander G. Sullivan, Royal Navy**

**Naval Liaison Officer to the Meteorological Office**

Extract from the December 1937 edition of the *Meteorological Magazine*:

The Admiralty have established a branch of the Hydrographic Department to take over the administrative duties connected with meteorology in the Fleet. The new Admiralty branch is to be known as the Naval Meteorological Branch of the Hydrographic Department and Captain L.G. Garbett, R.N. (retd.), has been placed in charge with the title Chief Superintendent of Naval Meteorology. The change will involve a reorganisation in the Meteorological Office, the remaining duties of the old Naval Division, of which Captain Garbett has been in charge since 1921, being allocated to other Divisions.

Such were the terms in which this publication announced, 50 years ago, the termination of the Meteorological Office's responsibility for providing meteorological support for the Royal Navy. In fact that responsibility had lasted for only 16 years. With the advent of naval aviation an Admiralty Meteorological Section had been established in 1916. This was initially formed within the Naval Air Department and subsequently transferred to the Hydrographic Department. It was in 1921 that this section was taken over by the Naval Division of the Meteorological Office.

However, with the rapid expansion of the Fleet Air Arm in the 1930s, the training of naval officers as meteorologists, and the establishment of meteorological offices on board aircraft carriers, it became obvious that the navy needed a dedicated support organization of its own and thus on 1 August 1937 the responsibility for naval meteorology was transferred back to the Hydrographer of the Navy.

The split from the Meteorological Office proved to be more of an amicable separation than a divorce. The Royal Navy relied, as it continues to rely, on the Meteorological Office for raw and some processed data, and for the maintenance of shore-based meteorological communications and instruments.

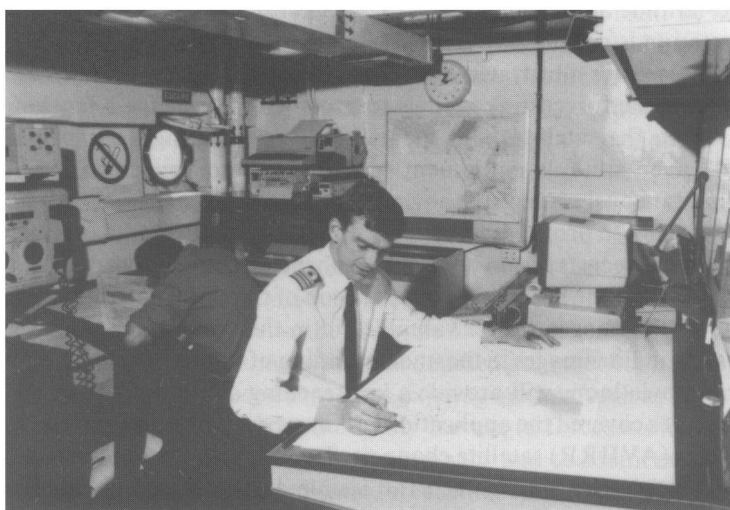
In its 50-year history the Naval Meteorological Branch has changed dramatically. In the 1940s and 1950s the Branch expanded. The tasks were heavily orientated towards support of fixed-wing carrier aviation and at one stage 70 ships and 30 Naval Air Stations were manned. In 1950 the Branch became the Naval Weather Service Department under its own Director (DNWS). In the 1960s the carrier fleet diminished rapidly but new responsibilities emerged as the importance of oceanography to submarine and anti-submarine warfare (ASW) became apparent. In 1966, to reflect these new responsibilities, DNWS became the Director of Meteorology and Oceanographic Services (Navy), with a second change in 1974 to the Director of Naval Oceanography and Meteorology, DNOM. To emphasize the shift of responsibilities the naval meteorologist acquired the new and unlovely title of the 'METOC' officer. Naval METOC training and responsibilities now cover the assessment and prediction of the oceanographic environment and its effect on a wide range of surface ship, submarine and aircraft acoustic sensors and weapons systems. The tasks of the navy's aircraft carriers are now predominantly ASW and in addition to this traditional 'big ship' requirement the services of the METOC officer are now in great demand in frigates equipped with low-frequency passive sonar.

Today a total of 85 officers are serving in dedicated METOC billets (26 of them at sea) supported by approximately 145 ratings of the Naval Airman (Met) and WRNS Met (Observer) Branch.

On 18 September 1987 more than 100 retired and serving officers of the Meteorological Branch attended a Reunion Dinner at HMS *Daedalus*, Lee-on-Solent. The opportunity to reminisce and to expound on the dramatic changes of the last 50 years was not missed! Neither was the opportunity to speculate as to what the next 50 years might hold.



**HMS *Invincible*.** Aircraft complement; normally 9 ASW Sea King Helicopters and 5 Sea Harriers, but can carry up to 22 aircraft in any combination. METOC complement; 1 Commander, 1 Lieutenant Commander, 1 Lieutenant, 1 Petty Officer Airman (Met), 2 Leading Airmen (Met) and 2 Naval Airmen (Met).



**The Meteorological Office, HMS *Ark Royal*.** Equipment includes Weather Satellite Image Receivers, Dedicated Radio Teletype and Facsimile Communications, Computer Systems for Evaluating Sonar Performance, and the only scuttle in the ship!

## Conference Report

### **Workshop on Satellite and Radar Imagery Interpretation, Meteorological Office College, Shinfield Park, England, 20–24 July 1987**

A Workshop on Satellite and Radar Imagery Interpretation was held at the Meteorological Office College, Shinfield Park from 20–24 July 1987. It was organized and hosted by the Meteorological Office and was also sponsored by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), who provided an excellent preprint volume of the papers presented at the workshop, and the World Meteorological Organization.

The proposal for a workshop came from a planning meeting of the Operational World Weather Watch Systems Evaluation for the North Atlantic (OWSE-NA) in 1984. It was intended that experts in the various aspects of imagery interpretation from around the world would gather together to exchange their knowledge and ideas, with a view to enhancing the value of the data from radars and satellites to weather forecasters. The workshop, which was a mixture of 30 lectures from invited speakers and periods of working group discussions, was attended by over 75 participants from 22 countries. The workshop focused on the application of image data from satellites and radar in the understanding and forecasting of weather systems affecting mid latitudes. The participants were a mix of research workers, practising forecasters and experts in systems development.

The lectures included a series describing the uses of imagery (principally satellite) in the identification, understanding and forecasting of synoptic-scale weather systems such as depressions and fronts and sub-synoptic-scale (mesoscale) features such as polar lows, convective clusters and sea fog. Various conceptual models of weather systems and their possible use by forecasters were described. The applications of the satellite images as diagnostic tools to aid in analysis and forecasting were shown. Of particular promise in this respect was the use of images from the satellite water-vapour channel in observing the location and evolution of upper-air circulations. The technique can be used in areas where no higher-level clouds are apparent on the infra-red images and at night when visible images cannot be used. Water vapour images are particularly valuable in explaining the structure of the moisture associated with mid-latitude depressions and fronts. However, as with other types of satellite images, very careful interpretation is required.

A second series of lectures illustrated the possibilities for using satellite and radar images in combination with mesoscale forecasting models to provide forecasts for a few hours ahead (so-called 'nowcasts'). Images from the satellites and radars could provide high-resolution input fields to the forecast model and, given suitable equipment to display these images and the forecasts from the mesoscale model simultaneously (we were shown the attractive French system), it would be possible to make detailed nowcasts and to provide interactive adjustment of the model products. It was shown too that reasonably accurate forecasts for an hour or two ahead (crucial for outdoor events or on occasions of severe weather) could be made by simple extrapolation of the cloud and rain shown on recent images. Animated sequences of the images were a valuable aid in this process. In other lectures, the value of animated sequences of satellite images in the understanding of the development of weather systems was clearly shown. These movie-loops will provide a key teaching aid in the future.

A third series of lectures covered the applications of the various images from the Advanced Very High Resolution Radiometer (AVHRR) satellite channels. Two topics were of particular interest: the use of Channel-3 data (with a wavelength between the visible and infra-red channels) in observing non-meteorological subjects (such as pollution and duststorms) and in identifying precipitating convective clouds, and the use of combined data from more than one channel for cloud classification or

nephelanalysis and for observing fog or low cloud at night. The use of separate colours for each channel gave remarkable results.

Three working groups were given the difficult tasks of:

- (a) Assessing the present situation and making proposals for future work on the use of imagery together with routine synoptic data and numerical forecast model products in forecasting, especially nowcasting.
- (b) Assessing conceptual models of atmospheric systems and their use in interpreting imagery as a precursor to improved analyses and forecasts.
- (c) Identifying the requirements and priorities for training forecasters in the interpretation and use of imagery.

The discussions within the working groups were wide-ranging and of considerable interest and value to the participants who were able to appreciate the viewpoints of people from other disciplines. For example, many research workers in this area have not been practising forecasters and at times have appeared unaware of the detailed requirements and problems of forecasters, such as time constraints. Hopefully that problem will have been resolved, to some extent, by the workshop discussions.

The group discussing the possible way ahead in the use of imagery in forecasting and nowcasting concluded that priority should be given to developing local and regional climatologies and statistics of parameters that can be observed using imagery, such as the occurrence of showers or sea fog as a function of wind direction and speed. These climatologies and statistics, together with conceptual models, would provide the bases for the future development of knowledge-based ('expert') forecasting systems which were seen as of probable value in forecast offices, but rather far into the future. The mixing of numerical and pictorial data was thought to have considerable potential. Radar and/or satellite images could be superimposed on analysed or forecast fields provided by numerical models of parameters such as pressure, rainfall, wet-bulb potential temperature, vertical velocity and many others, or simply displayed with routine synoptic observations. These processes would have the joint benefits of improving the understanding of the imagery or the forecasts, and of widening the possibilities for quality control or cross-checking of the observations or model analyses or forecasts. To facilitate this application the group identified a pressing requirement for the development of new display systems which would be geared to the needs of the forecaster. The new displays should be user-friendly, acting as a flexible tool to assist the forecaster, rather than having fixed timetables or preselected routines. The systems would need to be very fast, reliable and easy to use, capable of allowing interaction between forecasters and model analyses or forecasts and, bearing in mind the developing nature of the work, capable of being expanded to accommodate new ideas.

The group assessing conceptual models of atmospheric systems considered in detail the requirements of forecasters for the models. It was essential for a weather system to have a unique and repeatable satellite and/or radar pattern which could be related to analyses or forecasts of parameters which are readily available from numerical forecast models, such as pressure, vertical motion and vorticity. The conceptual model should accurately describe the life cycle of the weather system which can be observed using the imagery. The complete model should provide detailed guidance to the forecaster on when and how it should be used. The group concluded that some existing models, such as those explaining cyclone comma clouds, had merit and could be adapted easily for use in forecast offices. Many others were incomplete or inadequate and required further development and assessment to test, amongst other things, the robustness of the models under routine forecasting conditions. The advent of new display systems, as described above, would facilitate the work on model development and increase the receptiveness of the forecasters to the new ideas. The group recommended the formation of an

international committee to oversee the development and implementation of the conceptual models around the world.

The third group, reviewing training needs, saw the chief requirement as that of increasing the forecasters skill in interpreting the satellite and radar imagery. The benefits of the increased skill would be, amongst other things, better and earlier detection of dangerous weather, better analyses and forecasts over data-sparse areas, and a greater understanding of numerical model analyses and forecasts so that errors may be recognized. The group identified a need to develop training resources and materials and suggested that this should involve some forms of standardization and exchange between countries. Workshops were seen as a valuable method for co-ordinating the rapid exchange of ideas, but there was also a pressing need for the development of more modest training aids such as movie-loops, slide sets and manuals. These manuals should lead the forecaster through an understanding of the 'physics' of the imagery, such as the characteristics of the various satellite wavelengths, and on to detailed interpretation and use of images, including the application of conceptual models.

The workshop was extremely well organized and very successful. The invited speakers and working group chairmen were well chosen and their contributions to the success of the workshop are acknowledged. For the participants, particularly the forecasters, the workshop will have increased their perception of what can (and cannot) be achieved using satellite and radar imagery and in what directions progress is likely to be made in the future. It will be interesting to witness the gradual process of forecasters introducing the new ideas and techniques into their routines and as a result, hopefully, leading to an improvement in the quality and utility of their forecasts. As a start, all forecasters should delve into the preprint volume.

C.A. Nicholass

## Review

*Climate and plant distribution*, by F.I. Woodward. 150 mm × 228 mm, pp. xi + 174, *illus.* Cambridge University Press, 1987. Price £22.50 (hardback), £8.95 (paperback).

This book is part of the *Cambridge Studies in Ecology* series. The central thesis in plant ecology is that climate exerts the dominant control on the distribution of the major vegetation types of the world. Awareness of a link between climate and plants was expressed as early as 300 BC by Theophrastus. The ability to investigate the nature and cause of such links has improved tremendously with the introduction of new research techniques in recent years. Many of these have extended the temporal and spatial scale of inquiry.

Investigation of the relationship between climate and vegetation requires both theoretical and empirical input from a wide range of disciplines encompassing palaeoecology, climatology, ecology, physiology, biochemistry, genetics and many others. This difficult synthesis of topics has been achieved by the author at a level suitable for life-science undergraduates and generally interested scientists who do not wish to delve into the intricacies of the diverse disciplines.

The first three chapters form an important descriptive background of techniques used, basic ecological concepts applied and observations of the distributions of species in relation to climate at different spatial and temporal scales. This is built upon in chapters 4 and 5 in reviewing approaches to explanation and modelling of the observed correlations between climate and vegetation. In each chapter



interesting examples (particularly of field studies) are used to relate the theoretical discussions to tangible phenomena.

In chapter 1 the history of identification of links between climate and plant distribution is outlined. The clear correlation between temperature as derived by oxygen isotope studies and vegetation distribution, reconstructed via pollen analysis, is established. This leads to the question as to the nature and explanation of this correlation, which is tackled in the remainder of the book.

The fundamental concept of response time, which is used frequently in later chapters, is well explained and illustrated with specific examples in chapter 2. It is acknowledged that the simple relationship between response time and changes in geographical extent, as elicited by climatic fluctuations, may of course be interrupted by catastrophic events which take the conditions well beyond the species tolerance limits, but this aspect is in general omitted from further discussions.

Chapter 3 is the only chapter that deals directly with climate. The latitudinal variations in components of the surface energy balance are discussed. The energy available for botanic processes is dependent on this balance and thus susceptible to climatic change. A sample of some of the deterministic extrinsic factors and stochastic intrinsic influences on climate are reviewed, but only briefly.

The physiological response of plants to radiation and moisture is considered in chapter 4. A review of simple processes and reference to illustrative field studies are used to explain the increasing poleward impact of minimum temperature through mechanisms such as frost and drought. Higher temperatures are rarely a limiting factor at lower latitudes, where it is suggested that competitive exclusion due to factors such as soil or moisture availability dominate. It is proposed that minimum temperature can be used as a parameter to model plant physiography and a hydrological model based on the Penman–Monteith equation can be used to predict leaf-area index, vegetation structure and mass. The global climax vegetation distribution predicted by application of this model is compared to, and shows many common features with, observations. Further possible refinements to the global-scale model are suggested.

Having considered the impact, through temperature and moisture balance, of climate on global zonation of vegetation in chapter 4, the mechanisms by which climate may control variations in plant taxa, dispersal and migration, both within and between latitudinal zones, are considered in chapter 5. Many interesting examples from recent literature of dispersal and migration studies are cited. The main emphasis of the chapter being the importance of life stage and response time in determining the ability of plants to respond to climatic variations.

The book is concluded with a very short chapter which introduces briefly the topics of finer-scale climate–vegetation interactions such as genetic variation in life cycle between populations of one species under various climatic conditions. The reader may have benefited from a final chapter with greater emphasis on a résumé of the major ideas approached throughout preceding chapters.

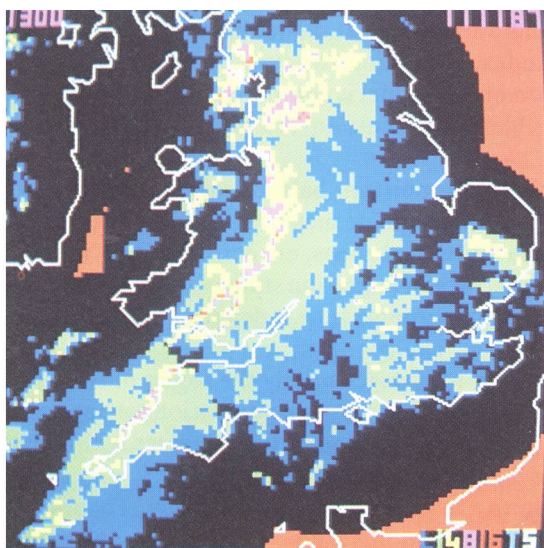
This is a well written and captivating introduction to the central theme of ecology. Theories are explained critically and simply with extensive reference to recent literature. The bibliographies which conclude each chapter provide a large selection of texts in which the topics that have been reviewed may be investigated further. Throughout, interesting examples of field studies are used to relate theory to reality, which adds greatly to the enjoyment of the reader. The book is recommended as a challenging introduction to the complex response of plants to climate.

### Radar photograph — 11 November 1987 at 1300 GMT

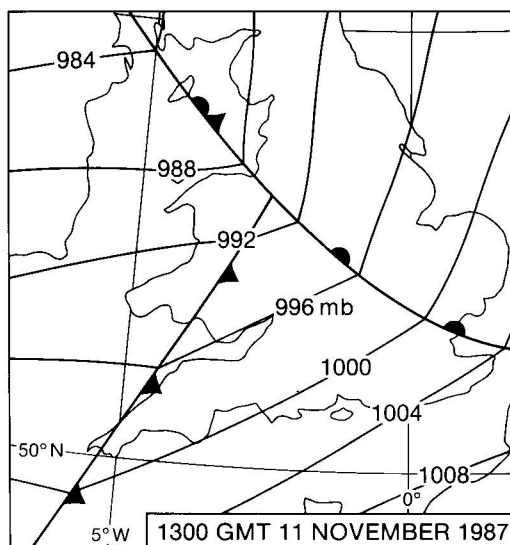
The colour picture (derived from the UK radar network) shows precipitation data from a composite of seven radars. It includes data from the radar at Castor Bay, Northern Ireland, which became operational in early November 1987. The corresponding surface analysis is also shown.

The precipitation is associated with a partly occluded frontal system. The occlusion is located close to the rear edge of the precipitation occurring over the Irish Sea and northern England. The surface warm front cannot be related to any precipitation feature; however, the cold front is marked by a line of heavy rain (line convection) which could be tracked for about eight hours as it crossed England and Wales until it moved out of radar coverage over south-east England.

The cold front, which turned out to be very active in terms of precipitation, but was weak in terms of thermal contrast, was intensely observed as it crossed the south-west approaches and Brittany as a part of the Mesoscale Frontal Dynamics Project\*. As the surface cold front crossed Brittany during the evening it continued to be marked by line convection.



Key. Rainfall intensity ( $\text{mm h}^{-1}$ ): cyan  $>32$ , red  $>16$ , magenta  $>8$ , yellow  $>4$ , green  $>1$ , blue  $<1$ .



\* Clough, S.A.; The mesoscale frontal dynamics project, *Meteorol Mag*, 116, 1987, 32–42.

# Meteorological Magazine

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