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ELECTRONIC DATA PROCESSING AND METEOROLOGY

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Introduction.—Every science and every business or technical service depends on recorded information—information which has first to be collected, processed and finally distributed in appropriate form. Scientific progress and industrial expansion have added enormously to the range, complexity and magnitude of these activities and although a certain amount of automatic or semi-automatic equipment has been developed for data handling, punched-card machines for example, technological progress has not until recently really kept pace. All too often the only expedient was to employ a small army of clerks, for the more sophisticated routines at least.

Now, fortunately, the situation is changing thanks to the invention of the electronic computer and the development of a wide range of high-speed ancillary devices (readers, printers, etc.) to match its performance. Computers are finding their way in ever-increasing numbers into business establishments, laboratories, government departments, etc., and there can be little doubt that they are here to stay. Not that the transition was easy: there has been much prejudice to overcome, much painful probing into time-honoured practices, much false optimism based on misunderstanding of what could and what could not be done with computers and many teething troubles with the equipment itself.

The purpose of this essay is to describe in non-technical language the nature and scope of some of the new electronic equipment which *may* be applicable in the day-to-day work of the professional meteorologist. The accumulation of meteorological data has now reached mountainous proportions—far beyond the capacity of the disposable staff to cope with it adequately—and every year sees a larger accretion. Clearly there is a need for improved processing methods. However, it is not intended to discuss here what sort of computer system would be best suited to Meteorological Office needs, especially as this involves a consideration of the relative economics of automatic versus hand methods which is a very thorny question. We shall be content merely to describe in the second part, present meteorological data-processing activities and to indicate the "areas" within which computers are likely to be most beneficially employed.

The main tools

Computers.—Computing machines are of two types: analogue and digital. In the former, numbers are represented by a physical quantity such as a length or an electrical potential, whereas the latter deal with numbers in the form of discrete entities like beads on a wire or electrical impulses in a circuit. Simple examples of each are the slide-rule and the abacus, respectively.

The analogue machine is not as flexible as nor is it capable of the extreme accuracy of its digital counterpart, and has found only limited application up to now. In meteorology it has been applied to the measurement of eddy-flux parameters and the automatic application of instrument reduction factors; it may also have possibilities in the analysis of autographic traces. But in the main, the future lies with the electronic digital machine of which there are many varieties.

The essential elements of a digital computer are: an arithmetic unit, a control or logical unit and one or more "memory" stores. There must also be provision for the input and output of information in digital form. Both integers and letters are handled by a computer in the binary mode as a string or "word" of binary digits (0 or 1) which might be stored individually on a matrix of magnetic cores (tiny rings of ferrite material) or in groups in separate sectors on the ferrite-coated surface of a magnetic drum or disc assembly, or sequentially on a reel of magnetic tape. The direction of magnetism of individual cores or of "spots" on the drum or tape surface, distinguishes which of the two binary digits (or "bits" as they are more often called) is represented.

Magnetic-core storage is rather expensive but permits very rapid *random* access, of the order of a few millionths of a second, to each item of stored information and is used on the arithmetic and immediate-access (or high-speed) store of the more powerful machines. Magnetic drums or discs rotate at speeds of the order of 5000 revolutions per minute, allowing random transfer of sectors of data to and from the high-speed store (to get at a single item the whole sector must be transferred) in a few thousandths of a second. They are relatively inexpensive and are used as "backing" storage in the faster computers for the larger masses of information relevant to the problem which may only be required at infrequent intervals. For the slower computers drums may be the only form of storage available. Magnetic tape may also be used as a cheaper backing store, but access to the data reels is relatively slow unless the information is required in the precise sequence in which it is recorded, which is difficult to arrange. It is more usually employed as a straight input or output medium as we shall see.

Communication with or internal transfer within the computer is effected by means of a pattern of electrical pulses generated photo-electrically from a corresponding pattern of holes in cards or paper tape or marks on micro-film or paper sheets, or inductively from magnetic charges on ferrite cores or surfaces. For the information to be intelligible to the computer it must be recorded in accordance with one of the many codes (not necessarily "straight" binary) available. Both data and "instructions" to the computer are conveyed in this form. If necessary input and output can be at a distance, directly from or to teleprinter lines, for example, or at one or more "enquiry" points situated several hundred feet from the computer and connected to it by cable.

The speed of operation varies greatly from one computer to another and for the same machine different operations (for example, addition, division, output to printer, etc.) take different times. Relatively simple operations such as transfer to or from the store may be effected at speeds ranging from a micro-second or less in the latest (all-transistor) machines to several milliseconds in the older ones. Times for arithmetic operations are usually multiples of this basic access time, more often being 5–10 times as slow. The speed of access to the various levels of internal storage is undoubtedly the most important single factor in determining the overall rate of processing and computation, and this and the amount of storage available determines the size of the problem that can be tackled. The read-in and read-out times may also be crucial where large amounts of data and/or results are involved.

Programming.—Whether the problem is a complex mathematical one or just a simple enquiry, it must be programmed, that is, broken down into the basic operations that the computer is capable of (for example, read into a particular "address" in the store, move to the arithmetic unit and add, compare with another number and take one course of action if equal and another if not, print out, etc.) and then turned into computer "language" which is the special number code corresponding uniquely with each of these steps. Practically every type of computer has its own order code.

Learning to programme proficiently is a painstaking task of many months: the programmer must not only learn the language but the literature in the library of existing programmes written by others. He must also know his own computer—the amount of "elbow-room" he has got to work in inside the stores and how best to use it so as to minimize the time that it will take to do the job.

The written programme has to be punched or recorded in the appropriate coded input form and medium (see next section) and read into the store of the computer before data is supplied and computation, or automatic processing, is initiated along the lines laid down by the programme. Every coded step and every symbol must be exactly right, otherwise the programme will fail and the whole procedure may have to be gone over in minute detail.

Writing and proving a single programme may take several months and converting a sizeable office routine into machine language is to be measured in man-years, even for specialists. However, once a programme has been proved it can be used time and time again for repetitive jobs such as making a numerical forecast or a standard climatological summary. But once-for-all problems (individual research or specific enquiries) will require a fresh programme to be written each time, although this may largely be built of "bricks" or routines (for example, to work out a correlation coefficient or tabulate results in a certain way) previously written and classified in the library.

Programming may in the long run become easier because there is a trend towards greater simplification of order codes and increasing use is being made of translation routines (autocode) which automatically convert from semi-plain language familiar to everyone to computer code. This decreases programming time and brings programming more into the "without tears" category, but the computer is almost invariably used less efficiently both as regards storage space and operating time.

Storage and computer media.—As we have implied above, a computer requires all its information to be recorded on one of several special media in a "dot" language—a sort of electronic braille. If it has to be kept for later use over long periods, as for example climatological data has, it is necessary that the recording be permanent, accurate and compact; moreover, compactness is never to be achieved at the expense of accessibility.

There is at present no perfect medium for all purposes, although magnetic tape is now becoming pre-eminent for large-scale data processing work. However, punched cards and punched paper tape are also widely used and there are other media which may come to be used more, for example, micro-film versions of cards, paper tape or any other convenient dot or hole pattern and digitape.*

It is highly desirable that data should be recorded *ab initio* in the required form and in the appropriate medium; otherwise it will have to be transcribed before computer use. Digitizers for direct recording of instrumental readings in a computer medium are increasingly being employed, especially where the sampling rate needs to be high or it would in other respects be inconvenient to make observations by eye. Tape is usually preferred for this rather than cards because the recording equipment is more compact and more reliable for long periods of continual use. However, by far the greater part of computer input data is still produced initially in manuscript or printed form, for human convenience and as a by-product of conventional business and professional transactions, and will probably continue so even when automatic recording is cheaper and more reliable than it is today. Thus for a long time to come there will be no alternative but to hand-punch much of the data from original manuscripts or printed records.

It would obviously be a great boon if automatic character readers, able to transcribe visible shapes directly into an appropriate pulse pattern, could be perfected. Some progress has indeed been made along these lines: the Solartron print reader in this country and one made by the Baird Atomic Co. in America can already cope with rather stereotyped printed documents of prescribed format and standard type-fount (the Baird reader can operate on 12 different sorts of type). But a device for scanning *any* miscellaneous printed documents, far less manuscript sheets, is a long way off being achieved. Reading speeds on conventional print readers have reached 500–600 characters per second using micro-film versions of the original documents to avoid some of the difficulties of repeated paper handling and incidentally to effect a sizeable reduction in storage space. Even so, these speeds and storage densities are not comparable with those of magnetic tape to which medium therefore print readers (and other devices like FOSDIC†) more usually act as a converter rather than as direct computer input.

Of the three common computer media, namely, cards, paper and magnetic tape, cards are by far the bulkiest, taking up about 10 times the storage space per unit amount of recorded data as paper tape which in turn is at least 10 times less compact than magnetic tape. Cards and paper tape may be read into a computer at 500–1000 characters (decimal or alphabetic) per second and punched out at around 250–300 characters per second, maximum. For magnetic tape, speeds of 20,000 characters per second, both in and out, are commonplace

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* Digitape consists of a very thin metal film deposited *in vacuo* on a transparent plastic tape. The recording is made by passing a low voltage current through an electrical "writing" stylus which vaporizes the metal film locally.

† FOSDIC stands for Film Optical Scanning Device for Input to Computers. It is presently being used in America in the 1960 census to convert specially marked and micro-filmed census returns into magnetic tape records. It could also be used in the same way to read micro-film versions of punched cards.

and speeds of 100,000 or more characters per second are now being offered by manufacturers. To achieve this, special transport units have to be used which run the tape through the reader at 200–300 inches per second and start and stop it in a few milliseconds.

Cards and paper tape are easily hand-punched and verified, and equipment to do this is fully developed. However, direct recording on magnetic tape and printing out for verification at slow keyboard speeds is not so easy. Although such equipment is slowly coming on to the market it is more usual to record the data initially on cards or paper tape and to use a special high-speed converter, or a computer itself, to transfer it to magnetic tape. The extra costs of conversion from the punched intermediary, which may arise in connexion with some other application (for example, paper tape in telecommunications) and may advantageously be retained for a time, are largely compensated by decreased storage and handling charges.

The high data density of tape has the disadvantage that it encourages the preservation of large amounts of data in a single roll (several million characters per roll in the case of magnetic tape) in invariable sequence. This might be the precise order in which they are required to be processed, but in the nature of things some different order or selection, possibly from different tapes, will sooner or later be demanded, necessitating several runs through a computer and the selective transfer of the required data to another tape. Cards, on the other hand, can be sorted on relatively inexpensive electro-mechanical machines prior to computer input. Moreover, if mistakes are detected on them or they are damaged during handling, only those cards concerned have to be replaced whereas the whole of a reel of tape may have to be remade. However, the undamaged parts at least can be copied automatically at high speed, and in the case of magnetic tape errors can simply be overwritten; the same tape can also be used over and over again for different data.

The information on cards and punched tape, although not readily decipherable by the uninitiated, is at least in visible form, whereas that on magnetic tape must be printed out (not necessarily via a computer) for eye indentification. However, after the initial editing and checking stage there is usually little need to read individual items of data: if there is, a printed archival copy is probably the answer even for the visible media. This would act as a safeguard in case of loss from any cause (fire, mutilation, etc.) although a second copy in the relevant medium is possibly more useful in this respect.

High-speed printers.—An account of computer ancillaries would be incomplete without some mention of printers as a direct high-speed computer output. There are obvious limitations of speed on the conventional printer where a heavy typehead has to be repeatedly accelerated and arrested to form each character. These moving parts have been eliminated in *mosaic* and *electrostatic* printers, which more often print a whole line at a time.

In mosaic printing the characters are formed by a compact rectangular grid of styli (5×6, say). Pressure pulses transmitted along (30) nylon hydraulic cables cause the appropriate styli to be thrust against a carbon tape, forming a black and white mosaic pattern. The characters so formed can be remarkably legible and attractive in appearance and printing speeds, character by character, of 100 characters per second are readily attainable. Line-at-a-time mosaic printers are now running at more than 10 times this speed.

In the electrographic printer in use in America a similar mosaic principle is employed but the character is produced as a pattern of electrostatic charges communicated by a wire "bundle" to a plastic-coated paper. An oppositely charged ink powder is then poured over the paper and the adhering particles are permanently fused to it by heat. Electrostatic printing, called *Xerography* in this country, has here developed along rather different lines. Briefly, it is concerned with the automatic reproduction of any visible representation—maps, manuscripts, micro-film, cathode-ray tube output from computers, etc. The image of whatever is to be copied, enlarged or reduced to any reasonable size, is cast on to a rotating selenium-coated drum which has been positively charged, whereupon the illuminated areas are discharged. A negatively-charged ink powder is then cascaded across the drum which adheres only to the positively charged areas, producing a latent electrostatic image of the original document. This is then rolled out on to a positively charged paper and "developed" by heat in the usual way.

Speeds of the order of 10,000 characters per second have already been demonstrated for computer output via a cathode-ray tube. Even higher speeds are possible in the latest (American) development called *videography*, an ingenious combination of television and electrostatic printing in which the electrons are conducted through the face of the tube by means of rows of tiny iron wires embedded in it so that the electrostatic picture is conveyed directly to paper.

All of the above devices may alternatively be operated "off-line", that is away from the computer and directly from magnetic tape.

Some computer capabilities and types.—In the first place it should be realized that computers can do much more than compute; in fact, for business and many scientific purposes this is often the least they are required to do. Here the need is to check, sort and list large amounts of information in many different ways, which calls for "memory" and powers of comparison and logical discrimination of the "greater/less than" and the "either/or" type, rather than arithmetical facilities.

For all these basic functions computers are unrivalled as regards both speed and reliability. However, it is not always easy to reduce many apparently simple office routines carried out by clerks to these elementary steps or, when this has been accomplished, to equal the human mind in speed even with the fastest machine. Part of the difficulty is that the computer can usually only "scrutinize" one character at a time and the information that a human operator derives in a flash from the layout of a document and the size of the items on it, has to be meticulously deduced and then only after all or a large part of the data has been read in.

For example, the average clerk will pick out the largest (or smallest) of a column of numbers in a fraction of a second. A computer has no option but to subtract any number from its neighbour, test whether the result is positive or not, retain the larger (or smaller) or both if equal and repeat the process for every other member of the list. This can be quite time-consuming even if the numbers are already in the high-speed store of the computer. If not, they have to be read in, and it has to be established that one is dealing with a number and not a heading, say, and the beginning and end of each item found, by testing *every* character for "space" and/or "carriage return/line feed".

This is a particular example of recognition which a trained human operator finds so easy—although he may be quite unable to describe what goes on in his mind—and which is the basis of so many activities ranging from making entries in a ledger to language translation. To do these things by computer a complete list (vocabulary) of all the relevant items must be stored and each item read in has to be compared with the list until a "pair" is found before the appropriate action (the specification of which also has to be stored somewhere) can be taken. Often, of course, the search through the list can be narrowed down by segregating items in some way, alphabetically or by size, but this all has to be programmed and takes computer time. And to extract a meaningful interpretation from a number of items (a phrase or sentence, say) is even more difficult. The most powerful computers available today are quite unable to make language translations of real literary merit.

In the earlier days of computer development, two distinct classes of computer with different internal designs and input/output facilities were produced, namely, scientific and business (or data-processing) computers. The former were intended for lengthy and involved calculations on small amounts of data in the form of decimal numbers of variable size and with few results to output. The latter dealt with relatively short and simple arithmetical operations performed on masses of data (integers and letters) the problem being to get them into and out of the computer fast enough. Nowadays it is recognized that there is often a whole range of application between these extremes, both in science and in business, and the "second-generation" computers now coming on to the market have been designed to cope with either or both.

Integrated systems.—Such all-purpose machines will have, or may be fitted with, a wide range of ancillary equipment—high-speed printers, magnetic tape units, card and paper tape readers and punches. They will be capable of handling many different programmes simultaneously, each employing several input and output channels. They will constitute the heart of what would better be described as a data-processing *system*, in which the same computer shares its time between several concurrent tasks.

The "creation" of such systems has been made possible by the development of the transistor, whose very much smaller size and power consumption than the thermionic valve permits much higher speeds of working. For example, addition times on Meteor, one of the fastest valve machines commercially available in this country, are 180 microseconds; second-generation transistorized computers will be about 5–6 times as fast and machines in the 1–2 microsecond range are being built. But what is equally important is the higher reliability of transistors, which makes it safe to put all one's eggs into one basket, if needs be. And, incidentally, a much bigger basket will be available for around about the same price as the larger present-generation machines.

A fully integrated system built round a computer with "time-sharing" or "parallel-processing" facilities, will be capable of utilizing practically every microsecond of computer time, irrespective of the speed at which data can be fed in or read out by the peripheral units, provided enough work is available to saturate the machine. Priorities can be allocated to the various tasks being performed, and a special automatic control unit will ensure complete harmony in the hive, with the minimum of intervention on the part of the programmer or the operator. For the first time it will be economic to do rather pedestrian jobs via a computer, for example, converting from one medium to another or extracting small amounts of information from large reels of data: they will simply be fitted into the inevitable gaps left by the larger programmes.

Meteorological data processing.—The previous sections will have given some idea of the powerful tools now available for data handling and the discerning meteorologist will already have realized some of their potentialities, and possibly their limitations too, in his own particular field. However, he may not be as aware of what is going on in other branches and the remainder of this article will be devoted to bringing together these various activities. There are three main data streams and associated processing activities in the Meteorological Office, springing from the needs of forecasting, climatology and research respectively. These will be briefly sketched and an attempt made to assess the direction and possible magnitude of future change.

Forecasting and communications.—Forecasting requires a continual collection and dissemination of observational and processed data on a hemisphere-wide scale, at least. The main centre in this country is at present the Central Forecasting Office, Dunstable (later Bracknell), and the main agency teleprinter and radio-teleprinter links operating at a speed of 400 characters per minute, using five-hole punched paper-tape for automatic transmission. Nearly three million characters a day, both in and out, are handled in the communication centre (M.O.5*c*) at Dunstable, on 15–20 major broadcasts, some of them multi-channel (for example, Channels I and II, each has around 25 channels). Of these, only 200,000 characters are British and only about 400,000 are plotted in the forecast room, while 20,000 are selected and edited daily for immediate publication in the *Daily Weather Report* and *Daily Aerological Record.* The sifting and compilation associated with the preparation of the various special broadcasts (for example, Dunstable IMTNE) are all done by torn-tape and manual repunching methods.

Communications traffic through Dunstable has doubled during the last decade and with radio-sonde ascents going to higher and higher levels and new sources of data (radar and space-satellite data being likely additions), a further increase, possibly as much as 50 per cent, is probable during the 1960's. Moreover, transmission speeds are already going up in some countries and in this jet and rocket age there is little doubt that this tendency will spread. Domestic transmission may only require a small increase, especially as the pressure has been relieved by the provision of special communication nets (for Civil Aviation, and Bomber and Fighter Commands), but on the main international links which are increasingly unable to collect remote data fast enough even to keep up with conventional hand-plotting and chart analysis, a more substantial increase may well be required.

A powerful stimulus in this direction will be numerical forecasting and analyses, for which computers have already been provided in several countries throughout the world. Already communications are a bottleneck both on the collection and the redistribution side, and as we are moving in the direction of at least partial automation of observing, data display, chart plotting and drawing, the situation will worsen. Apart from transmission speed the turn-round time at the main communication centres needs to be decreased, which is likely to entail automatic editing (recognition and correcting) and re-routeing of meteorological traffic.

If this were to come about, the speed, the logical facilities and the flexibility of the latest type computer would be required in view of the sheer bulk of data, the complexity of traffic flow and the rather heterogeneous and unscheduled nature of a lot of the broadcast material; there is also the possibility of further changes in the codes and message forms themselves if only to make them more amenable to electronic processing.

Climatology.—For climatology the main source of British data is postal manuscript returns, usually rendered monthly but occasionally weekly. About 200,000 characters a day are received from the 500 or so voluntary and official stations and the 6000 rainfall stations, of which 50,000 characters are duplicated in the teleprinter collectives. At present (since January 1957) most of these data are punched on Hollerith cards, about 50,000 cards being produced monthly together with a further 30,000 punched from ships' logs for the Marine Branch.

Various routine publications, including the *Monthly Weather Report* and *British Rainfall*, are compiled from these data, which then go to make up the library from which the numerous enquiries received by the Climatology Branch are answered. These range from a request for a single item of information to a lengthy statistical analysis for many stations and for many years' data.

The demand for climatological services of all kinds is growing in this country, and present methods are increasingly unable to satisfy it. In the Punched Card Machine Pool at Harrow there are no electronic aids to computing although some use of outside computers has been made and a card-to-tape converter has been installed which enables card data to be recorded automatically on paper tape for input to Meteor, the Ferranti Mercury-type computer installed at Dunstable for research. These are, of course, only make-shift measures; sooner or later a substantial library of data in a suitable computer medium will have to be created and electronic processing facilities provided, of the sort capable of extremely rapid file searching and tabulating.

Research.—Data from various special departments and research projects (for example, the Meteorological Research Flight, observatories, the Cardington rainfall project, etc.) constitute a miscellaneous collection in various forms (punched cards, working sheets, log books, micro-film, etc.) of no very great size but none the less of great, specialist importance. It is probable that with the increased use of instrument digitizers, the accumulation of this sort of data, in a computer medium, will accelerate. However, most research is *ad hoc* and once for all, and it is unlikely that amounts comparable with those of climatology will ever be amassed.

In a class of its own is synoptic research, hitherto done from plotted and analysed weather charts. But already as a by-product of objective analyses via a computer, matrix representations of charts consisting of best-fitting grid-point values are becoming available on tape, and in future synoptic patterns and if need be the accompanying observations may increasingly be stored and processed in this form.

Past data.—The vast heterogeneous accumulation of data from the above sources (manuscript forms, plotted charts, cards, autographic records, teleprinter rolls and tapes, pocket registers, etc.) has been supplemented over the years by untold miscellaneous publications from other meteorological services, mainly summaries or derived statistics of the basic observations. Most of these data are not suitable for direct computer input and will probably remain so unless character readers make unexpectedly rapid progress. The only alternative is to hand-punch those that are needed and this may amount to a fairly massive programme of punching. A proportion of British data is already available in punched card form, which is the internationally accepted medium of exchange for meteorological data so that access to a much larger library of world data of at least 500 million cards is open to us.

The total amount of data in all of these forms is difficult to assess, but at present we have 30 million cards (half of them marine data) and climatic returns, going back as much as a century for some stations, equivalent probably to some 40 million cards. What the precise dimensions of a library of "accessible" data (in a computer medium) would need to be for all future purposes, is even more difficult to assess. But for climatology alone, assuming a minimum library of 10 years' hourly data for all British stations and a selection of world data (surface and upper air), at least 25 million card-equivalent must be provided, only a small part of which already exists. Ultimately the equivalent of 50 or even 100 million cards may be required, preferably in a more compact (magnetic tape?) form.

If a tape medium is used for the main data library the precise form and order of the stored data will have to be laid down. For most climatological and some research work a sequential arrangement by station in strict chronological order, with all the simultaneously-read meteorological elements kept together, seems the most appropriate. For some purposes a grouping of observing stations may be desirable, although this may be difficult to realize. Rainfall users may want grouping into catchment areas, the climatologist by station elevation, and civil aviation will no doubt require quite a different arrangement again.

Recapitulation.—The main potential computer applications within the Meteorological Office are thus:

(i) *Meteorological communications:* The sorting, editing and re-routeing of synoptic data from the teleprinter network as and when it arises, for many different purposes apart from national and international exchange. These include conventional and numerical forecasting, routine publications and climatological data for permanent retention, suitably re-arranged.

(ii) *Climatological services:* Including both routine processing (publications and standard summaries) and *ad hoc* enquiries. These would be done from a large standing library of data in a suitable computer medium, which must be constantly brought up to date from the current data stream (teleprinter and monthly returns).

(iii) *Research problems:* Those involving heavy computing work such as numerical forecasting, but also those for which the emphasis is more on large-scale data searches for suspected relationships (statistical analyses).

Ultimately it will be necessary to carry out some of these computations as a regular routine rather than at the more leisurely pace of research. Numerical forecasting and chart analysis are cases in point, and so is statistical forecasting for much shorter or longer periods than the former.

(iv) *Miscellaneous office work:* Stores, accounting and supply jobs, etc.

Collectively all these functions add up to a sizeable total of work and it would be quite a problem to set up an efficient computer system to cope with it. However, whatever the system, it would have to satisfy certain general requirements. First and foremost, it must be absolutely reliable, particularly for item (i) above, for which unfailing round-the-clock operation is essential, while routine numerical forecasting and publications cannot be allowed to suffer very much delay. Moreover, it must permit several jobs to be done concurrently and must be flexible enough to allow for later modification in procedures and codes and further expansion in the amount of processing.

With respect to computer media, it is evident that the high storage density and scanning speeds of magnetic tape would be a boon for the large library of accessible data that will be needed. However, both cards and paper tape are well tried *working* media and one or other is a necessary intermediary for magnetic tape recording, so that facilities to handle all three media may well be required for a long time to come.

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VARIATION OF SURFACE WIND VELOCITY WITH HEIGHT IN HILLY TERRAIN

By E. N. LAWRENCE, B.Sc.

Introduction.—As a result of a project to measure the variation of atmospheric pollution (sulphur dioxide) in hilly rural terrain, there became available some useful information concerning the variation of surface wind velocity with height above mean sea level. Details of the distribution of sulphur dioxide will be published elsewhere[1] and this note considers only the results which are relevant to discussion of the variation of surface wind velocity.

Sites.—The eleven experimental sites were situated about one mile to the south-west of the small village of Helmshore (53°41′N, 2°20′W), Rossendale, Lancashire, at heights ranging from 750 feet to 1150 feet above mean sea level, in a small valley (Alden valley) of the hilly terrain of the Pennines, where the surrounding land rises to about 1200 feet. Positions of the sites and local contours are shown in Figure 1, and the general contours of the area are illustrated in Figure 2. The industrial West Riding of Yorkshire lies to the east of the area shown in Figure 2. Plates I–XII (between pp. 292–293) show the local topography from the sites.

Site A was the verandah (second storey) of Tor Side House (775 feet) which is well sheltered by trees. This site was chosen because it is the place of routine pollution measurements by the automatic (volumetric) method.[2] Site B was the Helmshore meteorological station enclosure (854 feet). Site C (750 feet) was on the opposite (south) side of the valley and near the valley bottom, while sites D to K, also on the south side of the valley, were approximately in a straight line, along a line of maximum slope, from 800 feet (near valley bottom) to 1150 feet, at 50-foot contour height intervals. This slope was selected as being the one with the simplest topography. Nevertheless, site D (800 feet) and site I (1050 feet) were somewhat over-sheltered, as can be seen from Plates IV and IX.

Equipment.—The equipment at each site consisted of a cup anemometer to measure the run-of-wind and a lead peroxide pollution gauge[2] (from which the reaction products of lead peroxide and atmospheric sulphur dioxide are analysed chemically). In addition, at site A, there was an automatic pollution meter[2] (which causes a known quantity of air to be sucked through a hydrogen peroxide solution which is subsequently analysed by a volumetric, chemical method). At this site, the anemometer and gauge were placed at about two feet above the verandah, as near as possible to the automatic equipment. At site B, the anemometer was at the standard height of two metres and the gauge at four feet above the ground. At the remaining sites, the anemometer was at approximately two metres above the ground, with the gauge alongside. At sites C and D, the equipment was attached to a fence about three feet high, while at sites E to K,

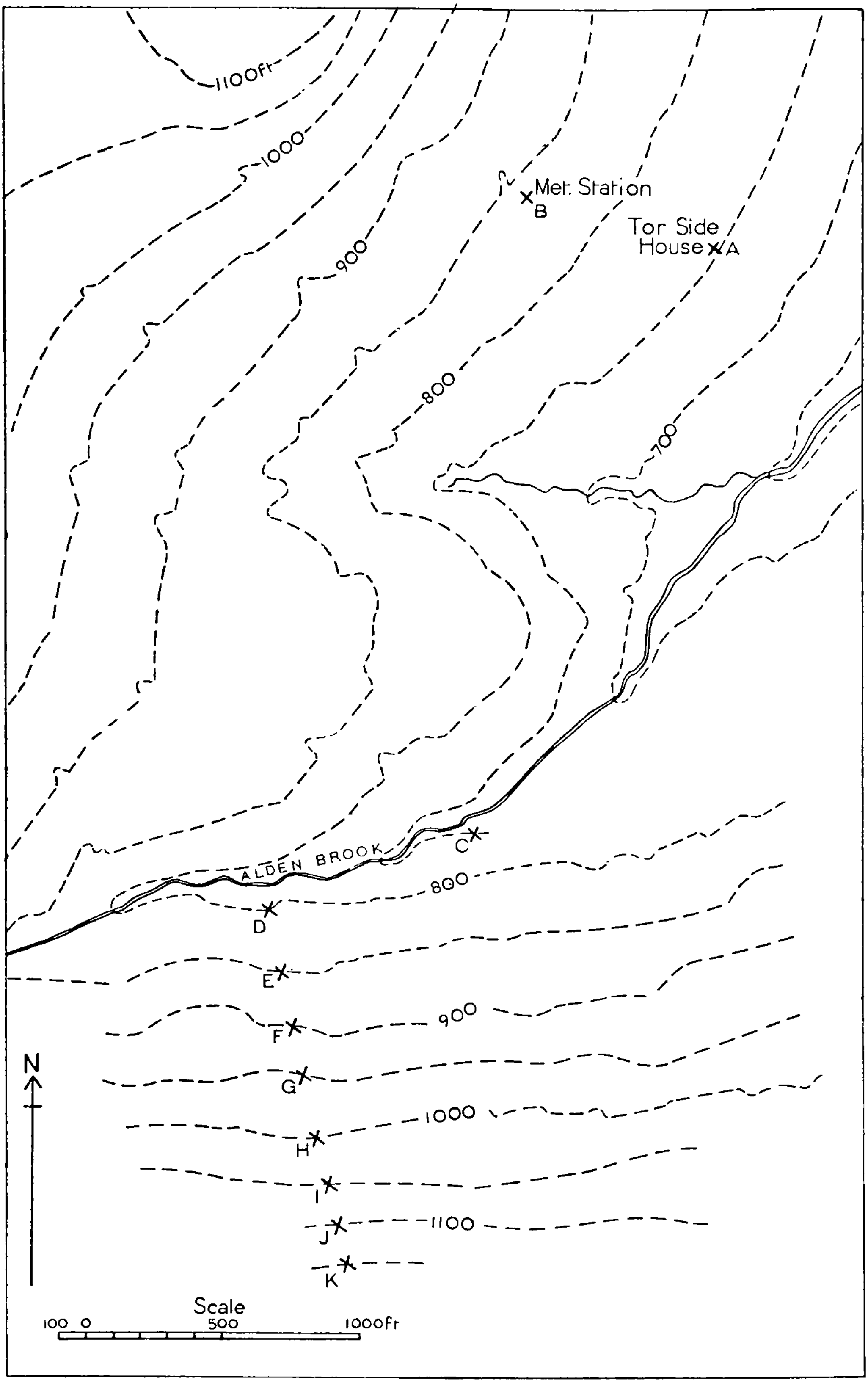

FIGURE I—GREAT HOUSE EXPERIMENTAL HUSBANDRY FARM
Crosses indicate site positions for measurements of wind and pollution.

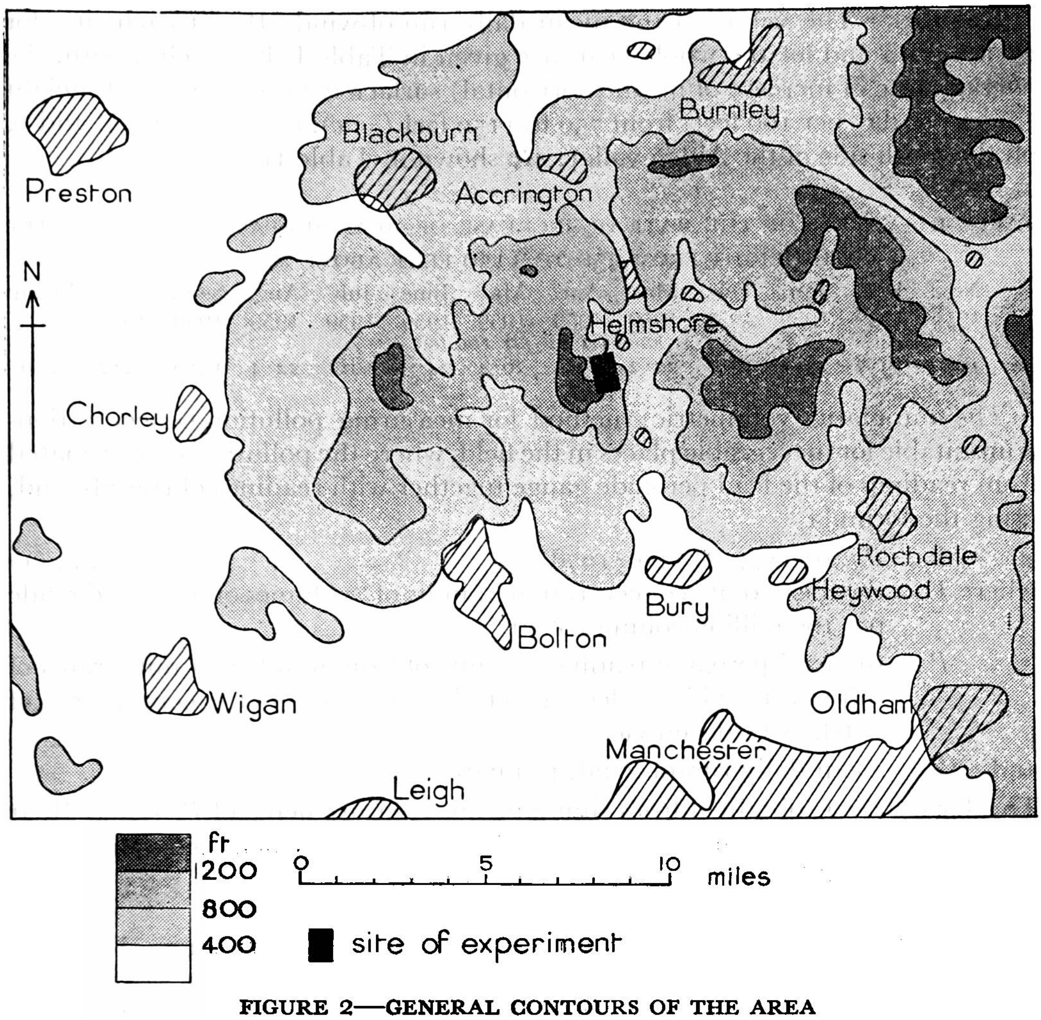

FIGURE 2—GENERAL CONTOURS OF THE AREA

the equipment was installed on a stone wall, of height three to four feet at sites E, F, G, H, and five to six feet at sites I, J, K. The increased height of wall at the upper sites is associated with steeper hillside slopes.

Observations.—Anemometer run-of-wind readings and lead peroxide pollution gauge readings were made at the end of each month, during the period November 1958 to October 1959 inclusive. Pollution by the automatic (volumetric) method was measured daily at site A.

TABLE I—MEAN DAILY RUN-OF-WIND (W)

		Nov. 1958	Dec. 1958	Jan. 1959	Feb. 1959	Mar. 1959	Apr. 1959	May 1959	June 1959	July 1959	Aug. 1959	Sept. 1959	Oct. 1959	Nov. 1958 Oct. 1959
								miles						
Site A	Tor Side House	19·1	38·5	15·5	27·9	47·8	31·2	42·5	—	—	—	—	—	—
Site B	Met. Stn.	44·6	80·9	125·8	117·4	178·9	175·4	138·3	141·2	130·7	131·2	76·2	178·8	126·6
Site C	750 ft	73·2	105·6	108·6	128·3	115·3	135·3	103·8	133·5	106·4	108·4	53·1	154·2	110·5
Site D	800 ft	54·0	76·6	86·8	84·6	95·0	102·8	89·6	106·6	82·5	86·4	48·4	127·2	86·7
Site E	850 ft	102·5	135·9	152·9	140·7	154·3	167·8	151·0	183·6	143·9	151·5	85·9	218·0	149·0
Site F	900 ft	95·1	132·1	154·6	133·4	149·4	167·4	153·1	184·7	143·0	151·7	86·3	222·7	147·8
Site G	950 ft	96·8	124·9	154·4	125·9	144·7	157·4	151·2	169·4	132·8	143·3	82·2	209·7	141·1
Site H	1000 ft	99·5	129·1	164·0	135·1	143·8	168·0	156·8	180·5	128·1	150·4	82·2	221·4	146·6
Site I	1050 ft	60·2	77·2	108·1	85·4	91·4	113·1	102·4	119·9	121·5	64·3	47·3	*132·9*	93·6
Site J	1100 ft	124·7	151·8	205·2	156·5	167·4	190·6	171·8	*201·2*	*166·4*	179·6	92·1	260·3	172·3
Site K	1150 ft	140·9	184·6	241·9	198·1	204·1	229·1	185·5	230·6	182·6	197·9	104·9	283·0	198·6
Mean	C to K	94·1	124·2	152·9	132·0	140·6	159·1	140·6	167·8	134·1	137·1	75·8	203·3	138·5

Values in italics are estimated.

Results.—The values of the mean daily run-of-wind (W) at each site, for each month and for the whole year, are given in Table I. For each month, the average rate of increase of mean (horizontal) surface wind velocity with height (miles per day per 100 feet) from 750 to 1150 feet ($=w$), based on sites C and K on the south side of the Alden valley, are shown in Table II.

TABLE II—VALUES OF THE RATE OF INCREASE OF MEAN SURFACE WIND VELOCITY WITH HEIGHT FROM 750 TO 1150 FEET ABOVE M.S.L. (w)

	Nov. 1958	Dec. 1958	Jan. 1959	Feb. 1959	Mar. 1959	Apr. 1959	May 1959	June 1959	July 1959	Aug. 1959	Sept. 1959	Oct. 1959	Mean
					miles per day per 100 feet								
w	16·9	19·7	33·3	17·4	22·2	23·4	20·4	24·3	19·1	22·4	13·0	32·2	22·0

The automatic (volumetric) method for measuring pollution concentrations is unsuitable for inaccessible places in the field, where the pollution was estimated from readings of the lead peroxide gauge together with readings of run-of-wind, using the formula

$$V = P / (0 \cdot 00332\, W + 0 \cdot 1078), \qquad \ldots . (1)$$

where V = the mean daily concentration in units of "volumes of sulphur dioxide per 100 million volumes of air"

P = the lead peroxide reading in units of "the number of milligrams of sulphur trioxide collected per day on 100 square centimetres of batch A lead peroxide"

and W = mean daily run-of-wind, in miles.

This formula was obtained from simultaneous measurements of P, V and W at site A: further details will be published elsewhere.[1] The calculated values of V are shown in Table III.

TABLE III—VALUES OF ESTIMATED MEAN DAILY CONCENTRATION (V)

		Nov. 1958	Dec. 1958	Jan. 1959	Feb. 1959	Mar. 1959	Apr. 1959	May 1959	June 1959	July 1959	Aug. 1959	Sept. 1959	Oct. 1959	Nov. 1958 Oct. 1959
						volume of sulphur dioxide per 100 million volumes of air								
Site A	Tor Side House	7·83	9·04	13·47	9·73	4·84	4·73	3·25	—	—	—	—	—	—
Site B	Met. Stn.	9·50	7·04	5·96	4·68	2·66	2·12	1·75	1·40	1·57	1·31	2·99	2·22	3·60
Site C	750 ft	6·53	5·74	5·96	4·40	3·42	2·10	2.06	1·47	1·69	1·73	3·94	2·29	3·44
Site D	800 ft	4·91	5·85	5·73	5·12	3·05	2·38	1·55	1·54	1·68	1·70	4·66	2·38	3·38
Site E	850 ft	5·96	4·76	5·51	—*	3·08	2·54	1·66	1·31	1·90	2·10	4·30	2·25	3·41
Site F	900 ft	6·73	6·15	5·39	5·61	3·08	2·50	1·90	1·46	1·89	1·54	3·85	2·47	3·55
Site G	950 ft	5·94	5·59	5·27	4·49	2·87	2·27	1·66	1·40	1·80	1·68	3·89	1·43	3·19
Site H	1000 ft	6·00	5·56	4·66	4·53	2·96	2·13	1·93	1·61	1·78	1·76	3·94	1·45	3·19
Site I	1050 ft	4·87	4·56	4·61	4·32	2·48	1·99	2·08	1·30	1·27	2·09	3·29	*1·71*	2·88
Site J	1100 ft	4·83	4·33	3·85	4·22	2·52	1·96	1·93	*1·64*	*1·24*	1·79	3·77	1·92	2·83
Site K	1150 ft	5·26	3·70	4·04	3·16	2·62	1·84	1·48	1·33	1·58	1·66	3·55	1·69	2·66
Mean	C to K	5·67	5·14	5·00	4·59	2·90	2·19	1·81	1·45	1·65	1·78	3·91	1·95	3·17

Values in italics are based on estimated run-of-wind.

*Value of 5·50 assumed for averages.

It was interesting to compare these profiles of V with some profiles of P which were obtained by the writer for other purposes, and which were based on values of P from a wide Pennine network of routine or special survey stations between 550 and 1200 feet above mean sea level, over the period August 1956 to July 1957. In contrast to the experimental sites of the present study, the stations of this wider network were especially exposed and considered to have experienced runs-of-wind of the same order as the common geostrophic wind: that is, W was considered to be approximately constant, and therefore, from equation (1), V would be approximately proportional to P, and hence the profiles of P for this network were considered to show the relative values of V.

Discussion

(1) *Wind profiles: three wind régimes.*—The wind profiles (see Table I) for the valley slope (sites C to K) suggest that there are three distinct surface wind régimes:

(*a*) a sheltered zone in which the mean wind velocity increases considerably with height (750 to 800 or 850 feet),
(*b*) a zone in which the mean wind velocity varies but little with height (800 or 850 to 1000 or 1050 feet),
(*c*) a comparatively exposed zone in which the mean wind velocity increases rapidly with height (1000 or 1050 to 1150 feet or more).

The alternative height figures are inserted to allow for the sites at 800 feet and 1050 feet, which were especially sheltered by contour obstructions in the immediate environs—a small gulley at site D, 800 feet, and a small hollow at site I, 1050 feet (see Plates IV and IX).

The corresponding pollution profiles (for sites C to K), based on the values of V in Table III, and the additional profiles of P for the wider network (see section on results) in which it was considered that P was proportional to V, supply further evidence for this type of wind profile. Apart from a tendency for a maximum pollution concentration at the valley bottom, which could be due to local sources (Helmshore village), the profiles for sites C to K, as with those for the wider network, showed a tendency for an "inversion" of pollution with a maximum concentration at about 900 feet above mean sea level, that is, in and perhaps rather nearer to the lower boundary of zone (*b*) where there was little or no vertical mean wind gradient. This maximum pollution suggests that this is the zone with the most frequent temperature inversions or stable vertical temperature gradients. Both wind and pollution profiles may be explained by the presence of (i) an upper valley, comparatively exposed and turbulent eddy zone, and a maximum sheltered zone at the valley bottom, in which thermal and turbulent convection would tend to lift pollution, and (ii) an area of gently inclined land surface at medium valley-levels and the tendency for radiation inversions to develop below the upper exposed zone and to be maintained above the convection and anabatic zone below. Apart from mixing by thermal and turbulent convection, katabatic processes in the middle zone would help to remove the vertical mean wind gradient, especially during periods of unusual anticyclonic activity such as those of 1958–59. The magnitude of katabatic effects[3] could well be of a sufficient order to neutralize or mask the tendency for mean wind velocity to increase with height.

(2) *Mean wind velocity: differences between opposite sides of the valley.*—For sites C to K on the south side of the valley, the monthly wind profiles were strikingly similar in shape, which would not be so if sites (A and B) on the north side of the valley were incorporated in the profiles. This is probably due to significant differences in topography between the two sides of the valley: differences between sites on the south side appear to be maintained more consistently from month to month.

The mean wind velocity at the meteorological station (site B, 854 feet) is rather less than at site E (850 feet), a difference which could be caused (at least partly) by the steeper slopes and greater "funnelling" effect on the south side of the valley.

(3) *Effects of shelter by minor irregularities of contours in immediate vicinity.*—Even at high levels, small irregularities of topography, such as the hollow at site I

(1050 feet), may provide a considerable degree of shelter; the mean wind velocity at site I (1050 feet) was approximately 54 per cent of the mean wind at the adjacent site at 1100 feet and 64 per cent of the mean wind at the adjacent (lower) site at 1000 feet.

(4) *Vertical wind gradient.*—The values of w shown in Table II were closely related to the monthly mean wind velocities (miles per day) at 1150 feet($=u$), shown in Table I. The value of the coefficient of correlation between w and u is 0·90 and the regression equation is:

$$u \simeq 7w + 43,$$

for which the residual standard deviation is 21·4 and u is within $\pm$ 47·7 at the five per cent level of significance. A high positive correlation would naturally result if the bottom site (C) were completely sheltered and registering a run-of-wind which was effectively "zero"; but the wind at site C (750 feet) is certainly not negligible. From Table I, it can be seen that the mean wind velocity at site C is about 50 per cent of that at site K (1150 feet).

September 1959, which was the month of lowest mean wind velocity (at site K) and smallest vertical wind gradient, was particularly subject to light anticyclonic winds; while October 1959 was the month with the highest mean wind velocity (at site K) and the largest vertical gradient. February 1959, which was subject to an average wind velocity (at site K), experienced a comparatively low vertical wind gradient: this is attributed to the effect of wind direction, which was easterly (that is, from the more open end of the valley) for a considerable proportion of the time.

It is of interest to note that, for the year November 1958 to October 1959 (not a notably stormy year), the mean wind velocity at site K (1150 feet) was about 8 m.p.h. (at two metres above the ground), while the long-term average mean wind velocity for this region is estimated to be about 10 m.p.h. at 33 feet above the ground.[4]

Conclusions.—Although the data was obtained for only one area, there is a suggestion that the results are much more general. If so, then the important effects of both main features and minor irregularities of orography on mean surface wind velocities which are suggested in the discussion should be borne in mind when siting meteorological stations in hilly terrain and interpreting their data. Useful estimates of mean surface wind velocity might be derived for comparable topography and applied in town planning, forestry and agriculture.

Wind velocity and pollution data together help in forming a complete picture of meteorological mechanisms over hilly terrain.

Acknowledgements.—Thanks are due to the Director and staff of Great House Experimental Husbandry Farm, Ministry of Agriculture, who carried out the observations, and to the Regional Headquarters of the Yorkshire–Lancashire region of the National Agricultural Advisory Service for help in numerous ways, particularly to the Soil Chemistry Department for analysing the lead peroxide gauge samples.

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3. LAWRENCE, E. N.; Nocturnal winds. *Prof. Notes met. Off., London,* **7**, No. 111, 1954.
4. London Meteorological Office; Climatological atlas of the British Isles. London, 1953.

PLATE I—SITE C, 750 FEET, LOOKING NORTH

PLATE II—SITE C, 750 FEET, LOOKING EAST

Photographs by E. N. Lawrence

PLATE III—SITE C, 750 FEET, LOOKING WEST

PLATE IV—SITE D, 800 FEET, LOOKING WEST

PLATE V—SITE F, 900 FEET, LOOKING EAST

Photographs by E. N. Lawrence

PLATE VI—SITE F, 900 FEET, LOOKING WEST

PLATE VII—SITE G, 950 FEET, LOOKING EAST

PLATE VIII—SITE G, 950 FEET, LOOKING WEST

Photographs by E. N. Lawrence

PLATE IX—SITE I, 1050 FEET, LOOKING WEST

PLATE X—SITE K, 1150 FEET, LOOKING EAST

PLATE XI—SITE K, 1150 FEET, LOOKING WEST

Photographs by E. N. Lawrence

PLATE XII—SITE B, 854 FEET, LOOKING EAST

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THE ANNUAL AND DIURNAL VARIATION OF SHOWER FREQUENCY AT ST. EVAL AND ST. MAWGAN

By F. P. SIMS

Introduction.—This was a statistical study, designed to investigate the variations in shower frequency at St. Mawgan. However, 24-hourly observations for St. Mawgan date back only to 1 November 1955, so in order to obtain a sufficiently long series, observations from St. Eval taken before that date were used to form a combined series covering the 10-year period from 1949 to 1958 inclusive. The airfields of St. Mawgan and St. Eval lie about three miles apart and each within a mile or so of the north Cornish coast between Newquay and Trevose Head, and are at similar altitudes, so that there is little significant difference in location or exposure (see Figure 1).

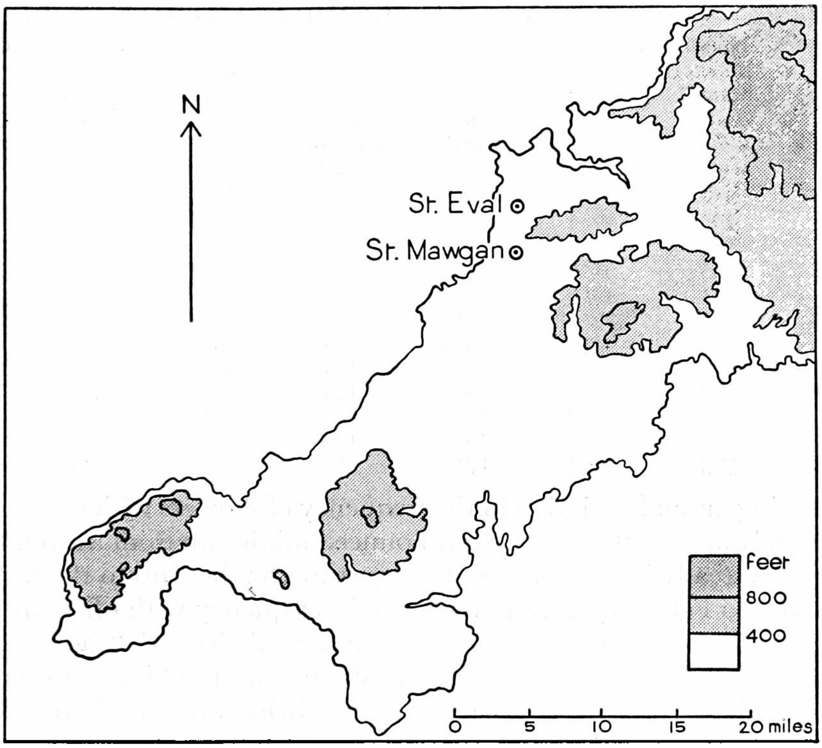

FIGURE 1—THE LOCATION OF ST. EVAL AND ST. MAWGAN

That portion of the investigation dealing with diurnal variation was on somewhat similar lines to a study made independently by Briggs and Johns[1] at Acklington, and the results make an interesting comparison.

Treatment of data.—For the purpose of this investigation, a "shower hour" was defined as an hourly observation in which a shower of rain, hail or snow was recorded as occurring at the time of observation, or in the past hour. With this convention, it was possible for the same shower to be attributed to two consecutive hours, but the error thus introduced was not thought likely to affect a qualitative interpretation of the results. Thunderstorms in which precipitation occurred at the station were included if they were clearly of the "thundery shower" type (23 cases, chiefly in winter) but were excluded if they appeared to be frontal, or due to medium-level instability (25 cases, chiefly in summer).

All observations throughout the 24 hours for the 10-year period given above were examined, and each "shower hour" found was tabulated according to the surface wind direction, classified as either "on-shore" (230 to 020 degrees inclusive, through west), or "off-shore" (030 to 220 degrees inclusive, through east). Gradient-level winds would have been preferred, but were not readily available. Showers occurring with calms, amounting to less than 0·5 per cent of the total, were omitted.

Annual variation.—Table I gives the results of taking each month separately. The total numbers of "shower hours" in each month for each of the two classes of wind directions were combined with the frequency of winds in the corresponding directions for the same 10-year period to give the values of percentage frequency of showers. These values are shown in histogram form in Figure 2.

TABLE I—THE ANNUAL VARIATION OF THE FREQUENCY OF SHOWERS WITH ON-SHORE AND OFF-SHORE WINDS AT ST. EVAL AND ST. MAWGAN, 1949–58

	No. of "shower hours" with on-shore winds	Frequency of on-shore winds %	Frequency of showers with on-shore winds %	No. of "shower hours" with off-shore winds	Frequency of off-shore winds %	Frequency of showers with off-shore winds %	Frequency of calms %
January	518	44·9	15·5	88	52·5	2·3	2·6
February	495	46·4	15·8	143	50·4	4·2	3·2
March	178	33·9	7·1	135	62·8	2·9	3·3
April	255	51·5	6·9	74	45·1	2·3	3·4
May	161	45·8	4·7	165	51·0	4·3	3·2
June	184	56·4	4·5	67	39·3	2·4	4·3
July	252	64·0	5·3	94	33·0	3·8	3·0
August	329	52·2	8·4	127	43·4	3·9	4·4
September	360	49·5	10·1	144	47·5	4·2	3·0
October	350	41·3	13·4	205	54·2	5·1	4·5
November	459	35·5	18·0	129	61·3	2·9	3·2
December	563	42·7	17·7	85	55·0	2·1	2·3

The striking annual variation in the frequency of showers with on-shore winds is immediately apparent. The very pronounced minimum from March to July is followed by a steady increase through August to October, up to the high values of November to February. As the variation in frequency with off-shore winds is relatively small, we find that there are three well defined "shower seasons" resulting from the on-shore cases, the transition from the high values of winter to the low values of spring and early summer being apparently quite abrupt.

The high values in winter with on-shore winds are, of course, due to the frequent incursions of polar air at this season. The low values of the months from March to July are thought to be due to several factors. Sea temperatures in the mouth of the Bristol Channel tend to be lower in spring than those of the sea further to the west and north-west, but the main reasons probably lie in the prevalence of spells of dry weather with a general easterly component in the air stream. Under these conditions, even if the air is unstable, on-shore winds (that is, between north-north-west and north-north-east) are unlikely to produce showers in the short sea-track over the Bristol Channel. Late spring and early summer also show a high frequency of sea fogs around the coast of Cornwall, indicative of air masses stable to sea temperatures.

The tendency for long spells without appreciable shower activity (irrespective of wind direction) is shown by the fact that in six years out of the ten examined, at least one of the months March to June showed an almost total absence of showers.

With off-shore winds the annual variation is small, and the absence of a pronounced maximum in summer is significant. The western part of Cornwall is not sufficiently extensive for land heating to cause vigorous convection, except in a narrow belt down the middle, the associated sea-breezes inhibiting convection up to several miles from the coast, both in the north and the south, and often right across the peninsula. Thus, even if, as in the case under discussion, the wind on the north coast remains off-shore and the air is unstable, showers are relatively infrequent. On the other hand, showers which do occur with off-shore winds, especially in winter, are mainly due to the passage of minor troughs of low pressure in returning maritime polar air, with little contribution from land heating.

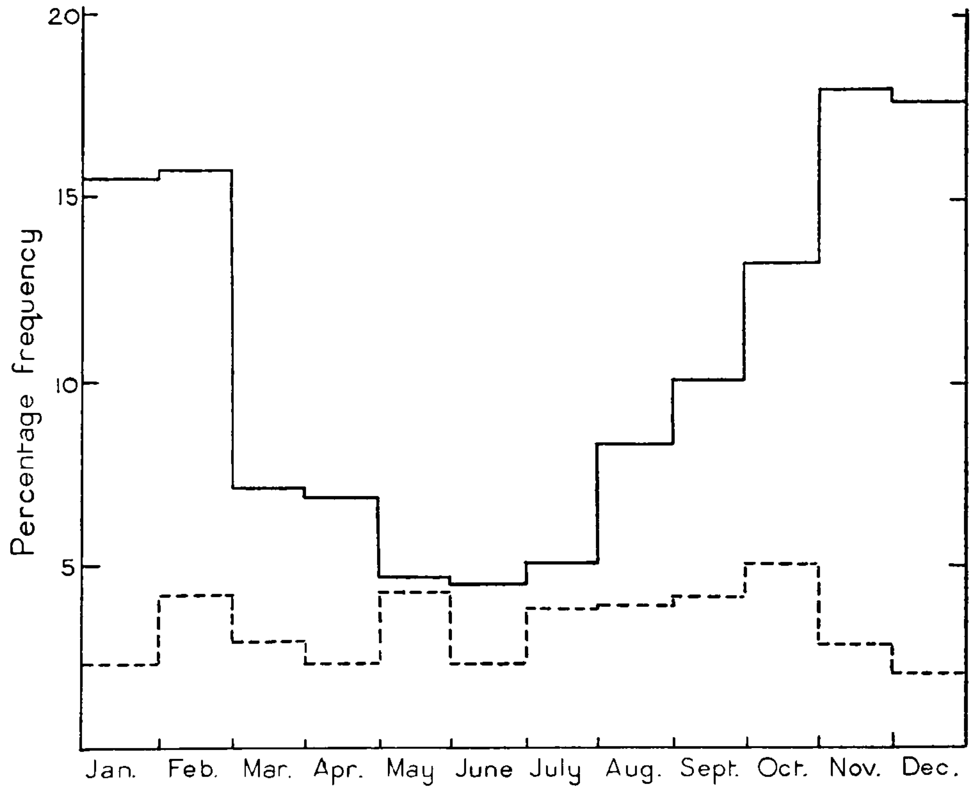

FIGURE 2—HISTOGRAMS OF THE FREQUENCY OF "SHOWER HOURS" FOR EACH MONTH AT ST. EVAL AND ST. MAWGAN, 1949–58

Continuous and broken lines are for on-shore and off-shore surface winds respectively.

Diurnal variation.—Figure 3 shows in histogram form the diurnal variation of shower frequency hour-by-hour for each of the three "shower seasons" defined in the previous section. The diurnal variation of wind direction was not taken into account, and the values given are the total number of "shower hours" for each hour in the 10-year period, divided as before into "on-shore" and "off-shore" cases.

With on-shore winds there is shown a tendency for activity at all seasons to increase in the early morning, reaching a maximum around 0900 GMT, followed by a slight decrease before a second maximum in the early afternoon. After this there is a steady decrease, reaching a minimum around, or just before, sunset. It should be noted, however, that the time of onset of the afternoon decrease does not follow the sun, being earliest in summer and latest in winter.

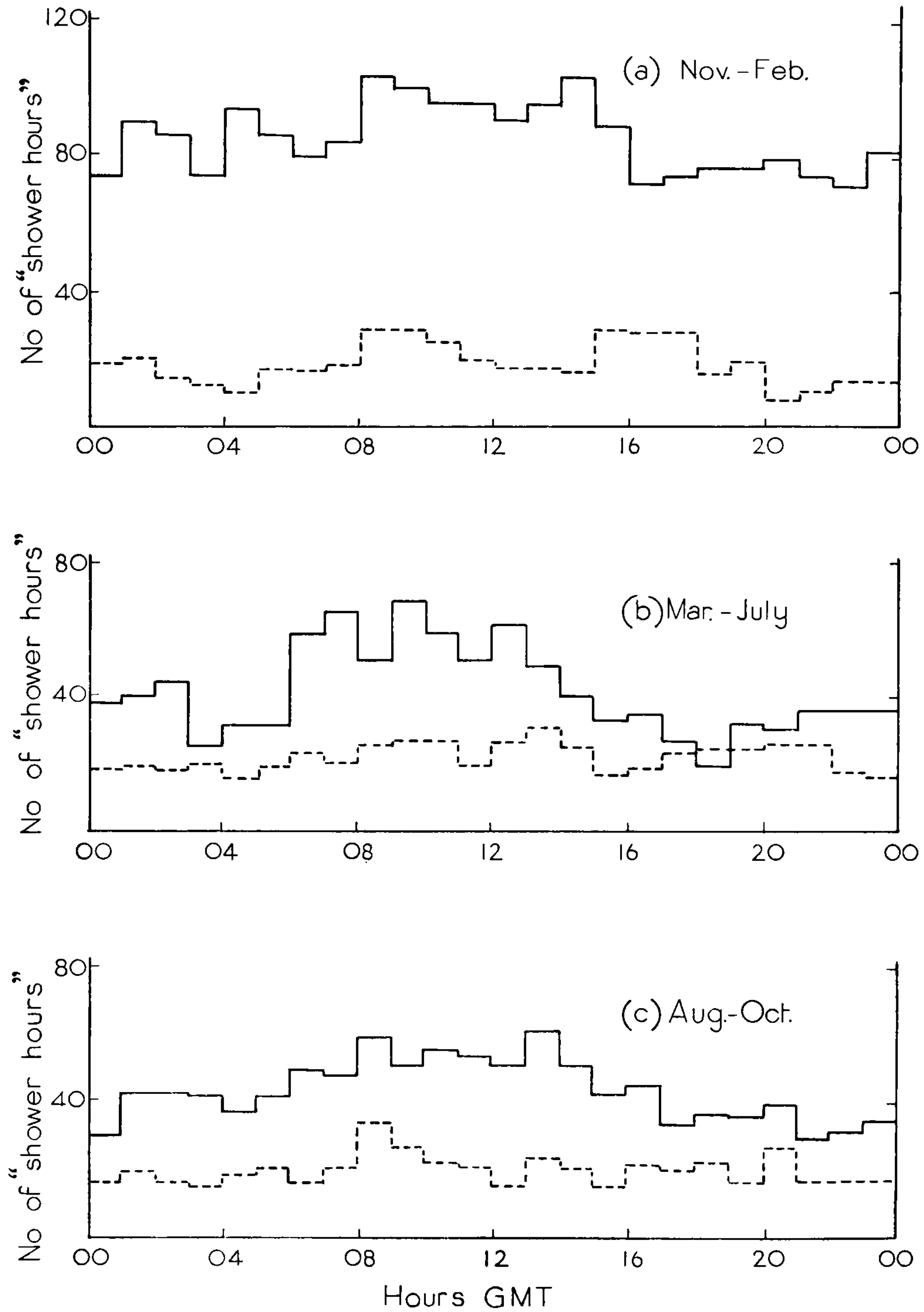

FIGURE 3—HISTOGRAMS OF THE NUMBER OF "SHOWER HOURS" FOR EACH HOUR OF THE DAY AT ST. EVAL AND ST. MAWGAN IN THE 10-YEAR PERIOD 1949–58

Continuous and broken lines are for on-shore and off-shore surface winds respectively.

The most interesting feature of the histograms for the off-shore cases is the absence of a pronounced overall difference between day and night, and especially of an afternoon maximum in summer, which lends support to the suggestion already made in a previous paragraph that land heating is not very effective, even if the wind continues to blow off the land. There is, in fact, a tendency for the off-shore cases to show somewhat the same characteristics as those for direct on-shore winds, suggesting perhaps the maritime origin of much of the activity, though it is not easy to see why the frequency increases around 1600–1800 GMT in winter.

The tendency for a maximum of showers around 0900 GMT found by Briggs and Johns[1] at Acklington in February appears to exist in some degree at all seasons at St. Mawgan, irrespective of wind direction. Some tendency for a resurgence of activity around, or just after, sunset may also be detected at St. Mawgan, as it was at Acklington.

The explanations suggested by Briggs and Johns for the diurnal variations with on-shore winds, though not directly supported by this type of investigation, might nevertheless be equally applied to St. Eval and St. Mawgan, since at both these katabatic flow from the hills to the south-east is a marked feature at all seasons. The orientation of the north Cornish coast is such that there is a high frequency of winds blowing almost parallel to the coast, and with such winds it has been observed on occasions that lines of showers visible at sunrise a short distance out to sea have later moved in over the coastline.

Conclusions.—With on-shore winds at St. Mawgan, showers are much less frequent in the months from March to July, while with off-shore winds activity in summer is not much greater than in winter, in spite of increased insolation.

There is a general tendency for showers to increase in frequency after dawn, reaching a maximum value around 0900 GMT. With off-shore winds (except in March to July) a decrease tends to occur soon afterwards, but with on-shore winds the most marked decrease begins in early or mid-afternoon. In nearly all cases frequency tends to be lowest just before sunset and to increase again (at least temporarily) soon afterwards.

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U.D.C. 551.576.36:551.507.352

ANALYSIS OF CLOUD DISTRIBUTION BETWEEN LONDON AIRPORT AND JOHANNESBURG FROM COMET IN-FLIGHT REPORTS

By M. J. KERLEY

Introduction.—During the planning of detachments of the Meteorological Research Flight's Canberra aircraft to Nairobi to investigate, amongst other parameters, the latitudinal variation of humidity and cloud in the upper troposphere, it was decided to compile statistics of the distribution of cloud over a large range of latitudes. Since observations of high cloud are often impossible from the surface due to lower clouds and haze, the best source of information is aircraft flight reports. A particularly useful series, comprising Comet reports during 1952–53 between London Airport and Johannesburg, was kindly provided by Mr. E. Chambers, Meteorological Superintendent of B.O.A.C., and analysed statistically for the summer (May to October) and winter (November to March) periods, about 120 reports being available for each season. In view of their usefulness for other flight planning, and also for research purposes, the results of this investigation are given below.

Method of analysis.—The route flown by the Comets was London Airport–Rome–Cairo/Beirut–Khartoum–Entebbe–Livingstone–Johannesburg. Each leg comprised a climb to 30,000 feet covering some 150 to 200 miles, a cruise climb to about 38,000 feet and a descent again of about 150 miles. Elements generally recorded by aircrew on cross-sections were temperature, wind, turbulence and cloud. Only the cloud information was used in this work. Every flight was split into six legs, the climb, cruise and descent sections each being divided into two parts. The presence or otherwise of each category of cloud in each section was then noted. The selected categories were cirrus, medium cloud, low cloud, cumulonimbus, no cloud, and cloud distribution not reported (N.R. in Figures 1 and 2). As the chief interest was the horizontal extent of the main cloud areas, and also as the data were inadequate to cover details such as cloud amounts and height of bases and tops, the analysis was restricted simply to the occurrence or otherwise of the clouds. Histograms in terms of percentage of occurrence were then compiled for each section, and are shown in Figures 1 and 2. These give the outward flights, London Airport to Johannesburg, in their top portions and the return flights below. Sections of the route flown at night are indicated on the histograms. The outward and return journeys have been presented separately and as the night period for each occurs at a different section of the route, any possible errors in reporting at night are covered by a corresponding daylight observation over that area by the return flight.

Discussion.—The distribution of the main cloud areas shows considerable cloud in low latitudes, small amounts at 20° to 30°N and larger amounts again in temperate latitudes. The limits of the different régimes in both seasons is quite well defined on the histograms. The general distribution is, of course, well known and often associated with the Hadley cell, giving ascent near the thermal equator and descent some 20 degrees of latitude to north and south. The details are reflected in the distribution of all the cloud types with the reversed distribution for the "no cloud" observations. The "no reports" occasions refer mainly to beginning and end of flights when observations were not possible. The agreement between the outward and inward flight reports is considered to be satisfactory and indicates that the observations made at night can be accepted. The observations of cumulonimbus (which often give rise to the other types of cloud reported in equatorial regions) have well defined maxima lying between about 5° and 10°S in winter, and 5° and 10°N in summer. Similarly, the "no cloud" areas move north in the summer and south in the winter, although their seasonal movement is not so large. Little seasonal variation is found in the reports in temperate latitudes.

These results are in general agreement with the more detailed observations of the Meteorological Research Flight's detachments which will be reported elsewhere.

In conclusion, it appears that the large body of aircraft reports of clouds, now available on many air routes from routine civil flights, could be analysed in a similar manner to provide this type of statistics which are not available from other sources, and they could add considerably to our knowledge of the climatology of various regions.

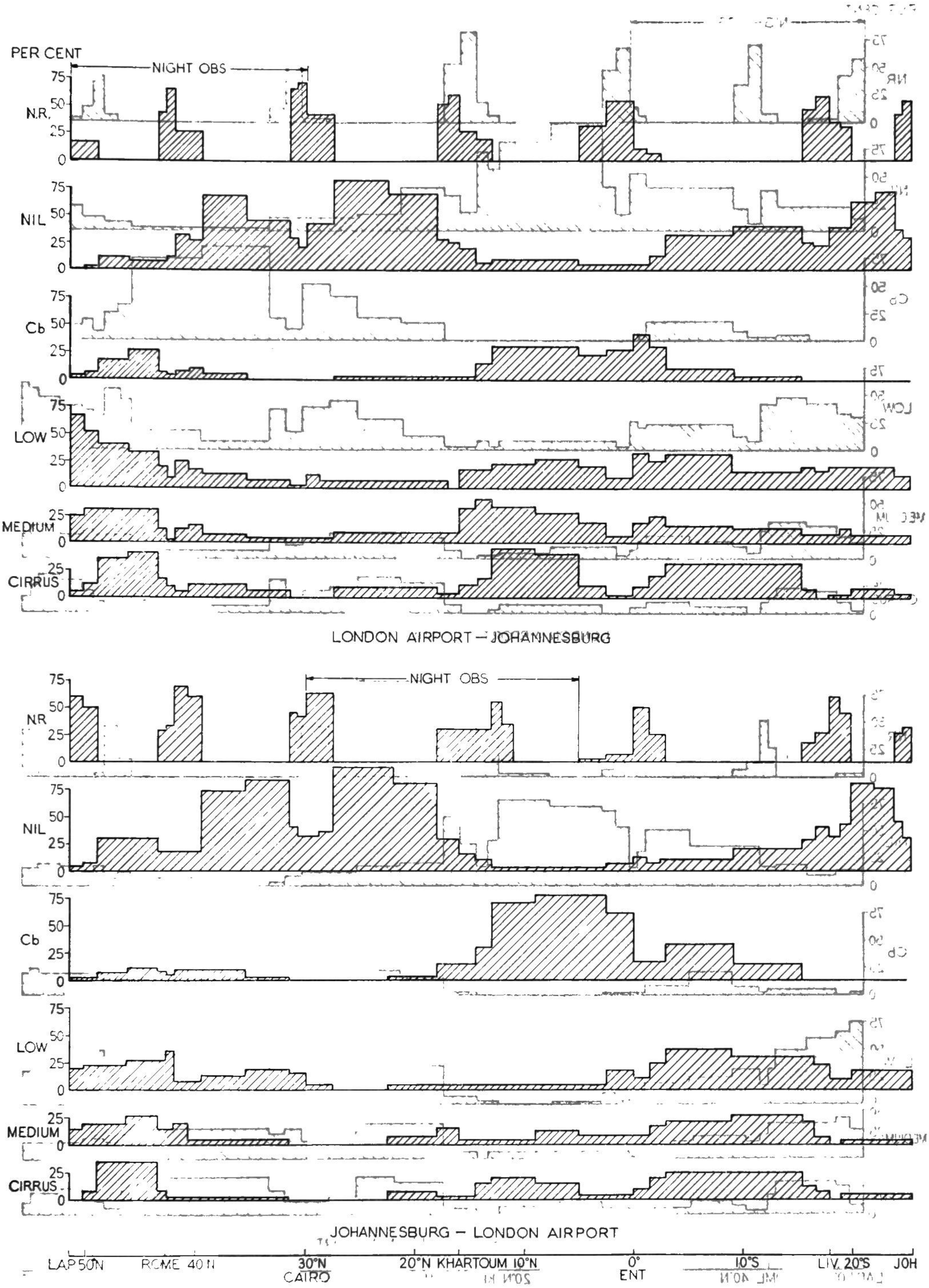

FIGURE I—PERCENTAGE OCCURRENCE OF CLOUD DURING SUMMER FLIGHTS

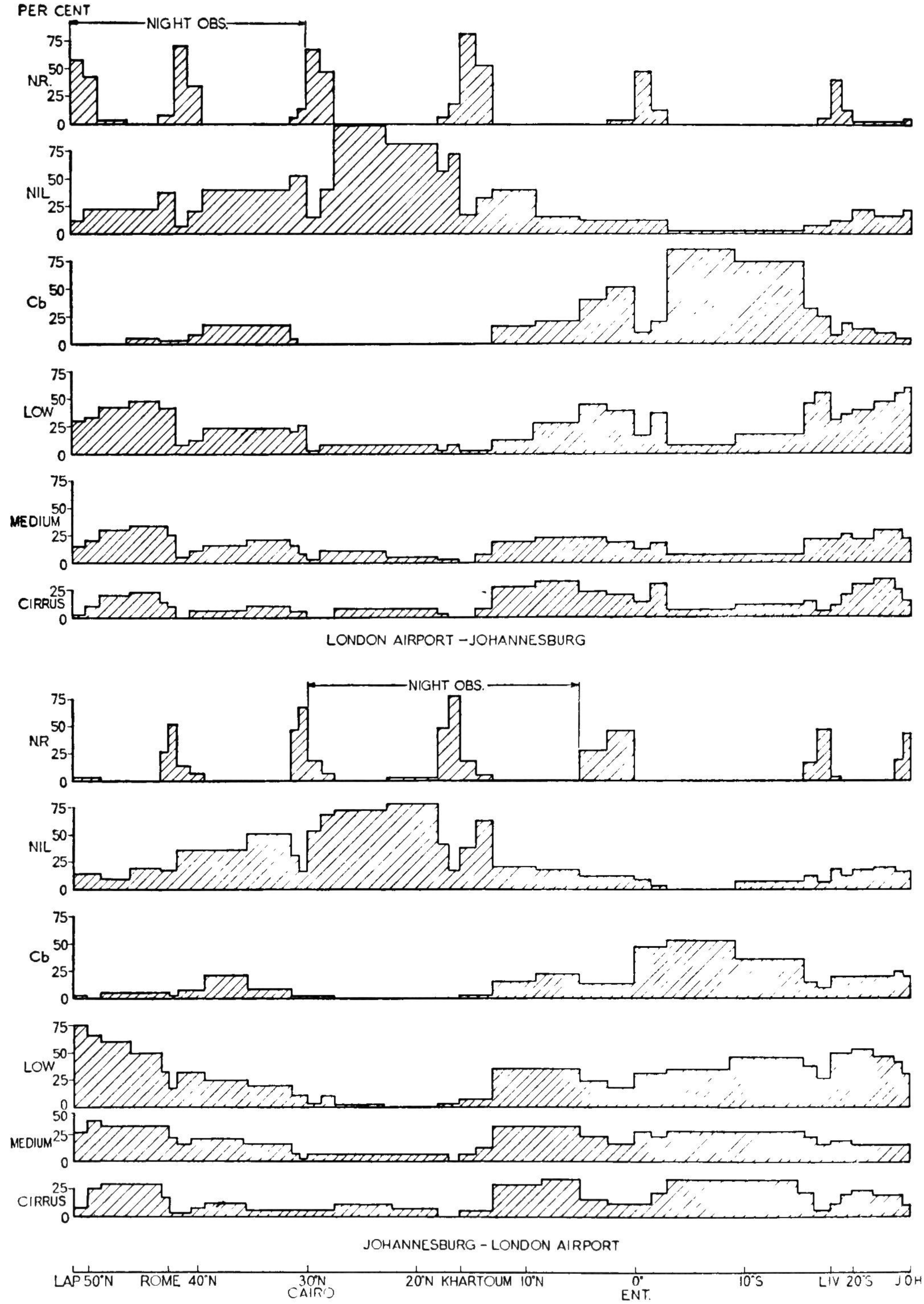

FIGURE 2—PERCENTAGE OCCURRENCE OF CLOUD DURING WINTER FLIGHTS

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INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS TWELFTH GENERAL ASSEMBLY, HELSINKI, 1960

By E. KNIGHTING, B.Sc.

The twelfth General Assembly of the International Union of Geodesy and Geophysics was convened at Helsinki from 26 July–6 August 1960. These General Assemblies are held triennially to discuss recent progress in geodesy and geophysics and there are seven associations within the Union. They are the International Associations of Geodesy (IAG), Seismology and Physics of the Earth's Interior (IASPEI), Geomagnetism and Aeronomy (IAGA), Physical Oceanography (IAPO), Volcanology (IAV), Scientific Hydrology (IASH) and Meteorology and Atmospheric Physics (IAMAP). Each Association holds its own programmes, running concurrently, with some joint symposia such as that on Tsunamis and Storm Surges (IASPEI/IAPO/IAMAP). Recent progress is reviewed by way of short papers, read by authors and followed by discussion.

The IAMAP papers were divided into five sections: Dynamical Processes in the Atmosphere, Meteorological Uses of Rockets and Artificial Satellites, Climatology, The Structure of the Atmosphere, and Atmospheric Chemistry and Radio-activity, with joint symposia on Tsunami and Storm Surges, Carbon Dioxide in the Atmosphere and Sea Surface, and on the High Atmosphere. This very varied fare totalled more than one hundred separate papers. Forgetting for a moment the detail, is it possible to tell from these papers the way in which research into meteorological problems is going? In attempting such an assessment it is very necessary to remember that the papers might well have been on quite different subjects and that the progress reported at these meetings is not necessarily representative of the whole of research into atmospheric physics. In particular, there was no report on the unending struggle to improve weather forecasting as distinct from forecasting the pressure and temperature distribution. Nevertheless, certain trends seemed apparent in the papers that were read.

Five years ago the interest in dynamical meteorology was mainly centred on what is, rather unfortunately, called numerical weather prediction. The problem was, given the details of the present pressure and wind fields what will they be in one or two days' time? This is a very practical problem and has its roots in the forecasting problems which face all national weather services; a very great effort is still being put into the investigation of this problem and was reflected in a variety of papers on the direct integration of the Eulerian equation of motion instead of the vorticity equation, on the amount of vertical detail required to explain the observed motions, on the vertical velocities in the atmosphere and so on. These papers represented efforts to extend the first simple atmospheric models in order to make the numerical forecasts more successful than they are at present: a consolidation and a rather slow advance. Recently meteorologists have been asking—why are the synoptic-scale atmospheric motions as observed? This is a more fundamental question than the previous one and the proper answer would also answer the first question, although perhaps not in the detail that is required for the forecasting problem. The papers concerning this "general circulation" problem showed that much effort is now being made to formulate the problem to be answered. Numerical experiments have been carried out with simple models which include not only the dynamics of the flow, including turbulent effects, but also the radiational heating effects; other papers showed how authors intended to attack the problem. The stage reached may be likened to that in numerical weather prediction some five years ago. It is proper that ideas should be discussed in such a meeting as the UGGI General Assembly, but it is to be hoped that publication in the meteorological journals should await, and report, the results of the experiments and not be statements of intention. It was of considerable interest to note that the effects of asymmetric heating are also being studied in rotating dishpan experiments. Smaller-scale dynamics is also receiving much attention, as witnessed by papers concerned with turbulence and the circulation near fronts, to mention but two. The impression is that dynamical meteorology is on the move and that there are more than enough problems for the workers in this subject. Noticeable, too, were the extra-mural discussions which took place and the communication which exists between workers in different countries.

The papers on atmospheric chemistry and radio-activity show that research is yielding results at a very rapid pace. Since Dobson's pioneering work ozone has been useful as a tracer, since the ozone concentrations must be explainable in terms of sources, sinks and atmospheric motions. Now that sampling of the atmosphere at very high levels has become a recognized and repeatable technique, many isotopes are effective tracers. Some of these isotopes are produced by cosmic ray activity, others are produced artificially as the result of nuclear fission tests at high altitudes. The relative density of elements and their isotopes provides a time-measuring mechanism and when the isotopes are produced artificially the initial position is also specified. The meteorological study of the concentration of radio-active substances is of course most important for the problem of the contamination of the atmosphere and the earth's surface after artificial nuclear fission. The question is—where does the debris go? and the answer must be in terms of circulation of the atmosphere. Sample analysis in space reveals the epoch and so allows trajectories to be traced. The naturally produced isotopes provide similar tracers. In this way observations of the circulation of the atmosphere are provided and it cannot be long before these observations, when properly sorted and adjusted, form the basic data for upper atmospheric models, and have a marked effect upon ideas of the general circulation. Such a synthesis of two different branches of meteorology can only enrich the subject.

If the two subjects, dynamical meteorology and atmospheric chemistry, seemed alive and progressive, then even more so appeared the results obtained from meteorological satellites. The Tiros results are new, visual and exciting even if their interpretation and application still remain a little obscure. The future possibilities, such as temperature soundings made by satellites in inaccessible regions, are yet to be explored and the state of this study is much the same as that of radar studies when the first few observations had been made. The relevance to dynamical studies is not hard to see, especially the radiational measurements which were described.

A variety of papers was read concerning the structure of the atmosphere. Of course, such a title comprises a much more loosely knit section of meteorology than those just considered so that the feeling of integration, which was so conspicuous in dynamical studies and clearly to come in the tracer and the satellite studies, was lacking. For this reason some of the studies appeared to be a little out of date in not contributing to the onward flow of the organization of the science of meteorology. Yet the value of such work should not be underestimated, especially when it lays bare the problems of smaller-scale dynamics which must receive attention in the future. Some awkward questions were asked of the theoretical meteorologists, for example, concerning the detailed structure in the vicinity of jet streams. Similarly, the papers on climatology, which often concerned detailed treatment of an area in statistical form, lacked a unifying principle. Of course, some of the papers were extremely practical, for example, as affecting the agricultural economics of a country and the establishment of the existence of synoptic régimes of different characters, and would give rise to rules invaluable to the forecaster.

It seems then from the papers read at Helsinki that meteorological research is in a healthy state. The unifying principles of dynamical meteorology allied to the observations made available by satellites and atmospheric chemistry should reveal much about the general circulation and especially the motions in the upper atmosphere. Smaller-scale problems are not so advanced but the observational ground is being prepared for the theoreticians to go to work. Any thriving scientific subject appears to be in a state of flux and meteorology is no exception, but it is now apparent that meteorology is a science, and a firmly established one. The impact of the work described in these meetings on forecasting as we know it now may not be very great but upon longer-range forecasting may be immense, as will be the economic return on the money spent on meteorological research.

A word about the meetings themselves. We were greeted by the most intense thunderstorm I have ever seen, in itself a happy augury. The arrangements made for the comfort and well-being as well as for the amusement of the delegates were first-class. If the 2000 or so delegates were a nuisance in that they filled the hotels and restaurants, no sign of it was afforded. We were welcome.

Criticisms could be made within the lecture halls. Each contributor was informed of the length of time allotted to him. To exceed this time is a discourtesy to the chairman and to the audience, and stifles discussion. Some of the slides which were shown were very clear, with a title and the axes or tabular matter suitably marked in printing big enough to read. Some slides might as well not have been shown for they were so indistinct as to be valueless. The heinous practice of talking to the blackboard or screen is still too prevalent. It may be that the organizers of the symposia should consider whether fewer papers should be presented with more time for discussion.

REVIEWS

The atmosphere and the sea in motion (Scientific contributions to the Rossby memorial volume), edited by B. Bolin. $10\frac{1}{2} \times 7\frac{1}{4}$ in., pp. 509, *illus.*, Rockefeller Institute Press, New York, in association with Oxford University Press, Amen House, Warwick Square, London, E.C.4, 1960. Price: £5 5*s*. 0*d*.

Originally planned as a special volume of papers by colleagues and former students to honour Rossby's sixtieth birthday (he was born on 28 December 1898), this book was changed by his tragic death in July 1957 into a memorial volume. Otherwise, however, the plan remained unchanged, and the first and longest of the forty contributions which make up the book is an essay (the last he wrote) by Rossby himself on current problems in meteorology.

This essay is characteristic of Rossby in breadth of vision, clear-sightedness and humility. "It is hardly possible any longer", he wrote, "for one meteorologist to acquire detailed knowledge of the whole front along which meteorological research is carried out today." So Rossby quite frankly preferred the large-scale global problems. He also had a preference for those studies where different branches of geophysics, especially meteorology and oceanography, were most clearly interrelated, and by this means he infused new light into many branches of research. He wrote of V. Bjerknes that he "had exceptional ability to think simply, to see the basic problem and to create enthusiasm around himself. His [Bjerknes'] work became of extraordinary importance, partly because his strong belief in the formulation of the problem gave theoretical studies in the following decades a well defined goal . . . " All this is equally true of Rossby himself. Indeed the attributes named are the essential hallmark of the master of modern science.

The contents of the book register the wide range of Rossby's interests and the fields of research which he stimulated. In a reasonably brief review one cannot even list them all. They include, for instance, many aspects of intimate correspondence or interaction between the flow of the sea and of the atmosphere; the characteristic streakiness of both flow systems; the origins and behaviour of the Gulf Stream and the atmospheric jets; circulation models and simulation experiments with differentially heated fluids in rotating dishpans; the circulation of atmospheric constituents in the sea and of sea salt, sulphur and every kind of pollutant or radio-active tracer in the atmosphere, and their residence times; numerical computations and prediction attempts, applied to atmosphere and ocean; seasonal, secular and climatic changes, and the radiation budget and heat storage problems involved; the possibilities of artificial control or disturbance of normal atmospheric processes. Rossby's own two-page summary (pp. 14–16) of the present state of knowledge of the carbon dioxide cycle, and probable changes now occurring in it, is itself a little masterpiece of clarity in a complex subject.

The book suffers from the lack of an index common with this type of work—the reviewer's copy is already heavily underlined and side-marked to facilitate reference. This is eminently a book to refer to. Indeed, its nearly half a million words incorporate far too much for quick digestion. The only other criticism is the occurrence of a few misprints, including authors' names and in one rather awkward case (p. 266) "southward" for "northward" and "poleward" for "equatorward".

The international distribution of contributors, and of further bibliographical references, reflects Rossby's world-wide contacts and influence, even in Peking where some of his former students in Chicago are now working and producing valuable studies of the seasonal changes of the atmospheric circulation over the Far East (which have appeared in *Acta Meteorologica Sinica* and in *Tellus*). One is of course struck by the dominant contributions to our science from Scandinavia and the United States, where again Scandinavian (and German) emigrés are prominent. Inevitably those countries which did not, or could not afford to, send meteorologists to work in the International Meteorological Institute, which Rossby established in Stockholm, are somewhat under-represented. Thus one might have liked to see included some allusions to Soviet oceanographic work or to the classification of large-scale northern hemisphere circulation types used by Wangenheim, Girs and their followers (both of which appear to show some influence from Rossby's writings). No doubt for the same reason, the southern hemisphere (which interested Rossby) is under-represented, though its problems and the lessons to be learnt from inter-hemisphere compositions are by no means ignored.

Not least among the attractive features of the book are two biographical sketches, one by Bergeron and the other by Byers, and a long, thought-provoking historical article by Bergeron on methods in scientific weather analysis and forecasting and the conditions for progress.

Bergeron's thesis that the great steps forward have depended on improvements either in the meteorological observation coverage (**O**), or in the tools (**T**) for handling the observations and making them accessible, or in our models of atmospheric structure and their degree of realism (**M**). He adds an analysis of the things that hinder progress, for example, (*a*) "the stock of knowledge already acquired, or the views of the dominating school or personality, will to some extent block the recognition, or even the observation, of certain otherwise obvious facts which do not fit in with this knowledge or view"; (*b*) "a true and valuable discovery may be made from data that at a later inspection turn out (1) not really to represent the phenomenon, or (2) to have been quite insufficient as proof. Unfortunately, such a discovery is then easily turned down . . . "; (*c*) "The value, importance and wide applicability of new observations, methods or deductions will often not be recognized even by the discoverer himself, and . . . doomed to oblivion". These hindrances in the psychological climate are illustrated by many abortive discoveries of fronts and unlike airstreams (a map by Fitzroy (1863) is reproduced) and also of the jet stream (map by Teisserenc de Bort (1887)). Attention is turned finally to dangers in the present state of meteorology. After remarking that the ideal weather analysis is not the most "objective" one but the one that in all probability lies nearest to the true state of the atmosphere, the writer enjoins meteorologists to beware of excessive reliance on easy-seeming or automatic solutions. Use of the best tools for handling the fullest and most appropriate observations possible must go hand in hand with an ever more realistic understanding of how the atmospheric circulation works.

This book is indeed a fitting memorial and one that will be prized by those who knew Rossby and by all who came, or may yet come, under the influence of his stimulating mind and outlook.

H. H. LAMB

Hydrodynamics of oceans and atmospheres, by Carl Eckart. 9 in. × 6 in., pp. xi + 290, *illus.*, Pergamon Press Ltd., Oxford, 1960. Price: 63*s*.

This is a book devoted to the application of perturbation theory to the hydrodynamics and thermodynamics of stratified fluids and hence to the earth's atmosphere and oceans. The scope is immediately limited since the text does not deal with any feed-back processes which are the crux of the general hydrodynamical problem and incidentally of the problem of baroclinicity which is fundamental to the general forecasting problem at least for short periods. Nevertheless, it must be added that perturbation theory can go a long way towards explaining the sort of motions that can occur and give reasonable estimates of the relation between the measurable physical parameters and the way in which energy is propagated; indeed, until the advent of electronic computers it was the only practical way of relating the possible motions with the parameters and in some cases the difficulties encountered in the numerical methods of solving non-linear equations makes perturbation theory still extremely valuable.

The problems faced in this book are threefold. Firstly, a basic solution of the general equations has to be set up and the difficulty here lies in choosing one which is not complicated and which is broadly representative of the observed motions; there are difficulties if the perturbed values are of the same order as the basic values. Secondly, the perturbation equations have to be set up. Thirdly, the latter are to be solved in particular, interesting cases. The first two of these problems are dealt with in the first quarter of the book, which includes a discussion of the earth's atmospheres and oceans, and the latter will be very interesting to meteorologists who want to see the facts which have to be explained in oceanography. The basic solution selected is the static barotropic case and the parameters in the perturbation equations are worked out for several idealizations.

The remainder of the book is devoted to a leisurely and detailed examination of the solution of the perturbation equations in special cases. Since the predictive equations are linear and hyperbolic the mathematics can take two turns, either a Hamilton type of theory giving a description in terms of rays or, the more usual for meteorologists, a description in terms of eigenfunctions. The author deals with both, and the less mathematically inclined may fear that the going will be hard. But the author must be congratulated upon his clear handling of the mathematics. He does not read any deep significance into his use of, say, the Hamiltonian or the other concepts which have proved valuable in quantum mechanics, and nothing previous need be known of them. The partial differential equations which occur in the text are simple enough to be separable and the reader can get by with the fundamentals of ordinary differential equations. Some of the mathematics may judiciously be skipped since each chapter has an introductory paragraph and the main results are interpreted physically with numerous diagrams to indicate the possible wave-motion solutions with given parameters. In each development the simplest problem, usually assuming isothermal conditions without rotation, is dealt with first showing the method and results and then the more difficult problems, including rotation and more realistic temperature gradients, are treated. In particular, motions within the thermocline and the upper atmosphere are examined.

The problems dealt with are those on a large scale since the equations do not deal with local variations in the stratification. Thus the meteorological problems dealt with do not bear upon the problem of forecasting for periods up to at least a month. Indeed, it is known from previous work that the perturbation method does not yield accurate enough results for use in prediction of the kind with which most meteorologists are concerned. The methods developed may be important in climatology and in large-scale atmospheric motions of other planets. The main reason why meteorologists should read this book is the broad outlook which unifies certain meteorological and oceanographical problems.

The solutions are generally formal and there is no indication that modern computing methods could profitably be applied. It is doubtful if formal solutions which are expressed in recondite functions, such as Whittaker's functions, will be usable, for it is unlikely that special functions which have not already been tabulated will ever be so, except perhaps extremely accurately at a few isolated test values.

The book is well produced, but there are occasional errors in the equations (for example, Equn. 9 of p. 92), the diagrams are satisfactory and the index proved to be good when tested. The price is reasonable by modern standards.

E. KNIGHTING

Über die Korrelation interdiurner Druck- und Temperaturänderungen in der Troposphäre und sich ergebende Folgerungen für Tropo- und Stratosphäre, by Horst Matzke. 12 in. ×8 in., pp. 56, *illus.*, Akademie-Verlag, Berlin W1, 1960. Price: *D.M.* 18.00.

This paper deals with the correlation between the 24-hour pressure changes at fixed heights in the atmosphere and the corresponding changes in the mean temperature of the whole of the atmosphere below. It has been known since the publication in 1912 of W. H. Dines's results for 9 km that this correlation is large and positive in the upper troposphere.

The object of the paper is to show that an expression for the correlation coefficient between the variations specified above as a function of height in the troposphere can be computed from the assumptions that the atmosphere is in hydrostatic equilibrium, that horizontal variations are negligible, that mean temperatures and pressures can be substituted in the coefficients of the expression, derived from the hydrostatic relation, giving the first order variation of pressure at any height as a function of the first order variations of surface pressure and mean temperature, and that the pressure variations at any level are the sum of a number of random variations of mean value zero.

The paper is in places obscure: notably in the statement of the correspondence between the statistical model with its drawing of counters marked $+\delta$ or $-\delta$ from urns and the actual variations in the atmosphere. One formula, apparently of importance, referred to by number could not be found.

G. A. BULL

OFFICIAL PUBLICATION

The following publication has recently been issued:

SCIENTIFIC PAPER

No. 3—*The rainfall of Malta.* By B. F. Bulmer, M.A., B.Sc., and K. Stormonth, B.Sc.

This paper on the rainfall of Malta provides a record of monthly rainfall extending over a period of 100 years from 1854 to 1953. By using a close network of reporting stations, maps have been produced showing the spatial distribution over the island. From the knowledge of the variation from place to place, conversion factors have been deduced which enable gaps in the existing records to be filled to produce a homogeneous record, referred to a standard location. The space and time variations are examined and indicate a balance between the diurnal convection cycles appropriate to the sea and land, which may well have parallels in other fairly small islands.

METEOROLOGICAL OFFICE NEWS

Retirements.—The Director-General records his appreciation of the services of:

Mr. R. T. Andrews, Senior Experimental Officer, who retired on 3 October 1960. He joined the Office as a Technical Assistant in June 1920, after service during the First World War in the Royal Air Force. The whole of his career has been spent at aviation outstations, including a tour of duty in Iraq. Since 1947 he has served almost entirely at stations in Devon and Cornwall, and at the time of his retirement he was at St. Mawgan. Mr. Andrews has accepted a temporary appointment in the Meteorological Office.

Mr. P. W. Dingle, Experimental Officer, who retired on 3 October 1960. He joined the Office as a Technical Assistant in April 1919, after service during the First World War in the Meteorological Section of the Royal Naval Air Service. Apart from a period between 1927 and 1930 at an aviation outstation, the whole of his career has been associated with services for the Army. Since 1930 he has served continuously at Larkhill.

Miss E. V. Freeman, Experimental Officer, who retired on 2 October 1960. She joined the Office as a Probationer in May 1918. After a year in the Forecast Division she was transferred to the Climatology Division where she remained for six years. From 1925 to 1939 she worked in the Instruments Division. After short spells in the Administrative and Climatology Divisions she was posted in 1940 to the Special Investigations Section, and she remained in that section for sixteen years. From 1956 until her retirement she worked in the Climatological Research Division, first in the Editing Section and then in the World Climatology Section.

Sports activities.—The Air Ministry Annual Sports meeting was held at the White City Stadium on 21 September 1960. It was a wonderfully successful day for the Meteorological Office. The Bishop Shield was retained with a lead of 21½ points over their nearest rivals, the Department of the Air Member for Supply and Organisation. The W. S. Jones Memorial Cup was won by the Meteorological Office for the Division scoring the highest number of points at the Annual Sports. Miss V. J. Lewis of the Climatological Services Division won the Victrix Ludorum Cup and the Halahan Shield was won by the tug-of-war team from Dunstable.