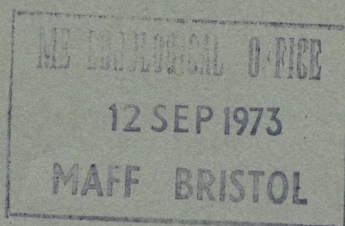


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Her Majesty's Stationery Office

SCIENTIFIC PAPERS

No. 31 The three-dimensional analysis of meteorological data

By R. Dixon, B.Sc. and E. A. Spackman, M.Sc.

The advent of modern observational devices such as satellites and long-life free drifting balloons has greatly complicated the process of data analysis by computer. This paper presents a possible method for effecting this data analysis by fitting a high-power polynomial to all the observations from within a large volume of the atmosphere.

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No. 32 The Bushby-Timpson 10-level model on a fine mesh

By G. R. R. Benwell, M.A., A. J. Gadd, Ph.D., J. F. Keers, B.Sc.,
Margaret S. Timpson, B.Sc., and P. W. White, Ph.D.

A full description is given of the 10-level numerical weather prediction model which has been developed by the Meteorological Office during the past few years for use in investigating the dynamics of fronts and in predicting rainfall. The formulation includes representation of the effects of surface friction, topography surface exchanges of sensible and latent heat, sub-grid-scale convection, and lateral diffusion. An example of a recently computed forecast is included.

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A PLAN FOR THE DETERMINATION OF THE LARGE-SCALE WEATHER PATTERNS DURING THE PERIOD 1493-1860

By J. M. CRADDOCK

Summary. This paper describes a reconnaissance along a line of thought suggested earlier this year and considers the practical steps by which a co-operative undertaking, depending mainly on voluntary effort, can produce a permanent improvement in our knowledge of weather processes since the Middle Ages. Starting with the general objective of systematizing our knowledge of weather and climate in the period from 1493 to 1860, it arrives at a definite plan, in which both amateur and professional meteorologists can co-operate in different ways, with the prospect of seeing worthwhile returns for their efforts within a reasonable time.

Introduction. In a paper (Craddock¹) which discusses ways in which the amateur meteorologist, or the retired professional, can still contribute to the development of meteorological science, I suggest the possibility of collecting early information relevant to large-scale weather patterns which may be processed for use in present-day long-range weather forecasting. The beginning of the target period for determining the large-scale weather patterns, 1493, is the year after the discovery of America. Before that time, direct evidence of weather situations over the American sector of the northern hemisphere does not exist, and the interpretation of indirect evidence, such as that furnished by tree-ring studies, is a different problem from the one considered here. The end of the target period is the date from which the records are already arranged in manageable form in the long-range data bank described by Craddock.² Within this period, the investigator, besides realizing the general satisfaction of having contributed a little to the organization of knowledge, may help to attain one of two clear and practical objectives.

- (a) The first, which applies to the more recent years, is to collect enough information to allow convincing daily weather charts to be plotted for a good part of the British Isles and north-west Europe, so that more years can be included in classifications such as those of Lamb³ and Hess and Brezowsky,⁴ and
- (b) for the earlier years, for which the weather conditions on individual days may always remain indeterminate, it may yet be possible to produce valid indices, such as the *PSCM* indices of Murray and Benwell,⁵ which give the general character of each month and have applications in long-range weather forecasting.

The date which divides the earlier period for which every scrap of information should be used, from the later, for which attention may be confined to the better sources, is uncertain, but probably lies between 1660 and 1780. Perhaps the best way to find it is to start with the early years for which data are scarce, and work forward until the amount of information per year becomes embarrassing. Making the best of scanty data involves both examining the original records, and considering the circumstances under which they were made, and also examining all the records for a given date or period, presented in chart form, and both types of investigation should be carried out by, or under the supervision of, a competent synoptic meteorologist. Moreover, if the examination of, say, the weather observations on a given day throws doubt on some of the observations, the analyst must be able to check these back to source. For this to be possible, the original records, or accurate copies of them, must be collected at a centre where they are readily accessible both as records for individual stations or observers, and as collections relating to different periods. The need for this dual treatment was brought home to me as I examined the material discussed below.

Some preliminary searches. As the first part of my reconnaissance, I borrowed the *Diary of John Evelyn*⁶ (I knew Pepys's *Diary* had been worked over) and read it through, noting every bit of information I thought had meteorological interest. I soon realized that the meteorological notes could not be evaluated without knowing something of John Evelyn: for example, that the first part of the diary was made up from previous notes, while the rest consists of remarks made at the time, almost up to his death at the age of 86. To save future meteorologists the trouble of borrowing the book, and reading the 1100-odd pages, I prepared a short biography of John Evelyn giving only the facts relevant to his remarks on weather followed by over 500 verbatim extracts either of actual weather, or of circumstances from which the weather can be inferred. Two copies of this I have kept for future processing, while others will be deposited in the National Meteorological Library, so that a future meteorologist interested, say, in the year 1684 can read exactly what Evelyn said about it. If the principle of maintaining accurate copies of original material in a readily accessible centre, each accompanied by a report by a synoptic meteorologist, will help to make better use of a comparatively familiar work like Evelyn's diary, it has even greater advantages when applied to rare and inaccessible works :

- (a) it minimizes the possibility of copying errors,
- (b) it ensures that each observation can be assigned as nearly as possible to the right place, something which is essential if, for example, information from Plymouth and Edinburgh is being combined with London data to place a pressure centre, but which is often omitted in extracts,
- (c) it allows the inclusion of information, for example on shipwrecks, or the arrival of news from the continent, from which a meteorologist can infer the wind régime, which a bare catalogue of weather would miss,
- (d) it reduces the wear and tear on original records which may be both irreplaceable and difficult of access, and
- (e) it allows the meteorologist to form an opinion of the character and reliability of the observer, and of his instruments, if any.

After Evelyn, I examined some works containing meteorological information extracted from other sources such as those of Lowe,⁷ Baker⁸ and Easton.⁹ These all prompt the questions whether the authors have personally read all the works they quote, and whether they have extracted from these works all the original information relevant to weather.

Since Easton deals only with winters, ignoring the other seasons, while Baker is interested mainly in meteorology in relation to agriculture, it seems most unlikely that either writer has exhausted his source material. With Lowe, there are more grounds for confidence, but even with him, the reader should be able to retrace the ground for himself. With these early writers, unlike their modern counterparts such as Lamb¹⁰ and Le Roy Ladurie,¹¹ the references are so incomplete that the first task, in getting a clear picture of the total weather information for any period, must be to make a full bibliography, without duplication, with adequate references, either to the original source or to the closest point to the source which can be found at present.

Forming a catalogue of sources of information. Forming a catalogue of sources of information involves not only visits to libraries, but also using the bibliographies given by some authors to find others. The bibliography given by Easton,⁸ who seems to have been one of the most assiduous collectors, suggests that a comprehensive bibliography for our period would include perhaps 50 main sources and up to 2000 subsidiary ones, with possibly 10 000 or more references to weather in matter which is basically unrelated to meteorology.

An efficient catalogue would contain an entry for every source, with the following properties :

- (a) that each entry contains enough information about the form, content and importance of the item concerned, and its place of observation, period and location of the record;
- (b) that the catalogue can readily be extended by new entries, and
- (c) that it can easily be searched for all items which fulfil reasonable conditions as to content, place or period.

Since such a catalogue will be a good deal of trouble to create and to maintain, it is most desirable that it should be easy to reproduce, both for protection, and for the convenience of intending users. These conditions are quite hard to satisfy with a conventional card index, indeed, I have never had a satisfactory answer from a librarian as to what he would do if his main card index was destroyed by fire, but they can readily be satisfied by means of the computerized cataloguing and retrieval system which I have recently been involved in developing for the World Meteorological Organization, which is described in *World Weather Watch Planning Report* No. 34.¹² This system cannot be described in a few words; it deserves an article to itself, but it is already in use for the cataloguing of information of all kinds relevant to long-range weather forecasting, a field which includes most of the sources of information discussed here, so there is a clear saving in using it in the present plan.

Comments on individual sources and authors. The ideas concerning preliminary researches took a definite shape while I was reading the potential source documents listed below.

Although I read the *Diary of John Evelyn* for relaxation, I found it intensely interesting, giving a clear picture of an upright, humane man in the early stages of the scientific era. He was a founder member of the Royal Society, and a strong Royalist and supporter of the Church of England. His general interest in religious topics suggests that when, as occasionally happened, he was prevented from going to church by wet or cold, the weather was a real deterrent and not a feeble excuse. Although Evelyn travelled as far as Rome and Venice, and gives some useful accounts of crossing the Channel, most of over 500 observations refer to the area London–Deptford–Dorking, and supplement a similar number of observations made by Pepys.

James Yonge was a naval surgeon who lived from 1642 to 1721 (see reference No. 13) and went to sea as an apprentice before he was 11 years old, but rose to be something like a consultant surgeon, a member of the Royal Society, and Mayor of Plymouth. His *Diary* falls into three parts. The first part, written from memory in 1667 when he was a prisoner of war at Rotterdam from notes lost when he was captured, includes accounts of two voyages to Newfoundland and one to Algiers; the second part gives an excellent record of the weather during two voyages from Plymouth to Newfoundland and back in 1668 and 1669, with ships' logs; the third, from 1671 to 1707 contains much of medical interest, but only about 20 direct references to weather. Unlike Evelyn, Yonge does not always give his dates explicitly, and it will take perhaps a fortnight's detective work to make the best of the weather information in the first and third sections. However, the second section is most rewarding, and taken in all, Yonge's comments on people and affairs make this diary as interesting as those of Pepys and Evelyn.

Both these diaries suggest that more should be made of the marine evidence, ships' logs, records of sea passages, etc. than the compilers seem to have attempted.

E. J. Lowe,⁷ a botanist who specialized in ferns, and a Fellow of the Royal Society, produced many meteorological observations from his home at Highfield House, Nottingham. He preserved his modern outlook when looking into the past (this compilation ends in 1753). In his own words 'many phenomena are described in the exact words in which they are written at the time of occurrence; and this has been done because a more perfect estimate can be formed from an author's own words'. He gives short references to the items which he found in unusual sources, and lists a few publications as requiring systematic study. The following extract may be the first record of a sonic boom. '1628 Stone from sky; Hatford, Berkshire, On April 9, 5 p.m., warm, windy, WNW, a hideous noise in the air, followed by a strange and fearful thunder, then another, till twenty peals were heard. A stone fell at Barolkin Green (1½ miles from Hatford) and was dug up by Mistress Green. It broke, one piece weighed 19½ lbs, and another 5 lbs.' In Lowe¹⁴ he continues his extracts up almost to the date of publication, and also gives more early extracts from other sources. In all, a valuable compilation.

E. T. Baker⁸ is a compiler of very different calibre. Although he was a Fellow of the Meteorological Society and gives over 1200 references up to 1792, his main interest lay in agriculture, and probably half refer to the price of wheat. His references are short and cryptic, (e.g. F.A. or Smith) and

although over 140 sources are mentioned, only 21 of these produce 10 or more items. He gives over 90 quotations from Lowe, including the above extract, somewhat abbreviated, and given for the year 1627, a mistake which casts doubt on his treatment of other sources. In spite of this evidence of unreliability, Baker's work has its uses. It shows that Holinshed, with entries up to 1586, and Gilbert White, who continues up to 1792, were better observers than most of his sources, and his references, if they can be deciphered, are at any rate evidence that certain authors were active at certain periods.

A. Angot¹⁵ has given a list of nearly 300 observational records made in France before 1850, including in most cases, the elements observed, and the place where the original record is stored.

R. C. Mossman¹⁶ has given a painstaking account of the climate of Edinburgh, in course of which he gives details of one instrumental record for the years 1731-36, and an almost unbroken succession of records for the years from 1764 onwards. Mossman¹⁷ lists representative wheat prices at Haddington for the years 1627-1897, which could be a better starting point than most for an attempt to relate wheat prices to weather.

H. Teonge¹⁸ recounts the diary of a cheerful naval chaplain, which was kept during two voyages from London to Aleppo and back in the years 1675 to 1679. There is a good deal of weather information, mostly for the Mediterranean, but few dates are given explicitly and the positions must be estimated. The diary mentions the ships passing various ports and headlands, so estimation should be possible. It could provide a synoptic meteorologist with an interesting fortnight's detective work.

C. Easton⁸ has made a monumental study, with over 300 references, on the winters in the climatic region extending from Bremen to Toulouse. He seems to have been a senior member of the Netherlands Meteorological Service, and his text, which contains sections in French, English, German, Latin and Dutch, is not always easy to follow. The work gives an impression of thoroughness, but the area considered excludes information from most of Germany and the British Isles. Many of the references are incomplete, but they provide a most useful contribution to the total.

C. E. Britton¹⁹ produced about 20 papers, mostly during the 1930s, in which he reproduced some of the early records, or reported research on their authors, and the circumstances in which they were made. These unpretentious papers, which fall naturally into the present plan, will retain their value when many more ambitious contributions have been forgotten.

G. Manley²⁰ is mentioned here because besides his excellent series of monthly mean temperatures, he gives the sites and periods of many of the early instrumental records. Taking only his sources with those of Mossman would provide a good start for daily weather charts for most dates from 1764 to the present.

E. Le Roy Ladurie¹¹ started with studying agriculture in Languedoc, and expanded naturally to the study of climate. His evidence on Alpine glaciers, and his bibliography of texts in the French language seem particularly good.

Some of these compilations contain data for years before 1493 and also there is bound to be some duplication; some detective work will be needed before a catalogue of sources for the period can be produced which has any claim to completeness without redundancy.

General impressions. The synoptic meteorologist has the advantage over the old-fashioned climatologist, when analysing data in chart form, because if the time-step between charts is short enough, the weather systems have continuity between one chart and the next. A time-step of one day is used in long-range weather forecasting, as the best compromise which preserves continuity between charts without retaining unnecessary detail, and is also suitable for the present purpose, since enough data are never likely to be found to justify a shorter step. If the objective is to plot a daily chart for each day of the years 1660 to 1859, 73 048 days in all, then the sources already mentioned contain enough data to plot something on almost every chart, and several observations on some. If an average of from 5 to 10 well-spaced observations on a series of charts will support an analysis, then many years within the period can be processed by using known sources of data, and a systematic search for data may bring a good many more years to this standard.

It is difficult to judge the true value of many of the sources until they have been examined and catalogued, but it is worth mentioning that the scatter of sources, which was a handicap to authors like Mossman¹⁶ and Manley²⁰ who were interested in conditions at a point, is an advantage when it comes to plotting a chart. It is also difficult to judge how much additional information can be found in local newspapers, county archives, etc., but probably there will be a good deal about weather which was out of the ordinary. However, throughout the period there were British ships moving in the English Channel, the Bristol Channel and in the North Sea to ports such as Bergen and Königsberg. Merchant ships often travelled in convoy under the protection of men-of-war, and the number of ships' logs still in existence must be quite considerable. These logs may be the biggest source of information not already tapped by the climatologists.

Comments on the plan. The plan outlined in the paragraphs concerning preliminary researches is for a co-operative effort, not only because it is far too big for one man, but also because different aspects may attract different people. A search through local records such as the *Norwich Register* mentioned by Baker,⁸ those for Bristol in Lowe⁷ or for the Scottish stations mentioned by Mossman¹⁶ may interest a retired meteorologist living in the district, or form the subject of a school project. Once an interesting record has been found, the meteorological entries should be copied, and a report written about the source. The first copy will often have to be made by hand, but this should be replaced by a clean typed copy which can be checked against the original, and certified correct. The centres which should hold copies have yet to be decided, but it is already clear that any such reliable extracts of original information would be most welcome additions to the National Meteorological Library. If there is a synoptic meteorologist able to make or check the report on the original record, so much the better.

To facilitate future processing, a full reference to the source should be included at least once for each year, so that if the record is cut into pieces, each piece can be traced back to its origin.

Rearranging information according to period. When enough records have been prepared, reported on, and collected at a centre, one copy of each should be rearranged in sections relating to different periods. For printed

matter, such as my extracts from John Evelyn, Samuel Pepys, James Yonge, etc., this can be done simply by cutting up one copy of each, and pasting the pieces together in sections corresponding to period. The new listing can be copied, but since there is some loss of quality at every copying, the original should be very clear.

For numerical data, however, it is preferable to punch the data on a computer medium from the original record, or from a direct copy, and to carry out any required scaling, correction or rearrangement by computer.

The inclusion of a full reference with every year means that if the analyst in the next stage feels doubt about an observation, he can trace it back to source. This is most important if, as occurs once or twice in Evelyn, remarks for neighbouring days are hard to reconcile, or when there is doubt about the year or the date of the event described. Further the effect of age on meteorological instruments was not understood in early years, and a single incredible value may indicate that a whole record has been affected by instrumental drift and requires correction, by computer or otherwise, as may be most convenient.

Analysing the information for a period. Once enough progress has been made with the collection of information, and it seems unlikely that anything new can upset the consensus of what there is, then the information for one period can be passed to a group of meteorologists who are prepared to analyse it. For years since 1800, there will be a good many observations, and perhaps one year would be enough to tackle at a time. For the 1600s however, it might be better to take a decade. The team taking on each period should preferably include at least one experienced forecaster and they should live close enough together to be able to meet and discuss progress. A supply of blank charts will be essential if daily charts are to be plotted and desirable in all cases and these should come from the central organizing unit. The final product could be a scientific paper suitable for publication, and a series of analysed charts to be returned to the central unit, and in due course included in the National Meteorological Library.

Concluding remarks. The attack is based on the principle that one objective of any sound scientific investigation is to put the reader in possession of the basic facts, so that he can, if he wishes, reconsider these facts and form his own conclusions. In making these proposals, I do not overlook the work of authors such as Professor H. H. Lamb and Dr D. J. Schove, who have spent many years collecting information on this and allied topics. However, the emphasis in the present scheme at this stage is on the collection of basic data, and the keeping of such data in forms convenient for reference at accessible centres, rather than on the possible applications. Moreover, the plan envisages the use of modern technology, (e.g. in forms such as computers and copiers) for tasks which do not involve human judgement, with the aid of the judgement of present-day synoptic meteorologists whenever the material deserves it. Several references have been given to interesting material which should repay careful study, and the comprehensive bibliography which I am collecting is sure to provide many more. If any meteorologist, amateur or professional, who is willing to take part would send his comments to the editor, or to me, then I will try to report progress within the next 6 to 12 months.

Since drafting this paper I have read the first *Annual Report* of the Climatic Research Unit at the University of East Anglia, which shows that daily charts for the area discussed for the years 1782 to 1784 have been analysed by Mr J. A. Kington and classified by Professor H. H. Lamb. This news confirms the practicability of the present proposals, and may encourage others to join in the search for meteorological information in ancient records.

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THE DIURNAL VARIATION AND DURATION OF THE SEA-BREEZE AT THE NATIONAL OBSERVATORY OF ATHENS, GREECE

By J. D. ZAMBAKAS

Athens University Climatological Institute

Summary. Records of pure sea-breezes at Athens Observatory, situated on a promontory, are examined for April, July and October 1961-67 and for January 1938-67 (the longer period compensating for the lower frequency of occurrence in winter); there were 24 such cases in July (7 years) and 26 in January (30 years). Since the sea-breeze is not in balanced motion the ends of the wind vectors during the diurnal variation lie approximately on an ellipse, and the eccentricities of these ellipses are discussed.

Introduction. The diurnal variation of the sea-breeze wind has been given theoretically by Haurwitz¹ for a straight coastline. If equilibrium exists between the general pressure gradient force, the pressure gradient force due to the land-sea temperature difference, the Coriolis force and the frictional force, then the speed of the sea-breeze changes but not its direction. If the wind is not in balanced motion, as is actually the case, owing to its inertia, then the ends of the wind vectors lie on an ellipse and change in a clockwise direction with time. The greater the frictional force the greater the eccentricity of the ellipse.

Gill² found that the location of the station and the shape of the coastline near it governs both direction and diurnal variation of the sea-breeze. The ellipse is always approximated to, but the theoretically expected clockwise change in direction of the wind vectors with time round the ellipse does not occur at Wick, a station which is situated on a promontory.

The National Observatory of Athens (Latitude $37^{\circ}58'N$, Longitude $23^{\circ}43'E$, height 107 metres above sea-level), for which the above-mentioned sea-breeze characteristics are examined here, lies on a promontory and about 5 km from an indented coastline (Figure 1).

Data. Sea-breeze days occur in Athens all the year round. These days were tabulated for the 7-year period 1961-67 for the months April, July and October. Because of the rareness of this phenomenon during the winter period, January was considered for a 30-year period 1938-67. Only days

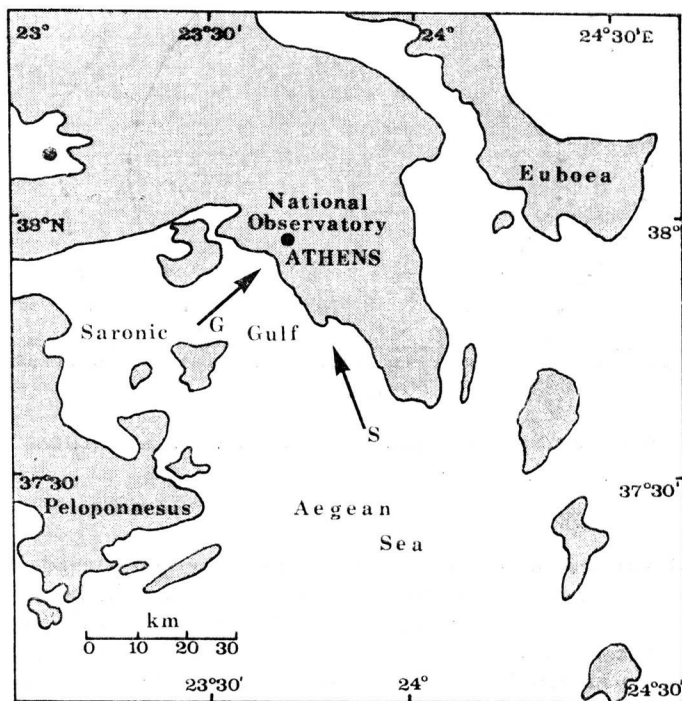


FIGURE 1—LOCATION OF THE STATION USED

with pure sea-breeze were selected to avoid interference by any other wind component during the period of the sea-breeze day. The nights, before and after the chosen day, showed only a light land-breeze or calm. Data were derived from the records of a pressure-tube anemograph, and the hourly vector mean winds were calculated by hand for the above months. It is assumed that the diurnal variations remain reasonably constant over the period of a month.

Duration. The characteristics as regards the duration and the time at which the sea-breeze starts and ends in relation to the time of sunrise and sunset are given in Figure 2. The times when the wind vector was parallel to the coastline in the morning and in the afternoon, have been considered as times of start and end of the sea-breeze, respectively. These times have been computed for all months. The end of the sea-breeze is noted about 2 hours after sunset, whereas Gill² found that at Kinloss the end of the sea-breeze occurs 2–3 hours before sunset. This difference is explained by the higher latitude of Kinloss and the consequent smaller heat supply there.

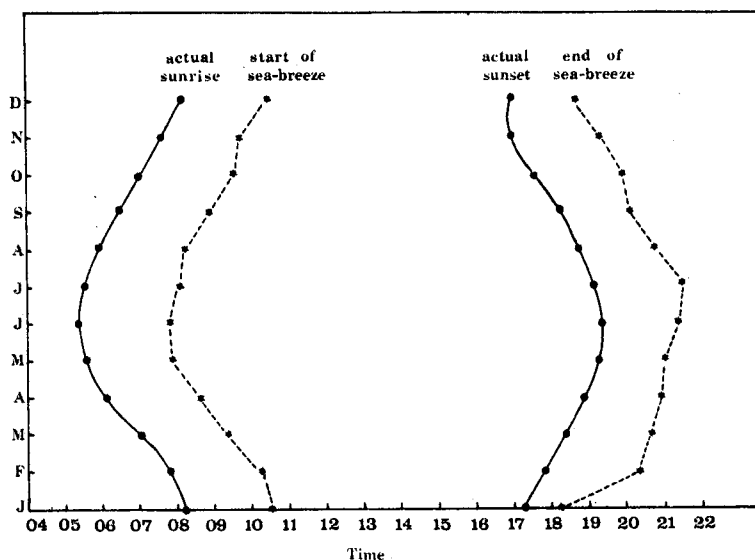


FIGURE 2—DURATION OF SUNSHINE AND SEA-BREEZE AT ATHENS (1961–67)
Times in local zone time (GMT + 2 hours)

Diurnal variation. Figures 3 and 4 show the constructed hodographs for the 26 selected pure sea-breeze days which occurred in January and the 24 which occurred in July, respectively, with the station in the centre of the diagrams. The orientation of the coastline near the station is also shown. The hourly mean wind vectors are plotted from the station towards the direction from which the wind blows. The ends are labelled with the hour to which they apply, in local zone time (GMT + 2 hours). The envelopes of

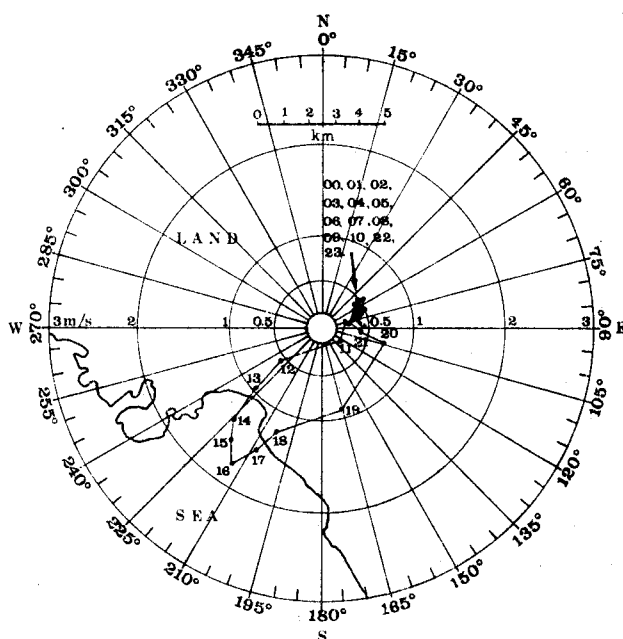


FIGURE 3—HOURLY VECTOR MEAN WINDS AT ATHENS IN JANUARY BASED ON DATA FOR 26 PURE SEA-BREEZE DAYS DURING THE 30 YEARS 1938-67

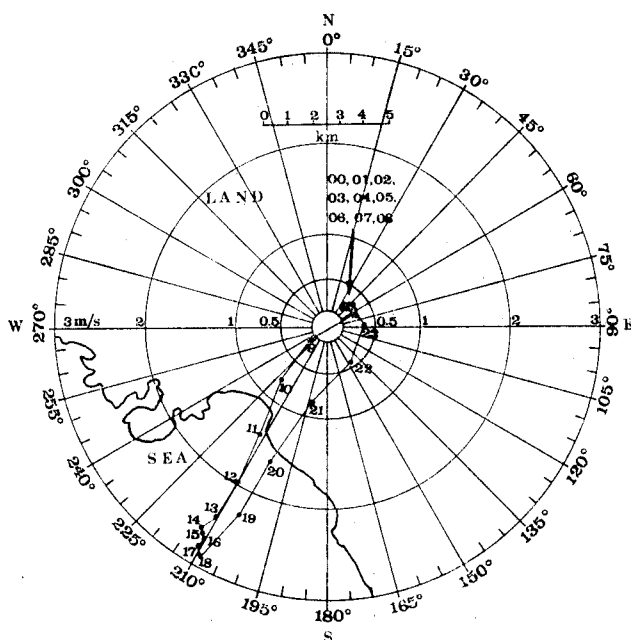


FIGURE 4—HOURLY VECTOR MEAN WINDS AT ATHENS IN JULY BASED ON DATA FOR 24 PURE SEA-BREEZE DAYS (1961-67)

the wind vectors are nearly ellipses. For the other seasonal representative months the results are nearly the same with the following detailed characteristics. During the night and early morning the direction of the wind remains almost unchanged, and the speed is small, in conformity with the expected weaker nocturnal land-breeze. The maximum mean intensities of the sea-breeze occur between 1600 and 1800 local time and range from 1.78 m/s in January to 2.88 m/s in July. The eccentricity of the ellipses ranges from a minimum in January to a maximum in July.

Discussion. The maximum eccentricity in summer indicates, according to the theory, that the mechanism distributing the heat vertically by thermals is stronger in summer, increasing the friction in the lower atmospheric layer.

As to the diurnal variation, in all four months the wind backs and only for short periods during the day does the wind veer in agreement with the theory. A similar backing is traced by Gill² at Wick, situated on a promontory too, as is the Athens Observatory. As can be seen the sea-breeze recorded first in the morning is blowing from the Saronic Gulf (G-direction, see Figure 1). Therefore a rough explanation of the backing at Athens may be that the bulk masses of air arriving later from the open sea (S-direction, see Figure 1) and increasing in intensity during the development of the circulation, prevail as a component which conceals the Coriolis effect. Another fact that supports this explanation is that during some relatively weak sea-breeze days, when the component from the S-direction becomes negligible early in the decay stage of the circulation in the afternoon, the wind at Athens stops backing and starts veering.

Conclusion. The theoretically expected ellipses are formed approximately but the diurnal variation of the sea-breeze is governed by the location of the station and the shape of the coastline near to it. At Athens, lying on a promontory, the sea-breeze wind backs in disagreement with the theory. A similar study, with two stations lying on either side of a promontory having the open sea just before it, would be of considerable interest. It would show whether the bulk masses of air arriving later from the open sea affect the diurnal change of sea-breeze direction in an opposite sense on each side of the promontory.

Acknowledgement. The author would like to express his sincere thanks to Professor L. N. Carapiperis for going through the manuscript of the paper.

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SOME METEOROLOGICAL EFFECTS ON GUN AND SHELL DETONATION NOISE AT DISTANCES $\frac{3}{4}$ TO $2\frac{1}{2}$ MILES FROM SOURCE

By F. C. JACKSON and P. G. F. CATON

Summary. Sound-level measurements at distances between $\frac{3}{4}$ and $2\frac{1}{2}$ miles from explosive detonations have been compared with the gradient of sound speed in the lower atmosphere as revealed by surface and upper-air temperature and wind measurements. Relationships have been established for three distances in conditions of negative gradient of sound speed. By interpolation, estimates are made of meteorological conditions necessary to avoid nuisance at various distances and for various types of detonation.

Introduction. The general public, living in the neighbourhood of Experimental Establishments or Practice Camps, are becoming increasingly sensitive to the nuisance and occasional damage caused by gunfire and other explosive detonations. It is important to be able to predict the meteorological conditions in which guns may be fired or explosives detonated without causing serious nuisance to members of the public living close to firing ranges. This paper considers the problem at distances $\frac{3}{4}$ to $2\frac{1}{2}$ miles from the noise source, and excludes description of the sound focusing effects which often occur at greater distances.

A blast wave formed by gunfire or detonation attenuates rapidly to become similar to a sound wave and the laws of propagation of sound may be applied. The speed of sound (c) in still air is given by

$$c = \text{const. } T_V^{\frac{1}{2}},$$

where T_V is the virtual temperature in kelvins. Thus, in the real atmosphere, the speed of sound is dependent on temperature, humidity, and wind speed and direction. It follows from Snell's Law of Refraction that if the speed of sound in the atmosphere increases or decreases with height a sound wave originating near the surface will be turned towards or away from the ground and the resulting overpressure, measured at a distant position near the ground, will be modified from that obtained in an atmosphere with uniform sound speed.

Sound-level measurements were made to ascertain whether a correlation could be obtained between gun and shell detonation noise measured at distances between $\frac{3}{4}$ and $2\frac{1}{2}$ miles from source and the change in the speed of sound in the atmosphere from the surface to a height of 500 feet (150 metres), derived from surface and upper-air temperature and wind measurements.

Observations. The sound-level measurements were made at the radio-sonde station at Landwick ($51^{\circ} 33' \text{N}$, $00^{\circ} 50' \text{E}$) during the course of routine proof and experimental firing on the Shoeburyness Ranges. The measurements, at height 3 feet above ground, used a Bruel and Kjaer Impulse Precision Sound Level Meter, Type 2204, with 1-inch microphone, Type 4145, extension rod and windscreen orientated towards the noise source. The instrument was calibrated before and after each set of measurements with a Sound Level Calibrator Type 4230.

The Impulse Sound Level Meter, according to its manufacturers, is 'an instrument that approximates a subjective impression of a short duration sound' and for these experiments it provided sound-level values without

analysis of frequency content and duration of the noise. In view of the expected low-frequency content the 'C' scale was used in preference to the 'A' scale (see Figure 1). It is significant also that the low-frequency content of the noise may lead to rattling windows and other vibrations inside buildings, thus causing annoyance not experienced in the open.

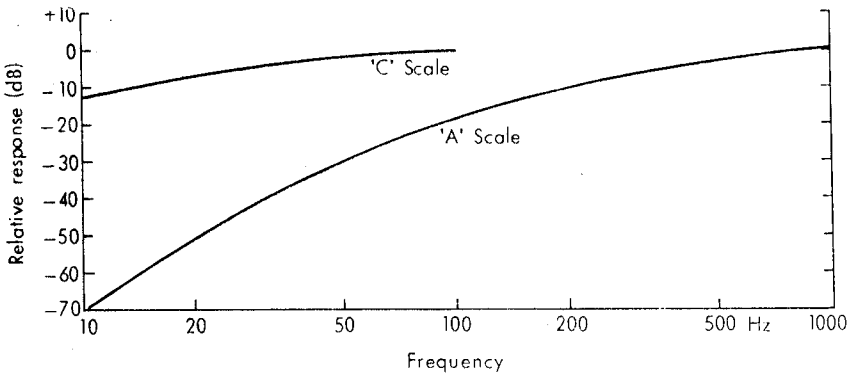


FIGURE 1—SOUND LEVEL METER RESPONSE

The radar wind measurements were supplemented by pilot-balloon observations so that upper-wind data were available at half-hourly intervals. Upper-air temperature data were obtained normally every 4 hours.

The area around Landwick is flat with unobstructed line of sight from the position of measurement to two gun batteries at distances 1380 and 1750 yards, at which the majority of firings were made. Sound-level readings were also obtained from shell detonations on sand at distances 4300 to 4650 yards (approximately $2\frac{1}{2}$ miles).

The change in the speed of sound from the surface to a height of 500 feet was calculated for the relevant azimuth from the temperature lapse rate and vector wind change. Humidity was not taken into account, as changes of the speed of sound in air due to changes in humidity are relatively small. Owing to turbulent motion near the surface and the limitations of wind-finding techniques in indicating shear over narrow layers, scatter was expected in sound-level readings with the same measured sound speed structure.

All measurements were made in temperature lapse conditions, the temperature decreasing by between 0.5 and 3.2 degC from the surface to 500 feet. Further, the vast majority of measurements were made in conditions of negative gradient of sound speed.

Results.

(a) *At distance 1380 yards.* Figure 2 shows a plot of the data obtained from 133 firings of Gun 'A' during the period 13 July–4 August 1971. The means of a number of sound-level readings measured over a short period of time are plotted against the change in the speed of sound from the surface to 500 ft (expressed as a sound speed gradient in units feet per second per foot, i.e., in SI units, reciprocal seconds or s^{-1}). The number of sound readings and their range in decibels is shown alongside each plotted point. All sound pressure levels are measured in decibels relative to a reference pressure of 2×10^{-5} Pa.

Good linear correlation is obtained. The calculated regression line $y = 550x + 104.2$ is drawn, and the correlation coefficient is $+0.90$.

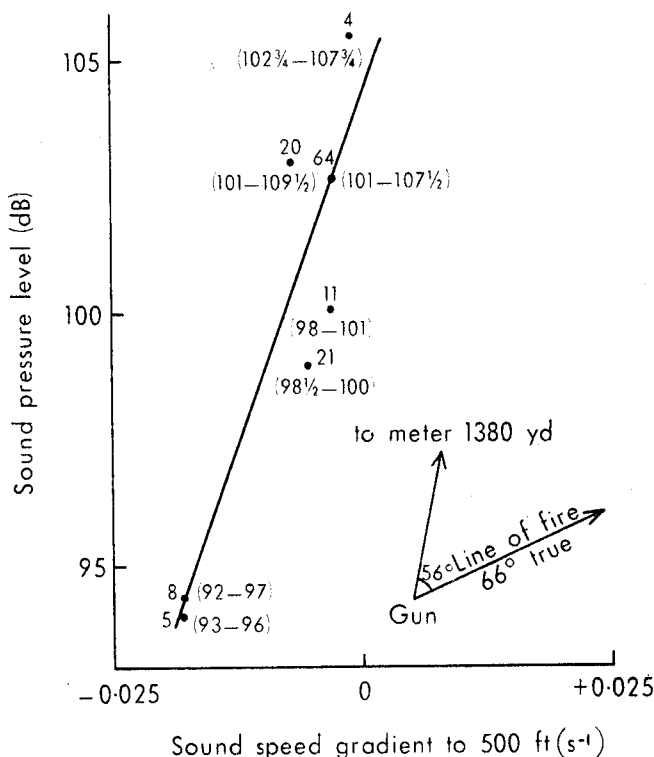


FIGURE 2—SOUND PRESSURE LEVEL MEASUREMENTS FROM GUN 'A' AT DISTANCE 1380 YARDS

Sound pressure levels are measured in decibels relative to a reference pressure of 2×10^{-5} Pa. Numbers adjacent to plotted points indicate numbers of observations and, in brackets, the range in decibels of the observations.

(b) *At distance 1750 yards.* Figure 3 shows the results obtained from 159 firings of Gun 'B' during the period 6 April 1971–9 December 1971. The data are separated into two groups (i) charge weights $6\frac{1}{4}$ to $7\frac{1}{4}$ lb and (ii) charge 'super' heated, corresponding to different noise levels at source. Also, unlike the Gun 'A' firings, the range of azimuths of 'line of fire' varied randomly over about 30 degrees, possibly requiring consideration of an additional variable. As in Figure 2 comparison is between the mean of sound meter readings and the gradient of sound speed from the surface to 500 ft.

In group (i) linear correlation (coefficient $+0.76$, regression line $y = 690x + 105.1$) is obtained, by discarding the 13 observations plotted at 98.4 dB. These observations were made on 3 August 1971, when a cold front with waves was in the vicinity of the station. The wind observations before and after the firings were consistent in indicating a positive gradient of sound speed from the surface to 500 ft, but there was considerable change in magnitude; further, in the wind observations after the firing the gradient of sound

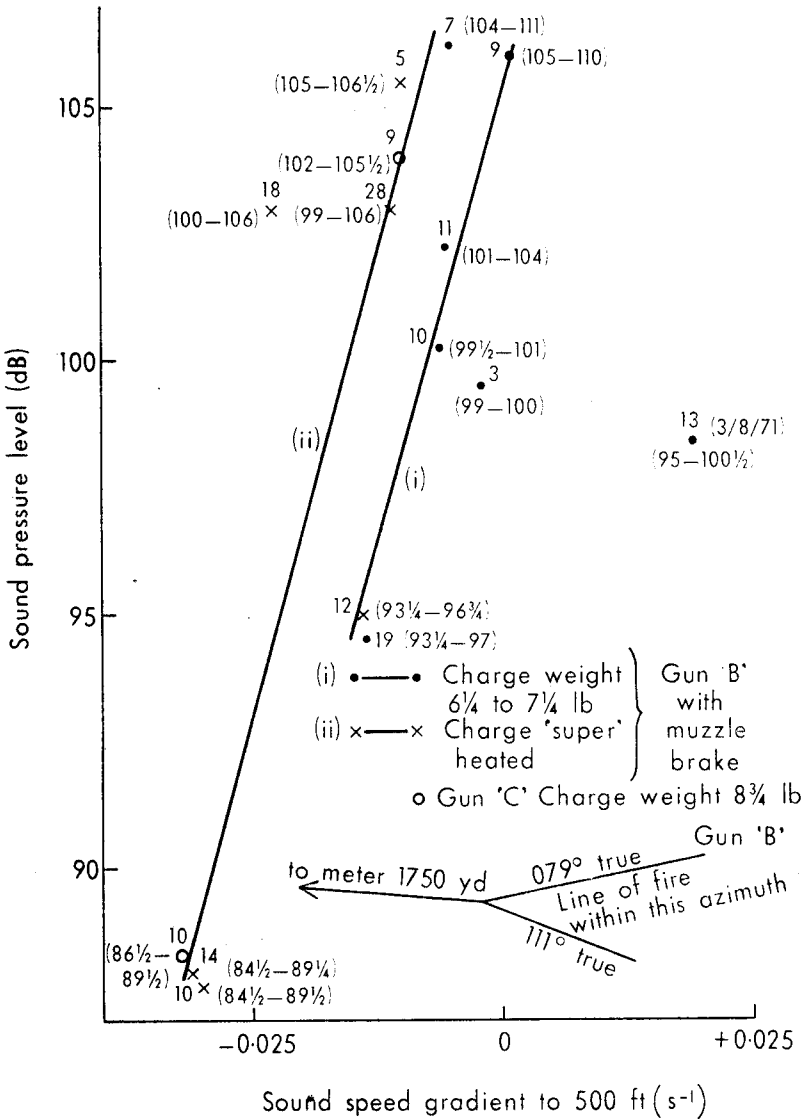


FIGURE 3—SOUND PRESSURE LEVEL MEASUREMENTS FROM GUNS 'B' AND 'C' AT DISTANCE 1750 YARDS

See notes under Figure 2.

speed was negative above 500 ft. It may be that even at these distances a layer of atmosphere deeper than 500 ft is important, and that the simple correlation breaks down when the gradient of sound speed is complex.

In group (ii) linear correlation (coefficient +0.81, regression line $y = 720x + 111.0$) is obtained, with the slope of the regression line very similar to that for group (i). However it must be admitted that the crosses plotted at 95.0 dB, $-0.014 s^{-1}$ and 103.0 dB, $-0.023 s^{-1}$ are respectively 6 dB

and $8\frac{1}{2}$ dB off the line. No explanation is available in the first case other than the possibility that noise differences at source may account for part of the discrepancies. In the second case the wind profiles measured before and after the firings were unusual, and it is possible that a lower value of gradient of sound speed, -0.012 s^{-1} , would be more representative.

Finally, data for two occasions totalling 19 rounds from Gun 'C' are plotted on Figure 3. They confirm the slope derived from the previous data, but it is of course coincidental that the ordinates fit so closely those of Gun 'B' with 'super' heated charge.

(c) *At distances 4300 to 4650 yards.* Figure 4 shows sound-level measurements made on three occasions (28, 29, 30 April 1971) corresponding to detonations on sand of 67 shells fired from guns of the same calibre. The values of sound-speed gradient are those from the points of detonation (not from the guns). It will be seen that linear correlation is possible (coefficient $+0.97$, regression line $y = 1220x + 105.6$). The line must be regarded as provisional, being based on three data points only.

(d) *Use of surface wind measurements alone.* At a number of Establishments upper-air temperature and wind measurements are not available. It is important therefore to see what success is possible when surface measurements alone are used. Broadly speaking, the temperature lapse conditions (surface to 500 ft) to which all the data refer may be identified by forecast from the nearest meteorological office, and in these lapse conditions the wind shear to 500 ft usually contributes the larger term in the calculated sound-speed change. Further, unless the surface wind is very light or the local topography is uneven, the wind shear to 500 ft often bears a rough relation to the surface (10-m) wind. Therefore, in temperature lapse conditions, there is prospect of useful results using surface wind data alone, provided that it is recognized that a proportion of failures will occur.

Figure 5 shows all of the data at distance 1380 yards (Gun 'A' charge 5) plotted against the component of the surface (10-m) wind in the direction gun to meter. Good linear correlation is obtained (coefficient $+0.99$, regression line $y = 0.22x + 98.1$), by excluding the data for 3 August 1971—the wind structure at the time of these observations was unusual.

Figure 6 shows the data at 1750 yards (Gun 'B') subdivided according to charge as in Figure 3. In these cases also linear relationships are obtained, but the slopes of the lines corresponding to the subdivisions are different and the lines are not displaced vertically as in Figure 3. These discrepancies make physical interpretation of the 'best-fit' lines very difficult. The use of surface wind measurement alone as a successful indicator of sound level at distance requires, ideally, that the vertical wind shear increase as the surface wind speed increases, or, at least, that wind speed increase with height. A study of the data used for Figure 5 showed an increase in wind speed with height for all points plotted, whereas for 5 of the 13 points plotted on Figure 6 the wind speed decreased with height in the lowest layers. Clearly there are limitations to the use of surface wind measurements alone.

Discussion. Consideration of Figures 2, 3 and 4 shows that the slope of the regression lines increases with increasing distance. Thus the influence of the gradient of sound speed increases as the distance from a detonation increases. For example, if the change in the speed of sound from the surface

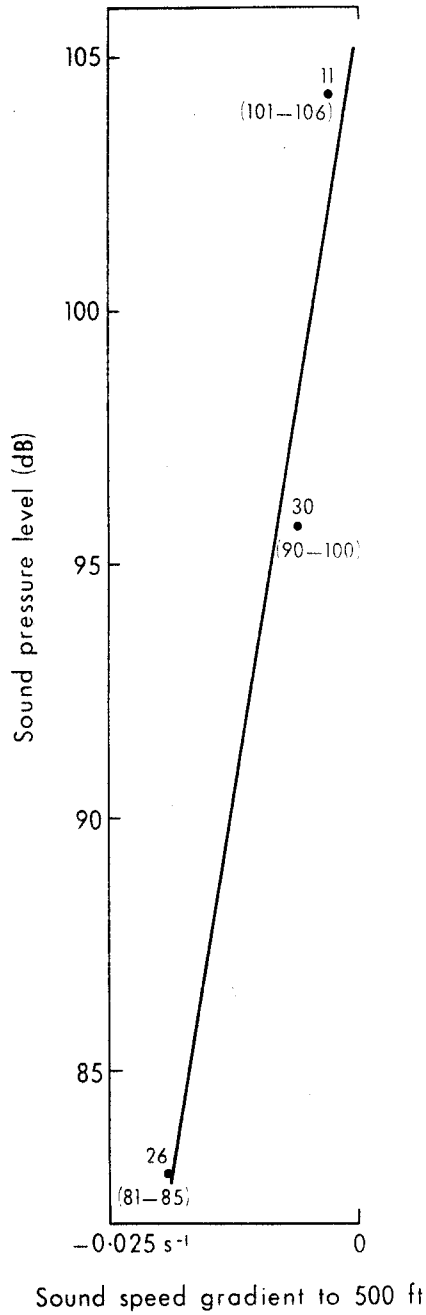


FIGURE 4—SOUND PRESSURE LEVEL MEASUREMENTS FROM SHELLS DETONATING ON SAND AT DISTANCES FROM 4300 TO 4650 YARDS

See notes under Figure 2.

to 500 ft is -5 ft/s (gradient -0.010 s^{-1}), the observed noise at distances of 1380, 1750 and 4500 yd will be attenuated respectively to $5\frac{1}{2}$ dB, 7 dB and $12\frac{1}{4}$ dB below the levels which would obtain in a uniform sound-speed field.

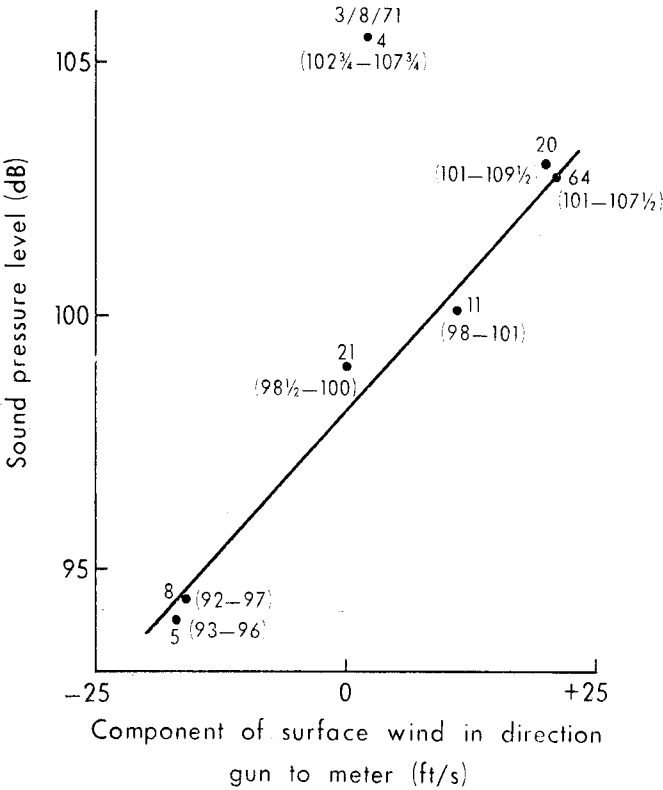


FIGURE 5—SOUND PRESSURE LEVEL MEASUREMENTS FROM GUN 'A' AT DISTANCE 1380 YARDS COMPARED WITH COMPONENT OF SURFACE WIND

See notes under Figure 2.

These results appear physically reasonable and in Figure 7 the slope of the regression lines (indicating change of sound level at fixed distance per unit of gradient of sound speed) is plotted against distance, using a logarithmic scale. The three points fall close to a straight line. The line provides a *provisional* basis for extension of our results to other distances within the range 1380–4650 yd (approximately $\frac{3}{4}$ – $2\frac{1}{2}$ miles). For example, at distance 3000 yd, Figure 7 suggests a change of sound level of 1 dB for each 0.001 s^{-1} unit of gradient of sound speed.

Report No. 1240 of the Ballistics Research Laboratory, Maryland, U.S.A.,* contains a graph, reproduced as Figure 8, which relates overpressure at the surface at various distances from detonations of various charges of High

* PERKINS, B. and JACKSON, W. F.; Handbook for prediction of air blast focussing. Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, U.S.A. Report No. 1240, 1964.

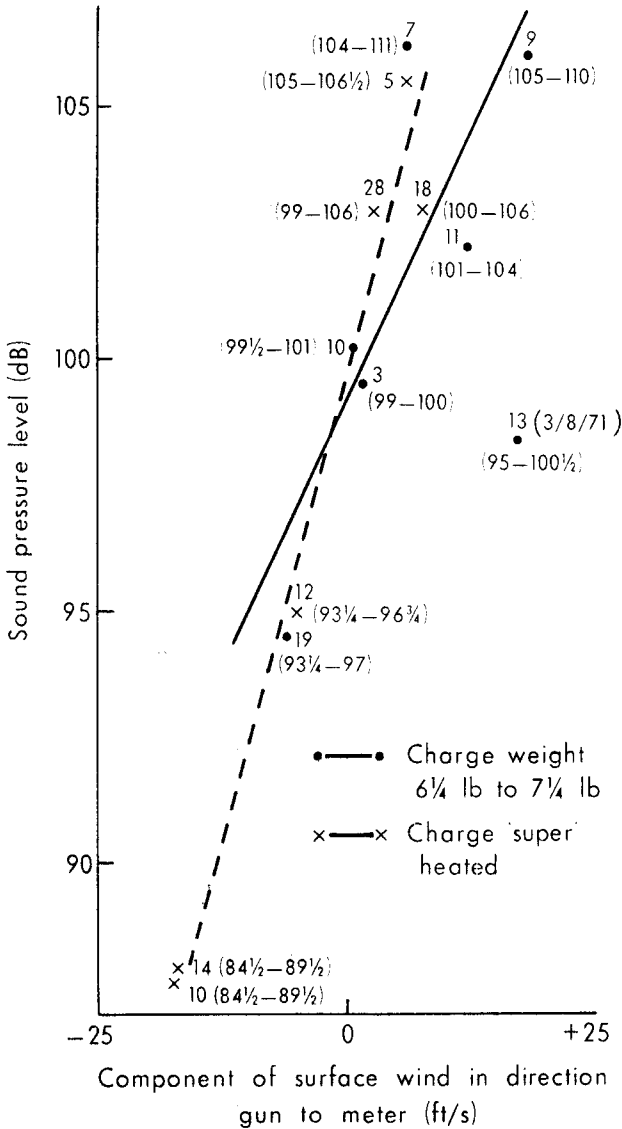


FIGURE 6—SOUND PRESSURE LEVEL MEASUREMENTS FROM GUN 'B' AT DISTANCE 1750 YARDS COMPARED WITH COMPONENT OF SURFACE WIND

See notes under Figure 2.

Explosive (HE) when the speed of sound is unchanged with height, i.e. the vertical gradient of sound speed is zero. It is suggested that this graph may now be extended to conditions of negative gradient of sound speed. For example Figure 8 indicates that 6 lb HE (approximate content of shell) at 4500 yards (13.5 kilofeet) will produce an overpressure of 0.00075 pounds per square inch (p.s.i.) (= 108.5 dB), in conditions of zero gradient of sound

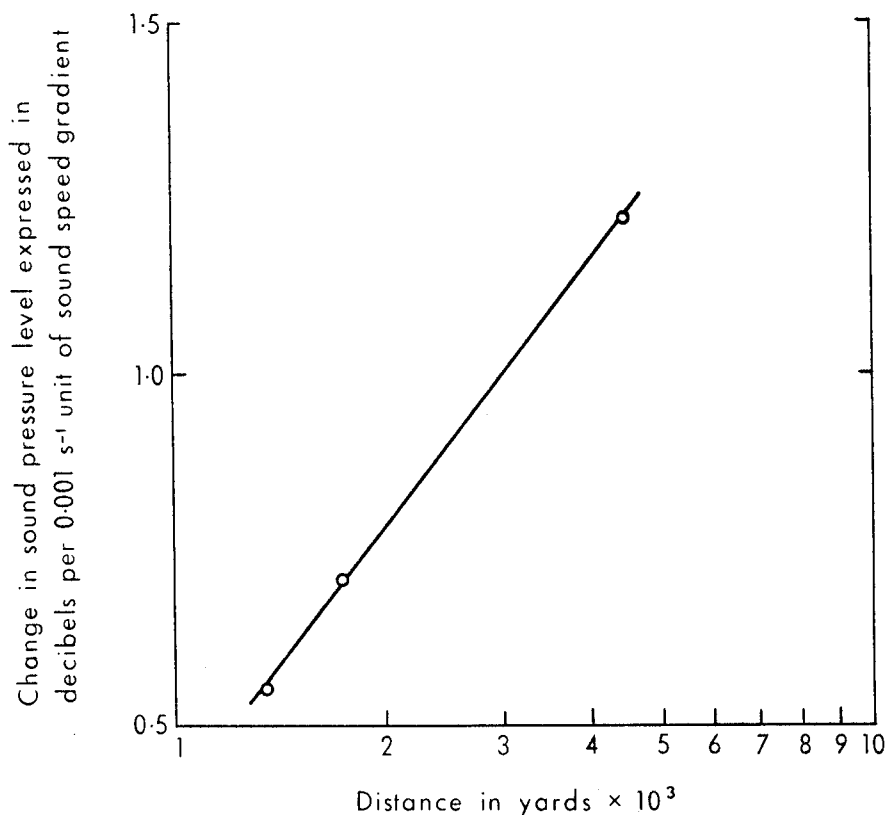


FIGURE 7—COMPARISON OF THE SLOPES OF FIGURES 2, 3 AND 4

speed. This is in reasonable agreement with the value of 105.6 dB indicated by Figure 4, considering that the detonations were on sand. Figure 4 and Figure 7 further indicate that in a negative gradient of sound speed of -0.010 s^{-1} the overpressure will be reduced by $12\frac{1}{4}$ dB to $93\frac{1}{4}$ dB for a detonation on sand. Repeating the calculation for identical conditions and a distance of 3000 yards produces a value close to 100 dB.

Estimation of gun noise is slightly more complicated, since it is necessary to consider the muffling effect of the gun which may well vary according to the angle between 'line of fire' and 'direction to meter'. Thus Figure 8 indicates that $6\frac{3}{4}$ lb HE detonated in the open will produce at 1750 yards an overpressure of 0.003 p.s.i. (121 dB) in conditions of zero gradient of sound speed, whereas Figure 3 indicates gun noise (Gun 'B') of 105 dB when the meter is sited almost directly behind the gun. Attenuation factors for other guns and other directions relative to the line of fire may be determined experimentally, and thereby permit complete calculations of overpressure at various distances and for various *negative* gradients of sound speed.

It should be emphasized that our useful data are limited to conditions of temperature lapse from the surface to 500 ft, negative gradient of sound speed (zero to -0.030 s^{-1}) from the surface to 500 feet, and distances of $\frac{3}{4}$ – $2\frac{1}{2}$ miles. At this stage we should not feel confident about extending predictions outside these limits.

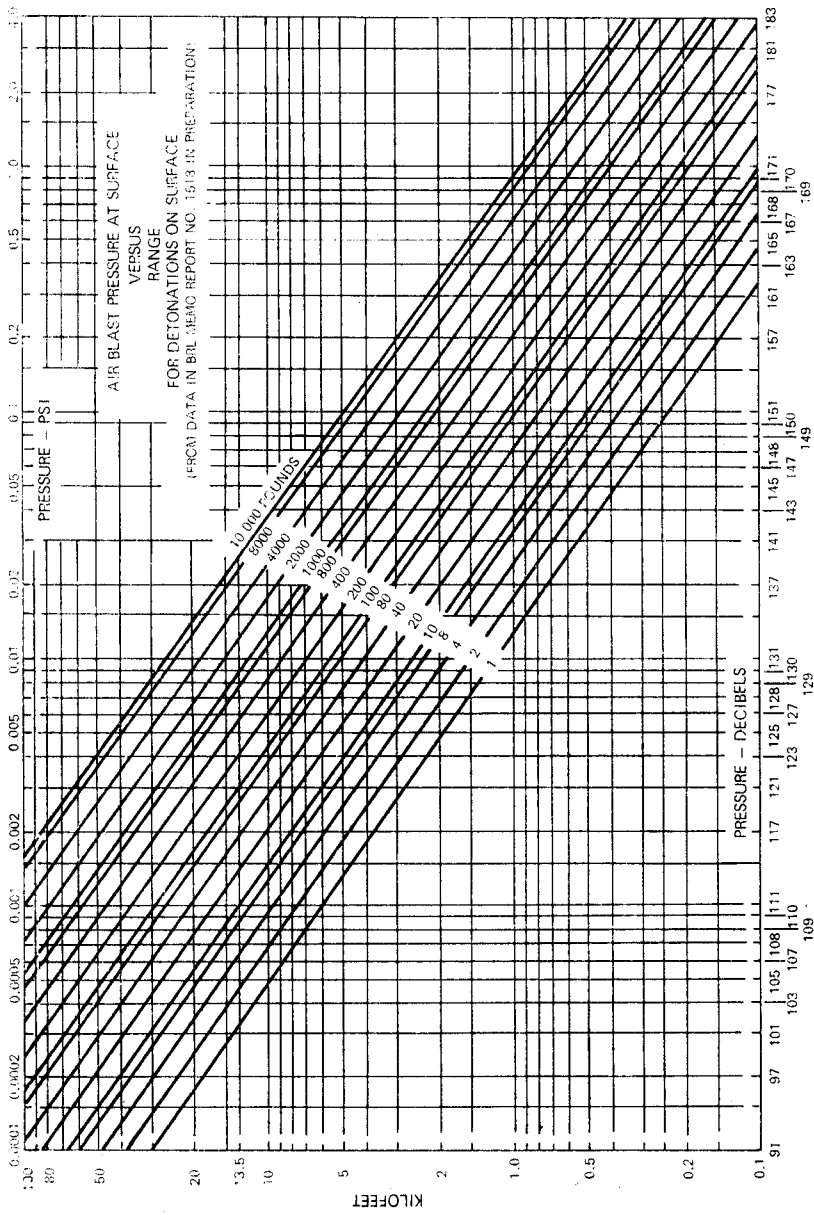


FIGURE 8—PRESSURE VERSUS DISTANCE WHEN THE SPEED OF SOUND IS UNCHANGED WITH HEIGHT

As an alternative to the simple but multi-stage calculations described above we may attempt to define 'GO - NO GO' limits for detonations of various types. Our rough subjective assessments of noise nuisance in the open suggest that with most guns and surface detonations on sand, sound-level values greater than 100 dB ('C' scale) are necessary to cause annoyance. This critical limit is obviously affected by the rate of firing, the frequency content of the noise (especially when indoors) and the conditioning of the populace. In view of the observed variability of sound-level readings, due principally to small-scale variability in the atmosphere, we have designed limits based on an expected average noise level of 97 dB. Table I shows estimates of the minimum negative gradient of sound speed (in units s^{-1} from the surface to 500 ft) in the direction of sensitive areas necessary to avoid nuisance at various distances for some types of detonation. The calculations assume attenuation with distance in a uniform sound speed field in accordance with Figure 8, with superimposed attenuation in negative gradients of sound speed as indicated in Figure 7. The Table should be regarded as a guide, to be modified in the light of local experience. Adjustments will almost certainly be necessary at Establishments not located in flat open country.

TABLE I—ESTIMATES OF METEOROLOGICAL CONDITIONS NECESSARY TO AVOID NUISANCE AT VARIOUS DISTANCES WITH SOME CHARGE WEIGHTS

Noise source	Charge weight	Distance	Minimum negative gradient of sound speed from the surface to 500 ft in the direction of the sensitive area
		<i>yd</i>	s^{-1}
High explosive (HE) in the open	1 lb	1500	— 0.028
		3000	— 0.009
		4500	— 0.004
	10 lb	3000	— 0.019
		4500	— 0.011
	100 lb	3000	— 0.028
		4500	— 0.020
Shell detonating on sand	6 lb (approx. HE content)	1500	— 0.036
		3000	— 0.013
		4500	— 0.007
Gun 'A' (assuming attenuation factor 18 dB)	No. 5	1500	— 0.011
		3000	(+ 0.002)
Gun 'B' (assuming attenuation factor 16 dB)	$6\frac{1}{4} - 7\frac{1}{4}$ lb	1500	— 0.015
		3000	zero
Gun 'C' (assuming attenuation factor 11 dB)	$8\frac{3}{4}$ lb	1500	— 0.026
		3000	— 0.007
		4500	— 0.002

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THE PERSISTENCE OF WET AND DRY SPELLS IN SUNGEI BULOH, SELANGOR

By W. C. YAP

Rubber Research Institute of Malaya

Summary. A study was made of the length of dry and wet spells at the Rubber Research Institute of Malaya's Experimental Station at Sungei Buloh. From the results of the study it is learned that after a wet day the probability of the following day being wet increases with the increasing length of the spells, and the same is true of the dry spells. By comparing the rates of increase of the probabilities, dry spells seem to be more persistent than wet ones.

Introduction. The success of crop establishment and growth depends largely on the availability of adequate rainfall. For this reason, planting of seedlings for most crops, including rubber, is usually confined to periods in which there is a good expectation of rain. Long periods of dry weather are avoided for planting if possible.

Weather also plays a large part in the total output of rubber in a particular area. Rain falling during the usual daylight working hours often disrupts or prevents tapping of *Hevea* rubber trees and results in loss of yield. The harvesting of latex is also particularly susceptible to interference from rain, especially when the downpour is heavy enough to result in latex wash-out. Rain, therefore, can cause substantial loss of income to the rubber tappers.

Various aspects of the rainfall pattern in West Malaysia have been studied by Dale^{1,2} and more recently by Nieuwolt,³ Wycherley,⁴ and Lockwood.⁵ Apart from these aspects, specific investigations of the occurrence and pattern of rainfall within Selangor have also been carried out by Chia.⁶ In particular, in Selangor, rainfall records at the Experimental Station of the Rubber Research Institute of Malaya (RRIM) in Sungei Buloh (3° 12' N, 101° 35' E) have been analysed statistically by Narayanan⁷ in a study of the daily, monthly and annual variations in rainfall.

The present study analyses the length of dry and wet spells at the RRIM Experimental Station and estimates the probability of their occurrences.

Rainfall data. The data used are the rainfall records collected from January 1951 to December 1971. Days on which at least one hundredth of an inch of precipitation was recorded are classified as wet days. Precipitation has been observed daily at about 0730 local time, and the rainfall recorded for any day refers to the previous 24 hours. The term 'spell' or 'run' is defined here as a sequence of days of the same kind, i.e. wet or dry, and the length of the spell is the number of whole days in it.

Distribution of the length of spells. The frequencies of wet and dry days over the period of 21 years (1951-71) are counted. Wet days exceeded dry ones by about 6 per cent of the total number. The frequencies are classified according to their run lengths and the results for wet and dry spells are shown in columns 2 and 7 respectively of Table I. Although there are only 3631 dry days, these are distributed in 1542 periods whose lengths range from 1 to 23 days. In the case of wet days, the number over the 21 years is 4019, and these are contained in 1540 spells of length 1 to 19 days. Generally, the frequency distributions of the run lengths for both the wet and the dry days are about the same (Figures 1 and 2).

TABLE 1.—FREQUENCY DISTRIBUTION OF DURATION OF SPELLS OF WET AND DRY DAYS AT THE EXPERIMENTAL STATION OF THE RUBBER RESEARCH INSTITUTE OF MALAYA, SUNGEI BULOH, FOR THE PERIOD 1951–71, TOGETHER WITH CORRESPONDING VALUES CALCULATED FROM THE COMPOUND GEOMETRIC AND LOGARITHMIC MODELS

Length of spell days	WET				DRY				$(O-E)^2/E$ C.G. Log.
	Observed frequencies (O)	Expected Compound geometric (C.G.)	Logarithmic (Log.)	Observed frequencies (O)	Expected Compound geometric (C.G.)	Logarithmic (Log.)	Observed frequencies (O)	Expected Compound geometric (C.G.)	
1	686	634.6	743.8	758	721.0	791.6	311	357.2	1.90
2	320	346.5	303.1	311	2.02	309.5	194	188.7	5.97
3	176	192.0	164.7	194	1.33	161.4	107	105.1	0.15
4	123	123.6	100.7	107	0.00	94.6	54	59.2	0.03
5	77	75.9	65.6	54	0.02	61.2	37	37.0	0.85
6	49	47.7	44.6	37	0.04	38.6	18	23.2	0.00
7	33	30.6	31.1	18	0.19	25.9	25	15.0	1.17
8	26	20.0	22.2	25	1.80	17.7	10	10.0	3.01
9	13	13.3	16.1	10	0.01	12.3	3	6.7	3.60
10	10	9.0	11.8	3	0.11	8.7	1	4.6	1.63
11	7	6.2	8.7	1	0.10	6.1	2	3.2	0.19
12	10	4.7	6.5	2	5.98	4.4	3	2.3	
13	6	3.5	4.9	3		3.2	1	1.2	
14	1	2.8	3.7	1		2.3	1	0.4	
15	2	2.1	2.8	1		1.7	1	0.3	
16	—	—	—	1		—	1	0.2	
17	—	—	—	—		—	—	—	
18	—	—	—	—		—	—	—	
19	1	1.0	1.0	1	0.04	0.5	—	—	0.00
20	—	—	—	—		0.3	—	—	1.09
21	—	—	—	—		—	—	—	
22	—	—	—	—		—	—	—	
23	—	—	—	—		—	—	—	

Parameters $a = 12.64$ $b = 8.86$ $q = 0.815$ $a = 7.14$ $b = 6.27$ $q = 0.782$
 chi-square values 15.80 17.86 0.09
 $P(\chi^2)$ 0.11

In order to study the frequency distribution of the spells mathematically and to derive certain information from them, the observed frequencies are fitted to three theoretical models, namely the geometric, the compound geometric and the logarithmic.

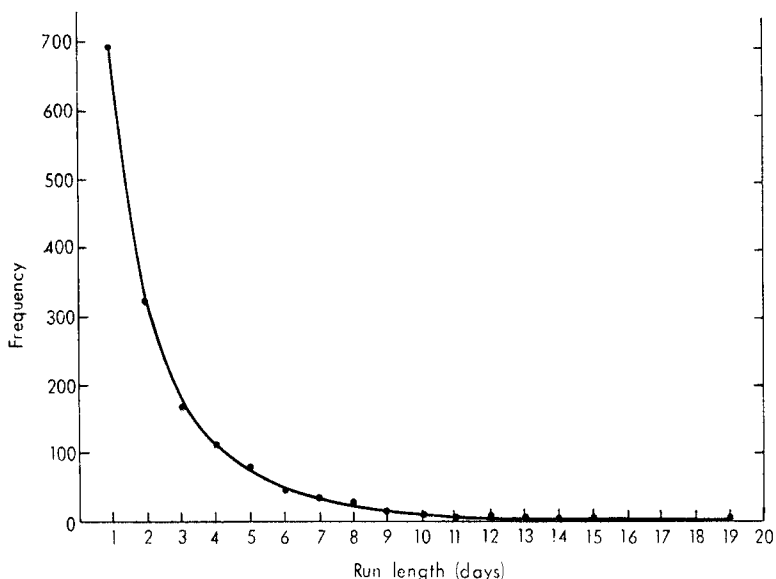


FIGURE 1—DISTRIBUTION OF LENGTHS OF RUNS OF WET DAYS AT RRIM EXPERIMENTAL STATION IN SUNGEI BULOH FOR 1951-71

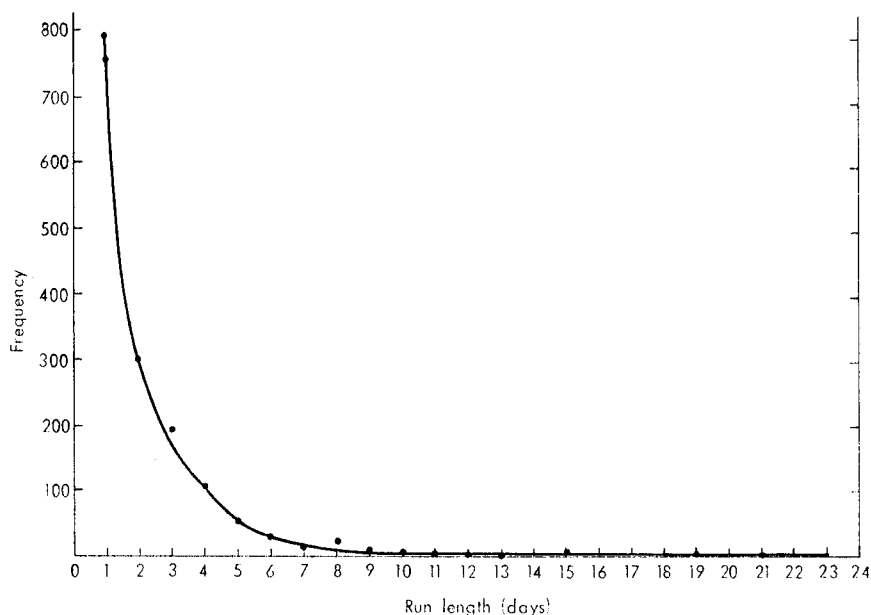


FIGURE 2—DISTRIBUTION OF LENGTHS OF RUNS OF DRY DAYS AT RRIM EXPERIMENTAL STATION IN SUNGEI BULOH FOR 1951-71

The data fail to fit the geometric model, which assumes a constant probability for the spells of all lengths. However, good fits are obtained in the case of the other two models.

The compound geometric model is based on the assumption that the probability of a wet (or dry) day being followed by another wet (or dry) day is p , where p is a random variate having a constant value within any one run, but different values in different runs. Following the approach analogous to that of Skellam,⁸ p is assumed to be a beta variate.

$$\text{Then} \quad f(p) = \frac{p^{a-1}(1-p)^{b-1}}{B(a, b)} \quad 0 \leq p \leq 1,$$

where a and b are the constants of the distribution. Writing the probability of a run of r days as $P(r)$, this is given as

$$\begin{aligned} P(r) &= \frac{1}{B(a, b)} \int_0^1 p^{r-1}(1-p)p^{a-1}(1-p)^{b-1} dp \\ &= \frac{1}{B(a, b)} \int_0^1 p^{a+r-2}(1-p)^b dp \\ &= \frac{B(a+r-1, b+1)}{B(a, b)}. \end{aligned}$$

$$\text{Then} \quad P(1) = \frac{b}{a+b},$$

and for $r \geq 2$,

$$P(r) = \frac{a+r-2}{a+b+r-1} P(1). \quad \dots (1)$$

To derive the parameters a and b , it is convenient to use the factorial moments about the origin. (For a brief exposition on factorial moments, and their relationship with the ordinary moments, see Johnson and Leone⁹.) Let the first and second moments be denoted as U_1' and U_2' respectively. Then

$$\begin{aligned} U_1' &= \frac{1}{B(a, b)} \int_0^1 \frac{1}{(1-p)} p^{a-1}(1-p)^{b-1} dp = \frac{a+b-1}{b-1} \\ U_2' &= \frac{1}{B(a, b)} \int_0^1 \frac{2p}{(1-p)^2} p^{a-1}(1-p)^{b-1} dp = \frac{2a(a+b-1)}{(b-1)(b-2)}. \end{aligned}$$

Expressing a and b in terms of these moments gives

$$b = \frac{2U_1'(U_1'-1)-2U_2'}{2U_1'(U_1'-1)-U_2'}, \quad \dots (2)$$

$$\text{and} \quad a = (U_1'-1)(b-1). \quad \dots (3)$$

The compound geometric distribution is fitted to the observed distributions of run lengths by estimating a and b . These parameters are found by substituting sample values for U_1' and U_2' in equations (2) and (3). The sample values of U_1' and U_2' are themselves obtained by equating with

$$\sum_r f_r r / \sum_r f_r (= \bar{r}) \text{ and } (\sum_r f_r r^2 / \sum_r f_r) - \bar{r} \text{ respectively,}$$

where f_r denotes the observed frequency of spells of length r days. The expected proportions are then calculated from equation (1).

The logarithmic model was first used by Williams,¹⁰ who successfully fitted it to runs of wet days and of dry days at Harpenden, England. According to this model, the probability of a spell of r days is $-q^r/r \log(1-q)$, where q is a constant — the probability of runs of unit days. To specify the probability distribution, only the parameter q needs to be estimated. By using iteration, it is easily derived from the maximum likelihood formula

$$-\frac{q}{(1-q) \log(1-q)} = \bar{r} \text{ (the mean run length).}$$

Table I also shows the estimated frequencies of the dry and the wet spells of various lengths obtained from the fitted models. At the bottom of the table are given the estimated values of the parameters of the probability distributions and the chi-square values for the fit. The contribution of each of the cells, $(O-E)^2/E$, to the chi-square is also presented in the table.

Regarding wet spells, both the compound geometric and the logarithmic models are acceptable, but the former is preferred because it gives a larger probability to the chi-square value. For this model, the main contributions to the chi-square values are due to a deficiency of runs of 1 day and of 8 and 12 days and a surplus of runs of 2 and 3 days. For dry spells neither model seems really satisfactory. However, the logarithmic model is preferred to describe the distribution of the run lengths of the dry days.

Conditional probabilities. The chances of a spell lasting one further day are determined by the values of the probabilities of run lengths estimated from the fitted distributions. Suppose a particular type of weather (dry or wet) has lasted one day; the chance that the following day will be similar is $1 - P(1)$. If the spell has lasted r days (for $r = 2, 3, 4 \dots$), the probability that it will be extended another day is

$$\frac{1 - \sum_{x=1}^r P(x)}{1 - \sum_{x=1}^{\infty} P(x)}.$$

These probabilities for the wet and the dry spells up to 15 days are presented in Figure 3. For the wet spells, 59 per cent of first days will be followed by a second, 61 per cent of second days will be followed by a third, and 62 per cent of the third days will be followed by a fourth, etc. The corresponding values for the dry spells are 49, 59, and 63. Persistence of the spells, as indicated by the rate of increase of the probabilities with the run length, is more pronounced for shorter dry spells than the corresponding wet ones (Figure 3).

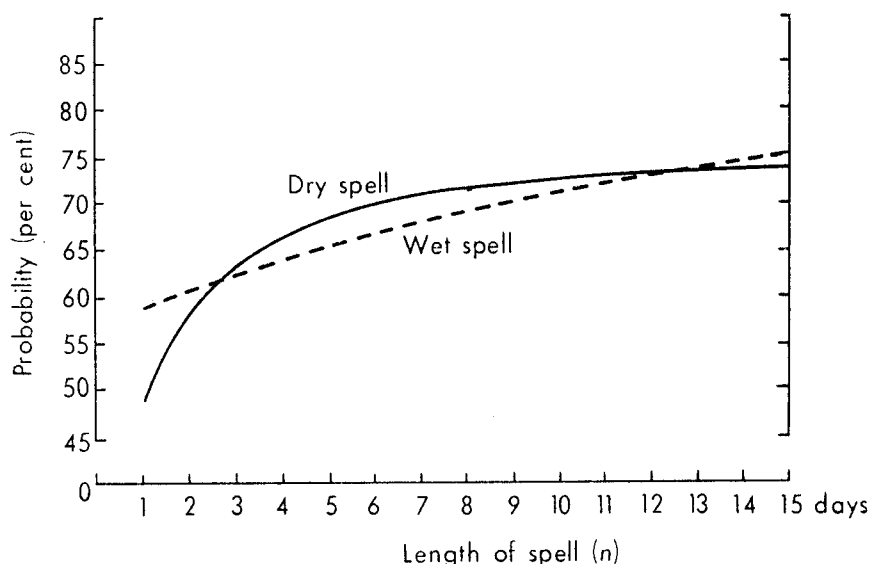


FIGURE 3—PROBABILITY THAT A SPELL WILL BE EXTENDED BY ANOTHER DAY

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REVIEW

An introduction to dynamic meteorology, by James R. Holton. 240 mm × 160 mm, pp. xi + 319, Academic Press Inc., Publishers, 111 Fifth Avenue, New York, New York 10003, 1972. Price: \$15.95.

The volume of meteorological research has been increasing markedly over the last two decades, witnessed by the increase in the number of meteorological journals and papers, and there has been a corresponding change in the syllabus for university students in meteorology, at both undergraduate and post-graduate levels; perhaps nowhere has the change been greater than in dynamical meteorology where the advances have been greatly aided by the rapidly developing capability for computation provided by digital computers. The changing courses are reflected by new textbooks distilling the research into easily potable draughts for the student. Such is Professor Holton's book and welcome because there are few books covering quite the same ground.

The first five chapters are given to developing the equations of fluid motion referred to rotating axes and are carefully written so that the reader is proceeding at a gentle pace, with many of the difficult conceptual points well explained. The scale analysis is introduced at an early stage so that the importance of the various terms quickly becomes apparent, leading naturally to geostrophic and hydrostatic approximations and to the important terms in the vorticity equation. The illustrative material in these chapters is excellent and, as throughout the book, is supplemented by examples at the end of the chapters which are designed to make the reader think, often numerically, without being so involved as to take up a lot of time. The treatment of the planetary boundary layer in the sixth chapter is rather cursory and seems to have been added for the sake of completeness rather than as an integral part of the development required for the later parts of the book.

Having set up the apparatus which allows the main features of atmospheric motions to be treated quantitatively, the author then applies it in the next two longish chapters to the fundamental ideas of analysing the current situation in order to infer the likely developments and to laying the foundation of numerical prediction, dealing with both vorticity and primitive-equation models without going into details of any particular model. There follow two chapters dealing with atmospheric oscillations, mainly gravity waves, and instabilities in atmospheric motions. These are often taken before developing the equation for numerical prediction, so that the development of ideas about the general circulation will naturally follow those on short-range forecasting. The author now treats the general circulation and if his order seems a bit strange, there is nothing logically against it. These five chapters form the meteorological core of the book and are clearly and carefully written, with a nice gradation in difficulty; they give the basic ideas upon which the student can build, without developing the detail which may obscure the fundamentals.

The final chapter on tropical motion systems is welcome because, even if it seems to indicate that our knowledge is more numerate than it really is, it does indicate that there are particular problems to be faced which need to be tackled in a quite different way.

This is a textbook which will be welcome to students and teachers alike for its modern and clear exposition, and also for its useful set of problems at

the ends of the chapters. A criticism is that the author has not been very helpful to the student in his references for further reading. A number of these references are substantial books, e.g. Batchelor's *Introduction to fluid dynamics* and Greenspan's *The theory of rotating fluids*, and the author might have indicated not only the title but also the sections that are of most value.

E. KNIGHTING

HONOUR

The following honour was announced in the Queen's Birthday Honours List 1973 :

I.S.O.

Mr H. B. Rowles, Principal Scientific Officer, Central Forecasting Office, Bracknell.

NOTES AND NEWS

Retirement of Mr R. F. Zobel, O.B.E.

Mr R. F. Zobel, Assistant Director in charge of the Central Forecasting Office at Bracknell retired on 30 June 1973 after 34 years' service in the Meteorological Office. Prior to this, however, Mr Zobel started work in 1929 in the National Physical Laboratory at Teddington, where he became an expert on the repair of watches and clocks and, whilst still at work, took an honours B.Sc. degree in Physics at London University. This was in the days before study concessions and the achievement of obtaining a degree whilst working at a full-time job was even more difficult and praiseworthy than it is today.

Ron joined the Meteorological Office in 1939 and spent the first few years of the war forecasting for Bomber and Coastal Command operations. He was commissioned as a Flight Lieutenant in the RAFVR (Meteorological Branch) in 1943 and was in at the birth of the 'thickness' development theory, as he was Dr Sutcliffe's deputy at Exning for some time. During the period 1945-47 he served in the Far East as Senior Meteorological Officer, Ceylon, Bengal-Burma, and later in the East Indies. He was promoted to the rank of Wing Commander in 1947 and became Chief Meteorological Officer, Far East and Japan.

Soon after demobilization Ron took up the post of Senior Meteorological Officer, HQ No. 1 Group, RAF as a Principal Scientific Officer and then in 1953 he was appointed to the post of Chief Meteorological Officer at HQ Bomber Command. After a spell of five years at High Wycombe he was posted to Aden as Chief Meteorological Officer. In 1959 he was appointed an Officer of the Order of the British Empire. In 1960 he returned to the United Kingdom and served as Editor of the *Meteorological Magazine* and later in the Aviation Services Branch of the Office.

In 1963 Ron was promoted to Senior Principal Scientific Officer and was posted to the Meteorological Research Flight at Farnborough and then in 1966 he became Assistant Director in charge of the Central Forecasting Office, where he stayed for the rest of his Office career. In this post he was almost immediately asked to introduce the three-level numerical forecasting model into operational practice on the KDF9 computer in order to supply, for the first time in the Meteorological Office, numerical forecasts of upper-air charts on a routine basis.

Mr Zobel has contributed several papers to the literature, probably the best known being a paper on the heating below an inversion in summer time and another showing that, at 200 millibars, gradient winds are a far truer representation of the actual wind field than are geostrophic winds. This fact, of course, plays a large part in the development of surface pressure systems.

Ron has wide interests in fields other than meteorology. In his spare time he made himself expert in the Russian language so that his services as a translator have often been used in the Office. He is also an expert on everything pertaining to motor vehicles and this has always been one of his relaxations, especially from his worrying job as AD Met O(CF). In his younger days he was a keen and very good cricketer and though no longer an active player still follows the progress of his county — Sussex.

We all wish Mr and Mrs Zobel many years of happiness and good health in their retirement.

V. R. COLES

PUBLICATIONS RECEIVED

Fog and road traffic, by R. L. Moore and L. Cooper (TRRL Report LR 446). 300 mm × 200 mm, pp. iv + 43, *illus.*, Transport and Road Research Laboratory, Department of the Environment, Crowthorne, Berkshire, 1972.

Readers' guide to books on geography, 2nd edition. The Library Association County Libraries Group. 180 mm × 120 mm, pp. 52. The Library Association, County Libraries Group, County Library Headquarters, Column House, 7 London Road, Shrewsbury, Salop SY2 6NW, 1973. Price: 25p.

CORRECTION

Meteorological Magazine, April 1973, p. 110. The date in the first line of the Summary should read 9 May 1972.



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NOTICES

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