MONTHLY WEATHER REVIEW

Editor, ALFRED J. HENRY

Vol. 58, No. 12
W. B. No. 1034

DECEMBER, 1930

Closed February 3, 1931
Issued March 7, 1931

WEATHER RECURRENCES AND WEATHER CYCLES[1]

By Sir Richard Gregory, D. Sc., LL. D., President

[An address delivered before the Royal Meteorological Society on January 15, 1929]

Speculations and explorations relating to cycles of natural phenomena have always been of popular interest; and even when the evidence relating to them is tested by statistical standards of correlation coefficients their study is of value, however discouraging the results may be. It seems worth while, therefore, to devote my address this year to a general description of some weather recurrences and weather cycles which have at various times been accepted as articles of belief or derived from rigorous examination of evidence. From a strictly scientific point of view, it may be thought that no cycle is of substantial interest unless the proximate or ultimate cause of it is understood. Such a view can not, however, be maintained, particularly in meteorology, in which purely empirical knowledge may be the basis of methods of forecasting weather. The waxing and waning of solar activity in a period of about 11 years can be used to predict variations of solar radiation with fair precision, yet we do not know the cause of this cycle any more than we know the cause of gravitation which determines the movements of the planets. The first duty of science is to collect facts, and if these lead to a hypothesis, to test by observation any predictions suggested by it. When prediction is confirmed by sufficient experience, the hypothesis may be raised to the dignity of a theory, or even a law of nature.

With the generous aid of our encyclopedic secretary, Dr. C. E. P. Brooks, I am able to present a general survey of some studies of cycles or periodicities of weather from the point of view of possible forecasting. He has, however, himself remarked that the search for the golden cycle in weather is similar in its history to the search for the philosopher's stone—it has not been found, and we are more and more compelled to the belief that it does not exist. Periodicities in weather there undoubtedly are, but they are usually either so small in amplitude as to be of academic interest only, or they show baffling changes of phase and amplitude.

If in what I say I may seem to deal too critically with some beliefs which are still cherished by many amateur meteorologists, as well as by the general body of the public, my excuse must be that in these matters there is a very real danger of misconception. In judging the work of an official meteorological service there is a tendency to forget the successes and remember only the failures; whereas the prognostications which depend on wise saws and cycles receive more lenient treatment from the public. The failures are forgotten while the occasional successes are proclaimed from the houstops. Perhaps it is our habit of treasuring rarities which is responsible.

7-DAY RECURRENCES

There is a general popular belief in the existence of a 7-day weather recurrence, but this is probably due to the 7-day week, which impresses Saturday and Sunday rain disagreeably or otherwise on the memory of holiday makers and amateur gardeners, rather than on the existence of any marked periodicity of this length. In Australia, for example, there is a saying that if it rains on a Saturday it will rain on the next six or seven Saturdays. There does seem to be a little evidence in support of this belief, which is by no means always the case in weather proverbs, for a 7-day periodicity has frequently been brought forward in meteorological literature.

The most thoroughgoing investigation was described by A. Defant[2] in 1912. At individual stations the vagaries of the weather are too great to permit of systematic treatment, so Defant took as his basis the average rainfall on each day at some hundreds of stations in each of a number of countries. The laboriousness of the investigation limited it to a single year (1904), but the results were very far-reaching. In the Argentine he found that the rainfall undergoes marked variations, which result from the superposition of four waves having lengths of 7.1, 12.0, 16.8, and 31.2 days, the measurements being accurate to 10 per cent. In Australia he obtained four waves of almost identical length, 7.2, 12.1, 16.4, and 31.2 days. From the lengths of these periodicities, and the rate at which they moved from west to east, Defant proceeded to some remarkable conclusions which made them an integral part of the dynamics of the atmosphere; here it is sufficient to note their existence and the fact that the 7-day recurrence was by far the most imposing. In the Northern Hemisphere, with a different land and sea distribution, he also found four periodicities in the grouped values of daily rainfall for western United States, Europe, and Japan, of 5.7, 8.7, 12.7, and 24.5 days, respectively. These also move round the earth from west to east and form part of an exact dynamical scheme. Thus Defant draws for us his picture of an ordered rhythmic world.

Defant's system was ordained when the earth was born and the continents appeared above the oceans; Dr. J. R. Ashworth[3] gave us last year a glimpse of the power of man to modify the order of nature and introduce a weekly periodicity of rainfall. His contention was that "in a confined manufacturing area, such as the town of Rochdale, with a large number of factories burning quantities of coal of the order of 500 to 1,000 tons a day, it is not unlikely that the volume of heated gases which rises is

[1] Reprinted from Quart. Jour. Royal Meteorological Soc, April, 1930, vol. 56; pp. 103-120.

37966—31

[2] Die Veränderungen in der allgemeinen Zirkulation der Atmosphäre in den gemässigten Breiten der Erde. Wien, SitzBer. Akad. Wiss., (2a), 121, 1912, p. 379.

[3] London, Q. J. R. Meteor. Soc., 55, 1929, p. 341.

sufficient to give that uplift to the atmosphere which is required to provide an increase of rain." In support of this conclusion he produced a table showing that on Sundays, when the mills are closed down, the average rainfall at Rochdale is less than on any other day of the week, whereas at Stonyhurst, remote from any large manufacturing center, Sunday rainfall, though still below the average, is greater than that of Friday. The resulting discussion revealed two opposing camps; one thought that the result was probably real, the other that it was simply due to errors of sampling.

Doctor Ashworth's 7-day periodicity, whether real or not, is too slight to be appreciable to the "man in the street," and has no value for forecasting. Defant's 6 or 7 day periodicities required elaborate arithmetic to magnify them up to the stage when they became visible to the human eye. This does not presage well for the success of forecasts based on short periodicities, the most familiar of which are those formerly published in the Daily Mail, and described by one of their supporters as a "billion times better than fortuitous predictions" and as "a notable advance in meteorological science." These were examined impartially by Capt. C. J. P. Cave,[4] who, after giving the results of a number of careful comparisons between forecasts and the observed weather, wrote: "It would appear, therefore, from the foregoing considerations that the forecasts, even for one week ahead, have not any success. They are not, in fact, any better than could be obtained by purely fortuitous predictions, and they agree with what one would expect from chance in a very marked way."

The application of short-period weather cycles to the elucidation of variations in the distribution of pressure from day to day has reached its greatest development in the hands of L. Weickmann.[5] The pressure variations at any one station are regarded as made up of a number of waves of various lengths. The combination of these waves gives a curve which is at first sight irregular, but close examination shows that certain series of day-to-day variations can be divided into two parts, the second of which is a reflection of the first. Reflection may be either single, as if the first half had been drawn and the paper folded over at the point of inflection while the ink was still wet, or double, the curve being not only reflected but also inverted.

If the same point of single reflection occurs at a number of stations, we have a series of daily weather charts which, after the date of reflection, are repeated in inverse order, and Weickmann illustrates a remarkable series of such charts extending from May 1 to July 11, 1922, and symmetrical about June 9. When such a series is established it obviously offers great prospects for successful forecasting, but the difficulty is to discover the points of reflection in time to be of service.

MONTHLY RECURRENCES

The monthly cycle of changes of the moon is believed by many people to be associated with changes of weather. As the moon is chiefly responsible for the rise and fall of the tides, it would seem reasonable to suppose that the earth's atmosphere is affected in the same way, and that there are air tides which may vary through the lunar month, like the spring and neap tides of the sea. Such atmospheric tides have indeed been detected, but they represent a difference at Greenwich of appreciably less than one-thousandth of an inch in a barometric reading, and are, therefore, scarcely worth considering as a sign of change of weather or a factor in forecasting.

As on the average our weather changes every four days, it is not surprising that such changes should occasionally coincide with changes of the moon which occur every seven days. Any success achieved by weather prophets who base their predictions upon the time of day when the moon enters one of its four quarters must, therefore, be attributed to the laws of chance and not to any actual relationship. Even when weather does change with change of moon, there is no regular cycle of weather conditions corresponding to the monthly cycle of lunar phases.

A subject which was given much attention last year is the recurrence of the same kind of weather at the same date in successive years. Here again popular imagination is apt to seize upon a few chance coincidences and to magnify them into a fixed law, such as the belief that Good Friday is always fine. In 1927 Mr. Milward stated in the Meteorological Magazine[6] that there was a definite tendency for storms to occur in the middle of the months rather than at the beginning or end, and he supported his thesis with what seemed like strong statistical evidence. Faith has been defined as "the art of believing that which we know to be untrue"; and faith in statistics needs to be highly developed to make such conclusions convincing.

ANNUAL PERIODS

Though weather is independent of the moon's movements or aspects, the same kind of weather tends to recur at definite dates annually on account of the succession of changes in the sun's position. Each year the seasons—summer and winter—come round with some approach to regularity, while spring and autumn also have their characteristics. In addition to the four seasons, a cold spell has been stated to occur regularly early in May, and has been associated with the so-called "Ice Saints." Various explanations have been offered to account for this cold spell, the most popular being that in the course of the regular annual series of pressure changes which result from the increasing power of the sun in spring, an anticyclone develops over northern Europe at the time and causes a period of northeasterly winds. Another cold spell is supposed to occur in June, caused by the development of monsoon winds blowing into the interior of Europe.

The chief explorer of these regular spells was Alexander Buchan[7] who defined them as follows: "Deductions from all observations hitherto made show that there are certain periods more or less well defined when the temperature, instead of rising, remains stationary or retrogrades instead of falling, stops in its downward course, or even rises, and at other times falls or rises respectively for a few days at a more accelerated speed than usual."

Buchan enumerated as many as nine such periods, to which he assigned the following dates:—

Cold periods	Warm periods
1. February 7–14.	1. July 12–15.
2. April 11–14.	2. August 12–15.
3. May 9–14.	3. December 3–14.
4. June 29–July 4.	
5. August 6–11.	
6. November 6–13.	

These 9 periods were deduced from observations in Scotland during a period of 10 years in the middle of the nineteenth century. In spite of this limitation, however,

[4] Nature, 109, 1927, p. 52.
[5] Wellen im Luftmeer. Neuere Untersuchungen uber Gesetzmässigkeiten im Gange und in der Verteilung des Luftdruckes. Leipzig, 1924.
[6] Vol. 62, 1927, p. 229.
[7] Edinburgh, J. Scot. Meteor. Soc., 2, 1869, p. 4.

they have been assumed by many newspaper correspondents to be equally valid for the temperature of London in the twentieth century. Such an assumption is quite unwarranted, and Buchan, if he were alive to-day, would be the first to reject it. No scientific evidence has ever been adduced that cold or warm periods have any tendency to occur in London on Buchan's dates.

LONG-PERIOD CYCLES

From these considerations of belief and evidence in weekly, monthly, and annual recurrences of similar weather we may pass to cycles having periods of several years. A lunar cycle which may have suggested weather cycles is that which determines eclipses. The Chaldeans and the Egyptians knew that eclipses recur after an interval of a little more than 18 years, and this cycle, known as the Saros, formed the basis of their very successful eclipse predictions. The cycle was discovered thousands of years before the astronomical movements which determine it were understood, but it was established as the result of observation; and no similar evidence is available upon which a related weather cycle can be based. It is true that H. C. Russell [8] in 1896 concluded from an inquiry into droughts extending over a period of a thousand years, particularly those in New South Wales in a period of 108 years, that the records fitted into a cycle of 19 years but this cycle does not stand the test of critical examination.

Doctor Russell suggested that the ancient Egyptians knew of the 19 years' cycle and that Joseph was versed in the wisdom of the priests and therefore able to predict Pharaoh's drought. He regarded Elijah's prediction as a repetition of this drought 49 × 19 years after it and Elisha's as 19 years after Elijah's, but the factor might just as well have been 14 instead of 19, as this was apparently the cycle upon which Joseph based his long-range forecast. It will be remembered that Pharaoh dreamed that seven fat kine came up out of the river, followed by seven lean kine, which devoured the fat kine. Then he dreamed that seven ears of corn came up upon one stalk, rank and good. Then seven thin ears and blasted with the east wind came up after them, and devoured the seven good ears. Joseph interpreted the dream thus: "Behold there come seven years of great plenty throughout all the land of Egypt. And there shall arise after them seven years of famine; and all the plenty shall be forgotten in the land of Egypt; and that famine shall consume the land." As we know from Biblical writ this forecast was successful, and the probable basis for it was a weather periodicity of about fourteen years. The periodicity could not have been very highly developed, or it would have been common knowledge, but it must have been sufficiently well marked to influence the general character of the succession of years.

Since that time many attempts have been made to discover weather cycles which can be used for long-range forecasting, but in none are prediction and fulfilment combined so dramatically as in the story told in Genesis. This cycle and some others already mentioned have received much popular attention; and most of them are in a different category from those which have merged from close meteorological inquiry.

Every year the weather is in some sense abnormal, but the past 12 months have given us rather more than our fair share of extremes, beginning with the most severe winter since the famous frost of 1895, continuing through several long periods of drought to the rainiest November and stormiest December on record. Unusual weather always leads to much discussion in the press of the time-honored subject of weather cycles, and 1929 was no exception. The point that the interval of 34 years since 1895 was within a year of the famous Brückner cycle was not missed, and the spells of cool rainy weather which tempered the dryness of spring and summer have been widely hailed as manifestations of the "Buchan cold spells." In fact, Buchan's credit soared so high that one enthusiast advocated the dethronement of St. Swithin, whose 40 day prognostic has long been exploded, in order that his place in the calendar might be given to St. Buchan.

BRÜCKNER'S CYCLE

Alone among modern weather cycles, that of 35 years has a background of tradition, for it was described by Sir Francis Bacon before 1625. Many of you are familiar with the passage from his essay "On Vicissitudes of Things."

"There is a toy, which I have heard, and I would not have it given over, but waited upon a little. They say it is observed in the low countries (I know not in what part) that every 5 and 30 years the same kind and suit of years and weathers comes about again, as great frosts, great wet, great droughts, warm winters, summers with little heat, and the like, and they call it the prime; it is a thing I do the rather mention, because, computing backwards, I have found some concurrence."

This weather cycle was rediscovered and carefully investigated by the late Dr. Eduard Brückner, then professor of geography at the University of Bern, and it is now known generally as the Brückner cycle. His great work, Klimaschwankungen seit 1700, nebst Bermerkungen über die Klimaschwankungen der Diluvialzeit, published in 1890, has become a classic for the patient collection and analysis of material from a great variety of sources. He studied all the long records of rainfall, pressure, and temperature available at the time, and carried the record back into earlier centuries by utilizing the variations of level in the Caspian Sea and other lakes in inclosed basins and in the great river systems of the world, the historic variations of ice conditions on the rivers of Europe, the dates of the wine harvest and the frequency of severe winters. From all this material he deduced the existence of a long succession of cycles—series of generally warm and dry years alternating with series of generally cool and rainy years. From 1020 to 1890 A. D. he found 25 cycles, giving an average length of 34.8 years, but the individual cycles varied between 20 and 50 years. With this in mind we must not expect too much from the Brückner cycle, for so great is this variation that only one cycle out of five comes within two and one half years of the expected length. When in addition one remembers that the amplitude of the variations is so small that in meteorological statistics the existence of the cycle can only be seen at all as the result of extensive smoothing, it becomes obvious that the Brückner cycle is useless for the purpose of making long-range forecasts of weather, and the interval of 34 years between the cold winters of 1895 and 1929 takes its proper place as a mere coincidence.

Brückner himself was far from claiming the mathematical regularity for his cycle that such exact recurrences would require, for he wrote:

"This is no single periodical meteorological phenomenon, which must fulfil itself with mathematical exactitude from one occurrence to another. Of the reality of a marked annual period of temperature or of rainfall there can not be the slightest doubt, and yet we see the epochs

[8] Roy. Soc. New South Wales, June 3, 1896.

from year to year fall not exactly on the same months, but now on the one, now on the other month, owing it may be to the influence of disturbing factors, which enter differently from year to year, or it may be to certain accidents. It would be very remarkable, if such accidents did not enter into our secular variations."

The true value of Brückner's work lies in a different direction. Although the amount of rainfall may vary widely from one year to the next, the quantity of water which is stored up on the land areas, in the soil, in lakes, and in glaciers, varies far more slowly. This stored water is not so closely related to the rainfall of the 1 preceding year, as to the average rainfall of the 10 preceding years, and if these 10 years fall in the wet half of a Brückner cycle, the quantity of stored water will be great. Again, in the dull rainy countries of northwest Europe, warm dry years are favorable for crops and vegetation, and on the whole the dry warm half of a Brückner cycle will yield better crops than the cool wet half, although there may be wide variations from one year to the next. An agricultural community must take the bad years with the good, and trust to the surplus from a rich harvest to tide over a year of dearth, but at the end of the warm half of the cycle the community will be prosperous, while at the end of the cold half it will be poor. Hence waves of emigration and the movements of peoples are closely related to climatic cycles such as Brückner's, which in this way may leave their mark on history. That, and not long-range forecasting, is the rôle of the weather cycle.

This view of its importance in economic life was in fact taken by Brückner himself, for he concluded his great work with the following words:

"I have attempted to sketch a picture of the climatic variations through which our earth has passed in the last centuries. Like the wheels of a clock the different meteorological elements engage with one another. We see the wheels turn and the hands move in predetermined rhythm, but the driving force of the spring is hidden from us. We can only recognize its effect and infer from it the powerful strength of the force. It raises the levels of the lakes, the rivers, even the sea itself, it pushes forward the glaciers and hastens the ripening of the plants. It goes deep to the root of human life, for it greatly influences traffic, husbandry, and health, and even repeats itself in theories and scientific observations. Only, itself, the cause of the climatic changes, we do not know."

This idea was further elaborated in the United States by Henry Ludwell Moore, a professor of political economy, who turned meteorologist for the occasion, and in his well-known book, "Economic Cycles: their Law and Cause" (New York: Macmillan, 1914), he summarized his conclusions as follows:

"The rhythm in the activity of economic life, the alternation of buoyant, purposeful expansion with aimless depression, is caused by the rhythm in the yield per acre of the crops, while the rhythm in the production of the crops is, in turn, caused by the rhythm of changing weather which is represented by the cyclical changes in the amount of rainfall. The law of the cycles of rainfall is the law of the cycles of the crops and the law of economic cycles."

Moore discovered two periodicities in the rainfall of the Mississippi Valley from 1839 to 1910, one of 8 years and the other of 33 years, and the latter may reasonably be identified with the Brückner cycle. Its exact length is a matter for dispute, different authorities giving various values ranging from 33 to 36 years, but this uncertainty need not disquiet us. The noninstrumental records, like severe winters and fluctuations of water level, are by their nature somewhat vague; even the records of the annual rings of tree growth have not the exactitude of good observations with meteorological instruments. On the other hand, trustworthy instrumental observations go back little more than a hundred years, and cover only three or at most four cycles, a period which is not sufficient for an accurate determination of length. The general average of all the estimates, however, can not be far from Brückner's original figure of 34.8 years, which thus gains in probability from the attempts to improve or supplant it.

Further inquiries, however, reveal departures from this estimate. The Brückner cycle has received a great deal of attention, but this is probably due more to the fact that it has a name and a history than to its intrinsic importance. Brunt's elaborate examination of long meteorological records in western Europe [9] did not display the 35-year periodicity as any more noteworthy than several others; in fact, it could only be found at all in 6 of the 12 long records examined. Brückner took his material largely from the records of severe winters in Europe, but the late Dr. C. Easton, who reexamined the periodicity of winter severity, using data far more complete than Brückner's, found no evidence of a 35-year cycle, giving his vote instead to a periodicity of 89 years with a well-marked half cycle of 44½ years.[10] He summarized his conclusions as follows:

"Within each interval of 44½ years, to begin with A. D. 759.5 (1872.0) the first half is colder than the

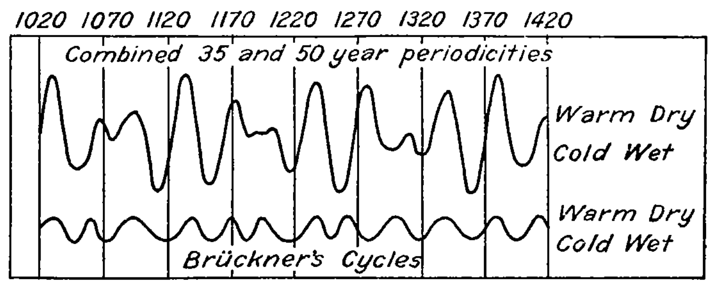

FIGURE 1

second." To this rule there have been no exceptions since 1200.

"Within each interval of 89 years, to begin with the year 759.5 (1827.5) the first half is colder than the second." Since 1116 there has been only one exception.

It should be noted that both these rules would give a period of cold winters commencing in 1917.

50-YEAR CYCLE

In the rainfall of Great Britain the Brückner cycle is far less important than one of 50 years. The authoritative pronouncement made by the council of the Royal Meteorological Society in the matter of the supposed influence of broadcasting on weather contained a passage pointing out that groups of wet years in England have occurred about 1770, 1821–1830, 1871–1880, and 1922–1928, four recurrences at intervals of about 50 years, separated by groups of dry years in 1741–1750, 1801–1810, 1851–1870, and 1891–1910, the inference being that the wet years since 1922 were due to some natural period of oscillation of the rainfall, and not at all to the relatively small electrical disturbance of the ether by human agencies.

Before leaving the subject of the 35 and 50 year weather cycles, mention may be made of one feature of

[9] London, Q. J. R. Meteor. Soc., 53, 1927, p. 1.
[10] Periodicity of winter temperatures in western Europe since A. D. 760. Sci. Proc. A. Akad. Wetenschap, Amsterdam, 20, 1918, p 1092.

Brückner's results which is not without interest. He found that the length of his cycle varies from 20 to 50 years, but it does not seem to have occurred to him that this variation most probably came about because he was actually dealing with two periodicities of about the same amplitude but of different lengths. Figure 1 shows a series of alternating warm and cool periods as determined by Brückner from the incidence of severe winters between A. D. 1020 and 1420, and for comparison the curve obtained by combining two such periodicities (actually 35 and 50 years). The agreement is reasonably close, and suggests that the Brückner cycle is in fact a composite affair made up of two periodicities of about those lengths.

THE 11-YEAR SUN-SPOT CYCLE

There is one other cycle which has claimed great attention in relation to weather, namely, the sun-spot cycle of 11 years. The literature of this subject is enormous, but critically examined, it may be reduced to very little. Sun-spots are a useful index of the activity of the sun, and they go through a not very regular cycle with an average length of 11.125 years. Taking account of the change of polarity discovered by Dr. G. E. Hale,[11] it is more accurate to say that sun-spots go through a double cycle of 22.25 years. In terrestrial phenomena, these changes of solar activity are accompanied or closely followed by fluctuations in the elements of terrestrial magnetism and by variations in the frequency of auroræ. E. J. Lowe, after an elaborate investigation of the dates of all droughts and frosts of historic times in Britain of which he could find mention, concluded that there was an 11-year cycle of the seasons with maximum variability at the end of each century.[12] Writing in May, 1880, he stated that the drought which had begun in October, 1879, could be expected to last three years, and that "the intensity of the winters about 1896 will be greater than those we have just experienced." Actually the drought ended at the close of the month in which he wrote, but 1896 might be taken as a fairly close estimate for the cold winter of 1894–95.

In matters of weather, a connexion with temperature was first suspected by Riccioli as early as 1651, and was clearly demonstrated, for tropical regions, by W. Köppen in 1873. There also appears to be a fairly close relationship between the sun-spot number and the rainfall in certain parts of equatorial Africa, especially the plateau of Lake Victoria; and the 11-year cycle in the level of this lake, which rises and falls with the rise and fall of solar activity, is one of the best known and most striking illustrations of the connexion between solar and terrestrial phenomena.[13] This is shown by Figure 2, which has kindly been supplied to me by the meteorological office. A similar relationship is found in Lake Albert and further south in Lake Nyasa, though in the latter it is somewhat obscured by the large annual variation in the level of the lake, and by other factors.

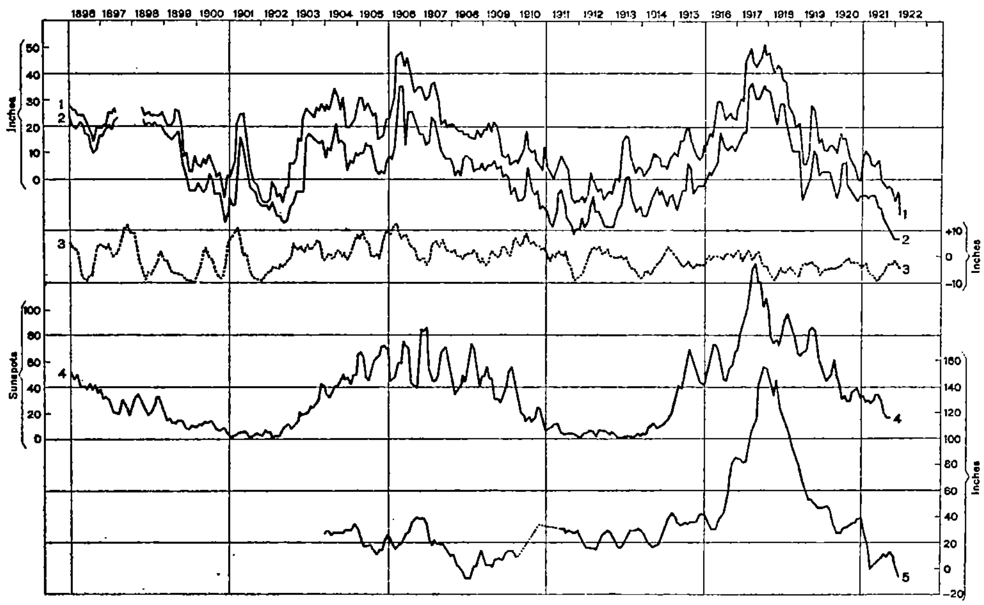

FIGURE 2.—Curves 1 and 2 monthly maximum and minimum lake levels in inches above or below zero level. Curve 3 rainfall Uganda, deviations from normal summed in overlapping periods of six months. Curve 4, monthly sun-spot numbers. Curve 5 mean level of Lake Albert in inches above zero level. (The above diagram was prepared from the original Memoir and published in this REVIEW 52:149—ED.)

In Great Britain the 11-year sun-spot cycle, like the Brückner cycle, is of little importance. Although we are undoubtedly governed in the long run by solar influences, these find their way from equatorial to temperature latitudes by many and sometimes devious routes—winds, ocean currents, etc.—so that their unity becomes lost and they appear as an irregular series of changes following no apparent law. For example, it was found by Dr. G. Hellmann that the rainfall of Europe has two maxima and two minima in each sun-spot period, and he explained this as due to the combination of two causes, the direct effect of the solar variations on the weather of Europe and the indirect effect due to changes at the equator extending their effect northwards.[14]

The pioneer in the investigation of the 11-year cycle in Great Britain was Alexander Buchan, who found evidence for its existence in the long record of rainfall at

[11] Sun-spots as magnets and the periodic reversal of their polarity. Nature, 113, 1924, p. 105.
[12] The coming drought, or the cycle of the seasons. London, May, 1880.
[13] London, Air Ministry, Met. Office, Geophysical Memoirs, No. 20, 1923.
[14] Untersuchungen über die Schwankungen der Niederschläge. Berlin, Veröff. K. Preuss. Met. Inst., Abh. 3, 1909–10.

Rothesay, in Bute, throughout the nineteenth century,[15] the heaviest rainfall coming about a year after the sun-spot maximum. He also found traces of a similar cycle in the rainfall of other stations in the western Highlands and the Hebrides, which confirmed the evidence of Rothesay, though the records were too short to provide independent evidence. Moreover, these stations being all in mountainous regions, Buchan inferred that the greater rainfall at sun-spot maximum must be due to a greater frequency of southwesterly winds at that time, and a subsequent examination of the wind records at a number of stations confirmed the inference.

Buchan's mantle in this respect fell upon A. MacDowall, who has published a number of short papers showing that there is a real sun-spot effect in the weather of western Scotland, though that effect is both smaller and more complex than Buchan supposed. Over the rest of the country, however, it is now recognized that sun spots have practically no influence, for though Brunt [9] found a periodicity of 11.4 years in the temperature of Edinburgh with an amplitude of 0.55° F., he concluded that the connection between this periodicity and sun spots was not at all clearly established, and that "the variations of temperature are so complex that no obvious relationship can be discovered between temperature in individual years and the phase of the sun-spot variation." Similarly F. Baur [16] examining the records for a group of eight stations well distributed over England, found for the 11-year cycle an amplitude of less than one-twentieth of a Fahrenheit degree, while the late Dr. C. Chree, in his presidential address to this society delivered in 1924, found correlation coefficients between sun spots and weather at Kew to be 0.03 for mean temperature and cloudiness, 0.04 for rainfall, and 0.10 for duration of sunshine. The last attempt was made in 1928 by Doctor Brooks,[17] who examined the relation between sun spots and pressure, both at individual stations and the distribution of pressure as a whole, and concluded "that at present the variations of sunspots in the 11-year cycle can not be taken into account in predicting quarterly mean deviations of pressure in the eastern North Atlantic or western Europe." In the realm of economics we have the well-known theory of Prof. W. Stanley Jevons,[18] published after his death in 1882, that financial crises are related to the sun-spot cycle:

"A mania is, in short, a kind of explosion of commercial folly, followed by the natural collapse. The difficulty is to explain why this collapse so often comes at intervals of 10 or 11 years, and I feel sure the explanation will be found in the cessation of demand from India and China, occasioned by the failure of harvests there, ultimately due to changes in solar activity."

When Stanley Jevons wrote that paragraph, the length of the sun-spot cycle was believed to be between 10 and 11 years; since then the cycle has been found to be rather more than 11 years, which to some extent destroys the value of the argument. Moreover, Sir William Beveridge,[19] in his well-known paper on Wheat Prices and Rainfall in Western Europe, found that except between 1632 and 1697 the periodicity of about 11 years was not particularly important in wheat prices, while over the whole interval from 1500 to 1869 its average length is 10.9 years, so that its connection with the sun-spot cycle is by no means certain.

[15] The rainfall of Scotland in relation to sun spots. Edinburgh, J. Scot. Meteor. Soc., 12, 1900–1901, p. 117.
[9] London, Q. J. R. Meteor. Soc., 53, 1927, p. 1.
[16] Washington, D. C., MONTHLY WEATHER REVIEW, 53, 1925, p. 204.
[17] London, Air Ministry, Met. Office, Professional Notes, No. 49, 1928.
[18] Investigation in currency and finance.
[19] London, J. R. Statist. Soc., 85, 1922, p. 412.

PERIODS OF TWO TO FIVE YEARS

Equally imposing in its bulk with that of the sun-spot cycle is the literature of cycles of two to five years. The suggestion has been made, notably by Defant, that there is a natural period of about three and one-half years in the oscillation of the earth's atmosphere, which requires to be set going by some vigorous impulse; Defant found such an impulse in a violently explosive volcanic eruption. Others, notably Sir Norman and Dr. W. J. S. Lockyer, saw in them yet another manifestation of solar influence, usually shown in the form of solar prominences. In some parts of the world, notably the East Indies, these periodicities of a few years are of undoubted value in forecasting the general rainfall some months ahead; in Great Britain they have at times reached a spectacular development, but always, just when they seemed to have established themselves thoroughly, they changed their length or their phase, or otherwise proved themselves unstable as water.

Those who have rashly challenged nature by predicting the rainfall of future years on the basis of such cycles have usually been defeated in the end. An early example was Mr. Charles Fullbrook, who in 1861 predicted that the years 1863 and 1864 would be extremely wet in England.[20] His preface was to the effect that with certain minor exceptions "meteorologists still remain as ignorant of the great laws which govern the weather as were the ancients." Later he added, "In making the remarks I have respecting our meteorologists, I do not mean to imply that they have done nothing to advance the science. On the contrary, I would say that they have done a great deal, but this consists chiefly in making extensive and accurate observations and records of the weather, and these will prove of the greatest importance, as affording materials with which to build up the noble and promising science of meteorology; but they have not penetrated through the absurdities that have mystified the science, so as to enter the only road which leads to a knowledge of its laws."

The "only road" was the calculation of weather cycles, but beyond stating that these cycles had been deduced on strictly scientific principles from the rainfall of 60 years, and that they correspond precisely with certain astronomical periods, the author does not give away trade secrets by stating their length. We may, however, penetrate his "mystery" by suspecting that cycles of three to five years played the major part. In spite of the author's weighty introduction, however, his calculations were seriously at fault, for 1863 was well below normal and 1864 was probably the driest year since the beginning of the nineteenth century. One is reminded of the remark of the Yankee at the Court of King Arthur that whenever Merlin issued a gale warning there was a week's dead calm.

To come to more modern and less assertive attempts we find that the Quarterly Journal for 1913 contains a detailed study by Mr. A. P. Jenkin [21] entitled "A 3-year period in rainfall," which began in hope and ended, as the late Mr. Carle Salter remarked in opening the discussion, in doubt and difficulty. More recent was Mr. J. Baxendell's contribution in the Quarterly Journal for 1925, on "Meteorological periodicities of the order of a few years, and their requisitely local investigation; with especial reference to the term of 5.1 years, in parts of

[20] The west and dry seasons of England, from the year 1846 to 1860, inclusive; their agreement with rule and system; with some remarks on the probable character of the following four years, 1861 to 1864, inclusive, and on the expected extremely wet season, founded on rules deduced from a long series of observations of the rainfall. Dallington, Hurst Green, Sussex, March, 1861.
[21] 39, 1913, p. 29.

Britain." [22] The latter paper embodies the results of a great amount of research into a single definite problem, with the result that we possess more exact information about the 5.1-year periodicity in British weather than about any similar phenomenon.

The story of the periodicities of two and five years, as unfolded by the late Carle Salter and J. Glasspoole,[23] begins in 1868. For 15 years, up to 1882, each fifth year (1872, 1877, 1882) was very much wetter than any of the remaining 12. Then this series broke down, but from 1889 to 1909 there was a most remarkable sequence in which every third year was abnormally wet. The years 1891, 1894, 1897, 1900, 1903, 1906, and 1909 were all wetter than the average; of the remaining 14, one was exactly normal and the others were all dry. The sequence of British weather seemed to have been revealed, but Dr. H. R. Mill pointed out in 1903 that caution should be exercised in accepting it. Though this curious and quite empirical 3-year recurrence went on, Doctor Mill three years later repeated his warning with greater emphasis. "As," he wrote, "a sequence of one wet and two relatively dry years does not seem to have held good before 1891, it is only reasonable to expect that it will cease to hold good some time in the future."

The warning was justified, for the sequence was already breaking down, but after 1909 it changed to an almost equally remarkable 2-year oscillation. From 1910 to 1922 the even years were all much wetter than the average, while the odd years were all dry with the sole exception of 1915, and even that year was drier than either 1914 or 1916. After 1922 this 2-year sequence broke down, and now we seem to have returned temporarily to the 3-year type.

Sir Gilbert Walker,[24] my predecessor in the presidential chair of this society, has performed a useful service to meteorology by setting out some of the considerations which have to be borne in mind when going in quest of meteorological periodicities, and explaining briefly and clearly some criteria which ought to be applied to every supposed periodicity before it is given to the world. He has also described some methods of shortening the labor in the calculation of periodicities without sacrificing reliability of results.

WEATHER CYCLES AND CROPS

On account of the importance of weather to agricultural operations and yields, many investigations have been made to discover periodicities connecting them. In his presidential address to this society in 1921 Mr. R. H. Hooker [25] gave a detailed summary of the various researches into crop forecasting. The best work has been done by a direct study of the relations between variations of weather and subsequent variations of crops—Mr. Hooker has himself provided a notable example of such research—but cycles have not been without their enthusiasts, without, however, any results of practical value being reached, one set of enthusiasts often conflicting with another. For example, Hooker remarked, "If I understand Moore's diagrams correctly, his cycles point to maximum crops at the critical dates indicated by Beveridge as years of dearth."

Hooker found the rainfall in the autumn of great importance for wheat growth and held that this was the most important season for wheat. The critical period was the thirty-seventh to the forty-fourth weeks in the calendar year. There is also a strong connection between the weather in which the seed wheat was grown and the yield of the crop from this seed. For wheat a lack of rain during flowering and hot weather during ripening is necessary for good quality, while for yield cool weather is desirable. This explains the sequence of good and bad years which has been observed for wheat. A bad harvest gives a good quality wheat and a good harvest gives grain which is less suited for seed. In 1906 Sir Napier Shaw [26] directed attention to a remarkable symmetry in the yield of wheat for eastern England between 1885 and 1905, which can be represented with great fidelity by a series of harmonic components which are integral fractions of 11 years. The periodicities having the greatest amplitude are those of 11, 3.7 and 2.75 years. The agreement maintained itself with fair precision until 1908, but after that date it broke down; the minima which should have occurred in 1911 and 1914–15 falling instead in 1910 and 1916, while the general run of the figures from 1907 onward is decidedly different from the run between 1885 and 1907, which they should have resembled.

Recently Ernst Rietschel,[27] analysing the results obtained by Sir Napier Shaw from the discussion of the yield of wheat in eastern England, was led to investigate the distribution of periodicities of three to three and one-half years and of two years in winter temperature over the whole world. His results, being based on a period of only 12 years, are of limited value, but are set out in great detail. He concludes that the three to three and one-half year period had the character of a standing oscillation, which he interprets as a characteristic of the general atmospheric circulation. It vanishes at points in the United States and North Africa and reaches maxima in Alaska, Greenland, Siberia, and Australia. The other periodicity has a length of about 2.2 years, and is more uniformly developed, spreading out north and south from the north temperate and southern tropical regions.

The methods now adopted at the Rothamsted Experimental Station for all accurate field experiments make it possible to discover with considerable precision the influence on crop yields of rain, temperature, sunshine, or any other meteorological factor that can be measured and expressed in figures. Dr. R. A. Fisher has already traced the connection between rainfall in the different months of the year and wheat yields under different fertilizer treatments; a similar investigation into barley yields has now been made. The effect of hours of sunshine on wheat yields has also been examined; the most striking effect is of autumn sunshine just before or just after the sowing of the crop; whether the benefit arises from the warming or the drying of the soil is not yet found. For the rest of the year, even in July, actual sunshine seems unimportant; the great weather factors seem to be the temperature and the rainfall.

Dinsmore Alter has devoted a great deal of attention to the investigation of periodicities in rainfall. Two papers of especial interest may be mentioned. In the first [28] Alter examined, among others, a composite record covering an interval of 173 years in northern Europe, and found periodicities of about 10 years and 15 to 16 years. These conclusions were confirmed by shorter records from the eastern United States and the Punjab, India. There was no trace of the 11-year sun-spot cycle, and on the European record, which alone was long enough to deter-

[22] 51, 1925, p. 371.
[23] London, Q. J. R. Meteor. Soc., 49, 1923, p. 207.
[24] On periodicity. London, Q. J. R. Meteor. Soc., 51, 1925, p. 337.
[25] Forecasting the crops from the weather. London, Q. J. R. Meteor. Soc., 47, 1921, p. 75.
[26] Shaw, W. N. An apparent periodicity in the yield of wheat for eastern England, 1885–1905. London, Proc. R. Soc., A. 78, 1906, p. 69.
[27] Rietschel, Ernst. Die 3–3½ jährige und die 2 jährige Temperaturschwankung. *Leipzig, Veröff. Geophys. Inst. Univ.*, Bd. 5, H. 1, 1929.
[28] Application of Schuster's periodogram to long rainfall records, beginning 1748, *Washington*, MONTHLY WEATHER REVIEW, 52, 1924, p. 479.

mine it, there was only a slight indication of a "Brückner cycle" of 37 to 40 years.

In the second [29] paper he applied the method of correlation to rainfall data for the British Isles from 1834 to 1924 and found a number of periodicities of which the most important were 24½, 41, and 51 years, which are in the ratio ¾, 1, and 5/4. Others were slightly over 43 years and the Brückner cycle of 34 years. All these are submultiples of a major period of 613 years. Alter calculated the 6-monthly rainfall from the periodicities, and extended the calculated curve to 1940, and though he emphasized that "the future values are given for test purposes only," it is interesting to note that his test prediction indicates a remarkably low rainfall in the first half of 1929, followed by a recovery in the second half—and incidently a slight excess of rain in the first half of 1930, which is repeated here "for test purposes only."

LONG-RANGE FORECASTING BY WEATHER CYCLES IN SUBTROPICAL LATITUDES

It is in subtropical latitudes that rainfall cycles of a few years in length seem to offer the greatest prospect of practical utility. In Java they have been investigated by C. Braak [30] and later by H. P. Berlage [31] and tentative forecasts have been issued for some years. The dominant periodicity here is one of three years, but this breaks down from time to time and begins again at a different phase, so that the statistical result is a periodicity of between three and three and three-fourths years. It is probable that there is a local natural period of oscillation between the East Indies and Australia to which the succession of the seasons gives a length of exactly three years, but this oscillation is alternately set in motion and stopped by some more general cause which recurs at intervals of about three and one-half years or of some multiple of that. Berlage has discovered a cycle in the atmospheric and oceanic circulations of the Pacific which has a length of seven years, and this may be the more general cause which modifies the local 3-year oscillation. A picture of these swings may be given by supposing that a pendulum has a natural period of three seconds, but that the bob is struck from right to left every seventh second

[29] A group or correlation periodogram, with application to the British Isles. *Washington*, MONTHLY WEATHER REVIEW, 55, 1927, p. 263.

In southern Rhodesia Mr. C. L. Robertson [32] has been making tentative rainfall forecasts by a method of correlation similar to that employed successfully in India, and so highly developed by Sir Gilbert Walker. It is interesting to notice, however, that one of the terms of Robertson's equation is the rainfall of Rhodesia four years before, which has a correlation of —0.33 with the rainfall of the season to be forecast. This negative correlation points to a periodicty having a length of about 8 years or possibly of 2 to 3 years, or of both combined, so that the Rhodesian forecasts are in part based on cycles of rainfall.

In the rainfall, of Algeria [33] L. Petitjean has discovered periodicities of 6, 15, and 35 years, as a result of which the rainfall curve in its broad lines is symmetrical about 1903, that is, the rainfall of 1898–1902 resembles that of 1904–1908, 1894–1898 resembles 1909–1913, and so on. On the strength of this resemblance the author boldly prophesies the general course of rainfall in Algeria up to 1975, and foretells severe famines between 1940 and 1945 and between 1970 and 1975.

The most recent application of weather cylces to long-range forecasting in subtropical regions was made in Australia by Mr. H. A. Hunt,[34] who found evidence for a 4-year cycle in rainfall and temperature, which he attributed to a purely local chain of causes and effects. Some striking results were advanced, but the series of general rainfall values available in Australia appears to be too short as yet for them to be used with confidence in making predictions.

This seems, indeed, to be the chief conclusion to which a consideration of various weather cycles leads. They are either indefinite, or if they are expressed precisely they usually break down when tested over long periods. When a cycle has been found which is of real practical value in forecasting, it will be welcomed by meteorologists even though science may be unable to furnish any clue as to its origin.

[30] *Batavia, K. Mag. en Meteor. Observatorium. Verh.* no. 5. Atmospheric variations of short and long duration in the Malay Archipelago, and the possibility to forecast them. By C. Braak. Batavia, 1919.

[31] *Batavia, K. Mag. en Meteor. Observatorium. Verh.* no. 20. East Monsoon forecasting in Java. By H. P. Berlage. Batavia, 1927. (See *Meteor. Mag.* 62, 1927, p. 268).

[32] Robertson, C. L. The possibility of seasonal forecasting and prospects for rainfall season 1922–23. *Salisbury, Rhodesian Agric. J.*, 1922, pp. 648–655.

[33] Petitjean, L. Sur une périodicité et une symmétrie de la courbe des pluies à Alger. Application à la prévision des périodes sèches et pluvieuses en Algérie. *C. R.*, 185, 1927, pp. 472–473.

[34] Quart. Jour. Roy. Met. Soc. 55:323-330

ARE METEOROLOGICAL SEQUENCES FORTUITOUS?

By C. F. MARVIN

[Weather Bureau, Washington, January, 1931]

Any reader who expects this will carry an answer to the question raised in the title is destined to disappointment, but he may profit possibly by the information presented, which is the outcome of a file of correspondence with Mr. S. L. Moyer, civil engineer, interested in flood control and other hydrological problems.

Mr. Moyer says:

> The dilemma of contradictory weather cycles as shown by well authenticated data from two adjoining counties in the States of Washington and Idaho, may perhaps be explained by the examination of the premise which assumes periodicity.
>
> The existence of apparent rhythmic fluctuations in weather phenomena naturally suggests an assumption of periodicity; but to regard such periodicity as proven by the apparent rhythmic flow of the phenomena, is really quite unwarranted. It may possibly be true that haphazard contributions [i. e., departures from normal due to fortuitous influences C. F. M.], considered as resulting in accumulated departures from normal, may also display an apparent periodicity.

Without quoting his reasoning, he, briefly, assumed precipitation could be likened to the haphazard casts of four dice scored by the products of the points, and he adds:

> With this multiple haphazard premise in mind, 600 throws of four ordinary dice were made, the numbers exposed being multiplied together to arrive at a score. Theoretically, the mean or normal score for four dice in multiplication is 150.06, when the full range of opportunities is exhausted. For convenience, the normal was taken to be 150, and the excess above or shortage below this value was carried forward for each throw into a subtotal of accumulated departures. The annexed graph (fig. 1) gives a picture of the results of this process.
>
> This diagram suggests the unsoundness of assuming that an apparent rhythm proves periodicity; but, on the other hand, neither can it be said that the haphazard premise is demonstrated thereby. Each of these views has its value, and when the smoke of controversy clears away there may be reason to believe that the fluctuations in the weather arise out of both periodic and fortuitous sources.