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WORLD WEATHER

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Our knowledge of the connections between weather in distant parts of the earth, like most of our physical knowledge, has been won step by step. The first fact emerged in 1878 when Hoffmeyer pointed out the association between pressure in the N. Atlantic and weather in Europe; and he was soon followed by Blanford, who in 1880, with inadequate means at his disposal, found an opposition between pressure in Siberia and in the Indo-Malay region. Further details regarding conditions in the Atlantic were worked out by a group of continental meteorologists, including Teisserenc de Bort, Hann, Meinardus and Pettersson; but the far-reaching character of the subject was first visualised by Hildebrandsson, who in 1897 published the pressure data from 1875 to 1884 of 68 stations scattered over the world, and drew attention to relations between them as indicated by plotted curves. As might be expected, deductions from only ten years were unreliable, but among them was the opposition between Sydney and Buenos Aires that was fated to lead to far-reaching results. His subsequent studies brought out a number of similar relations involving temperature and rainfall.

In 1902 the Lockyers confirmed Hildebrandsson's discovery of the see-saw between pressure in the Argentine and in India or Australia, and made it the basis of a classification of pressures, those being called positive which oscillated with India and those negative which oscillated with Cordoba. Their methods were still purely graphic, but they produced the first map showing the distribution of a world-wide surge. A somewhat similar classification, including temperature as well as pressure, was carried out by Bigelow with solar prominences as the standard of comparison; but the value of his work was lessened by excessive and rather arbitrary smoothing.

Time will not permit of our dwelling on the researches of Exner, Wiese, Helland-Hansen and Nansen, who have added much to our knowledge of variations in northern latitudes, and of Mossman, who has unearthed some interesting relationships, and we will turn to the work done in India where the demand for a forecast of the monsoon made the study of conditions over a very wide area unavoidable. For such purposes it was necessary to have quantitative information as to relationships, not mere visual impressions from plotted curves; and to work with seasonal, not annual, values because relationships at different times of year vary greatly. Also there was no hope of unravelling the tangled threads of causes and effects unless help was got by finding cases in which the conditions of one or two related factors occur one or two seasons before those of the other; this first factor may then be the cause, but we know that it cannot be the effect of the second. Statistical methods were therefore indicated, and two papers appeared in the Indian departmental memoirs giving all the correlation coefficients between the data of twenty stations for each of the four seasons, and for seasons separated by three and six months as well as contemporary. This network left a number of areas without representation, and with the assistance of Mr. Bliss[1] an effort has recently been made to fill in some of the gaps; the number of centres is now thirty-two and relationships with sunspots have been added.

The total number of coefficients worked out is considerable; but by confining attention to those figures which are larger than the biggest that chance can be expected to produce, the number of significant coefficients is reduced to about four hundred.

The main conclusion reached is that there are three big swayings or oscillations:—

(*a*) The N. Atlantic oscillation already referred to;
(*b*) The N. Pacific oscillation between the high pressure belt and the winter depression near the Aleutian islands; and
(*c*) The southern oscillation, mainly between the S. Pacific and the land areas round the Indian Ocean.

The general facts regarding the first are so well known that it is not necessary to specify them now, but the relationships are closer than is generally realised; the influence of pressure gradients on the temperatures at Stornoway and Charleston in January is shown in Fig. 1.

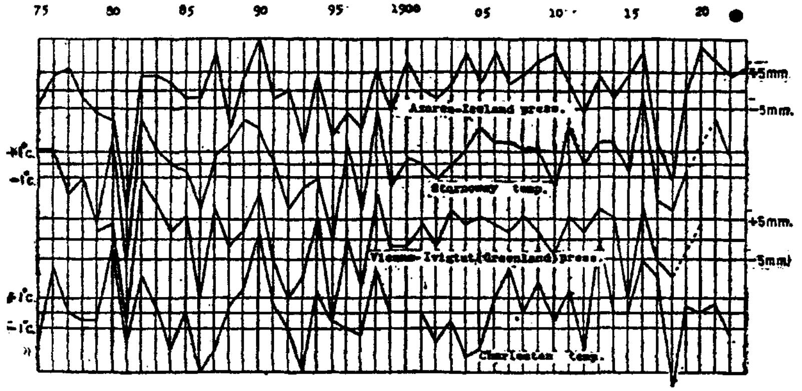

FIG. 1.—The effect of the North Atlantic oscillation on temperatures at Stornoway and Charleston.

Regarding the N. Pacific we have Fig. 2 showing the relations with winter (Dec. to Feb.) temperature at Dutch Harbour in the Aleutians; depressions there bring cold northerly winds, so that pressure and temperature fall together, and the diagram shows a

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[1] *Mem. R. Meteor. Soc.*, 2, No. 17, 1928.

relationship with Alaska pressure of +.68; accordingly with pressure at Honolulu and San Francisco coefficients are negative. With Honolulu[2] in winter there is, as we should expect, an opposition

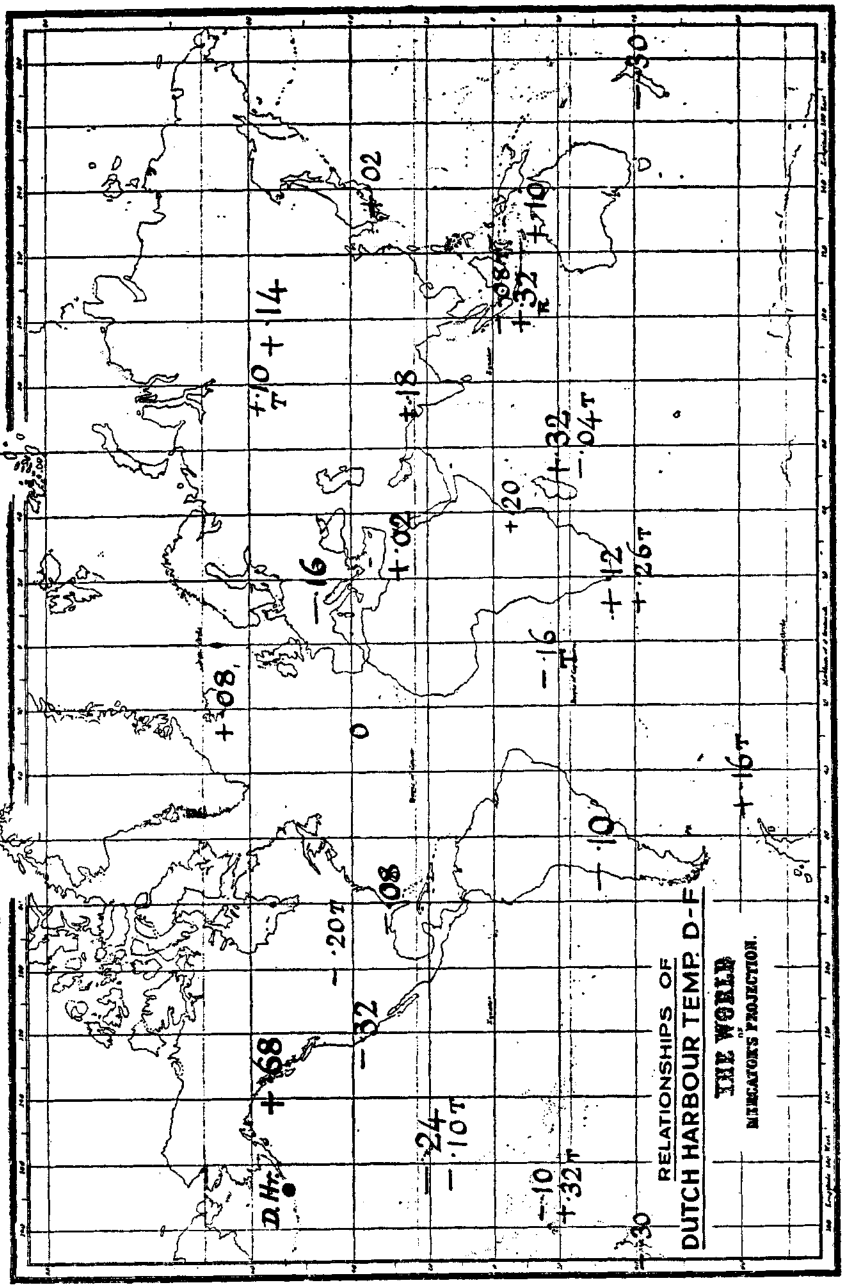

FIG. 9.
Correlation coefficients with temperature have a suffix T, and with rain a suffix R; those without a suffix are with pressure.

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[2] *Ind. Met. Mem., Calcutta*, Vol. **24**, Pt. 9, pp. 296-7, 1924. For relations with the new centres reference should be made to *Mem. R. Meteor. Soc.*, **2**, No. 17, 1928.

of $-.70$ with Alaska in the N. Pacific oscillation; also there is sympathy with pressure and temperature in the Indian Ocean and opposition to rain there. In summer,[2] however, there is an opposition with pressure in the Indian Ocean and sympathy with that in the S. Pacific. Thus, between summer and winter, Honolulu reverses its relationships with the S. oscillation.

The term " centre of action " was created by Teisserenc de Bort for permanent centres of high or low pressure whose displacement or intensification controlled weather at a distance; but these limitations must be swept away. Thus, pressure in N.W. India in summer when it is the centre of a deep depression is decidedly less important than in winter when it is far from the centre of an area of high or low pressure. Rainfall and temperature may also produce centres; thus, the associations of Batavia temperature of December to February are well marked[3]; temperature there is high when pressure is low in the Pacific and high in the Indian Ocean; and we may express this by saying that it belongs to the second group of the S. oscillations. Note, too, that it rises with increased gradients both in the N. Atlantic and N. Pacific.

A further distinction that may be drawn is between active and passive centres. As an example of the latter we may take Port Darwin[4] in summer, which is controlled by four other factors in the S. oscillation in the previous winter, but has significant effects on only two factors six months later. On the other hand S. America in its winter has not one significant relation with conditions of the S. oscillation of the previous summer, but six with contemporary ones and nine with the following summer.

There are two questions that urgently call for reply—what is the mechanism that binds together the variations in the three oscillations, and what is the driving power behind each of them, which prevents the oscillations from dying out? To the first question the natural reply is that it is an increase in the general circulation in all cases. This is usually accepted as far as the N. Atlantic is concerned; and conditions in the N. Pacific are largely similar. With regard to the S. oscillation it is worthy of note that the second group consists, largely at least, of places like India, Australia and N. and S. Africa, which are areas of markedly low pressure in summer,[5] while stations of the first group are on or close to high pressure areas in the Pacific Ocean; further, S. Africa is neutral in winter, but belongs to the second group in summer, when it is an area of low pressure, while Honolulu, the Argentine and Chile are in an area of high pressure from June to August, and it is then that they belong to the first group.

An obvious suggestion is that as the margin of the Antarctic is a strongly marked area of low pressure this should belong to the second group; and the limited information available strongly indicates, as pointed out by Mossman and Simpson, opposition between pressure there and in the Argentine, and that Antarctic

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[3] *Mem. R. Meteor. Soc.*, **2**, No. 17, p. 120, 1928.

[4] *Ind. Met. Mem., Calcutta*, **24**, Pt. 9, pp. 310-1, 1924.

[5] Reference may be made to charts of normal pressure over the globe in July and January, as on pp. 54-5 of Shaw's *Forecasting Weather*.

pressure moves in sympathy with that in N. Australia. It seems likely that further observations will confirm the opposition that Simpson found between Antarctic pressure and pressure in Mauritius, S. Australia and N. Zealand; and in that case the existence of a fourth oscillation, corresponding with those in the N. Atlantic and N. Pacific, may have to be admitted.

Let us now turn to the second question and consider for a moment the force which produces these surges. That it is not solar conditions as measured by sunspot numbers can be demonstrated statistically, for the closest relation with sunspots is much less than some of the relations between conditions on opposite sides of the world; and yet there is a most remarkable similarity between the distribution of centres in the first and second groups of the S. oscillation and classification into + and – relationships with sunspots.[6] So we are led to the view that the S. oscillation is a group of physically connected changes upon which solar radiation exercises some influence.

The belief held by Hildebrandsson in 1910 was that in the tropical and temperate regions circumstances were too regular to afford an explanation, and it must lie in the ice conditions of the polar seas; he believed also that in the southern hemisphere types of season were propagated eastwards like waves, the character of the pressure at the Cape during its summer appearing at Mauritius in the next winter, in Java and Australia the succeeding summer, and finally in S. America six months later, or eighteen months after its original appearance at the Cape. This generalisation was founded on inadequate materials, and the feature which stood out most prominently in my first tables of relations[7] was that while winter pressure in the Argentine and Chile was not controlled by any centre in the S. oscillation six months before, it controlled conditions six months later round the Indian Ocean, appearing as a reversed pressure wave which took six months to reach the Cape. It seemed therefore probable that S. America was the origin of the variations and likely that a modification of Hildebrandsson's hypothesis would solve the problem. For owing to the shape of the Antarctic continent it would appear inevitable that the ice which flows in a westerly direction along the coast would be thrown off northwards into the Drake Strait by the projection of Graham Land, so that it would then flow northeastward and eastwards in the currents of the roaring forties. The few data forthcoming from that neighbourhood indicated that a winter of low pressure in Chile was a winter of much ice at the S. Orkneys, and as this would take some months to produce an area of chilled ocean and therefore of high pressures at the Cape, it seemed as if we might hope to understand how a period of low winter pressure in S. America could produce a period of high summer pressure at the Cape. But subsequent examination showed that although low winter temperature at the S. Orkneys produced low temperature at the Cape a year later, the coefficient between the two temperatures being +.56, the effect six months later was small; and, apart from this, the explanation would break

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[6] See §§ 14, 15, p. 105, of *Mem. R. Meteor. Soc.*, **2**, No. 17, 1928.

[7] *Ind. Met. Mem. Calcutta*, **24**, Pt. 4, 1923.

down because the effect of Cape temperature on Cape pressure proves on calculation to be negligible.

Unfortunately it is easier to reject this hypothesis than to replace it. If we count in the tables the number of significant relationships we find that pressure at Port Darwin has no less than 76 with other places, of which 32 are with subsequent seasons; next in importance come temperatures at Batavia and Samoa each with about 60 relationships, of which only 13 are with subsequent seasons; and then come the pressures of N.W. India and Samoa with smaller numbers. So pressure at Port Darwin seems to exercise more control over other regions than any other world factor, and its influence seems to be increased by Batavia temperature, which varies in close sympathy as we may see in Fig. 3. Temperature at Samoa, whose oscillations closely resemble those of Batavia temperature, is an equally important world centre; but it belongs to the second group, while Samoa pressure belongs to the first group and has not more than half its influence. On the whole then, although certain pressures appear to come earlier than any temperatures in the sequence of cause and effect, it is clear that ocean temperatures play a most important part in world weather. Their effectiveness may be due in part to their extreme persistence, so that successive seasons produce cumulative instead of antagonistic results. Thus, in Fig. 4 we have graphs showing close relationships between temperature at Samoa (2, 3) and the previous Nile floods (1) and also with previous pressures at Port Darwin (4) and Zanzibar (5); the similarity of (2) and (3) will also be noted.

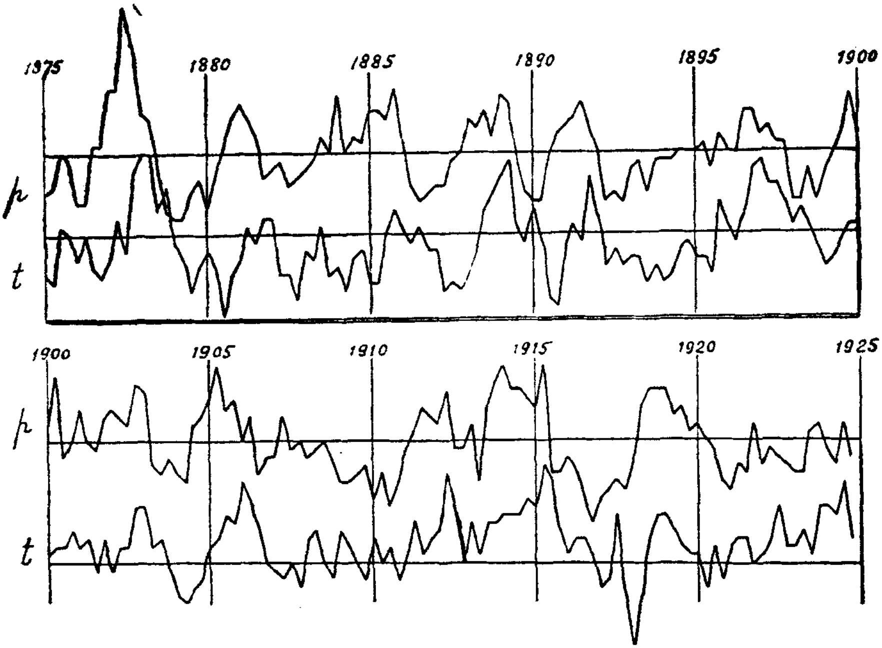

FIG. 3.—Pressure and temperature at Batavia.

Although it may be some time before we learn the processes by which nature effects these enormous oscillations, and the relationships found must in general be regarded as empirical, there is no reason why they should not be utilised when possible for administrative or commercial purposes such as seasonal forecasting. Thus methods of predicting the general character of the winter and spring temperatures of a large part of northern Europe have been known for twenty years,[8] and much additional knowledge has been won in recent researches by Brooks, Wiese, Exner and others. The facts of the S. oscillation have been systematically utilised in predicting the rice crops of Japan, and the Java rainfall; and the recent tables have been shown by Bliss to have an immediate application to the Nile, the final relationship for forecasting being .72. The latest purpose to which they have been directed is in connection with Ceara, a state in N.E. Brazil liable to terrible droughts; and, as rainfall there belongs to the second group in the S. oscillation,[9] a formula with a coefficient of .82 follows at once, the effect of its application to past years being shown in Fig. 5.

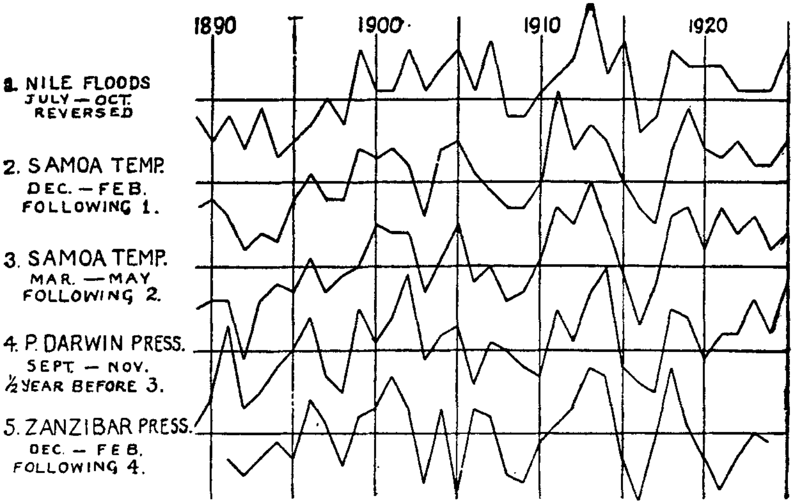

FIG. 4.—The southern oscillation.

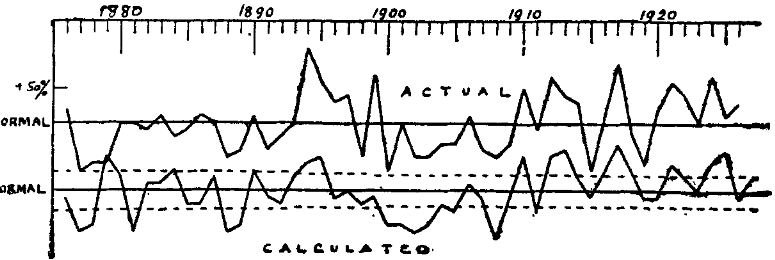

FIG. 5.—Forecast on December 1 of Ceara rainfall, January—June.

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[8] For the situations as far back as 1898 see *Met. Zs., Braunschweig*, pp. 85-105 and their summary in Tafel II., p. 120.

[9] A paper on "Ceara (Brazil) famines and the general air movement" will shortly appear in the *Beitr. Physik Atmosph., Leipzig*.

Now there is in England an attitude of scepticism in such matters that is of the greatest value as an antidote to rashness; but it is, in my view, excessive when applied to conclusions based on an adequate number of years such as forty or fifty. My view claims to be based not merely on the theory of probability, but on actual experience. For in 1908 I published an admittedly imperfect formula for predicting the Indian monsoon based on about 34 years of data; and its reliability can be definitely estimated in Fig. 6 by comparing the indication given by it during the past 19 years with the actual rainfall. Now the coefficient expressing the closeness of fit between the results of the formula and past data in 1908 was .58, and I should have been satisfied under the conditions if the indications of the past 19 years had a closeness of fit of .45 instead of .58; actually, however, the relationship has worked out as .56, and it may be claimed that our present formulæ based on 50 or 55 years instead of 35 are worthy of confidence if used with due caution. It is essential that forecasts should only be issued when the indications are well marked, and if during the past 19 years a prediction had only been made in the 11 years when an excess or defect of one inch or more had been indicated, the character of the season's rainfall, expressed merely as "in excess" or "in defect," would have been correctly given nine times.

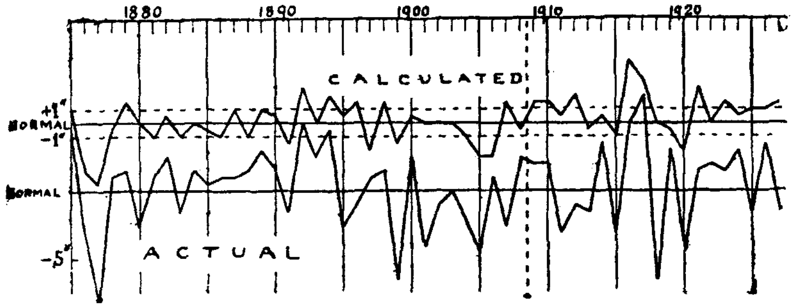

FIG. 6.—Forecast on June 1 of Indian monsoon, June—September. (1908 Formula, R=0.58).

Since 1908 many new relationships have been ascertained, and the present formulæ for N.W. India and for the Peninsula have coefficients of .76 instead of .58. Also there is no reason whatever for thinking that finality has been reached; for with the seasonal changes in India are associated very big changes in the strength of the upper currents; and it is an obvious hypothesis that when the change in the upper currents takes place with unusual vigour the seasonal rainfall will be abundant. The pilot balloon observations hitherto made strongly support this hypothesis, and what appears to hold in India very probably holds over a far wider region. Moreover, the idea that upper air conditions are vital to the study of world weather derives support from the table of relations with the Nile. The significant relationships with other stations for a single season number 31, while the greatest number for a single season at any other centre is 24 at Port Darwin;

and as the corresponding number for pressure at Cairo is only 8, it seems likely that this effect of the Abyssinian rainfall is brought about by the agency of the upper air, not by surface conditions. Similarly the monsoon rainfall of India has eight significant relationships elsewhere, but June to August pressure in N.W. India only one.

It is obvious that the continuation of our present methods of publication, as exemplified in the *Réseau Mondial,* will provide students of world weather of the next generation with invaluable series of data from regions where such series are not now available. Many questions to which the reply is now impossible can then be answered. But I would plead that this is not enough, and that we should at an early date start publishing monthly means of air motion at fixed heights above such observatories as can provide the data. Only then shall we be doing for our successors what we should do for them without hesitation if they were able to ask for the information to-day.

International Mathematical Congress.

An International Mathematical Congress under the auspices of the Rector of the University of Bologna will be held from September 3-10, 1928, at Bologna. The Congress will be conducted with plenary and sectional meetings, the sections being :—I. Arithmetic, Algebra, Analysis; II. Geometry; III. Mechanics; IV. Statistics, Probabilities, Actuarial Science; V. Engineering and Industrial Applications; VI. Elementary Mathematics, Logic; VII. Philosophy, History of Mathematics. Persons attending the Congress will be able to obtain a reduction of fares on the Italian railways and ships.

Royal Observatory, Greenwich. Report to the Council of the Royal Meteorological Society of Observations during the year 1927. (Communicated by the Astronomer Royal.)

The routine meteorological observations have been continued as in previous years. These include estimates of visibility according to the international scale, and a record of the clearness of the night-sky as indicated by the photographic trace of polar stars.

During the year 1927 the temperature of the air varied between 84°.9 F. on June 16 and 18°.5 F. on December 19. A temperature of 80° F. was exceeded on three days only. A temperature of 32°.0 F. or less was recorded on 38 days, one of which was in May (May 1).

The mean temperature for the year was 49°.5 F., that is 0°.1 below the average for the 75 years 1841-1915. The first five months were all, on the average, warmer than normally, particularly March, when mean temperature was 3°.6 F. in excess of normal. On the other hand, June and December provided mean temperatures considerably below the average, that of December being 4°.1 F. lower than the normal. On the four days December 17 to 20 the maximum thermometer reading was less than 32° F. Not since February 1895 has this occurred on four consecutive days.

The highest reading of the solar radiation thermometer *in vacuo* was 157°.2 F., which was registered on June 16. The lowest ground thermometer reading of the year occurred on December 16, when the