sun-spot maximum centering about 1860, 1870, 1883, 1894, and 1906 and computed the annual rainfall departure for the central year and the single year immediately preceding and following; thus the years 1859, 1860, and 1861 would represent the epoch of spot maximum of 1860. Four out of the five epochs were, on the average, periods of more than normal rainfall and but one, that of 1894, was a time of deficient precipitation. Casual inspection of the precipitation record for Berlin discloses the fact that in the 60 years 1848–1907 there were more wet than dry years, a condition directly contrary to that which is the rule in the United States, but whether this condition is common to northern Europe is not at this time known.

The concluding chapters of Dr. Douglass's work are devoted to a discussion of "Methods of Periodic Analsis," "Cycles" with an appendix giving tables of mean tree growth extending back to 1306 B. C. The book should be read by all students of weather periodicities.

CLEMENTS ON DROUTH PERIODS AND CLIMATIC CYCLES.[1]

By A. J. HENRY.

[Weather Bureau, Washington, D. C., April 1, 1922.]

Dr. Clements refers briefly to the work of Douglass [2] in relating the annual rings of trees to rainfall and the sun-spot cycle as suggesting the possibility of using the latter for forecasting the rainfall from year to year.

He also adds, seemingly in confirmation of Douglass's work, the statement that "practically all the groups of trees studied gave a clear record of growth cycles corresponding closely to the sun-spot cycle. They confirmed the hypothesis that years of sun-spot maxima were generally marked by deficient rainfall, and those of sun-spot minima by rainfall above the normal."

A preliminary examination of the rainfall records of the States west of the Mississippi River showed that the two major drouth periods of 1893–1895 and 1870–1873 coincided with sun-spot maxima. It was also evident that abundant precipitation had occurred frequently, if not regularly at times of sun-spot minima and from these facts the inference was drawn that the spot minimum of 1913 would be accompanied by an excess of rainfall and that the spot maximum of 1917 would likewise be associated with a deficit in the rainfall. Partial confirmation of these inferences led the author to make the following statements: [3]

> The most attractive and promising feature of the summer's work has been the checking and tracing of the course of the present climatic cycle. The second recorded absolute minimum of no sun spots occurred in 1913 and served as the focus of a period of exceptional rainfall in the West. The drouth of the present summer (1916) in the Western and Mountain States suggests the beginning of the dry phase of the cycle. Its effect upon the carrying capacity of the ranges and upon the production of dry farms has been critical. Whether it be followed by the full period of several dry years or not, it has furnished further confirmation of the fact that all grazing and dry farming must be based upon the recurrence of dry periods; in both a scientific system of expansion and contraction must be devised to prevent disaster during dry years. If the next two or three years prove to be dry in harmony with the maximum of the sun-spot cycle, the possibility of anticipating dry seasons will be greatly enhanced. In the field of forestation much evidence has been obtained to show that planting is successful only during wet phases and that natural reproduction occurs practically only during such phases.
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> The investigations of climatic cycles has been continued from both the biological and astronomical approach. The former gains interest from the fact that the years 1916, 1917, and 1918 have in general been years of drouth in the West and especially the Southwest. This was suggested as a probability upon the approach of the sun-spot maximum in 1916. The maximum was passed in 1917 and attention is now centered upon the expected increase of rainfall generally as the sun-spot minimum is approached during the next four or five years. It is proposed to follow the biological effects as seen in growth, reproduction, and abundance as closely as possible and to correlate these with the climatic phases. Striking evidence of these effects have been obtained during the drouth of the past two years. By far the most important problem, however, is the relation of the sun-spot cycle to the climatic and growth cycles. There appears to be little question of the usual coincidence of these three cycles, but the existence of a causal relation is still in doubt. In the endeavor to make use of the sun-spot cycle to anticipate climatic changes, this matter is of paramount importance.[4]

The remainder of the article is devoted to an examination of the rainfall records of 23 States west of the Mississippi in an effort to establish a basic relation between rainfall and the spottedness of the sun. The method of collating the rainfall records was as follows: In the 23 States there were 323 rainfall records in 1881 and more than 1,300 in 1919. For the seventies the number was less than 100—76 in 1869, and for earlier years still less. The yearly departures of the annual totals from the normal were tabulated and classed as positive or negative by years, or rather by groups of five years, the central year of each group being the year in which the epoch of maximum sun spots occurred. The groups, therefore, center about the years 1837, 1848, 1860, 1871, 1883, 1894, 1907, and 1917. Concerning these epochs of maximum, Doctor Clements further remarks:

> Since the beginning of observations in 1750 the yearly number of sun spots at the maximum has varied from 46 to 154, though the number has fallen below 80 for but 5 of the 16 maxima. For the 8 maxima considered here, the number of spots falls below 80 only in 1907 [5] and 1883, when the numbers were 62 and 64, respectively. In other words, 6 of the maxima lie above 77; i. e., half the number of spots for the highest maximum, 154.

DISCUSSION.

The chief interest in Doctor Clements's paper is, of course, the coupling of the period of solar activity manifested in the spottedness of the sun with terrestrial rainfall and the endeavor to anticipate the character of the seasonal rainfall some years in advance. I shall therefore first consider the connection between the occurrence of sun spots and rainfall.

SUN-SPOT RAINFALL RELATIONS.

Since Meldrum, in 1872, called attention to the possible connection between the phenomena above mentioned, much discussion has arisen or, rather, many persuasive reasons have been adduced in support of the idea that there must be a basic connection between the two events. It is scarcely necessary to analyze the large literature on the subject already available, but it will be desirable to touch upon the several stages of the arguments which have been advanced in support of the hypothesis.

The effort to relate sun spots with terrestrial weather dates back many years, but the specific attempt to show a relation between sun spots and *rainfall* is of comparatively recent origin. The discovery of what is popularly

[1] *Ecology*, Vol. II, No. 3, July, 1921.
[2] MO. WEATHER REV. 37: 225–236 and abstract of a later work in this REVIEW, immediately preceding.
[3] Carnegie Inst. Wash. Pub. No. 242, 1916.
[4] Loc. cit., pub. 304, 1917.
[5] According to Wolfer, the epoch of maximum at this time occurred in 1906.4, and the maximum number of spots was 64.2 (smoothed) in February. The epoch of 1883, according to the same authority, occurred 1883.9, and the maximum number of spots was 74.6 in November of that year.

known as "Brückner's[6] long period climatic oscillations of 35 years" in 1890 led to renewed efforts to connect these oscillations with solar activity.

Brückner himself investigated the subject, and although he was not successful in establishing a relation, yet he felt that such a relation must really exist, even if it does not appear in sun-spot data.

The following is a résumé of the literature on the precipitation sun-spot relations to the end of 1917.[7]

VARIATIONS IN PRECIPITATION AND SUN SPOTS.

The relation between the variations in the precipitation and the sun spots has led to many investigations since Meldrum in the year 1872 showed for several tropical stations that the rainfall varies directly as the sun spots, so that a maximum of rainfall occurs at the maximum of sun spots, and vice versa. Sir Norman Lockyer showed this also for several stations in Ceylon and in India. Investigations of Symons and Jelinek indicated the same conclusion, that more rain falls at sun-spot maximum than at sun-spot minimum, but it appeared that the periodicity is most marked and regular in the tropical regions. Hahn pointed out that in the period from 1820 to 1870 dry summers were most prevalent during the time of increasing sun-spot numbers. On the whole, the investigations on the relation between precipitation and sun spots are very conflicting and have led to more or less doubtful results. Meteorologists have here, as in most similar investigations, made the error of assuming that the same cause should everywhere produce the same effect, without taking sufficiently into consideration that the same cause at different places may act oppositely. Archibald and Hill have independently shown that the winter rain in India has the opposite course to that which Meldrum found. They obtained, in fact, a minimum at the maximum of sun spots and a maximum of winter rain about at the time of the minimum of sun spots. On the other hand, Hill seeks to show that the Indian summer monsoon rain has a great tendency to vary in coincidence with the sun spots in this manner that an excess of precipitation occurs in the first half of the cycle after the sun-spot maximum, and vice versa, but on the whole the curves show little agreement. Blanford came meanwhile to the conclusion (1889) that the precipitation in India on the whole gave no sure indication of a 10 or 11 year period for the last 22 years.

For Europe, the connection between precipitation and sun spots has also been investigated. (See Schreiber (1896, 1903), A. Buchan (1903), and others.) P. Schreiber (1896, 1903) found a probable 11-year period in the precipitation at different stations in Europe, but with two maxima, one, two years after sun-spot maximum, the other at the time of sun-spot minimum, and with two minima, one coincident with sun-spot maximum and the other three years after the sun-spot minimum.

A. Buchan (1903) found a double period in the precipitation in Great Britain, so that a minimum occurs shortly after sun-spot minimum and another shortly after sun-spot maximum. The first and weaker maximum is much less marked in Scotland and west Europe than in southeast England where the principal maximum occurs nearer the sun-spot maximum.

G. Hellmann (1909) has investigated the relation of variation of precipitation in different parts of Europe to the sun-spot period and finds that there is no universally followed rule about it. In most cases of the stations examined by him there occur within a sun-spot period two maxima of rainfall which occur about six or five years from one another. At the time of sun-spot minimum there occurs at most stations a maximum of rainfall, but in consequence of the progress of wet and dry years from south toward north, in western Europe the maxima and minima of precipitation tend to be progressively displaced in the sun-spot cycle.

The subdivision of the 11-year period of rainfall Hellmann explains by an assumed double influence of the variation in the solar radiation during the sun-spot period. First is a direct influence arising from the equatorial region and acting indirectly as an influence upon the place itself. Hellmann proceeds from the assumption, now proved erroneous, that at the time of sun-spot minimum there is a greater radiation of the sun that at the time of sun-spot maximum. This increased radiation, he thinks, would act principally in the equatorial regions of the earth to produce an increase of temperature, evaporation, and precipitation, and thereby would increase the energy of the total circulation of the atmosphere. This equatorial influence would be delayed in reaching the higher latitudes. But, on the other hand, the direct influence on the precipitation in these latitudes themselves due to the sun spots would be considerably weaker than in the equatorial regions. The impulses derived, respectively, in the equatorial regions and in places of higher latitude would exercise together either a cumulative or an interfering action. It would be therefore conceivable, he thinks, that in one place the minimum of rainfall would be associated with maximum of sun spots, while in another place the opposite association would prevail.

E. H. Chapman[8] has collected correlation coefficients between sun spots and rainfall for 147 places scattered over the globe. The value of the coefficient of correlation r, ranges from zero to ± 0.50 and there are but two cases where r equals or exceeds 0.50, viz, for Edmonton, Canada, -0.50, and Bathurst, Gambia, $+0.51$. In both cases the records of rainfall were relatively short. In the great majority of cases the magnitude of r was not great enough to be of significance.

Notwithstanding the failure to establish any definite relation between sun spots and rainfall, the opinion is held by some that a real relation subsists; for example, Prof. W. H. Pickering,[9] in discussing droughts of Jamaica; concludes:

> The 13 droughts have occurred on the average at intervals of 4.17 years. If their relation to the sun spots was due merely to chance the average deviation should be one-fourth of this, or 1.04 year. Not one of the deviations in Table 6 reaches this figure. From this we conclude, considering the inevitable errors occurring in fixing the exact dates of sun-spot maxima and minima, that a real relation subsists between these dates and those of Jamaica droughts.

RAINFALL DATA OF TABLE 1.

I now pass to a consideration of the rainfall data as presented in Dr. Clements's Table 1.

[6] E. Brückner, Klimaschwankungen seit, 1700, Vienna, 1890.

[7] Temperature variations in the North Atlantic Ocean and in the atmosphere, Björn Helland-Hansen and Fridtjof Nansen, Smithsonian Mis. Coll., vol. 70, No. 4, 1920.

[8] Chapman, E. H., The Computers Handbook M. O. Section V, Computations related to the theory of probabilities, pp. 108–111.

[9] Pickering W. H., The relation of prolonged tropical drouths in Jamaica to sun spots. MO. WEATHER REV. 48:589.

TABLE 1.—*Number of rainfall stations in the groups and years named that had positive and negative annual rainfall departures, respectively.*

[The figures in the top line of each group are positive, those in the second line negative, and those in the third line are the algebraic sum of the two preceding.]

Sun spots	54	58	65	63	51	70	84	79	61	43	59	60	56	51	41	46	59	96	83		Number.	Years.
Years	1881	1882	1883	1884	1885	1892	1893	1894	1895	1896	1905	1906	1907	1908	1909	1915	1916	1917	1918	1919	+	−
Group 1	37	25	7	87	19	99	105	158	71	191	97	284	249	31	250	1,185	176	34	68	54	.....	.....
	65	80	97	20	95	97	91	66	153	50	220	35	77	304	25	78	62	188	186	204	.....	.....
	−28	−55	−90	+67	−76	−2	+14	+92	−82	+141	−123	+249	+172	−273	+225	+107	+114	−154	−118	−150	9	11
Group 2	19	23	15	37	15	29	35	43	21	55	82	103	107	83	100	73	87	33	66	67	.....	.....
	22	16	21	4	26	49	48	51	80	42	56	26	27	53	29	52	28	101	68	90	.....	.....
	−3	+7	−6	+33	−11	−20	−13	−8	−59	+13	+26	+77	+80	+30	+71	+21	+59	−68	−2	−23	10	10
Group 3	11	8	5	15	11	35	23	32	77	51	119	166	110	99	134	123	88	28	122	128	.....	.....
	6	17	11	5	14	62	76	71	43	75	61	49	114	119	61	42	84	157	85	118	.....	.....
	+5	−9	−6	+10	−3	−27	+53	−39	+34	−24	+58	+117	−4	−20	+73	+81	+4	−129	+37	+10	11	9
Group 4	82	76	80	75	60	153	74	17	45	227	311	215	215	194	348	300	185	60	153	234	.....	.....
	20	27	23	34	56	51	169	255	260	107	81	172	152	196	54	52	176	321	206	132	.....	.....
	+62	+49	+57	+41	+4	+102	−95	−238	−215	+120	+230	+43	+63	−2	+294	+248	+9	−261	+653	+102	14	6
Group 5	30	29	34	33	34	95	15	41	100	157	302	234	128	262	174	332	104	28	200	256	.....	.....
	31	25	16	21	22	82	185	180	138	102	44	115	222	104	219	59	299	399	219	149	.....	.....
	−1	−4	+18	+12	+12	+13	−170	−139	−38	+55	+258	+119	−94	158	−45	+273	−195	−371	−19	+107	10	10
Total	179	161	141	247	139	411	252	291	314	681	911	1,002	809	669	1,006	1,013	640	183	609	739	.....	.....
	144	165	168	84	213	341	569	623	674	376	462	397	592	776	388	283	649	1,166	764	693	.....	.....
	+35	−4	−27	+163	−74	+70	−317	−332	−360	+305	+449	+605	+217	−107	+618	+730	−9	−983	−155	+46	10	10

Group 1. Washington, Oregon, California.
Group 2. Idaho, Utah, Nevada, Arizona.
Group 3. Montana, Wyoming, Colorado, New Mexico.
Group 4. Minnesota, Iowa, Missouri, Wisconsin, Indiana, Illinois.
Group 5. North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, Texas.

It is always a difficult matter to combine climatological data for large areas and to properly interpret the results and this is particularly true in the case of precipitation. This element is probably the most variable of all in point of horizontal distribution.

Precipitation, in common with some other meteorological elements is characterized by an unsymmetrical frequency distribution about the mean, there being a much larger number of dry years than wet years generally in all parts of the world.

The method of assembling the annual departures of the rainfall from the average used by Dr. Clements, while not without its limitations, can be properly used when qualitative results only are essential. When the number of rainfall stations in any district is small, as in the case of the years prior to the eighties, the results may be inaccurate.

The results shown in Table 1 are significant, whatever may be one's opinion as to the connection between sunspots and rainfall. To those who may not be familiar with previous investigations on this subject, it will probably seem that there is little, if any, doubt but that a direct connection exists; to others, the results will not be conclusive. I have sought, therefore, to obtain and present additional information bearing upon the question in order that we may the better appraise the records at their true value. There is, of course, considerable contemporary evidence as to the existence of drought when rainfall records are wanting. Douglass has skillfully used biological evidence to carry the rainfall record back into the preobservational period.

The net result of Table 1 is that epochs of sun-spot maxima are as likely to be associated with wet as dry years, taking the 23 States as a single geographic unit. Some groups, however, differ from the whole area and from each other; for example, the Pacific Coast States show a tendency to be dry rather than wet and the Missouri Valley States show a rather decided tendency to the contrary. In this connection it is interesting to consider quantitative results for practically the same geographic area as are included in Table 1. In Table 2 are given the monthly and annual precipitation departures for the climatic districts as published in Table 1 of the MONTHLY WEATHER REVIEW for each of the years 1909–1921. This term of years contains the results for the five years 1915–1919 of Table 1 and the six years immediately preceding. It will be found that important results will flow from the study of years of sun-spot minima as well as maxima.

TABLE 2.—*Annual precipitation departures, by districts, 1909–1921.*

	Missouri Valley.	Northern Slope.	Middle Slope.	Southern Slope.	Southern Plateau.	Middle Plateau.	Northern Plateau.	North Pacific.	Middle Pacific.	South Pacific.	Total.	Average.
1909	+5.5	+0.5	+1.7	−7.8	+0.1	+2.0	+0.6	−0.8	+6.6	+9.8	+18.2	+1.82
1910	−5.0	−3.0	−7.7	−12.2	−2.9	−3.5	−1.8	−2.9	−10.9	−7.6	−57.6	−5.76
1911	−3.6	−0.5	−2.9	−4.5	+2.7	+0.5	−2.8	+0.9	−2.2	+5.5	−6.9	−0.69
1912	−4.1	−0.1	−0.2	+0.4	−0.6	−0.3	+2.3	−2.1	−6.3	−3.4	−14.4	−1.44
1913	−3.5	+0.4	+0.5	+0.5	−1.2	−0.3	−0.9	−8.3	−5.6	−1.4	−19.8	−1.98
1914	−0.4	−2.3	−3.9	+6.3	+1.1	−0.9	−2.0	−2.5	−1.9	+3.5	−3.0	−0.30
1915	+7.7	+2.5	+7.1	+0.6	+0.9	−1.5	−0.2	−4.1	+2.4	+3.2	+18.6	+1.86
1916	−5.8	+0.2	−3.9	−4.7	+1.0	+0.6	+0.7	−9.7	−1.8	+4.8	−18.6	−1.86
1917	−6.0	−0.7	−7.7	−8.9	−3.3	−3.5	−1.5	−6.1	−9.8	−6.3	−53.8	−5.38
1918	−1.9	+0.9	+2.8	−4.8	+0.4	−0.9	−3.0	−7.0	−5.3	+3.0	−15.8	−1.58
1919	−2.2	−1.8	−3.8	+0.1	+1.2	−2.2	−2.3	−9.6	−6.3	−4.9	−31.8	−3.18
1920	−1.6	+0.2	+0.3	+0.1	−1.0	−0.8	−0.3	−3.4	−5.2	−2.8	−14.5	−1.45
1921	−0.1	−0.2	−0.3	−0.3	±0.0	−0.1	−0.1	+0.2	−0.6	+0.2	−1.3	−0.13

Comparing the figures of the two tables for the five-year period 1915–1919, it is seen that in the main they are in agreement. The year 1917—a year of maximum sunspots—was a year of deficient precipitation practically throughout the United States, but not especially in Arizona; 1916, however, which from Table 1 might be considered a year of nearly normal precipitation, is clearly a year of deficient rain by Table 2. When the entire United States is considered as in the matter of Table 2, some interesting results are disclosed. The year 1909, which in Table 2 is a year of above normal rain, comes out with a deficiency of 0.4 inch for the entire United States. Actual and smoothed precipitation departures for the United States as a single geographic unit from 1893 to 1920 appear in Table 3.

From Table 3 (see below) I have selected the years when precipitation on the average for the entire area was above, or very close to, normal. It is found that but 8 of the 40 years considered meet those requirements. The years and the average departures follow:

Years.	Average departures.	Years.	Average departures.
	Inches.		*Inches.*
1884	+2.0	1905	−0.1
1882	+1.0	1915	−0.1
1881	+0.4	1912	−0.2
1906	+0.3	1909	−0.4

On the other hand, the years of marked drouth in some part or parts of the United States were as follows:

Years.	Average departures.	Years.	Average departures.
	Inches.		*Inches.*
1910	−6.6	1918	−3.4
1917	−6.1	1893	−3.4
1887	−4.1	1894	−3.3
1895	−4.0	1886	−3.2
1904	−4.0	1890	−3.1

The outstanding feature of the above exhibit is the skewness of the distribution about the mean and the magnitude of the negative departures as compared with the positive. It seems to be a rule of precipitation the world over that departures below the mean are greater than departures above and this, I take it, is the explanation of the large number of years with negative departures in Table 3.

It is probably not generally recognized that there has been no period of rainfall so generally abundant as that of the early eighties since the Weather Bureau records began. If that maximum be taken as the starting point, the next maximum occurred about 22 years later, and the second maximum, that of 1915—if a departure of 0.1 inch below the normal can be called a maximum—about 33 years later, both numbers being multiples of the ordinary 11-year sun-spot cycle.

The intervals between severe drouth years, considering the drouth of 1886–87 as the point of origin, are 3, 6, 17, 23, and 30 years, respectively. One of these drouths, 1886–87, lasted two years, and another one three years, 1893–1895; in the above count I have considered the years from the end of the 1886–87 drouth until the *beginning* of the succeeding drouth as comprising the interval between.

The local as compared with the general distribution of precipitation.—In order to study the rainfall distribution for specific areas I have tabulated the rainfall

statistics of the State of Arizona beginning with the early seventies. At that time five rainfall stations were in operation, and while the geographic distribution is not as good as might be desired there is no alternative other than to use them as they stand. The average departure of the annual rainfall for the two groups of years 1869–1873 and 1881–1885 is shown in the statement below:

Mean.	1869	1870	1871	1872	1873	Mean.	1881	1882	1883	1884	1885	Mean.
Departures (inches)	−0.7	−3.3	−3.3	+1.9	−2.5	−1.6	+1.0	+0.3	−1.0	+5.9	−4.2	+0.4

From the above it is clear that for Arizona rainfall was deficient for the spot maxima of 1870, but with a year of more than the average, 1872 intercalated in a series of dry years. For the spot maxima of 1883.9 rainfall on the average of the five years was greater than the mean contrary to hypothesis; in this group of years there was a single year of deficient rainfall intercalated in a series of wet years.

Elsewhere in this paper it is remarked that the early eighties were years of abundant rainfall generally in the United States; Arizona seems to have been no exception to the rule.

I now pass to a consideration of the period when rainfall statistics for Arizona are more numerous than for the earlier years. The Weather Bureau publication, *Climatological Data* (Arizona), contains yearly values of the average precipitation computed from the whole number of records in the State. The published record begins with the year 1897 and is continuous to date. I have computed the State averages for 1893–1896, thus making available a continuous record for the 29 years 1893–1921. From these data I have computed the annual departure of the State average from the 29-year mean. The actual and the smoothed departures are presented in Table 3, to which have been added, for the sake of comparison, the actual and smoothed departures for the United States for the 41 years 1881–1921.

The smoothing has been accomplished by the formula $b=\frac{1}{4}(a+2b+c)$, where b is the middle year in any consecutive series of three years.

TABLE 3.—*Rainfall departures, United States (as a unit) and Arizona.*

Years.	Departures—United States.		Departures—Arizona.	
	Actual.	Smoothed.	Actual.	Smoothed.
1881	+0.4	+0.4	.....	.....
1882	+1.0	+0.2	.....	.....
1883	−1.6	±0.0	.....	.....
1884	+2.0	+0.4	.....	.....
1885	−0.3	−0.4	.....	.....
1886	−3.2	−2.7	.....	.....
1887	−4.1	−3.2	.....	.....
1888	−1.4	−2.1	.....	.....
1889	−1.7	−2.0	.....	.....
1890	−3.1	−2.4	.....	.....
1891	−1.9	−1.3	.....	.....
1892	−2.4	−2.5	.....	.....
1893	−3.4	−3.1	−2.2	−2.2
1894	−3.3	−3.5	−2.2	−2.2
1895	−4.0	−3.2	−2.1	−1.6
1896	−1.6	−2.1	+0.1	−0.6
1897	−1.3	−1.6	−0.5	−0.4
1898	−2.2	−2.1	−0.7	−1.7
1899	−2.6	−2.2	−4.9	−3.9
1900	−1.3	−2.0	−5.0	−4.4

TABLE 3.—*Rainfall departures, United States (as a unit) and Arizona*—Continued.

Year.	Departures—United States.		Departures—Arizona.	
	Actual.	Smoothed.	Actual.	Smoothed.
1901	−2.8	−2.1	−2.7	−3.4
1902	−1.4	−2.0	−3.0	−3.4
1903	−2.4	−2.5	−3.5	−3.0
1904	−4.0	−2.6	−3.5	+0.7
1905	−0.1	−1.0	+13.3	+6.4
1906	+0.3	−0.4	+2.6	+4.9
1907	−2.2	−1.6	+1.3	+1.8
1908	−2.3	−1.8	+2.2	+1.2
1909	−0.4	−2.4	−0.7	−0.9
1910	−6.6	−3.8	−4.3	−1.9
1911	−1.8	−2.6	+2.0	−0.2
1912	−0.2	−1.1	−0.7	−0.2
1913	−2.3	−1.8	−1.3	±0.0
1914	−2.6	−1.9	+3.5	+1.9
1915	−0.1	−1.5	+2.2	+2.9
1916	−3.3	−3.2	+3.7	+2.3
1917	−6.1	−4.7	−0.5	+1.2
1918	−3.4	−3.4	+1.4	+2.0
1919	−0.9	−1.5	+5.8	+3.2
1920	−0.9	−0.9	−0.1	+1.8
1921	−0.2	.....	.....	.....

The smoothed departures in both cases have served to form the two rainfall departure curves of Figure 1 and the smoothed sun-spot numbers as published in this REVIEW (**30:** 176 and **48:** 460) serve to form the curve of sun-spot numbers which also appears on Figure 1.

The Arizona rainfall departure curve does not show agreement with the sun-spot curve in the manner set forth in the hypothesis put forward in Dr. Clements' article. There is, of course, some agreement of a general character, as has been pointed out on a former page, but not such specific agreement as might be expected did the phenomena stand in the relation of cause and effect. While Dr. Clements has not made that claim, many other writers have sought to explain variations in precipitation as being due to a chain of events beginning with variations in terrestrial temperature which might properly react upon evaporation and that in turn upon cloudiness and the precipitation of rain.

The points in favor of the hypothesis which can be drawn from Figure 1 are a minimum of rainfall at the epoch of maximum sun spots of 1894.1 and also, though in a less degree, in 1917.6. It also appears that the maximum of sun spots in 1870 was associated with a minimum of rainfall in Arizona. On the other hand, there are the following inconsistencies between the facts and the hypothesis (1) the chief maximum precipitation of the 29 years occurred in 1905, about one year before spot maximum of 1906.4; the chief minimum of precipitation occurred in 1899–1900 and a prominent secondary minimum occurred in 1910, neither period being a time of maximum sun spots as required by the hypothesis.

SUMMARY.

The difficulty of combining rainfall statistics for large areas is discussed; it is also pointed out that investigations of the suggested relation between the occurrence of sun spots and terrestrial rainfall have been made in various parts of the world, and further that the net result of those investigations is inconclusive and in some cases conflicting.

The rainfall statistics for 23 States west of the Mississippi have been presented in slightly condensed form from that adopted by Dr. Clements and it is pointed out that for the 20 years considered a wet year is as likely as a dry one at times of spot maxima.

Rainfall statistics for Arizona and also for the United States as a single geographic unit are considered. These data may be interpreted as showing in some cases a relation such as is claimed; in other cases, however, there are large outstanding differences which have not been accounted for.

The diagrammatic method of presenting the data of Arizona and the United States for comparison with the sun-spot curve has been tried; the degree or success may be left to the reader. Generally the results reached by this method are more or less unsatisfactory. For the practical work of forecasting, this method can not be recommended.

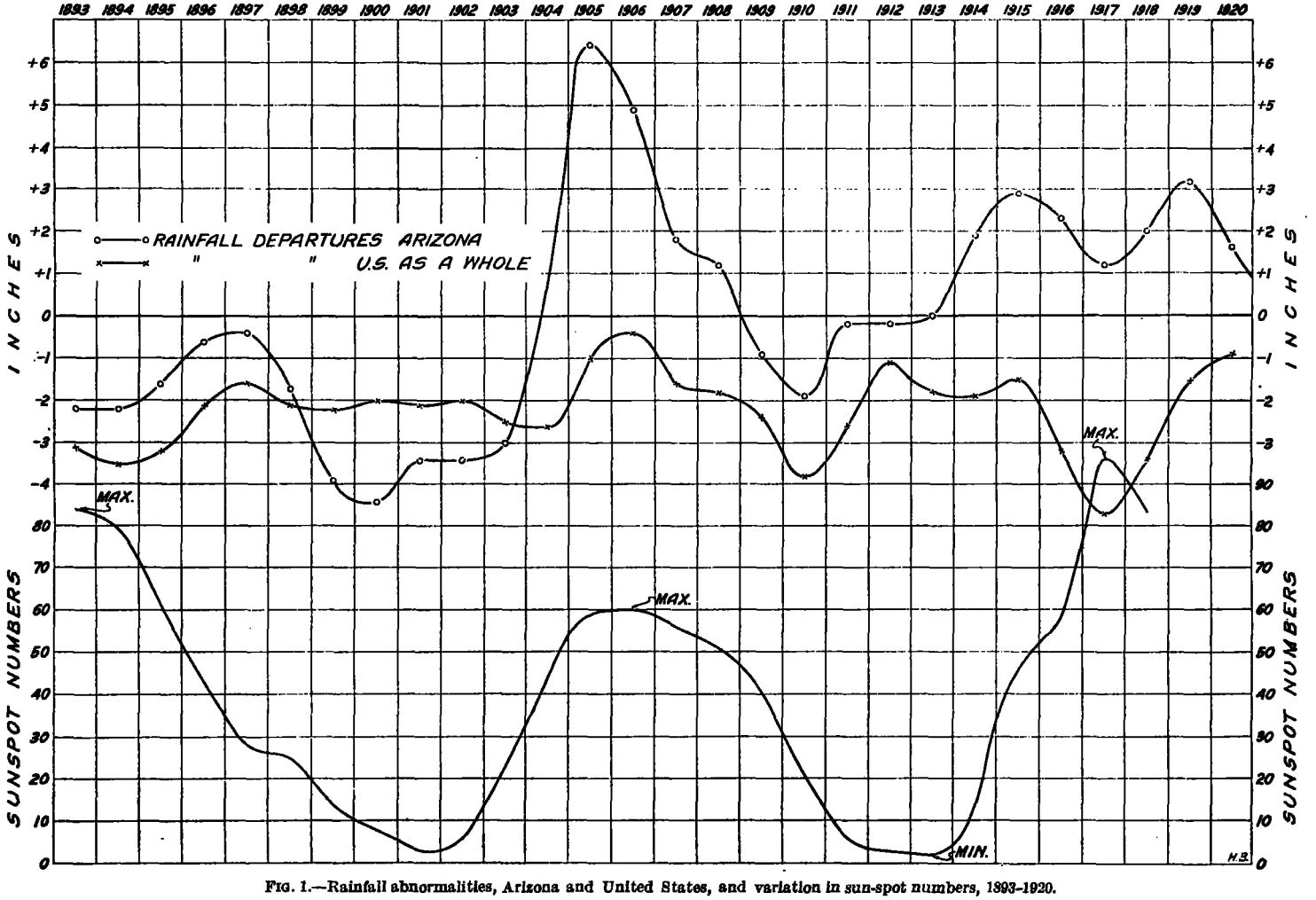

FIG. 1.—Rainfall abnormalities, Arizona and United States, and variation in sun-spot numbers, 1893-1920.

AN UNUSUAL HALO OBSERVED AT NEW HAVEN, CONN., FEBRUARY 25, 1922.

By CHARLES S. HASTINGS.

[Yale University, New Haven, Conn., Feb. 26, 1922.]

The halo was first seen by the writer at 10:10 a. m. At no time, either then or subsequently, was there a complete development. The feature which rendered it noteworthy was the effective presence of a single type of ice crystal. The common 22° circle was very faint, showing the approximate absence of fortuitously directed crystals, while the extreme faintness of the circumscribing oval, hardly more than suspected, demonstrated the almost total lack of elongated hexagonal crystals. On the other hand, the parhelion north of the sun was of a dazzling brightness, surpassing any which have previously been seen by me. The sky to the south of the sun was of a fine clearness, and therefore lacking in all indications of halo phenomena. Through the parhelion on the north was a well-defined portion of the parhelic circle, which extended through an azimuth angle of 20° to 30° beyond the parhelion to a portion of the sky free from haze. In the contrary direction it extended until lost in the light of the sun, being quite as bright where it crossed the 22° circle as at any other point.

Ten or fifteen minutes later the parhelion had become quite inconspicuous, with an added purity of the sky in its region, but of exceptionally pure spectral colors. At the same time upon a limited area of haze in the southwest appeared a well-marked portion of the parhelic circle and a paranthelion more distinct than any heretofore under my observation. The paranthelion was perfectly white, with no extension in any direction, and of a diame-