SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 146, NUMBER 3

Roebling Fund

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A SUMMARY OF THE EVIDENCE, COMPLETELY ILLUSTRATED AND DOCUMENTED

BY
C. G. ABBOT
Research Associate, Smithsonian Institution

(PUBLICATION 4545)

CITY OF WASHINGTON
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SOLAR VARIATION AND WEATHER

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From 1920 to 1955, with the aid of John A. Roebling, the Smithsonian Astrophysical Observatory under my direction, and later under that of L. B. Aldrich, made "solar-constant" observations from mountain tops in cloudless deserts in Africa, Asia, South America, and the United States. Although all the results were highly accurate, they were especially so from 1924 to 1944, for it was not till 1924 that the "short method" was fully perfected, and after 1944 the transparency of the atmosphere was less perfect than before.

From 1935 to the present I have sought to correlate the solar-constant measures with weather phenomena. I have published in Smithsonian Miscellaneous Collections [1] more than a score of papers on this subject. These papers and the volumes of the Annals of the Astrophysical Observatory, as well as several papers in outside journals, are referred to in the Appendix. They give in detail the evidence I shall rely upon in what follows.

I have been led to conclude firmly that variations of the sun's emission of radiation are associated intimately with weather changes. Since the death of H. H. Clayton I know of no professional meteorologists in the world, with the exception of Dr. Irving P. Krick, who have acknowledged support of my main conclusion. They all, indeed, credit us with highly accurate solar measurements, but in the absence as yet of connecting theory they distrust my proofs that solar variation has any considerable influence on ground weather.

Being now past 91 years of age, and firmly convinced that the sacrificing years of residence of my colleagues on high desert mountains have given to astrophysics and meteorology a long series of measurements of great practical importance, I feel compelled in jus-

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[1] In the Appendix I give full references to all sources I refer to here. Nearly all are from Smithsonian Miscellaneous Collections. For brevity in the text I shall cite the Smithsonian publication number as "P." so and so.

SMITHSONIAN MISCELLANEOUS COLLECTIONS, VOL. 146, NO. 3

tice to them to write a summary of the whole research. I hope to make it so thoroughly supported by varied evidences as to convince the professional scientists that it can no longer be ignored and allowed to sink into oblivion. But it is quite impossible for me to give half the evidence which saturates my mind with the certainty that the family of regular harmonics of 273 months, in solar radiation and terrestrial weather, is a controlling geophysical fact.

1. THE "SOLAR CONSTANT"

Pouillet invented his pyrheliometer, and about 1876, after measuring the heat of sun rays at different solar altitudes, he estimated that the instrument would have indicated 1.76 calories per square centimeter per minute if exposed outside the atmosphere at the earth's mean solar distance. Langley strongly argued that since the atmosphere transmits different wavelengths unequally, spectroscopic measures are necessary additionally to pyrheliometry to estimate the solar constant. He invented the bolometer for this purpose and used it at Allegheny Observatory and on and near Mount Whitney. Erroneous theory caused him to prefer 3.0 calories as the solar constant. K. Ångström, from solar measures on the Island of Teneriffe, attributing excessive influence to atmospheric carbon dioxide, preferred a value of 4.0 calories.

In volume 2 of Annals, A.P.O.,[2] is demonstrated the true theory for the spectrobolometric determination of the solar constant. An improved pyrheliometer similar to Pouillet's is described. Measurements at Washington, D. C., during the years covered by volume 2 indicated an average solar constant of 2.20 calories. A hint of solar variation appeared to be indicated by results of 1903 and 1904. By invitation of Director George E. Hale, we made measurements of the solar constant on Mount Wilson, Calif., in 1905 and 1906. From 1908 to 1920 the Smithsonian sent expeditions to Mount Wilson. A long-focus vertical telescope was installed in addition to solar-constant apparatus. Every day that solar constants were observed, the distribution of brightness over the diameter of the sun's disk was observed by allowing the 8-inch solar image from the telescope to drift without a clock over the slit of the spectrobolometer, in rays at various wavelengths. (See fig. 52, p. 62.)

In volume 3, Annals, A.P.O., pages 21-29, a full description of solar-constant measurement is given. The silver-disk pyrheliometer

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[2] We thus abbreviate Smithsonian Astrophysical Observatory.

is described on pages 47-52. More than 100 of these instruments have been constructed, standardized, and sold at cost by the Smithsonian Institution to observers in all parts of the world. For their standardization in absolute units, I devised the water-flow and water-stir absolute black-body pyrheliometers (see Annals, A.P.O., vol. 3, pp. 52-69). With certain improvements, the water-flow double-barreled electrical-compensation pyrheliometer has been used for standardizing pyrheliometers hundreds of times. It is now recognized as the world's standard for measurements of solar radiation. The double-barreled water-flow design was suggested by V. M. Shulgin of Russia about 1927 and was immediately adopted by us.

About 1913, with F. E. Fowle and L. B. Aldrich, I did the original standardizations. We used thermometers certified in Paris and electrical instruments certified at the U. S. Bureau of Standards. Our solar measures from that time to this have always been expressed "on the scale of 1913." During the 40 years following, whenever improvements brought alterations we always made many checks and comparisons to keep the solar constant values still "on the scale of 1913." Observed solar-constant values have ranged irregularly from 1.900 to 1.960 calories and even higher. Their mean value "on the scale of 1913" is 1.944. We now recognize that the single-barrel standard pyrheliometer of 1913 in our hands gave values about 2 percent too high. This was cured by the new instrument used since 1930. Various other important changes in solar-constant work have been made. These include restricting the sky exposure, making larger corrections for wavelengths beyond the violet and far in the infrared not observed daily, evaluating ozone absorption, determining personal equation, introduction of "the short method," and other changes. The effects of all these we have applied retroactively to all the solar-constant determinations from 1920 to 1955. (See Annals, A.P.O., vols. 6 and 7.) Every published value was scrutinized extensively by L. B. Aldrich, Mrs. A. M. Bond, and W. H. Hoover, and generally by all three as a committee. So far as we have been able to bring it about, the solar-constant tables in volumes 6 and 7 of Annals A.P.O., and also published in my papers P. 4088 and P. 4213, form a homogeneous series, all "on the scale of 1913."

Johnson, of the Naval Research Laboratory, using data from rockets, and with critical studies and use of our work, has published the solar-constant value 2.00±0.04 calories.[3] I doubt if any de-

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[3] Johnson, F. S. On the solar constant. Journ. Meteorology, vol. 11, No. 6, 1954.

termination depending basically on observing from mountain tops can claim with certainty to be within 1 percent of the absolute scale of heat. But as will be shown below, a series such as ours, where every effort was made to retain a constant scale over many years, can be depended on to preserve its *relative* homogeneity to 1/6 of 1 percent in daily values, even though 1 or 2 percent away from the true absolute scale throughout.

Volleys of criticisms of our solar-constant determinations were published between 1910 and 1914 by numerous authors. These we answered by several papers, but as they still continued we published (P. 2361) the extensive paper "New Evidence on the Intensity of Solar Radiation Outside the Atmosphere." This has three distinct parts:

(1) On September 20 and 21, 1914, two of the clearest and most uniform days ever experienced on Mount Wilson, we observed for the solar constant continuously from sunrise to 10 o'clock. This yielded for both days, by Langley's spectrobolometric method, solar-constant values computed as between air masses 1.3 and 4.0; 4.0 and 12.0; 1.3 and 20.0. All these six solar-constant measures (Langley's method) fell between 1.90 and 1.95, which shows both the excellence of the sky conditions and the accuracy of the observing.

(2) At Dr. A. K. Ångström's suggestion I designed, and our instrumentmaker Andrew Kramer constructed, five copies of an automatic combined pyrheliometer and barometer. These were flown by balloons from Omaha by L. B. Aldrich, with the cooperation of Dr. William R. Blair and his assistants from the U. S. Weather Bureau, on July 11, 1914. One instrument was recovered uninjured in Iowa. It was calibrated both before and after flight under the same conditions of temperature and barometric pressure that obtained during flight. It rose to 24,000 meters, where 24/25 of the atmosphere lay below. It yielded a value of 1.87 calories, a value that lies within the limits of solar variation, as observed in those times at Mount Wilson, and as expressed on the Smithsonian "scale of 1913."

(3) Here I quote the concluding paragraphs of our paper:

> It seems to us that, with the complete accord now reached between solar constant values obtained by the spectro-bolometric method of Langley, applied nearly 1,000 times in 12 years, at four stations ranging from sea level to 4,420 meters, and from the Pacific Ocean to the Sahara Desert; with air-masses ranging from 1.1 to 20; with atmospheric humidity ranging from 0.6 to 22.6 millimeters of precipitable water; with temperatures ranging from 0° to 30° C.; with sky transparency ranging from the glorious dark blue above

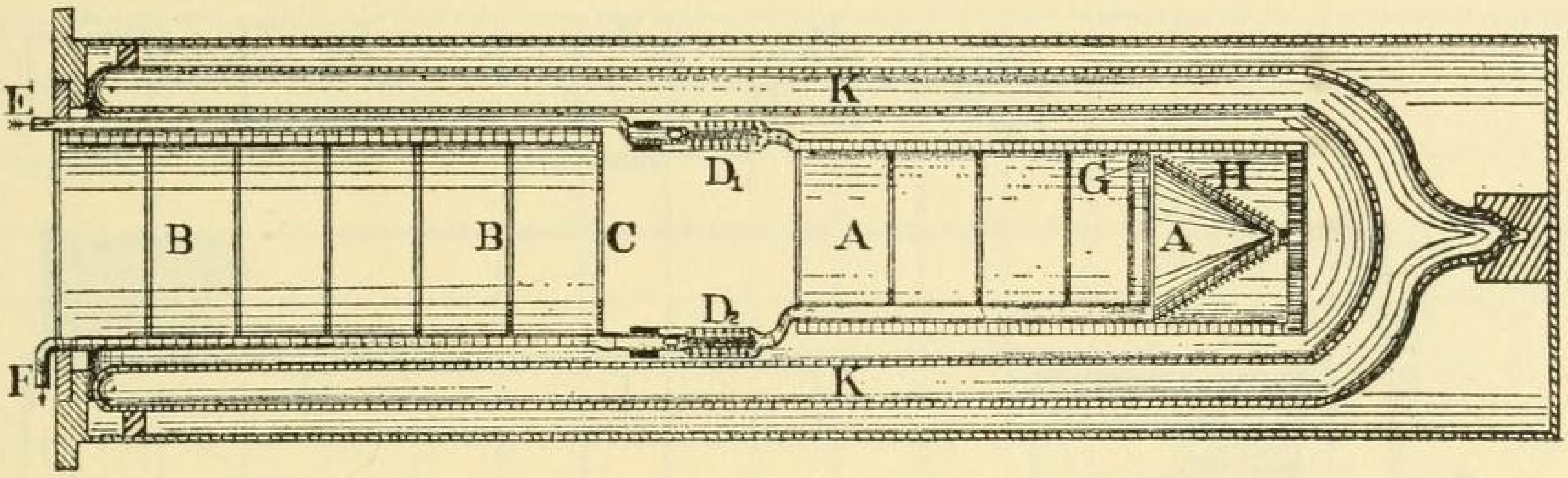


FIG. 1.—Water-flow standard pyrheliometer of 1913.

Mt. Whitney to the murky whiteness of the volcanic ash filling the sky above Bassour in 1912, it was superfluous to require additional evidence.

But new proofs are now shown in figure 10 [fig. 7, p. 10, of present paper]. This gives the results of an independent method of solar constant investigation. In this method the observer, starting from sea level, measures the solar radiation at highest sun under the most favorable circumstances, and advances from one level to another, until he stands on the highest practicable mountain peak. Thence he ascends in a balloon to the highest level at which a man may live. Finally he commits his instrument to a free balloon, and launches it to record automatically the solar radiation as high as balloons may rise, and where the atmospheric pressure is reduced to the twenty-fifth part of its sea level value. All these observations have been made. They verify the former con-

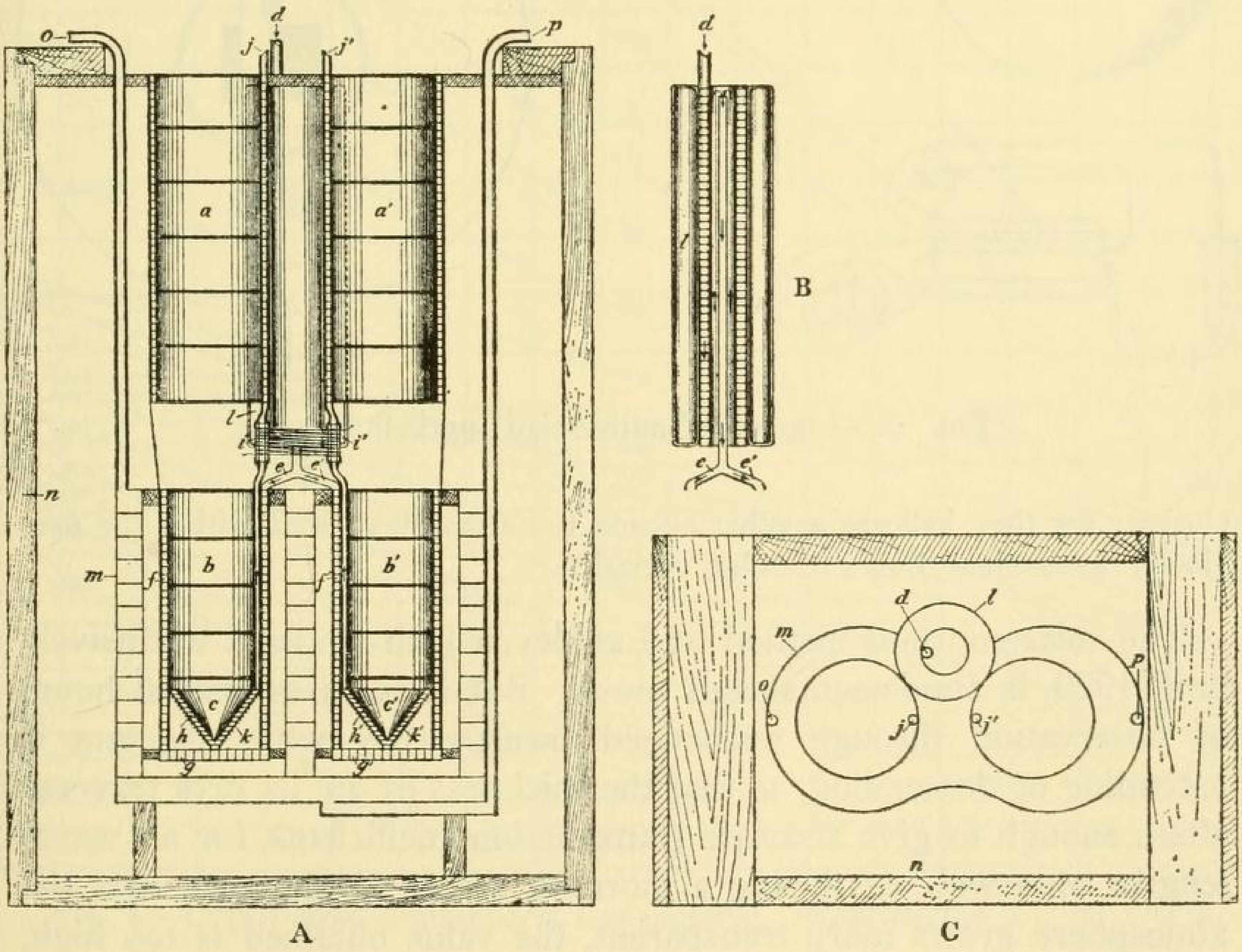


FIG. 2.—Double water-flow electrical compensation pyrheliometer.

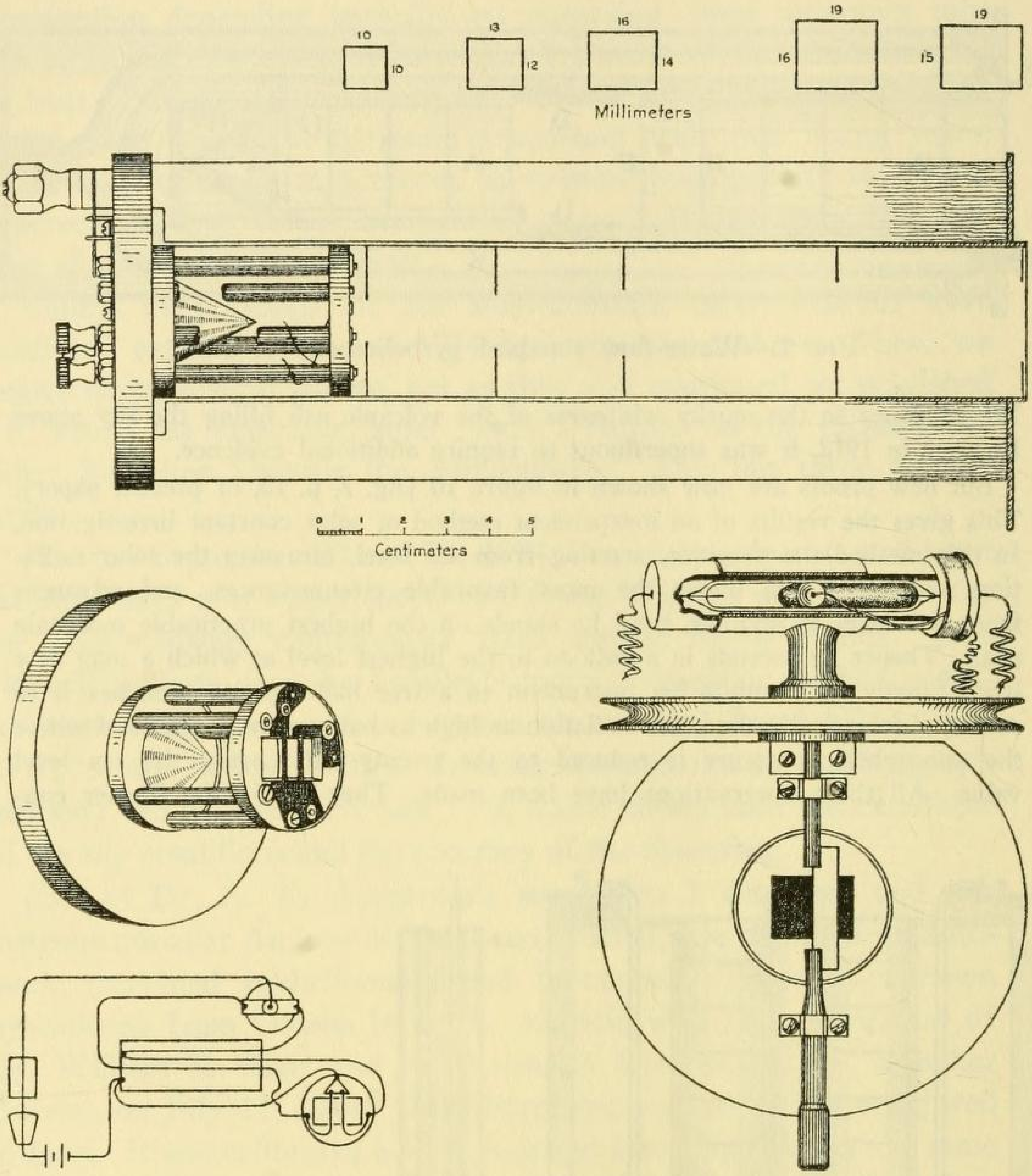


FIG. 3.—Ångström-Smithsonian pyrheliometer.

clusion; for they indicate a value outside the atmosphere well within the previously ascertained limits of solar variation.

The solar-constant method of Langley, which we used exclusively until 1920, is fundamental and sound. But it requires several hours of observation through unchanged transparency while the sun is ascending or descending, so that the thickness of air its rays traverse alters enough to give accurate transmission coefficients for all wavelengths observed. If during a morning series of measurements the atmosphere grows more transparent, the value obtained is too high, and *vice versa.* The opposite, of course, holds in the afternoon. We

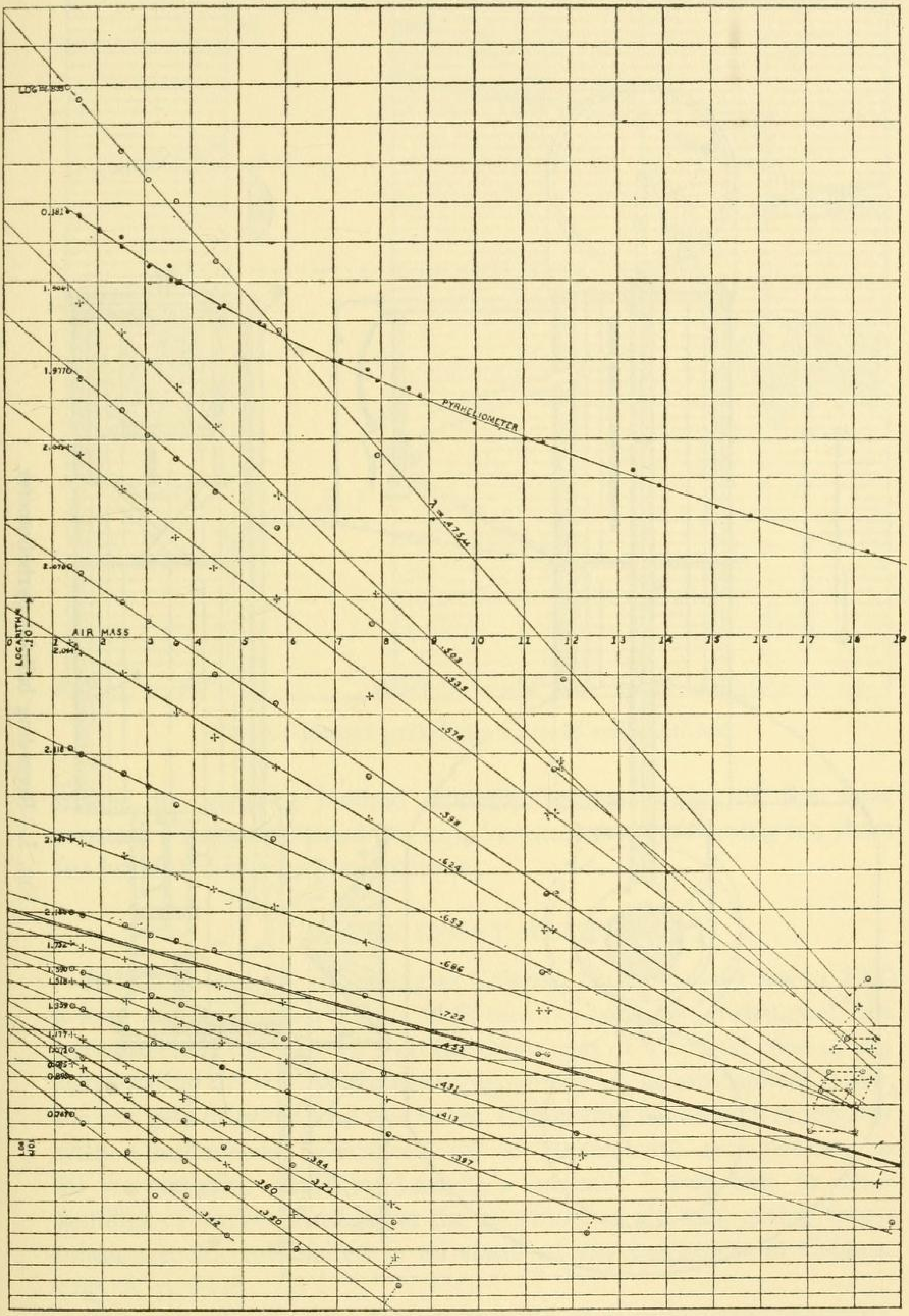


FIG. 4.—Logarithmic atmospheric transmission. Wavelengths 0.47 to 2.42 μ.

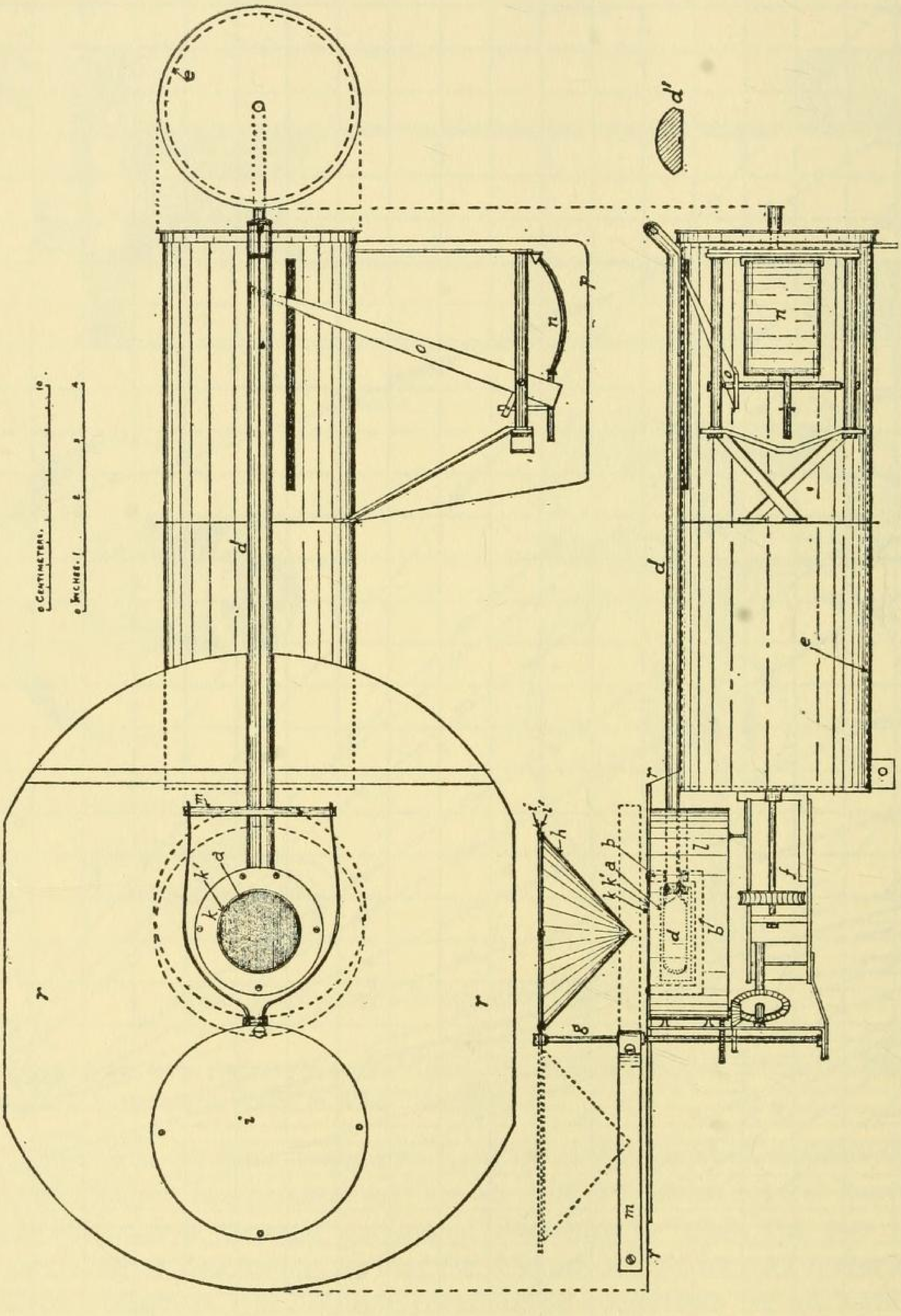


FIG. 5.—Recording balloon pyrheliometer.

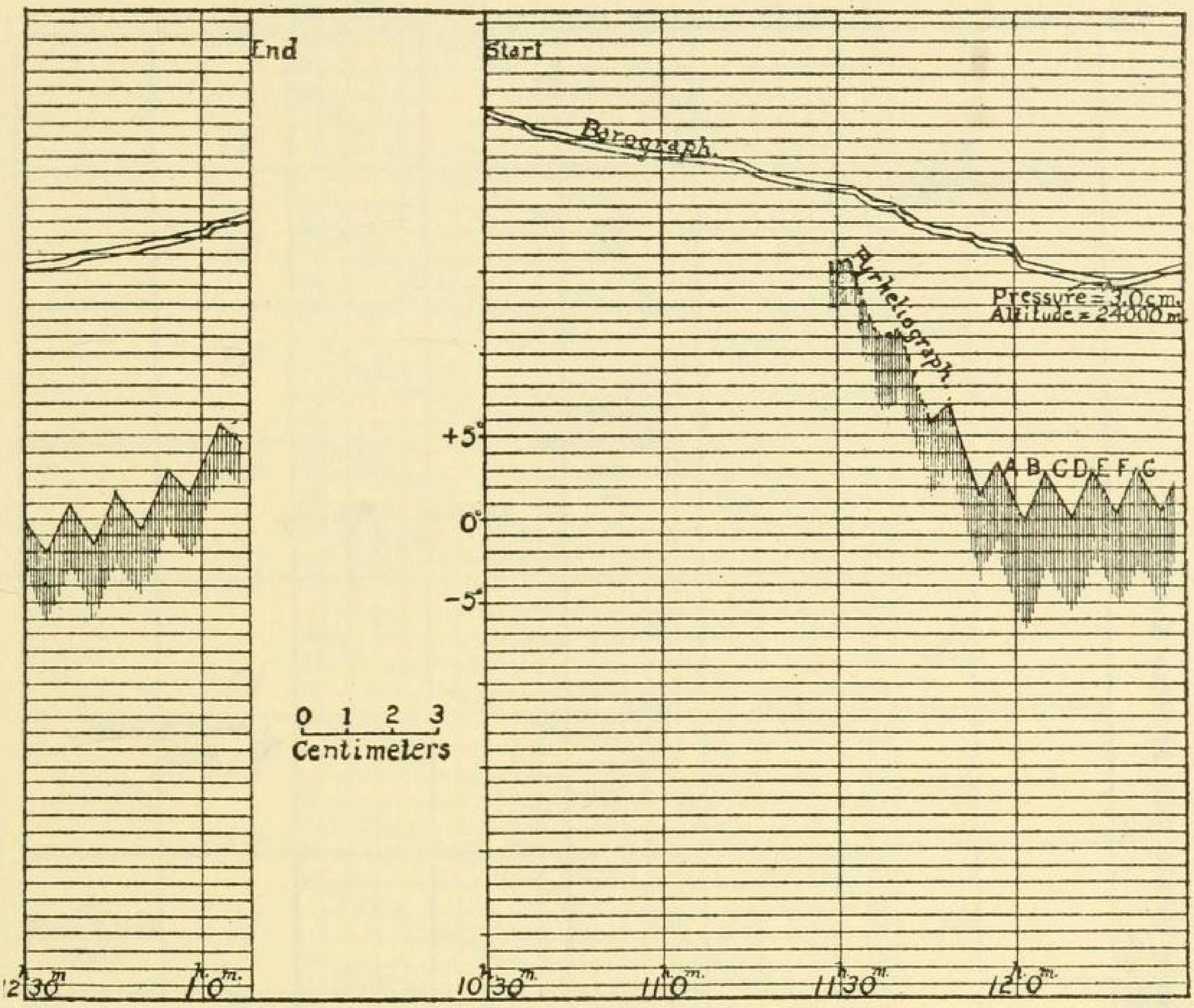


FIG. 6.—Record pyrheliometry to 15 miles altitude.

wished to devise a method whereby several values of the solar constant could be obtained per day, by intervals of observing too short for hurtful changes of transparency.

2. THE SHORT METHOD

Alfred F. Moore, observing at Calama, Chile, showed me in 1920 a long series of observations with our sky-radiation instrument, the pyranometer (fig. 9, p. 13), on the brightness of a limited zone of sky surrounding the sun. When the transparency of the atmosphere is low, the sky gets brighter, and *vice versa*. Comparing Moore's pyranometry with simultaneous determinations of atmospheric transparency at 40 wavelengths, made by Langley's method, I was able to draw families of curves throughout the spectrum of the sun, giving transmission coefficients suited to all states of sky brightness at Calama. (fig. 8, p. 11).

This is the basis of the "short method" of solar-constant observing. It requires only about 10 minutes of observing by spectrobolometer, pyranometer, and pyrheliometer. We became accustomed to making

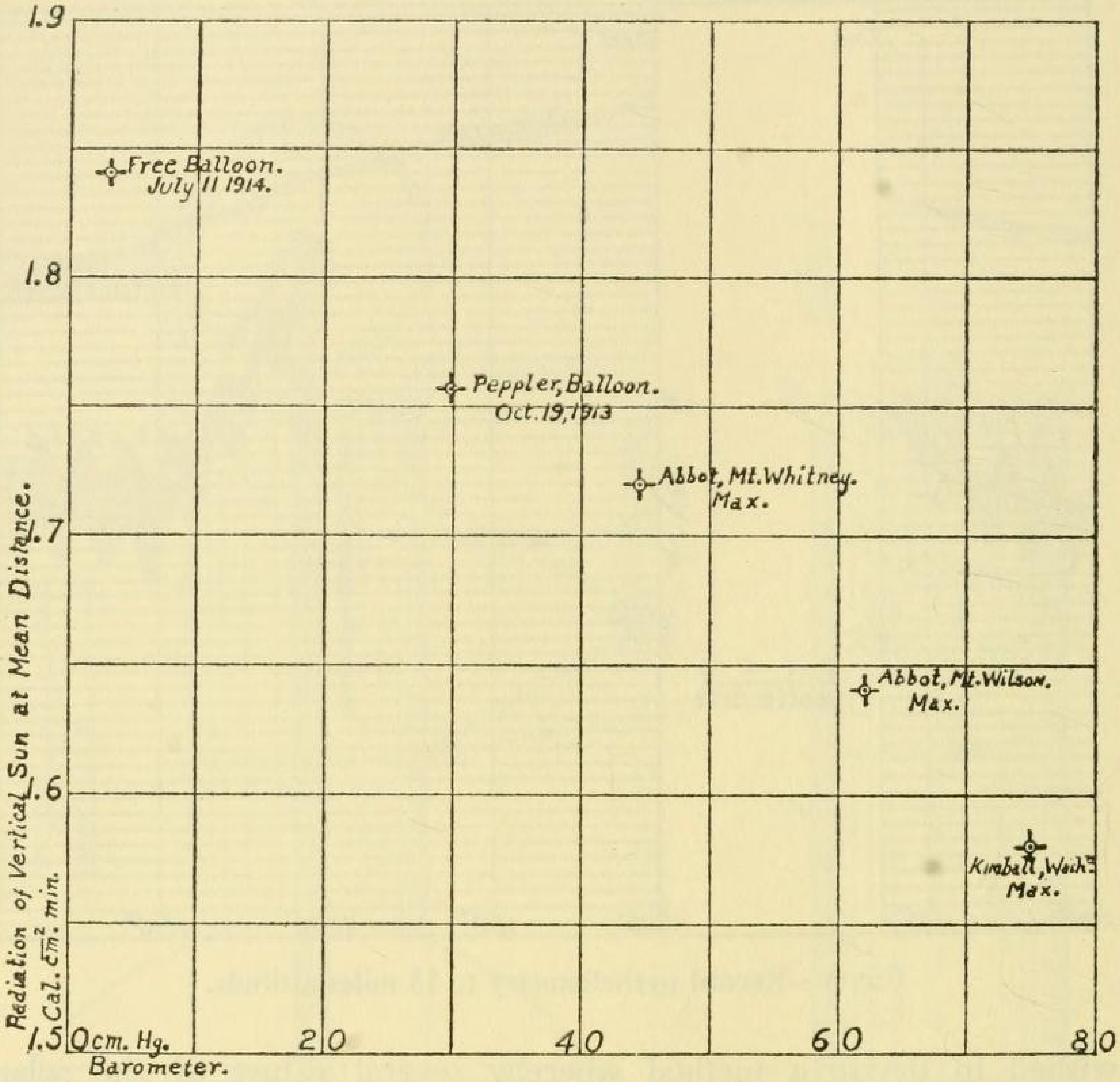


FIG. 7.—Maximum pyrheliometry, sea level to 15 miles altitude.

three or even five determinations of the solar constant per day and could utilize days with cumulus clouds intermittently—days quite unfit for Langley's method. The short method is, indeed, empirical and must be set up separately for each observing station by observing a year or more simultaneously with Langley's method to standardize it. We continually improved the "short method" till 1926, but after that we used it exclusively except for occasional checks by Langley's method.

3. ACCURACY OF "SHORT METHOD" SOLAR CONSTANTS

In volume 6, page 163, Annals, A.P.O., are compared the solar constants observed on 616 identical days at Mount St. Katherine in Egypt and Mount Montezuma in Chile. Winter at one station corresponds with summer in the other. The difference between daily results ranged from 0 to 0.028 calorie. The weighted mean differ-

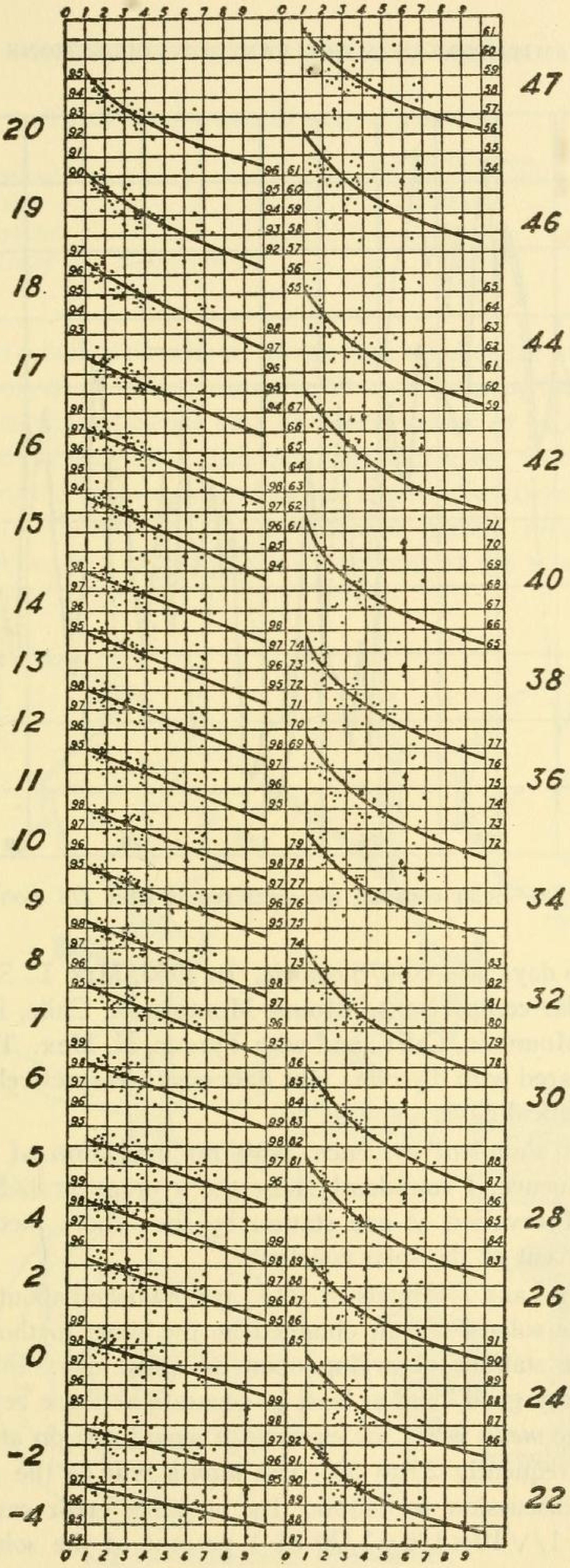


Fig. 8.—Atmospheric transmission by short method.

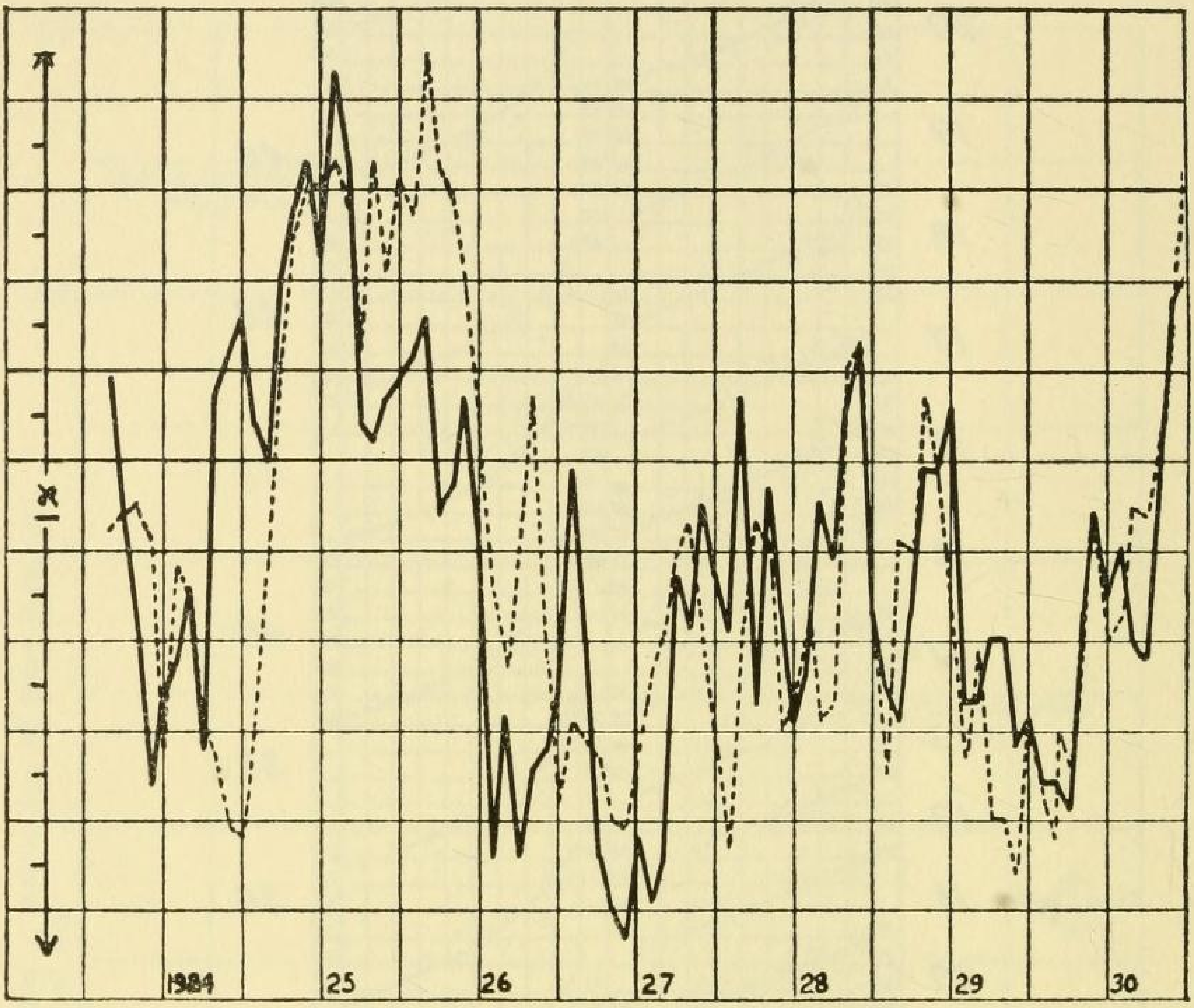


FIG. 8a.—Solar constant measures repeat after 273 months.

ence for 616 days is ±0.0076 calorie. In 1953, Mrs. L. S. Hill made several similar comparisons. Mount Montezuma, Chile, is compared with Table Mountain, Calif., and with Tyrone, N. Mex. Table Mountain is compared with Tyrone. Her data cover, respectively, 891, 283, and 202 identical days.

From this abundant evidence, with no indication of appreciable seasonal influence, I confidently take the average probable error of one day's observation at one station by the "short method" to be 1/6 of 1 percent of the solar constant.

In volumes 6 and 7, Annals, A.P.O., are published about 6,000 daily values of the solar constant obtained by the short method, often by two or three stations observing upon the same day. Fully half of them are "very good" and at least as accurate as those referred to in Table 1. The *mean* value for *one month* would rest on at least 10 of them, and frequently 20 to 30. The *month* will be the unit I shall use in the discussion to follow. Its probable error can justly be regarded as $1/\sqrt{10} \times 1/6 = 1/20$ of 1 percent of the solar constant.

TABLE 1.—*Accuracy of solar observations*

Station Pair	*Mean difference Calories ÷ 10,000*	*Number of comparisons*
Montezuma—Table	76.8	891
Montezuma—Tyrone	79.6	283
Montezuma—Mount St. Katherine	76.0	616
Table—Tyrone	77.9	202

In tabulations which we make of forms and amplitudes of harmonic solar variations, these range from 4 to 91 months in periods. Results on the solar-constant periods rest on mean values of tabulations of between 10 and 100 months, their numbers increasing as their period decreases. So the individual points on a periodic curve computed from monthly values will have probable errors ranging from $1/20 \div \sqrt{10}$ down to $1/20 \div \sqrt{100}$ of 1 percent of the solar constant.

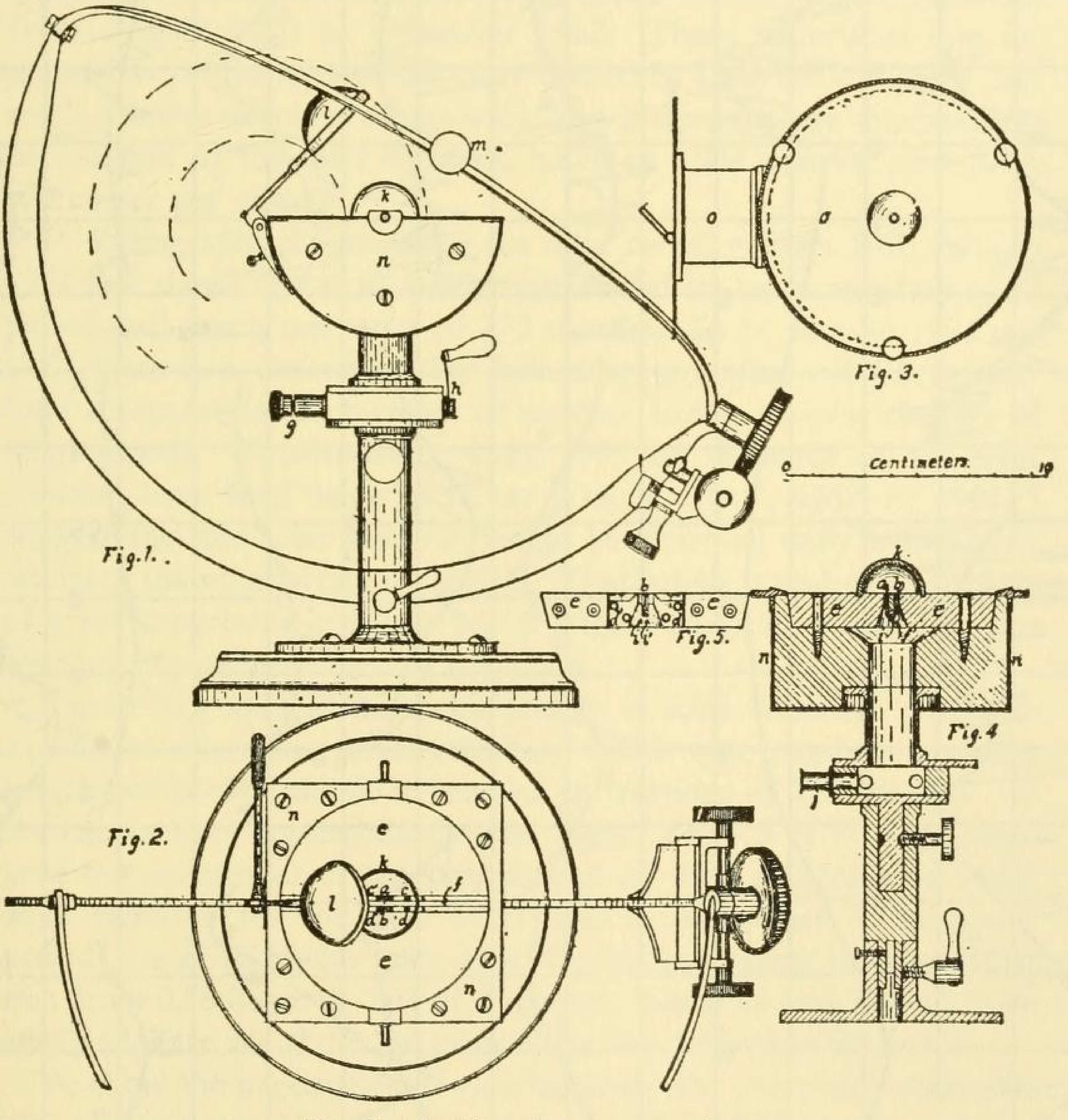
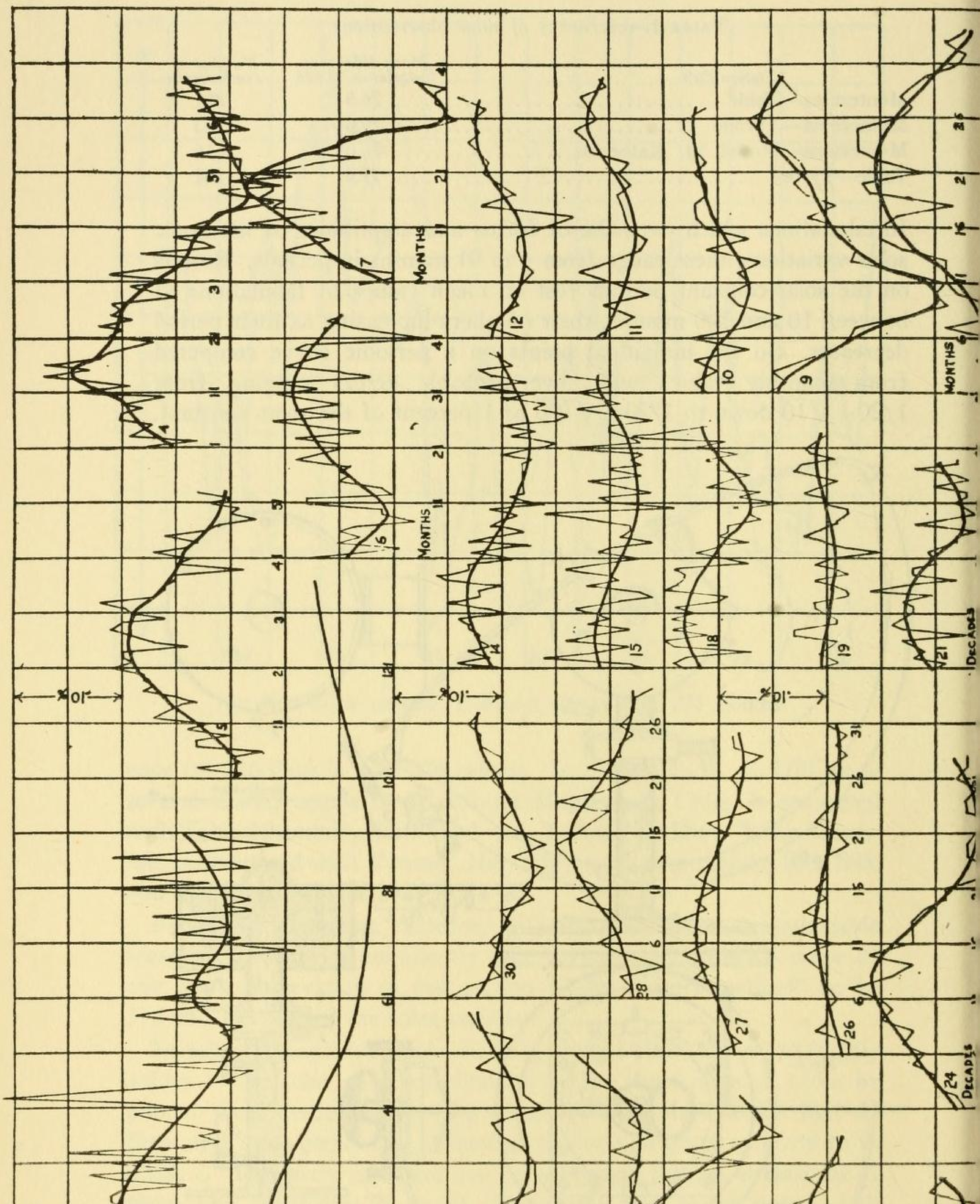


FIG. 9.—Smithsonian pyranometer.


.10%
.10%
.10%
MONTHS
MONTHS
MONTHS
MONTHS
DECADES
DECADES
2
3
4
5
6
7
9
10
11
12
14
15
18
19
21
24
26
27
28
30
34
39
45
53
67

The smoothed curves representing the periods, as will appear from figure 10, are nearly sine curves. Their regular shapes, of course, make them stronger evidences of real variation than their individual points. But these points, as just said, have probable errors ranging from 1/60 to 1/200 of 1 percent of the solar constant.

4. PERIODICITIES IN SOLAR VARIATION

Over 25 years ago I noticed periodic repetitions of dentlike depressions in graphs of the solar-constant record. These periods appeared to be harmonics of 273 months. Notably appeared 273/7, 273/21, 273/39. In my paper "Periodic Solar Variations" of June 1955 (P. 4213) I amplified what I had said earlier (P. 4088) in May 1952. For convenient tabulation I gave in the two papers together the departures from 1.90 calories of all mean monthly solar constants from August 1920 to December 1952. These departures are expressed as percentages of the solar constant. Thus the computer uses small positive numbers exclusively, and his results are expressed as percentages of the solar constant, taken as 1.944 calories per square centimeter per minute.

P. 3902 graphs the march of the solar constant from 1920 through 1951 and shows that it is closely represented by the summation of 23 periods, all exact harmonics of 273 months. To be sure, in 1922 and 1923 there is a depression far exceeding any observed since. Perhaps it represents one member of another family of solar changes of long periods. Unfortunately, since 1955 no measures of the solar constant have been made so far as I know. In P. 4462, of 1961, I suggest that the solar constant might be observed daily with higher accuracy than ours from a satellite. That might reveal solar changes of great importance in future years. Figure 8a, p. 12, shows the solar constant repeating after 273 months.

Figure 10 graphs 26 harmonic periods in solar variation. They are cleared of overriding subharmonics. Small type numbers give the length numbers of the 26 harmonics as fractions of 273 months. All the curves have approximately sine form. Table 3 of P. 4213 tabulates the amplitudes of the periods and of their submultiples which were removed for the sake of clearness. Altogether 31 harmonic periods are given in this table with amplitudes ranging in solar radiation from 0.18 down to 0.02 of 1 percent. Small as they are, all these amplitudes are far above the probable errors derived in Section 3.

To show the importance of clearing away the overriding submultiple periods, figure 11 is a graph of the period of 39.0 months recently

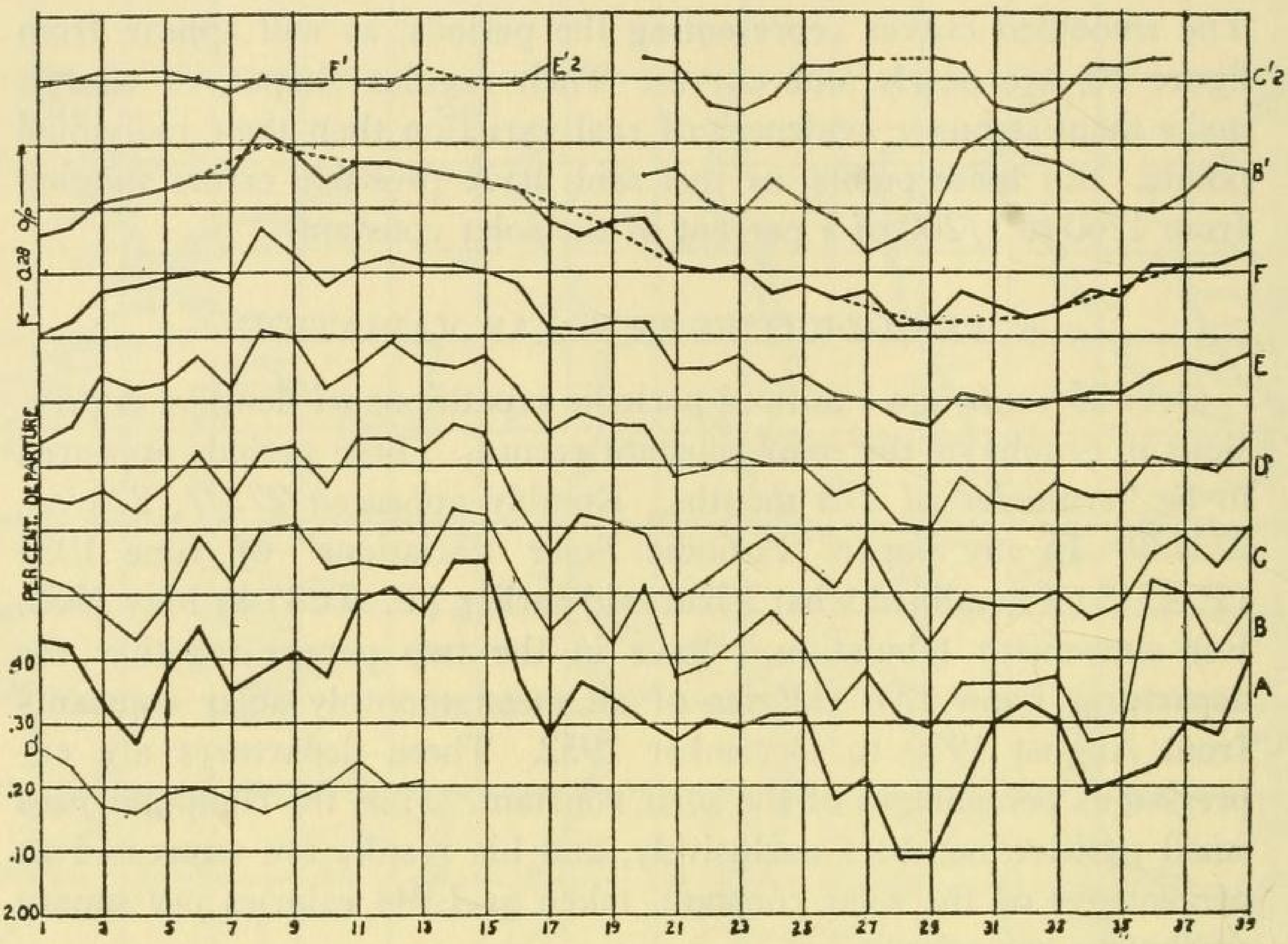


FIG. 11.—Thirty-nine-month period in solar variation cleared of shorter harmonics.

computed, using *all* the solar constant measures from the years 1923, January, through 1943, June. Periods 273/14, 273/21, 273/28, 273/35, 273/91 (and 273/24 doubtful) are shown successively removed by computation and are exhibited as graphs B′, C′, D′, E′, F′, leaving curves B, C, D, E, F. This leaves 273/7 almost fully cleared of irregularities. It is a very pretty sine curve with amplitude 0.28 percent of the solar constant.

5. ANOTHER TYPE OF PERIODIC VARIATION DUE TO SOLAR ROTATION

The late Dr. H. Arctowski published (Proc. Nat. Acad. Sci., vol. 26, pp. 406-411, 1940) graphs (here fig. 12) which show variable differences in brightness over the sun's rotating surface associated with corresponding variation of the solar constant. Figure 13 shows solar-constant results, March to April 1920. A huge sunspot group passed centrally over the sun's disk March 20-24 (see fig. 13). It produced a large depression of the sun's radiation. L. B. Aldrich gave extensive evidence (Smithsonian Report for 1952) proving the increase of solar radiation with increased sunspot activity (see fig. 14).

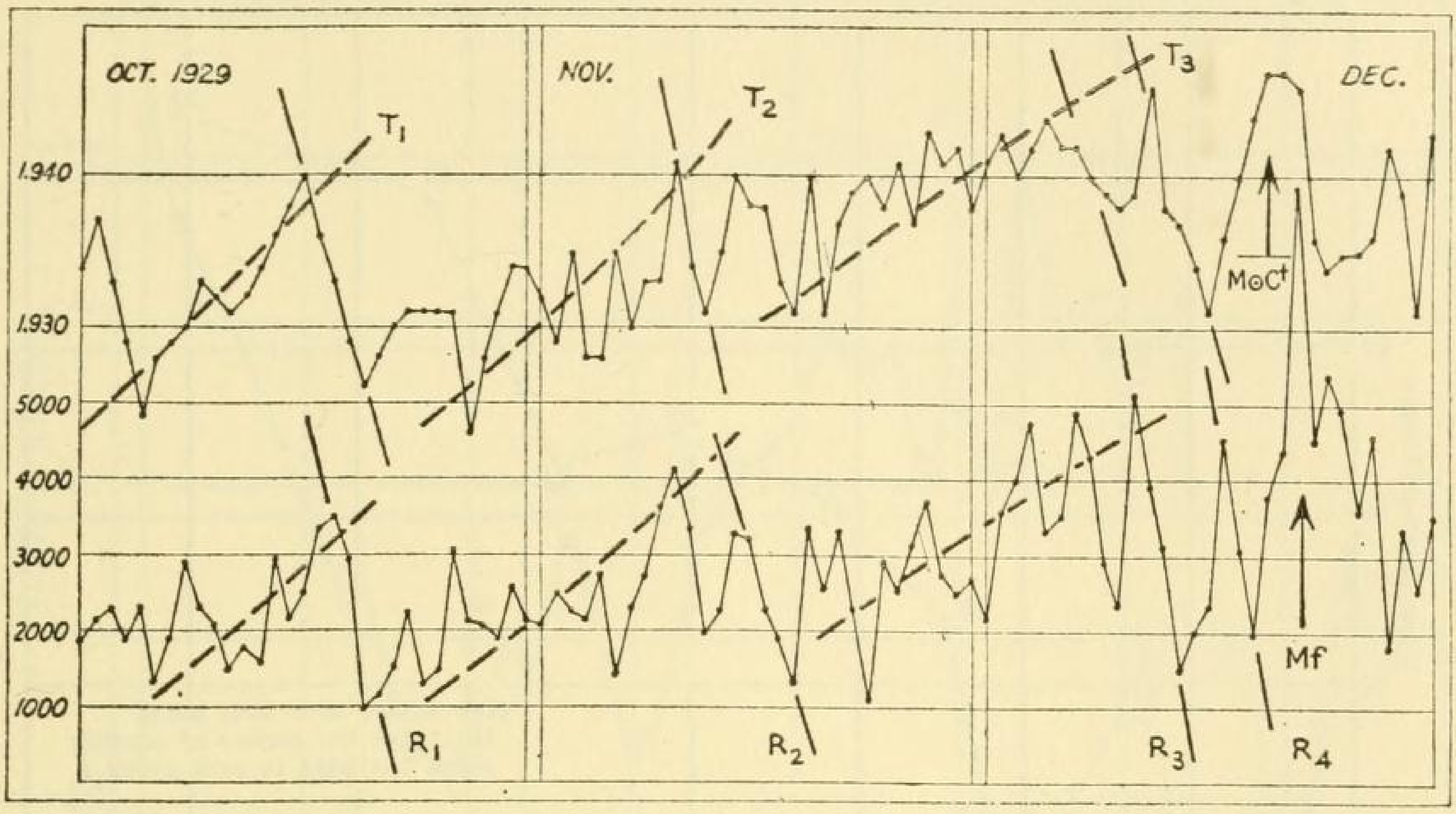


FIG. 12.—Relationship of calcium flocculi and solar constant as demonstrated by Arctowski

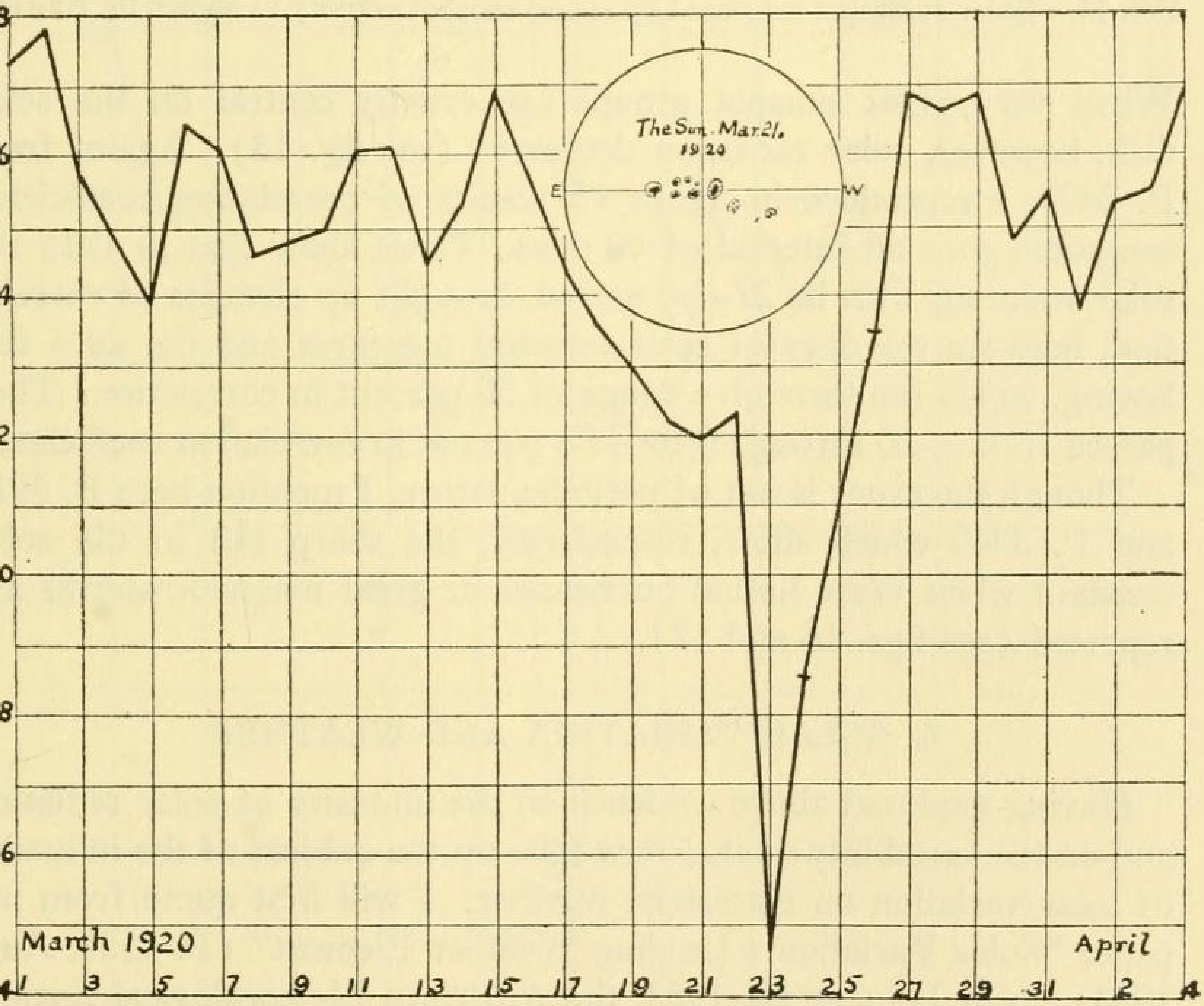
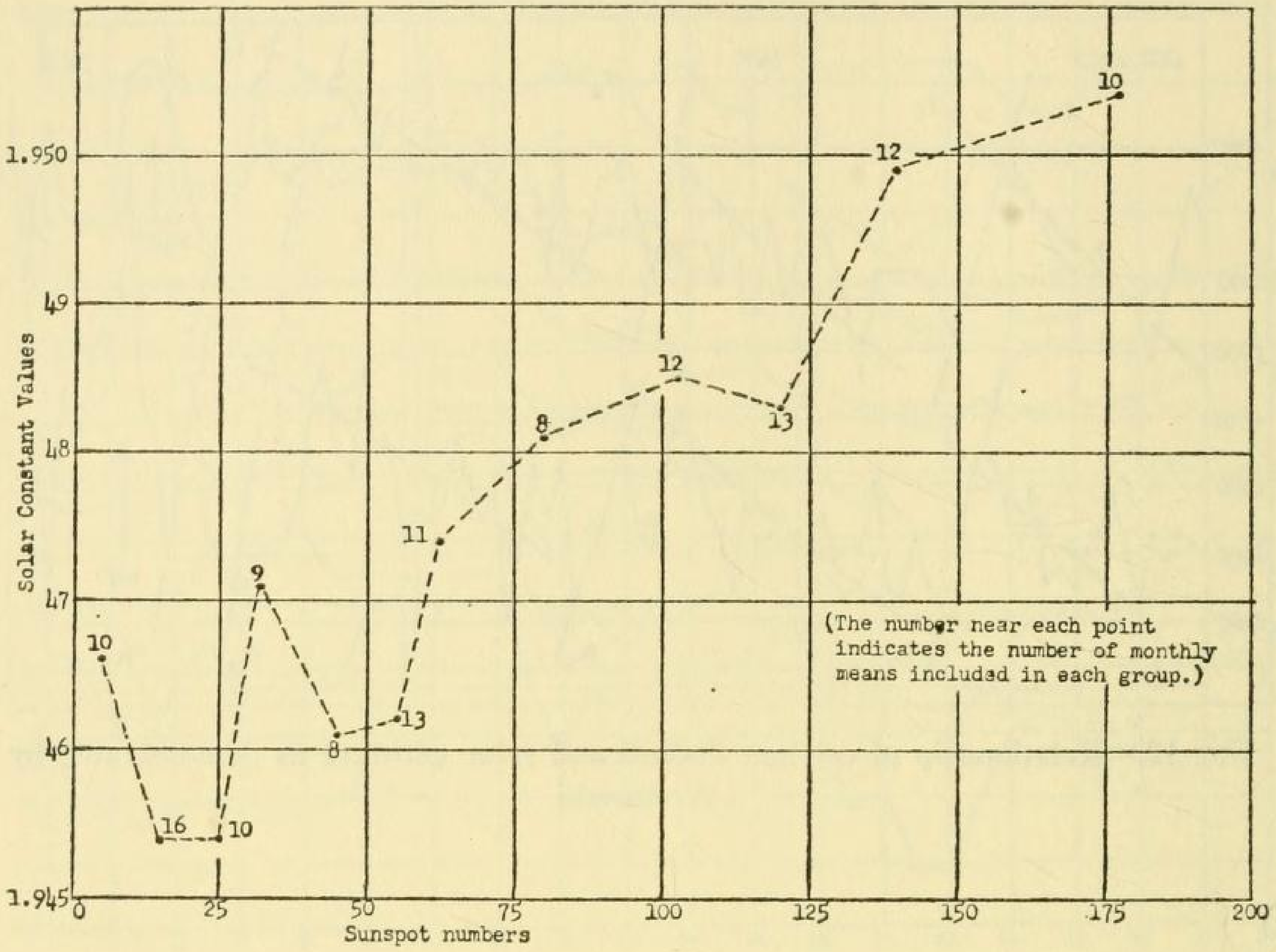


FIG. 13.—Huge sunspot central group of March 1920 depresses sun's radiation.



(The number near each point indicates the number of monthly means included in each group.)

FIG. 14.—Solar radiation increased by rising sunspot activity as shown by Aldrich.

When very great sunspot groups are *exactly* central on the solar disk, however, solar radiation decreases (see fig. 13). Again, from P. 2499, I reproduce in figure 15 results of correlation coefficients computed over an interval of 40 days. These show that in 1915 the solar rotation, with its 27-day period, brought up changes of correlation, between the days of solar-constant measures and the days following, which ran through a range of 50 percent in correlation. They passed from +20 through 0 to −30 percent in correlation coefficients.

Though the event is not of periodic nature, I mention here P. 3916 and P. 3940 which show, respectively, the sharp fall in the solar constant when West Indian hurricanes or great magnetic storms are reported (see figs. 16 and 17).

6. SOLAR VARIATION AND WEATHER

Having explored above evidence on the intensity of solar radiation and on the variability of it, I now take up the subject of the influence of solar variation on terrestrial weather. I will first quote from my paper "Solar Variation a Leading Weather Element" (P. 4135, Aug. 1953): "On January 28, 1953, the American Meteorological Society devoted the day to consideration of the influence of solar variation on

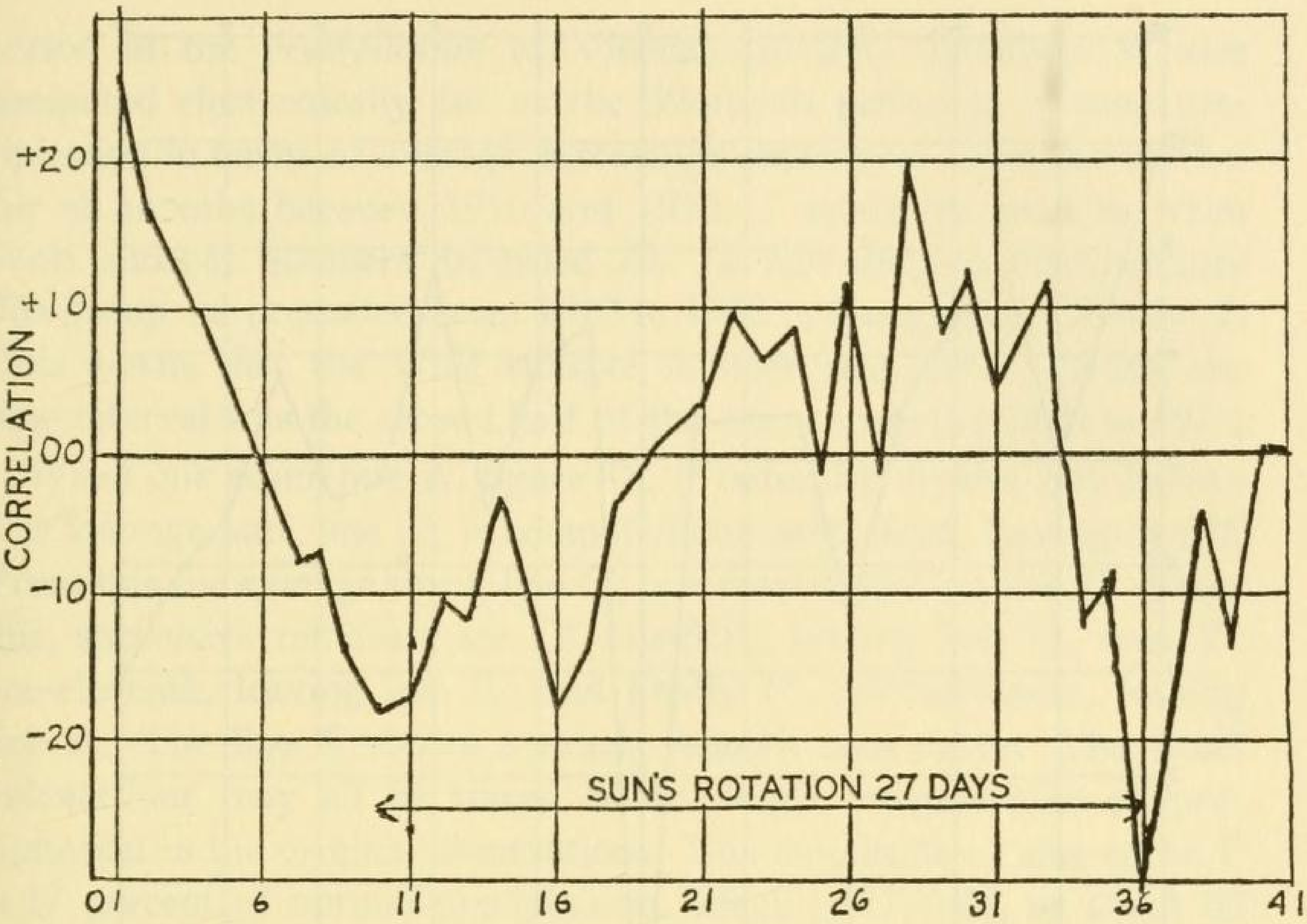


FIG. 15.—Sun's rotation in 27 days shown in 1915 solar-constant correlation.

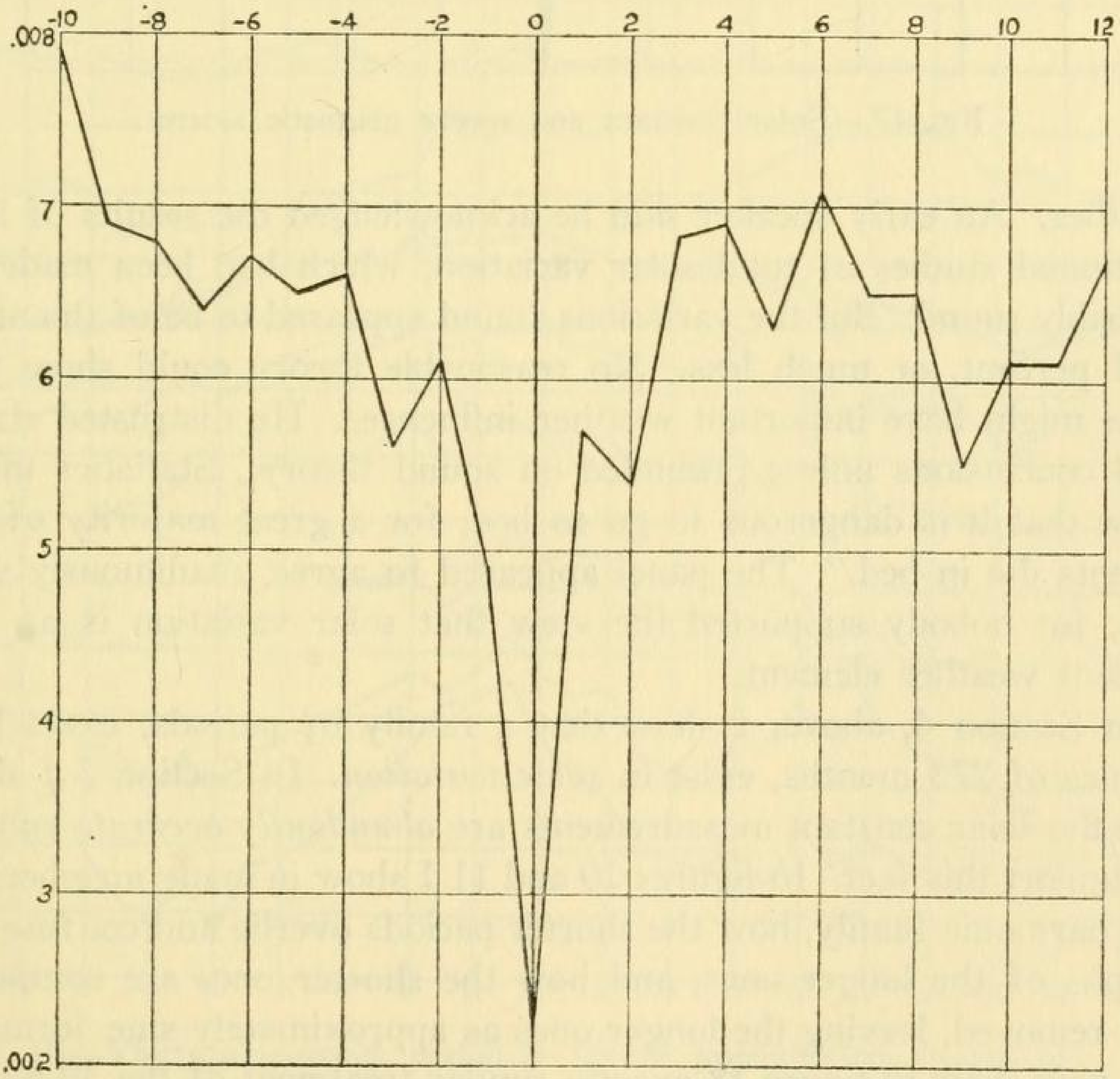


FIG. 16.—Solar constant and West Indian hurricanes.

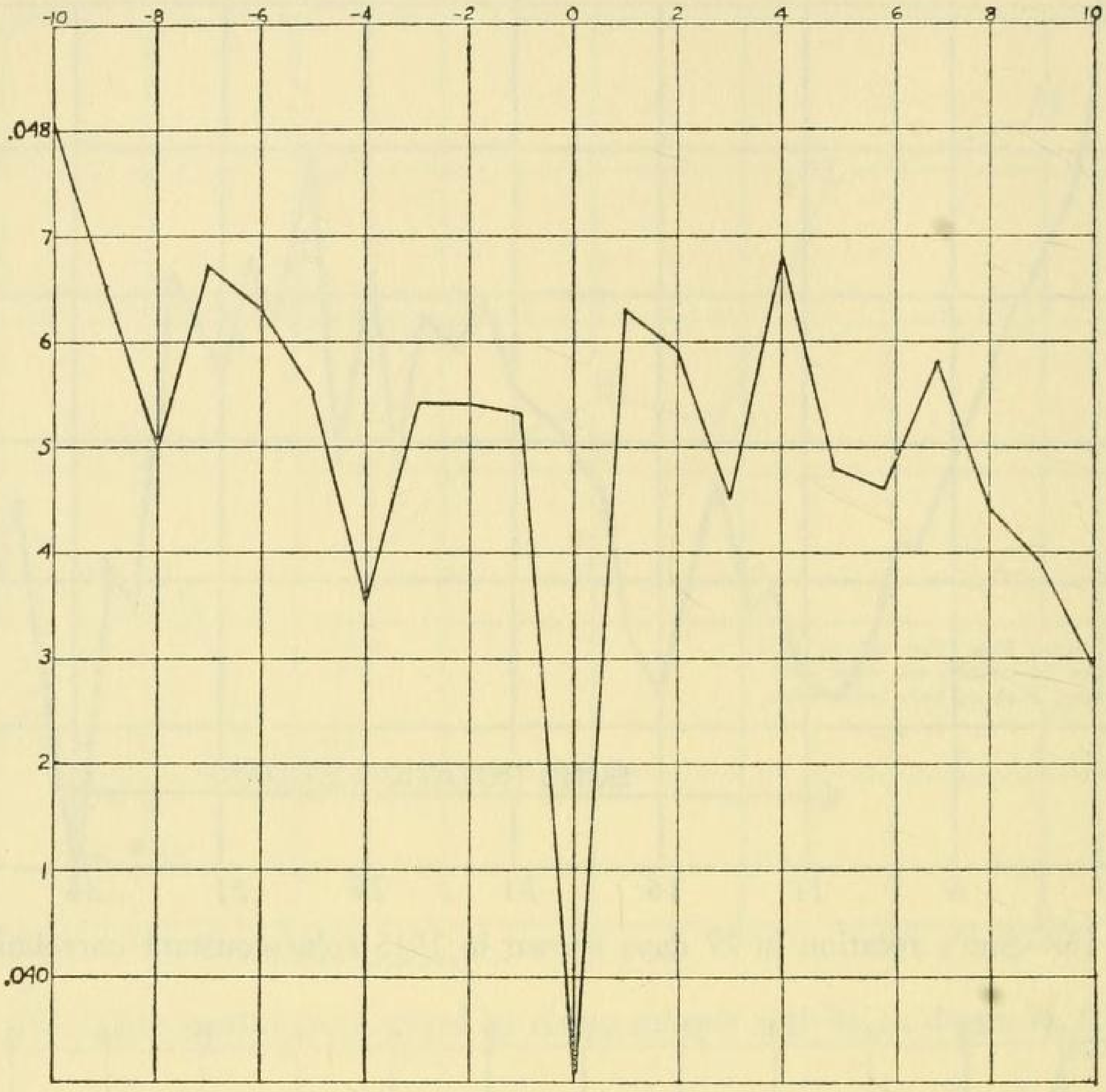


FIG. 17.—Solar constant and severe magnetic storms.

weather. An early speaker said he acknowledged the results of long continued studies of total solar variation, which had been made, as probably sound. But the variations found appeared to be of the order of 1 percent, or much less. No reasonable theory could show that these might have important weather influences. He distrusted statistical conclusions unless grounded on sound theory. Statistics might show that it is dangerous to go to bed, for a great majority of decedents die in bed." The panel appeared to agree unanimously with him, for nobody supported the view that solar variation is an important weather element.

In Section 4, above, I show that a family of periods, exact harmonics of 273 months, exist in *solar variation.* In Section 3 I show that the solar constant measurements are *abundantly accurate enough* to support this fact. In figures 10 and 11 I show in many members of this harmonic family, how the shorter periods overlie and confuse the graphs of the longer ones, and how the shorter ones are computed and removed, leaving the longer ones as approximately sine forms.

I now show in figure 18 exactly similar treatment of the 39-month period in the *precipitation* at Vienna, Austria. Jonathan Wexler computed electronically for us the 39-month period in Vienna precipitation in terms of average percentage departures from the normal for all months between 1910 and 1950. I select the months when Wolf sunspot numbers exceeded 20. In our adopted nomenclature this group as presented from 1910 to 1950 is Category 2, Division 2. This means that the Wolf sunspot number was above 20 and the time interval was the second half of the years spanning 1870 to 1950.

When one scans line A, figure 18, it naturally divides into halves. The average half, line B′, is computed and subtracted, leaving line B. From this the average third, line C′, is removed, leaving line C. From this, successive removals are D′, one-fifth, leaving line D; then E′, one-eleventh, leaving line E; and finally F′, one-thirteenth, leaving line F. The line F shows a nearly smooth sine curve. The small indentations may all be traced to accidental irregularities of precipitation in the original observations. The amplitude of sine curve F is 17 percent of normal precipitation, which is 17/0.28, or about 60

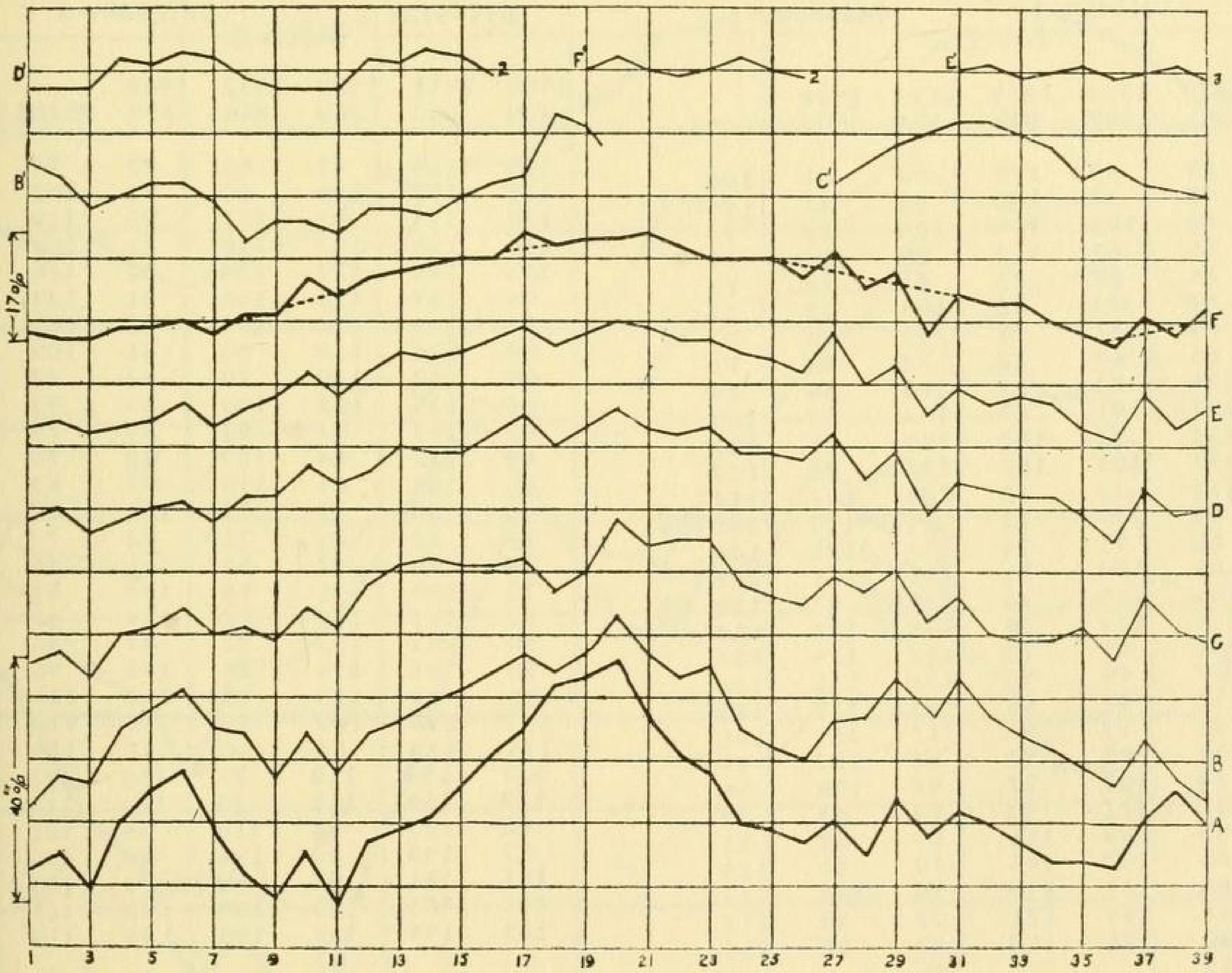


FIG. 18.—Thirty-nine-month period in Vienna precipitation, cleared of shorter harmonics.

times as great as the amplitude of sine curve line F (fig. 11), is in percentage of the solar constant.

I will now give in figures 19 and 20 two more examples from our study of the period 273/9, or 30-1/3 months, in the precipitation of Buenos Aires, Argentina. Tables 2 and 3 of Figure 19 are from a direct photograph of Jonathan Wexler's electronic computation of Category 1, Divisions 1 and 2, for the period of 30-1/3 months.[4] Taking first Division 1, Mrs. Hill's graph (fig. 20) from Wexler's means discloses an obvious overriding period of 273/18. Removing this as usual, the curve remaining discloses 273/27. After this I removed 273/45, then 273/63. This left a nearly smooth sine curve, 273/9, of about 30 percent amplitude, with minimum at the fifth, and maximum at the twentieth month.

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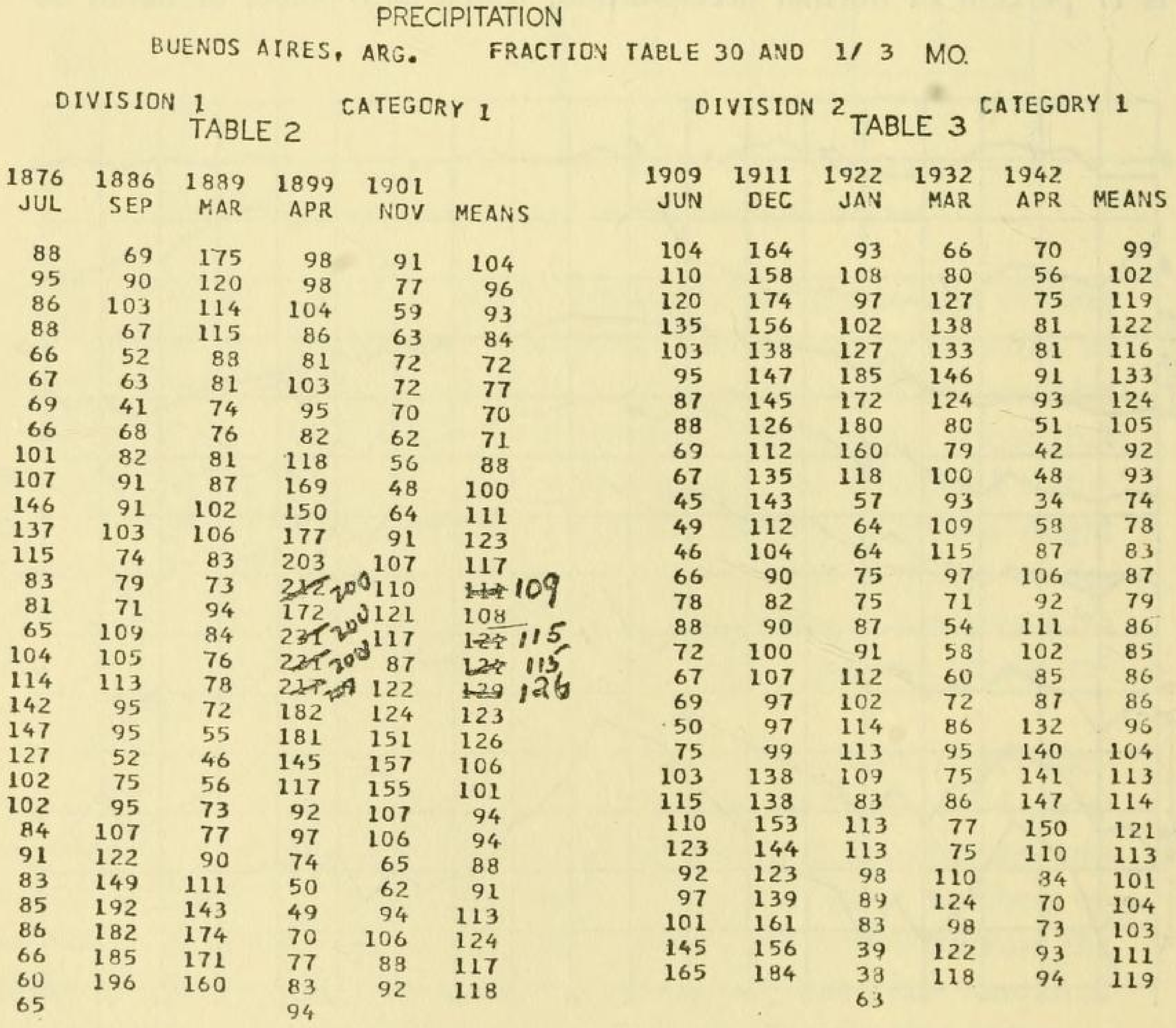
[4] As shown on figure 19 we arbitrarily cut down precipitation when very high to 200 percent normal.



PRECIPITATION

BUENOS AIRES, ARG. FRACTION TABLE 30 AND 1/ 3 MO.

DIVISION 1 CATEGORY 1

TABLE 2

1876 JUL	1886 SEP	1889 MAR	1899 APR	1901 NOV	MEANS
88	69	175	98	91	104
95	90	120	98	77	96
86	103	114	104	59	93
88	67	115	86	63	84
66	52	88	81	72	72
67	63	81	103	72	77
69	41	74	95	70	70
66	68	76	82	62	71
101	82	81	118	56	88
107	91	87	169	48	100
146	91	102	150	64	111
137	103	106	177	91	123
115	74	83	203	107	117
83	79	73	~~212~~ 200	110	~~111~~ 109
81	71	94	172	121	108
65	109	84	~~231~~ 200	117	~~122~~ 115
104	105	76	~~221~~ 200	87	~~122~~ 115
114	113	78	~~217~~ 200	122	~~129~~ 126
142	95	72	182	124	123
147	95	55	181	151	126
127	52	46	145	157	106
102	75	56	117	155	101
102	95	73	92	107	94
84	107	77	97	106	94
91	122	90	74	65	88
83	149	111	50	62	91
85	192	143	49	94	113
86	182	174	70	106	124
66	185	171	77	88	117
60	196	160	83	92	118
65			94		

DIVISION 2 CATEGORY 1

TABLE 3

1909 JUN	1911 DEC	1922 JAN	1932 MAR	1942 APR	MEANS
104	164	93	66	70	99
110	158	108	80	56	102
120	174	97	127	75	119
135	156	102	138	81	122
103	138	127	133	81	116
95	147	185	146	91	133
87	145	172	124	93	124
88	126	180	80	51	105
69	112	160	79	42	92
67	135	118	100	48	93
45	143	57	93	34	74
49	112	64	109	58	78
46	104	64	115	87	83
66	90	75	97	106	87
78	82	75	71	92	79
88	90	87	54	111	86
72	100	91	58	102	85
67	107	112	60	85	86
69	97	102	72	87	86
50	97	114	86	132	96
75	99	113	95	140	104
103	138	109	75	141	113
115	138	83	86	147	114
110	153	113	77	150	121
123	144	113	75	110	113
92	123	98	110	84	101
97	139	89	124	70	104
101	161	83	98	73	103
145	156	39	122	93	111
165	184	38	118	94	119
		63			

FIG. 19.—Electronic tabulation of precipitation at Buenos Aires, 30⅓-month period.

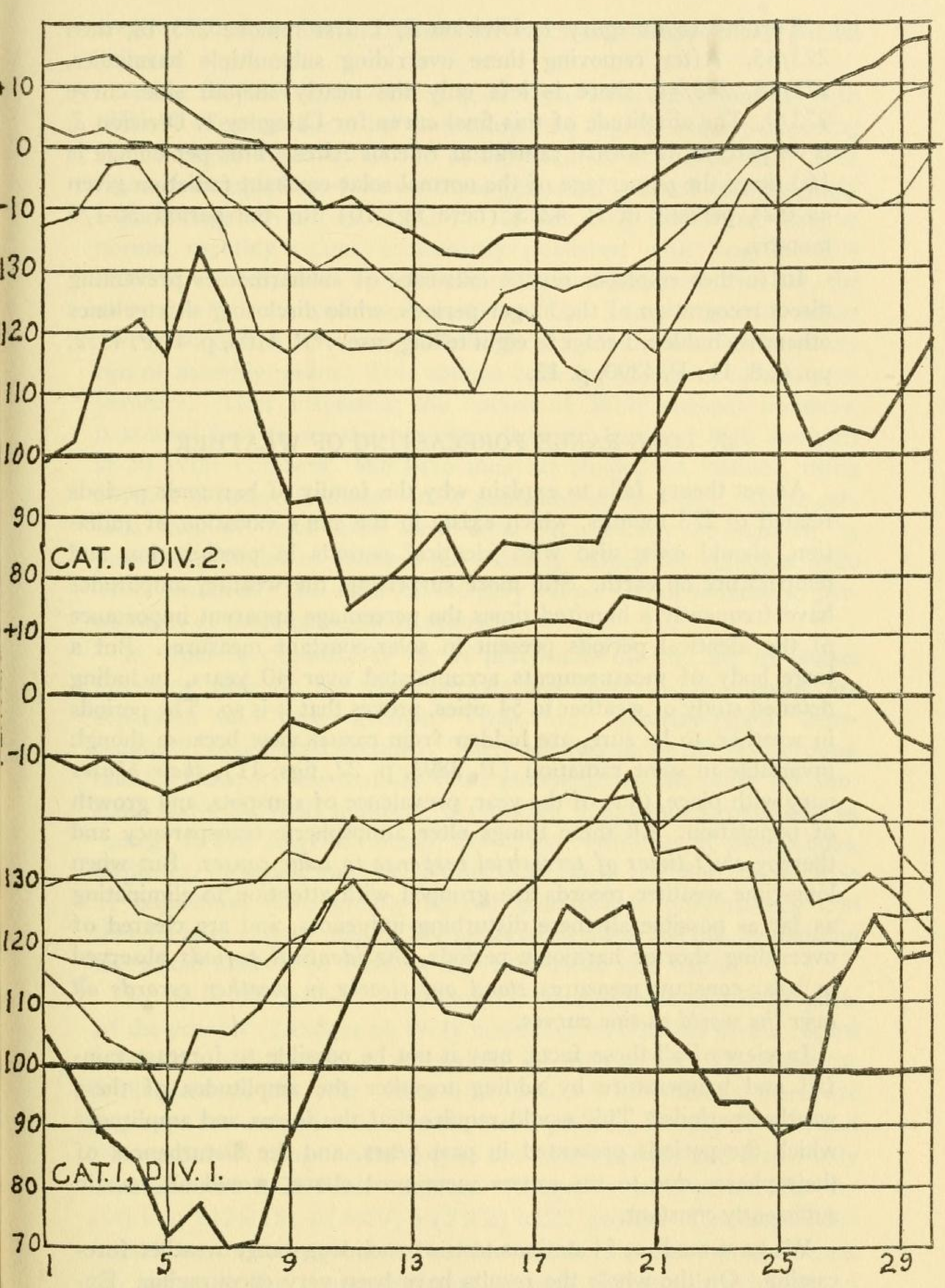


FIG. 20.—Buenos Aires precipitation, 30⅓-month period, cleared of shorter harmonics.

Turning to Category 1, Division 2, I first remove 273/18, then 273/45. After removing these overriding submultiple harmonics, 273/18, 273/45, there is left only the nearly smooth sine curve 273/9. The amplitude of this final curve for Category 1, Division 2, is 34 percent of normal rainfall at Buenos Aires. This percentage is 160 times the percentage of the normal solar-constant radiation given as 0.21 percent in P. 4213 (here fig. 10) for the period 30-1/3 months.

In further emphasis on the existence of subharmonics preventing direct recognition of the longer periods, while disclosing shorter ones otherwise hidden, I refer to eight telling cases: P. 4103, p. 4; P. 4352, pp. 6, 8, 11; P. 4390, p. 12.

7. LONG-RANGE FORECASTING OF WEATHER

As yet theory fails to explain why the family of harmonic periods related to 273 months, which exists in the sun's variation of radiation, should exist also with identical periods in precipitation and temperature on earth. Still more surprising, the weather amplitudes have frequently a hundred times the percentage apparent importance of the identical periods present in solar-constant measures. But a huge body of measurements accumulated over 40 years, including detailed study of weather in 54 cities, proves that it is so. The periods in weather, to be sure, are hidden from casual view because though invariable in solar radiation (P. 3893, p. 22, figs. 11), *their phases vary* with place, time of the year, prevalence of sunspots, and growth of population. All these things alter atmospheric transparency and thereby *shift times of terrestrial response to solar causes.* But when long-time weather records are grouped with attention to eliminating as far as possible all these disturbing influences, and are cleared of overriding shorter harmonic periods, *the identical periods* observed in solar-constant measures *stand out clearly in weather records all over the world* as sine curves.

In view of all these facts, may it not be possible to forecast rainfall and temperature by adding together the amplitudes of these weather periods? This would require that the forms and amplitudes which the periods presented in past years, and the disturbances of their phases due to the causes mentioned above, would all remain sufficiently constant.

We have made at 54 stations tests of such long-range weather forecasting. On the whole the results have been very encouraging. Examples will show both excellent successes and disappointing partial failures.

About 10 years ago, working quite alone from the beginning with "World Weather Records," and computing myself every succeeding step, I began the study of the precipitation at St. Louis, Mo. This research occupied me for over three years and resulted encouragingly beyond expectation (see P. 4211). It was early discovered that the normal monthly values, customarily published with long monthly weather records, must be recalculated in two parts, one for low, the other for high sunspot numbers (P. 4090). Sunspot activity makes a very important difference, both in the magnitudes and in the yearly run of monthly means. This obtains both for precipitation and temperature. After inspecting the curves of Wolf sunspot numbers, it seemed best to set the boundary between low and high sunspots at 20 Wolf numbers. We have thus far studied 54 stations, using "World Weather Records" (now published up to 1950). These records that we have used have been electronically recomputed by Jonathan Wexler to give normal monthly values for sunspots $\gtrless 20$ Wolf numbers. The observed monthly values are all reduced to percentages of these new sets of normals.

In order to eliminate as far as practicable the shifting of phases attending time of the year, periods less than 15-1/6 months are separated into three groups. These are: January-April; May-August; September-December. There are two series of these groups, one for sunspots less than 20 Wolf numbers, and the other for sunspots above 20 Wolf numbers. As we see, exaggerated conditions as "smog" in Los Angeles County, Calif., the multitudes of automobiles, airplanes, factories, and forest fires which have attended the increase of population have greatly altered atmospheric transparency and thereby have shifted phases. We imperfectly allow for this by dividing the whole interval of records, say 1870-1950, into halves.

So, up to the period 15-1/6 months, consideration of the (*3* parts of the year) × (*2* ranges of Wolf numbers) × (*2* halves of the record interval) yields 12 groups of records for each period. Dropping the 3 divisions of the year, from 18-1/5 to 45-1/2 months there are 4 groups for each period. For the last 3 periods, 54-3/5, 68-1/4, and 91 months, we drop the halving of the time interval, and retain only separation of $\gtrless 20$ Wolf numbers. Altogether we separate the record into $(12 \times 15) + (4 \times 9) + (3 \times 2) = 222$ groups. This separation would restrict many groups to too few members to deserve confidence. So we make the assumption that, though different individually in phases, the groups of the same Wolf number will be approximately of nearly the same form of distribution, and amplitude of intensity, and may be combined. But if combined, the individual phases must not be lost sight of. So when six columns of means are averaged to yield one general mean, the columns must be shifted bodily upward or downward to be as nearly as possible in the same phase. We use symbols, ok, $\uparrow_m$, $\downarrow_n$, to indicate shifts. Then the general mean column of the six numbers must be shifted back to the original phase relations of its individual members when tabulated for the summation to make up a forecast.

Beyond 15-1/6 months period, practically every period when plotted betrays confusion, for shorter harmonic periods override the period sought. This requires what is by far the most arduous computation of all. After the electronically prepared tables are received from Mr. Wexler they must be treated as was seen in figure 18 to clear the overriding shorter harmonics away. It is sometimes difficult to decide which submultiples are present until after one or two futile trials. Such repeated trials with periods 54 to 91 months in length are very tedious.

The combination of 6 member columns into a general mean, as we do for periods less than 15-1/6 months, will best be understood by a numerical example. The letters a, b, c denote, respectively, data of January-April; May-August; September-December. Subscripts 1 and 2 with them mean first and second halves of the records. As expected, these columns are not in the same phase. The signs, ok, ↑, and ↓, show how much the columns must be moved up or down bodily to be brought into the best posture for uniform phases. When the mean percentage departures from normal in the final column of table 5 are used in the summation for prediction, the columns marked "ok" are to be replaced by the general mean column *without shifting.* The general mean values are to be *lowered* 2 months

TABLE 4.—*Berlin. Period, 7.0 months*
Wexler's table. Means

Cat. 2, Div. 1						Cat. 2, Div. 2					
a_1	ok	b_1	$\uparrow_2$	c_1	ok	a_2	$\uparrow_3$	b_2	$\downarrow_3$	c_2	ok
94		96		93		114		94		100	
97		100		96		105		97		100	
99		99		96		103		105		101	
99		95		91		100		109		97	
99		99		94		105		109		97	
99		95		101		103		115		89	
95		91		95		109		112		98	

TABLE 5. *Berlin. Period, 7.0 months.*
Rearranged table with symbols unchanged.

Cat. 2, Div. 1			Cat. 2, Div. 2				
a_1 ok	b_1 $\uparrow_3$	c_1 ok	a_2 $\uparrow_3$	b_2 $\downarrow_3$	c_2 ok	Sums Σ	General mean ÷ 6
99	99	93	109	109	100	+9	+1
99	95	96	114	115	100	+19	+3
99	99	96	105	112	101	+12	+2
98	95	91	103	94	97	−22	−4
94	91	94	100	97	97	−27	−4
97	96	101	105	105	99	+3	+0
99	100	95	103	109	98	+4	+1

at b_1, *raised* 3 months at b_2, and *lowered* 3 months at a_2, so as to be in proper phases in the summation. As for the modification of results in periods from 18-1/5 to 91 months, examples of the removal of overriding submultiples are given in figures 11, 18, and 20.

8. EXAMPLES OF FORECASTING

Figure 21 is from a direct photograph of my work when computing alone, beginning from "World Weather Records," 1854-1939, and finally forecasting St. Louis precipitation, 1875-1879. (See P. 4211.) *All* the records, 1854-1939, of precipitation at St. Louis were used to fix every individual year. Every year computed, therefore, is equally as really a forecast as if it were after 1939 and stems from zero year (the median) 1895. The forecast gives a correlation coefficient of +80 percent for the 5 years 1875 to 1879 between forecast and observation. Figure 22a, which includes Figure 21, is also a direct photograph from my comparison of forecast and event from 1860 to 1887. Throughout this interval there is an average correlation coefficient of 70±10 percent. Figure 22b gives direct photographs of results I obtained from forecasts of precipitation and temperature during the interval 1934 to 1939 for St. Louis and Peoria. I employed *all* records for the period 1854-1939 to fix the forms and amplitudes. In all these examples just given the departures in forecasts and events, in short all the computation, is done with 5-month consecutive means.

The reader will see that since *all* records, 1854-1939, were used impartially to fix every number forecasted or backcasted in figures 21 and 22 and beyond, the number of years forecasted forward or backward is to be determined as *starting at zero* for the year (1939+1854)/2=1896. Hence, the forecast of St. Louis precipita-

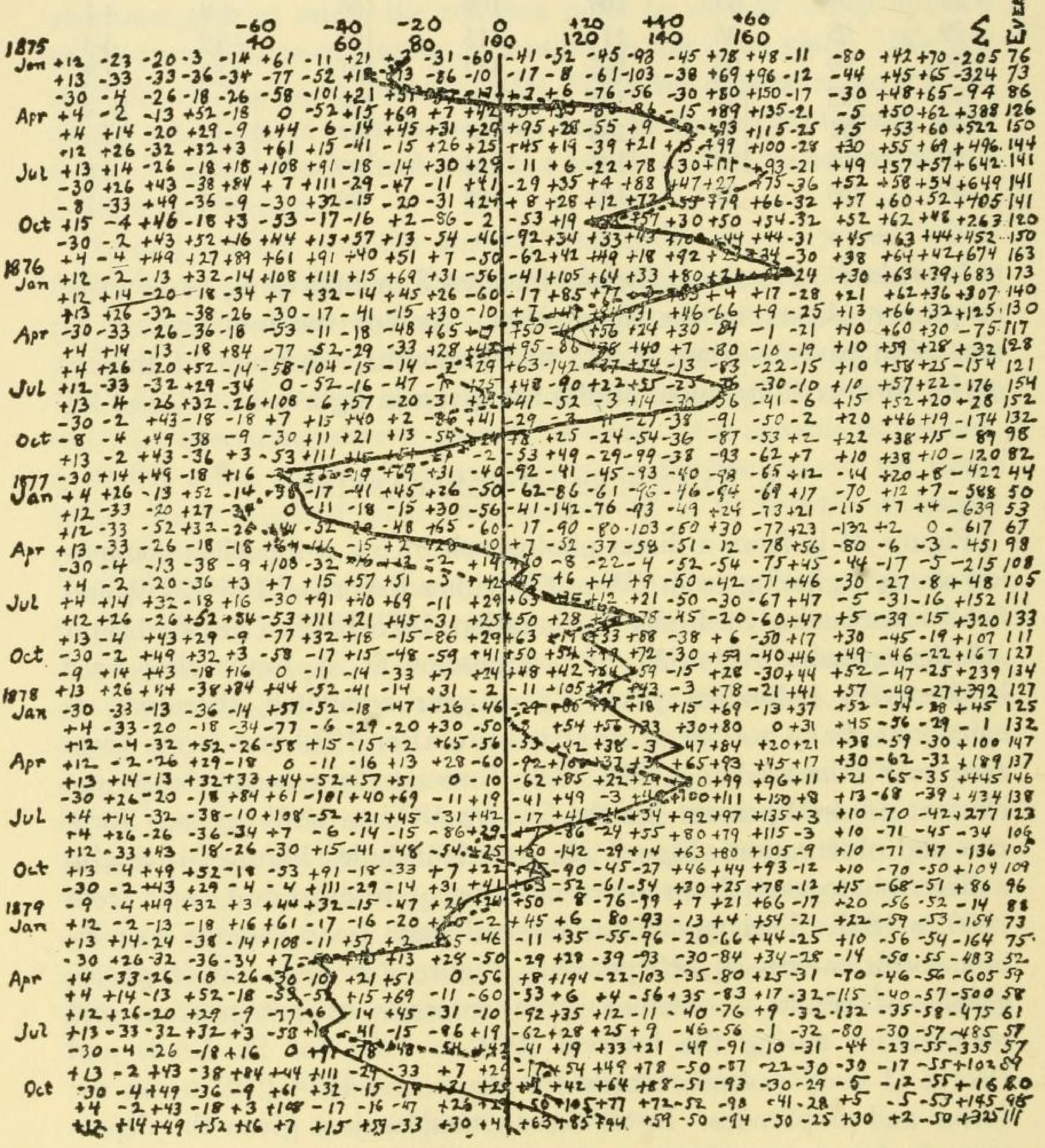


FIG. 21.—Forecast of St. Louis precipitation, 1875 to 1879, compared to observed. Forecast dotted.

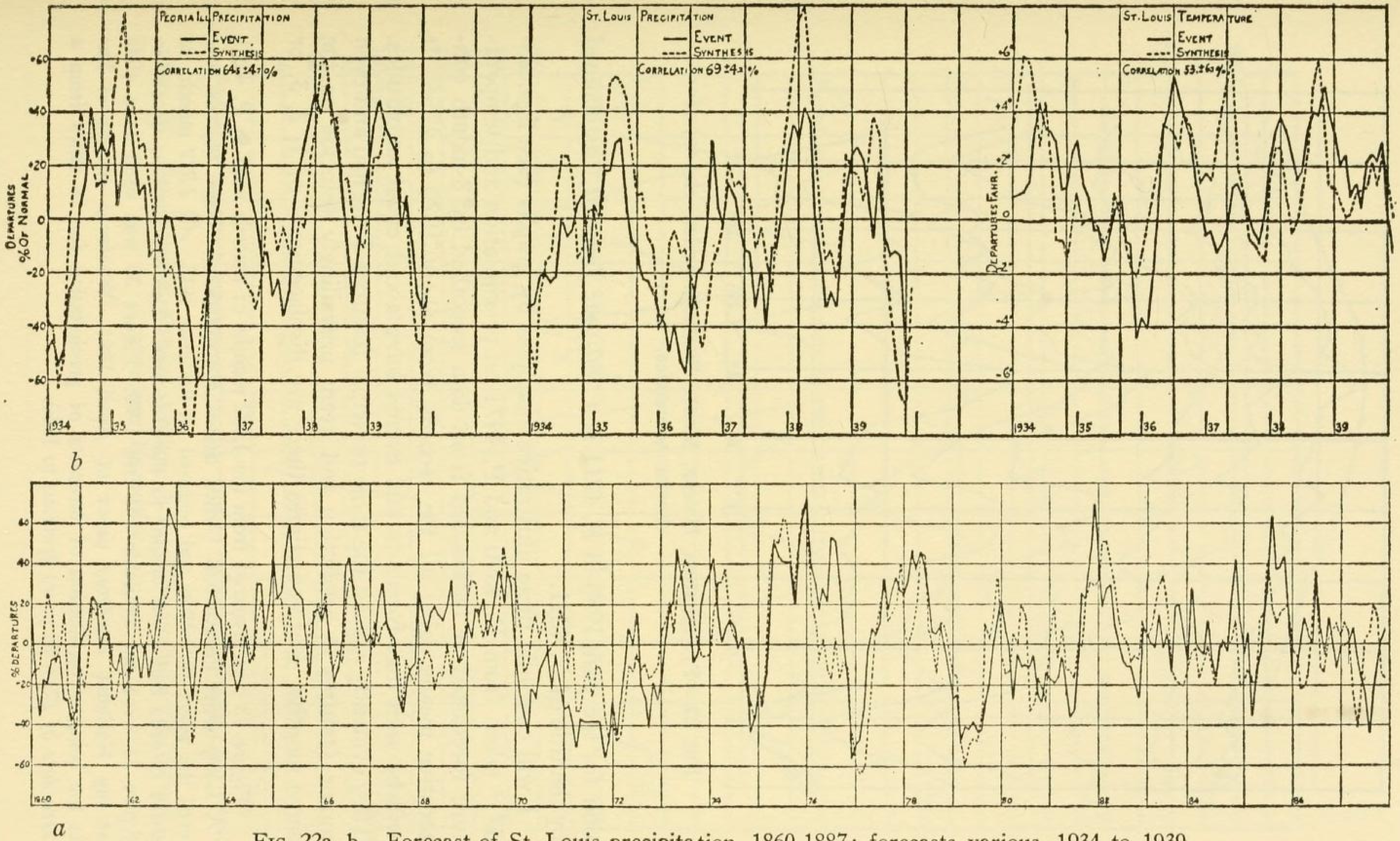


FIG. 22a, b.—Forecast of St. Louis precipitation, 1860-1887; forecasts various, 1934 to 1939.

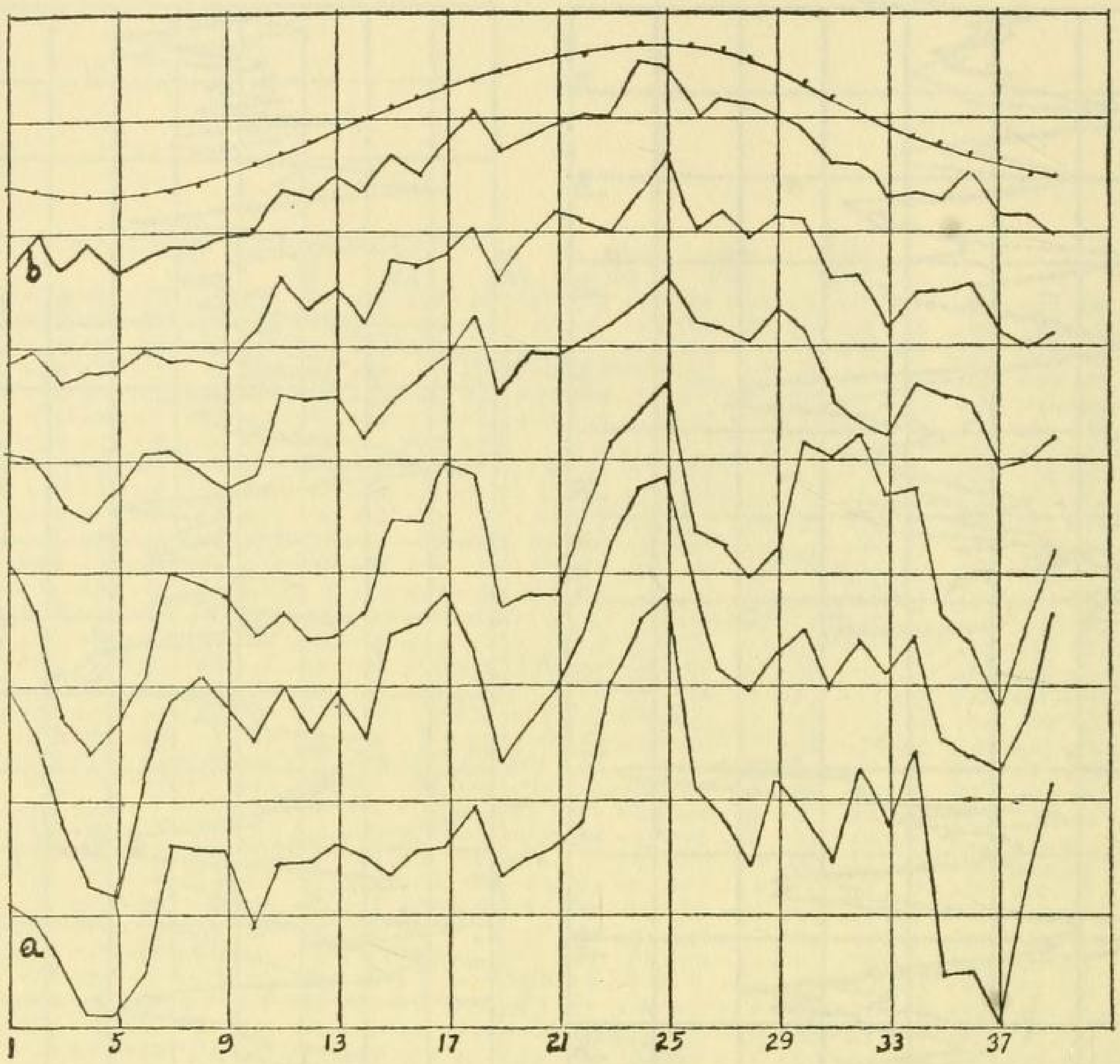


FIG. 23.—Precipitation, Helena, Mont., 39-month period, cleared of shorter harmonics.

tion for the year 1956 in P. 4211 is a *"60-year forecast,"* as claimed by the title of P. 4211.

I will conclude these illustrative examples by graphs (see figs. 28-37)[5] taken from P. 4390 and P. 4471 on precipitation and temperature forecasted or backcasted from data smoothed by 3-month consecutive means using *all* the records from about 1870 to 1956. It will be seen that forecasts and events have about equal amplitudes. They evidently exhibit the same principal features. Principal and even minor features in prediction and event prevailingly coincide on the same months. But sometimes there are displacements of 1, 2, 3, or

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[5] Figure 33 was prepared from the 1,032 months of records used in P. 4390, "A Long-range Forecast of United States Precipitation." These records covered the years 1870-1956 and centered on the year 1913. *All 1,032* months of these records had *equal weight* in the forecasts. The observations quoted in figure 33 were not available till late 1960. Figure 33 was used as a slide at my National Academy paper of April 1961. Whatever success it has is for being a verification of forecasts of precipitation for 14 cities from a *zero date of 1913, 46 years previous* to 1959.

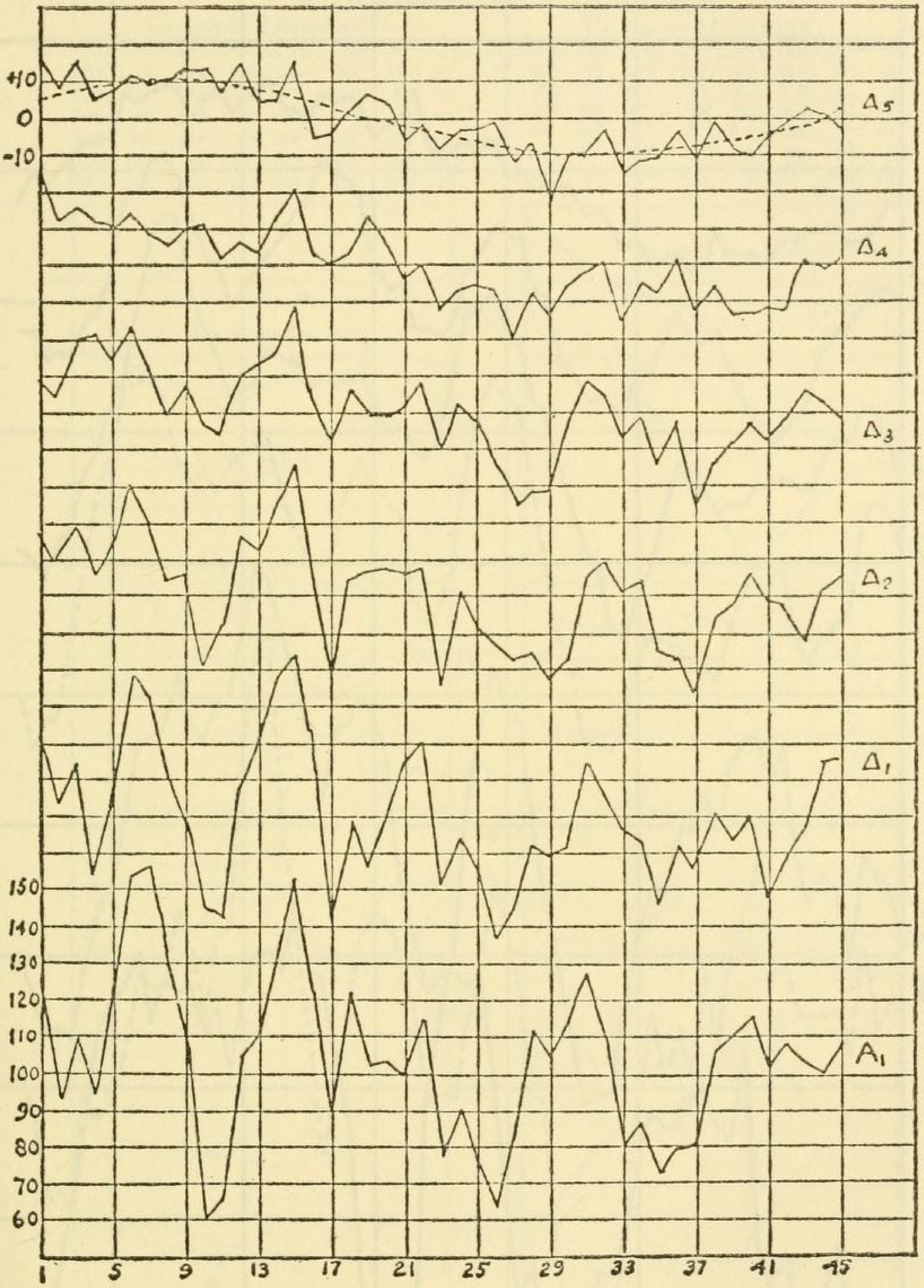


FIG. 24.—Precipitation, Natural Bridge, Ariz., 45½-month period, cleared of shorter harmonics.

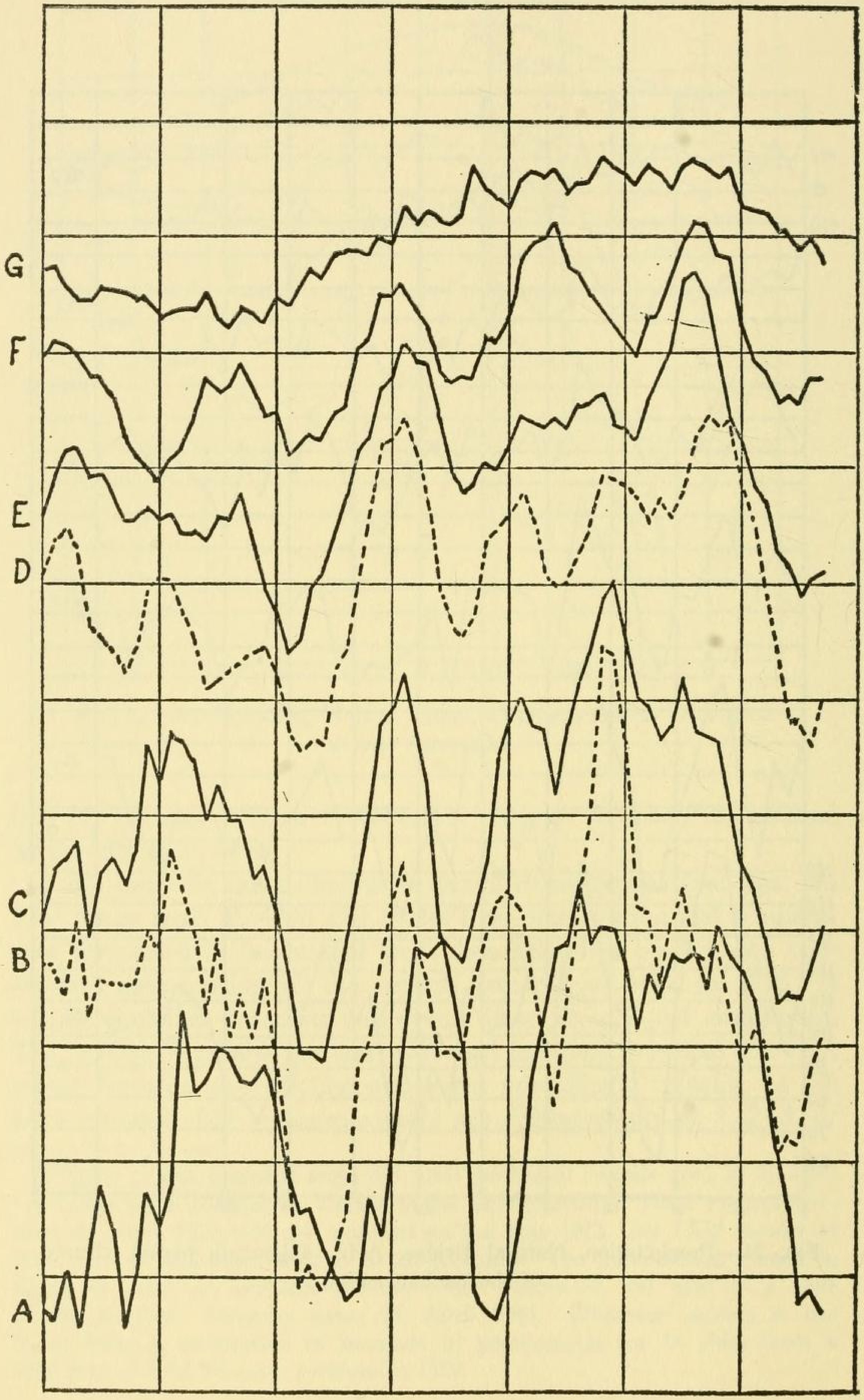
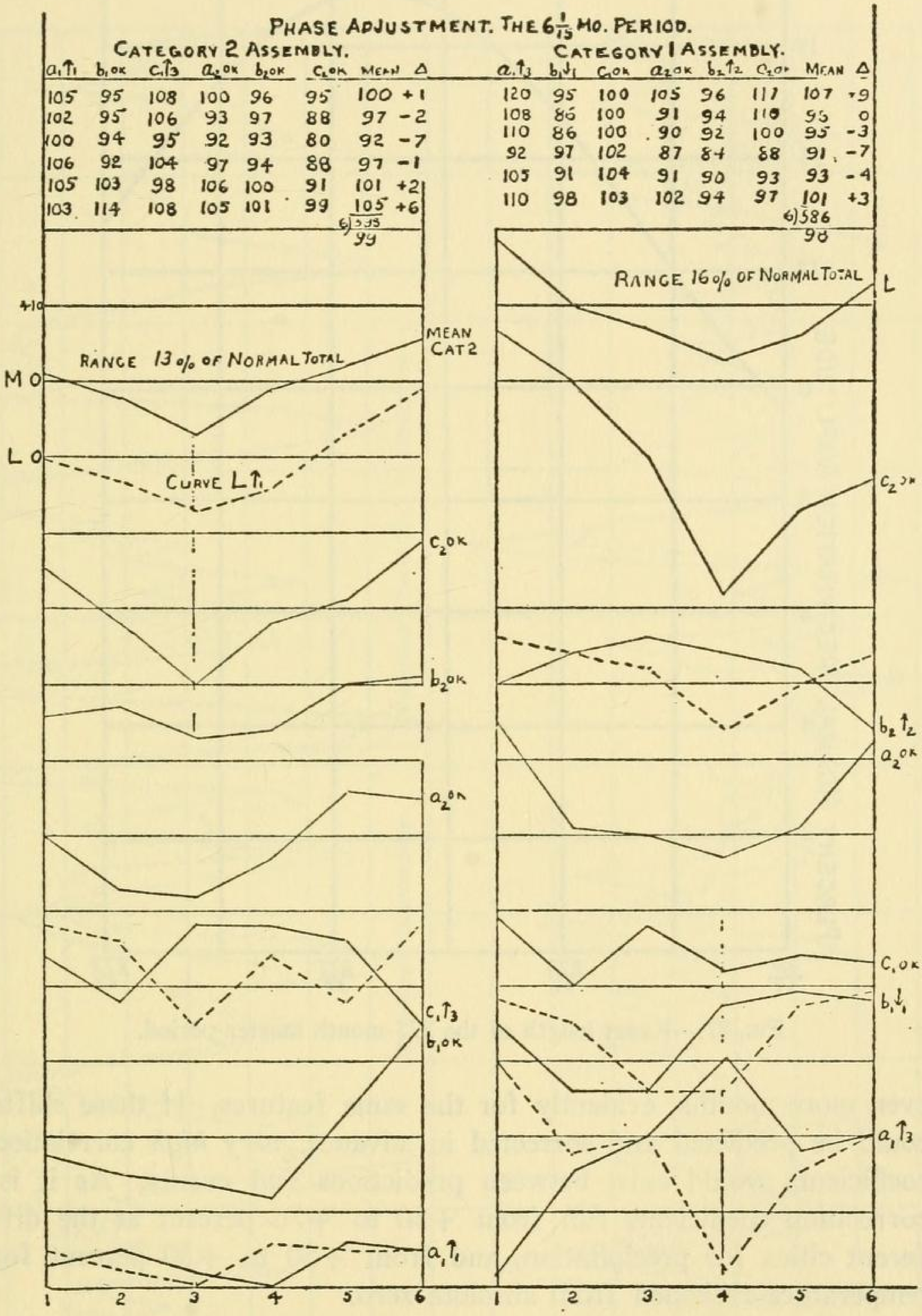


FIG. 25.—Precipitation, St. Louis, 68¼-month period, cleared of shorter harmonics. Three months shift of A. A and C observed before and after 1900 combined in B for further work.



PHASE ADJUSTMENT. THE $6\frac{1}{15}$ MO. PERIOD.

CATEGORY 2 ASSEMBLY.

$a_1\uparrow_1$	$b_1$ok	$c_1\uparrow_3$	$a_2$ok	$b_2$ok	$c_2$ok	MEAN	Δ
105	95	108	100	96	95	100	+1
102	95	106	93	97	88	97	−2
100	94	95	92	93	80	92	−7
106	92	104	97	94	88	97	−1
105	103	98	106	100	91	101	+2
103	114	108	105	101	99	105	+6
						6)593 99	

CATEGORY I ASSEMBLY.

$a_1\uparrow_3$	$b_1\downarrow_1$	$c_1$ok	$a_2$ok	$b_2\uparrow_2$	$c_2$ok	MEAN	Δ
120	95	100	105	96	117	107	+9
108	86	100	91	94	110	98	0
110	86	100	90	92	100	95	−3
92	97	102	87	84	88	91	−7
105	91	104	91	90	93	93	−4
110	98	103	102	94	97	101	+3
						6)586 98	

FIG. 26.—Phase adjustment for 6-column combination. Eastport, Maine, precipitation, 6¹⁄₁₅-month period.

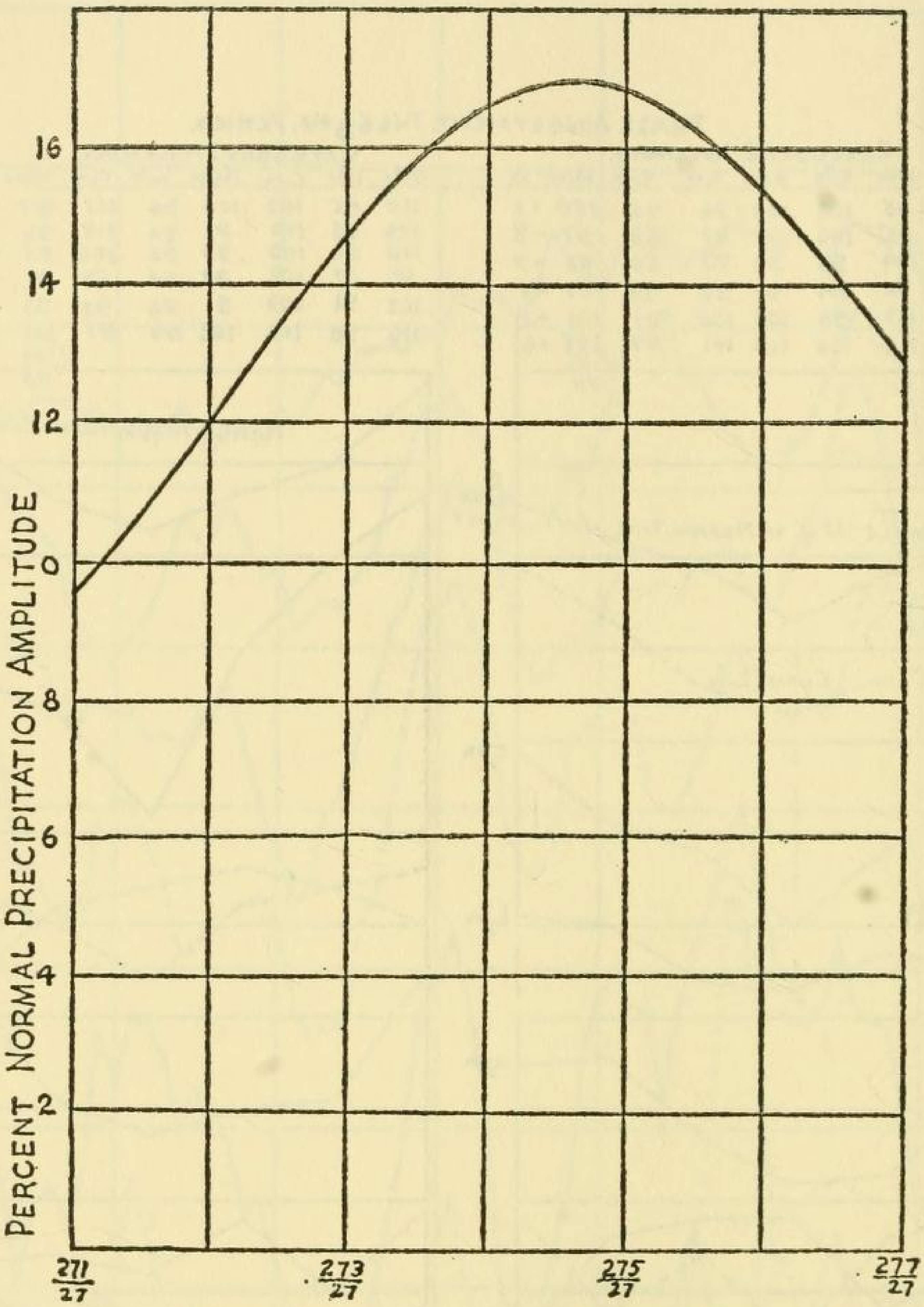


Fig. 27.—Exact length of the 273-month master period.

even more months, evidently for the same features. If these shifts could be predicted and corrected in advance, *very high* correlation coefficients would exist between predictions and events. As it is, correlation coefficients run from +50 to +70 percent at the different cities for precipitation, and from +30 to +50 percent for temperature reckoned from absolute zero.

9. ACCURACY OF PREDICTIONS

The average percentage difference between forecasts and events runs from 15 to 30 percent for monthly precipitation values at different cities. It runs from 1.5° to 2.7° F. monthly for temperature

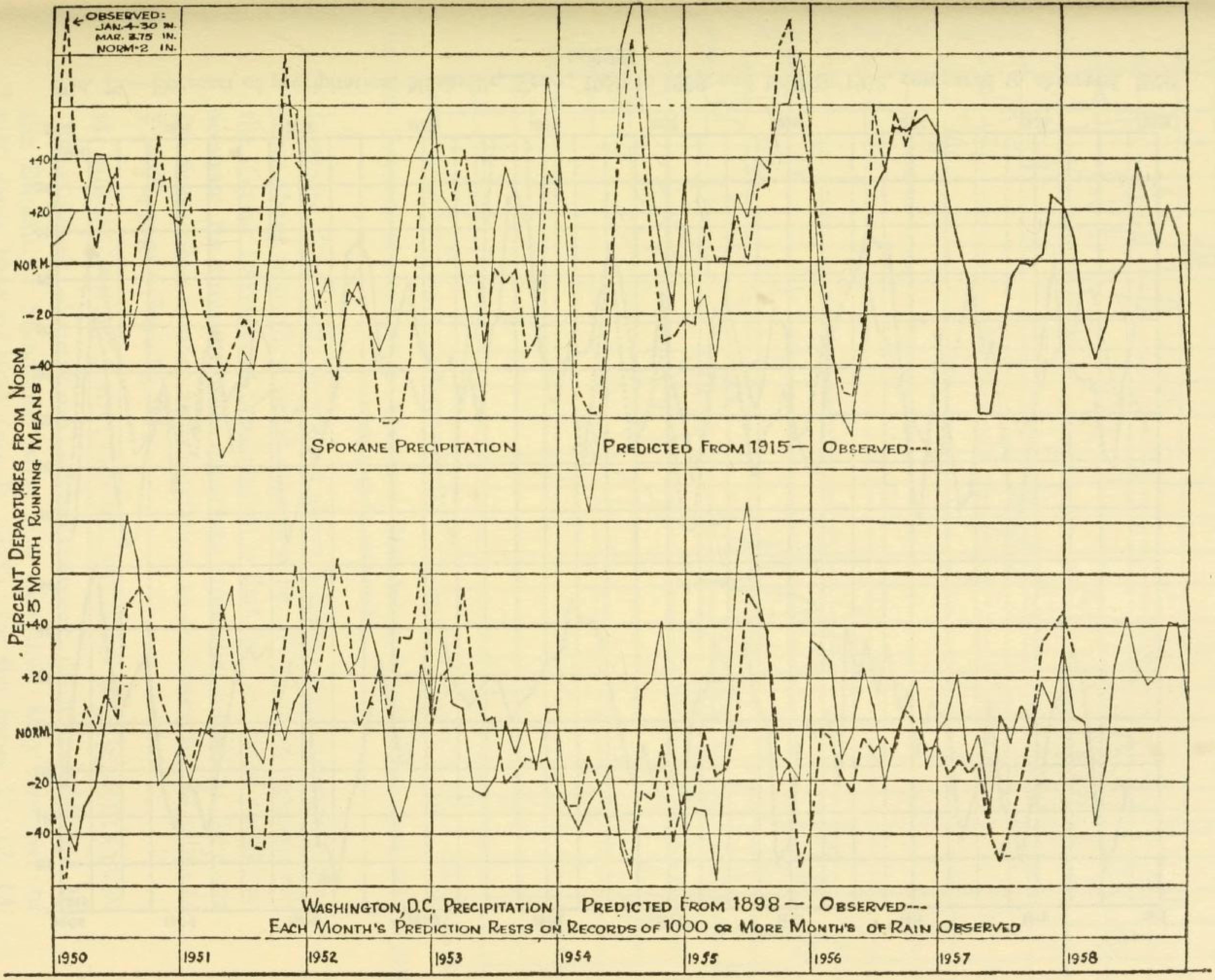


FIG. 28.—Forecast of precipitation, Washington, D.C., and Spokane, Wash., 1950 to 1958, compared with observed.

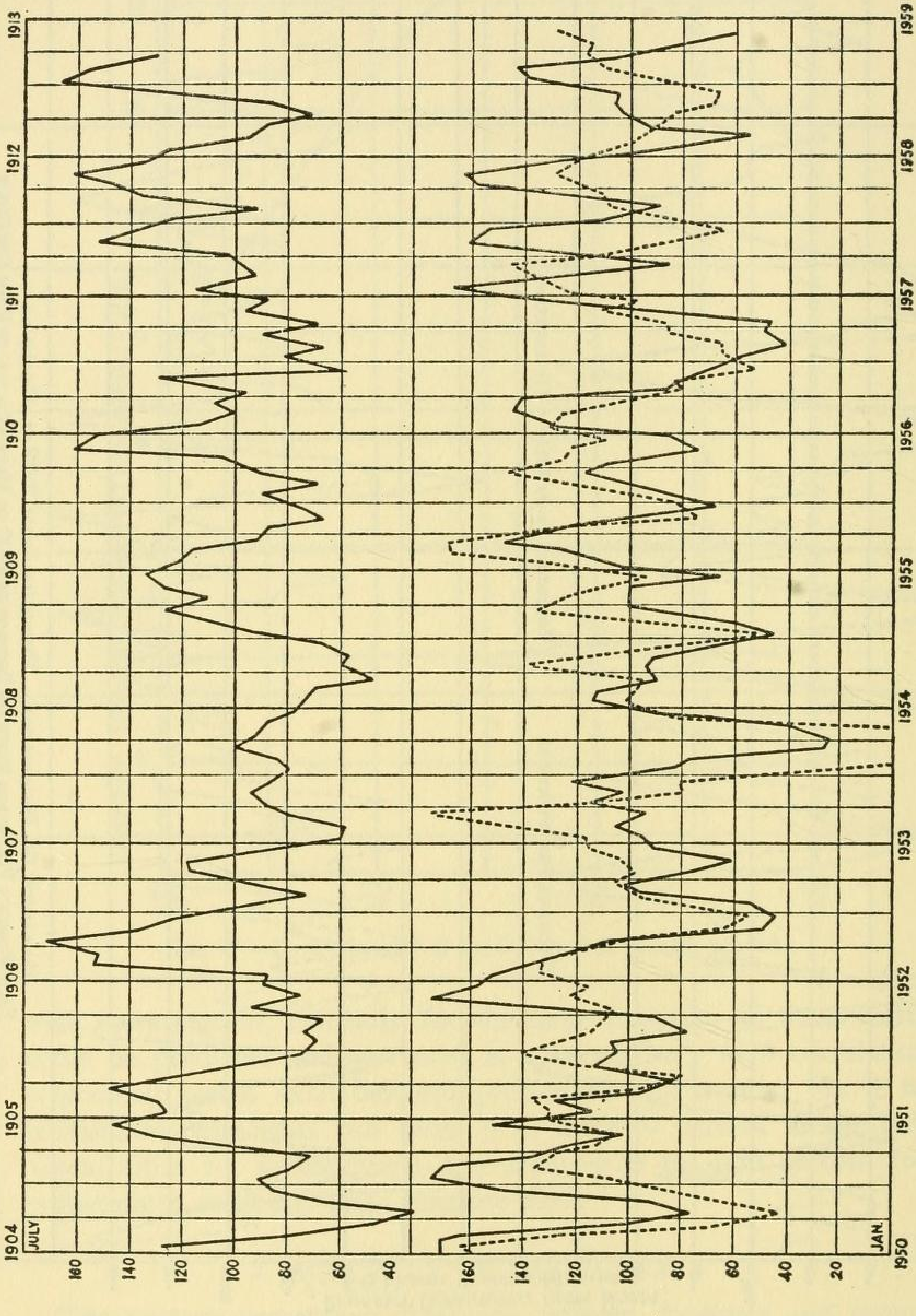


FIG. 29.—Forecast of precipitation, Nashville, Tenn., 1950 to 1958, and 1904 to 1912, compared to observed, 1950 to 1958

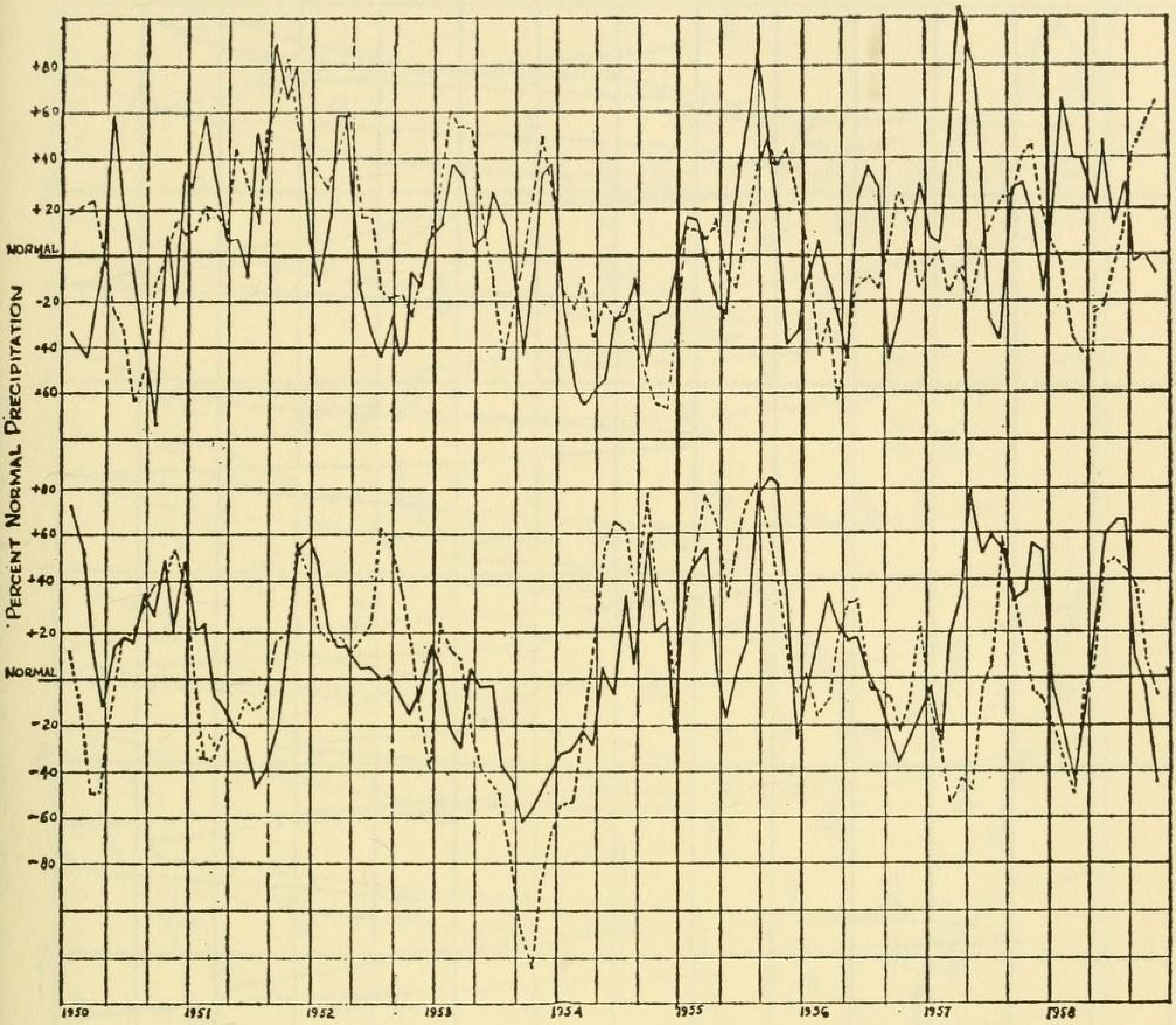


Fig. 30.—Forecasts of precipitation: Cincinnati, Ohio, below, Denver, Colo., above, 1950 to 1958, compared to observed.

forecasts. The shifts mentioned above heighten these average differences above what they would otherwise be. What most recommends the 10-year forecasts of precipitation is that they are about equally as accurate for times of wide departure from the normal as they are for times close to normal precipitation, as is shown for 14 cities in P. 4471, page 6 (here fig. 33).

10. MISCELLANEOUS MATTER RELATED TO SOLAR VARIATION

Ionospheric observations.—From measure of h'F_2 published by the Bureau of Standards, Mrs. Hill computed daily averages of h'F_2 from 1944 to 1957 (see P. 4338), for the hours 11, 12, 13. An earlier study had fixed the average monthly value for these

[Cont. p. 45

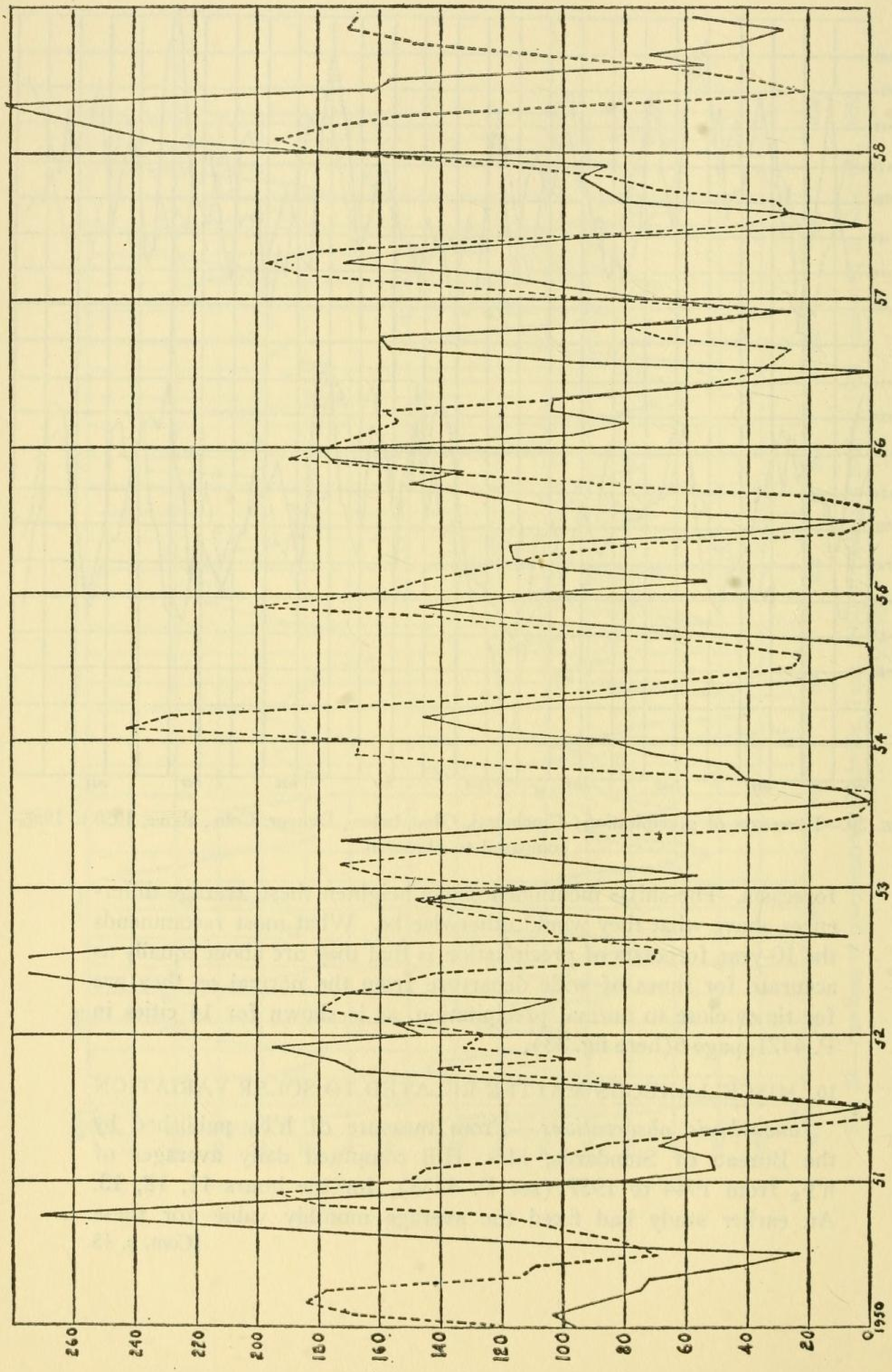


FIG. 31.—Forecast of precipitation, Sacramento, Calif., 1950 to 1958, compared to observed.

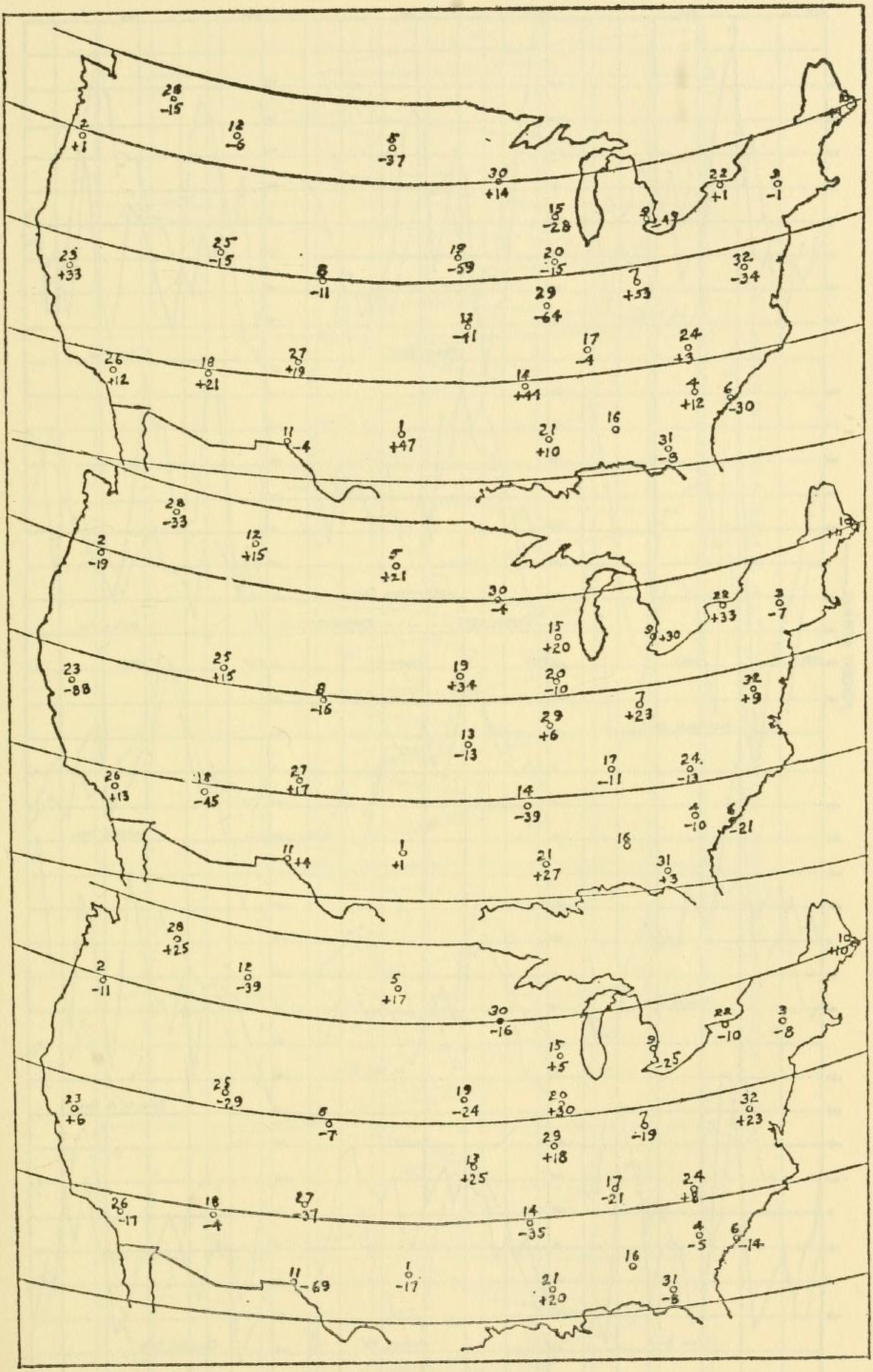


FIG. 32.—Map, forecast of precipitation, 32 stations, 1963, in 4-month means. Note: P. 4390 gives maps like this covering the years 1963 to 1967.

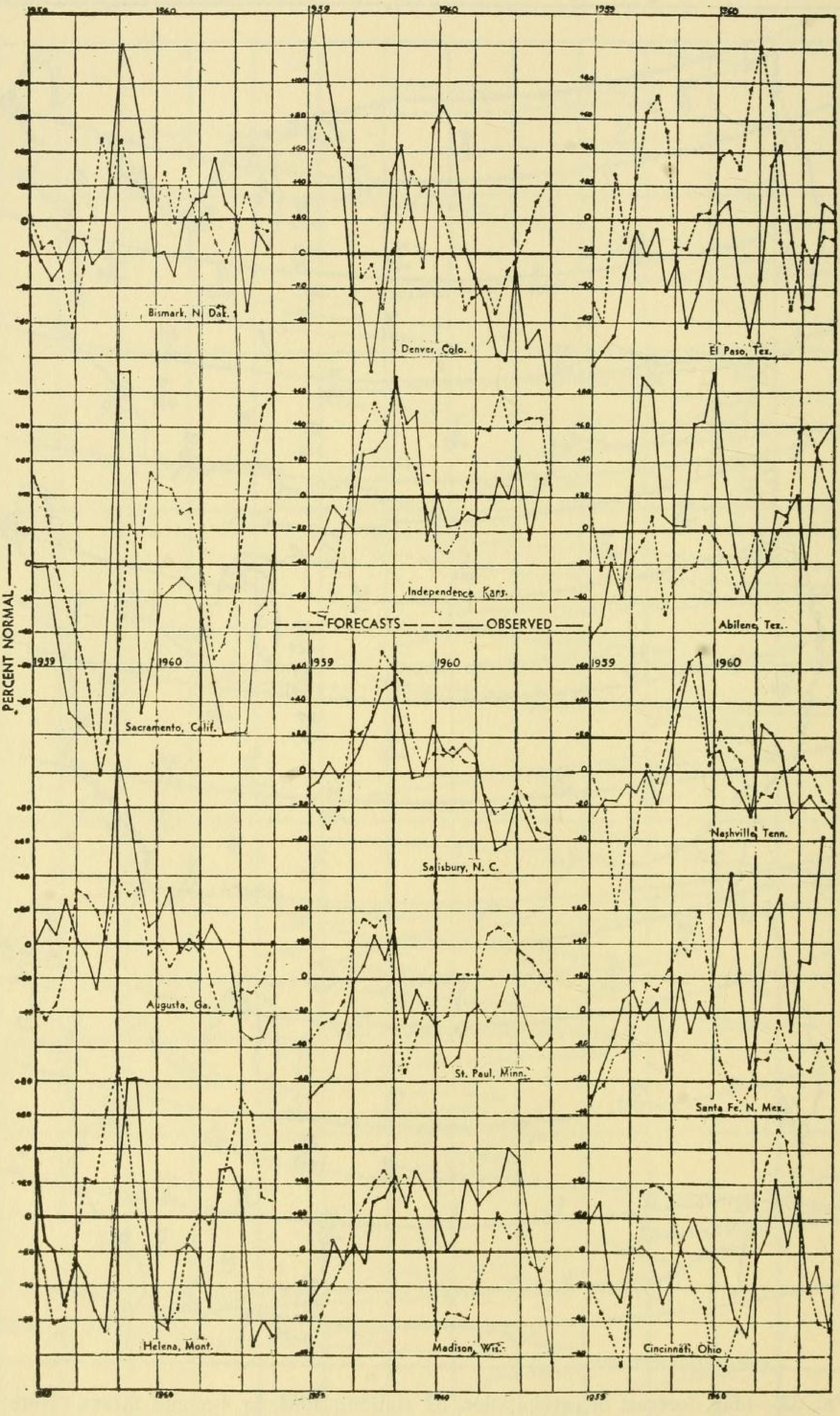


FIG. 33.—Verification of monthly forecasts of precipitation, 1959, 1960, for 14 stations.

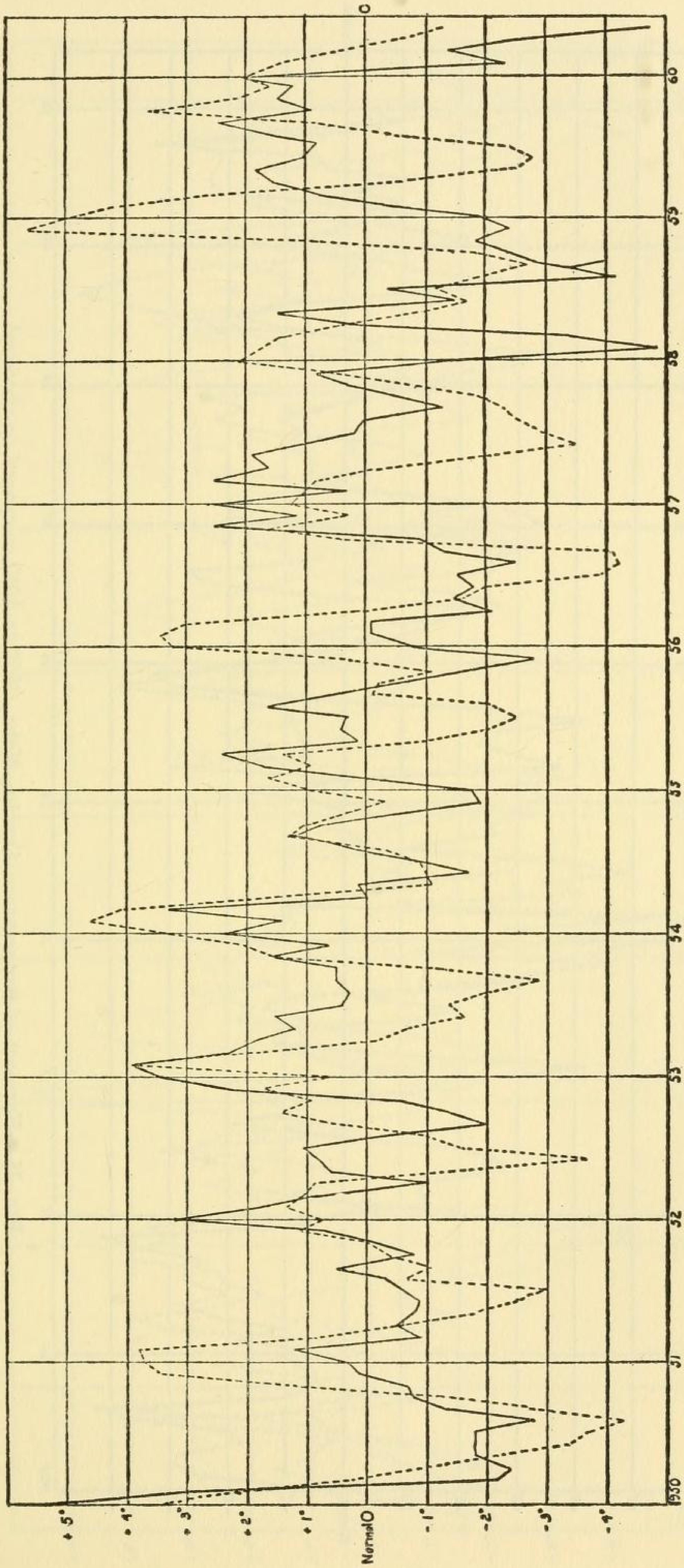


FIG. 34.—Forecast of temperature, Washington, D.C., 1950 to 1960, compared to observed.

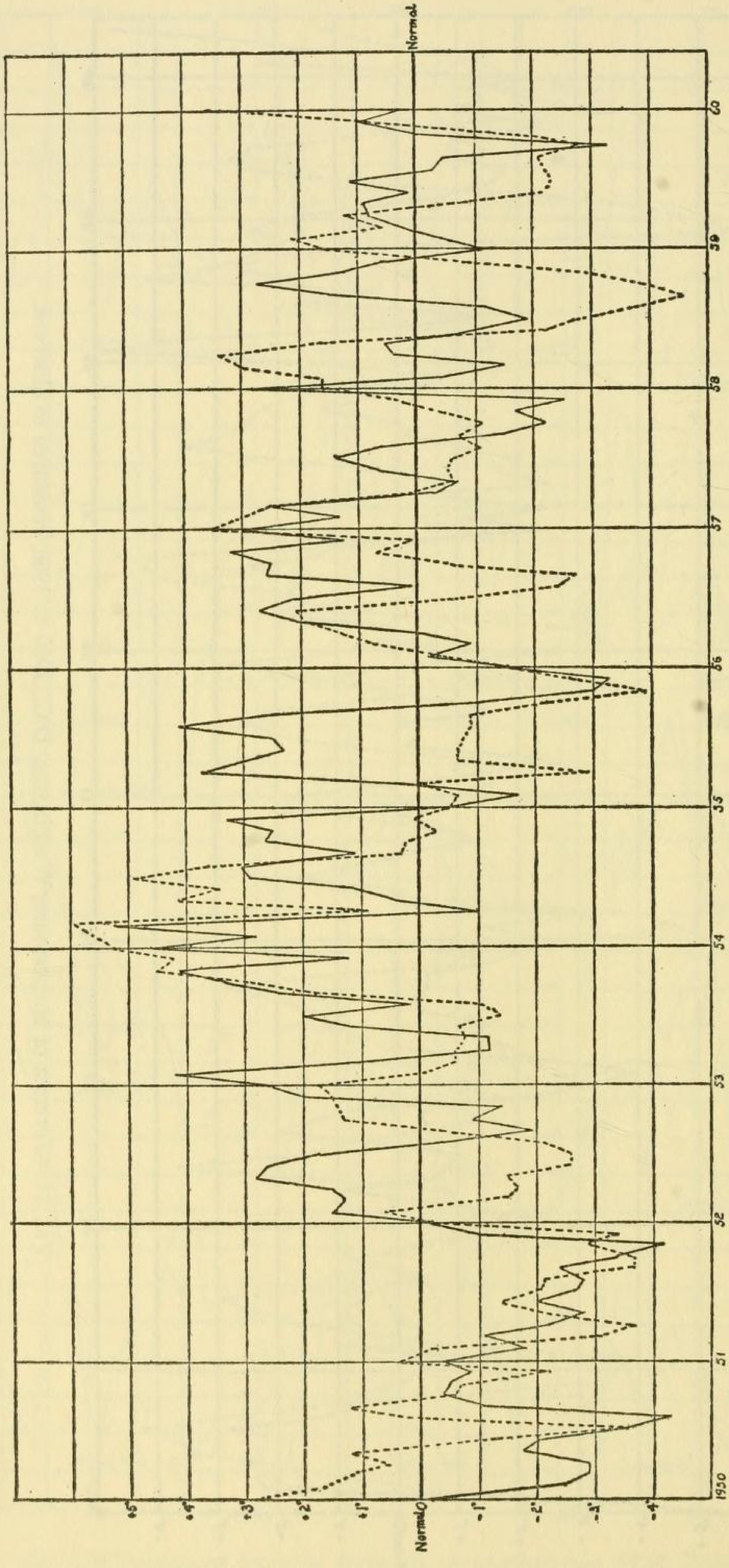


FIG. 35.—Forecast of temperature, Omaha, Nebr., 1950 to 1960, compared to observed.

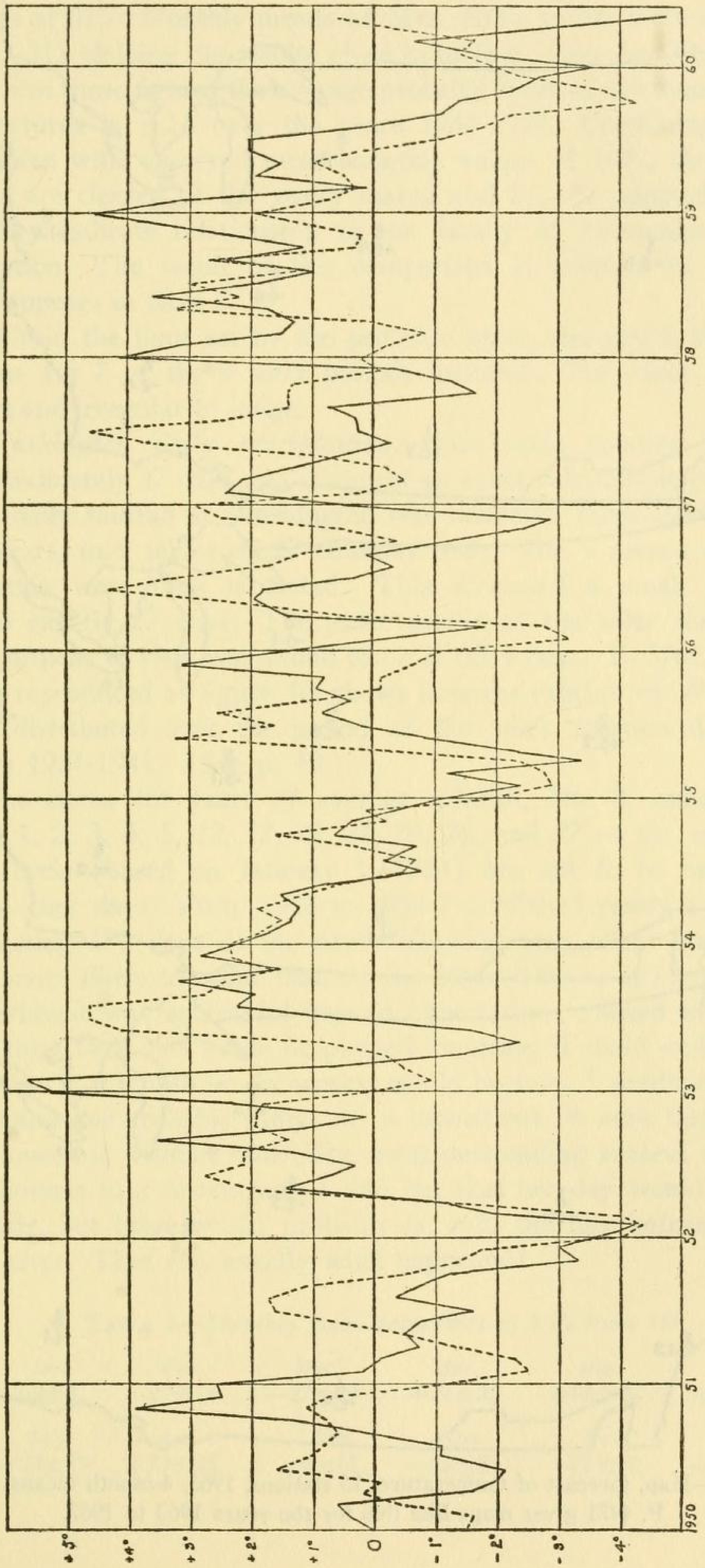


FIG. 36.—Forecast of temperature, Salt Lake City, Utah, 1950 to 1960, compared to observed.

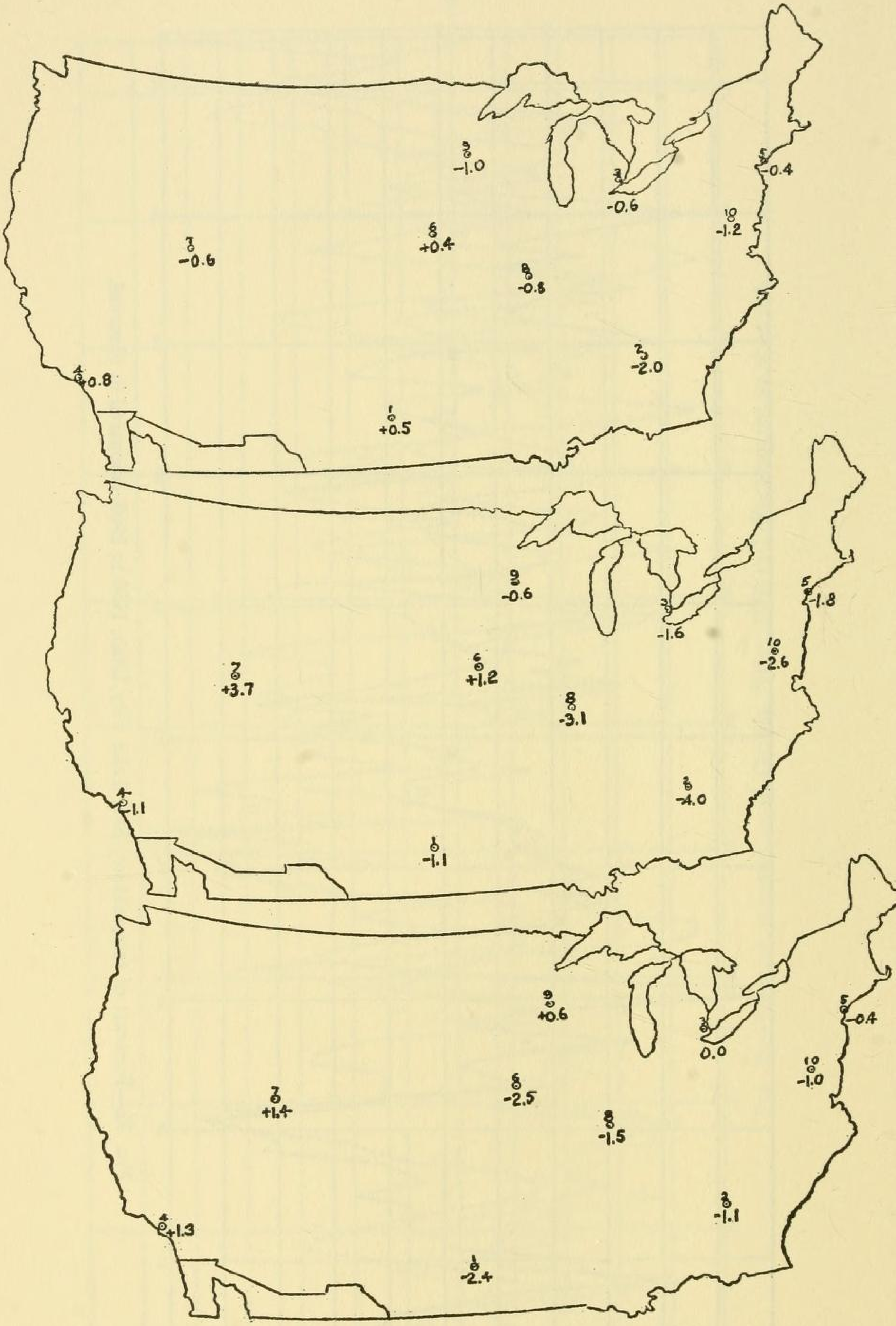


FIG. 37.—Map, forecast of temperature, 10 stations, 1963, 4-month means. Note: P. 4471 gives maps like this for the years 1963 to 1967.

hours at 315. Monthly means of Mrs. Hill's values were subtracted from 315 yielding the results given in table 6. (See fig. 39, p. 48.)

From these figures the average probable error of the monthly mean departures is ±15 over the years 1944-1957. Combining the departures with observed mean monthly values of $h'F_2$, the observations are cleared of the yearly march and become adapted to show if they indicate relationship to the family of harmonics in solar variation. The result of this comparison is graphed in figure 39 and appears in table 7.

Within the limit set by the probable error, the graph shows sine forms for 7 of the 9 solar periods included. The other 2 are too short and irregular to judge.

Washington daily precipitation.—The sun's rotation period is approximately 27 days and is almost an exact submultiple of 2 years. The daily rainfall at Washington was tabulated from 1924 to 1941, 18 years, in 9 tables of 27 columns each. The 9 means of the 27 columns were then tabulated. This disclosed a small departure from exactly 27 days. The exact period of the solar rotation for the purpose in view was found to be 27.0074 days. P. 3765, figure 1, here reproduced as figure 40, shows how the rainfall of Washington was distributed over the period of the sun's rotation during the years 1924-1941. (See p. 49.)

The curve for years of average rainfall, No. 3, indicates that days 1, 2, 3, 4, 5, 12, 17, 22, 24, 25, 26, and 27 of the sun's rotation cycle (based on January 1, 1924) are apt to be more rainy than other days. From 1941 to 1954 I published yearly a pamphlet predicting 175 days of the next following year when precipitation was more likely to occur than on the other 190 (or 191) days. The experiment was successful beyond expectation. Indeed in 1948 no less than 14 brides wrote or phoned inquiring if their wedding day, to come in a month or six weeks, would be fair. I predicted 13 fair days and one probably rainy. As it turned out 14 were fair, but one was overcast without rain. The most outstanding success concerned the hostess in a restaurant. I told her that her day would probably be fair, but there would probably be rain the day before and the day after. That was exactly what happened!

TABLE 6.—*Monthly mean departures of $h'F_2$ from 315.*

Jan.	*Feb.*	*Mar.*	*Apr.*	*May*	*June*
−69±9	−27±14	−27±24	+29±30	+88±26	+89±25
July	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
+93±19	+73±35	0±11	−52±13	−71±10	−73±9

TABLE 7.—*Periodicities in monthly values of departures in* $h'F_2$

Monthly periods	*March of departures and probable errors*							
2-23/24	+1.6	−2.5	+0.2					
	±1.1	±1.1	±1.1					
4-1/3	−5.4	+0.7	+0.1	+4.8				
	±1.5	±1.5	±1.5	±1.5				
5-1/18	−4.2	+2.6	+2.6	+1.5	+0.5			
	±1.6	±1.6	±1.5	±1.5	±1.5			
6-1/15	+6.9	+2.7	−2.7	−7.4	−2.2	−0.6		
	±1.8	±1.8	±1.8	±1.8	±1.8	±1.8		
7	−3.3	+1.1	+2.6	+3.4	−0.7	−3.3	−3.2	
	±2.0	±2.0	±2.0	±2.0	±2.0	±2.0	±2.0	
9-3/4	+2.1	−2.9	−4.2	−5.0	−2.2	+4.6	−1.4	−4.4
	±2.1	±2.1	±2.1	±2.1	±2.1	±2.1	±2.1	±2.1
	+3.9	+1.0	..	..	..	..	..	..
	±2.1	±2.1	..	..	..	..	..	..
10-1/9	−8.5	−7.2	−4.1	−1.7	+1.6	+2.4	+8.5	+7.2
	±2.1	±2.1	±2.1	±2.1	±2.1	±2.1	±2.1	±2.1
	−0.5	−3.9	..	..	..	..	..	..
	±2.1	±2.1	..	..	..	..	..	..
11-3/8	+4.2	+7.9	+7.8	+0.5	+0.1	−10.0	−4.9	−4.3
	±2.2	±2.2	±2.2	±2.2	±2.2	±2.2	±2.2	±2.2
	−5.1	−2.8	−0.7	..	..	..	..	..
	±2.2	±2.2	±2.2	..	..	..	..	..
15-1/6	−3.4	+8.3	+6.0	+7.1	+5.1	−1.4	−2.5	+0.2
	±2.3	±2.3	±2.3	±2.3	±2.3	±2.3	±2.3	±2.3
	−3.1	−1.7	−5.3	−7.3	−8.7	−4.7	−0.3	..
	±2.3	±2.3	±2.3	±2.3	±2.3	±2.3	±2.3	..

The following table 8 shows the results from 1934 to 1954. I give the ratios of yearly rainfall which came on 175 preferred days to that which came all other days. The expected ratio is 1.42.

In the year 1952 a peak rainfall 6 times the average of all other days of the cycle appeared on the eleventh day. In 1953 the peak had fallen to 3 times but was still extraordinary. I have wondered if the surprise was caused by atomic bombing. After 1954 I was too immersed in long-range forecasts, solar boilers, and my second marriage to continue with Washington daily rainfall.

Various periods.—

1. The 6.6485-day period.

TABLE 8.—*Precipitation of Washington.*
Ratio 175 preferred to 190 (191) other days

Years ..	1934-1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	Mean Ratio
Ratio ...	1.55	1.48	1.06	1.45	1.10	1.28	1.56	1.49	1.34	—	—	1.31	1.45

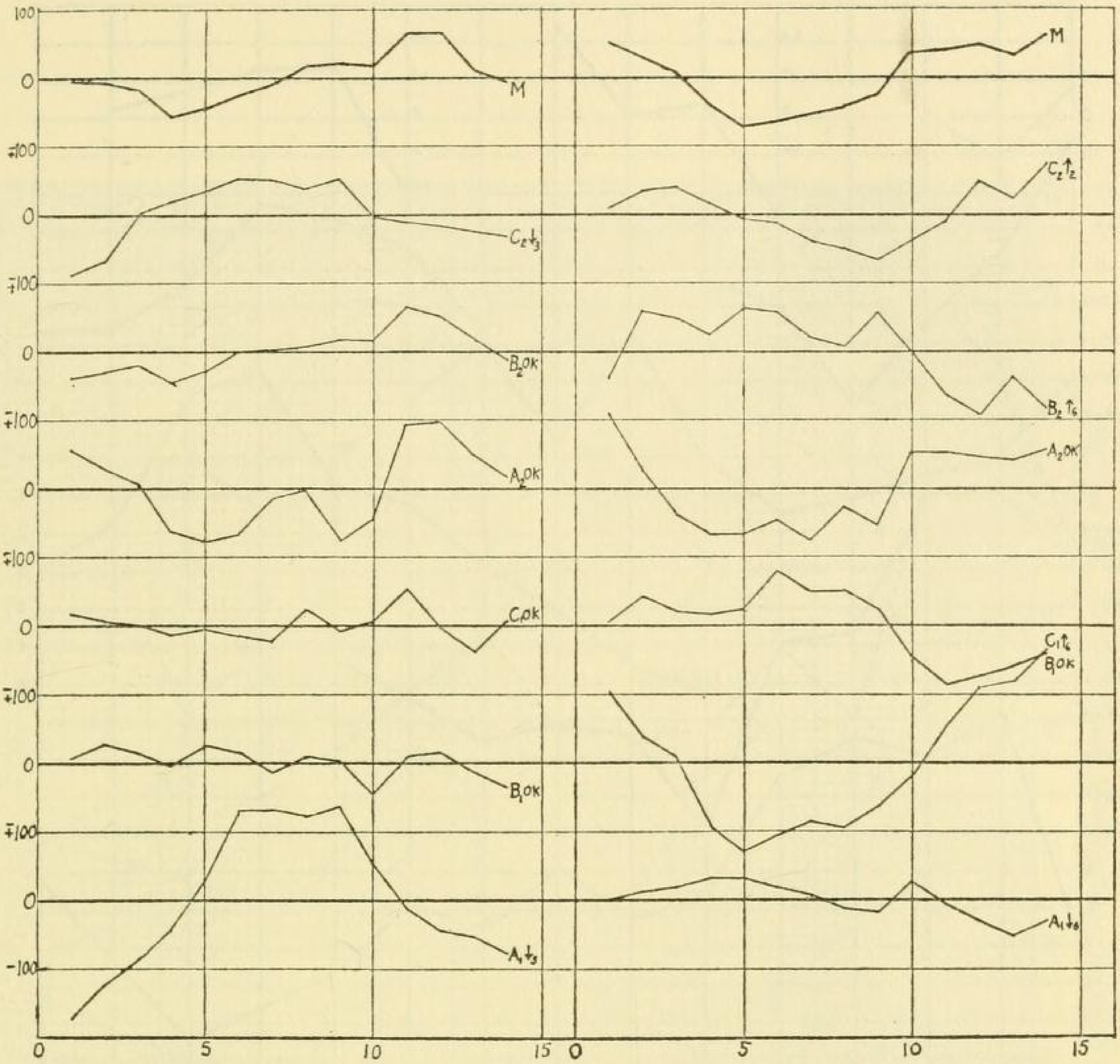


Fig. 38.—Phase adjustments for 6-column combinations, Washington D.C., temperature, 13⁶⁹⁄₁₀-month period.

Many have noticed that if a rain comes Saturday it may recur on several succeeding Saturdays and after that on Fridays. We have tabulated daily temperature in New York and Washington to investigate this observation. We discovered a well-marked period (fig. 41) of 6.6456 days (later improved to 6.6485 days) and also the half of it in the weather of New York and Washington. (See also P. 2499, P. 3893, P. 3990, and P. 4015.) The period was found to be within 1 percent or less of 1/1250 of 273 months as computed employing the exact period of the earth's revolution about the sun. The shorter period is exactly 273/2500 months.

2. Human pulse periods.

My friend Dr. Frances P. Marshall has a 3-year daily record of her pulse taken before rising each morning. She permits me to publish my analysis of it (see P. 4265, pp. 15-17). A very smooth

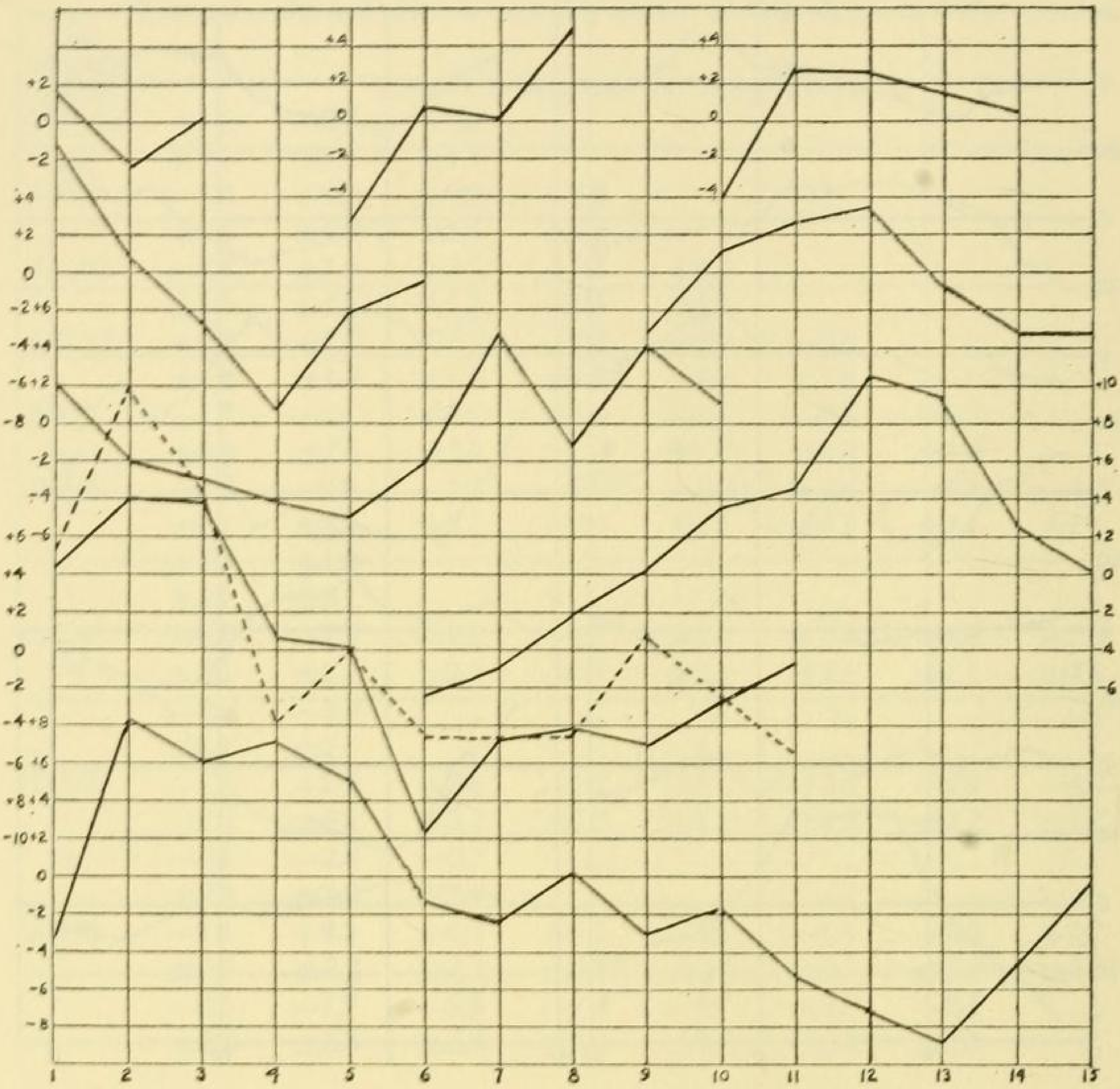


FIG. 39.—Periods in ionospheric h′ F_2, harmonics of 273 months.

sine curve of 7.0 months, shown in figure 42, was found after clearing the original 7 months observations of harmonics of 1/2, 1/3, 1/6, 1/7, 1/11 of 212 days. Its amplitude is 2 pulses on 67. All the periods named are of course exact submultiples of 273 months (p. 51).

3. Droughts at long periods.

By invitation I published in the year 1938 an article on solar variation and weather in Zvlaštni Otisk, the organ of the physicists at Prague in Czechoslovakia. In that article, so far as I can discover now, appeared my first prediction of very long-range solar periods. I quote: "Records have been kept of the levels of the Great Lakes of North America regularly since 1860. In addition, partial records exist which fairly indicate the levels of some of the lakes since 1837. From these sources I have prepared figure 6 [here fig. 43, p. 52] which indicates the water-gauge values for Lake Huron for a cen-

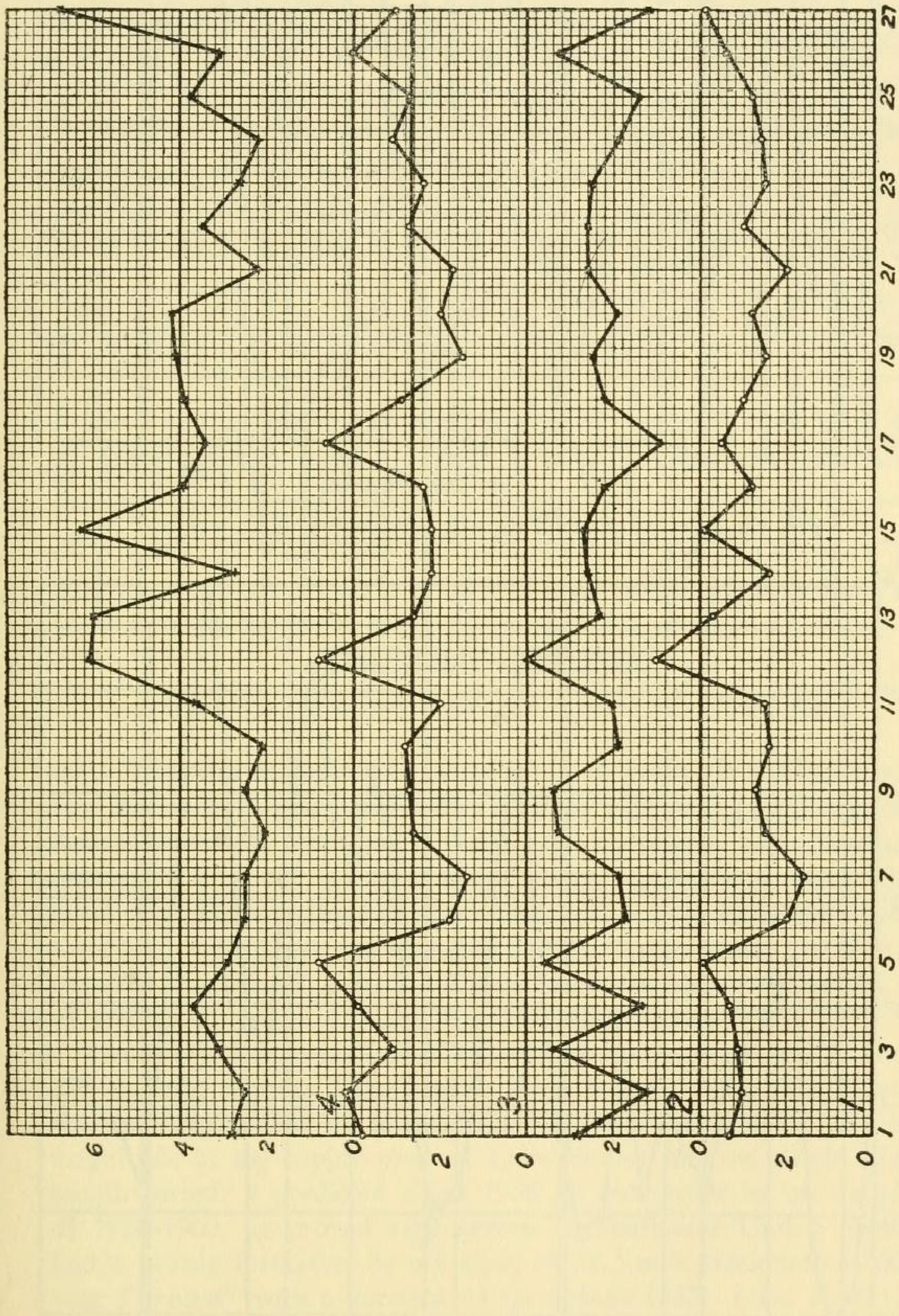


FIG. 40.—Period of 27.0074 days in Washington precipitation. See P. 3765.

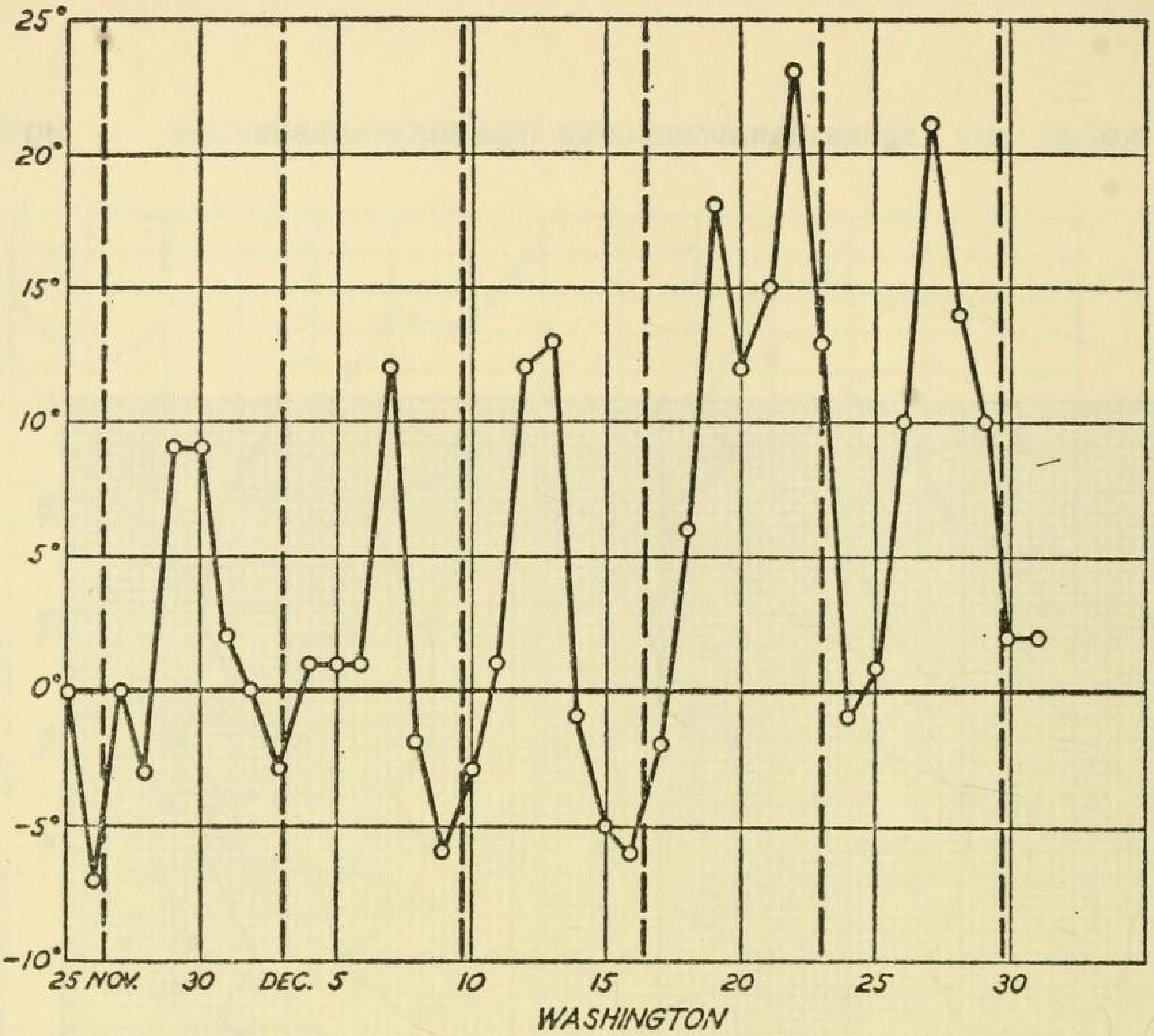


FIG. 41a.—Period of 6.6485 days in Washington, D.C., weather.

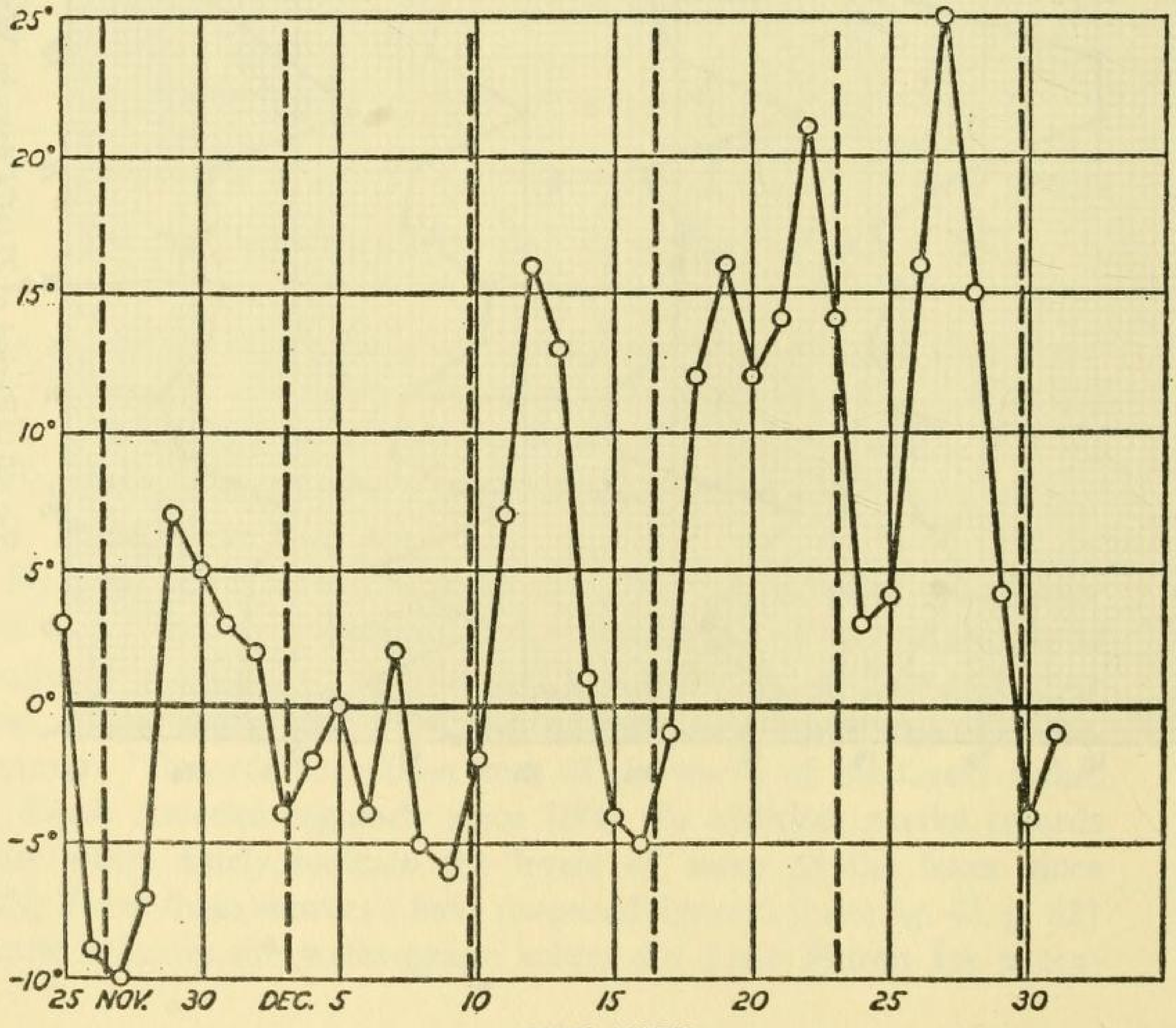


FIG. 41b.—Period of 6.6485 days in New York City weather.

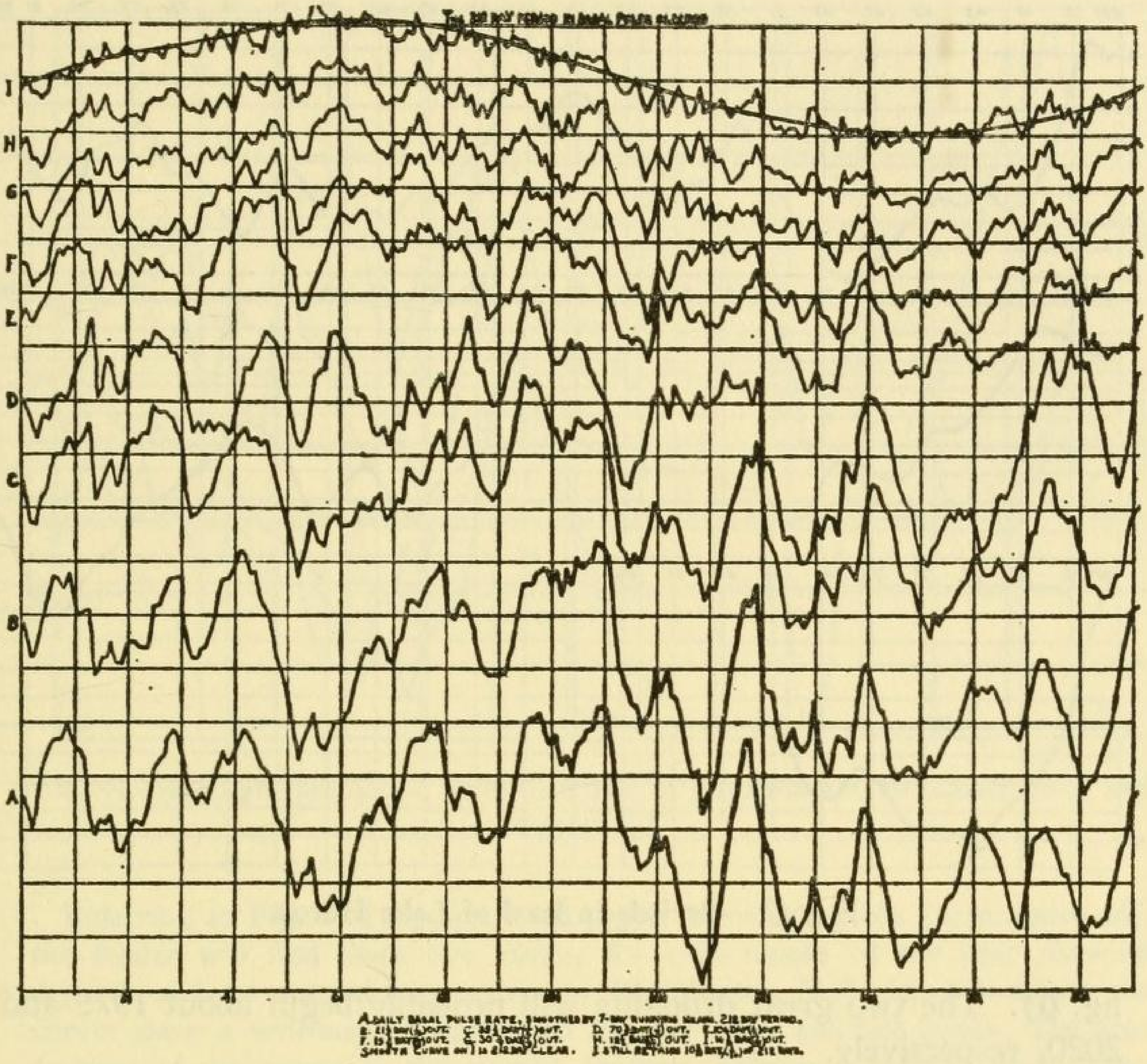


FIG. 42.—Periods in human pulse rate, harmonics of 273 months.

tury. The data are arranged in cycles of 46 years. It will be manifest that each 46-year cycle shows near its beginning a great depression of about 10 years length from crest to trough, and a smaller depression of about the same length following 23 years later. The great depressions following years 1838, 1885, and 1929 were each associated with disastrous droughts in the Northwestern States and adjacent regions of Canada. There is much reason to expect a recurrence of such a drought beginning about 1975."

The two principal periods of 91 and 45-1/2 years, 4 and 2 times 273 months, depress Lake Huron about 5 feet. They last before complete restoration of level about 10 years. A drought of less magnitude in the supply area of Lake Huron has the single 273-month period. I predicted about 1938 its recurrence in the decade of 1950-1960. It proved very severe in Southwest United States and is plainly forecasted by my study of St. Louis precipitation "60-year Forecast" with a forecast of its end in 1957. (See P. 4211,

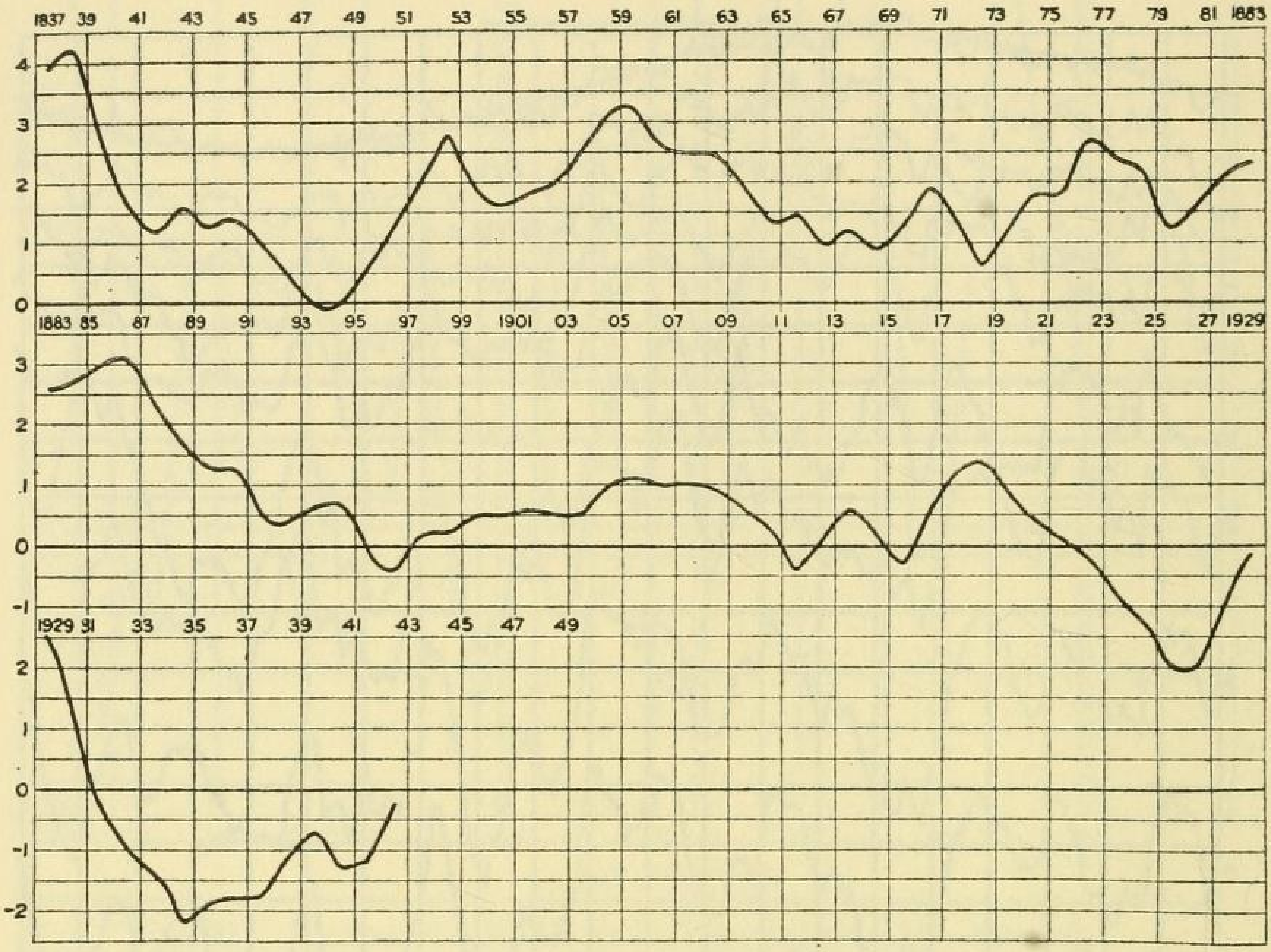


FIG. 43.—Periods in level of Lake Huron.

fig. 6). The two great droughts will probably begin about 1975 and 2020, respectively.

11. SHORT ACCIDENTAL TRENDS IN SOLAR VARIATION

Measurements of the solar constant of radiation reveal trends of rising and of falling radiation several times each month lasting from 3 to 10 days each (see fig. 45). We noticed as early as 1925 that the temperature at Washington seemed to respond to these accidental solar changes. This led us to make a very extensive investigation of this matter, in which we found (P. 3771, P. 3893, P. 4462) that not only the measures of the solar constant of radiation but also measures of the areas of solar flocculi and measures of Fe in the ionosphere precede up-and-down temperature trends. These trends, observed either in solar constant, calcium flocculi, or Fe changes, produce opposite effects, like the right and left hands, on temperatures the world over. (See figs. 45, 46, and 47.) The temperature changes are not small. I cannot better bring out this phenomenon than by quoting from pages 219-221 of my paper of 1939 (Quarterly Journal Royal Meteorological Society, vol. 65, No. 280, April 1939).

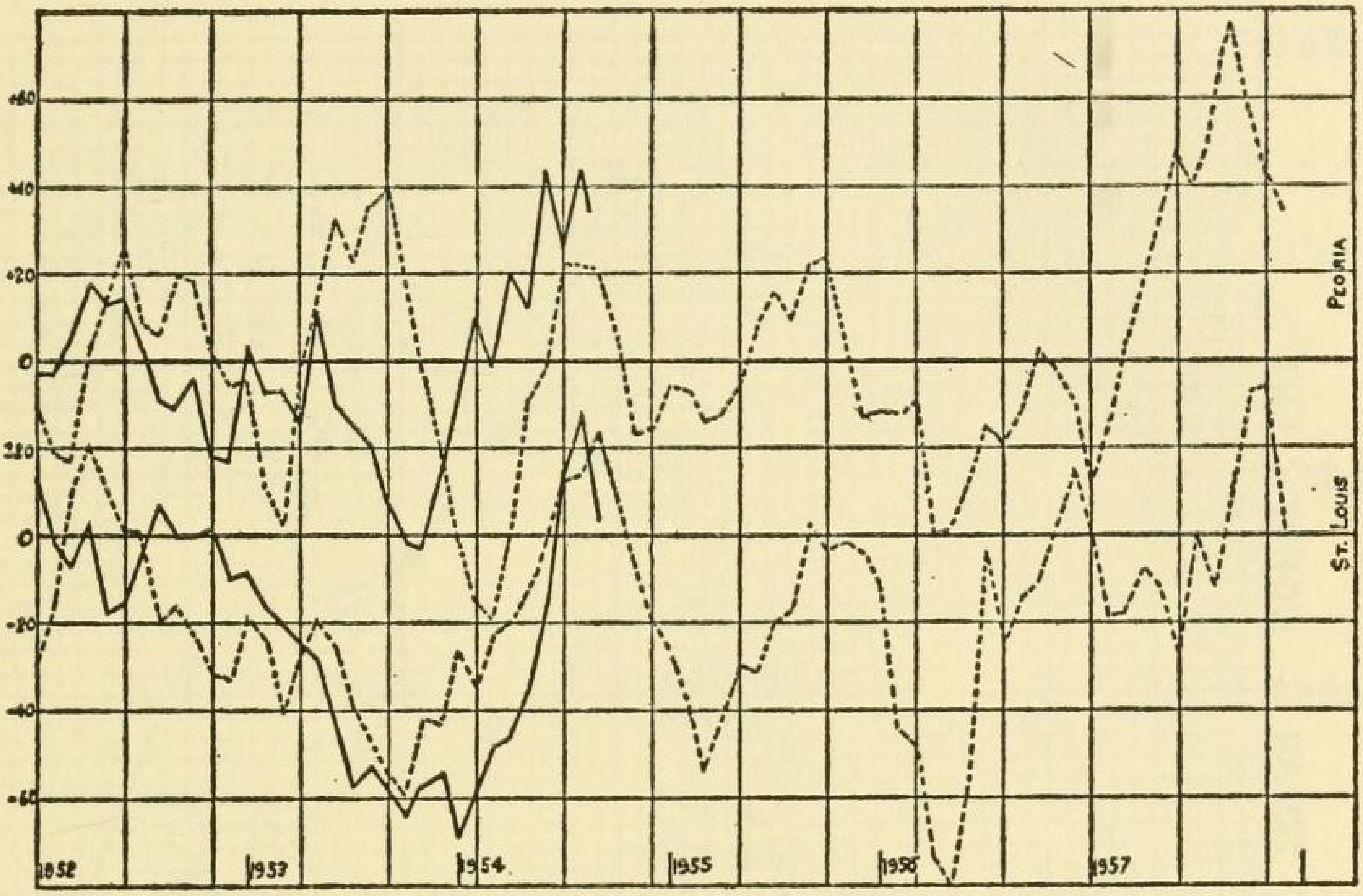


FIG. 44.—Drought prediction from forecasts of precipitation, St. Louis, Mo., and Peoria, Ill.

Referring to Fig. 1 of my just cited paper, here reproduced [here figure 46], the reader will find there two curves for each month of the year showing departures from normal temperature at Washington, D.C. In each month the curves show a well-marked opposition like the right and left hands. The separations of the curves in the months January, February, March, April, May, June, August, October, November, and December range from 14° to 24° F., and evidently constitute major departures from normal temperatures. Similar results, showing in almost all cases opposition like the right and left hands, but differing widely in actual march of the pairs of curves, are shown for St. Louis, Helena, and Potsdam, in other illustrations in the cited publications. The curves are computed for all these cities starting from identical dates, 320 in number, scattered over 12 years. Some 10 to 20 cases combined are in each curve shown. The data of temperature departures in each case cover 16 days following the starting date selected.

How were these 320 dates selected? They are chosen as dates when solar variations commenced. As shown in Fig. 1 and Table I of "The dependence of terrestrial temperatures on the variations of the sun's radiation," they comprise all the dates during 12 years when good consecutive solar constant observations, made mostly at Montezuma, Chile, began to indicate rising or falling sequences of the sun's output of radiation. The range of these sequences was small, rarely exceeding 1 percent, and their mean range is only about 0.7 per cent of the solar constant. Owing to the interference caused by changes in atmospheric transparency, superposed on the inevitable accidental errors of measurement, it is highly probable that some of these 320 cases are spurious. If the spurious cases could be eliminated the average temperature departures would doubtless be increased above their already large magnitudes.

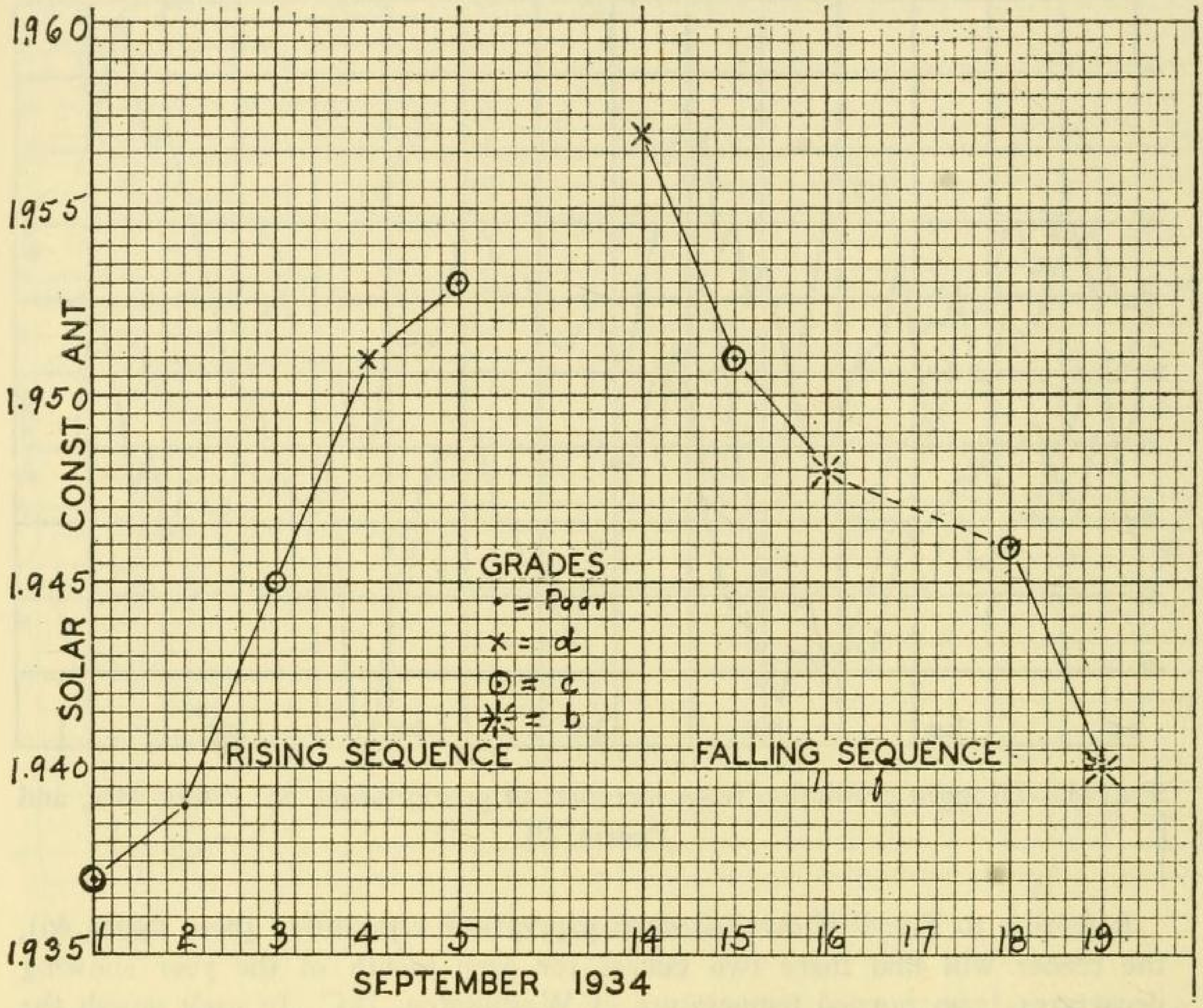


FIG. 45.—Solar constant, rising and falling trends.

Our critics, however, maintain that they have demonstrated by correlation methods, and by references to my writings, that the supposed variation of the sun is largely due to defects in our methods of observing, and that the consequences deduced from such supposed variations are illusory.

If so, we must assume that these interesting curves, which show such extraordinary inversions of temperature departures, would as likely as not result from a haphazard choice of any 320 dates, quite as well as from the selection of 320 dates which were chosen because they were observed to be the dates of commencing solar changes. This is of course absurd.

Several of my friends have urged me to omit the just-preceding part of my defense. They consider that meteorologists are so firmly fixed in their disbelief in the meteorological importance of day-to-day solar variations that no meteorological evidence whatever can persuade them to reconsider the matter. But though I may be singular in my opinion, I regard the present argument as unanswerable. Though it may be futile for the present, owing to this prevailing attitude, I shall proceed to place on record still more support of my argument.

First, as I showed in my paper, "The dependence of terrestrial temperatures on the variations of the sun's radiation," above cited, not only do several cities show large opposing trends of temperature following rising and falling sequences

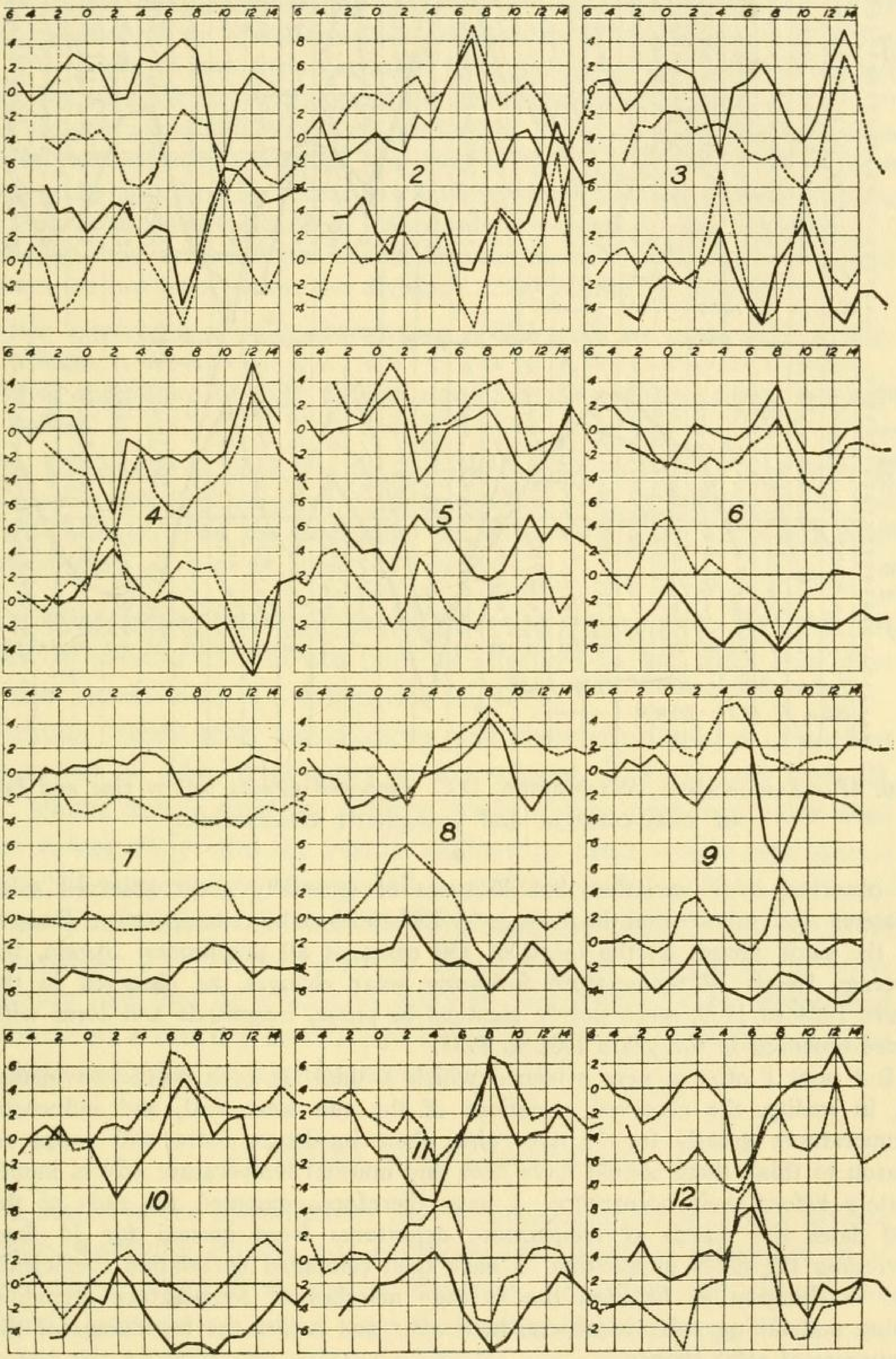


FIG. 46.—Temperature, Washington, D.C. Opposed effects follow rise and fall of solar constant and, 2 days later, of calcium flocculi observations, January to December.

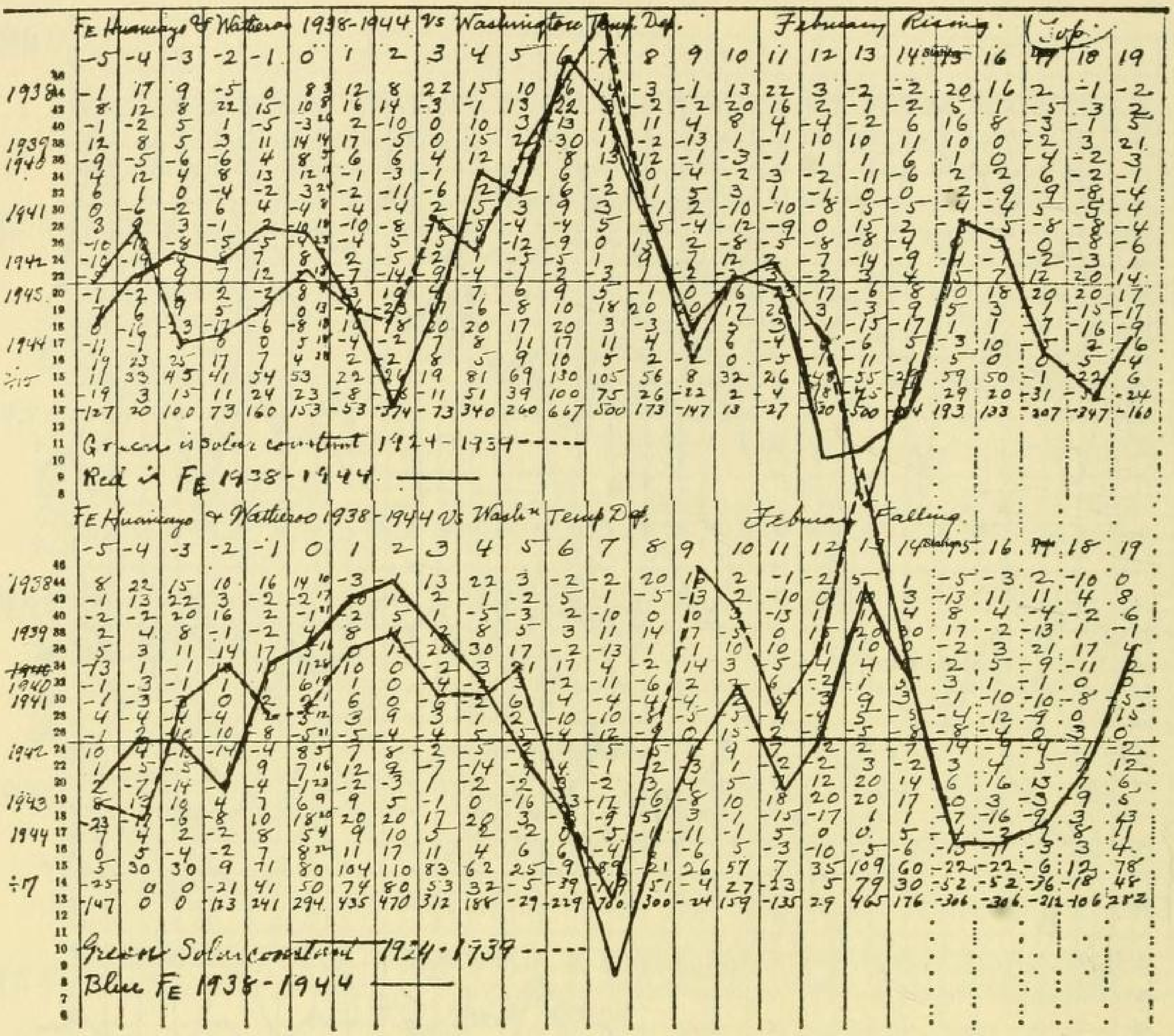


FIG. 47.—Temperature, Washington, D.C. Opposed effects follow rise and fall of solar-constant and ionospheric observations.

of observed solar variation, but 46 cases of unusually great observed solar changes were followed on the average by 1.95 times as large temperature changes in the same phases as the mean of 150 cases of all amplitudes. Again, the average trends of temperature following solar changes, as observed in the years 1924 to 1930, were nearly identical in phase, magnitude and form with those observed in the years 1931 to 1935.

But now I offer a new evidence which I think is even more convincing. If, in reality, the observed variations of the sun were real, and influenced temperatures greatly for 16 days *after* their incidence, there still seems no reason to think there should have been any unusual temperature effects immediately *before* their occurrence. I have therefore computed for each of the 320 dates the march of temperature departures from normal for 16 days *preceding* the dates in question. I have then computed correlation coefficients for Washington as between the average marches of temperature attending rising and falling solar sequences, both *after* and *before* the beginnings of the sequences of solar change.

To fix ideas, I recall that in each division of this test there are 24 lines comprising 17 values each, two lines for each month of the year, selected from the 12 years, 1924 to 1935. These pairs of 24 lines of the divisions are separated into two types, one type containing 17 values for days following, and 17 for days preceding the beginning of sequences of observed *rising* solar radiation. The other type comprises 17 values for days following and 17 values for days preceding the beginning of sequences of observed *falling* solar radiation. Two correlation coefficients are to be computed, one including the 204 values of the two contrasted types *following* the supposed critical dates, the other for the 204 values of the two types *preceding* them.

In order to avoid diluting the correlations by including extraneous influences due to previous conditions, each line was first reduced to the level of zero temperature departure, by adding to all 17 values in that line a constant quantity such as to make the average temperature departure for that line zero.

Having thus arranged the values, correlation coefficients were computed between the two types for the two divisions. They resulted as follows:

After appearance of solar change, $r = -54.3 \pm 4.9$ per cent, which is significant.

Before appearance of solar change, $r = 11.1 \pm 6.0$ per cent, which is meaningless.

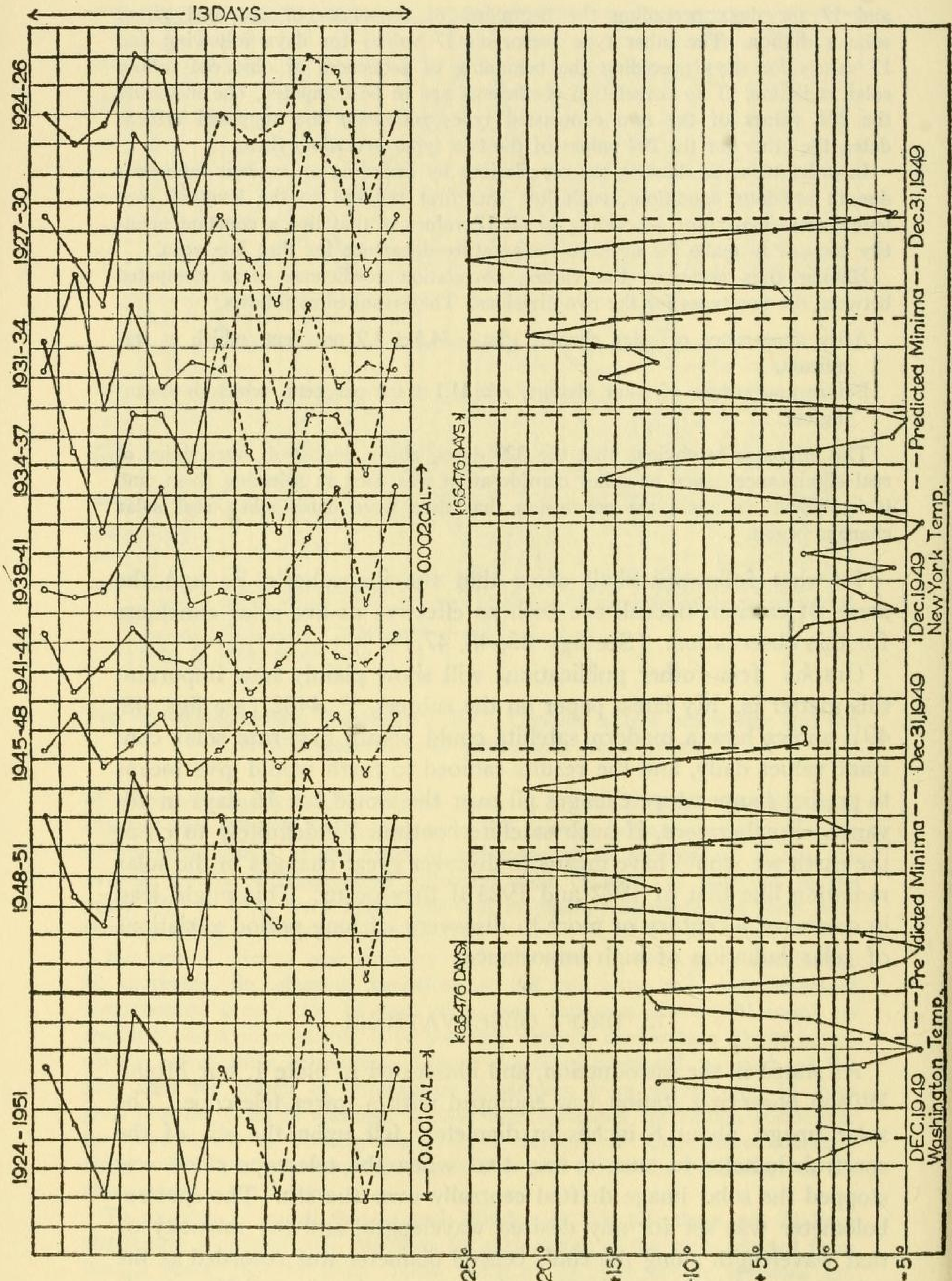
The inference is obvious that the 320 dates, above described, were dates of real significance, since no other consideration was used in selecting them, and it is difficult to avoid the conclusion that they were dates when real solar changes began.

In what follows I shall show that the ionospheric Fe and the areas of calcium flocculi are both as effective as are solar constants for this observation. (See figs. 45, 46, 47.)

Graphs from other publications will show plainly how important this matter is. My latest paper on the subject, P. 4462 (see figs. 48, 49), shows how a modern satellite could obtain first-rate solar constant values daily, and the results radioed to earth would give means to predict temperature changes all over the world for 16 days in advance. Furthermore, if such satellite continued indefinitely to circle the earth we would have means to discover great changes in the solar radiation like that of 1922 and 1923 if they occur. This might lead in course of a century or more to discovery of long-period variations of solar radiation of high importance.

12. DRIFT OBSERVATIONS

As stated in the introduction, and illustrated in plate 1, our Mount Wilson observing station was equipped with a tower telescope. The solar image, about 8 inches in diameter, fell upon the slit of the spectrobolometer in such a way that when the telescope clock was stopped the solar image drifted centrally over the slit. The spectrobolometer was set for any desired wavelength, and the intensity of that wavelength along the sun's central diameter was recorded as the solar image drifted. In 1908 we began to make these drift records


13 DAYS
1924-26
1927-30
1931-34
1934-37
1938-41
1941-44
1945-48
1948-51
1924-1951
0.002 CAL.
0.001 CAL.
6.5476 DAYS
6.5476 DAYS
+25°
+20°
+15°
+10°
+5°
0°
-5°
Predicted Minima
Dec.31,1949
1 Dec.1949
New York Temp.
Predicted Minima
Dec.31,1949
DEC.1949
Washington Temp.

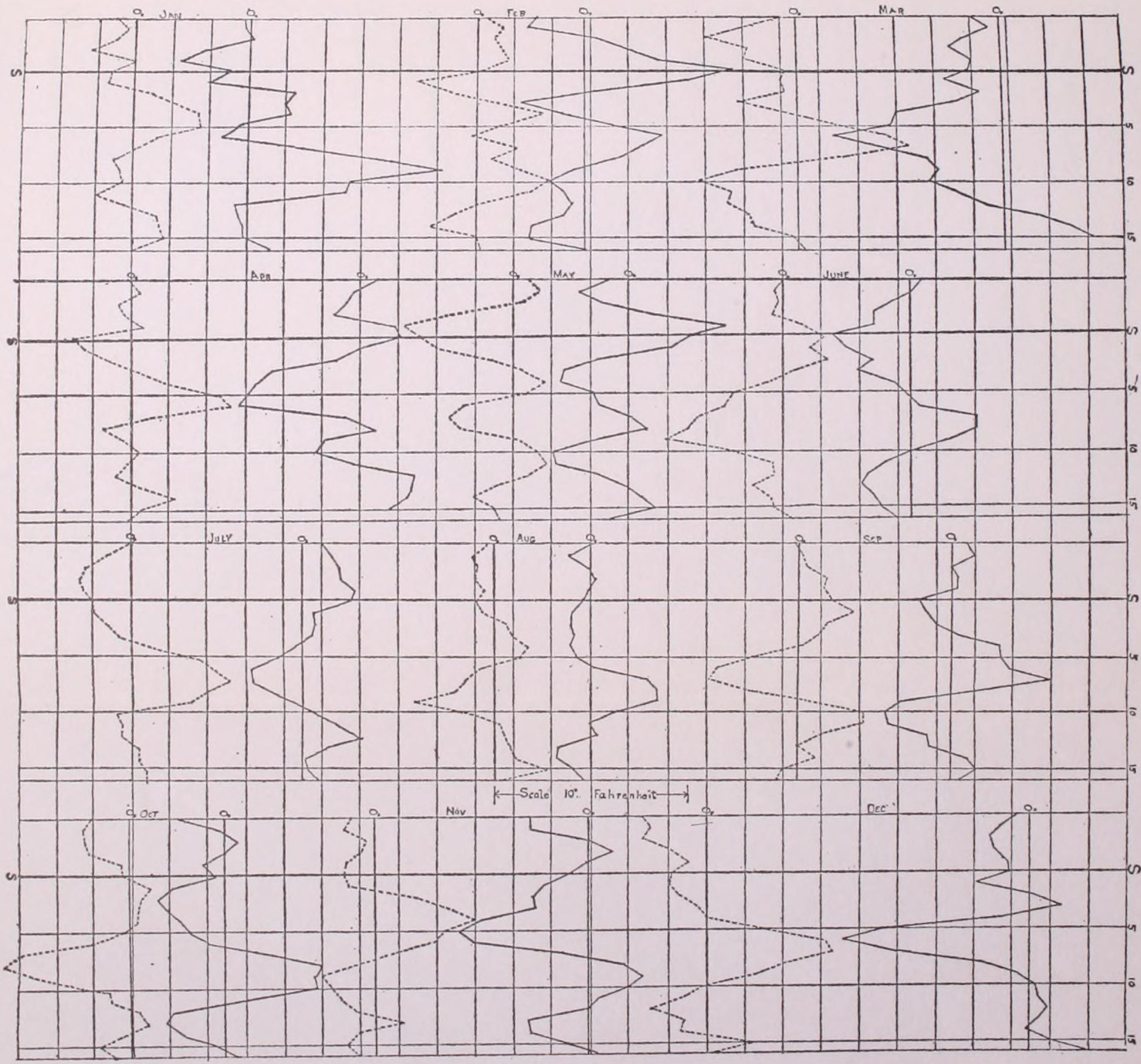


FIG. 49.—Washington temperature controlled 16 days by sun's variation. The sun changes at *S*. Washington temperature, —5 to 16 days. Full curves, solar radiation rises, dotted curves, falls. Zero departures at *O*. See P. 4462.

every time bolographs of the solar spectrum were made for measuring the solar constant of radiation. This continued until 1920, when we removed from regular observation on Mount Wilson.

Our purpose was to determine if changes in the solar constant are accompanied by correlated changes in the U-shaped drift curves. Dr. Langley had hoped that they would be and that drift observations would serve as an easy means to measure solar variation.

The entire series of comparisons between solar-constant variation and solar-contrast variation is studied in chapter 7 of A.P.O. Annals, volume 4, pages 217-258. The discussion of this long series of careful measures gave conflicting results, hard to understand. Sometimes it indicated increased solar constant with increase of contrast in brightness between center and limb of the sun. Indeed, for the results of 1913, the correlation coefficient was $+0.601 \pm 0.067$, and a change of 1 percent increase of the solar constant was accompanied by +17 in the arbitrary solar-constant number. But at some times even the sign of the correlation coefficient changed from plus to minus. So the hope that Dr. Langley had held before his death in 1906 proved illusory. Solar-contrast observations did not yield an easy way to measure the variation of solar radiation.

In May 1952, however, P. 4088 threw new light on this difficulty. We then knew of the family of harmonic periods in solar variation. Synthetic solar constant values computed from these periodic terms marched in close accord with observed values from 1920 to 1951 (P. 3902). So good was this agreement that I computed the probable march of the solar constant from 1900 to 1920, the years before good determinations had been possible. For, as I have said, the Langley solar-constant method, though sound and fundamental, must always give values too high or too low if the transparency of the atmosphere changes during the several hours required to measure it. The synthetic solar-constant values (see fig. 50) were based on "the short method" which has no such drawback, and besides gives several values of the solar constant on each day of observation, thus providing mean values. (See pp. 61, 62).

Figure 50 shows that before 1920 there is no visible correlation between the observed and the synthetic Mount Wilson solar constant values. But figure 51, in its graphic comparison of synthetic solar constant with observed solar-contrast values, shows a fairly high degree of correlation. Increased contrast goes with increased solar constants. So if the A.P.O. was still in short-method operation as formerly, and in a good location, and with a tower telescope, perhaps Dr. Langley's hope might be at least partly realized.

13. FINAL EVIDENCE

Notwithstanding the evidences contained in the references cited below some meteorologists may still be reluctant to accept forecasts many years in advance. In the absence of conclusive *theoretical* demonstration that the small percentage changes in solar radiation can cause changes of identical periods of many times larger percentage in weather, and that these are hidden by phase changes from direct disclosure, they may still withhold belief. Therefore I present an additional observation which is so striking that some have considered it conclusive.

If it is true that the 273-month family of regular harmonic periods exists in weather, with such amplitudes that by their summation a controlling influence is exerted, then it follows that the weather should tend strongly to repeat its features at intervals of 22 years 9 months. I showed such a tendency in the precipitation of Peoria, Ill., in 1934 by figure 33 of P. 3339, reproduced as figure 1 of P. 4095, 1952. But now I will present a much more telling evidence from the records of precipitation at Nashville, Tenn.

Taking from our files the computations on Nashville prepared for P. 4390 in 1958, I lengthened my forecast for Nashville through 1970. Considering only the 6 years 1965 through 1970, I looked back 22 years and 9 months to the interval April 1942 to March 1948, 6 years.

Figure 53 gives a graphical comparison of my *forecast,* from 1965 through 1970, with the *observed* precipitation at Nashville from April 1942 through March 1948. The values plotted are, as stated in P. 4390, smoothed by 3-month consecutive means and are departures from the normals given in table 9, P. 4390. I have computed the correlation coefficient for the 6 years between the two curves of figure 53, and also the correlation between the two curves of figure 2, page 3, of P. 4390, for the 6 years 1950 through 1955, all from Nashville precipitation. The two correlation coefficients are, respectively, $+0.469 \pm 0.061$, and $+0.737 \pm 0.024$.

So the correlation coefficient between the *direct forecast* and the *event,* 1950 through 1955, is 30 times its probable error, and the correlation coefficient between the *forecast,* 1965 through 1970, and the *observed* precipitation at Nashville, April 1942 through March 1948 (22 years 9 months previous) is 7.6 times its probable error.

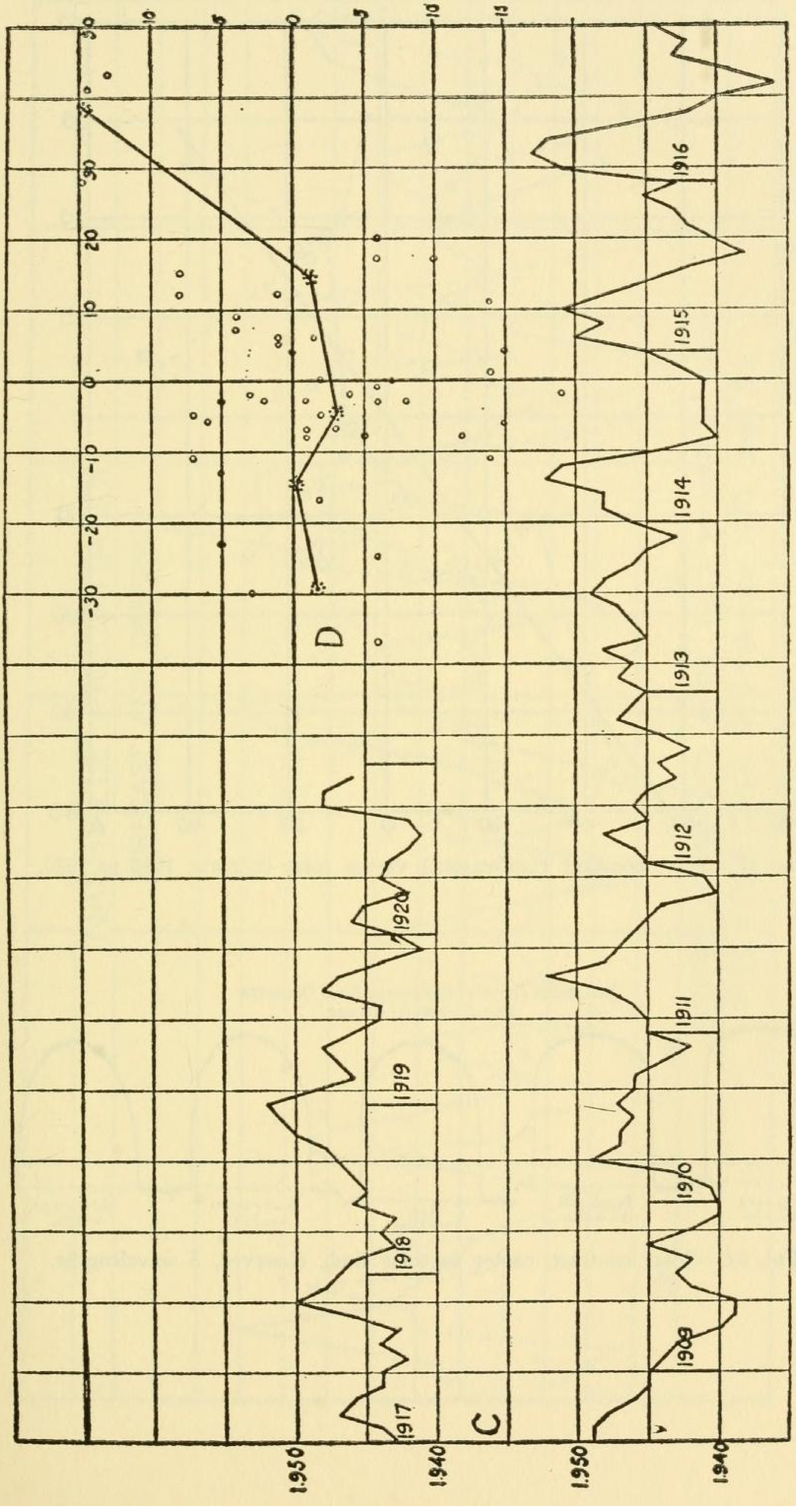


FIG. 50.—Solar constant backcasted, 1920 to 1909. No correlation with Mount Wilson *observed*.

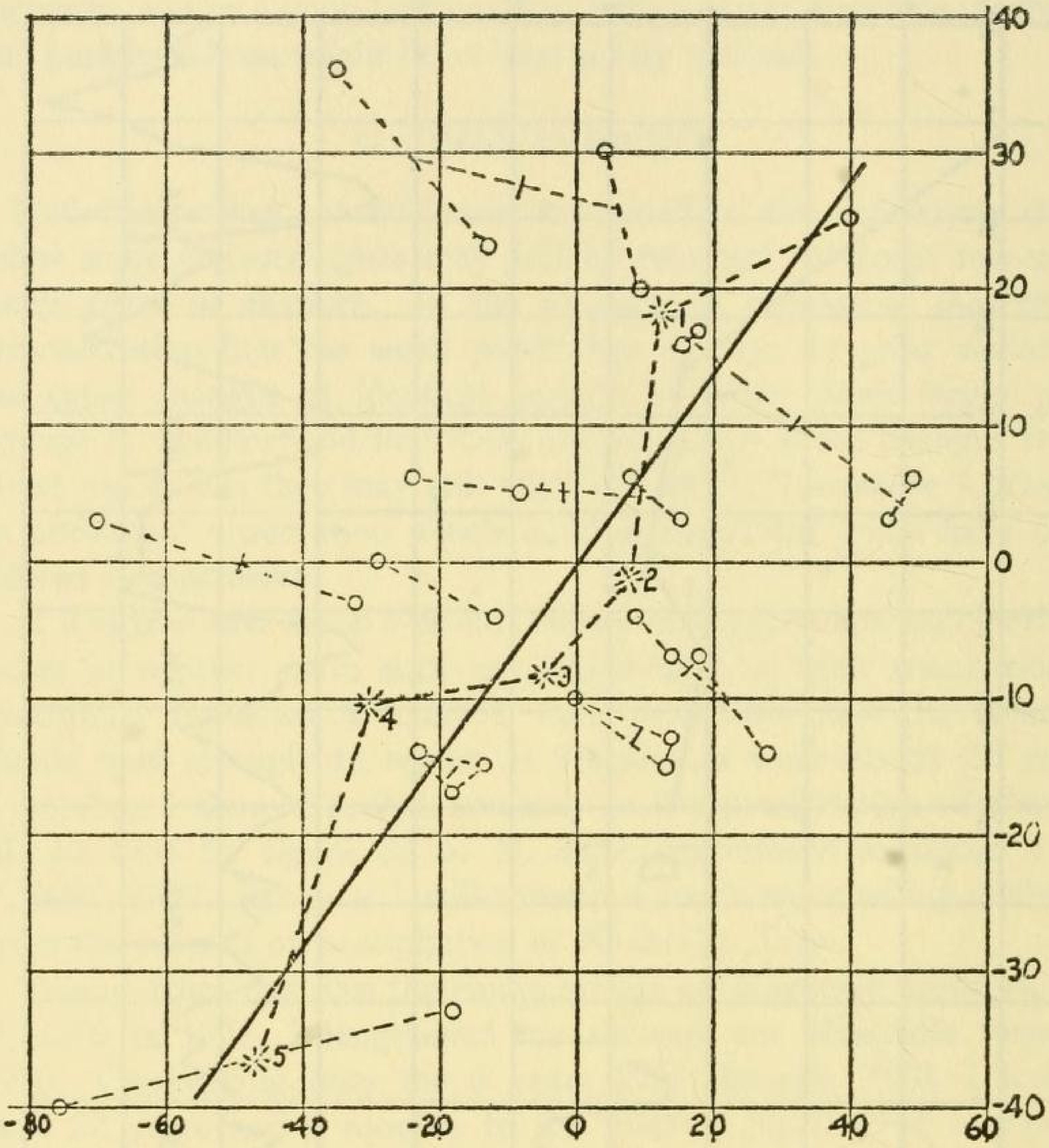


FIG. 51.—Solar constant (backcasted) versus solar contrast, 1913 to 1920.

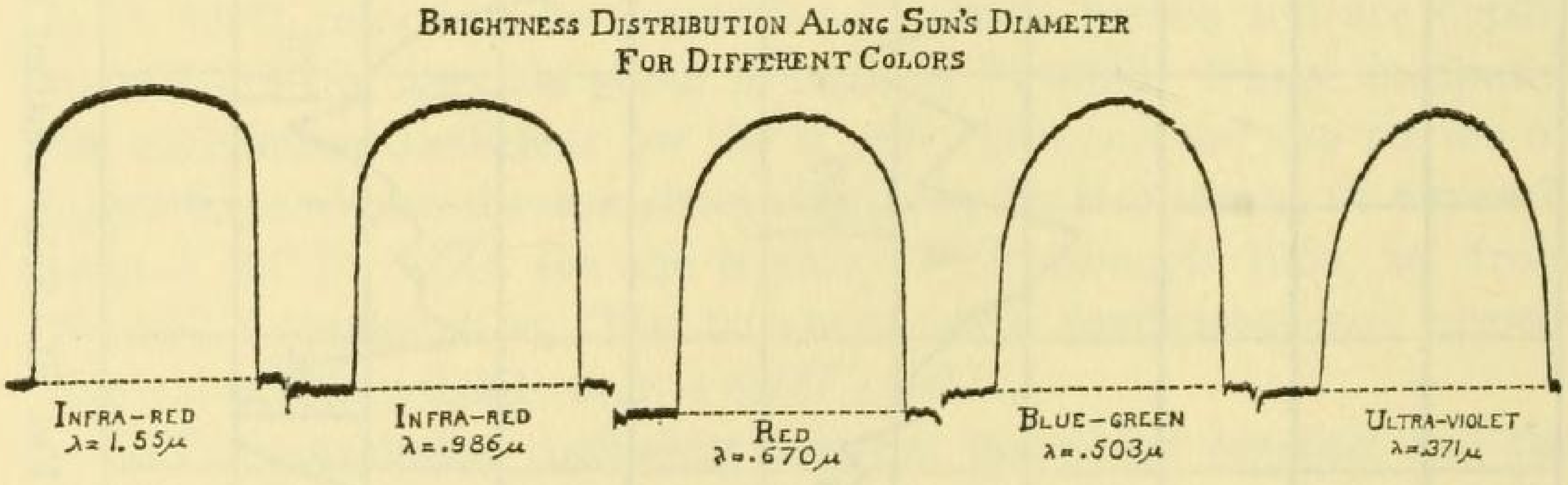


FIG. 52.—Solar contrast, center to solar limb, observed, 5 wavelengths.

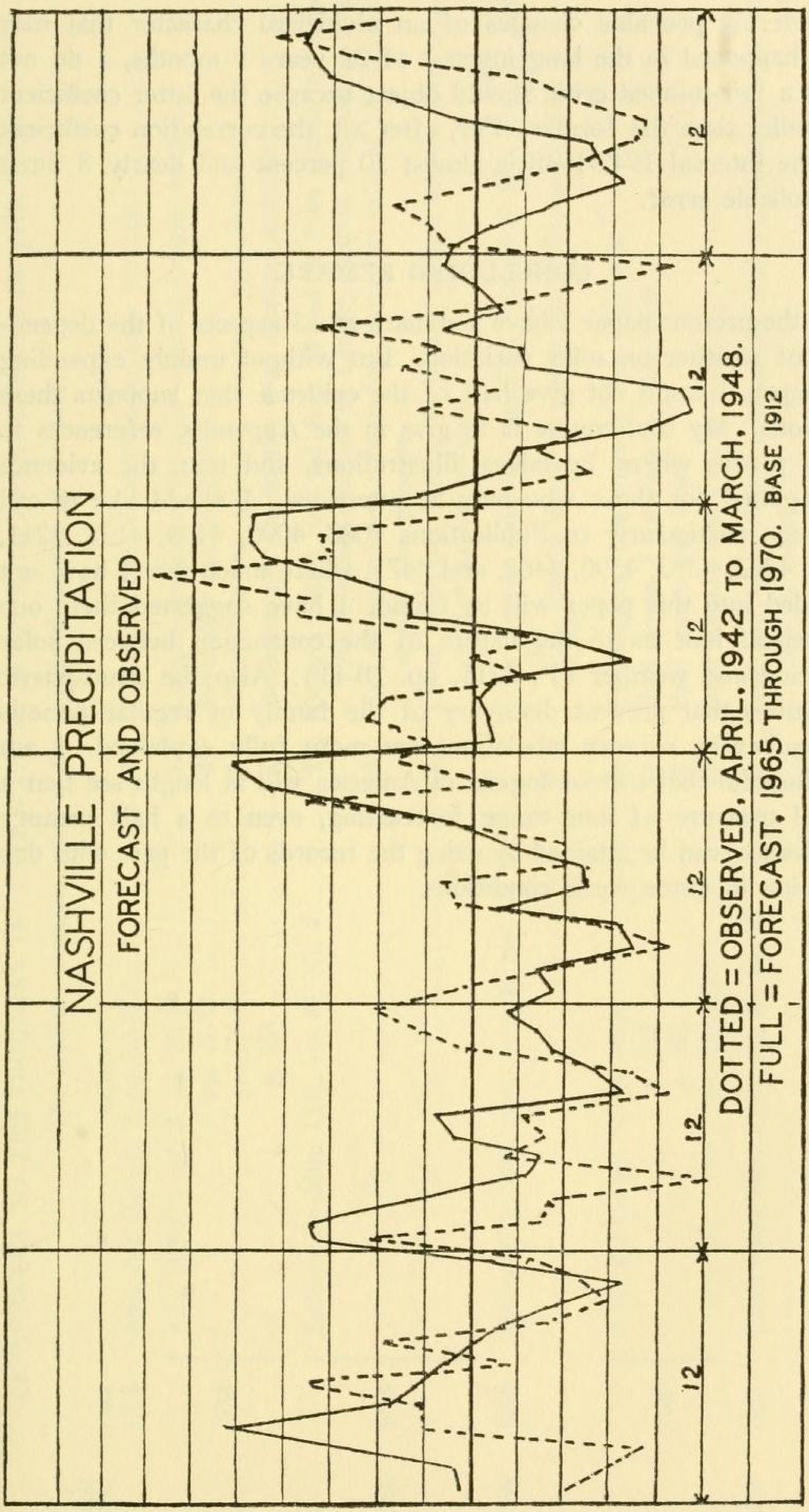


FIG. 53.—Nashville precipitation: Forecast, 1965 to 1970, versus observed, 1942 to 1948, 273 months previous.

Considering probable changes of an accidental character that may have happened in the long interval of 22 years 9 months, I do not think a fair-minded critic should object because the latter coefficient is smaller than the former. For, after all, the correlation coefficient for the interval 1942-1948 is almost 50 percent and nearly 8 times its probable error.

CONCLUDING REMARK

In the present paper I have summarized 13 aspects of the dependence of weather on solar variation. But without unduly expanding the paper, I could not give half of the evidence that supports these positions. My best course is to give in the Appendix references to many papers where, by tables, illustrations, and text, the evidence is amplified for those who may be interested. I would like to call attention particularly to Publications 4088, 4090, 4103, 4135, 4211, 4213, 4222, 4352, 4390, 4462, and 4471, where much that I have not crowded into this paper will be found. I have suggested there one theoretical hint as to the nature of the connection between solar variation and weather (P. 4211, pp. 10-11). Also the atmospheric conditions that prevent discovery of the family of regular periods in weather by *cursory* tabulations are more fully explained. I am still hopeful that meteorologists in America will at length see that a useful measure of long-range forecasting, even to a half century in advance, can be attained by using the records of the past with due attention to atmospheric conditions.

APPENDIX

REFERENCES TO THE ORIGINAL INVESTIGATIONS SUPPORTING STATEMENTS IN THE TEXT

(The boldface numerals refer to the numbered sections of the text)

Publ. No.	*Date*	*Reference*		*Subject*
	1908	Ann. A.P.O., vol. 2, pp. 13-17	**1**	Theory of Langley method for solar constant.
	1913	Ann. A.P.O., vol. 3, pp. 21-39	**1**	Complete procedure for solar constant, Langley method.
		pp. 47-52	**1**	Silver-disk pyrheliometer.
		pp. 52-69	**1**	Water-flow and water-stir standard pyrheliometers.
		p. 158	**1**	Radiation and wavelength, solar diameter distribution.
2361	1915	Smithsonian Misc. Coll., vol. 65, No. 4	**2**	Solar constant observed Sept. 20 and 21 from sunrise to noon. All 6 values obtained by Langley method. All 1.90 to 1.96.
		Do	**2**	Balloon pyrheliometer flown July 11 records value of 1.87 calories at 2.63 mm. pressure.
		Do	**2**	Curve of highest values, sea level to highest balloon, gives solar constant of 1.93 calories.
2499	1918	Smithsonian Misc. Coll., vol. 66, No. 6		Solar rotation and solar variation. Periods 27 days and $\frac{273}{1250}$ and $\frac{273}{2500}$ months shown by correlation in 1915 and 1916.
	1922	Ann. A.P.O., vol. 4, pp. 65-84	**2**	Pyranometer; brightness of sky; solar disk.
		p. 219	**12**	Drift curves, 5 wavelengths; solar disk.
		p. 250	**12**	Drift curves and haze.
		pp. 217-257	**12**	Solar constant and solar contrast.
3182	1932	Smithsonian Misc. Coll., vol. 87, No. 15	**1**	Improved water-flow pyrheliometer and its standard scale of solar radiation.
	1938	Zvlaštni Otisk XVIII, Prague	**10**	Some periodicities in solar physics and terrestrial meteorology; droughts predicted from Great Lakes level records.

APPENDIX—*continued*

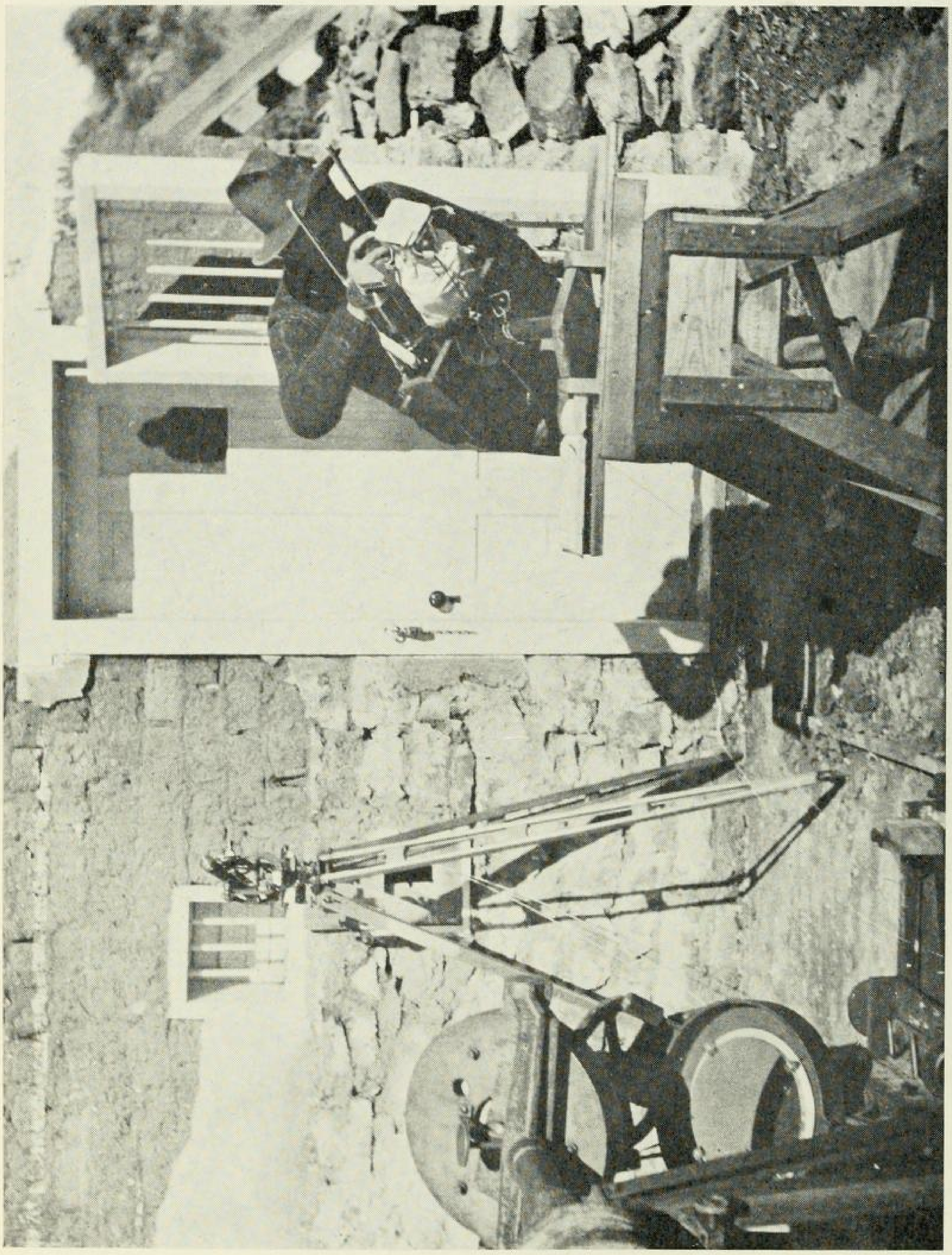
Publ. No.	*Date*	*Reference*		*Subject*
	1942	Ann. A.P.O., vol. 6, pp. 83-162	**2**	Solar-constant measurements.
		p. 163	**3**	Station values compared for accuracy.
3765	1944	Smithsonian Misc. Coll., vol. 104, No. 3	**10**	A 27-day period in Washington precipitation.
3771	1944	Smithsonian Misc. Coll.. vol. 104, No. 5	**6**	Weather predetermined by solar variation.
3893	1947	Smithsonian Misc. Coll., vol. 107, No. 4	**10**	Sun's short period. 6.6456 days $= \frac{1}{1250} \times 273$ months.
			10	Also sun's radiation has irregular trends up and down, which produce opposite marches of temperature for 2 weeks thereafter. These trends occur also in ionospheric Fe and in areas of calcium flocculi near central sun.
3916	1948	Smithsonian Misc. Coll., vol. 110, No. 1	**10**	Solar variation attending West Indian hurricanes.
3940	1948	Smithsonian Misc. Coll., vol. 110, No. 6, fig. 1 (see also fig. 4 and pls.)	**10**	Solar variation attending magnetic storms; effects of great sunspot group, Mar. 20, 1920.
3990	1949	Smithsonian Misc. Coll., vol. 111, No. 13		Washington and New York respond equally to temperature influence of the 6.6456-day solar period.
4015	1950	Smithsonian Misc. Coll., vol. 111, No. 17		Predictions of Washington and New York minimum of temperature in Dec. 1949 verified.
4088	1952	Smithsonian Misc. Coll., vol. 117, No. 10, fig. 6	**4**	273-month period graph, 1924 and 1947.
		p. 27	**12**	Solar constant 1908-1920 backcasted. Reveals no correlation with Mount Wilson values but fairly good correlation with solar contrast values.
		p. 29	**1**	Langley method for solar constant always gives individual day values too high or too low; only means of many days are reliable.

Publ. No.	*Date*	*Reference*		*Subject*
4090	1952	Smithsonian Misc. Coll., vol. 117, No. 11	**6**	Interferences with normals in weather records.
4103	1953	Smithsonian Misc. Coll., vol. 121, No. 5	**8**	Solar variation and precipitation at Albany.
4135	1953	Smithsonian Misc. Coll., vol. 122, No. 4	**6**	Meeting of professional meteorologists.
4211	1955	Smithsonian Misc. Coll., vol. 128, No. 3	**8**	60-year weather forecasts.
4213	1955	Smithsonian Misc. Coll., vol. 128 No. 4, pp. 12-13	**4**	Periodicities in solar variations.
4222	1955	Smithsonian Misc. Coll., vol. 131, No. 1	**1**	Leading operations of the Astrophysical Observatory, 1895-1955.
4265	1956	Smithsonian Misc. Coll., vol. 134, No. 1, pp. 15-17	**10**	Periods related to 273 months. Human pulse period of 212 days = 7.0 months ± 0.5 percent, with subperiods ½, 1/3, 1/6, 1/7, 1/11, all harmonics of 273 months. 7 months $= \frac{273}{39}$ months.
4338	1958	Smithsonian Misc. Coll., vol. 135, No. 10	**10**	Periodicities in ionospheric data.
4352	1959	Smithsonian Misc. Coll., vol. 138, No. 3	**7**	Long-range weather forecasting; exact length of master period 273 months.
4390	1960	Smithsonian Misc. Coll., vol. 139, No. 9	**8**	Long-range forecast of U.S. precipitation.
4462	1961	Smithsonian Misc. Coll., vol. 143, No. 2	**10**	16-day weather forecasts from satellite observations.
4471	1961	Smithsonian Misc. Coll., vol. 143, No. 5	**7** **9**	Long-range temperature forecast. See comparisons of accuracy of forecasts of precipitation in P. 4390 for large and small departures from the normal, p. 6.

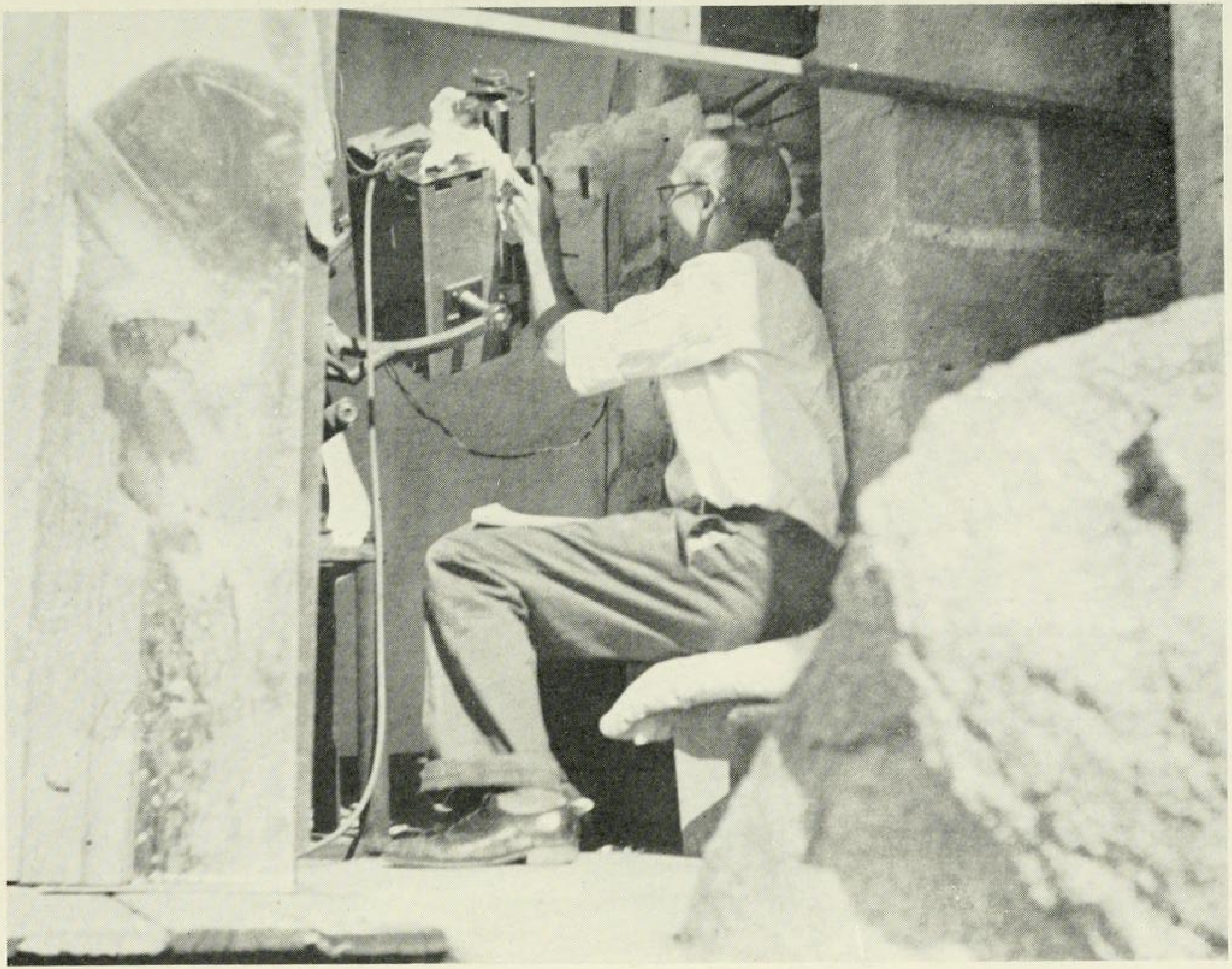
SUPPLEMENTARY REFERENCES

	1957	Smithsonian Contr. Astrophysics, vol. 3, No. 3	**5**	Papers on the solar constant by Sterne, Abbot, Aldrich, and Hoover.
	1957	Journ. Solar Energy Sci. and Eng., vol. 1, No. 1.	**7**	Weather and solar variation, Abbot.
	1958	Journ. Solar Energy Sci. and Eng., vol. 2, No. 2.	**7**	Detailed procedure used in Abbot's method of long-range weather forecasting, Abbot.

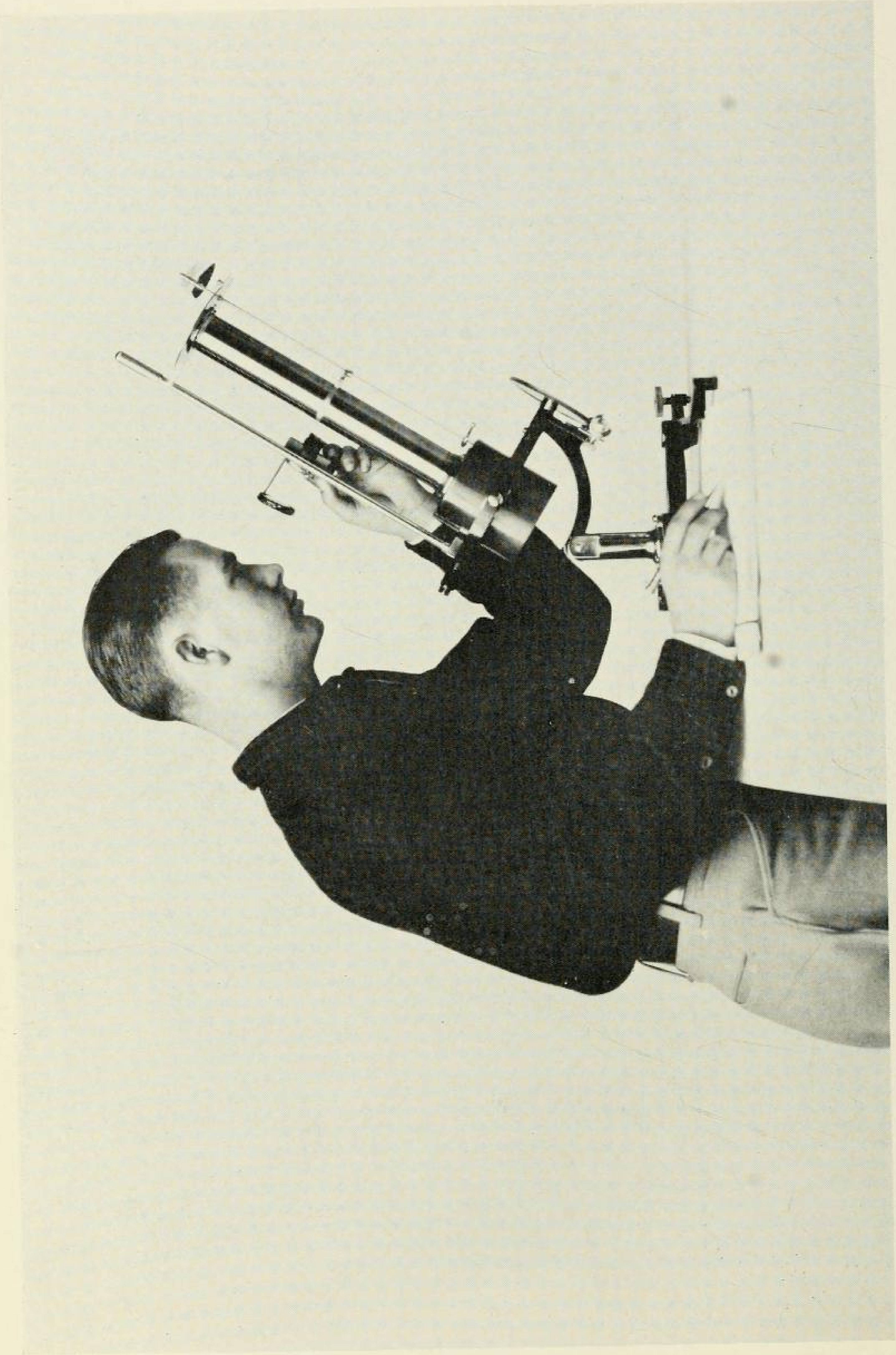
Smithsonian Observatory, Mount Wilson, Calif., with solar-constant outfit and tower telescope.



Smithsonian Observatory, Table Mountain, Calif. Observer with pyrheliometers and pyranometer. Coelostat and theodolite for solar-constant work within.



Aldrich observing with double water-flow electric compensation pyrheliometer.



Boffman observing with silver-disk pyrheliometer.