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# SOLAR VARIATION AND PRECIPITATION AT PEORIA, ILLINOIS

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In a recent paper [1] it was shown that the intensity of the sun's radiation, as it is outside the earth's atmosphere, varies simultaneously in 23 regular periods, all aliquot parts of approximately 272 months. It would naturally follow that details of variation in observed values of the solar constant of radiation would tend to repeat at intervals of about 23 years. Figure 4A of the paper cited shows that this is indeed the case.

Many years ago it was shown that the precipitation at Peoria, Ill., also tended very strongly to exhibit repetitions of features at intervals of 23 years. I reproduce here as figure 1, the figure 33 of an earlier paper.[2]

Intending to trace the effect of the solar variations above noted on weather, it seemed well to study first the records of precipitation at Peoria, as these were already known to exhibit influences of the master cycle of about 23 years. I have been engaged over 3 years in this investigation, for unexpected complexities kept cropping up, which made it necessary again and again to scrap all results and begin at the beginning. Without being tedious, it may be said that I have tabulated over 1,000 months of precipitation records, of the years between 1856 and 1939, separately in 20 to 30 supposed periods, and repeated the whole tabulation no less than 14 times.

*Futility of determining periods from weather records.*—Knowing that the sun's radiation varies in regular periods, which are integral submultiples of about 23 years, but being restricted by available solar-constant observations to little more than 20 years with many gaps and inaccuracies in these records, I hoped at first to use the continuous series of Peoria precipitation records from 1856 to 1939 to establish which submultiples of 23 years are active, and to fix their exact lengths.

[1] Smithsonian Misc. Coll., vol. 117, No. 10, 1952.
[2] Smithsonian Misc. Coll., vol. 94, No. 10, 1935.

It was soon disclosed that the phases of periodicities, though invariable in solar variation, shifted in Peoria precipitation records, depending on the time of the year. I suppose the cause to be associated with considerations of lag in response to solar impulses. It is patent that though the sun's heating potential reaches a maximum daily at noon, maximum temperatures do not come until several hours after noon, and their arrival displays different lags in different localities, and in the same locality at different times and seasons. Similar it must be with regard to all weather responses to all solar periodicities.

*Subdivision of the year.*—Accordingly, one of my first modifications of procedure was to prepare separate tabulations for each periodicity in three fractions of the year, namely: January to April, May to August, September to December. Doubtless a finer subdivision of the year would theoretically be better, but for periodicities of 10 to 20 months in length the number of columns in a tabulation becomes few.

*Interference between periodic effects.*—It is plain that the determination of every periodic fluctuation in precipitation must be affected by the presence, implicitly in the data, of above 20 other periods of different lengths. Theoretically these disturbing influences can only be completely sifted out of the result for one period, if the mean values are computed from an infinite number of repetitions of the chosen period. When, instead of infinity, one becomes limited to a few repetitions, the computed march of the investigated periodicity must evidently be very imperfectly determined. Hence, on account of paucity of data, it was impracticable to divide the years beyond the triple division mentioned above.

*Sunspot frequency affects phases.*—But still another limitation of freedom in tabulation soon appeared. The phases of features in the periodicities computed were found different in different years. This was found to be associated with sunspot frequency. As said above, the cause of the phenomena of phase changes is probably to be assigned to variable lag of response in weather to solar impulses, depending on the condition of the atmosphere. Such changes in lag are evidently attributable to the varying character of the atmosphere at different seasons of the year as regards transparency, cloudiness, and other conditions. But sunspots continually bombard the atmosphere with multitudes of electric ions. These act as centers of condensation for the constituents of haze. Hence it was only to be expected that phase changes would be associated with Wolf sunspot numbers. Here, again, a compromise had to be made. It was decided to subdivide the precipitation data in two groups, for Wolf numbers $\gtreqless 20$.

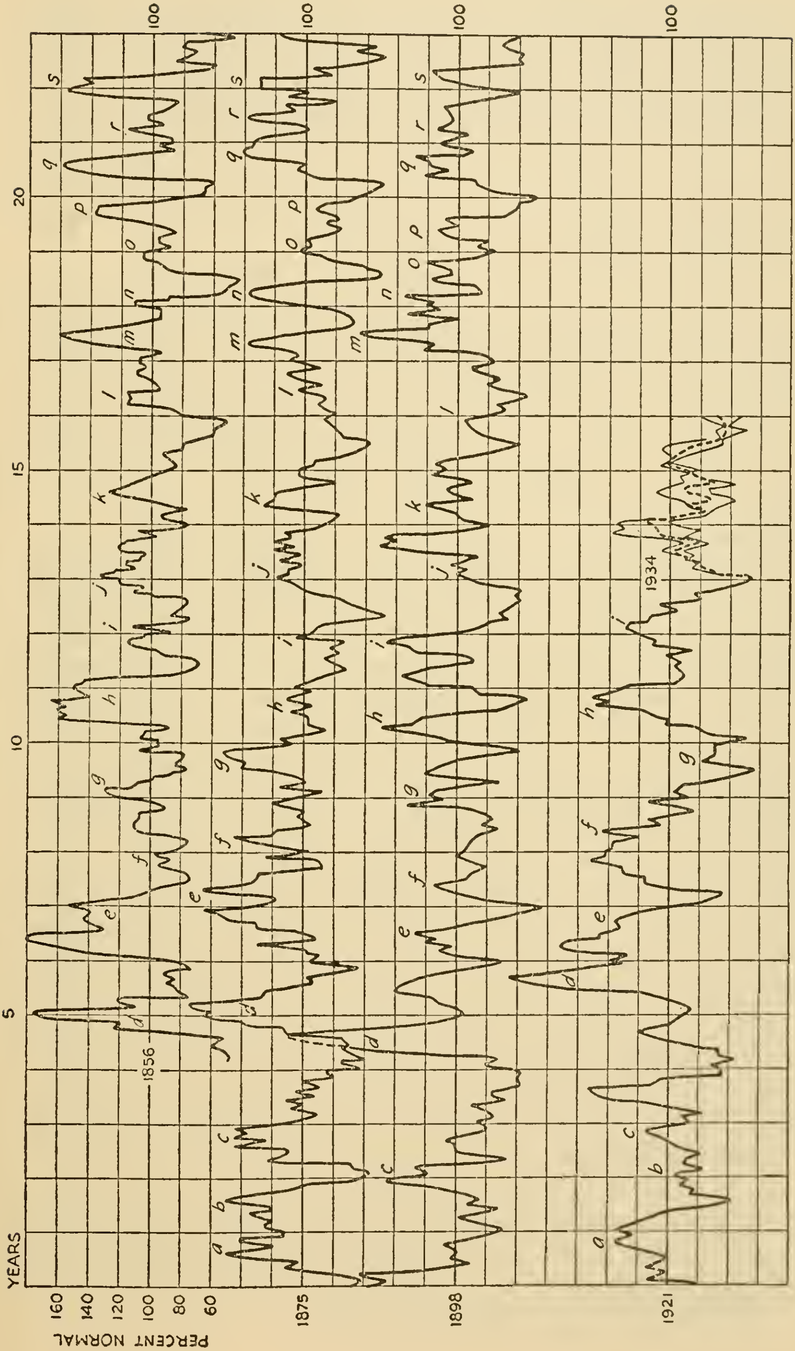



FIG. 1.—Twenty-three-year periodicity in Peoria precipitation.

*Necessary roughness of determinations.*—Between the accidental influences associated with rainfall, cloudiness, haziness, etc., the undeterminable interferences of some 20 periodic solar variations on the periodicity being considered, and the necessary subdivision of the data for seasonal and sunspot alterations of atmospheric quality, the determinations of periodicities in precipitation became too rough to warrant conclusions that such and such submultiples of 23 years were real, effective periods in solar variations.

*Length and number of periods necessarily determined from solar observations.*—Thrust back on the solar-constant observations as the only sound source of knowledge of the solar periods, I laid aside the investigation of Peoria precipitation to prepare the paper above cited (footnote 1). In that paper are listed 23 periods that appear to be real in solar variation, and 15 others that were tried and found wanting. In the latter part of the Peoria tabulations the investigation was limited to the confirmed 23 periods. However, for convenience in tabulating, the lengths of some periods were slightly altered.

*Faulty normals.*—Still another unsuspected hitch occurred in the investigation, which caused several weeks delay and a completely new tabulation of the precipitation data. This is explained in another recent paper.[3] In substance it amounts to this: The monthly normal values printed at the bottom of the pages in World Weather Records [4] make no distinction between times of sunspot maximum and times of sunspot minimum. Two consequences result. First, the average of the monthly data computed as percentages of the published normals of precipitation at Peoria is about 9 percent higher for times when Wolf sunspot numbers exceed 20 than for times when these Wolf numbers are below 20. Second, far more serious, and indeed fatal to success in my investigations made theretofore, is the fact that when averages of data timed for sunspots $\gtrless 20$ are separated, there is found a large discrepancy, month by month, between these averages for Wolf numbers $<20$ and for Wolf numbers $>20$. This plays havoc with tabulations of periodicity. The published normals, in fact, combine two contradicting sets of data as foreign to each other in attitude as dogs are from cats, and tabulations including both sorts in the same periodicity are worthless.

*Final preparation of the data.*—The recorded monthly values of precipitation at Peoria for the years 1856 to 1950, found in World Weather Records and later publications, were segregated in two

[3] Smithsonian Misc. Coll., vol. 117, No. 11, 1952.
[4] Smithsonian Misc. Coll., vols. 79, 90, and 105.

groups, for Wolf numbers $\gtrless 20$. Monthly normal values were computed separately, 52 years in the high-sunspot group, 30 years in the other. Two years were omitted, when the months were about evenly divided between the two classes.

The new normals for Peoria precipitation, as expressed in inches, are as follows:

| Sunspots | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $>20$ | 1.84 | 1.87 | 2.80 | 3.62 | 3.90 | 4.04 | 3.70 | 3.06 | 3.56 | 2.22 | 2.36 | 1.91 |
| $<20$ | 1.58 | 1.71 | 2.82 | 2.79 | 3.88 | 3.24 | 3.40 | 2.66 | 3.85 | 2.56 | 2.22 | 1.88 |

From these new normals percentages of normal precipitation were computed for every month, 1856 to 1950. There are such large and suddenly changing jumps from month to month in these percentages of normals that the data were then smoothed by 5-month consecutive means. Thus, for March compute

$$\frac{\text{Jan.}+\text{Feb.}+\text{Mar.}+\text{Apr.}+\text{May}}{5}.$$

For April drop January and add June, and so on. Even then, as some exceptionally rainy months occurred, the smoothed data would soar above 200 percent for a brief interval. With the necessarily few columns in a tabulation, such an exceptional case might quite vitiate the determination of a periodicity. Hence for some 20 exceptional months out of over 1,000, the original values were scaled down to 200 before the smoothing process was done.

*Division of the interval.*—While the number and lengths of the periodicities to be sought in Peoria precipitation had been fixed by study of solar-constant observations, and nothing was to be learned as to the reality or the exact length of these periodicities in solar radiation from the precipitation data, it still was desirable to tabulate Peoria precipitation in several parts independently. Certain of the solar periodicities might produce such weak responses in precipitation that the several groups might give no agreeing results distinguishable from accidental error. Such weak periodic effects could be neglected. Such indeed proved to be the case with periods of $2\frac{1}{7}$ and $3\frac{1}{15}$ months, and with the periodicity of 68 months. There were strong features in the separate determinations of the periodicity of 68 months, but they were so confused by overriding interference from various shorter periods as to be uncertain. Hence that period was dropped.

More important, however, just as the changing atmospheric conditions were found to alter phases with the seasons, and with the prevalence of sunspots, it proved that, apart from these already noted phase alterations, there were secular changes of phases. One group of years, though yielding the same forms of periodicities as another, yielded them in different phases. Such effects were found to vary in character for periods of different lengths.

In the tabulations, therefore, the years 1856 to 1900 were tabulated separately from the years 1900 to 1939. Discordant phases appearing in the earlier interval were shifted to accord with the phases for the years 1900 to 1939. Then the two determinations were averaged together. So the full strength of the data from 1856 to 1939 was concentrated in the phases prevailing from 1900 to 1939.

*Fractional months in periods.*—In order to preserve the exact period in such cases as $9\frac{1}{6}$, $11\frac{1}{5}$, and $15\frac{1}{6}$ months, and others not exactly even months in length, some columns in tabulating were made a month longer or a month shorter than others. In case of long periods, months were interpolated or cut out of the columns from place to place as required to make the average length of the columns equal to the period. Such additions to columns may be noted in tables 1 and 2 for the $9\frac{1}{6}$-month periodicity, and in tables 3 and 4 for $15\frac{1}{6}$ months.

*Examples of tabulation.*—In order to fix ideas, I now give two actual tabulations and corresponding plots, to bring out the process employed, and to clarify the explanations above. I select the periods of $9\frac{1}{6}$ and $15\frac{1}{6}$ months. Table 1 gives the tabulation for $9\frac{1}{6}$ months suited to Wolf numbers $>20$, and table 2 that for Wolf numbers $<20$. In each table the segregation of the year by 4-month intervals is preserved. Also, two separate tables for each 4-month interval are made, one for the first half, the other for the last half of the 84-year interval. As stated above, there is often found a discrepancy in phase between results of the first and second halves of the 84-year interval. In table 1, sections $A_1$ and $B_1$, the symbol $A_1\uparrow_1$ means that to bring the phase of the first half, $A_1$, to that of the second half, $B_1$, the mean values for $A_1$ are moved one month backward. The symbol $A_2\uparrow_2$ obtains in sections $A_2$ and $B_2$, and $A_3\downarrow_3$ was required for sections $A_3$ and $B_3$. Similar symbols for shifts appear in the tabulation of the data suited to Wolf numbers $<20$. The final columns, marked $\Delta$, give the departures from the average percentage of results in the general means. The use of these columns of departures will be explained below.

Tables 3 and 4, relating to the periodicity of $15\frac{1}{6}$ months, will be understood from the preceding description of tables 1 and 2 for $9\frac{1}{6}$ months. As before, symbols involving $\uparrow$ mean that the means of the first half of the data were shifted backward by one or more months, and symbols involving $\downarrow$ indicate the contrary.

TABLE I.—*Peoria precipitation. The $9\frac{1}{6}$-month period*

*Sunspots* > 20

**$A_1$**

| Jan. '59 | Feb. '62 | Mar. '65 | Jan. '69 | Apr. '71 | Jan. '72 | Mar. '81 | Apr. '84 | Jan. '85 | Feb. '91 | Mar. '68 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 149 | 103 | 105 | 108 | 82 | 67 | 96 | 111 | 106 | 82 | 113 | 102.0 |
| 124 | 101 | 112 | 90 | 86 | 67 | 126 | 97 | 112 | 88 | 111 | 101.3 |
| 102 | 80 | 101 | 102 | 95 | 56 | 101 | 109 | 87 | 86 | 111 | 93.9 |
| 96 | 113 | 99 | 127 | 118 | 90 | 85 | 127 | 79 | 91 | 91 | 105.0 |
| 84 | 135 | 118 | 139 | 139 | 124 | 99 | 140 | 90 | 99 | 98 | 115.0 |
| 72 | 135 | 121 | 149 | 139 | 135 | 122 | 139 | 91 | 90 | 71 | 114.9 |
| 74 | 142 | 115 | 133 | 139 | 142 | 122 | 153 | 96 | 86 | 102 | 118.5 |
| 77 | 139 | 95 | 116 | 109 | 137 | 146 | 154 | 108 | 105 | 113 | 118.5 |
| 87 | 142 | 109 | 106 | 79 | 118 | 151 | 131 | 97 | 115 | 106 | 112.9 |
| 96 | | | | | | | | | 91 | 109 | |

**$B_1$**

| Mar. '94 | Feb. '04 | Mar. '07 | Feb. '17 | Apr. '26 | Jan. '27 | Mar. '36 | Apr. '39 | Mean | $A_1\uparrow_1$ | Mean | Δ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 96 | 93 | 84 | 83 | 96 | 133 | 67 | 153 | 98.1 | 101.3 | 99.7 | − 5.9 |
| 89 | 106 | 64 | 77 | 103 | 121 | 50 | 128 | 92.3 | 93.9 | 93.1 | −12.5 |
| 79 | 98 | 89 | 93 | 126 | 149 | 39 | 121 | 99.2 | 105.0 | 102.1 | − 3.5 |
| 73 | 94 | 113 | 100 | 155 | 158 | 41 | 97 | 103.9 | 115.0 | 109.4 | + 3.8 |
| 86 | 89 | 114 | 106 | 167 | 155 | 75 | 108 | 112.5 | 114.9 | 113.7 | + 8.1 |
| 80 | 107 | 106 | 98 | 178 | 132 | 97 | 90 | 111.0 | 118.5 | 114.7 | + 9.1 |
| 84 | 87 | 101 | 106 | 158 | 137 | 104 | 71 | 106.0 | 118.5 | 112.2 | + 6.2 |
| 95 | 76 | 92 | 70 | 136 | 135 | 132 | 64 | 100.0 | 112.7 | 106.4 | + 0.8 |
| 93 | 80 | 58 | 68 | 124 | 135 | 148 | 69 | 96.9 | 102.0 | 99.5 | − 6.1 |
| | | | | | | | | | Mean | 105.6 | |

**$A_2$**

| Aug. '60 | May '61 | Aug. '63 | June '64 | July '70 | Aug. '73 | May '74 | July '83 | June '93 | July '96 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| 99 | 91 | 92 | 75 | 57 | 87 | 54 | 95 | 84 | 136 | 87.0 |
| 101 | 81 | 96 | 55 | 87 | 84 | 83 | 93 | 66 | 109 | 85.5 |
| 93 | 74 | 113 | 79 | 93 | 104 | 76 | 107 | 49 | 116 | 90.4 |
| 91 | 84 | 114 | 98 | 102 | 129 | 79 | 102 | 58 | 83 | 94.0 |
| 105 | 82 | 104 | 115 | 107 | 124 | 88 | 106 | 63 | 91 | 98.5 |
| 127 | 76 | 85 | 107 | 104 | 111 | 80 | 124 | 89 | 77 | 98.0 |
| 128 | 100 | 105 | 122 | 89 | 115 | 47 | 107 | 87 | 108 | 100.0 |
| 107 | 87 | 72 | 114 | 93 | 85 | 65 | 86 | 103 | 105 | 91.5 |
| 105 | 85 | 69 | 125 | 91 | 62 | 70 | 100 | 96 | 108 | 91.1 |
| | | 80 | | | | | | | | |

**$B_2$**

| June '06 | June '09 | Aug. '15 | May '16 | Aug. '18 | June '19 | July '25 | Aug. '28 | May '29 | June '35 | July '38 | Mean | $A_2\uparrow_2$ | Mean | Δ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 70 | 101 | 111 | 63 | 117 | 100 | 101 | 131 | 137 | 109 | 129 | 106.3 | 90.4 | 98.3 | +0.1 |
| 82 | 87 | 120 | 86 | 120 | 106 | 116 | 132 | 124 | 112 | 107 | 108.4 | 94.0 | 101.2 | +3.0 |
| 77 | 109 | 100 | 98 | 131 | 106 | 123 | 135 | 101 | 86 | 87 | 105.1 | 98.5 | 101.8 | +3.6 |
| 82 | 131 | 108 | 106 | 93 | 111 | 112 | 150 | 113 | 88 | 68 | 105.6 | 98.0 | 101.8 | +3.6 |
| 85 | 132 | 84 | 109 | 109 | 98 | 99 | 138 | 106 | 88 | 85 | 103.0 | 100.0 | 101.5 | +3.3 |
| 114 | 152 | 95 | 121 | 114 | 78 | 96 | 138 | 86 | 101 | 104 | 109.0 | 91.5 | 100.2 | +2.0 |
| 88 | 149 | 85 | 102 | 100 | 61 | 92 | 130 | 97 | 100 | 120 | 102.6 | 91.1 | 96.8 | −1.4 |
| 95 | 107 | 86 | 84 | 90 | 81 | 84 | 129 | 114 | 98 | 135 | 100.3 | 87.0 | 93.6 | −4.6 |
| 90 | 93 | 60 | 73 | 109 | 89 | 83 | 112 | 90 | 73 | 143 | 92.3 | 85.5 | 88.9 | −9.3 |
| | 90 | | | 101 | | | | | | | | Mean | 98.2 | |

**$A_3$**

| Nov. '59 | Nov. '62 | Oct. '69 | Oct. '72 | Dec. '81 | Oct. '82 | Oct. '85 | Dec. '91 | Sept. '92 | Dec. '94 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| 89 | 132 | 94 | 88 | 162 | 88 | 102 | 99 | 69 | 72 | 99.5 |
| 98 | 137 | 94 | 96 | 143 | 91 | 91 | 110 | 70 | 67 | 99.7 |
| 87 | 142 | 94 | 87 | 121 | 92 | 81 | 100 | 78 | 58 | 94.0 |
| 76 | 135 | 111 | 89 | 116 | 126 | 77 | 115 | 96 | 57 | 99.8 |
| 73 | 107 | 87 | 98 | 139 | 98 | 83 | 131 | 107 | 45 | 96.8 |
| 77 | 79 | 68 | 112 | 120 | 114 | 72 | 129 | 119 | 82 | 97.2 |
| 92 | 70 | 49 | 89 | 110 | 129 | 84 | 116 | 124 | 89 | 95.2 |
| 100 | 66 | 49 | 98 | 105 | 136 | 67 | 104 | 120 | 101 | 95.6 |
| 103 | 72 | 39 | 97 | 106 | 114 | 72 | 75 | 103 | 98 | 87.9 |
| | | | 91 | 88 | | | | | | |

**$B_3$**

| Sept. '95 | Nov. '04 | Sept. '05 | Dec. '07 | Sept. '08 | Nov. '14 | Nov. '17 | Oct. '24 | Oct. '27 | Dec. '36 | Oct. '37 | Mean | $A_3\downarrow_3$ | Mean | Δ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 125 | 66 | 88 | 83 | 67 | 88 | 62 | 106 | 140 | 132 | 73 | 93.6 | 95.2 | 94.4 | −1.4 |
| 127 | 44 | 81 | 98 | 54 | 88 | 63 | 65 | 134 | 109 | 102 | 87.7 | 95.6 | 91.7 | −4.1 |
| 126 | 57 | 91 | 106 | 53 | 76 | 50 | 67 | 120 | 123 | 119 | 89.8 | 87.9 | 88.8 | −7.0 |
| 119 | 78 | 101 | 129 | 67 | 83 | 69 | 67 | 99 | 106 | 127 | 95.0 | 99.5 | 97.2 | +1.4 |
| 121 | 87 | 94 | 142 | 74 | 103 | 77 | 72 | 76 | 99 | 137 | 98.4 | 99.7 | 99.0 | +3.2 |
| 110 | 100 | 88 | 122 | 93 | 93 | 83 | 54 | 62 | 85 | 145 | 94.1 | 94.0 | 94.0 | −1.8 |
| 96 | 108 | 86 | 122 | 103 | 102 | 84 | 64 | 90 | 88 | 139 | 98.4 | 99.8 | 99.1 | +3.3 |
| 93 | 102 | 84 | 104 | 104 | 128 | 116 | 65 | 95 | 70 | 150 | 101.0 | 96.8 | 98.9 | +3.1 |
| 111 | 90 | 78 | 71 | 109 | 146 | 105 | 82 | 112 | 78 | 138 | 101.8 | 97.2 | 99.5 | +3.7 |
| 134 | 92 | | | | | | | 114 | | | | Mean | 95.8 | |

TABLE 2.—*Peoria precipitation. The 9⅙-month period*

*Sunspots* < 20

$A_1$

| Apr. '58 | Feb. '75 | Mar. '78 | Feb. '88 | Apr. '97 | Jan. '98 | Apr. '00 | Feb. '01 | Mar. '65 | Mean |
|---|---|---|---|---|---|---|---|---|---|
| 148 | 65 | 97 | 119 | 79 | 157 | 101 | 80 | 105 | 105.7 |
| 159 | 80 | 115 | 115 | 92 | 159 | 58 | 84 | 112 | 108.2 |
| 156 | 95 | 104 | 102 | 65 | 165 | 88 | 85 | 101 | 106.8 |
| 139 | 113 | 123 | 121 | 54 | 140 | 96 | 94 | 99 | 108.8 |
| 127 | 106 | 101 | 110 | 48 | 113 | 90 | 73 | 118 | 98.4 |
| 137 | 132 | 109 | 126 | 67 | 98 | 98 | 81 | 121 | 107.4 |
| 144 | 137 | 93 | 109 | 54 | 108 | 100 | 81 | 115 | 104.6 |
| 138 | 125 | 100 | 122 | 93 | 103 | 84 | 61 | 95 | 102.3 |
| 138 | 106 | 80 | 110 | 118 | 100 | 85 | 62 | 109 | 100.9 |
| | | | | | | 93 | | | |

$B_1$

| Jan. '11 | Apr. '13 | Jan. '14 | Mar. '20 | Mar. '23 | Jan. '24 | Feb. '30 | Mar. '33 | Apr. '10 | Mean | $A_4 \downarrow_4$ | Mean | Δ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 97 | 110 | 85 | 102 | 93 | 92 | 86 | 132 | 70 | 96.3 | 107.4 | 101.3 | +4.4 |
| 109 | 77 | 75 | 102 | 92 | 95 | 87 | 118 | 76 | 92.3 | 104.6 | 98.4 | +1.5 |
| 101 | 74 | 79 | 108 | 91 | 81 | 71 | 114 | 78 | 88.6 | 102.3 | 95.4 | −1.5 |
| 112 | 62 | 69 | 81 | 83 | 105 | 54 | 101 | 68 | 81.8 | 100.9 | 91.3 | −5.6 |
| 99 | 77 | 58 | 57 | 96 | 119 | 53 | 110 | 58 | 80.8 | 105.7 | 93.2 | −3.7 |
| 94 | 87 | 65 | 59 | 100 | 150 | 41 | 87 | 61 | 82.7 | 108.2 | 95.4 | −1.5 |
| 114 | 92 | 79 | 59 | 99 | 154 | 63 | 82 | 55 | 88.6 | 106.8 | 97.7 | +0.8 |
| 129 | 95 | 84 | 70 | 114 | 154 | 79 | 83 | 80 | 98.7 | 108.8 | 103.7 | +6.8 |
| 115 | 97 | 70 | 75 | 115 | 114 | 76 | 76 | 91 | 92.1 | 98.4 | 95.7 | −1.2 |
| | | 85 | | 107 | | | | | | Mean | 96.9 | |

$A_2$

| July '57 | June '67 | Aug. '76 | May '77 | June '80 | July '86 | May '87 | Aug. '89 | May '90 | Mean |
|---|---|---|---|---|---|---|---|---|---|
| 84 | 85 | 154 | 120 | 118 | 83 | 50 | 125 | 69 | 98.7 |
| 88 | 76 | 139 | 112 | 103 | 85 | 64 | 111 | 68 | 94.0 |
| 86 | 62 | 110 | 106 | 85 | 78 | 67 | 81 | 62 | 81.9 |
| 94 | 62 | 98 | 129 | 88 | 85 | 77 | 107 | 75 | 90.6 |
| 74 | 59 | 75 | 127 | 81 | 77 | 82 | 110 | 76 | 84.6 |
| 82 | 50 | 63 | 136 | 65 | 97 | 104 | 111 | 77 | 87.2 |
| 88 | 55 | 59 | 127 | 85 | 87 | 107 | 102 | 77 | 87.4 |
| 111 | 85 | 70 | 138 | 95 | 86 | 113 | 102 | 86 | 96.2 |
| 135 | 85 | 103 | 117 | 87 | 83 | 125 | 81 | 78 | 99.3 |
| | | | 111 | | 79 | | | | |

$B_2$

| July '99 | Aug. '02 | May '03 | July '12 | June '22 | Aug. '31 | May '32 | Mean | $A_2 \downarrow_2$ | Mean | Δ |
|---|---|---|---|---|---|---|---|---|---|---|
| 94 | 188 | 113 | 95 | 79 | 118 | 80 | 109.6 | 96.2 | 102.9 | +3.5 |
| 84 | 176 | 127 | 103 | 67 | 145 | 86 | 112.5 | 99.3 | 105.9 | +6.5 |
| 89 | 153 | 132 | 106 | 60 | 134 | 81 | 107.9 | 98.7 | 103.3 | +3.9 |
| 101 | 122 | 129 | 88 | 86 | 147 | 87 | 108.5 | 94.0 | 101.2 | +1.8 |
| 116 | 101 | 126 | 103 | 83 | 138 | 86 | 107.5 | 81.9 | 94.7 | −4.7 |
| 134 | 94 | 110 | 120 | 92 | 131 | 113 | 113.4 | 90.6 | 102.0 | +2.6 |
| 123 | 98 | 89 | 113 | 87 | 104 | 111 | 103.6 | 84.6 | 94.1 | −5.3 |
| 110 | 104 | 70 | 124 | 100 | 99 | 118 | 103.6 | 87.2 | 95.4 | −4.0 |
| 116 | 105 | 83 | 122 | 81 | 76 | 126 | 101.3 | 87.4 | 94.3 | −5.1 |
| | | | | | | 140 | | Mean | 99.4 | |

$A_3$

| Dec. '65 | Sept. '66 | Nov. '75 | Dec. '78 | Sept. '79 | Nov. '83 | Oct. '98 | Mean |
|---|---|---|---|---|---|---|---|
| 80 | 121 | 132 | 86 | 112 | 114 | 107 | 107.5 |
| 83 | 112 | 116 | 68 | 112 | 99 | 92 | 97.5 |
| 99 | 100 | 122 | 81 | 135 | 92 | 84 | 101.9 |
| 104 | 100 | 116 | 64 | 158 | 87 | 82 | 101.5 |
| 79 | 90 | 129 | 70 | 164 | 82 | 73 | 98.2 |
| 97 | 97 | 134 | 79 | 155 | 100 | 94 | 108.0 |
| 109 | 98 | 143 | 80 | 170 | 135 | 101 | 119.4 |
| 124 | 98 | 134 | 78 | 144 | 134 | 88 | 114.3 |
| 133 | 80 | 138 | 90 | 119 | 128 | 76 | 109.1 |

$B_3$

| Nov. '01 | Oct. '11 | Dec. '20 | Sept. '21 | Nov. '30 | Dec. '33 | Sept. '34 | Mean | $A_3$ | Mean | Δ |
|---|---|---|---|---|---|---|---|---|---|---|
| 59 | 123 | 68 | 126 | 72 | 55 | 141 | 92.0 | 107.5 | 99.6 | − 5.8 |
| 60 | 114 | 86 | 139 | 75 | 50 | 123 | 92.4 | 97.5 | 95.0 | −10.4 |
| 92 | 89 | 121 | 131 | 64 | 56 | 127 | 97.2 | 101.9 | 99.7 | − 5.7 |
| 98 | 83 | 112 | 129 | 53 | 45 | 123 | 91.9 | 101.5 | 96.7 | − 8.7 |
| 89 | 101 | 108 | 142 | 77 | 50 | 132 | 99.9 | 98.2 | 99.0 | − 6.4 |
| 118 | 101 | 122 | 137 | 85 | 73 | 105 | 105.9 | 108.0 | 107.0 | + 1.6 |
| 143 | 108 | 116 | 130 | 110 | 77 | 130 | 116.3 | 119.4 | 117.8 | +12.4 |
| 144 | 124 | 96 | 115 | 111 | 103 | 142 | 119.3 | 114.3 | 116.8 | +11.4 |
| 170 | 122 | 108 | 110 | 120 | 113 | 126 | 124.4 | 109.1 | 116.7 | +11.3 |
| | | | | | | | | Mean | 105.4 | |

TABLE 3.—*Peoria precipitation. The* $15\frac{1}{6}$*-month period*

*Sunspots* > 20

| | | | $A_1$ | | | | | | | | | $B_1$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb. '59 | Mar. '64 | Apr. '69 | Jan. '73 | Feb. '83 | Jan. '92 | Mean | Apr. '93 | Mar. '07 | Jan. '16 | Apr. '17 | Feb. '26 | Apr. '36 | Mean | $A_1 \downarrow_5$ | Mean | Δ |
| 24 | 72 | 127 | 89 | 114 | 110 | 106.0 | 120 | 84 | 95 | 93 | 84 | 50 | 87.7 | 105.0 | 96.3 | − 2.0 |
| 02 | 69 | 139 | 98 | 129 | 100 | 106.2 | 103 | 64 | 85 | 100 | 83 | 39 | 79.0 | 101.2 | 90.1 | − 8.1 |
| 96 | 80 | 149 | 112 | 136 | 115 | 114.7 | 84 | 89 | 86 | 106 | 96 | 41 | 83.7 | 89.0 | 86.3 | −12.0 |
| 84 | 75 | 133 | 89 | 114 | 131 | 104.3 | 66 | 113 | 60 | 98 | 103 | 75 | 85.8 | 94.7 | 89.7 | − 8.6 |
| 72 | 55 | 116 | 98 | 112 | 129 | 97.0 | 49 | 114 | 63 | 106 | 126 | 97 | 92.5 | 89.5 | 91.0 | − 7.3 |
| 74 | 79 | 106 | 97 | 95 | 116 | 94.5 | 58 | 106 | 86 | 70 | 155 | 104 | 96.5 | 106.0 | 101.2 | + 2.9 |
| 77 | 98 | 94 | 91 | 93 | 104 | 93.0 | 63 | 101 | 98 | 68 | 167 | 132 | 104.8 | 106.2 | 105.5 | + 7.2 |
| 87 | 115 | 94 | 87 | 107 | 75 | 94.2 | 89 | 92 | 106 | 62 | 178 | 148 | 112.5 | 114.7 | 113.6 | +15.3 |
| 96 | 107 | 94 | 84 | 102 | 69 | 92.0 | 87 | 58 | 109 | 63 | 158 | 132 | 101.2 | 104.3 | 102.7 | + 4.4 |
| 89 | 102 | 111 | 104 | 106 | 70 | 97.0 | 103 | 83 | 121 | 50 | 136 | 109 | 100.3 | 97.0 | 98.6 | + 0.3 |
| 98 | 114 | 87 | 129 | 124 | 78 | 105.0 | 96 | 98 | 102 | 69 | 124 | 123 | 102.0 | 94.5 | 98.3 | 0.0 |
| 87 | 125 | 68 | 124 | 107 | 96 | 101.2 | 96 | 106 | 84 | 77 | 133 | 106 | 100.3 | 93.0 | 96.7 | − 1.6 |
| 76 | 105 | 49 | 111 | 86 | 107 | 89.0 | 89 | 129 | 73 | 83 | 121 | 99 | 99.0 | 94.2 | 96.6 | − 1.7 |
| 73 | 112 | 49 | 115 | 100 | 119 | 94.7 | 79 | 142 | 83 | 84 | 149 | 85 | 103.7 | 92.0 | 97.8 | − 0.5 |
| 77 | 101 | 39 | 85 | 111 | 124 | 89.5 | 73 | 122 | 77 | 116 | 158 | 88 | 105.7 | 97.0 | 101.3 | + 3.0 |
| | | | | 97 | | | | | | | | | | Mean | 98.3 | |

| | | | $A_2$ | | | | | | | | | $B_2$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| May '60 | July '70 | June '84 | July '94 | May '03 | Mean | Aug. '04 | June '08 | May '27 | Aug. '28 | July '37 | July '18 | Mean | $A_2 \downarrow_5$ | Mean | Δ |
| 92 | 57 | 109 | 86 | 113 | 91.4 | 87 | 122 | 155 | 131 | 70 | 105 | 111.7 | 92.0 | 101.8 | − 0.2 |
| 100 | 87 | 127 | 80 | 127 | 104.2 | 76 | 104 | 132 | 132 | 78 | 117 | 106.5 | 95.4 | 100.9 | − 1.1 |
| 103 | 93 | 140 | 84 | 132 | 110.4 | 80 | 71 | 137 | 135 | 64 | 120 | 101.2 | 99.0 | 100.1 | − 1.9 |
| 99 | 102 | 139 | 95 | 129 | 112.8 | 66 | 67 | 135 | 150 | 73 | 131 | 103.7 | 104.6 | 104.1 | + 2.1 |
| 101 | 107 | 153 | 93 | 126 | 116.0 | 44 | 54 | 135 | 138 | 102 | 93 | 94.3 | 110.6 | 102.4 | + 0.4 |
| 93 | 104 | 154 | 72 | 110 | 106.6 | 57 | 53 | 135 | 138 | 110 | 109 | 100.3 | 91.4 | 95.8 | − 6.2 |
| 91 | 89 | 131 | 67 | 89 | 93.4 | 78 | 67 | 140 | 130 | 127 | 114 | 109.3 | 104.2 | 106.7 | + 4.7 |
| 105 | 93 | 106 | 58 | 70 | 86.4 | 87 | 74 | 134 | 129 | 137 | 100 | 110.2 | 110.4 | 110.3 | + 8.3 |
| 127 | 91 | 112 | 51 | 83 | 92.8 | 100 | 93 | 120 | 112 | 145 | 90 | 110.0 | 112.8 | 107.8 | + 5.8 |
| 128 | 82 | 87 | 45 | 93 | 87.0 | 108 | 103 | 89 | 137 | 139 | 109 | 109.5 | 116.6 | 113.0 | +11.0 |
| 107 | 86 | 79 | 82 | 106 | 92.0 | 102 | 104 | 76 | 124 | 150 | 101 | 109.5 | 106.6 | 108.0 | + 6.0 |
| 105 | 95 | 90 | 89 | 98 | 95.4 | 90 | 109 | 62 | 104 | 138 | 100 | 100.5 | 93.4 | 96.9 | − 5.1 |
| 91 | 118 | 91 | 101 | 94 | 99.0 | 92 | 101 | 90 | 113 | 129 | 106 | 105.2 | 86.4 | 95.7 | − 6.3 |
| 81 | 159 | 96 | 98 | 89 | 104.6 | 88 | 87 | 95 | 106 | 107 | 111 | 99.0 | 92.8 | 95.9 | − 6.1 |
| 74 | 139 | 108 | 125 | 107 | 110.6 | 81 | 109 | 112 | 86 | 87 | 98 | 95.5 | 87.0 | 91.3 | −10.7 |
| 84 | | | | | | | | | 97 | | | | Mean | 102.0 | |

| | | | $A_3$ | | | | | | | | | $B_3$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nov. '57 | Sept. '61 | Dec. '62 | Dec. '67 | Oct. '71 | Nov. '81 | Sept. '90 | Mean | Oct. '95 | Nov. '05 | Oct. '14 | Oct. '19 | Nov. '24 | Dec. '34 | Oct. '38 | Mean | $A_3 \uparrow_5$ | Mean | Δ |
| 74 | 82 | 137 | 55 | 139 | 151 | 76 | 102.0 | 127 | 91 | 85 | 98 | 65 | 123 | 68 | 93.9 | 101.3 | 97.6 | − 3. |
| 82 | 76 | 142 | 85 | 109 | 162 | 77 | 104.7 | 126 | 101 | 88 | 78 | 67 | 132 | 85 | 95.3 | 102.1 | 98.7 | − 2. |
| 88 | 100 | 135 | 85 | 79 | 143 | 77 | 101.0 | 119 | 94 | 88 | 61 | 67 | 105 | 104 | 91.1 | 103.7 | 97.4 | − 3. |
| 111 | 87 | 107 | 113 | 67 | 121 | 86 | 98.9 | 121 | 88 | 76 | 81 | 72 | 130 | 120 | 98.3 | 105.9 | 102.1 | + 1. |
| 135 | 85 | 79 | 111 | 67 | 116 | 78 | 94.4 | 110 | 86 | 83 | 89 | 54 | 142 | 135 | 99.9 | 115.3 | 107.6 | + 6. |
| 148 | 103 | 70 | 111 | 56 | 139 | 82 | 101.3 | 96 | 84 | 103 | 102 | 64 | 126 | 143 | 102.6 | 116.1 | 109.3 | + 8. |
| 159 | 101 | 66 | 91 | 90 | 120 | 88 | 102.1 | 93 | 78 | 93 | 102 | 65 | 109 | 133 | 94.7 | 114.4 | 104.5 | + 3. |
| 156 | 80 | 72 | 98 | 124 | 110 | 86 | 103 7 | 111 | 70 | 102 | 108 | 82 | 112 | 128 | 101.9 | 109.4 | 105.6 | + 5. |
| 139 | 113 | 92 | 71 | 135 | 105 | 81 | 105.1 | 134 | 82 | 128 | 81 | 101 | 86 | 121 | 105.6 | 115.7 | 110.6 | + 9. |
| 127 | 135 | 96 | 102 | 142 | 106 | 99 | 115.3 | 136 | 77 | 146 | 57 | 116 | 88 | 97 | 102.4 | 109.7 | 106.0 | + 4. |
| 137 | 135 | 113 | 113 | 137 | 88 | 90 | 116.1 | 109 | 82 | 111 | 59 | 123 | 88 | 108 | 97.1 | 102.0 | 99.6 | − 1. |
| 144 | 142 | 114 | 106 | 118 | 91 | 86 | 114.4 | 116 | 85 | 120 | 59 | 112 | 101 | 90 | 97.6 | 104.7 | 101.0 | − 0. |
| 138 | 139 | 104 | 100 | 88 | 92 | 105 | 109.4 | 83 | 114 | 100 | 70 | 99 | 100 | 71 | 91.0 | 101.0 | 96.0 | − 5. |
| 138 | 142 | 85 | 108 | 96 | 126 | 115 | 115.7 | 91 | 88 | 108 | 75 | 96 | 98 | 64 | 88.6 | 98.9 | 93.7 | − 7. |
| 149 | 132 | 105 | 90 | 87 | 98 | 91 | 109.7 | 77 | 95 | 84 | 68 | 92 | 73 | 69 | 79.7 | 94.4 | 87.0 | −14. |
| | | | 102 | | | 99 | | | 90 | | | | 67 | | | Mean | 101.1 | |

*Graphical presentation.*—The results on the $9\frac{1}{6}$-month periodicity, in tables 1 and 2, are shown graphically in figures 2 and 3. In each of the six charts shown in each figure, the lower curve (*a*), in light

TABLE 4.—*Peoria precipitation. The* $15\frac{1}{6}$*-month period*

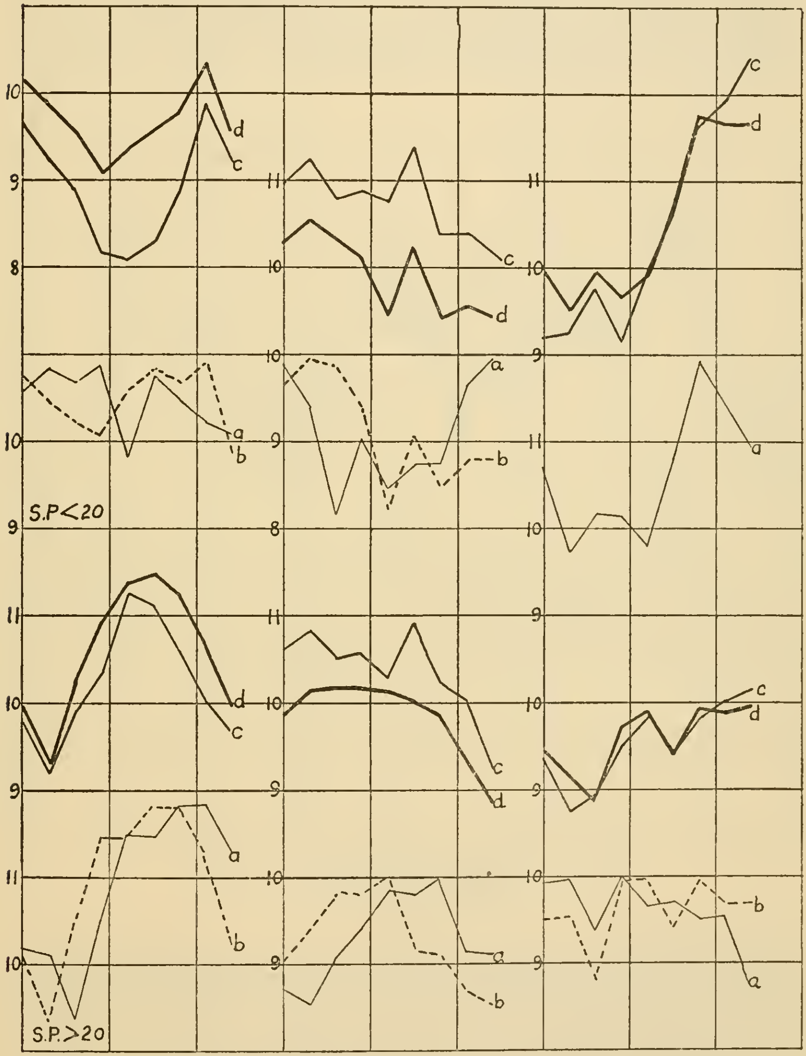
*Sunspots* < 20

| | | $A_1$ | | | | | | | | | $B_1$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Apr. '74 | Feb. '78 | Mar. '88 | Jan. '97 | Apr. '98 | Mean | Feb. '02 | Mar. '12 | Jan. '21 | Mar. '31 | Apr. '98 | Mean | $A_1{\downarrow}_5$ | Mean | Δ |
| 62 | 111 | 115 | 108 | 140 | 107.2 | 98 | 101 | 86 | 77 | 140 | 101.0 | 81.8 | 91.4 | −10.4 |
| 54 | 97 | 102 | 105 | 113 | 94.2 | 89 | 108 | 121 | 85 | 113 | 106.8 | 89.4 | 98.1 | − 3.7 |
| 83 | 115 | 121 | 108 | 98 | 105.0 | 118 | 124 | 112 | 110 | 98 | 111.0 | 103.2 | 107.1 | + 5.3 |
| 76 | 104 | 110 | 79 | 108 | 95.4 | 143 | 122 | 108 | 111 | 108 | 112.2 | 104.4 | 108.3 | + 6.5 |
| 79 | 123 | 126 | 92 | 103 | 104.6 | 144 | 95 | 122 | 120 | 103 | 105.0 | 110.4 | 107.7 | + 5.9 |
| 88 | 101 | 109 | 65 | 100 | 92.6 | 170 | 103 | 116 | 118 | 100 | 109.2 | 107.2 | 108.2 | + 6.4 |
| 80 | 109 | 122 | 54 | 107 | 94.4 | 188 | 106 | 96 | 145 | 107 | 113.5 | 94.2 | 103.8 | + 2.0 |
| 47 | 93 | 110 | 48 | 92 | 78.0 | 176 | 88 | 108 | 134 | 92 | 105.5 | 105.0 | 105.2 | + 3.4 |
| 65 | 100 | 114 | 67 | 84 | 86.0 | 153 | 103 | 126 | 147 | 84 | 115.0 | 95.4 | 105.2 | + 3.4 |
| 70 | 80 | 99 | 54 | 82 | 77.0 | 122 | 120 | 139 | 138 | 82 | 119.8 | 104.6 | 112.2 | +10.4 |
| 65 | 86 | 92 | 93 | 73 | 81.8 | 101 | 113 | 131 | 131 | 73 | 112.0 | 92.6 | 102.3 | + 0.5 |
| 80 | 68 | 87 | 118 | 94 | 89.4 | 94 | 124 | 129 | 104 | 94 | 110.5 | 94.4 | 102.4 | + 0.6 |
| 95 | 81 | 82 | 157 | 101 | 103.2 | 98 | 122 | 142 | 99 | 101 | 113.5 | 78.0 | 95.7 | − 6.1 |
| 113 | 64 | 100 | 157 | 88 | 104.4 | 104 | 110 | 137 | 76 | 88 | 102.7 | 86.0 | 94.3 | − 7.5 |
| 106 | 70 | 135 | 165 | 76 | 110.4 | 105 | 77 | 130 | 80 | 76 | 90.8 | 77.0 | 83.9 | −17.9 |
| | | | | 94 | | | | 115 | | | | Mean | 101.8 | |

| | | $A_2$ | | | | | | | | | | $B_2$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Aug. '56 | June '65 | May '79 | Aug. '80 | June '89 | July '75 | Mean | Aug. '99 | June '13 | May '22 | Aug. '23 | June '32 | Mean | $A_2{\uparrow}_2$ | Mean | Δ |
| 53 | 99 | 79 | 85 | 134 | 132 | 97.0 | 84 | 74 | 110 | 100 | 86 | 90.8 | 106.2 | 98.5 | − 4.3 |
| 80 | 118 | 80 | 88 | 128 | 137 | 105.2 | 89 | 62 | 79 | 99 | 81 | 82.0 | 98.0 | 90.0 | −12.8 |
| 107 | 121 | 78 | 81 | 125 | 125 | 106.2 | 101 | 77 | 67 | 114 | 87 | 89.2 | 107.2 | 98.2 | − 4.6 |
| 101 | 115 | 90 | 65 | 111 | 106 | 98.0 | 116 | 87 | 60 | 115 | 86 | 93.8 | 115.3 | 104.5 | + 1.7 |
| 138 | 95 | 112 | 85 | 81 | 132 | 107.2 | 134 | 92 | 86 | 107 | 113 | 106.4 | 109.7 | 108.0 | + 5.2 |
| 153 | 109 | 112 | 95 | 107 | 116 | 115.3 | 123 | 95 | 83 | 92 | 111 | 100.8 | 109.8 | 105.3 | + 2.5 |
| 124 | 80 | 135 | 87 | 110 | 122 | 109.7 | 110 | 97 | 92 | 95 | 118 | 102.4 | 120.8 | 111.6 | + 8.8 |
| 95 | 83 | 158 | 96 | 111 | 116 | 109.8 | 116 | 85 | 87 | 81 | 126 | 99.0 | 111.2 | 105.1 | + 2.3 |
| 105 | 99 | 164 | 126 | 102 | 129 | 120.8 | 101 | 75 | 100 | 105 | 140 | 104.2 | 106.3 | 105.2 | + 2.4 |
| 71 | 104 | 155 | 101 | 102 | 134 | 111.2 | 58 | 79 | 81 | 119 | 132 | 93.8 | 104.5 | 99.1 | − 3.7 |
| 80 | 79 | 170 | 85 | 81 | 143 | 106.3 | 88 | 58 | 93 | 150 | 118 | 101.4 | 107.3 | 104.3 | + 1.5 |
| 84 | 97 | 144 | 99 | 69 | 134 | 104.5 | 96 | 65 | 92 | 154 | 114 | 104.2 | 111.0 | 107.6 | + 4.8 |
| 88 | 109 | 119 | 122 | 68 | 138 | 107.3 | 90 | 79 | 91 | 154 | 101 | 103.0 | 115.0 | 109.0 | + 6.2 |
| 86 | 124 | 118 | 122 | 62 | 154 | 111.0 | 98 | 84 | 83 | 114 | 110 | 97.8 | 97.0 | 97.4 | − 5.4 |
| 94 | 133 | 103 | 146 | 75 | 139 | 115.0 | 100 | 70 | 96 | 106 | 87 | 91.8 | 105.2 | 98.5 | − 4.3 |
| | | | | | 110 | | | | | | | | Mean | 102.8 | |

| | | $A_3$ | | | | | | | | | $B_3$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nov. '57 | Sept. '66 | Nov. '76 | Sept. '85 | Dec. '86 | Mean | Nov. '00 | Sept. '09 | Dec. '10 | Dec. '29 | Sept. '33 | Mean | $A_3{\downarrow}_5$ | Mean | Δ |
| 74 | 121 | 98 | 97 | 97 | 97.4 | 84 | 131 | 91 | 114 | 82 | 100.4 | 105.4 | 102.9 | +10.6 |
| 82 | 112 | 75 | 102 | 87 | 91.6 | 85 | 132 | 97 | 90 | 83 | 97.4 | 106.8 | 102.1 | +9.8 |
| 88 | 100 | 63 | 91 | 86 | 85.6 | 93 | 152 | 109 | 86 | 76 | 103.2 | 103.6 | 103.4 | +11.1 |
| 111 | 100 | 59 | 81 | 83 | 86.8 | 80 | 149 | 101 | 87 | 55 | 94.4 | 109.0 | 103.2 | +10.9 |
| 135 | 90 | 70 | 77 | 79 | 90.2 | 84 | 107 | 112 | 71 | 50 | 84.8 | 102.4 | 93.1 | + 0.8 |
| 148 | 97 | 103 | 83 | 50 | 96.2 | 85 | 93 | 99 | 54 | 56 | 77.4 | 97.4 | 87.4 | − 4.9 |
| 159 | 98 | 120 | 72 | 64 | 102.6 | 94 | 90 | 94 | 53 | 45 | 73.2 | 91.6 | 82.4 | − 9.9 |
| 156 | 98 | 112 | 84 | 67 | 103.4 | 73 | 70 | 114 | 41 | 50 | 69.6 | 85.6 | 77.6 | −14.7 |
| 139 | 80 | 106 | 67 | 77 | 93.8 | 81 | 76 | 129 | 63 | 73 | 84.4 | 86.8 | 85.6 | − 6.7 |
| 127 | 85 | 129 | 72 | 82 | 99.0 | 81 | 78 | 115 | 79 | 77 | 86.0 | 90.2 | 88.1 | − 4.2 |
| 137 | 76 | 127 | 83 | 104 | 105.4 | 61 | 68 | 123 | 76 | 103 | 86.2 | 96.2 | 91.2 | − 1.1 |
| 144 | 62 | 136 | 85 | 107 | 106.8 | 62 | 58 | 114 | 72 | 115 | 84.2 | 102.6 | 93.4 | + 1.1 |
| 138 | 62 | 127 | 78 | 113 | 103.6 | 59 | 61 | 89 | 75 | 141 | 85.0 | 103.4 | 94.2 | + 1.9 |
| 138 | 59 | 138 | 85 | 125 | 109.0 | 60 | 55 | 83 | 64 | 123 | 77.0 | 93.8 | 85.4 | − 6.9 |
| 149 | 50 | 117 | 77 | 119 | 102.4 | 92 | 80 | 101 | 53 | 127 | 90.6 | 99.0 | 94.8 | + 2.5 |
| | | | | | | | | | | | | Mean | 92.3 | |

lines, represents the first half of the interval. Along with it, in heavy dotted lines (*b*) appears the same curve, shifted in phase as indicated in the tabulation, tables 1 and 2. The medium-heavy full curve above (*c*) in each chart, gives the results tabulated for the second half of the interval. The reader will perceive a considerable similarity in form between curves (*b*) and (*c*). Owing to the causes producing roughness in the mean results, as explained above, this correspondence




FIGS. 2 (lower) AND 3 (upper).—Graphs of the $9\frac{1}{16}$-month periodicity.

is not as close as one could wish. However, it is the best available, and mean curves in heavy lines are plotted in lines (*d*). Their general similarity to the curves (*c*) indicate that the first half of the data, when in the same phase, supports the second-half determinations of the periodicity.

*Amplitudes of Peoria periodicities.*—The reader will note that all the curves (*d*) in figures 2 and 3 indicate an amplitude for the $9\frac{1}{6}$-month periodicity of above 10 percent and several of them above 20 percent. Of the 19 periodicities determined in Peoria precipitation, none have a less average amplitude than 5 percent, and 10 of them

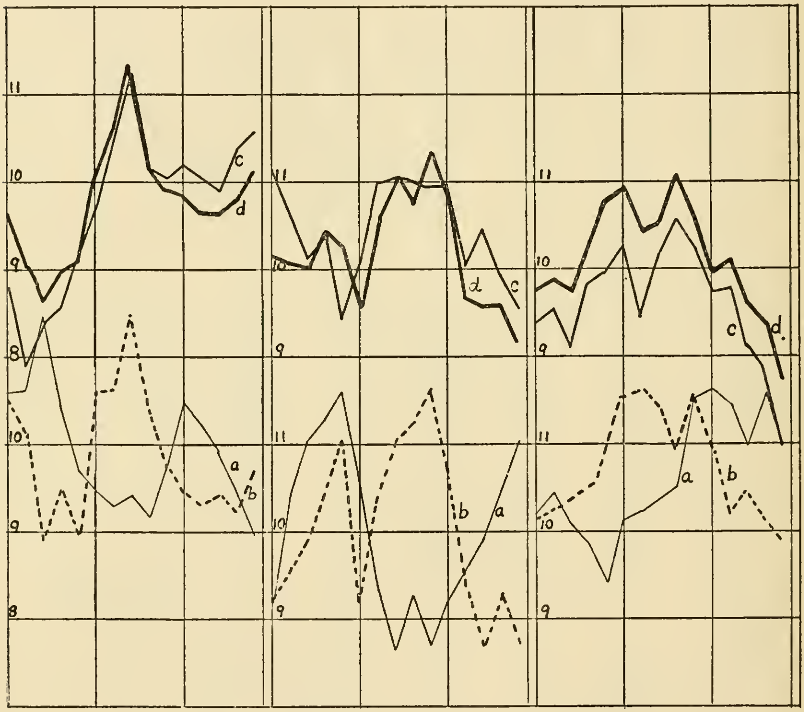



FIG. 4.—Graphs of the $15\frac{1}{6}$-month periodicity.
Wolf numbers $> 20$.

exceed 20 percent in average amplitude. This may seem extraordinary to those who recall that the solar variations which control these periodicities in precipitation, as recorded in the paper cited above, seldom had amplitudes as great as 0.2 percent. But the explanation is not as yet susceptible to theory; we have to accept the results of tabulations.

Figures 4 and 5, suited to Wolf numbers $\gtreqless 20$ for the periodicity of $15\frac{1}{6}$ months, will be understood from the preceding description, relating to $9\frac{1}{6}$ months. It will be noted that in figures 4 and 5 the amplitudes of the curves (*d*) are in all cases about 20 percent.

*Forecasts of precipitation for future years.*—The reader will perceive that since the periodicities fixed by tabulations of Peoria precipitation employ only data of the years 1856 to 1939, it is perfectly justified to use them to predict from a synthesis the precipitation expected to be observed at Peoria in the years 1940 to 1950. This operation has been performed. The data for it are such as given in the columns Δ of tables 1–4.

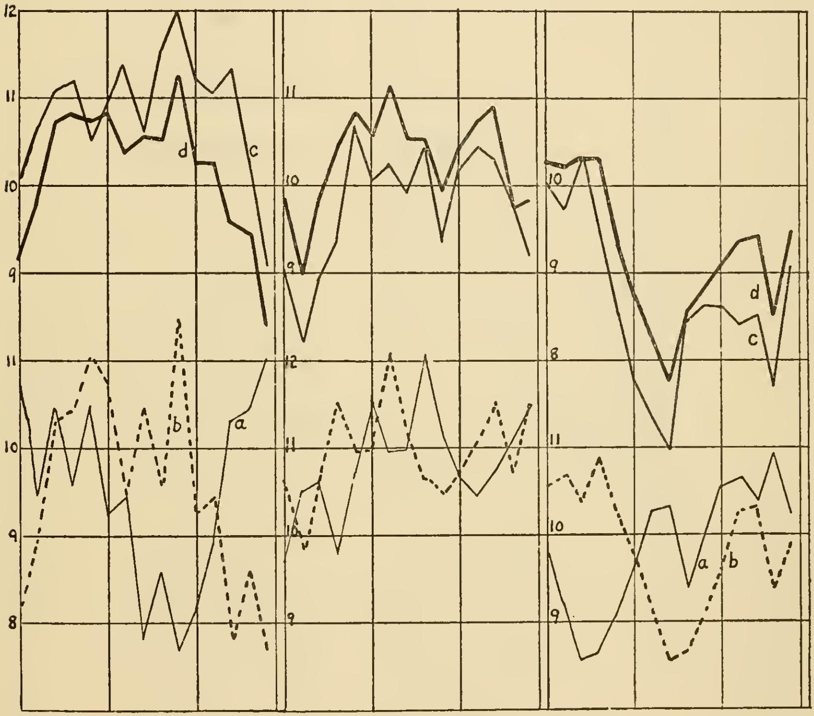


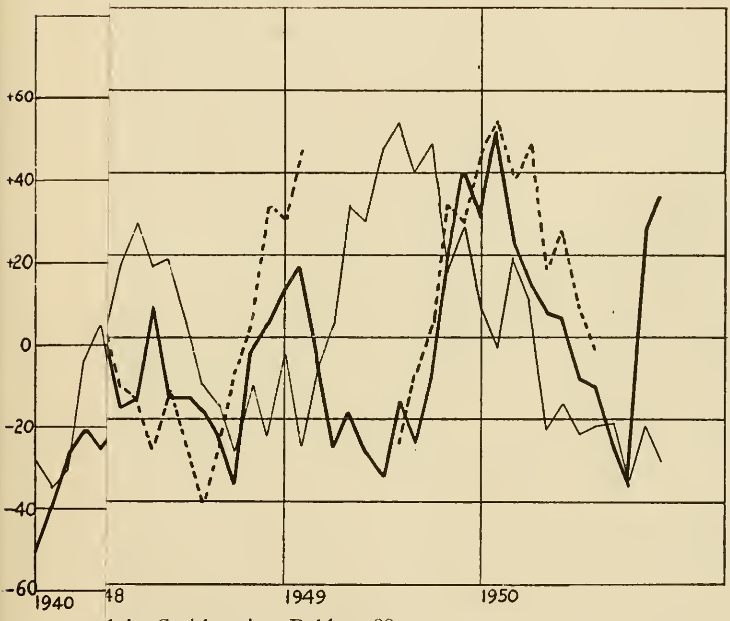

FIG. 5.—Graphs of $15\frac{1}{6}$-month periodicity.
Wolf numbers < 20.

To fix ideas, there is given in table 5 as much of this tabulation as covers the years 1940 and 1950. The summation of the 19 columns purports to show for these future years what will be the percentage departures from the normals that were printed above. In the next to final column of table 5 are given the actual observed departures from those normals, computed from Weather Bureau records. The final column gives the percentage differences between predicted and observed. The reader will recall that all these data were smoothed by 5-month consecutive means before the tabulation.

TABLE 5.—*Sample of synthesis prediction and verification*

Percentages in tenths of percent
Sums given to nearest percent

| | 4⅓ | 5⅛ | 6 1/15 | 7 | 8⅛ | 9⅛ | 9¾ | 10⅗ | 11⅕ | 13 1/10 | 13⅗ | 15⅛ | 22⅘ | 24⅘ | 30⅓ | 34⅕ | 38⅘ | 45½ | 91½ | Σ | Obs | Δ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940 | | | | | | | | | | | | | | | | | | | | | | |
| Jan. .... | +12 | −23 | −21 | +27 | +21 | −59 | −12 | +7 | +3 | −45 | +68 | −20 | −18 | −39 | −6 | −19 | +3 | −65 | −99 | −28 | −50 | +22 |
| Feb. .... | −28 | −13 | −8 | +68 | +1 | −125 | −20 | +52 | −43 | −34 | +65 | −81 | +27 | −36 | −28 | −20 | +22 | −54 | −94 | −35 | −39 | +4 |
| Mar. .... | −1 | −34 | +33 | +19 | +1 | −35 | +10 | +48 | −39 | −3 | +24 | −120 | +5 | −13 | −52 | −22 | +2 | −34 | −88 | −30 | −27 | −3 |
| Apr. .... | +19 | −6 | +35 | −18 | +15 | +38 | +49 | +100 | −22 | +31 | +32 | −86 | +8 | −26 | −66 | −6 | −36 | −19 | −79 | −4 | −20 | +16 |
| May .... | +10 | +32 | −6 | −16 | +45 | +81 | +57 | +73 | −47 | +31 | −29 | −73 | +52 | +8 | −30 | −59 | −36 | +22 | −69 | +5 | −26 | +31 |
| June .... | +26 | +35 | −31 | −61 | +25 | +91 | −26 | +2 | −61 | +53 | −47 | +29 | +35 | −68 | −27 | −28 | −35 | −20 | −59 | −17 | −20 | +3 |
| July .... | −28 | −17 | −10 | −21 | −46 | +62 | +28 | −24 | +33 | +56 | −65 | +72 | +49 | −75 | −40 | −60 | −21 | +2 | −49 | −15 | −35 | +20 |
| Aug. .... | −9 | −2 | −10 | +14 | −58 | +8 | 0 | −27 | +9 | 0 | −51 | +153 | +81 | −89 | −18 | −53 | −9 | +22 | −42 | −8 | −25 | +17 |
| Sept. .... | ±0 | −23 | +13 | +34 | +90 | −61 | −41 | −61 | +83 | −55 | −114 | +44 | +10 | −50 | −57 | +8 | −19 | +53 | −31 | −17 | −25 | +8 |
| Oct. .... | +9 | 0 | +29 | +27 | +17 | +2 | −48 | −92 | +36 | +11 | −72 | +3 | −22 | −75 | +1 | +68 | −19 | +62 | −19 | −8 | −10 | +2 |
| Nov. .... | −31 | +6 | −2 | +12 | −31 | −21 | +102 | −83 | +45 | −1 | −8 | 0 | −51 | −6 | −6 | +84 | −23 | +60 | −14 | +3 | +7 | −4 |
| Dec. .... | +23 | +17 | −10 | +13 | −48 | −39 | +74 | +25 | +66 | −31 | +16 | −16 | −76 | +5 | +40 | +114 | −56 | +70 | −5 | +18 | +11 | +7 |
| 1950 | | | | | | | | | | | | | | | | | | | | | | |
| Jan. .... | −1 | −34 | −21 | +18 | −84 | −21 | −74 | −74 | +36 | +52 | +16 | −74 | +49 | +10 | +27 | −1 | +2 | +125 | +106 | +6 | +29 | −23 |
| Feb. .... | +12 | −6 | −8 | +24 | −76 | −39 | −77 | −84 | +45 | +54 | +77 | −141 | +81 | −48 | −6 | +30 | −36 | +55 | +111 | −3 | +50 | −53 |
| Mar. .... | −28 | +32 | +33 | +17 | +21 | +16 | −43 | −27 | +3 | +24 | +68 | −20 | +10 | −43 | −28 | +63 | −36 | +25 | +112 | +19 | +23 | −4 |
| Apr. .... | −1 | +35 | +35 | +8 | +1 | +18 | 0 | −1 | −43 | +21 | +65 | −81 | −22 | −17 | −52 | +31 | −35 | +16 | +110 | +9 | +13 | −4 |
| May .... | +19 | −17 | −6 | −25 | +1 | −2 | +6 | +20 | −39 | −22 | +24 | −120 | −51 | −39 | −66 | +1 | −21 | 0 | +106 | −29 | +6 | −35 |
| June .... | +14 | −2 | −31 | −20 | +15 | +10 | +13 | +58 | −22 | −25 | +32 | −86 | −76 | −36 | −30 | −26 | −9 | −42 | +104 | −16 | +5 | −21 |
| July .... | +10 | −23 | −10 | +14 | +45 | +25 | +1 | +78 | −47 | −49 | −29 | −73 | −80 | −13 | −27 | −80 | −19 | −62 | +96 | −24 | −10 | −14 |
| Aug. .... | +26 | 0 | −10 | +34 | +25 | −10 | −4 | +22 | −61 | −18 | −47 | +29 | −25 | −26 | −40 | −113 | −19 | −63 | +76 | −22 | −12 | −10 |
| Sept. .... | −28 | +6 | +13 | +27 | −46 | +2 | −10 | +28 | +33 | −59 | −65 | +72 | −19 | +8 | −18 | −75 | −23 | −70 | +16 | −21 | −24 | +3 |
| Oct. .... | −9 | +17 | +29 | +12 | −58 | −21 | −56 | +22 | +9 | −76 | −51 | +153 | +25 | −68 | −57 | −38 | −56 | −97 | −36 | −36 | −37 | +1 |
| Nov. .... | +9 | +2 | −2 | +13 | +90 | −39 | −35 | +24 | +83 | −36 | −114 | +44 | +10 | −75 | +1 | −7 | −55 | −69 | −99 | −22 | +26 | −48 |
| Dec. .... | −31 | +24 | −2 | −25 | +17 | +16 | +13 | +30 | +36 | +4 | −72 | +3 | −16 | −89 | −6 | −7 | −5 | −83 | −104 | −23 | +36 | −59 |




d in Smithsonian Publ. 4088.
5-month running means.

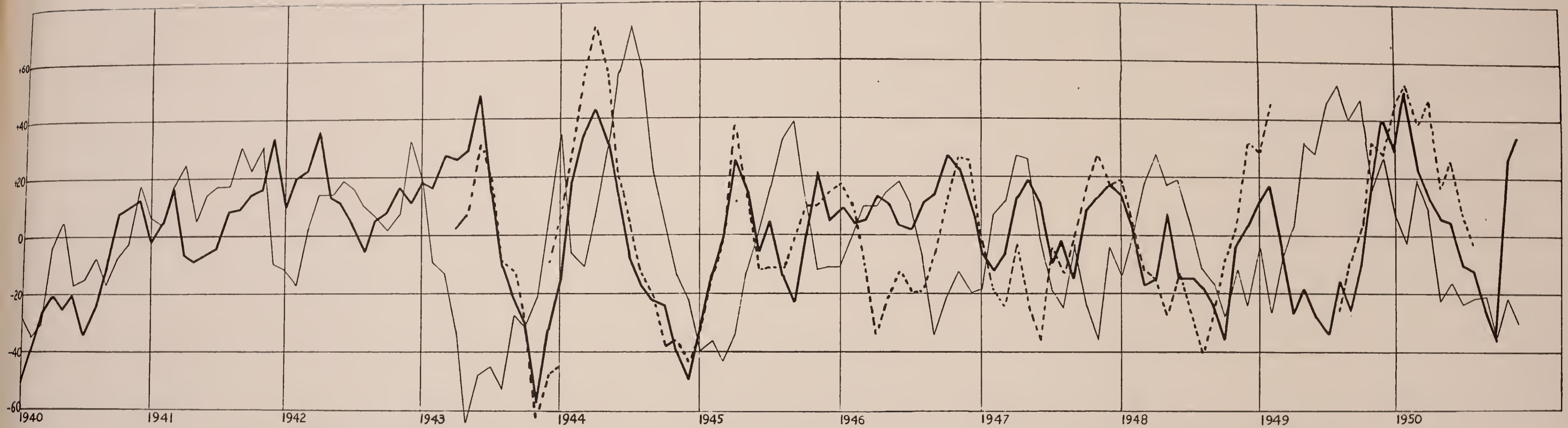


Fig. 6.—Predicted precipitation at Peoria, Ill., 1940 to 1950, and verification. Prediction based on sun's variation as determined in Smithsonian Publ. 4088. Thin line is prediction, thick line is event. Dotted line is prediction altered in phase as stated in text. All curves from 5-month running means.

*Graphical comparison of forecast and event.*—In figure 6 the whole march of the synthetically forecasted expected departures from normal precipitation at Peoria from 1940 to 1950 are plotted along with the actual departures observed. The reader will still recall that the data were smoothed by 5-month running means before any tabulating was done.

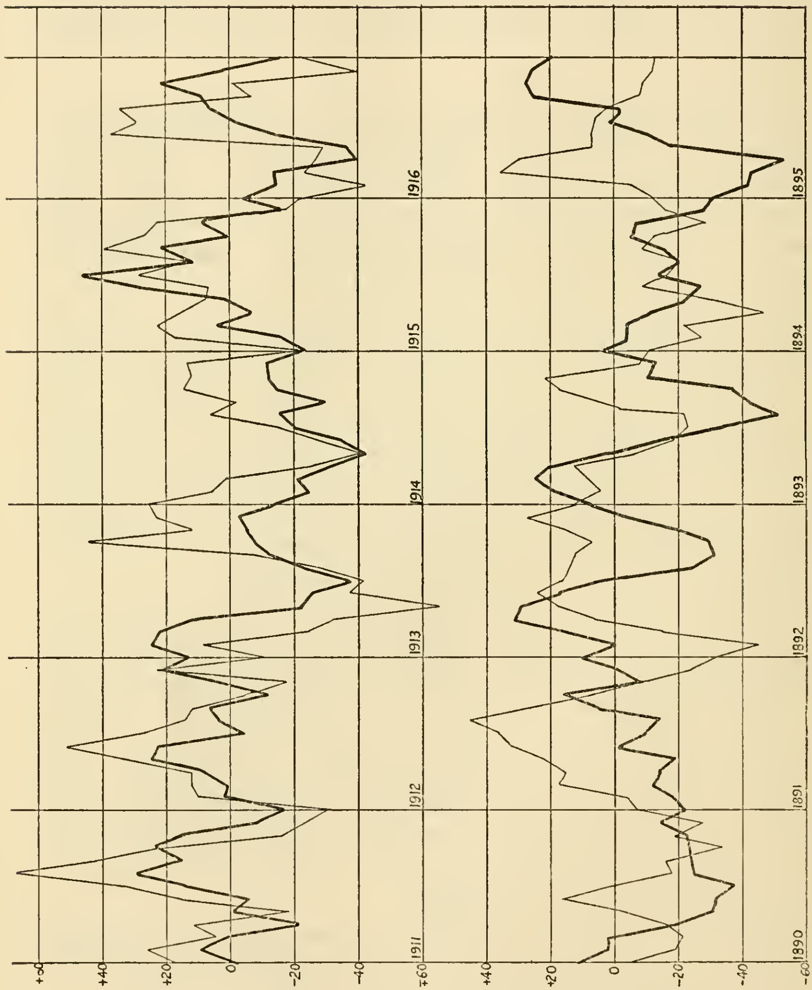
*Fit of the curve of prediction.*—For 3 years, 1940 to 1942, there is fair agreement between prediction and event. The average divergence between the two curves for 37 months is 13.9 percent. This is quite as close an agreement between prediction and synthesis of periodicities as obtained in the years prior to 1940, when, as one might say, the curves are "tailored to fit." Illustrations of this are given in figures 7 and 8, which deal with the intervals 1890 to 1895 and 1911 to 1916.

*Phase changes.*—After 1942 came changes of phase, but not of form. Heavy dotted curves are drawn in figure 6 to show the great similarity of form of the two curves when certain changes of phase are permitted. From October 1942 to July 1943 the predicted curve is moved forward 6 months. From March 1944 to June 1945 the predicted curve is moved backward 3 months. Thereafter, for the long interval extending until July 1949, the predicted curve is moved backward bodily 6 months. Finally, from February 1949 to February 1950 the predicted curve is moved forward 6 months.

With these changes of phase admitted, the two curves show for 81 months after 1942 an average divergence between them of 15 percent. Adding the first 3 years, which showed 35 months of fairly close fit, prediction would agree with event for 116 months out of 132, with an average divergence of 15 percent, though including several large swings of from 70 to 90 percent in amplitude. With such a good measure of success an 11-year prediction of precipitation at Peoria would confront us, though based on solar variation alone with no recourse to meteorology, if the several phase changes above suggested could be understood and anticipated.

Taking no consideration whatever of phase changes, the average departure between prediction and event is 14.7 percent for 99 months out of 136. Large divergences occur in the other 37 months.

*Quality of representation.*—To throw light, if possible, on phase changes, and to expose the roughness of the representation of precipitation by syntheses of periodicities as it stands before attempting a prediction, owing to causes already discussed, two intervals of curves of synthesis and observation prior to 1940 are shown in figures 7 and 8. The intervals chosen are from 1890 to 1895 and from 1911 to 1916. The synthetic curve in figure 7 is at a disadvantage, compared to that




FIGS. 7 (lower) AND 8 (upper).—Comparisons of synthesis with event in years prior to 1940. See comments in text.

in figure 8, because, as stated above, all the mean values from tabulations of the first half of the data were shifted in phase as required to match the phases of the mean values of data of the second half. Hence the general mean used for the syntheses is not so well suited to the first half of the 84-year interval as to the second half.

This disadvantage shows plainly, for figure 7 shows less good agreement than figure 8, yet a considerable part of the curves in figure 7 show fair correspondence. What is particularly interesting in figure 7 is that several cases of phase shifting, similar to those noted above in figure 5, are obvious. Such shiftings appear in the years 1890, 1892, 1893, and notably in 1895. One clearly marked phase shift is seen in the year 1913, in figure 8, and a lesser one in the year 1916.

The reader will see, by comparing figures 7 and 8, which relate to years employed for computing the data for prediction, with figure 6, where the basic periodicities were used for forecasting, that the "tailored to fit" curves, figures 7 and 8, agree no better, if indeed quite as well, with observation as the predicted curve agrees with the event in figure 6.

*Solar variation controls weather.*—The outcome of this attempt to forecast precipitation for a decade in advance by knowledge of periodicities in solar variation, without recourse to meteorology, is somewhat disappointing because of the phase changes encountered. It had been hoped that forecasts of percentage precipitation for coming seasons over a 10-year interval to within 10 or 15 percent might be made. If this could be done for one station, perhaps it might also be done for many. Then a network of lines of equal percentage precipitation for coming seasons for several years in advance might be laid down on the map. Possibly meteorologists, if they take interest in the idea, may find some means to conquer the phase-changing obstacle, and realize this dream of long-range seasonal forecasts.

Hitherto, for 40 years there has been a reluctance on the part of scientists, and especially meteorologists, to recognize the reality of observed changes of solar radiation. Even if it were admitted that very small solar changes occur, they were thought by these scientists to be insignificant for weather. As one said: "If a room be lighted with 100 lamps, and one is extinguished, no one could notice the loss of illumination." This paper, and Smithsonian Publ. 4088, indicate a contrary conclusion.

## SUMMARY

I have sought, in a preceding paper cited above (footnote 1) to demonstrate the reality of 23 periodic changes in the intensity of the

solar rays that warm the earth. In this present paper it is shown that periodicities of the same length as 19 of those discovered in solar variation are accompanied by changes of 5 to 20 percent amplitude in the precipitation at Peoria, Ill. By samples graphed in figures 2, 3, 4, 5, and in no way unrepresentative of all the periodicities tabulated, it is shown that these periodic variations of precipitation occur in nearly equal amplitudes and with moderate differences of phase in 12 separate independent intervals, each several years long, between 1856 and 1939.

Using these results as a basis, I predict the precipitation for Peoria from 1940 to 1950. With a range of actual precipitation from 50 to 150 percent of normal, occurring in that interval in the smoothed records, prediction matches the event for 8 out of 11 years to within an average deviation of 14.7 percent. In the other 3 years, large fluctuations in actual precipitation were matched by strikingly similar large fluctuations in the curve of prediction, but with phase differences of from 3 to 6 months. The prediction matches the event as well after 10 years as at the beginning. The fluctuations in the curve of prediction have almost precisely the same scale of range as those in the curve of actual precipitation.

While it is difficult to conceive, theoretically, how solar changes, seldom as large as 0.2 percent, could produce variations of from 5 to 20 percent in precipitation, the facts are there. It may be that adequate theory will eventually be found to explain them. In the meantime it would be of no importance, practically, whether theory had overtaken fact, if it were found that these periodic changes of precipitation could be synthesized to forecast seasons for years in advance.

A partial success in that direction has been achieved. For 3 years in advance the curve of prediction shown in figure 6 follows generally a rise of actual precipitation amounting to 90 percent. For 99 months out of 136, indeed, the average divergence is 15 percent. But the long-range prediction is marred by changes of phase, which, thus far at least, cannot be anticipated and allowed for in advance.

To the interested general reader, unfamiliar perhaps with considering percentages of normal precipitation, the meat of the matter may be expressed as follows: A prediction for 11 years in advance, based on knowledge of the sun's variation, without any consideration of meteorology, fits the rainfall curve at Peoria, Ill., for 99 months out of 136, to within an average error of one medium rainfall per month, or about 0.4 of an inch per month. Sometimes, however, dry or wet spells occur 3 to 6 months from when they are expected. Unless these phase changes can be anticipated, the method fails to come up fully to what is hoped for.