SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 148, NUMBER 7

Roebling Fund

AN ACCOUNT OF THE ASTROPHYSICAL OBSERVATORY OF THE SMITHSONIAN INSTITUTION, 1904-1953

By
C. G. ABBOT
Research Associate, Smithsonian Institution

(Publication 4656)

CITY OF WASHINGTON
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AN ACCOUNT OF THE ASTROPHYSICAL OBSERVATORY OF THE SMITHSONIAN INSTITUTION, 1904-1953

By Charles G. Abbot, D.Sc.
Research Associate, Smithsonian Institution

The Smithsonian's Astrophysical Observatory was founded by Secretary Samuel P. Langley in 1890. Until 1900 the Observatory's original research activities included developing and improving apparatus, and mapping the then little-known infrared spectrum of the sun. The bolometer, which Langley had invented about 1878, was given photographic registration, tamed to be as quiet and reliable as a mercury thermometer, and used to record small depressions where absorption lines occurred in the solar spectrum. The Observatory's highly exact determinations of the dispersion of rock-salt and fluorite prisms fixed the wavelengths of these absorption lines. Volume 1 of the *Annals,* describing all of this work, was published in 1900. Expeditions to North Carolina and to Sumatra observed the total solar eclipses of 1900 and 1901, and a small eclipse volume was published in 1903.

The Observatory then took up measurement of the intensity of the sun's radiation, the variability of it, and the transmission of radiation by the earth's atmosphere in the visible and infrared spectrum. The average intensity of solar radiation received by the earth, called the "solar constant," was then unknown between the limits 1.76 and 4.0 calories per square centimeter per minute. Solar constant research and the dependence of weather on solar variation principally occupied the Observatory from 1904 through 1953.

ADMINISTRATION OF THE OBSERVATORY, 1904-1953

FINANCIAL SUPPORT

A breakdown of the Observatory's financial support from 1904 through 1953 shows that the average yearly support for this period was $37,000.

SMITHSONIAN MISCELLANEOUS COLLECTIONS, VOL. 148, NO. 7

Congressional appropriations	$1,148,000
Gifts by John A. Roebling	617,000
Grants by National Geographic Society	65,000
From Smithsonian funds	10,000
Other gifts	10,000
Total	$1,850,000

The finances were managed by the Smithsonian Disbursing Office.

STAFF

The number of persons employed for all purposes varied from 2 to 14.

BUILDINGS

With headquarters in Washington, instruments were designed and constructed there, and early observations were made there. However, most of the observing later was done on several high mountains in distant arid lands. In all, 16 structures were built in these far-off lonely places to house observers and instruments. A valuable suggestion by E. B. Moore led us to construct underground laboratories in sloping ground for the spectrobolometric apparatus. Thus we obtained constant temperature. We fed the sun-rays into these tunnels horizontally with coelostats.

ACTIVITIES OF THE OBSERVATORY, 1904-1953

INSTRUMENTS

Five kinds of pyrheliometers for measuring the intensity of sun-rays were designed. These included the silver-disk, the water-flow, the water-stir, the improved Ångström, and the automatic-balloon pyrheliometers. For measuring sky-radiation the pyranometer was designed. Other instruments designed included the vacuum bolometer, special extrapolator for spectral atmospheric transmission measures, apparatus for observing stars by day for guiding airplanes, a compact spectrobolometer for expeditions, eclipse apparatus, high intensity lamps for Fowle's infrared investigation, numerous supports for mirrors, and many other observing devices. All of these instruments were constructed by Andrew Kramer, instrument maker for the Observatory, 1891-1950, and after 1950 by Darnel Talbert.

PUBLICATIONS

Quarto volumes 2-6 of the *Annals*, prepared by C. G. Abbot, F. E. Fowle, and L. B. Aldrich, and volume 7, prepared by L. B. Aldrich and W. H. Hoover, were published 1908-1953. About 150 papers, mostly published in Smithsonian Miscellaneous Collections, were written by members of the staff.[1]

THEORETICAL FINDINGS

Langley showed about 1880 that, to determine the solar constant, the spectral transmission of the atmosphere must be measured. This was always done by us with a clock-operated recording spectrobolometer in Langley's Method (now often called the "long method"). Langley did not publish a complete theory of this method, and he used it erroneously in publishing his Mount Whitney Expedition of 1881. This error gave his preferred solar constant value 3.07 instead of 2.0 calories. The full theoretical demonstration, and examples of the correct application of Langley's method are published in *Annals*, volume 2.

Although Langley's method is fundamental, it requires several hours of observing while the sun's air mass or atmospheric path changes from (say) 3.5 to 1.5 times that for vertical sun. During this considerable time the transparency of the atmosphere always changes. If it grows clearer for small air masses the resulting solar constant is too large, and vice versa. Hence only large groups of solar constant measures by Langley's method can be trusted; these give mean values nearly correctly.

A brief method for measuring spectral transparency was required, so that several values of the solar constant could be obtained daily, with little atmospheric variation affecting any one of them. Then the day's mean value would be good.

From 1920 to 1924 the A.P.O. developed the "short method." This is empirical, depending on the fact that the brightness of the sky near the sun is greater as the sky becomes more hazy. It is found possible to draw curves suited at all times to yield transmission coefficients suited to each station occupied for all of the 40 wavelengths used in Langley's method. A "short method" measurement requires only one reading of the pyranometer of sky-brightness near the sun. So in the 10 minutes employed for making a spectrobolometric graph of

[1] I will use the abbreviations "A.P.O." for Astrophysical Observatory, and "Pub." for publication.

the solar spectrum, with a reading of the pyranometer on a limited sky area surrounding the sun, a reading of the pyrheliometer on the sun itself, and a theodolite measurement of the sun's zenith distance, the observations are complete.

We made three or sometimes five determinations of the solar constant a day by the short method, and used their mean value for the day's result. From 1924 to 1952 over 9,000 mean daily values of the solar constant were obtained. Many of them were observed from three independent stations on the same day. It is shown by table 1, page 13 of Smithsonian Publication 4545,[2] that by comparing 1992 pairs of solar constant observations of the same day, made individually at stations separated by thousands of miles, some in the Northern, others in the Southern Hemisphere, and at all times of the year, the probable error of a single day's observation of the solar constant at one station is $\frac{1}{6}$ of 1 percent. All of the approximately 9,000 daily determinations, published in volumes 6 and 7 of *Annals,* were scrutinized at Washington, and unanimously approved for publication by a committee comprising L. B. Aldrich, W. H. Hoover, and Mrs. A. M. Bond.

TOWER TELESCOPE

Langley hoped that these 9,000 daily determinations would prove that a strong correlation could be found between daily solar constant values and simultaneous observations of the distribution of the intensity of solar radiation along the east-west diameter of the sun's disk. Some preliminary observations of that distribution were made in Washington in 1908. Later a tower telescope to form an 8-inch image of the sun was erected on our observatory on Mount Wilson, about 1913. From 1913 to 1920, on all observing days, the telescope also was adjusted between observations to form a solar image on the slit of the spectrobolometer. The telescope clock was then stopped, and the solar image was allowed to drift centrally over the slit. Thus was recorded ∩-shaped distribution curves in five wavelengths on each day that a solar constant value was obtained. See figure 52, Pub. 4545.[2]

Owing to inexactness of solar constant values due to the fluctuation of atmospheric transmission during the several hours required for solar constant measures by Langley's method (used exclusively on

[2] *Solar variation and weather*, by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 146, No. 3. 1963.

Mount Wilson, 1905-1920) it was not then possible to be assured of the correlation between solar constant and diametral distribution. But when the family of harmonic variations in the solar constant values became known about 1940, the solar constant value was back-casted from 1920 to 1913, and such correlation seemed indicated. See figures 50 and 51, Pub. 4545.[2] Solar contrast observations were discontinued in 1920, and solar constant determinations have never been made anywhere in the world since 1955. So this correlation cannot now be fully proved.

PRINCIPAL RESEARCHES

Leading Operations of the Smithsonian Astrophysical Observatory, 1895 to 1955[3] (Smithsonian Pub. 4222) gives brief summaries of 82 researches, with bibliographic references to the original publications of them. I select here for notice a few of the most important researches which occupied the years 1904 to 1953.

1. Inventions of pyrheliometers, vacuum bolometer, pyranometer, honeycomb pyranometer, two-mirror coelostat, highly sensitive radiometer, and solar heat collector.
2. Absolute measurement in heat units to 1 percent of the solar constant, with probable error of a day's measurement at one station $\frac{1}{6}$ of 1 percent *relative* to other day's measures.
3. Fixing the limits of sun's radiating temperature as between 5800° and 7000° C. Abs. Four methods used.
4. Measurement of atmospheric spectral transmission in 40 wavelengths at 10 stations located between sea level and 14,500 feet elevation.
5. Determining the distribution and intensity of radiation in the solar spectrum at 10 stations, and outside the earth's atmosphere.
6. Short method for the solar constant, and also automatic balloon determination.
7. Discovery of solar variation between limits of 2.0 percent in amplitude.
8. Discovery of a 27-day period in "solar constant" variation.
9. Discovery of a numerous harmonic family of exact periods in solar variation with a master period of exactly 273 months.

[3] *Leading operations of the Smithsonian Astrophysical Observatory*, 1895 to 1955, by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 131, No. 1. 1955.

10. Discovery of these identical harmonic periods in terrestrial temperature, and in precipitation, and a method of long-range forecasts based thereon.
11. Discovery of opposing trends in terrestrial temperature, attending for 16 days after rising and falling trends in solar radiation.
12. Fowle's work on terrestrial radiation and its absorption.
13. Aldrich's measure of the earth's albedo.
14. Aldrich's work with the honeycomb pyranometer.
15. Aldrich and Hoover's work, in volume 7 of *Annals,* on the solar constant, and on solar and sky radiation at military camp sites.
16. Work of the Division of Radiation and Organisms, a subsidiary branch of the A.P.O., founded by Secretary Abbot in 1929.

CRITICISM OF CERTAIN METEOROLOGICAL FINDINGS

While many of the pieces of work are everywhere praised and accepted,[4] professional meteorologists have disparaged the alleged results indicated by numbers 2, 7, 8, 9, 10, and 11, listed above. I had hoped to overcome their doubts by my publication 4545.[2] However, recent private advices from responsible officers of the U.S. Weather Bureau, the American Meteorological Society, and the High Level Atmospheric Observatory at Boulder, Colorado, convince me that their doubts still remain. As I feel quite certain of the soundness of these A.P.O. results, I feel a duty to dispel these official objections. In the remainder of this paper new evidence will be presented.

A DEFENSE OF CERTAIN METEOROLOGICAL FINDINGS

SOLAR RADIATION AND ITS VARIABILITY

Numbers 2 and 7—The accuracy of A.P.O. measures of the solar constant, and the limits of its variation.

Referring to table 1, page 13 of Pub. 4545,[2] the probable error of one day's solar constant measure at one station (usually the mean of three independent observations) is $\frac{1}{6}$ of 1 percent. It is certified by 1992 pairs of solar constant measures on identical days made at four observing stations at all times of the year. One station is in the Southern, three in the Northern Hemisphere, and they are separated by thousands of miles. Table 1, just cited, is composed of four sec-

[4] See expert opinions given in volume V of *Annals*, A.P.O., pp. 32-35.

tions whose individual mean values differ only through the small range from 76.0 to 77.9 parts in 10,000 of the solar constant.

As for the extreme limits of solar variation, I sent Dr. Roberts of High Level Observatory a rough plot of all Montezuma solar constant daily mean values, 1923 to 1952. He retains a copy of it. From numerous of these values, some as low as 1.910, some as high as 1.970, I believe it fair to set solar variation limits as above 2 percent. Dr. Franz Baur of the University of Frankfurt, A.M., Germany, has published 2.2 percent as his conclusion.[5]

On one occasion the solar constant appears to have gone as low as 1.870 calories in 1922 and 1923, for a considerable time. This unique depression may be associated with a long-range period in solar variation that would require scores or centuries of years of observation to verify.

PERIODIC SOLAR VARIATION

Number 8—The 27-day period in solar variation.

It has long been known that the sun's surface shows rotation varying in velocity from the sun's equator to its poles. At the equator the sun rotates in about 25 days, and in about 35 days at 80° latitude. A weighted value of the sun's rotation period, considering areas and latitude, may be taken at 27 days. In Pub. 2499,[6] I showed strong correlation in solar constant measures ranging continuously from +25 to −30 percent, with a period of 27 days. See figure 15, Pub. 4545.[2] This wide range was observed in Mount Wilson values *in 1915,* but **not** in other years, *1912-1920.*

Having discovered the master period, 22 years, 9 months (273 months) in solar variation about 1940, it seemed to me probable that the highly accurate solar constant measures made at Montezuma would show a 27-day period strongly in the year 1937 (1915+22 years), perhaps repeated several times. I have computed from records in volume 6 of the Observatory's *Annals* for four recurrences of the 27-day period in daily solar constant values observed at Montezuma from early April to late September of 1937. Table 1 and accompanying Figure 1 show the detailed and mean results. A 27-day periodic

[5] *Met. Rundschau,* 17 January, Jahrb. 1, Heft 1964, pp. 19-25.

[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,* by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 66, No. 6. 1918.

TABLE 1.—*The 27-day period in solar radiation during 1937.*[1]

Solar constants; Montezuma values

Day	Date	Calories	Date	Calories	Date	Calories	Date	Calories	Mean
1	Apr. 9	1.935	May 5	1.937	June 3	1.941	Sept. 1	1.942	1.938
2	—	—	—	—	4	1.944	—	—	1.944
3	—	—	—	—	5	1.945	—	—	1.945
4	—	—	—	—	6	1.956	—	—	1.956
5	—	—	—	—	—	—	5	1.938	1.938
6	14	1.930	—	—	8	1.955	6	1.941	1.942
7	15	1.951	11	1.947	9	1.953	7	1.951	1.950
8	16	1.934	12	1.940	—	—	8	1.948	1.941
9	17	1.947	13	1.942	11	1.944	9	1.950	1.947
10	18	1.946	—	—	12	1.950	10	1.943	1.945
11	19	1.946	15	1.948	13	1.949	11	1.947	1.948
12	20	1.942	16	1.949	14	1.942	12	1.951	1.948
13	—	—	17	1.950	15	1.940	13	1.946	1.944
14	—	—	18	1.950	—	—	14	1.948	1.949
15	23	1.928	—	—	—	—	—	—	1.928
16	24	1.948	—	—	18	1.949	16	1.948	1.948
17	25	1.947	—	—	19	1.941	17	1.957	1.948
18	26	1.945	22	1.958	—	—	18	1.947	1.950
19	—	—	—	—	—	—	19	1.947	1.947
20	28	1.948	—	—	22	1.945	20	1.946	1.946
21	29	1.940	—	—	—	—	21	1.951	1.946
22	30	1.946	—	—	—	—	22	1.946	1.946
23	May 1	1.934	27	1.949	25	1.946	23	1.943	1.943
24	2	1.932	28	1.949	—	—	24	1.943	1.941
25	—	—	29	1.943	—	—	25	1.930	1.937
26	—	—	30	1.946	28	1.942	26	1.937	1.942
27	5	1.937	31	1.949	—	—	27	1.938	1.941

[1] It is a pity but unavoidable that so many days were lost by clouds. Fortunately the *first* day of the 27 is very strong. It was observed in all four repetitions of the period with an over-all range between them of but 0.007 calorie. Figure 1 shows very stoutly the well-evidenced rise of ½ percent from both ends to the middle of the period. The individual points have an average deviation from the mean curve of figure 1 of only ⅛ of 1 percent of the solar constant.

variation, with an amplitude of about ½ percent of the solar constant, appears as the mean result of four well-observed repetitions.

This new evidence and that of 1915 (Pub. 4545, fig. 15) seems to me to show decisively the 27-day rotation period in solar variation.

I have referred to the apparent 27-day effect on Washington precipitation at pages 45 and 46, and table 8 of Pub. 4545.[2] Using 27.0074 days as the exact period, I found good success in predicting the

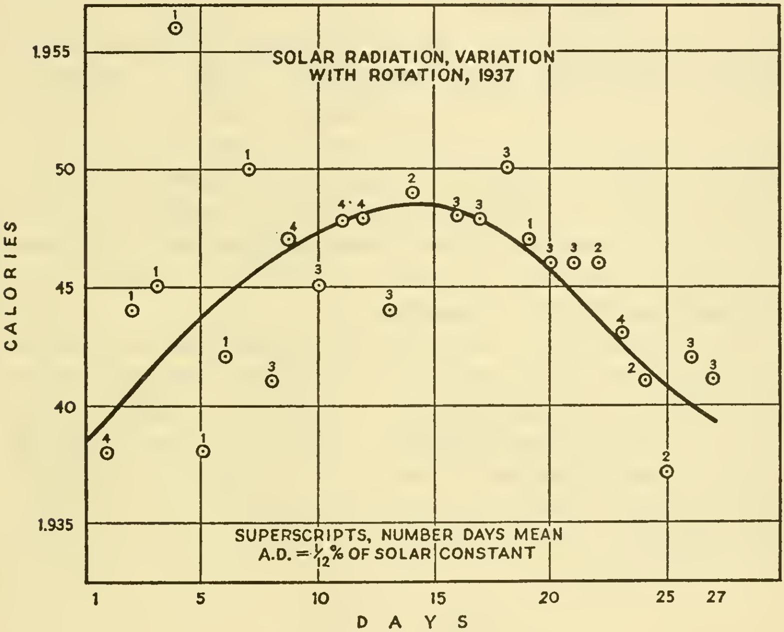

FIG. 1.—The 27.006-day period in solar variation.

175 days more apt to have rain in Washington than the other 190 or 191 days of the years 1942-1954. (See table 8, Pub. 4545.[2]) The formula failed only in 1952 and 1953 (possibly because of bomb explosions and fallout). Continuing to use the same formula in prediction for the year 1963, the whole group of preferred days proved displaced, recurring one day too early. But if the period is slightly changed to 27.0056 days it would have made no difference in forecasts prior to 1954, but in 1963 the preferred days (one day earlier) would have had 1.30 times the average precipitation falling in all others.

OPPOSING SOLAR TRENDS

Number 11—Important opposed trends in solar variation.[7]

The A.P.O. at Washington devoted much effort after 1942 to studying such upward and downward trends in solar variation as are shown in figure 46, Pub. 4545,[2] not here reproduced. It was found that the temperature in Washington and several other United States and European cities responded to these solar trends by long-lasting marches, opposed like right and left hands. So many papers have been published on this observation that it seems superfluous to bring more evidence here. Figures 46, 47, and 49, and pages 52 to 57 of the text of Pub. 4545 [2] show that large opposed temperature changes occurred simultaneously in Europe as well as in the United States in response to over 300 cases of such opposite solar trends. (See fig. 45, Pub. 4545[2].) Pub. 3771 [8] presents a long investigation of the subject. It ends with a summary containing 18 sections. Not only solar constant measures, but solar faculae, calcium flocculi, and ionospheric phenomena act as triggers to set off these opposed long-continued large temperature variations.

In Pub. 4462 [9] of 1961 it is suggested that much better solar constant measures could be made from earth satellites than from mountains, because the atmosphere would be eliminated. If that were done, forecasts of detailed *world* temperature, depending on trends of solar variation, could be obtained covering 16 to 20 days in advance continuously. (The above cited fig. 49 of Pub. 4545 [2] is given originally in Pub. 4462.[9])

TERRESTRIAL WEATHER

Number 10—Harmonic periods and long-range forecasts.

We now come to the important claim of a harmonic family in weather changes identical in periods with such a family in solar variation, but showing far more percentage change in weather than in solar variation. Even more obnoxious to meteorologists has been the claim that useful weather predictions can be made from knowledge

[7] I insert Number 11 before Number 10, because Number 10 is potentially our most important discovery, requiring extensive comment and deserving the most emphatic place of all our discoveries.

[8] *Weather predetermined by solar variation*, by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 104, No. 5. 1944.

[9] *16-day weather forecasts from satellite observations*, by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 143, No. 2. 1961.

of it, 10 or even 50 years in advance, or backwards. Recently, however, some meteorologists seem to be more favorably impressed.

Some confusion has been caused by over-riding periods.

It must be clear to all that if there actually is such a large harmonic family in weather periods, ranging in lengths from 4 months to the master period of 273 months, then a tabulation at individual stations of weather periods, e.g., of $\frac{273}{4}=68\frac{1}{4}$ months must be overlaid by shorter periods, such as $\frac{273}{8}, \frac{273}{28}$, et cetera. So the primary tabulation for a $68\frac{1}{4}$-month period must necessarily look very rough. It may not even suggest a "hidden" period of $68\frac{1}{4}$ months unless those overlying shorter harmonics can first be removed.

I now refer the reader to the accompanying figures 2, 3, and 4, prepared from Jon Wexler's electronic tabulations of monthly "World Weather Records," 1870 to 1940. He obtained monthly normals of precipitation at Rome, Italy, Kief, U.S.S.R., Capetown, South Africa, and other stations, separately for years when Wolf sunspot numbers $\gtreqless 20$. From these he obtained the departures in percentage of normal for all months, 1870-1949. These are divided into four groups which we call Category 1, Divisions 1 and 2; Category 2, Divisions 1 and 2. "Division" refers to first and second half of the interval 1870-1949. "Category" refers to Wolf numbers $\gtreqless 20$ sunspot numbers.

Figure 2, for the $68\frac{1}{4}$-month period in Category 2, combines Divisions 1 and 2 at Rome, Italy. It shows five starting dates: June 1902, February 1908, October 1913, June 1919, and March 1925. A lack of recorded observations in later years before 1949 prevented using a sixth column. The mean of these 5 columns is plotted in the bottom full curve. No one seeing this curve could suppose it would easily be resolved, and would disclose a smooth sine curve of $68\frac{1}{4}$ months. But when the over-riding periods $\frac{273}{8}, \frac{273}{12}, \frac{273}{28}, \frac{273}{16}, \frac{273}{20}, \frac{273}{44}$ are successively computed and removed, as shown in figure 2, there results the beautiful smooth sine curve shown at the top of figure 3, representing only $\frac{273}{4}$ or $68\frac{1}{4}$ months. Its amplitude is over 30 percent of normal precipitation.

I am sure it will not be necessary to so particularly describe figures 3 and 4 relating to Kiev, U.S.S.R. and Cape Town, South Africa, which each include one group of Jon Wexler's electronic tabulations, being for the periods $\frac{273}{8}$ and $\frac{273}{9}$ months, respectively. They display overriders, $\frac{273}{16}, \frac{273}{24}, \frac{273}{40}$, for Kiev, and $\frac{273}{18}, \frac{273}{27}, \frac{273}{45}, \frac{273}{63}$, for Cape Town. These two stations, cleared, show smooth sine curves, respectively, of amplitudes 25 and 16 percent of normal precipitation. I call attention

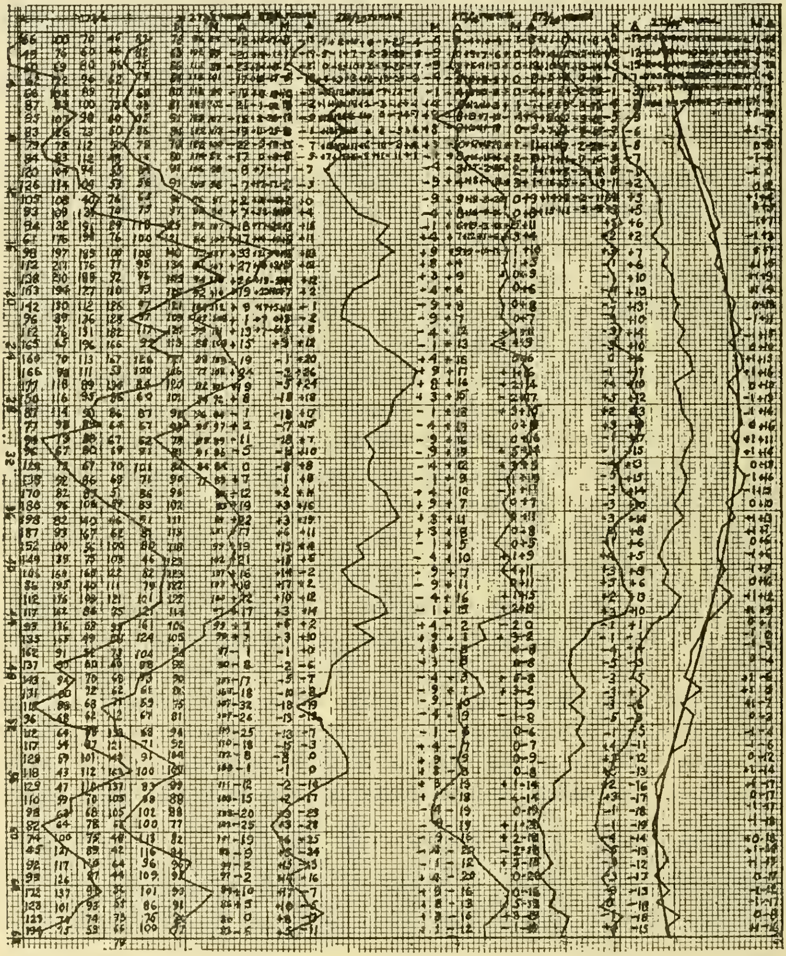

FIG. 2.—Rome, Italy. 68¼ Month Period Cleared.

to the far geographical separation of the three cities concerned in figures 2, 3, and 4. Similar results, not so fully exposed in the publishing of them as figures 2, 3, and 4, are shown for several U.S cities in figures 18, 19, 20, 23, 24, and 25 of Pub. 4545 [2] and for other stations not here cited. Altogether the figures just cited would display, necessarily as super-riders, the existence of nearly all of the 27 periods, harmonics of 273 months, which we use in forecasting weather. Similar clearing gives similar sine-curve results for long periods at all 54 stations so far forecasted.

Referring now to figure 21 of Pub. 4545,[2] it shows the actual plus

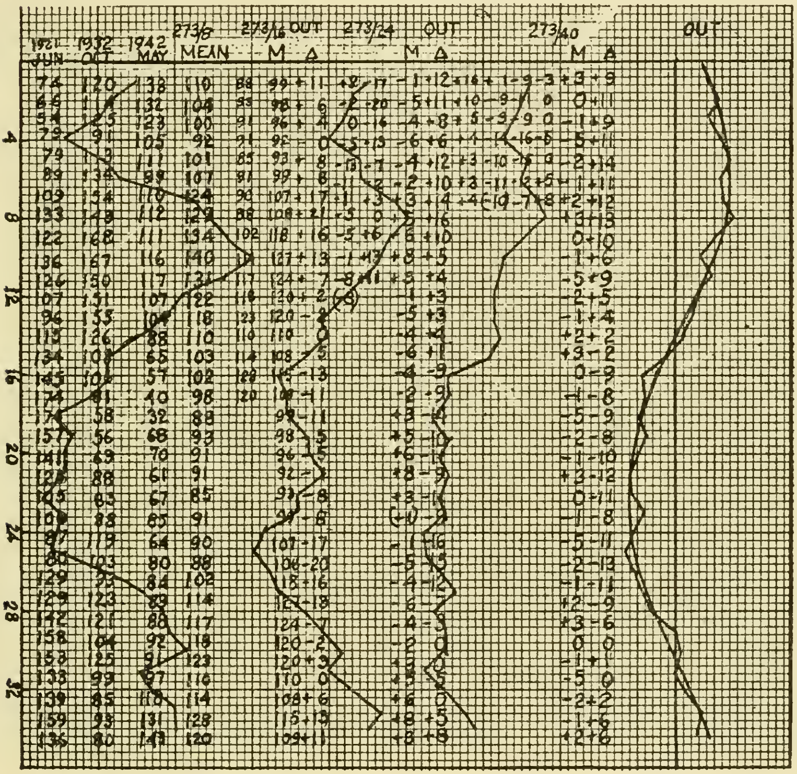

FIG. 3.—Kiev, U.S.S.R., Precipitation. 34⅛ Month Period Cleared.

and minus quantities which resulted from tabulations I made for St. Louis, working on them alone without electronic assistance. These 23 columns of figures, being added, gave a 20-year back-cast from the mean date 1897 of the precipitation at St. Louis, 1875-1879. It is nearly identical with the actual precipitation observed. As stated in Pub. 4211,[10] all that work was done on 5-month consecutive means

[10] *60-year weather forecasts*, by C. G. Abbot. Smithsonian Miscellaneous Collections, vol. 128, No. 3. 1955.

of the monthly records of St. Louis, 1854-1940. Such 5-month consecutive smoothing is also used in Jon Wexler's electronic tabulations for foreign stations, mentioned above. But that does not prejudice at all our discovery that very successful long-range forecasts can be made. See also figure 22 of Pub. 4545.[2]

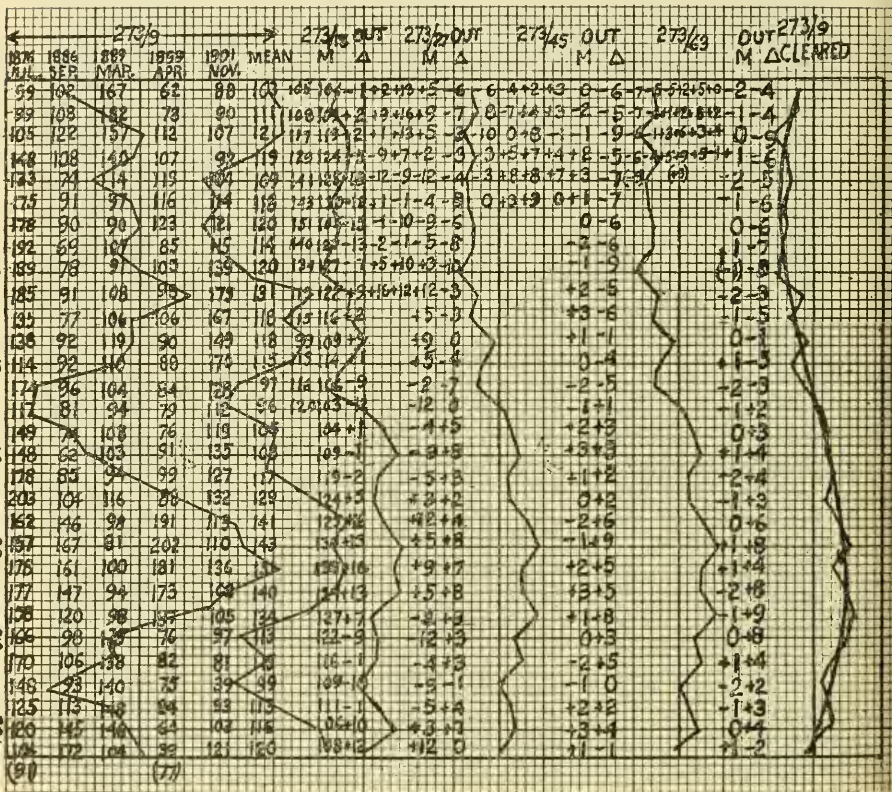

FIG. 4.—Cape Town, South Africa Precipitation. 30⅓ Months Cleared.

Landsberg, Mitchell, and Crutcher, in their paper on climatological data for Woodstock, Md., describe that station "as a member of the Weather Bureau's Climatological Benchmark Network." I feel very grateful to Dr. Landsberg that he has sent me two sheets of the monthly records of precipitation at Woodstock covering 1870 to 1963. Mr. Jon Wexler has prepared these records for my use to make an analysis with forecast through 1969. I have made such a forecast 1950 through 1969 for Woodstock, which shows correlation with observation from 1950 to 1963 of about +42 percent. Unfortunately displacements of obviously similar features made this correlation coefficient fully 10 percent lower than those for most U.S. stations. Rectifying these obvious displacements, I found a correlation coefficient of +72 percent for Woodstock.

Figures 2, 3, and 4 of the present paper, and figures 18, 19, 20, 21, 22, 23, 24, and 25 of Pub. 4545,[2] and many examples I have encountered in forecasts of precipitation for 54 cities show how over 30 regular periods, harmonics of 273 months, are "hidden" if one regards meteorological time as if it were a river running serenely forever in a smooth uniformly inclined channel. All researchers do so who neglect *time of the year, sunspot activity,* and *march of population,* all affecting atmospheric transparency, and neglect the *superposition of short-period harmonics* confusing longer ones.

CLASSIFIED REFERENCES FROM SMITHSONIAN PUBLICATIONS

A. Accuracy of the solar constant as measured.

(1) Annals, A.P.O., vol. 6, p. 163. Published 1942.

(2) Smith. Misc. Coll., vol. 134, No. 1, Pub. 4265, p. 2. Published 1956.

(3) Smith. Misc. Coll., vol. 146, No. 3, Pub. 4545, table 1, pp. 10-15. Published 1963.

B. "Hidden" periodicities.

In solar constant measures:

(1) Smith. Misc. Coll., vol. 117, No. 10, Pub. 4088. Published in 1952.

(2) Smith. Misc. Coll., vol. 128, No. 4, Pub. 4213, pp. 4 and 6, table 1, fig. 1, and pp. 9 and 10, fig. 2. Published 1955.

In weather:

(2) Smith. Misc. Coll., vol. 117, No. 16, pp. 11-18, 5 tables, 8 figs., Pub. 4095. Published 1952.

(3) Smith. Misc. Coll., vol. 121, No. 5, pp. 2-5, table 1, fig. 1, Pub. 4103. Published 1953.

(4) Smith. Misc. Coll., vol. 128, No. 3, pp. 1, 2, Pub. 4211. Published 1955.

(5) Present paper, Number 10 "Harmonic periods and long-range forecasts."

C. Weather forecasts do not require solar observations.

Their independence from all *solar* measures except Wolf numbers. $\gtrsim 20$.

(1) Smith. Misc. Coll., vol. 121, No. 5, line 22, p. 2; line 15, p. 11, Pub. 4103. Published 1953.

D. High positive correlation with events.

(1) Smith. Misc. Coll. vol. 128, No. 3, pp. 4-5, Pub. 4211. Published 1955.

(2) Smith. Misc. Coll., vol. 139, No. 9, p. 1, Pub. 4390. Published 1960.

(3) Smith. Misc. Coll., vol. 146, No. 3, pp. 60, 63, 64, Pub. 4545. Published 1963.

(4) Smith. Misc. Coll., vol. 143, No. 5, p. 5, fig. 4, Pub. 4471. Published 1961.

I have (unpublished) the correlation coefficient between back-cast and observation for St. Louis monthly precipitation, 24 months, 1878 and 1879. It is based on all records 1854 to 1939, centering at 1897. It is $+87.5 \pm 6.5$ percent.

E. Average deviations of forecasts from events are no greater at wide departures from normal, or after long lapse of time.

(1) Smith. Misc. Coll., vol. 143, No. 5, pp. 1, 6, table 1. Pub. 4471. Published 1961.

(2) Smith. Misc. Coll., vol. 128, No. 3, Pub. 4211. Published 1955.