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The Constancy of the Solar Constant

By Theodore E. Sterne [1] and Nannielou Dieter [2]

To evaluate possible real changes in the solar constant we have used two methods of studying the very precise determinations of it that were made by Dr. Charles G. Abbot and other Smithsonian workers, simultaneously and independently, at stations in Montezuma, Chile, and at Table Mountain, California, during a period of nearly 30 years. The first method depended on the principle that the covariance of independent measurements of a changing quantity equals the variance of the changing quantity itself, uninfluenced by errors of observation. The second method involved the calculation of a serial correlation coefficient from the measurements at each of the two stations separately. Even roughly periodic components of the solar constant would be expected to appear as periodic components of the plot of the serial correlation against lag, and if real should appear in the plots for both stations.

The method of covariance

All the solar constant values measured by the Astrophysical Observatory of the Smithsonian Institution from 1923 through 1952 have been published (Abbot, Aldrich, and Hoover, 1942; Aldrich and Hoover, 1954), and unpublished values from 1953 through June 1955 have been available to us. Information about the magnitude of changes in the solar constant can be sought from the correlation between measures independently obtained at different stations. For this purpose the measures at Montezuma in Chile and Table Mountain in California, which overlap during the interval from January 1926 through June 1955, appear best suited. Series of observations made at Harqua Hala, Arizona, and at Mount St. Katherine in Egypt were of short duration and were not used. "Ten-day" mean values of the solar constant measured at Montezuma have been compared with "ten-day" mean values of the solar constant measured at Table Mountain. The means are non-overlapping, and are really over intervals of 1/36 of a year.

As has been stated, the principle was employed that the covariance of simultaneous measurements, with independent errors, of the same changing quantity is equal to the variance of the changing quantity. To see this, let the changing quantity be denoted by z, which is observed at some station or by certain equipment that yields a value x where

$$x = z + \epsilon.$$

Here ϵ is an error that is statistically independent of z, but may have a constant bias so that its mean value, averaged over a long series of observations, may differ from zero. Let y be the simultaneous value of z as measured independently at a different station or with different equipment, so that

$$y = z + \eta$$

where η is an error statistically independent of z and of ϵ. Then it follows by simple algebra, and from the principle that the mean of a sum is the sum of the means, that the covariance

$$\overline{xy} - \overline{x}\cdot\overline{y} = (\overline{z^2} - \overline{z}^2) + (\overline{z\eta} - \overline{z}\cdot\overline{\eta}) + (\overline{z\epsilon} - \overline{z}\cdot\overline{\epsilon}) + (\overline{\epsilon\eta} - \overline{\epsilon}\cdot\overline{\eta}).$$

The bars denote mean values taken over the series of simultaneous observations of the changing quantity z. Now because z, ϵ, and η are all independent it follows that the contents of the last three sets of parentheses are zero. For

$$\begin{aligned}\overline{z\eta} - \overline{z}\cdot\overline{\eta} &= \overline{(z - \overline{z} + \overline{z})(\eta - \overline{\eta} + \overline{\eta})} - \overline{z}\cdot\overline{\eta} \\ &= \overline{(z-\overline{z})(\eta-\overline{\eta})} + \overline{(z-\overline{z})}\cdot\overline{\eta} + \overline{z}\cdot\overline{\eta} - \overline{z}\cdot\overline{\eta} \\ &= \overline{(z-\overline{z})(\eta-\overline{\eta})} \\ &= 0\end{aligned}$$

[1] Smithsonian Astrophysical Observatory and Harvard College Observatory.

[2] Harvard College Observatory.

because of the independence of z and η, and similarly

$$\overline{z\epsilon}-\overline{z}\cdot\overline{\epsilon}=0$$

$$\overline{\epsilon\eta}-\overline{\epsilon}\cdot\overline{\eta}=0$$

because of the independence of z and ϵ, and of ϵ and η. However,

$$\overline{z^2}-\overline{z}^2=\sigma_z^2,$$

the variance of z, where σ_z is the standard devi- ion of the values of z, defined by

$$\sigma_z^2=\overline{(z-\overline{z})^2},$$

and thus the principle

$$\overline{xy}-\overline{x}\cdot\overline{y}=\sigma_z^2$$

follows.

In the application of the principle, x denoted the 10-day mean values of the solar constant as measured at Table Mountain, and y as measured at Montezuma. There were 858 simultaneous pairs (x, y). The value of σ_z^2 was found to be 10.5885×10^{-6} (cal/cm^2 minute)^2, leading to the value 3.25×10^{-3} calories per square centimeter per minute for the standard deviation of the true 10-day mean values from 1926 through 1955.

There are two reasons, however, why the preceding value 3.25×10^{-3} cal/cm^2 minute must be regarded as only an upper limit to the standard deviation of the true 10-day mean values from 1926 through 1955. The first is that there may have been positive correlation between the observational errors at Montezuma and Table Mountain, arising from some part of the changing atmospheric absorption that was common to both stations and that was incompletely corrected for by the methods of reduction that were employed. It is conceivable that the amount of dust in the upper atmosphere, for example, may have changed during the long interval at both stations at about the same times, through general mixing, despite the considerable distance between Chile and California. The methods of reduction had been carefully devised to eliminate the effects of atmospheric absorption from the measures. Had the elimination been perfect, even a general and changing common absorption over two continents would have introduced no correlation; but the elimination was probably not perfect, and any imperfection would have allowed positively correlated errors to remain. Such residual errors would have contributed to the value 3.25×10^{-3} cal/cm^2 minute, since application of the statistical principle used in this paper would put any common part of incompletely independent ϵ's and η's into z.

The second reason why 3.25×10^{-3} is only an upper limit is that the values of the solar constant measured at Table Mountain were adjusted by small amounts before publication, as stated in the Annals, to bring them into closer conformity with the values at Montezuma.

For the preceding reasons it is concluded that if the solar constant changed at all in the interval 1926 through 1955, it changed by amounts whose root-mean-square value was no more than 3.25×10^{-3} cal/cm^2 minute. The mean solar constant being about 1.946 cal/cm^2 minute, the greatest possible root-mean-square value of the possible changes was only 1.7 parts in one thousand of the solar constant itself. The authors are aware of no other star that has been proved by measurement to be this constant.

An earlier study (Sterne, 1942) of the covariance of monthly mean values of the solar constant measured at Montezuma and Table Mountain, from 1926 to 1939, furnished an upper limit 0.0025 cal/cm^2 minute for the standard deviation of real changes in the solar constant over that period. The old and new limiting standard deviations are thus in substantial agreement, over the different periods of time. This agreement abated our mild doubts as to the wisdom of having employed unpublished values of the solar constant from 1953 to 1955. It had been conceivable that the unpublished values, which had not been obtained under the supervision of the same people as the published ones, were slightly inhomogeneous with respect to them. Such inhomogeneity would have tended to cause an erroneously large value, of the standard deviation of real changes in the solar constant, to be obtained from our analysis. The effect would have been very small because a standard deviation inferred from nearly 30 years of observations is not sensitive to solar constant values in only three of the years, and we had thought it

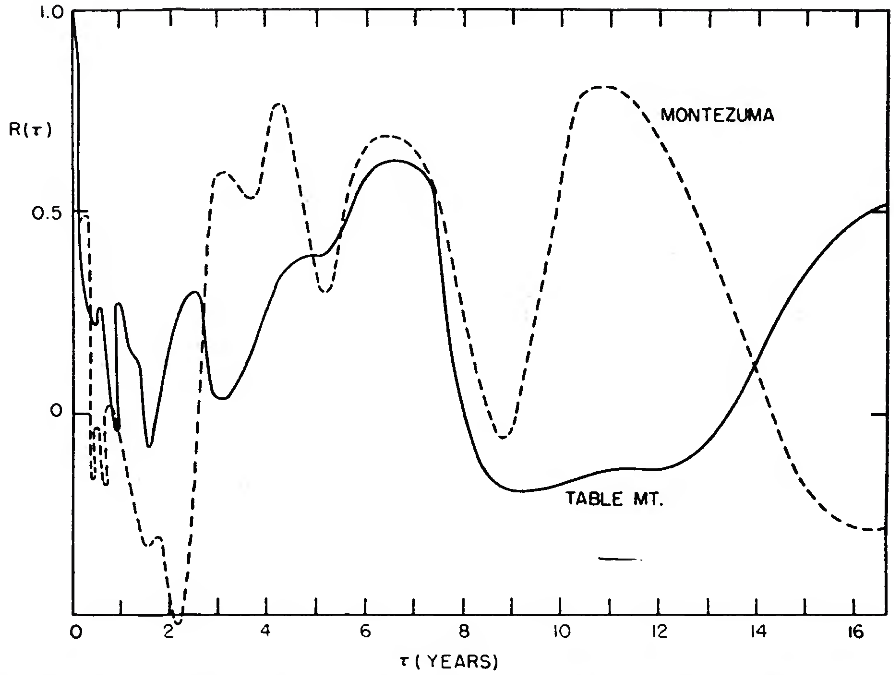

FIGURE 1.—Plots of the serial correlation coefficients, $R(\tau)$, of 10-day mean values of the solar constant as measured at Table Mountain and at Montezuma, against the lag, τ.

better to run the risk of introducing a slight inhomogeneity than to ignore two years of observations. Had we excluded observations since 1953, however, substantially the present results would have been obtained because, as is well known, statistical conclusions are usually rather insensitive to the amount of data used.

The random errors at the two stations may be of interest. The variance of the measures at either station, less the true variance of the solar constant, is clearly the variance of the random errors at the station. The standard (root-mean-square) error at Montezuma, of 10-day means, was thus found to be 0.00469 and that at Table Mountain to be 0.00690 cal/cm^2 minute. These are about a quarter and a third of one percent, respectively, of the total solar constant, and can be compared with the standard errors 0.0030 and 0.0054 of the monthly mean values, from 1926 to 1939 at the same two stations, found in the earlier study. If the accuracy of the measurements had been the same from 1926 to 1939 as from 1926 to 1955, and if the individual values involved in the 10-day and monthly means had independent errors, the standard error of a 10-day mean would be expected to be $3^{1/2}$ times as large as the standard error of a monthly mean. That the standard errors of the two sorts of means are more nearly equal than would be thus expected can possibly be attributed, it is thought, to serial correlation between the errors of 10-day means.

The method of serial correlation

To examine the possibility that the solar constant contains periodic components, serial correlation coefficients were computed separately for the two stations. The serial correlation coefficient, $R(\tau)$, of the 10-day means at a station where the observed 10-day mean solar constant at date t is $x(t)$, is defined as

$$R(\tau)=\left[\frac{1}{n}\sum_{t=0}^{T-\tau} x(t)x(t+\tau)-\frac{1}{n^2}\sum_{t=0}^{T-\tau} x(t)\sum_{t=\tau}^{T} x(t)\right]\Big/\sigma_{x(t)}\sigma_{x(t+\tau)}$$

where

$$\sigma^2_{x(t)}=\frac{1}{n}\sum_{t=0}^{T-\tau} x^2(t)-\frac{1}{n^2}\left[\sum_{t=0}^{T-\tau} x(t)\right]^2$$

and

$$\sigma^2_{x(t+\tau)}=\frac{1}{n}\sum_{t=\tau}^{T} x^2(t)-\frac{1}{n^2}\left[\sum_{t=\tau}^{T} x(t)\right]^2$$

in which n is the number of 10-day means from $t=0$ to $t=T-\tau$, and in which the series of 10-day means extends from $t=0$ to $t=T$. Thus $R(\tau)$ is merely the ordinary coefficient of correlation between $x(t)$ and $x(t+\tau)$ and is a function of the variable τ, called the lag. Certain approximations were made in calculating $R(\tau)$, to facilitate the making of the calculations by punch-cards. The $R(\tau)$'s for the two stations are plotted in the figure. Since fewer pairs of values enter into R for large τ than for small τ, the values of R for small τ have higher weights than the values of R for large τ.

The plots for the two stations are almost totally dissimilar except at about 76 months where there is a coincidence, of peaks, that may be fortuitous. That it is fortuitous, and that no significant, real, 76-month periodicity is present is indicated by the lack of a common minimum near 38 months. A real periodicity in the solar constant would give rise to nearly a cosine-curve, with maxima at zero and at integral multiples of the period. That both curves are high near zero indicates that successive 10-day means are positively correlated with each other and are not independent. Almost any real, nonperiodic, solar variation could cause such correlation, and so also could correlation between errors of measurement during successive 10-day intervals. The serial correlations thus indicate no periodicities in the solar constant common to both stations.

It is a pleasure to acknowledge the help of the Littauer Statistical Laboratory of Harvard University, where the calculations were carried out under the supervision of Mr. J. W. Houghten with much dispatch.

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Abstract

To evaluate possible real changes in the solar constant, the covariance was calculated of 10-day mean values of determinations of the solar constant made simultaneously at two stations, in Chile and California, over a period of nearly 30 years. Serial correlation coefficients were also calculated separately for the two stations. The covariance indicated that if real changes occurred their standard deviation over this period was smaller than 0.17 percent of the solar constant. The serial correlation coefficients indicated no periodicities common to both stations in the solar constant.

On Sterne and Dieter's Paper, "The Constancy of the Solar Constant"

By C. G. Abbot [1]

I am gratified by the appreciation the two authors of "The Constancy of the Solar Constant" express regarding the accuracy of the solar constant measures published in volumes 6 and 7 of the Annals of the Astrophysical Observatory of the Smithsonian Institution (Abbot, Aldrich, and Hoover, 1942; Aldrich and Hoover, 1954). To obtain these measures my associates worked long hours diligently, enthusiastically, ably, and sacrificially for years at a stretch on high arid mountains far from the comforts and associations of home. Had we been convinced, like the authors, that the small fluctuations we found were due to accidental errors of measurement and did not indicate any solar variability, we might have closed the series of daily measurements in 1930 and saved money and effort.

But notwithstanding the mathematical analysis of the authors, evidence convinces me that the sun's emission of radiation varies—both sporadically and in a family of integrally related periods—and that the variation is of real importance.

Sporadic solar variation

On Mar. 20, 1920, a tremendous sunspot group passed centrally over the sun's visible disk. Mr. Alfred F. Moore, observing in Chile, took solar constant observations in exceptionally fine weather nearly every day for over 100 days, using the fundamental method of Langley. The original publication (Abbot, Fowle, and Aldrich, 1922, pp. 186–187) presents details concerning March 20, with Mount Wilson solar photographs. I give here only average solar constant values: March 11–17, 1.957 calories; March 27–31, 1.961 calories; March 20–22, 1.922 calories.[2] The depression attending the central passage of the sunspot group is 0.037 calorie, almost 2 percent, as shown in figure 1. When the group reappeared in April it was reduced very greatly. The solar constant measures fell off at the April transit, but only by about one-tenth of 1 percent.

I now reproduce, as figure 2, L. B. Aldrich's (1953, p. 131, fig. 1) graph of the correlation between solar constant measures and Wolf sunspot numbers on identical days. Comparisons for 141 days between solar constant values and Wolf numbers show a steadily rising curve, with 0.005 calorie increase of solar constant measures attending an increase of 175 Wolf numbers.

Next I reproduce, as figures 3 and 4, two figures from my paper "Solar Variation, a Leading Weather Element" (Abbot, 1953b, figs. 5, 7). Figure 3 shows the mean result found from 53 great magnetic storms. The solar constant measures average 0.006 calorie lower on the days of maximum severity than on the average of 20 days before and after that event. Figure

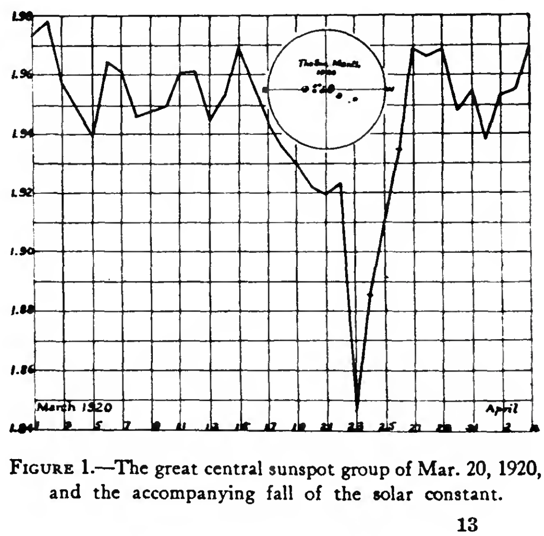

FIGURE 1.—The great central sunspot group of Mar. 20, 1920, and the accompanying fall of the solar constant.

[1] Research Associate, Smithsonian Institution.
[2] Even as low as 1.846 and 1.887 on March 23 and March 24.

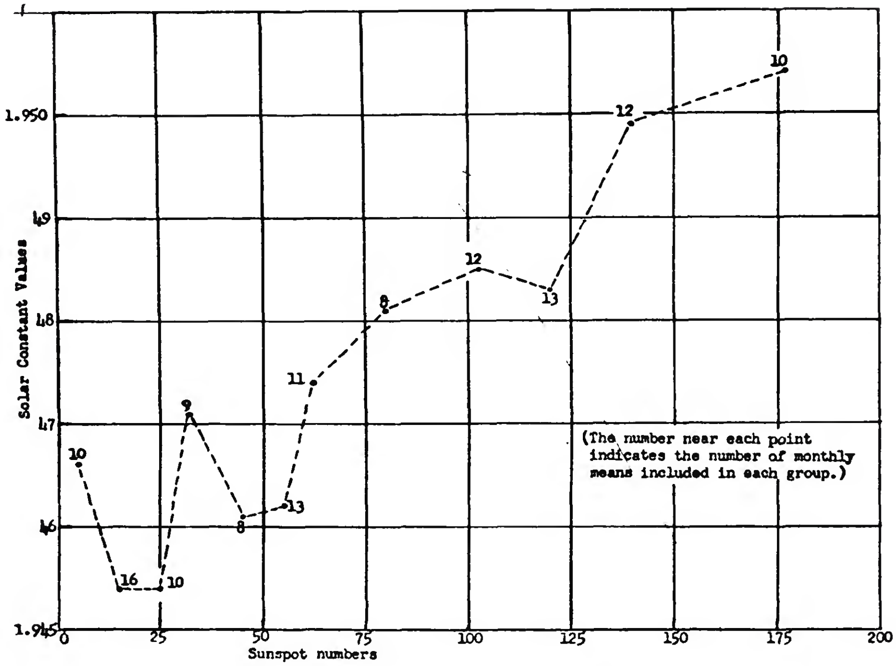

FIGURE 2.—Sunspots versus solar constants, 1940 through 1950.

4 shows, as the mean result from study of 45 West Indian hurricanes, that the solar constant values average 0.005 calorie lower on the days of first report of the hurricanes than the average of 20 days before and after that event.

As a final note regarding sporadic solar radiation change, I will only refer to the above-cited paper (Abbot, 1953b) which presents numerous correlations between solar constant variations and changes in the telescopic and spectroscopic observations of the sun, and changes of weather.

A family of integrally related periods in solar variation

In table 3 of my paper "Periodic Solar Variation" (Abbot, 1955) I listed over 60 regular periods found in solar constant measures, all integral submultiples of 273 months. This master period is double the so-called "sunspot period," and equal to Hale's period in sunspot magnetism. In figure 3 of that paper, reproduced here as figure 5, I graphed 26 of these periods. The amplitudes given in table 3 (cited above) range from 0.02 percent to 0.21 percent of the solar constant.

Lest readers suppose that periods of such small amplitudes are beyond the accuracy of solar constant measures to discover, I give the following evidence. Results of 616 days of simultaneous observation of the solar constant

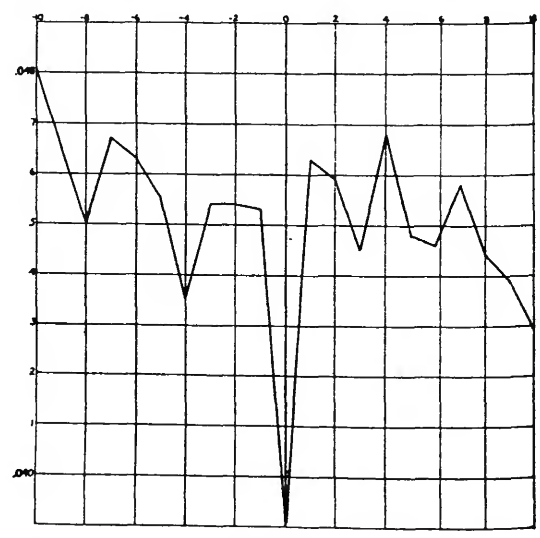

FIGURE 3.—Depression of solar constant attending severe magnetic storms. Abscissae, days before and after height of storm; ordinates, solar constant (to be increased by 1.9).

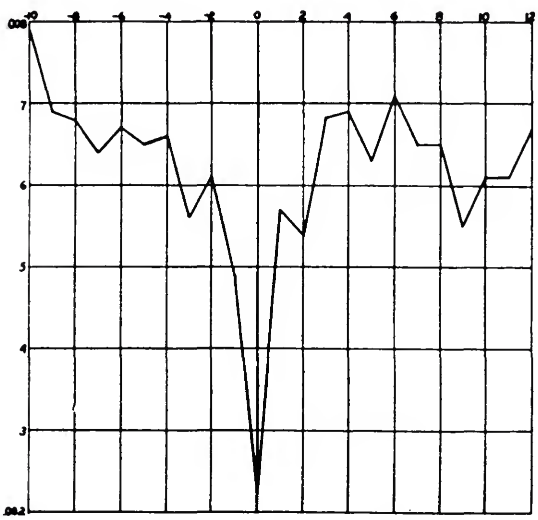

FIGURE 4.—Mean solar constant values preceding and following first reports of West Indian hurricanes. Abscissae, days before and after report dates; ordinates, solar constant values (to be increased by 1.94).

in the Northern and Southern Hemispheres during the years 1932 to 1936 have been published (Abbot, Aldrich, and Hoover, 1942, p. 163). The weighted mean discrepancy i 7.6 thousandths of a calorie per day, whence it follows that the probable error of one day's observation at one station is one-sixth of 1 percent.

At my request, Mrs. Lena Hill, statistical assistant at the Astrophysical Observatory, made a similar comparison between simultaneous observations at Montezuma, Chile, and at Tyrone, N. Mex.; between Montezuma and Table Mountain, Calif.; and between Tyrone and Table Mountain. (The observations are published in Aldrich and Hoover, 1954.) Mrs. Hill's results are: Montezuma-Tyrone, for 283 days, 7.96 thousandths calories; Montezuma-Table Mountain, for 891 days, 7.68 thousandths calories; Tyrone-Table Mountain, for 202 days, 7.79 thousandths calories. From the four determinations the daily discrepancy averages about 7.7 thousandths calories, or 0.038 percent of the solar constant, and the probable error of one day's observation at one station is just over one-sixth of 1 percent. In a 10-day mean, dividing by $\sqrt{10}$, the discrepancy reduces to one-eighteenth of 1 percent, and

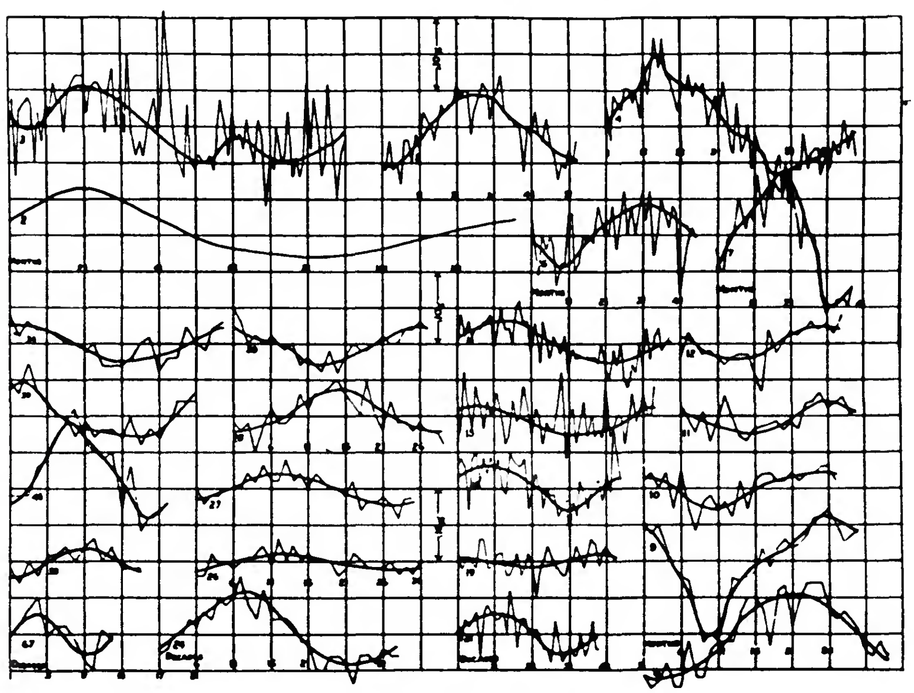

FIGURE 5.—Periods in solar variation, integral submultiples of 273 months. Percentages of the solar constant indicated by 1/10% arrows.

in a table where the means of 25 or more 10-day means are averaged for each line, the probable error of the mean is about one-hundredth of 1 percent. For the shorter and feebler periods in the above-cited table 3, many more than 25 10-day mean results are averaged in the several points defining the curves shown in figure 5. The curves (with which attending numbers indicate 273 divided by the period in months) are of such regular shape, approaching sine curves, that the several points plotted support one another. Therefore it is not beyond the accuracy of our work to discover a period whose amplitude is only 0.02 percent of the solar constant.

Though my demonstration of the existence of a family of regular periodic variations in solar constant measures has been published several times (Abbot, 1947, 1953a, 1956), it evidently has not convinced the authors of the preceding paper. As I see no additional way to convince them that the solar radiation varies, from use of the solar measurement only, I turn now to another aspect. However, I remind them of figure 8 in my paper "Solar Variation, a Leading Weather Element" (Abbot, 1953b, p. 11) where correlation with ionospheric changes is shown.

Periods integrally related to 273 months in weather

Believing as I did then, and still do, that there are regular periods of variation in solar radiation, I sought many years ago to trace their effects on weather. For this I obtained graphs, covering 23 years of departures from normals of both precipitation and temperature, at over 100 stations distributed over the world. Many of the graphs seemed to show that the many features of one 23-year interval were roughly duplicated in the following 23-year intervals. This appeared most distinctly in the station Peoria, Ill. Beginning about 10 years ago, I worked three years to see if periods related to 273 months occur regularly in Peoria precipitation. In that study I tabulated over 1000 months of records for each of 23 periods, no less than 14 times, from the beginning, before reaching fairly satisfying results.

The normal values published by meteorologists for the 12 months of the year are the means of observed monthly values for all years of the record, or at least for a continuous long interval of years. I found that, for Peoria, the monthly averages for years when Wolf sunspot numbers exceed 20 differ on the average 8 percent from those obtained when Wolf numbers <20. I also found that the phases of periods related to 273 months differ according to the time of year, the activity of the sun, and the growth of population at the station.

By eliminating approximately (by appropriate steps which I have described elsewhere) these and other difficulties, I at length obtained fair success with Peoria precipitation in tracing and evaluating the influences of 23 periods integrally related to 273 months. Since then I have further improved my procedure, and have applied it to weather forecasting at Washington, D. C., Charleston, S. C., Albany, N. Y., Peoria, Ill., St. Louis, Mo., Omaha, Nebr., Brownsville, Tex., and Natural Bridge, Ariz. All these stations yield strong regular periods in precipitation or temperature, or both, which are exact submultiples of 273 months. One difficulty, not mentioned above, requires much time, ingenuity, and work. Since all the periods are integral submultiples of 273 months, a tabulation of a long period carries several integrally related shorter periods confused together in the mean result. These must be discovered and eliminated before the long period can be evaluated. This hindering circumstance, however, offers a proof of the proposition that weather records contain regular periods of variation integrally related to 273 months. I show this by two examples:

(1) Figure 6 shows the direct result of two tabulations of the 68½-month period in St. Louis precipitation, respectively before and after the year 1898, and the removal therefrom of overriding subordinate periods.

(2) Figure 7 shows the direct result on the 45½-month period at Natural Bridge, Ariz., and the removal of subordinate periods.

These two examples, out of more than 100 that I have in my possession, demonstrate 10 regular weather periods of 1/4, 1/6, 1/8, 1/12, 1/18, 1/20, 1/28, 1/30, 1/36, and 1/42 of 273 months. That meteorologists did not long ago discover them, and even now disclaim them, is because all these periods are hidden in the records by the confusion of their phases, result-

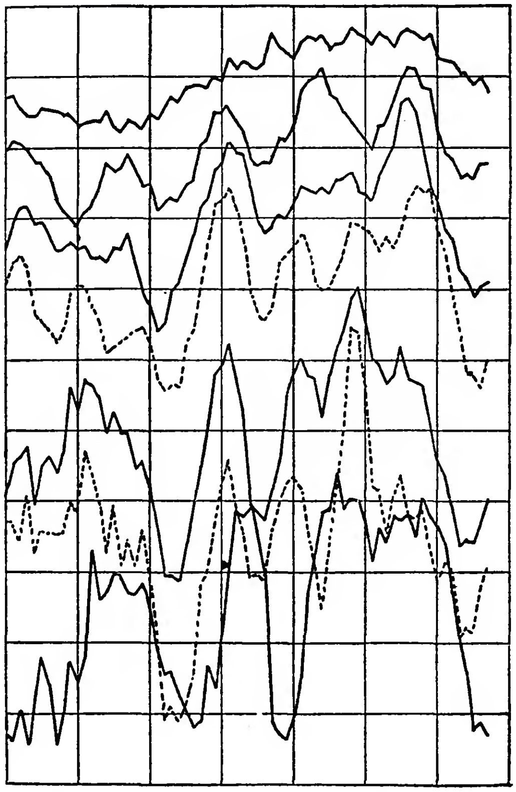

FIGURE 6.—The 68½-month period in St. Louis precipitation cleared of integrally submultiple periods. Curves A and B, independent mean determinations before and after 1900. Curve C, their mean after A is moved left 3 months. Curves D, E, F, and G, after successive removals of periods 1/3, 1/7, 1/2, and 1/5 of 68½ months. The amplitude of smooth 68½-month period, 13 percent of normal precipitation.

ing from lags due to atmospheric influences. These lags vary with locality, with time of the year, with solar activity, with growth of population, and with length of the periods. Without obtaining separate normals for high and low sunspot numbers the records of many stations are indeed unsuitable for tabulation.

If it is asked why a family of periods with amplitudes ranging only from 0.05 to 0.21 percent in the solar variation should produce the identical family of periods in weather, with ranges from 5 to 45 percent in precipitation, and up to 5° F. in temperature, I am unable to give a theoretical reason. I will only call attention to several facts of possible significance. The distribution of solar variation by wavelengths is given by Abbot, Aldrich, and Hoover (1942, pp. 164–166). The curve rises with rapidly increasing acceleration towards the ultraviolet, and shows very small variation in the infrared, where nearly half of the energy of the solar constant lies. English scientists have indicated, from indirect means depending on observations of various phenomena, that the solar variation reaches several hundred percent in the extreme ultraviolet. In that spectrum region the ozone balance in the atmosphere is determined by solar radiation. Dobson has demonstrated the large variation of atmospheric ozone. A powerful band of ozone lies in the spectrum of the strongest part of the earth's output of radiation to space, at about 10 microns. At the time of my retirement I had designed apparatus to observe daily the absorption of that ozone band and correlate it with solar constant measures of identical days at the same station. Mr. Aldrich prepared a tunnel to install this apparatus soon after he succeeded me as Director of the Astrophysical Observatory. However, at the request of the Quartermaster Corps of the Army, he turned attention to measuring solar radiation at the ground levels in different localities. These observations form a considerable section of a publication by Aldrich and Hoover (1954). Ozone absorption measures were not undertaken.

The identity of the periods in solar radiation and weather indicates a close association. Some may suggest that the periods are inherent in weather, and by atmospheric influence produce corresponding small errors in solar constant measures. This reversal of cart and horse seems untenable, for the weather phases are variable, depending on locality, time of year, solar activity, and other variables, while the solar phases are invariable.

When the form and amplitudes of this family of periods in a weather element are determined for 1000 months or more, the curve for any one year, as computed therefrom, can be influenced by only 12/1000 by the observations of that year. Hence, all such computations are forecasts, whether within, before, or after the interval of 1000 or more months which is the basis.

To illustrate the actual computation, I present figure 8, showing the forecast of precipitation at St. Louis, 1875 to 1879, and its remark-

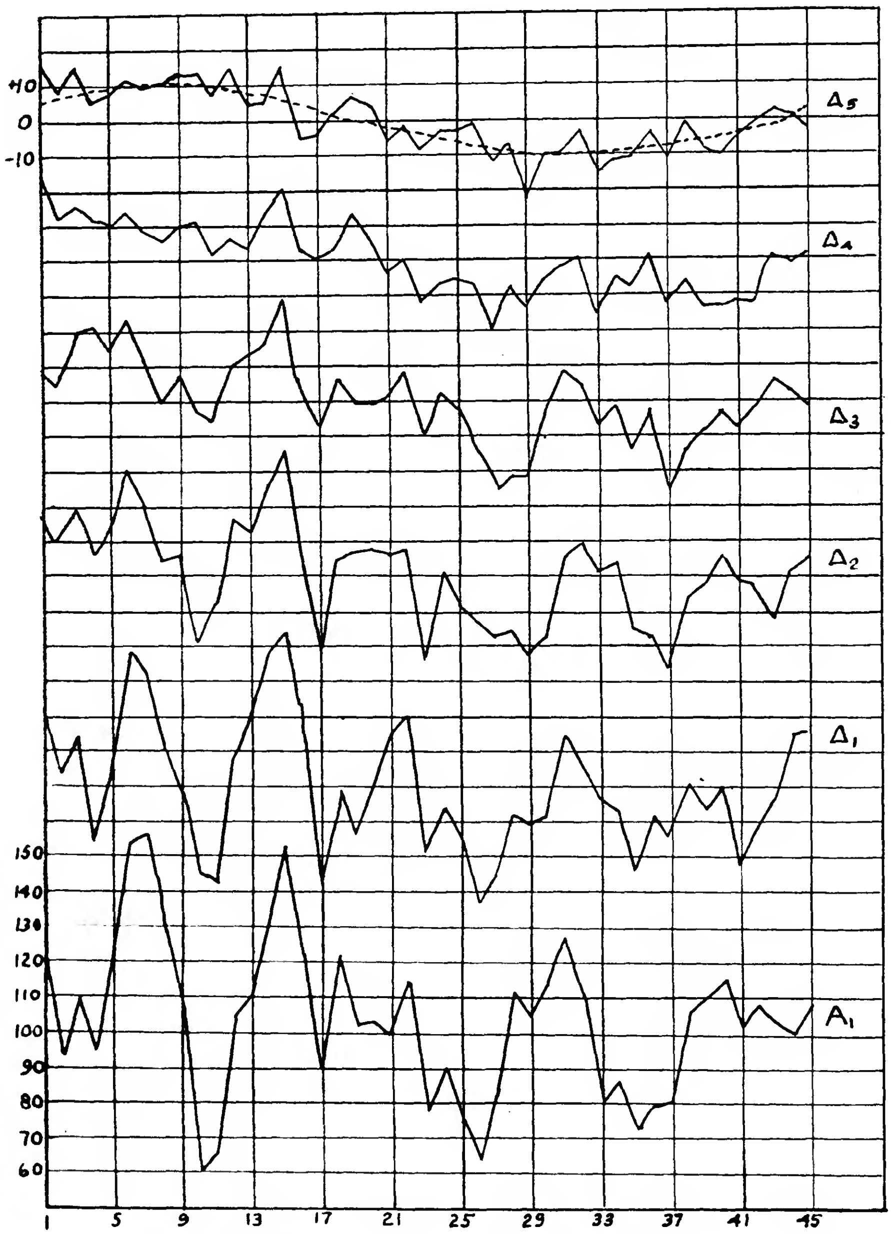

FIGURE 7.—The 45½-month period in Natural Bridge, Ariz., precipatition cleared of submultiple periods: A₁, the original mean; Δ₁, 45½÷3, out; Δ₂, 45½÷4, out; Δ₃, 45½÷6, out; Δ₄, 45½÷2, out; Δ₅, 45½÷7, out. The amplitude of the smoothed 45½-month period is 21 percent of normal precipitation.

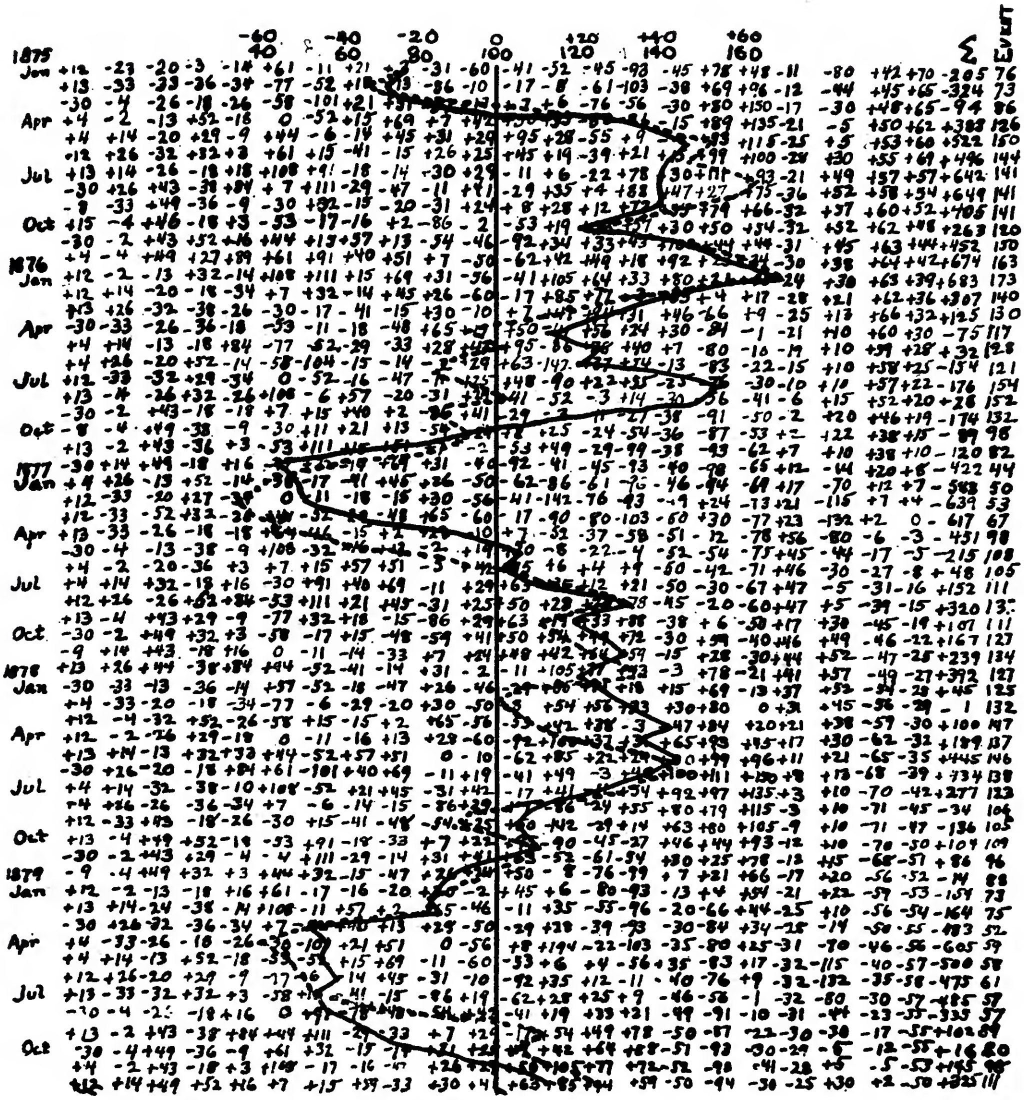

FIGURE 8.—Facsimile of computation of St. Louis precipitation, 1875–1879, compared with the observed precipitation as percentage of normal. Data from monthly mean precipitation smoothed by 5-month running means. Dotted curve from summation of 22 regular periodicites, determined as averages over the 84-year epoch, 1854–1939. Full curve, the event.

able agreement with what actually occurred. To illustrate long-range forecasts compared to the event, I present figure 9*b*, showing St. Louis precipitation, 1860–1887, and figure 9*a*, showing 6-year forecasts, 1934–1939, with correlation coefficients ranging from 53 to 59 percent between forecasts and events, for precipitation and temperature at several stations. These forecasts 38 years after the mean basis (1898) are based on 1032 months of records, centering at 1898. Excellent forecasts of the drought at St. Louis and Peoria, 1952 to 1956, were made from the same basis, centering 54 years before the drought came.

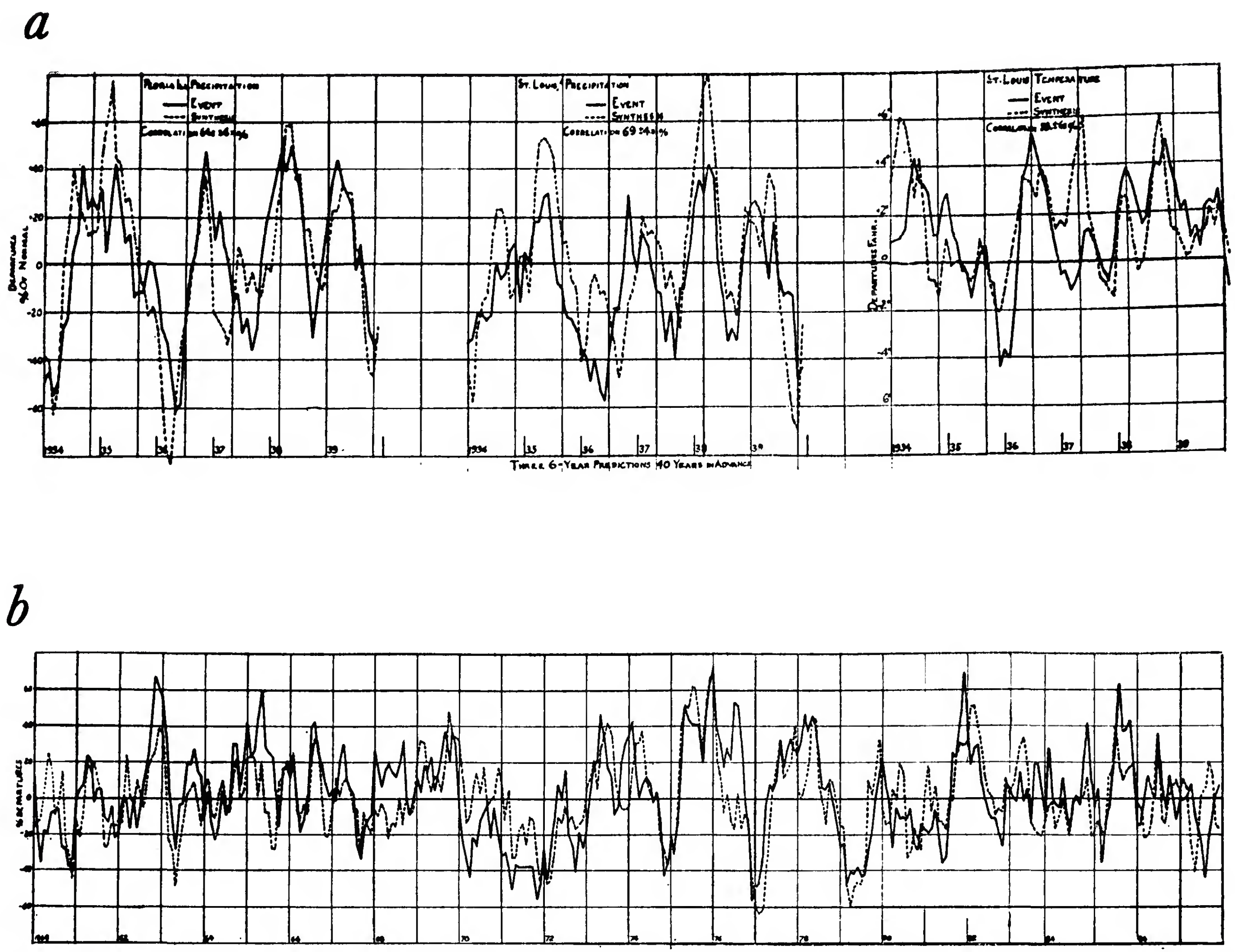

Figure 9.—*a*, Forecast, 40 years from mean basis, of precipitation at St. Louis and Peoria and of temperature at Washington, years 1934 to 1939. *b*, Backcast, 25 years preceding mean basis, of precipitation at St. Louis, 1860 to 1887, compared to the event.

Remarks

In my view, the principal value of the long Smithsonian series of daily solar constant observations is not to demonstrate "the constancy of the solar constant." Its great value lies in that it led to the discovery of a strong family of periodic variations, which control the larger features of weather. I foresee that when the power of these variations and their application to long-range forecasting is appreciated and exploited all over the world, the annual production of wealth thereby will many times exceed the whole cost of the Smithsonian Astrophysical Observatory, and its scores of researches, from its beginning in 1890 until its entire modification in 1953.

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The Solar Constant [1]

By L. B. Aldrich [2] and W. H. Hoover [3]

Strictly defined, the solar constant is the total energy received in one minute upon a unit of surface perpendicular to the sun's rays, in free space at the earth's mean distance from the sun. It is usually expressed in langleys per minute, or the equivalent, gram-calories per square centimeter per minute.

Early in the present century the Astrophysical Observatory of the Smithsonian Institution, under the direction of the pioneer astrophysicist S. P. Langley, began a long-range study of the solar constant and its probable day-to-day variations. The classic work of Abbot and Fowle that followed—their development of instruments and methods, their search for satisfactory sky conditions, their studies of the absorption and scattering of radiation by water vapor, ozone, and dust—placed the solar constant research on a firm foundation.

In continuation of this Smithsonian project, there has now accumulated over a period of nearly 30 years a chronological record of solar constants computed from very specialized observations at high altitude stations in desert regions. The mean of these thousands of values is 1.946 langleys per minute. This mean, it should be noted, is not intended to express the absolute value of the solar constant, since the effort throughout has been to maintain a homogeneous series, preserving the original scale unchanged. The record indicates a surprisingly small, irregular variation, seldom exceeding a range of 2 percent, with a gradual trend toward larger values. The total increase in the means of successive 5-year intervals is .3 per cent since 1925. The largest increase occurs in the 1946–50 interval, during which the number of sunspots reached a higher value than at any time since the year 1778.

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The probable absolute value of the solar constant based upon this mean is largely determined by three factors: First, careful study indicates that the original arbitrary scale of radiation, which has since remained unchanged, is 1.8 per cent below the standard scale adopted by the Smithsonian in 1913. This conclusion is based upon a re-examination of all intercomparisons between pyrheliometers (instruments that measure total solar radiation at the observing station). Second, all comparisons since 1932 against the improved Smithsonian standard pyrheliometer agree in indicating that the correct scale of radiation (in true gram-calories) is 2.4 per cent below the adopted 1913 scale. Third, the corrections applied to the summation of energy in the observed region (wavelengths .34–2.4 μ) to allow for the unmeasured energy above and below this range need revision. New data from recent infrared studies and from V–2 rocket ultraviolet results indicate that the corrections applied should be increased by several per cent. One would assume that adding a percentage correction to the measured energy would proportionately increase the resultant solar constant. However, in the process of extrapolating the observations to zero air mass, there is an indirect compensatory factor that acts in the sense to diminish the effect of the increased corrections. From actual re-reductions of several typical long-method days, using a total ultraviolet plus infrared correction larger by 4 per cent of the observed energy, the solar constant is increased only .6 per cent.

Applying the three factors just mentioned (+1.8% to bring to the 1913 scale, −2.4% to reduce to true calories, and +.6% for larger ultraviolet and infrared corrections), the probable absolute value is, curiously enough, equal to the mean value 1.94. It is also identical with the solar constant that has been generally adopted in meteorological literature, based upon early Smithsonian results.

There is currently much interest in travel beyond the stratosphere. When this is accomplished, direct measurements of the solar constant, unhampered by an ever-changing and complex atmosphere, will follow.

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