errors are referred to that may be considered to have been drawn independently and at random from some parent population whose mean is zero. Errors of all other sorts are called *systematic*. Hulme,[4] in a short paper with much of which we agree, appears to misunderstand this fairly conventional use of the expression *random errors*. Correlated errors, for us, are systematic errors.

‡ There is, of course, no reason why the 4th component should not be small.

[1] Sterne, *Proc. Nat. Acad. Sci.*, **25**, 559 (1939).

[2] Abbot, *Smithsonian Misc. Coll.*, **94**, No. 10 (1935).

[3] Abbot, *Ibid.*, p. 12.

[4] Hulme, *Observatory*, **63**, 101 (1940).

ON SOLAR FACULAE AND SOLAR CONSTANT VARIATIONS

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On January 4, 1845, experimenting with a thermopile of Ruhmkorff Professors Henry and Alexander of Princeton[1] made "twelve sets of observations, all of which, except one, gave the same indication, namely, that the sunspots emitted less heat than the surrounding parts of the luminous disc."

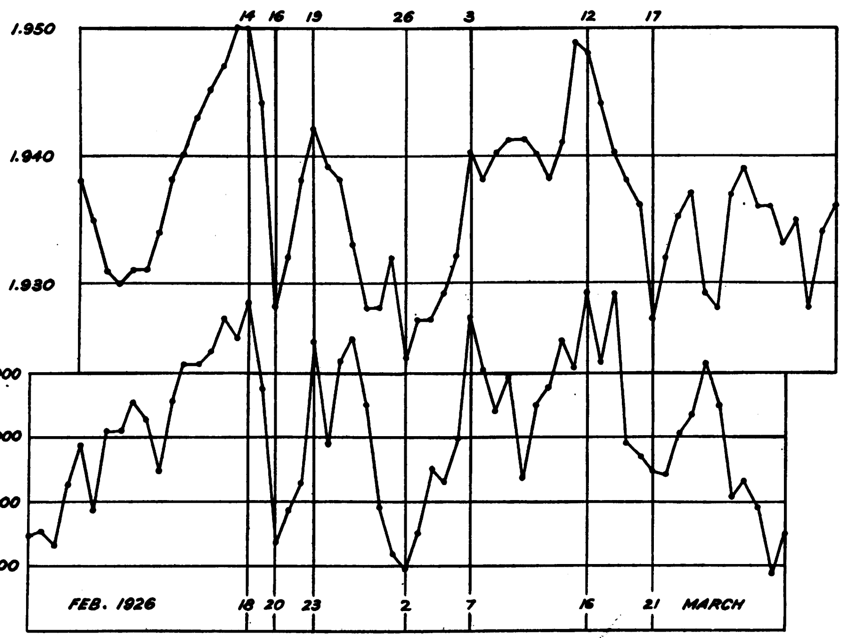
Exact measurements of the thermal conditions of sun-spots were made by S. P. Langley in 1874 and 1875.[2] He found that "taking the mean thermal photospheric radiation in the spots vicinity as unity, the mean umbral radiation is 0.54 ± 0.005, the mean penumbral 0.85 ± 0.01." Let us notice also that the ratios of the radiation from the umbrae and the neighboring photosphere, observed by W. E. Wilson[3] in 1893 and 1894, varied between 0.29 and 0.85, and that E. B. Frost,[4] comparing Langley's observations, made about three years after a solar maximum, with his own, made about two years after a minimum, writes that "it is impossible to assert that the thermal conditions of spots (and perhaps of the photosphere and atmosphere) are invariable during the eleven-year period of solar activity."

The solar faculae were correctly described long ago by Christ Scheiner in his "Rosa Ursina . . . " published in 1626, and by I. B. Ricciolo, as well, in his "Almagestum Novum . . . " published in 1651.

Secchi noticed that when a facula is observed at the edge of the solar disc, the chromosphere nearby extends higher. J. Fényi,[5] who cites this observation, writes that in the spectrum of faculae the lines of prominences appear very bright, the *K* line in particular. This fact allowed Hale and Deslandres to photograph the distribution of faculae all over the solar disc. Fényi considers the faculae as being redescending gas masses of the ascending prominences. He thinks it is because of adiabatic compression that the temperature of faculae should be higher than that on the corresponding levels of the solar atmosphere.

If, therefore, the spectrobolometric measurements of C. G. Abbot, F. B. Fowle and L. B. Aldrich, giving the mean radiation along the radius of the solar disc,[6] are accepted as standard, local deviations on the surface of the sun should be admitted, *a priori*, in particular over the areas occupied by faculae.

Daily contrast numbers of brightness, solar center-limb, observed by Dr.



Variations of the solar constant and of areas of solar faculae

FIGURE 1

Daily solar constant values for February and March, 1926, and areas of faculae.

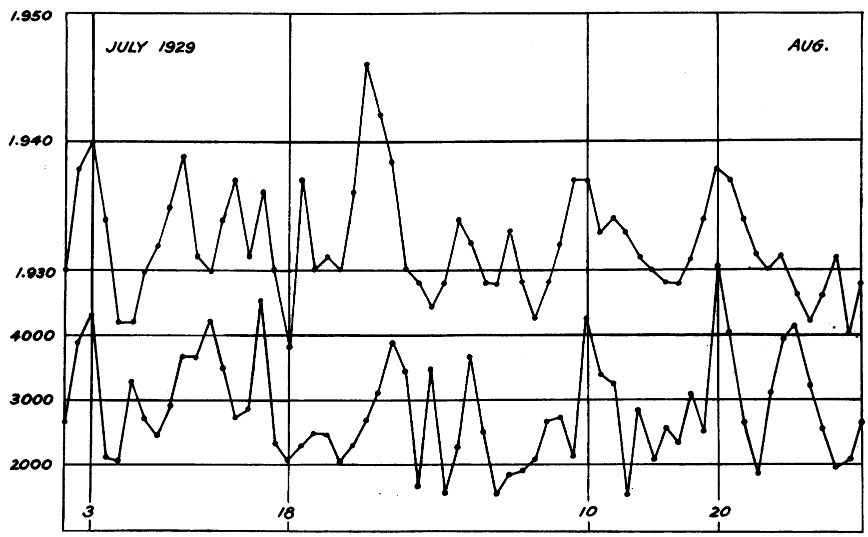
Abbot and his co-workers in 1913 and 1914, compare well, in their variations, with those of solar constant values.[7]

It was these facts which, in 1915, led me to the study of the variations of the daily areas of faculae, and their monthly means,[8] as recorded in the Greenwich photo-heliographic results.[9]

I found that, during the approximately 11-year period of sun-spots, there are five maxima of the quotients of faculae and umbrae areas and that the frequency variations of sun-spots should be considered as a subordinate manifestation of the variations of faculae.[10]

Dr. Abbot's researches on solar constant data led him to the conclusion that "an increase of 0.07 calory per square centimeter per minute in the solar constant accompanies an increase of 100 sunspot numbers," while my researches on the fluctuations of the solar constant led me to believe that sun-spots should be considered as only one of the acting factors, probably less important than the faculae or other unmentioned solar phenomena on which the areas of faculae depend.[12]

The fact is that F. E. Fowle, comparing the daily data of solar constants of radiation, observed during March, April and May, 1920, with the areas of calcium flocculi, measured at the del Ebro Observatory, noticed an excellent agreement of their variations.[13] Besides, H. H. Clayton ascertained



Solar constant and solar faculae

FIGURE 2

Solar constants and faculae, July and August, 1929.

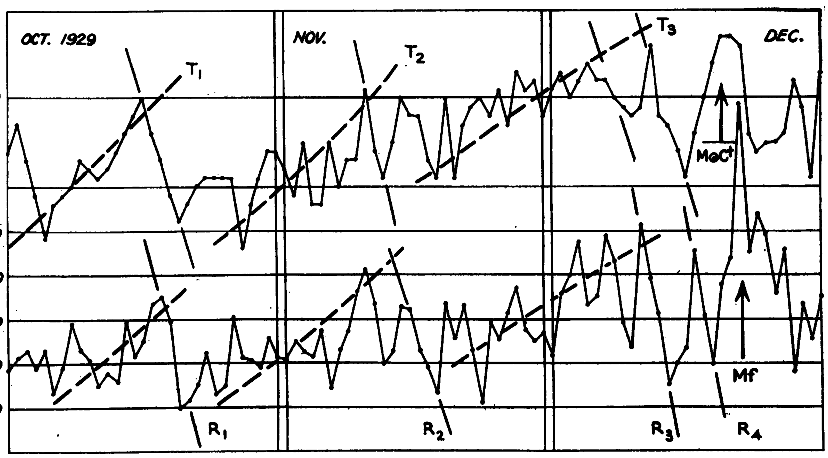
that from July, 1918, to December, 1921, maxima of faculae coincided with maxima of solar radiation, and beginning in May, 1924, he has made forecasts of solar constants from the visual observations of sun-spots and faculae.[14]

I began my work at the Smithsonian, last December, by studying the daily values of preferred solar constants observed from 1926 to 1930.[15] Dr. Abbot has given the following grades to the tabulated data: *S* satisfactory, *S*− not quite satisfactory, *U* unsatisfactory, *U* + better than unsatisfactory and *U*− very unsatisfactory. Four hundred ninety-four of these values, approximately only one-fourth of the total number of observations, were considered perfectly satisfactory. It follows that the establishment of many solar constant observatories would be advisable if continuous solar constant data are ever to be used in daily weather forecastings, in order to avoid unsatisfactory data which are due exclusively to the temporary local unfavorable atmospheric conditions.

At present let us examine the question of the cause of solar constant variations.

Leaving aside the eventual correlations between sun-spots (areas of umbrae) and the Smithsonian solar constant values, which lead to contradictory results, as I showed long ago, it is only the Greenwich data of areas of faculae, corrected for foreshortening, that will be taken into consideration.

Comparing the diagrams of areas of faculae, expressed in millionths of



Discontinuous trends in solar constant and solar faculae

FIGURE 3

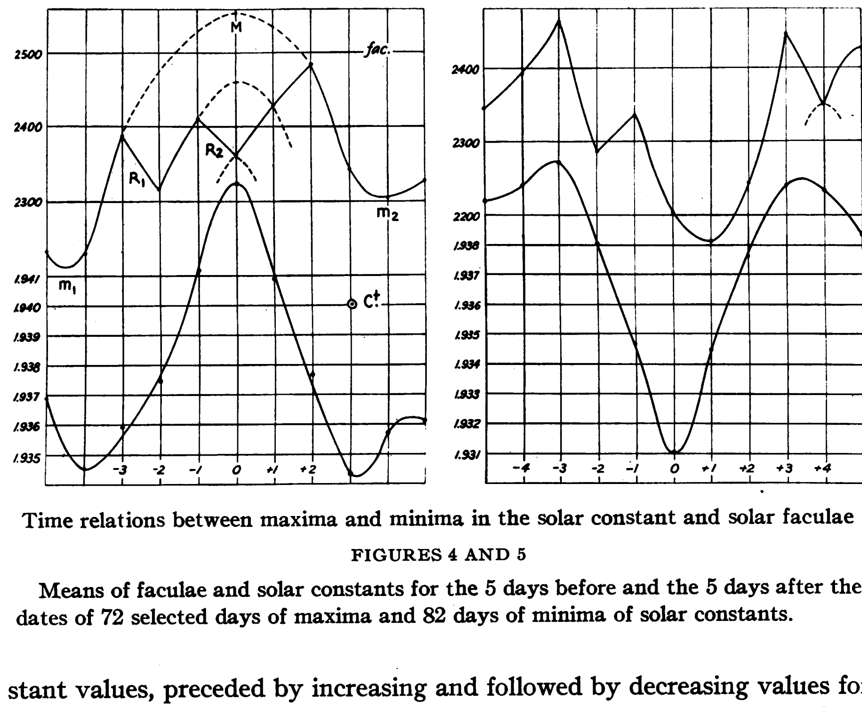
Solar constants and faculae, October, November and December, 1929.

the sun's visible hemisphere, with those of the solar constant values, I noticed that, in order to observe a more or less satisfactory agreement, we must admit that in most cases the maxima and minima of solar radiation precede those of faculae. Taking the daily data of February and March, 1926 (Fig. 1), we must admit a close agreement between the radiation minimum on February 16th and the minimum of faculae on the 20th. But this difference, of four days' advance, is far from being general. Maxima on July 3, August 10 and 20, 1929, for example (Fig. 2), occur simultaneously on both curves.

The months of October, November and December, 1929, may be taken as another example showing that not only the maxima and minima of both curves may correspond to each other, but also that characteristic interruptions in the trend may be observed, such as could happen only in the case of cause and effect. On figure 3 the upward trend T_1 repeats itself in T_2 and T_3, after the ruptures R_1 and R_2 and the well-pronounced maxima $M \odot C^t$ and Mf display perfectly the cause and its effect, in this case belated by two days.

It seems evident that if the curves are not more similar than they are, many not perfect or even unsatisfactory solar constant values may be the cause of it.

These comparisons justified taking into consideration mean values. Therefore, for the years 1926 to 1930, I took all the maxima of solar con-



Time relations between maxima and minima in the solar constant and solar faculae

FIGURES 4 AND 5

Means of faculae and solar constants for the 5 days before and the 5 days after the dates of 72 selected days of maxima and 82 days of minima of solar constants.

stant values, preceded by increasing and followed by decreasing values for at least three days before and after. The same was done for the minima. The means of the 72 series of figures for the maxima and 82 for the minima give the diagrams on figures 4 and 5. Now, taking the values of the faculae for the same dates, we find (Fig. 5) that the mean minimum of faculae occurs one day after the mean minimum of solar radiation. The time difference between Greenwich and Washington makes it more than a day.

In the case of the mean maxima there is a difference of two days (Fig. 4). But considering the lines R_1 and R_2, between the third and the second days before the maximum of the solar constant, as discontinuities of a regular variation m_1Mm_2, we would have a coincidence of maxima. Therefore this diagram induces the hypothesis that the solar atmosphere reacts against a full development of the faculae maximum, as it should have developed under the influence of the maximum of radiation. Nor is the minimum of faculae as deep as it should be.

In other words, the solar constant variations are not due to faculae, but the variations of the extent of faculae are due to the same variations of photospheric radiation as those of the solar constant.

A certain similarity to what occurs in our terrestrial atmosphere seems obvious: rain and hail subtract water from a thunderstorm cloud which is formed under the influence of strong ascending air currents; and, as we know, in the case of a minimum of such air chimneys, clouds may still be formed.

Do the solar constant variations affect the meteorological phenomena observed in our atmosphere?

For years Dr. Abbot has advocated such a thesis.

Meteorologists, in general, had doubts. I also was not entirely convinced, before the last few months of research work. But now I have the necessary data to prove, at least to my own satisfaction, not only that the processes in the solar photosphere—which produce changes in the extent of faculae, observed from day to day or from one group of days to another—directly affect the measured values of the solar constant, but also that in our atmosphere the changes of solar radiation, expressed by the figures of solar constant variations, are the direct cause of anomalies in the distribution of temperature and of all the complexity of the meteorological phenomena depending on temperature anomalies.

[1] *Proc. Am. Phil. Soc.*, **4**, 175, Philadelphia (1847).

[2] *M. N. R. Astr. Soc.*, **37**, 5, London (1877).

[3] *M. N. R. Astr. Soc.*, **55**, 460, London (1895).

[4] *A. N.*, **130**, 146, Kiel (1892).

[5] *A. N.*, **140**, 300, Kiel (1896).

[6] *Ann. Astroph. Obs. Smiths. Inst.*, **3**, 159, Washington (1913).

[7] *Smiths. Misc. Coll.*, **66**, No. 5, 18–19, Washington (1917).

[8] *C. R.*, **161**, 434, 485, Paris (1915).

[9] "Results of measures made . . . of Photographs of the Sun at Greenwich, the Cape and Kodaikanal in the year . . . "

[10] *C. R.*, **163**, 665–667, Paris (1916).

[11] *Ann. Rept. Smiths. Inst. for 1913*, p. 182.

[12] Loc. cit., p. 666.

[13] C. G. Abbot, *Smiths. Misc. Coll.*, **77**, No. 5, 23, Washington (1925).

[14] *Smiths. Misc. Coll.*, **77**, No. 6, 53, Washington (1925).

[15] *Ann. Astroph. Obs. Smiths. Inst.*, **5**, 279–285, Washington (1932).