THE VARIATION OF THE SUN

By C. G. ABBOT, F. E. FOWLE, AND L. B. ALDRICH

In the year 1902 preliminary experiments were begun at Washington to determine the solar constant of radiation. About 700 determinations of it have now been obtained, depending on observations at altitudes ranging from sea-level to 4420 meters. As originally devised by Langley, we determine spectral energy intensities and atmospheric transmission coefficients for numerous wave-lengths between about 0.30 \( \mu \) in the ultra-violet and 2.5 \( \mu \) in the infra-red, by spectrobolometric observations at high and low sun. The indications of the spectrobolometer are reduced to the standard scale of calories per square centimeter per minute by means of the readings of the pyrheliometer.

At the time when the observations were begun in 1902 there was no satisfactory establishment of the standard scale of pyrheliometry, nor indeed any pyrheliometer which was invariable relatively to itself from year to year. We at first made use of a modification of Tyndall’s mercury pyrheliometer. This was improved in 1906 as the copper disk pyrheliometer, which has been in use on Mount Wilson ever since, and which is described in Vol. 2 of the Annals of the Astrophysical Observatory. A still later improvement took place in 1910 with the introduction of the so-called “Silver-Disk Pyrheliometer” which has attained considerable favor, and which is now in use in numerous countries. Neither of these instruments is capable of yielding independently the standard scale of radiation, but they possess the valuable qualities of simplicity and of being constant from year to year. Beginning with the year 1903 and extending until the end of the year 1912 we have repeatedly devised and experimented with instruments to fix the standard scale of radiation. Three of these instruments (called Water-Flow Pyrheliometers Nos. 2 and 3, and Water-Stir Pyrheliometer No. 4) have been tested with satisfactory results which are stated in a publica-

1 Published by permission of the Secretary of the Smithsonian Institution.
tion by two of us.¹ We are now satisfied that the measurements
made since 1903 can be reduced to the standard scale of radiation
to within 1 per cent.

Measurements of the solar constant of radiation were begun at
Washington, practically at sea-level, and were continued when
favorable opportunities presented themselves from October 1902
until May 1907. Measurements were begun on Mount Wilson in
California (elevation 1730 meters) in 1905, and have been con-
tinued with the exception of 1907 during about 6 months in the
year in each of the succeeding years. Expeditions to Mount
Whitney in California, altitude 4420 meters, were made in 1908,
1909, 1910. Expeditions to Bassour, Algeria, altitude 1160 meters,
were conducted in the autumn of 1911 and the summer of 1912. In
all 696 complete determinations of the solar constant of radiation
have been made, and still others are unreduced. The differences
found between the results at different elevations are very small, and
seem attributable rather to experimental error or slight atmospheric
irregularities than to any difference of elevation. The mean of all
these 696 determinations made principally between the years 1905
and 1912 is 1.932 calories per square centimeter per minute.

Subject to the possibility that there may exist ultra-violet rays
of appreciable intensity beyond the wave-length 0.29 μ, which are
cut off by the absorption of ozone from reaching the earth’s surface,
we believe that this value represents the intensity of the radiation
of the sun as it would be found in space at the earth’s mean solar
distance for the epoch 1905 to 1912.

In the year 1903 we found indications that the radiation of the
sun is not constant from day to day.² It has been a main object
of the work to ascertain if these apparent variations of the sun are
really solar, or are due to some accidental or atmospheric influences
not fully eliminated. As early as the year 1910 it had been shown
that practically equal solar-constant values were obtained on good
days at sea-level, at 1730 and at 4420 meters elevation, and it had
been shown that the apparent fluctuations of the solar radiation

¹ See "Smithsonian Pyrheliometry Revised," Smithsonian Miscellaneous Collec-
tions, 60, No. 18, 1913.
found on Mount Wilson from day to day marched by regular steps from high to low values and return, not fluctuating wildly as they would have done had they been due to experimental error. Accordingly it seemed from the first consideration (namely, that altitude did not appear to affect the results) that the atmosphere was not the cause of the fluctuation; and from the second consideration (namely, that the values marched step by step from high to low or vice versa) that it was not an accidental fluctuation. Hence, the most probable conclusion was either that the radiation of the sun is actually variable, or that some meteoric or other matter, by interposition between the earth and the sun, alters the quantity of the radiation received at the earth from day to day. The fluctuations appeared to be of irregular magnitude and period, often ranging through 5 per cent or more, in an interval of 7 or 10 days.

However probable the result just stated might appear, it could not be fully verified without carrying out the observation simultaneously at two stations widely separated on the earth's surface, so that no local atmospheric influences could be supposed to affect both stations at once. This extension of the work was made possible by the Algerian expeditions of 1911 and 1912. Solar-constant determinations were made nearly simultaneously at Mount Wilson, California, and Bassour, Algeria, separated by about one-third of the circumference of the earth. A difference of time of about 8 hours generally occurred between the observations, but inasmuch as the apparent fluctuations of the sun seldom reach 1 per cent in a day, this difference of 8 hours seems not much prejudicial to the comparison.

We were somewhat unlucky in our expeditions. In 1911 a box containing the bolometer and other necessary parts was delayed one month in reaching Algeria, so that a long period of good weather in August was lost. Also the months of September, October, and November 1911 proved less favorable than usual at Mount Wilson and less favorable than had been hoped at Bassour. Thus the number of days in 1911 in which good observations were secured in both places was rather small. In the year 1912, although the sky was generally cloudless, the eruption of the volcano of Mount Katmai in Alaska of June 6 and 7 so filled the sky with haze,
both at Mount Wilson and at Bassour, that a great many days of July and August were rendered unsuitable for comparison between the two stations. Thus it occurred that of 75 days in which observations were secured at both stations in the years 1911 and 1912, only 48 were found good enough for satisfactory comparisons of the solar constant values obtained.

![Graph showing comparison of Bassour and Mount Wilson values of the solar constant.](image)

**Fig. 1.—Comparison of Bassour and Mount Wilson values of the solar constant.**

For the purpose in view, namely, to show whether the apparent fluctuation of solar radiation is due to something outside the earth, it is immaterial whether the days of observation are consecutive or not. It is only required to know whether if high values are found at Bassour, high values will occur on the same day at Mount Wilson, and if low values are found at Bassour, low values will be found on
Mount Wilson. It matters not whether the days in question be found in one year or another, provided that they be numerous enough to exclude the probability that an agreement, if obtained, is owing wholly to chance.

The accompanying illustration gives the results of all the days found suitable for comparison between Bassour and Mount Wilson. Ordinates are solar constant values as obtained at Mount Wilson, abscissae are solar constant values as obtained at Bassour. Circles represent the results of days of the year 1912, and crosses represent the results of days of the year 1911. If the solar radiation had varied, and all determinations of it had been free from error, the points must all have lain upon the straight line inclined at 45 degrees to the axis. As it is impossible that results shall be entirely free from error, we must expect that the points representing individual days will be well represented by the 45-degree line if the sun is variable, but will fall uniformly distributed about one point on that line if the sun's radiation is constant. There is no difficulty in deciding that the line and not some single point of the line best represents the results here given.

The variation of the sun shown between the extreme observations amounts to 11 per cent and many observations unite in showing a variation of 7 per cent. The average deviation of the separate determinations at Bassour from those of the same days at Mount Wilson is 1.6 per cent.

Hence the average deviation of a single day of solar-constant measurement at one station will be \( \frac{1.6}{\sqrt{2}} = 1.1 \) per cent, and the probable error of a single solar-constant measurement at one station will be 0.9 per cent. Had the condition of the sky in 1912 been free from the haze which prevailed owing to the volcanic eruption of Mount Katmai, we believe the probable error of the separate determinations of 1912 would have scarcely reached 0.5 per cent.

It will be seen that the measurements of 1912 are on the average above those of 1911, at both stations. The difference 1912–1911 is 0.04 calories per square centimeter per minute. This in itself may be regarded as an indication of the variation of the sun depending
upon nearly 20 days of observation in 1911 and about 30 days of observation of 1912.

In further study of the variation of the sun we have compared the mean solar-constant values obtained on Mount Wilson for the different months of the years 1905 to 1912 with the monthly values of the sun-spot numbers as published by Wolfer. We find a fluctuation of solar radiation in the sense that when the sun-spot numbers are high the solar radiation is high and vice versa.

It is also indicated that when the solar radiation is increased the intensity of the violet and ultra-violet rays of the solar spectrum (as it would be found outside the atmosphere) is increased with respect to the intensity of the red and infra-red.

Again it seems to be indicated that when the solar radiation is high the contrast between the brightness of the center and edge of the solar disk is greater than normal.

These and other results of this long investigation are published with details in Vol. 3 of the *Annals of the Astrophysical Observatory of the Smithsonian Institution*, now in press and expected to appear about July 1, 1913. The most important conclusions are as follows:

1. The mean value of the solar constant of radiation for the epoch 1905–1912 is 1.932 calories per square centimeter per minute.

2. An increase of 0.07 calories per square centimeter per minute in the “solar constant” accompanies an increase of 100 sun-spot numbers.

3. An irregular variation frequently ranging over 0.07 calories per square centimeter per minute within an interval of 10 days is established by numerous nearly simultaneous measurements at Mount Wilson, California, and Bassour, Algeria.

4. Indications of two wholly independent kinds incline us to think that these variations of solar radiation are caused within the sun, and not by interposing meteoric or other matter.

*Smithsonian Astrophysical Observatory*

*Washington*