Solar Radiation and its Changes.[1]

WHEN one reflects upon the wide knowledge gained by astronomers concerning stellar and nebular radiation and variability, it at first seems surprising that variation in the visible radiation emitted by the sun has been discovered only recently and with much difficulty. Not until the second decade of this century could the fact be regarded as established, as a consequence of simultaneous determinations of the "solar constant" made by the staff of the Astrophysical Observatory of the Smithsonian Institution, at two stations so widely separated as Bassour in Algeria and Mount Wilson in California. The solar constant is, of course, the estimated value of the intensity of total solar radiation, in calories per square centimetre per minute, at a point just outside the earth's atmosphere, *i.e.* before suffering absorption in transmission to the earth's surface.

The main difficulty arises from the necessity of making practically absolute determinations of the solar constant, because the sun's proximity to us renders it sufficiently unique and solitary in the daylight sky to prevent that comparison with many and similar neighbours which is the foundation of our knowledge of stellar variability. No real progress towards such knowledge regarding the sun could be made until it became possible to determine and allow for the radiation absorbed in the earth's atmosphere. Failing this, even long series of simultaneous observations of the changes in the solar radiation, as received at different points on the earth's surface, are of little use, because any features common to two stations may arise from some common terrestrial cause. A striking example of this was recorded by the Smithsonian observers during the fifty days on which observations were made both at Bassour and at Mount Wilson. On June 6, 1912, a great volcanic eruption occurred at Mount Katmai in Alaska; on June 19 the sky became slightly turbid in Bassour, and a day or two later also at Mount Wilson. The milkiness rapidly increased till in July and August a thick haze overspread the whole sky and cut off more than 20 per cent. of the sun's direct radiation at noonday; yet after applying properly determined corrections, normal and accordant values of the solar constant were obtained at Bassour and Mount Wilson during the above period.

The variability discovered in the sun's radiation is of two kinds; irregular variations occur over periods of a few days or weeks, amounting to a small percentage of the whole intensity, while small variations of longer period are found, showing some correlation with the periodicity of sunspot activity. Considering how marked are the changes in solar-spottedness, and in the accompanying magnetic and auroral phenomena upon the earth, it is remarkable how small are the variations in the main solar radiation. Many attempts have been made to connect the sunspot cycle with meteorological changes likely to depend on the solar radiation reaching the earth, but with very doubtful success—the terrestrial factors which share in determining the weather and crops are too complicated, and it now appears that the long-period changes in the solar radiation are themselves very small. Hence they were bound to remain undetected till direct methods and appropriate instruments were devised which made possible a frontal attack upon the problem. The method which has proved successful is due to S. P. Langley, and the spectro-bolometer which he invented (in 1880) is one of the chief instruments employed; but many improvements and additions both of method and in the instrumental equipment have been since made, and largely by the staff of the Smithsonian observatory under its director Dr. C. G. Abbot.

Langley's method is, briefly, as follows: Absolute measurements of the total solar radiation reaching the earth's surface are made with an instrument (the pyrheliometer) which indicates the heat energy absorbed by a blackened silver disc exposed to the radiation. It is claimed that the error of a single reading with this instrument is less than 1 per cent., and inter-comparison of pyrheliometers over periods of several years shows that the scale is free from secular changes exceeding 1 per cent. Such absolute observations are made at frequent intervals during a forenoon or afternoon, with the sun at different altitudes from 15° upwards; the measurements vary on account of the varying absorption as the radiation passes through a greater or lesser length of atmosphere.

The correction for the absorption is obtained with the aid of the spectro-bolometer, which consists essentially of a wire on which radiation of a particular wave-length is directed, after passing through a suitable prism. The resulting rise of temperature in the wire is measured by the change in its electrical resistance, and by passing the whole available spectrum over the wire a "bolograph" showing the energy-intensity curve over the solar spectrum is obtained. Such bolographs, corresponding to different successive altitudes of the sun, show the absorption in all parts of the spectrum during the passage of radiation through lengths of the atmosphere proportional to the secants of the sun's zenith distance; their comparison makes it possible to correct each bolograph for the absorption. In certain regions of the energy-curve where powerful selective absorption occurs by water and other atmospheric vapours, it is assumed that the absorption bands are absent outside the atmosphere, the curve being completed by interpolation between adjacent parts of the curve on either side.

While highly sensitive, the bolograph gives relative rather than absolute measures of solar radiation, and the scale of the uncorrected bolograph is obtained by comparing its area with the value of the total radiation as measured by the pyrheliometer. The bolograph corrected for absorption then gives the value of the solar constant. It is estimated that the probable error of an ordinary daily determination of the latter is from 0·2 to 0·3 per cent. as regards the relative values from day to day, *i.e.* omitting the probable error of the pyrheliometer scale value. The whole daily error should therefore be well below 1 per cent. under good conditions, though at times irregular or systematic errors of larger magnitude may occur.

The absolute value of the solar constant, determined from 1244 observations, mainly at Mount Wilson

[1] "Annals of the Astrophysical Observatory of the Smithsonian Institution." Volume iv. By C. G. Abbot, F. E. Fowle, and L. B. Aldrich. Pp. xii+390. (Washington, 1922.)

(1912–20), but also at Calama in Chile (1918–20), is given as 1·946. Dr. Abbot admits, however, a criticism by Kron, to the effect that this value may be 2 per cent. too low owing to a systematic influence tending to magnify the measured atmospheric transmissibility for ultra-violet rays. The error does not affect the evidence for variability in the solar radiation.

The above value is slightly greater than the mean (1·933) for the epoch 1902–12, and it is suggested that the increase is associated with the greater average solar activity during the later period. Whether this be so or not (and the more detailed comparison of values of the solar constant with sunspot numbers scarcely strengthens the evidence for such a connexion), the really remarkable result is the minuteness of the change; the solar agent which affects the diurnal variation of terrestrial magnetism must vary by 20 per cent. or more, instead of ½ per cent. or 1 per cent., as here. There is, of course, a very slight compensation for any general increase of solar emissivity at times of many sunspots, owing to the diminution of emitting surface caused by the presence of the low-temperature spots; if there are also absorbing vapours above the spots, the compensation may not be merely slight; an appreciable drop (about 5 per cent.) in the solar constant coincided with the passage of a very large group of sunspots across the sun's disc in March 1920.

The short-period "solar-constant" variation, of amount from 2 to 10 per cent., has been further confirmed by simultaneous observations at Mount Wilson and at Calama, Chile; these stations are about 5000 miles apart, on opposite sides of the equator, and at different altitudes. Their observations show a moderate degree of correlation (0·491). Attempts have been made by Dr. Abbot and his colleagues to find connexions between the variations of the solar constant and the variations of contrast of brightness on the sun's disc which have been revealed by observations of the distribution of radiation over the sun's surface. Such measures have been carried on now for more than eight years by the Smithsonian observatory. The association between the two phenomena, if real, is very complex, high contrast sometimes accompanying high, and sometimes low, values of the solar constant. A correspondingly complex theory is propounded to account for this, but a much longer series of observations is required to test the theory. Dr. Abbot urges the desirability of other observatories taking up solar-constant work, especially in view of the possibility that variations of radiation have predictable meteorological consequences, as Clayton's studies might suggest.

Various other cognate researches have been made by Dr. Abbot and his colleagues, Messrs. Fowle, Aldrich, Moore, and Abbot, during the period, since 1912, dealt with in the volume of Annals before us. Variations in the solar radiation have been tentatively sought by observing the changing brightness of the planets. The sun's total radiation has also been measured, at various terrestrial altitudes, from sea-level to high mountain stations, and beyond, up to 25,000 metres, by sounding balloons. A new empirical method of determining the solar constant by observations occupying only fifteen minutes in all has been introduced at Calama; this removes one of the chief sources of error in the longer method, namely, real variations in atmospheric transparency during the observations. In the new method the amount and character of the atmospheric absorption at the time of a pyrheliometer observation is inferred from a measure of the brightness of the sky in a zone 15° from the sun, and from the intensity of a particular water absorption band observed by means of the bolograph. Many observations of the brightness and transmissive power of the atmosphere have been made in the course of this and the other parts of the solar-constant work. Laboratory studies have been made on the absorption of long-wave radiation by water vapour, carbon dioxide, ozone, and by many common solid substances. The reflecting power of clouds has been measured by balloon observations at Mount Wilson in 1918; the ratio of reflection found was 78 per cent., independent of the solar altitude. From this the albedo of the earth is estimated at 43 per cent.

On account of over-frequent cloud and haze at Mount Wilson the solar-constant work carried on there since 1915 has been transferred to Mount Harqua Hala in Arizona, and the Calama station in the plain has been removed to Mount Montezuma, a few miles away. For a short time in 1917–18 observations were made at Hump Mountain in North Carolina, but the situation proved too cloudy. It is interesting to note, however, that one excellent observation was made at a lower air temperature than any experienced elsewhere during a complete solar-constant observation; both the hands and feet of the observer with the pyrheliometer were frozen in the course of the measurements!

Obituary.

W. H. Wesley.

William Henry Wesley, who died on October 17, at the age of eighty-one years, was appointed assistant secretary of the Royal Astronomical Society in 1875, and continued in that office till his death, a period of forty-seven years. He had excellent qualifications for the post, being most orderly and methodical in all secretarial and editorial work, and having great skill as a draughtsman and engraver, as was exemplified in his engravings of Dr. Boeddicker's drawings of the Milky Way, and the illustrations of the corona in Mr. Ranyard's memoir on solar eclipses. It used to be said that Wesley knew the corona better than any man living, although he had never seen it; however, after an unsuccessful effort in Norway in 1896, the equatorial *coudé* at Algiers was put at his service by M. Trépied in 1900, when he made a detailed drawing in the short duration of totality (64 seconds) and expressed his opinion that the eye was no more efficient than the photographic plate for this work. He made combination drawings from the negatives obtained by the Greenwich staff in the eclipses of 1898,