The Influence of the Heliographic Activity upon the Solar Constant,[1] with Two Appendices.

By

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ABSTRACT.

Abbot and his colleagues detected years ago some kinds of interrelations apparently existing between the variations of the solar constant and heliographic phenomena. A special attack on this problem has been made here from rich materials preserved in the Mount Wilson Observatory. Not only have the relations suggested by our forerunners been confirmed, but some similar cases extending the idea of these relations have been detected. Sudden drops of the solar heat corresponding to the central meridian passage of some solar activity area on the visible disc are seemingly due to the absorbing action of overlying gaseous matter on the sun. On the other hand, an accelerated development of such an active region on the sun causes an upheaval of the measured solar heat even when it is situated far from the apparent centre of the luminary, if the activity is not old enough to have sufficient gaseous screens over it. The general level of the solar constant, outside the temporary or short-lived fluctuations due to the above mentioned cases, is sensibly steady and not governed by the apparent circumstances of the solar surface, except in very recent times when the solar activity became weak and solar constant fell possibly as a consequence.

1. INTRODUCTION.

In 1913, Dr. C. G. Abbot, Director of the Astrophysical Observatory of the Smithsonian Institution, announced the discovery[2] of the actual variation of the solar heat due to some unknown causes possibly *in* the sun, or at least of trans-terrestrial nature. Subsequent observations of the sun's heat by him and others, made simultaneously at different places, confirmed the discovery. Since some time ago Dr. Abbot has been engaged in finding connections between the above-mentioned variations of the sun's heat and the apparent phenomena on the solar disc, being led to some suggestions recently. Mr. H. H. Clayton's paper[3] was one of the earliest on this subject. In it he described the idea on which he worked and gave some results showing an increase of the solar constant at the time when a sun-spot comes to some definite points on the apparent solar disc. Last July, when the writer met Dr. Abbot at the Mountain Laboratory of the Mount Wilson Observatory, the latter confided to him his "four principles[4]":

(1) New or increased spots are connected with higher values of the solar constant,

(2) Central spots result in lower values of the solar constants on the next day,

(3) Great activity of hydrogen, $H\alpha$, is connected with high values of the solar heat, and

(4) A long quiet period of the solar surface is connected with falling values of the solar constants.

These were the most promising ideas he had obtained in his study up to that time. In a letter dated August 14, 1923, Dr. Abbot wrote to the writer, commenting on (2) of the "four principles", as follows: "......There are a few cases of radiation minima for which such transits were not observed. It is hoped that some of these will be explained by transits of calcium flocculi disturbances."

The writer started his investigation at the end of July last. Although Dr. Abbot's "four principles" were not apparently consistent with each other, they were of course very precious suggestions to the writer.

2. THE MATERIALS USED IN THE PRESENT INVESTIGATION.

(a) *Values of solar constants.* The solar constant was observed more or less continuously at Washington, D. C., during 1902–1907. Since 1905, every summer, except 1907, has been spent at a station on Mount Wilson to observe the constant continuously during each period. In September, 1918, the Calama Station was opened in Chile, South America, with greatly improved equipments, and since then strictly continuous observations of the solar heat have been made there all the year round. In August, 1920, the station was removed to Montezuma, Chile, in the hope of getting better local conditions besides the better instruments, while a northern station of a similar kind was established in October of the same year at Harqua Hala, Arizona, U. S. A. At the present time, the two stations, Montezuma and Harqua Hala, are rendering splendid services by continuous observations, both enjoying exceptional series of clear weathers every year.

All the observations mentioned above are made by the staff of the Astrophysical Observatory of the Smithsonian Institution, Washington, D. C., and are regularly published in the ANNALS of the same Institution or in the current numbers of the MONTHLY WEATHER REVIEW of the U. S. Department of Agriculture. A series of small corrections is necessary in some recently published values of the solar constant according to Dr. Abbot's special review of the original observations and their reductions. These corrections are not yet published[5], and Dr. Abbot gave them to the writer in MSS.

The writer used all the data of the solar constants which were observed at Montezuma and Harqua Hala, beginning with the earliest days of their services and coming as far as the latest date available. As told by Dr. Abbot himself, these are the best of the serial observations of the solar constants. As a check on the final results of the present investigation, the writer used the data of the observations made at Calama.

The whole data used here are tabulated in Table I below. The first column gives the date, the second the values reduced from the observations at the southern stations, either Calama or Montenzuma, and the third the similar values from Harqua Hala station. The fourth column gives the weighted mean values of the solar constants. The unpublished corrections are applied already. So that these parts of the table are the reproductions of the corresponding data which were already published in the Annals of Astrophysical Observatory of Smithsonian Institution, Vol. IV, pp. 148–158, and the Monthly Weather Review, 1923 February, pp. 77 ff., except the following two points:

i. Unpublished corrections applied,

ii. The very latest values of the solar constant during the early part of 1923, just came to hand from Harqua Hala station.

(b) *Spectroheliograms.* Since the summer of 1915 three kinds of spectroheliograms have usually been obtained every clear day at the Mount Wilson Observatory with its 60-foot Tower Telescope. These are of the calcium K_2 line, the hydrogen C line, and the calcium prominence, which have all been used in the present investigation to give all possible ideas of the solar activity at any date. When some special sun-spots appeared, it was the usual policy of the Mount Wilson observer to obtain large-scale photographs of the region of the solar disc with the hydrogen C line, which have been particularly valuable sources of information of the

Table I.*

Daily Values of the Solar Constants.

Date	Calama Station		Harqua Hala Station		Mean Value	Calcium Area
	Value	Weight	Value	Weight		
1918						
July 27	1·944		—	—	1·944	5·5
28	1·901		—	—	1·901	5·2
29	1·899		—	—	1·899	5·0
30	1·929		—	—	1·929	5·6
31	1·932		—	—	1·932	5·0
August 1	1·945		—	—	1·945	5·2
2	—	—	—	—	—	5·5
3	1·966		—	—	1·966	5·5
4	1·948		—	—	1·948	5·0
5	1·954		—	—	1·954	5·0
6	1·972		—	—	1·972	—
7	1·948		—	—	1·948	3·5
8	1·955		—	—	1·955	3·0
9	—	—	—	—	—	3·0
10	1·954		—	—	1·954	3·0
11	1·965		—	—	1·965	4·0
12	1·959		—	—	1·959	4·5
13	—	—	—	—	—	5·0
14	1·925		—	—	1·925	5·0
15	1·947		—	—	1·947	—
16	1·987		—	—	1·987	5·5
17	1·888		—	—	1·888	5·3
18	—	—	—	—	—	5·3
19	1·948		—	—	1·948	5·2
20	1·940		—	—	1·940	5·5
21	1·995		—	—	1·995	5·5
22	1·953		—	—	1·953	5·6
23	1·979		—	—	1·979	6·0
24	1·932		—	—	1·932	5·0
25	1·968		—	—	1·968	4·5
26	1·949		—	—	1·949	4·5
27	1·955		—	—	1·955	—
28	1·894		—	—	1·894	5·0
29	1·954		—	—	1·954	4·8
30	1·953		—	—	1·953	—
31	2·018		—	—	2·018	5·0
Sept. 1	1·980		—	—	1·980	5·0
2	—	—	—	—	—	4·7

* This is merely a specimen page of the original MS of the present paper. The values of the solar constant have been published:

up to August, 1920 .... Annals of the Astrophysical Observatory, Smithsonian Institution, Vol. IV, pp. 149–152;

August, 1920, and after .... Smithsonian Miscellaneous Collections, Vol. 77, No. 3, (February, 1925);

so that I omit here the main part of the MS-Table. The last column of the present Table I, giving the estimated area of Calcium flocculi in the daily spectroheliograms of Mount Wilson Observatory, is my own; but, as I recently found that these values are quite parallel to those of "S. M." series of flocculi area given in Boletin Mensuel del Observatorio del Ebro, I have omitted them too.—*Author.*

sun's phenomena in the present work.

These spectroheliographic observations are of routine character at the Observatory, and the plate number of the running series exceeded 8800 in the end of June 1923, all the plates being preserved carefully in the basement of the Observatory Office, although they have not yet been published in any regular form.

(c) *Sketches of sun-spots and their magnetic polarities.* Since in 1908 Dr. Hale discovered the magnetic field in the sun-spot with the Zeeman Effect, this kind of solar observation has been one of the most characteristic works carried out at the Mount Wilson Observatory. In 1915 Mr. F. Ellerman and others started a routine work of this line, and since 1917 a beautiful series of records of every sun-spot and its magnetic polarity on every available day has been preserved in a uniform manner. Brief summaries of them have been published regularly in the current number of the Publications of the Astronomical Society of the Pacific since 1920. The full details will shortly be published in a special series of the Mount Wilson publications.

The above yet unpublished data were used in the present investigation to trace the phases of local activities of the solar surface. Generally the seeing of the solar image is very important in observing the magnetic field intensities and the fine details of the sun-spot. When the seeing is 2 or under in Ellerman's scale, the observed field-intensity reveals merely its *lower limit.*

3. NATURE AND PHASES OF THE HELIOGRAPHIC ACTIVITY.

It has become necessary in the present investigation to distinguish the "phase" of the solar activity. Generally speaking, an activity of the sun is represented by the existence of some apparent local disturbance of the uniformity of the solar surface besides the "darkening" of radiation toward the limb. Sun-spots are the most striking disturbances on the sun, and have long been known. The early days of the spectroheliograph revealed that the sun-spot is always surrounded by calcium flocculi, and moreover it is very often the case that many calcium flocculi are found quite independent of the appearance of any sun-spot. A patch of the flocculi usually survives the sun-spot which it surrounded. Also a new spot is born generally from pre-existent flocculi, so that the calcium flocculi are to be considered as the true home of a sun-spot, and are the most effective indication of the local solar disturbance on the disc, while the spot is only the "peak" of the local activity shown more or less strikingly.

Spectroheliograms show the dark filaments of absorbing hydrogen on the sun when observations are made with the Hα-line. Generally the structure of a hydrogen filament is streaky and curved, and the total length sometimes reaches the diameter of the solar disc. The orientation of the filament is not limited like that of the calcium flocculi, but occurs at any point of the sun. A few years ago, Mr. F. Ellerman identified the filament with the solar prominence, and the prominence was proved some time ago by Dr. Hale to be helical in its usual structure. In 1917 O. J. Lee[5] published a paper which disproved a definite relation between the sun-spot and the prominence. But, the writer's experience connected with the present investigation shows some very significant relations existing between the sun-spot and the hydrogen filament, not to speak of the "prominence." Generally speaking, a filament is connected to some group of spots or flocculi, although it is often apparently distant from them.

The typical development of a local solar activity, according to the writer's observation, might be sketched as follows: At first there is a small patch of calcium flocculi on a certain point of the solar disc. These flocculi come out of a minute pore of the sun's granulation more or less suddenly, and the patch becomes conspicuous both by the extension of its area and also by the increase in its brightness. At a certain period of its development, a point more or less central to the flocculi area becomes darker, and there comes a sun-spot, very often followed by another spot, within the area of the same flocculi. Usually the preceding spot maintains its circular form and continues its development, becoming larger up to a certain limit, the field strength of the magnetic polarity being intensified proportionately or otherwise. The following spot is generally unsteady in its structure, and apt to break up into several components, distributed over a wider area. Rarely some of the components retain the original intensity of the magnetic field for an interval, but usually the magnetism is weaker in any components of this following spot. The opposite character of the polarity between the preceding and the following spots within the same flocculi was discovered by Dr. Hale some years ago. As the spots develop further, the field intensity of the magnetic polarity reaches a maximum, and then begins to fall, while at the same time the whole system of the activity "degenerates", extending still further the total area of the all-surrounding flocculi with many indentations in its outlines. Absorbing hydrogen filaments usually develop right over the area of activity when it is reaching the climax of its development. From the beginning the filaments are curved and sometimes twisted, more or less concentrically surrounding the sun-spots at least partially. These filaments tend to recede afterwards from the central portions of the activity probably because of some expelling forces, and sometimes reach points as far as a considerable fraction of the apparent solar diameter. Very often a well-extended filament is seen stretching 20′ or more in arc over the solar surface, and looks like quite an independent feature from others on the hydrogen spectroheliogram. But the finer structures of the details of a filament are streaky and their partial curvatures are always concave to the same side of the body, on which side we can find some areas of great former disturbances in the form of sun-spots or calcium flocculi. Such is an outline of a typical development of a sun-spot and the appearances related to it. Actually there are many varieties of appearances as we see on the solar disc visually or photographically. But all are special cases of the typical one just sketched. In an ideal case we can distinguish the *phase* of the development of the solar activity by inspecting the spectroheliograms of calcium and hydrogen lights, namely in the following three ways:

(i) Sun-spot structure in its details. If compact, then it is young, and if decomposed into several members then it is so much degenerated.

(ii) Calcium flocculi. If the occupied area is extended, and if the outline is zigzag-shaped, it is so far developed.

(iii) Hydrogen filament. If it is seen very near the area of activity, more or less crooked or just coming out radially from the spot centre, then the whole system is of young development. If the filament is more or less detatched from the activity region surrounding it from a distance, then the development is already well advanced. If some long series of filaments are stretching over the solar surface and not directly connected with any particular spots, this possibly represents a story of some activity of former days.

There is one more way of distinguishing the phase of the sun-spot activity, that is by

(iv) Serial Observations of the magnetic field-intensity of the region as carried at by Mount Wilson observers.

I admit that the idea of the *phase* (or *age*) of solar activity is too new for a universally applicable quantitative definition of that activity to be possible by its means; it yields many ways of definition from diverse points of view. The writer assumes here, as a preliminary idea, that the degree of the activity can be represented by the intensity of the magnetic field of the sun-spot given by the Zeeman Effect. It is interesting to the writer that Dr. S. B. Nicholson[7] of Mount Wilson has obtained a significant relation between the sun-spot and its magnetic field intensity.

4. DECIPHERMENT OF VARIATION OF THE SOLAR CONSTANT IN TERMS OF THE HELIOGRAPHIC ACTIVITY.

In the early days of the writer's present investigation, he attempted to obtain some relation between the general tendencies of the solar constant and the calcium flocculi. For this purpose, eye-estimations of *apparent effective area** of calcium flocculi on daily spectroheliograms were made, which are given in the last column of Table I and plotted on cross-section papers so that they might be compared with the similar curves of the solar constant, both being in the same scale with regard to the abscissae representing time. The direct comparison was not promising at first, only sometimes showing parallelism positively as well as oppositely. During this stage of examination of the materials, the writer sometimes found very peculiar habits of quite a temporary character in the curve of the solar constant. Usually when a well developed area of solar activity comes to the apparent centre of the solar disc, a sudden drop in the solar heat occurs; the effect being in some cases for one or two days, and in others much longer. This is just what Dr. C. G. Abbot suggested in the second of his "four principles". But in some cases such near approach of the spot area to the solar centre does not bring the corresponding depression of heat: sometimes the curve of the solar constant remains calm, showing no effects at all, while sometimes the heat curve turns *upward*! Then the writer took some typical examples of the three cases: the falling, the rising and the unalteration of the solar heat corresponding to a central passage of a sun-spot. A close examination of all the available materials and exhaustive comparison of the three cases gave the following general conclusions:

(A) If the sun-spot is in its developing stage of activity into a higher order at the time of its central passage across the sun's apparent disc, the solar heat goes up.

(B) If the sun-spot is already well developed, and especially when it is in the degenerating stage of activity, then the solar heat falls down.

(C) The sun-spot which does not produce any apparent effect on the solar heat by its central passage across the sun is one which is

* *Apparent Effective Areas* of Activity are estimated here by putting relatively much weight on those near to the centre of the solar disc and less weight on those at the limb.

in its full development of activity, just not too young and yet not too old, so that it is near the climax of activity.

With these three principles, the writer was able to decipher many temporary variations of the solar constant. The following are some examples illustrating typical cases. Some of the most notable examples showing the *increasing* activity accompanying heat evolution are given in the following tables. See, also, the photographs in Fig. 1 illustrating these examples.

EXAMPLE I.

Table II.

Activity of Sun-spot No. 1840 (Mt. Wilson)

Date	Magnetic polarity		Solar Constant	K_2-Flocculi estimated.
	Intensity	Remarks		
1921 April 19	V ? R ?	at limb	1·920	3·5
20	V 7R 3		1·968	3·3
21	?	no obs.	1·921	3·0
22	V 4R 7		1·956	3·0
23	——	extinguished	1·919	3·0
24	——	invisible	1·933	3·0
25	V 5	revived !	1·946	——
26	V 4R 5		1·944	2·5

Solar meridian passage: April 24, 1921.

EXAMPLE II.

Table III.

Activity of Sun-spot No. 1873 (Mt. Wilson)

Date	Magnetic polarity		Solar Constant	K_2-Flocculi estimated.
	Intensity	Remarks		
1921 July 8	V12R 4		1·937	3·2
9	V18R 6		1·959	3·3
10	V26R10		1·964	3·2
11	V17R12		1·936	2·7
12	V17R 8		——	2·0
13	V17R14		1·951	2·0
14	——	weak	1·954	2·2

Solar meridian passage: July 8, 1921.

EXAMPLE III.

Table IV.

Activity of Sun-spot No. 1915 (Mt. Wilson)

Dete	Magnetic Polarity		Solar Constant	K_2–Flocculi estimated
	Intensity	Remarks		
1921 October 24	R24V23		——	3·0
25	R24V22		1·942	3·0
26	R25V22		1·952	3·0
27	R23V18		1·946	2·7
28	R27V25		1·962	2·5
29	R33V20		1·955	2·4
30	R28V18		1·962	2·0
31	R27V10		1·957	2·0
November 1	R26		1·949	1·5
2	?	limb	1·955	1·0

Solar meridian passage: October 27, 1921.

In these tables showing EXAMPLEs, the magnetic intensity, for examples, V7R3, means that the *maximum* intensity of the magnetic field of the preceding spot is 7 (ca. 700 gausses in Ellerman's scale) in the counter-clockwise vortex and the *maximum* intensity of the field of the following spot is 3 (ca. 300 gausses in Ellerman's scale) in the clockwise vortex; the columns of the Solar Constant and the K_2–Flocculi are simply reproduced from the Table I of the present paper for direct comparison. The case of Sun-spot No. 1873 is conspicuous for the rapid rising of the solar constant, which attained its temporary peak on July 10 as seen in Fig. 1. In the case of No. 1840, the spot made its appearance first on April 19 when it was seen near the east limb and numbered as No. 1839; this spot was extinguished on the solar disc by April 23 and suddenly *revived* later as No. 1840 on the first day after its meridian passage—a rather unique case—and the outburst of the new energy is shown in the rising of the solar constant at that time. No. 1915 made the solar heat go steadily upward, and then disappeared behind the visible hemisphere of the sun by its rotational effect; while after a due interval the spot came back into sight from the east limb in the middle of November, and passed the meridian on Nov. 23, by which time it had reached its full deveolpment and evolved conspicuous hydrogen filaments and consequently the cutting out of the solar heat thereby was very conspicuous in the observations of the solar constant.

Example of *temporary drops* in the solar constant simultaneous with the meridian passage of some solar activity area are numerous. The following cases are given here:

EXAMPLE IV.

Table V.

Activity of Sun-spot No. 1809 (Mt. Wilson)

Date	Magnetic Polarity		Solar Constant	K_2–Flocculi estimated
	Intensity	Remarks		
1921 February 13	V 5		1·960	2·5
14	V 5		——	——
15	V 5		1·960	2·0
16	V 5		1·961	2·2
17	——		1·955	——
18	V26R28		1·948	2·5
19	V23R19		1·926	3·0
20	V24R24		1·932	3·4
21	V20		1·959	——
22	V20		1·948	3·3
23	V18R16		1·943	3·0
24	?	limb		

Solar meridian passage: February 18, 1921.

EXAMPLE V.

Table VI.

Activity of Sun-spot No. 1842 (Mt. Wilson)

Date	Magnetic Polarity		Solar Constant	K_2–Flocculi estimated
	Intensity	Remarks		
1921 May 8	?		1·955	2·8
9	V17R14V12		1·944	3·0
10	R20V25		1·962	3·2
11	R24V33		——	3·5
12	R28V30		1·948	3·8
13	R34V32		1·964	4·0
14	R54V30		1·941	4·0
15	R31V23		1·934	——
16	R28V26		1·938	——
17	——	Cloud.	——	——
18	?		1·957	——
19	?		1·963	——

Solar meridian passage: May 14, 1921.

EXAMPLE VI.

Table VII.

Activtiy of Sun-spot No. 2014. (Mt. Wilson)

Date	Magnetic Polarity		Solar Constant	K_2-Flocculi estimated
	Intensity	Remarks		
1923 April 19	V ? R ?		——	2 0
20	V24R19		1·940	1·5
21	——	cloud	1·942	——
22	——	cloud	1·917	1·4 ? ?
23	V11R 5		1·908	1·5
24	V 9R 3		1·920	1·3
25	V12R 5		1·932	1·0
26	V12R 5		1·948	1·3
27	V10R15		1·924	1·2
28	?		1·927	1·3

Solar meridian passage: April 23, 1923.

Spot No. 1842 returned after a rotation of the luminary to the visible hemisphere as No. 1852, which passed the central meridian and effected heat absorption again. No. 2014 had disappeared by the time when its next return was due, but the calcium flocculi survived it and apparently effected a reduction in the solar heat at the time of its meridian passage on or about May 20.

The cases in which the *plus* and *minus* effects on the solar constant were almost equal and consequently balanced are relatively rare. The following are good examples:

EXAMPLE VII.

Table VIII.

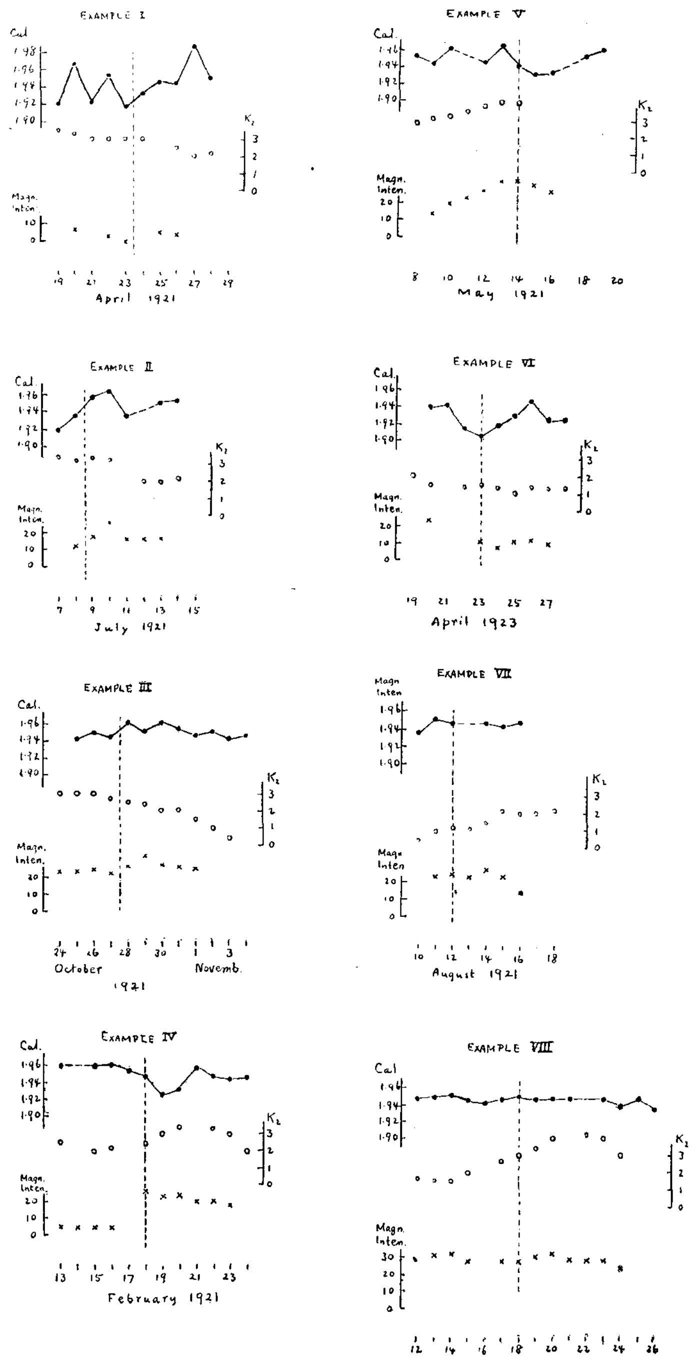
Activity of Sun-spot No. 1889 (Mt. Wilson)

Date	Magnetic Polarity		Solar Constant	K_2-Flocculi estimated
	Intensity	Remarks		
1921 August 11	R24V11		1·951	1·0
12	R25V 7		1·946	1·2
13	R23V 3		——	1·1
14	R28		1·946	1·5
15	R24		1·943	2·2
16	R14		1·947	2·0
17	?		——	2·0
18	?		——	2·2

Solar meridian passage: August 12. 1921.

Fig. 1.

Remarks: Dotted vertical lines show the dates of central meridian passages of the sun-spots.



EXAMPLE VIII.

Table IX.

Activity of Sun-spot No. 1903 (Mt. Wilson)

Date	Magnetic Polarity		Solar Constant	K_2–Flocculi estimated
	Intensity	Remarks		
1921 September 12	?		1·947	1·6
13	R31		1·949	1·5
14	R32		1·952	1·5
15	R28		1·944	2·0
16	R ? V 2		1·941	——
17	R28		1·946	2·6
18	R28V ?		1·950	3·0
19	R30		1·943	3·3
20	R32V ?		1·945	4·0
21	R29V 3		1·946	——
22	R28		——	4·2
23	R28		1·946	4·0
24	R24		1·939	3·0
25	?		1.946	——

Solar meridian passage: September 18, 1921.

No. 1903 returned to this side of the sun in the next month, and passed the solar meridian on October 16 effecting a conspicuous drop in the solar constant.

Some of the best plates of the Mount Wilson spectrograms, taken with the Hα–light, and sometimes with direct light, showing the characteristic features in connection with the present problems, are given in the appended Plates.

The physical meanings of these principles are probably as follows: When the solar activity is increasing, it means that some accelerating forces are acting upon the region, and consequently radiating energy is evolving, which affects the total heat received by our terrestrial instrument. But, along with further development of the activity area, hydrogen and other gaseous matter are evolving out of the region by mechanical or some other form of expulsion, and when these gases become predominant *over* the area absorption of out-going energy takes place, which absorption continues to prevail, sometimes becoming more powerful, even after the original active source (spots) has begun to die away. Hence, the effect under principle (1) is due to some direct action of the active area upon the earth, and that under (2) is due to absorption by overlying gases. When these two agencies are working at the same time, the result upon our terrestrial pyrheliometer is determined by the relative efficiency of them. The phenomena under principle (3) are the result of the two agencies, just balancing so to speak, which is the reason why it occured when the activity was in full development.

Later, upon examining many points of interest of the curve of the solar constant, keeping in mind the three principles as above, the writer found that it was not always necessary for an area of activity to come just upon the centre of the solar disc to affect a rise in the solar constant if its activity is increasing. It is really often the case that such kind of activity brings about the same result when it is situated rather distant from the apprent centre of the sun. Generally speaking, an increasing activity taking place upon the *visible* part of the solar surface is enough to produce a rise in the solar constant if it is sufficiently strong to do so. A new birth of a sun-spot is of course a special case of this type. When a sufficiently strong activity develops just at the time when it comes within the visible limb of the solar disc it may have the same effect: this type will explain the "limb effect" detected some years ago by Mr. H. H. Clayton.* Statistically, however, the number of cases where the absorption take place as shown in the solar constant curve is far greater than that of those where a rising in the solar heat is observed. This should be rightly justified from the physical meaning of the phenomena, because the rising stage of an area of activity upon the sun is much shorter in life than that of its falling stage. The cases, in which the two agencies opposite to each other just balance, are the least in number, because these must be really exceptional cases.

In No. (3) of his "four principles", Dr. Abbot mentions some connections between great activity of hydrogen and high values of the solar heat. The meaning of "hydrogen activity" is a little ambiguous. If he means by that phrase some energetic evolution of hydrogen filaments newly developing from the activity centre of a sun-spot, the writer's experience with the spectroheliograms in the present investigation confirm the statement eloquently. If he means by the term only splendid apparitions of big filaments over the visible surface of the sun without any rapidity of changes of structure, his principle cannot conform with the present study, because in such cases the writer often sees more or less absorption predominant upon the sun by the overlying gases.

* loc. cit.

Sometimes the calcium flocculi without any spots in them affected the solar constant, which is a direct proof of the comment on No. (2) of his "four principles" by Dr. C. G, Abbot. Downfalls of solar heat on

July	26–27,	1921,
July	5–7,	1922,
August	15–10,	1922,

are beautiful examples of the effects of the flocculi when they passed the meridian on those occasions. Rise in the solar constant was also often observed as due to effects of new births of flocculi, those on the dates:

April	16–18,	1922,
October	7–9,	1922,
August	24–26,	1922,

being examples of this.

Generally the date of the minimum of the solar constant due to the meridian passage of the local activity on the sun is one day later than the date of the passage. But this is not strictly the case for all of them. Sometimes the minimum comes just on the date of the meridian passage, and sometimes it comes a short while *after* that time apparently. Accurate determination of this kind of phase difference cannot be made from the present materials, because the time of observing the solar constant is not suffiiciently given for accuracy.

The writer has met several cases in which the solar surface was quite free from any activity upon it. In such cases the fluctuation of the solar constant is generally inappeciable, but it cannot be easily concluded whether the solar constant is usually falling down or going up during such a period. There are varieties among them. For example, in the following intervals the solar surface was quite calm:

May	13–16,	1922,
October	22–28,	,, ,
November	22–27,	,, ,
December	14–21,	,, ,
January	5–27,	1923,
February	17–28,	,, .

In four of these cases in 1922 the solar heat was going *up*, sometimes with rapidity. In examining the calcium spectroheliograms carefully, the writer detected in these cases some signs of flocculi just evolving from the photospheric background. On the other hand, the two cases in 1923 showed a falling down of the solar heat, and similar examinations of the Plates revealed some traces of old activity on the sun's surface.

Statistically speaking, however, a quiet period of the solar surface is connected with steadiness of the solar radiation, and if this means the absence of new sources of energy on the surface, with possible remnants of gaseous clouds of former days, it may result in a decline of the total heat anyhow.

5. STUDY OF THE RUN OF MEAN VALUES OF THE SOLAR CONSTANT.

The general run of curves, that is, of the solar constant and of the effective flocculi area plotted in the same form upon cross-section paper, short-lived variations being disregarded, was examined with a view to seeing whether there was any parallelism between them. No generalization in the question proved to be possible: sometimes they ran quite parallel, the rising and falling of the one corresponding to similar characters of the other, while sometimes the run was opposite in mutual correspondence, and in other cases there was no relation at all. From the curves extending over an interval of six years, the writer obtained the result shown in the following Table:

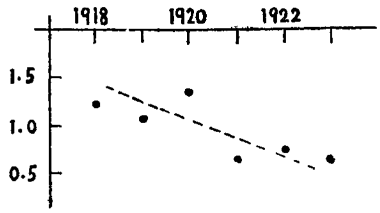
Table X.

Number of Days of Relationship.

Year	1918	1919	1920	1921	1922	1923
Parallel Run	44	116	166	99	107	28
Opposite Run	35	111	121	162	136	42
Ratio	1·24	1·08	1·37	0·61	0.75	0·66

It is to be remembered that the number of days of observations here used in the years 1918 and 1923 is not complete, being 155 and 142 days respectively. In the third row the ratio of the two kinds of runs, in the sense of *Parallel Run to Opposite Run*, is given. Stress need not here be laid upon the numerals strictly, but the acompanying Figure 2 shows the general tendency of the Ratio. As a rough suggestion, it may be stated that the sense of parallelism is changing, or at least is not the same, from the early part to the latter part of the interval. The last maximum of sun-spot activity was in 1917, as was widely observed,

Fig. 2.



so that the years 1918 and 1919 are still years of strong activity while in the later years the sun is becoming more and mare calm. Bearing in mind these circumstances existing *in* the sun, the writer is led to reflect that in the earlier years of the present interval the solar effect upon the solar constant was predominating in its energy-radiating power, while in the later years the effect of gaseous absorption was controlling the general field, so to speak.

Strictly continuous observations of the solar constant have been made since September 1918, but at the Mount Wilson Station of the Astrophysical Observatory of the Smithsonian Institution, observations of the same constant have been continued almost uninterruptedly every summer since 1905; so that we have here a precious series of materials for the study of the annual run of the solar constant here if that study be restricted to summer. The following Table XI gives all available values of the mean solar constant of every *August* since 1904 observed at several stations solely or simultaneously.

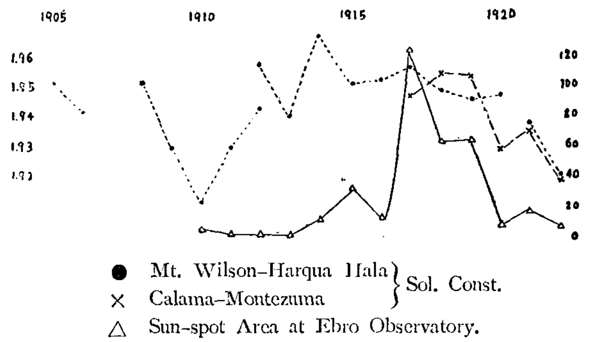
Table XI.
Solar Constant and Sun-spot Area Every August.

Year	Solar Constant			Sun-spot Aaea
	Mt. Wilson	Calama-Montezuma	Harqua Hala	
1905	1·951	—	—	—
1906	1·941	—	—	—
1907	—	—	—	—
1908	1·951	—	—	—
1909	1·930	—	—	—
1910	1·912	—	—	7·1
1911	1·930	—	—	0·8
1912	1·957	—	—	0·2
1913	1·940	—	—	0·3
1914	1·944	—	—	11·0
1915	1·951	—	—	31·2
1916	1·952	—	—	12·5
1917	1·956	1·947*	—	123·8
1918	1·948	1·954	—	61·8
1919	1.945	1.953	—	63·5
1920	1·947	1·929	—	7·2
1921	—	1·935	1·937	19·3
1922	—	1·918	1.920	4·8

* In 1917 a series of observations of the solar constant was made at Hump Mountain, N. C., with the instrument which was transported to Calama in the following year.

In Figure 3 the values of Table XI are plotted, together with the sun-spot observations (in terms of heliographic area per square millimeter of the solar disc) made at the Ebro Observatory and published in its

Fig. 3.



BOLETINs. We see here that in the early years there is no apparent relation between the heat and spots of the sun, but in the later years there is a decided parallelism between them. If we reduce the apparent relations of the two phenomena to numerical form from the best and unform materials obtained at the Calama-Montezuma and Ebro observatories, we obtain :

$$K = 1{\cdot}923 + 0{\cdot}000469\,x,$$

where K is the solar constant and x the Ebro Sun-spot area.

Next, the writer computed monthly the mean values of the solar constant from the data obtained at the Calama–Montezuma and the Harqua Hala station, and at the same time he obtained similar values of the estimations of the effective area of the calcium flocculi made by himself from the Mount Wilson spectroheliograms, all these values being given in Table XII below :

According to Dr. C. G. Abbot, the best of the determinations of the solar constant made under his supervision are those made in the interval from August 1920 up to the latest date of 1923 at the Montezuma and the Harqua Hala stations. The writer rounded the *weighted* mean values of them, still further to get a smoother curve, by taking the means of every consecutive three values, and these are given in the fourth row of Table XII. All the numerical values of Table XII are a'so plotted in Figure 4 given here.

An annual periodicity of the solar constant, which was now computed from the data up to the end of 1921, is apparent, because the rapid fall

Table XII.

Monthly Mean Values of the Solar Constant together with those of Calcium Area.

	Epoch	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1918	Calama	—	—	—	—	—	—	—	1·954 27	1·944 18	1·935 24	1·942 23	1·959 19
	Harqua Hala	—	—	—	—	—	—	—	—	—	—	—	—
	Calcium Area	—	—	—	—	—	—	—	4·8	4·5	5·4	5·0	5·3
1919	Calama	1·944 19	1·948 20	1·941 16	1·952 27	1·940 27	1·955 22	1·954 27	1·953 30	1·939 28	1·952 20	1·953 25	1·952 24
	Harqua Hala	—	—	—	—	—	—	—	—	—	—	—	—
	Calcium Area	4·8	5·2	5·0	4·5	4·8	5·2	5·1	5·1	4·9	4·1	4·0	4·6
1920	Calama-Montezuma	1·964 25	1·956 19	1·946 29	1·952 30	1·953 29	1·939 23	1·945 21	1·929 27	1·947 25	1·945 21	1·948 26	1·956 22
	Harqua Hala	—	—	—	—	—	—	—	—	—	1·944 14	1·953 11	1·937 5
	Weighted Mean	—	—	—	—	—	—	—	1·929	1·947	1·945	1·950	1·952
	Rounded									1·940	1·947	1·949	1·955
	Calcium Area	3·8	4·4	4·0	2·9	3·3	3·5	2·8	1·9	2·0	3·7	3·7	3·6
1921	Montezuma	1·955 9	1·956 7	1·946 13	1·944 16	1·943 13	1·939 17	1·949 18	1·935 1	1·953 5	1·951 12	1·949 15	1·952 12
	Harqua Hala	1·968 12	1·947 19	1·941 14	1·944 17	1·951 17	1·935 21	1·934 12	1·937 13	1·543 26	1·944 22	1·958 19	1·949 11
	Weighted Mean	1·962	1·950	1·943	1·944	1·948	1·937	1·943	1·937	1·944	1·947	1·954	1·950
	Rounded	1·958	1·952	1·946	1·945	1·943	1·943	1·939	1·941	1·943	1·948	1·950	1·949
	Calcium Area	3·0	2·6	2·9	2·8	2·5	2·5	2·8	2·1	2·1	2·2	2·0	1·8
1922	Montezuma	1·947 19	1·947 10	1·938 14	1·926 12	1·917 6	1·913 11	1·910 8	1·918 10	1·934 16	1·932 10	1·929 8	1·909 2
	Harqua Hala	1·940 15	1·946 12	1·926 15	1·921 20	1·929 22	1·920 24	1·911 20	1·920 11	1·909 22	1·919 29	1·910 24	1·921 16
	Weighted Mean	1·944	1·947	1·931	1·923	1·926	1·918	1·911	1·919	1·914	1·922	1·915	1·920
	Rounded	1·947	1·941	1·934	1·927	1·923	1·918	1·916	1·915	1·918	1·917	1·917	—
	Calcium Area	2·2	2·2	2·7	2·1	1·8	1·4	1·7	1·1	1·0	1·6	1·2	1·3
1923	Montezuma	—	—	—	—	—	—	—	—	—	—	—	—
	Harqua Hala	1·911 17	1·903 18	1·908 22	1·923 19	1·919 21	—	—	—	—	—	—	—
	Calcium Area	1·1	1·1	1·0	1·4	0·7	1·2	—	—	—	—	—	—

of the general curve in 1922 seems too unusual to be treated without consideration of some special kind. The annual term in the sense of deviations from the mean constant during the three and a half years, 1918–1921, is as follows:

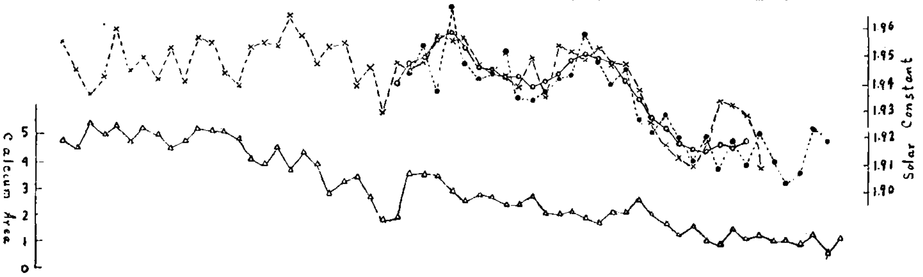
Table XIII.

Annual Variation of the Solar Constant.

Month	Mean Solar Constant	Rounded from consecutive three values
January	+·009	——
February	+·003	+·002
March	−·005	+·000
April	−·0021	−·002
May	−·001	−·001
June	−·004	−·002
July	−·001	−·003
August	−·005	−·004
September	−·005	−·004
October	−·003	−·002
November	+·002	+·001
December	+·005	+·005
(January)	(+·009)	+·006

The January value in the last row is repeated for convenience. Here the true cause of this annual variation of the solar constant is not easily identified; it may be due either to the effects of the sun's declination or to that of the sun's distance, or it may come from some instrumental origin as well as from the methods of reduction of the original observation.

Fig. 4.



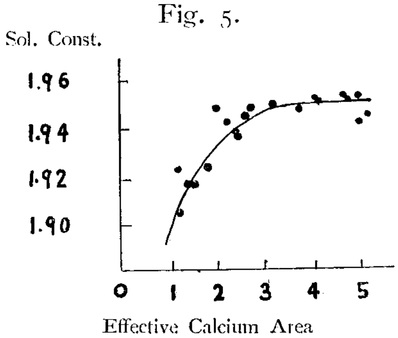
Now the above-obtained values of the annual term of the solar constant were applied as *corrections* to individual monthly means to bring them to normal values, which were then reduced to another series of mean values for each quarter year, the process being extended to the latest values of 1923. The result is shown in Table XIV below:

Table XIV.

Mean Normal Solar Constant and Calcium Area in each quarter year.

Month	1918		1919		1920		1921		1922		1923	
	Sol. Const.	Cal-cium	Sol. Const.	Cal-cium	Sol. Const.	Cal-cium	Sol. Const.	Cal-cium	Sol. Const.	Cal-cium	Sol. Const.	Cal-cium
January-March	—	—	1·942	5·0	1·953	4·1	1·949	2·8	1·938	2·4	1·905	1·1
April-June	—	—	1·951	4·8	1·950	3·2	1·945	2·6	1·924	1·8	1·923	1·1
July-September	1·953	4·6	1·952	5·0	1·942	2·2	1·939	2·3	1·918	1·3	—	—
October-December	1·944	5·2	1·951	4·2	1·948	3·7	1·949	2·0	1·918	1·4	—	—

Fig. 5.



These values are diagrammatically shown in Figure 5. It is apparent that calcium flocculi of a value of more than 3 in the present scale keeps the solar heat sensibly constant, while the effect is marked when it is below 3 in the scale.

6. SUMMARY AND CONCLUSION.

For the purpose of finding the influence, if any, of heliographic activity upon the solar constant, a considerable amount of data was examined, those data comprising the spectroheliograms of different kinds and magnetic observations of visible and invisible sun-spots made at the Mount Wilson Observatory, to compare them with the run of the solar constant values obtained at the Astrophysical Observatory of the Smithsonian Institution. The nature of the phenomena is pretty complex. Temporary or short-lived effects of the solar activity upon the solar constant are divided in two kinds according to the life-history of the area of activity concerned. An area of increasing activity on the sun makes the solar heat rise, the apparent heliographic position of the area not being of essential importance. An activity area in decay, on the other hand, makes the observed solar heat drop when it comes sufficiently near to the centre of the apparent solar disc, probably by some screening action of overlying gases evolved from the region. Sometimes the two agencies occur at the same time, naturally in the opposite sence in their effects upon the solar heat, so that a good balance occasionally results between them. For the general relation between the solar activity and the solar heat controlling circumstances of long duration, the case is not always the same for the earlier and the later half of one complete 11-year cycle of solar variation. An apparent conspicuous relation between them is revealed when the sun is generally calm in the cycle.

The present investigation was made by suggestions given to the writer early by Dr. C. G. Abbot, whose keen interests in and careful watch upon the progress of the work encouraged the writer, whose hearty thanks are naturally due to him. It was especially fortunate for the writer that Dr. W. S. Adams, Director of the Mount Wilson Observatory, allowed him to use freely the rich stock of materials accumulated in the course of many years by the staff of the observatory, to whom many thanks are also due.

Issei Yamamoto.

Mount Wilson Observatory,
Pasadena, California, U. S. A.

October 23, 1923.

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1 An abridged report of this investigation was published in Monthly Notices, R. A. S., Vol. LXXXV, p. 71, (1924).

2 Annals of the Astrophysical Observatory of the Smithsonian Institution, Vol. III. p 18.

3 Nature, Vol. **106**, 630, (1921) and Vol. **107**, 108. (1921).

4 Abbot has subsequently published these principles in Proc. Nat. Acad. Sc. U. S. A., Vol. **9**, p. 355, (1923).

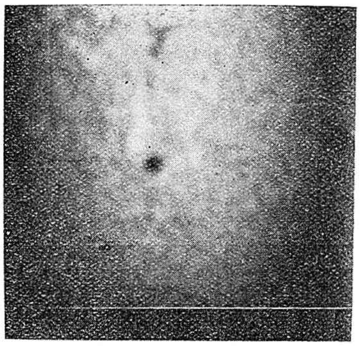
5 The final values with these corrections have recently been published in Smithsonian Miscellaneous Collections, Vol. **77**, No. 3, (1925).

6 Astrophysical Journal, Vol. **45**, p. 206, (1917).

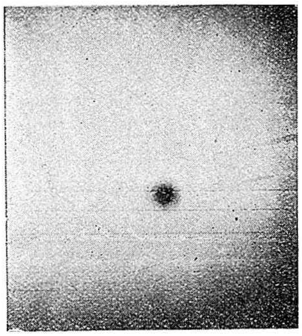
7 Publ. A. S. Pacific, Vol **31**, p. 182. (1919).

Plate I.

Mt. Wilson Sun-spot No. 1823, on March 29, 1921, in *growing* stage.



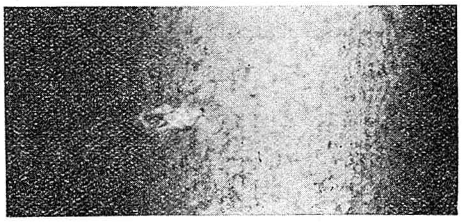
Hα image.



Direct image.

Plate II.

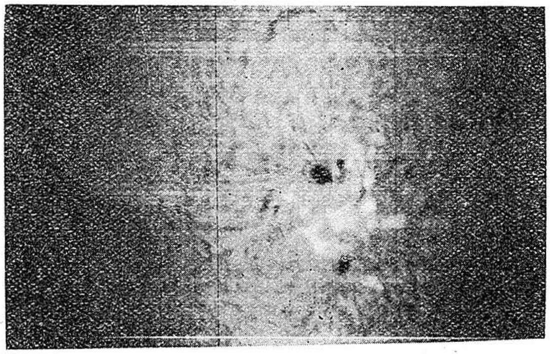
Mt. Wilson Sun-spot No. 1902, on Sept. 11, 1921, just *evolving*.



Hα image.

Plate III.

Mt. Wilson Sun-spot No. 2005, on Dec. 27, 1921, *growing* up.



Hα image.

APPENDIX I.

RECOMPUTATION OF THE RELATION BETWEEN THE SOLAR CONSTANTS AND THE CALCIUM FLOCCULI.

On the suggestion of Dr. W. S. Adams, I made two series of computations: first, for partial intervals of the solar constant value, and next, for those of the flocculi area. These results are shown in the accompanying Fig. 6, where the "small circles" represent the values obtained for each interval of flocculi area and the "crosses" those for intervals of solar constant. There, certainly, some kinds of regression are apparent. But, frankly, I was not quite convinced of the matter, partly, from the present computational experiences, and partly from some recollections of similar cases connected with the computation of Table XII of my principal paper dated October last. For, Table XIV and Fig. 5 in the preceding paper show, that the mean solar constant values connected with higher values of the flocculi are, without exception (!), belonging to earlier; while those values connected with the lower flocculi values generally belong to later dates; so that the regression curve in Fig. 6 is not only determined by the solar constant and the flocculi but also by the period.

For a clearer demonstration of the time-effect of the matter, I recomputed the relations which were already shown as cross-series in Fig. 6, and in this case the whole material was first divided into two series, one from the data of 1918–1920 and the other from those of 1921–1923. These two of computations were made separately, and the results are plottod. again, in the same figure (Fig. 6) here. The parallel character of each of the curves is quite clear, suggesting that the regression-form represented by the previous "crosses" is not so definite as might be supposed from its appearance.

Next, I proceeded to repeat similar computations further: but in this case I made them *for each year.* The results are shown in the following Table XV, and are given diagrammatically in Fig. 7.

In each of the annual rows of Table XV, the first row is the mean solar constant, the second, the mean flocculi area, and the last the weight; those values which have too small weights were conveniently combined with neighboring values to furnish data to be shown in Fig. 7. The values for 1918 and 1919 almost coincide; besides, the curves for 1922 and 1923 are as near to each other as those for 1920 and 1921;

Table XV.

Year	<1·896	1·900 −1·909	1·910 −1·919	1·920 −1·929	1·930 −1·939	1·940 −1·949	1·950 −1·959	1·960 −1·969	>1·970
1918	1·885 4·97 7	1·904 5·47 3	1·914 5·50 2	1·925 5·14 10	1·934 4·85 10	1·945 4·92 15	1·953 4·86 19	1·964 5·04 7	1·982 5·29 10
1919	1·898 2·20 1	— — —	1·918 4·83 3	1·926 5·00 13	1·935 5·05 17	1·945 4·85 24	1·955 4·77 41	1·963 4·82 37	1·977 5·04 14
1920	1·880 4·53 3	1·906 1·80 2	1·916 2·70 6	1·924 2·70 19	1·935 3·08 30	1·945 3·07 51	1·953 3·34 50	1·964 3·28 31	1·984 3·65 11
1921	1·871 3·55 2	1·903 3·15 2	1·915 2·63 6	1·924 2·89 13	1·935 2·37 32	1·944 2·48 65	1·954 2·22 41	1·963 2·40 30	1·982 2·43 9
1922	1·880 1·57 15	1·905 1·40 21	1·915 1·67 40	1·922 1·51 46	1·934 1·81 40	1·944 1·94 24	1·954 2·20 6	1·964 0·35 2	— — —
1923	1·884 1·09 8	1·905 0·88 18	1·914 1·08 14	1·925 0·82 17	1·932 0·94 5	1·943 0·83 4	— — —	— — —	— — —

so that these points of curves were finally combined, except those for 1920 and 1921, and reproduced in Fig. 8. (This may not be necessary, because the six curves in Fig. 7 are quite distinct; but anyway, those for 1918 and 1919 are rather convenient when they are united, their differences being insignificant apparently.) The values obtained by these numerical combinations are:

Table XVI.

Years	<1·899	1·900 −1·909	1·910 −1·919	1·920 −1·929	1·930 −1·939	1·940 −1·949	1·950 −1·959	1·950 −1·969	>1·970
1918–19	1·887 4·62 8	1·904 5·47 3	1·916 4·90 5	1·926 5·06 23	1·935 4·97 27	1·945 4·88 39	1·954 4·80 61	1·963 4·86 44	1·979 5·14 24
1922–23	1·881 1·40 23	1·905 1·16 3	1·915 1·52 54	1·923 1·32 63	1·934 1·71 45	1·944 1·78 28	1·955 2·20 6	1·964 0·35 2	— — —

It will be noticed that in both Figs. 7 and 8, the curve are all practically vertical, and only the annual run from large flocculi area to smaller is definitely shown.

Next, I re-computed the values as shown in the "small circle" series in Fig. 6, similarly, for each year. The results are:

Table XVII.

Year	<1·0	1·0 –1·4	1·5 –1·9	2·0 –2·4	2·5 –2·9	3·0 –3·4	3·5 –3·9	4·0 –4·4	4·5 –4·9	5·0 –5·4	>5·5
1918	— — —	— — —	— — —	— — —	— — —	1·953 3·10 3	1·945 3·50 2	1·924 4·03 7	1·949 4·63 12	1·939 5·07 30	1·945 5·66 29
1919	— — —	— — —	— — —	1·927 2·10 2	1·951 2·60 2	1·962 3·00 4	1·968 3·50 1	1·953 4·04 16	1·952 4·60 27	1·950 5·08 72	1·954 5·74 26
1920	— — —	1·936 1·13 18	1·944 1·61 17	1·947 2·16 26	1·946 2·63 24	1·949 3·13 31	1·952 3·55 21	1·948 4·12 21	1·950 4·60 24	1·939 5·09 15	1·952 5·60 6
1921	1·936 0·53 6	1·951 1·08 22	1·951 1·58 19	1·951 2·11 46	1·941 2·61 30	1·943 3·10 49	1·944 3·59 18	1·951 4·03 9	1·891 4·50 1	— — —	— — —
1922	1·922 0·55 39	1·920 1·13 51	1·915 1·59 29	1·925 2·13 49	1·932 2·55 20	1·922 3·10 13	1·941 3·50 1	1·932 4·10 3	1·933 4·50 1	— — —	— — —
1923	1·918 0·45 28	1·909 1·13 27	1·914 1·55 9	1·926 2·00 1	— — —	1·917 3·00 1	— — —	— — —	— — —	— — —	— — —

The meaning of each row is the same as that of the preceding tables. In Fig. 9, where these values are visualised, the curves for four years 1918–1921 are not much separated from one another, so that they can be combined into one, thus numerically:

Table XVIII.

Years	1·0 –1·4	1·5 –1·9	2·0 –2·4	2·5 –2·9	3·0 –3·4	3·5 –3·9	4·0 –4·4	4·5 –4·9	5·0 –5·4	<5·5
1918–21	1·943 1·03 46	1·948 1·59 36	1·949 2·13 74	1·943 2·62 56	1·946 3·16 87	1·949 3·56 42	1·947 4·07 53	1·947 4·60 64	1·946 5·08 117	1·950 5·69 61

These are shown in Fig. 10 together with the other data. Both in Fig. 9 and in Fig. 10, all the curves are practically horizontal, and only a general tendency of the solar constant to decrease along the year's advance, especially in later years, is apparent.

Now we come to a very definite conclusion: that is, there is no direct relation practically between the solar constant and the calcium flocculi area, at least when they are *statistically* treated. The apparent regressions seen in Fig. 6 of the present Appendix and also in Fig. 10 of my October paper are illusory to some extent, being caused only by the distribution of weights. In other words, each of the curves shown in Figs. 7, 8, 9, and 10 is not a partial contribution to the general curves in Fig. 6.; the natures of these two kinds of curves are quite different.

But, I do not mean by these conclusions to deny the possible relation between the two phenomena as obtained in the first part of my October paper. There they were treated *individually*, and the evidence is clear from actual examples.

My investigations, as a whole, include the results of two modes of attack on the problems of the solar constants: the short-lived variation and the long-enduring variation of the constant. As to the latter, the conclusion obtained just above is quite definitive. But, the method of treatment and the conclusions of the former part might be, in a sense, considered as not sound enough. As, however, this part was treated not statistically but individually, all the details were fairly complicated, so that the demontration of facts by means of some typical characters of actual phenomena was necessarily the only method possible. Moreover, the direct attack on these short-lived variations of the solar constant was the very point which Dr. Abbot induced me originally to investigate with our rich meterials. I do not think he expected me to use the statistical method of attack to explain his "four principles", notwithstanding my adopting this method in my last part. Each case of upheaval and depression of the solar constant of a few days' duration was no doubt expected to be explained by some corresponding apparitions on the solar disc. Under these circumstances, it may perhaps be necessary to preserve the main part of my October paper, especially those pages where the details of individual study of the solar surface from several sides, that is, from calcium K_2–plates and hydrogen C–plates are given as well as the data of magnetic polarity observations.

Therefore I know now that the variation of the heat radiation of the sun as received by the earth is not simple in its cause. Very rapid fluctuations within a week or so are probably explained by heliographic apparances when they are watched carefully by all the modern methods. But the general inclination of the solar radiation shown over a long period of several years, if any, is beyond our present understanding. I might say here that the decreasing mean latitude of solar-activity area towards the minimum epoch of the sun-spot may be, in some sense,

Fig. 6.

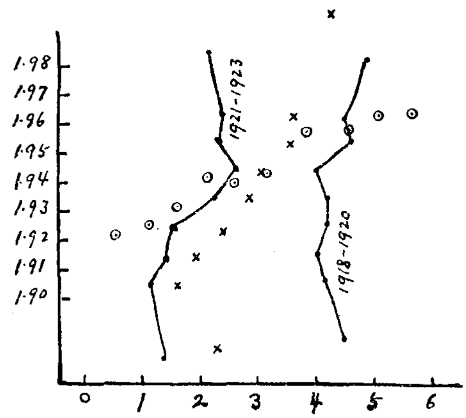


Fig. 7.

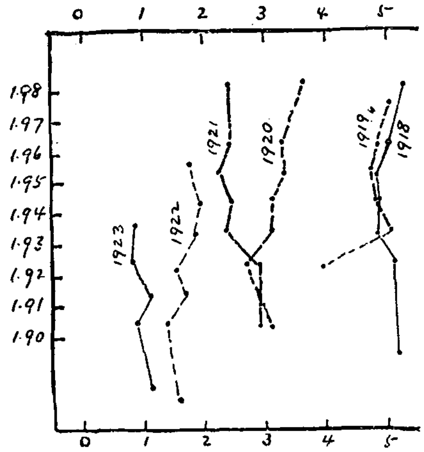


Fig. 8.

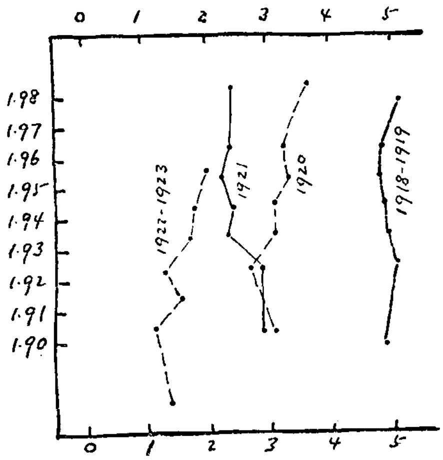


Fig. 9.

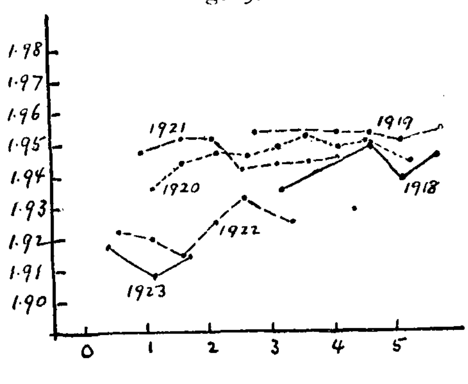
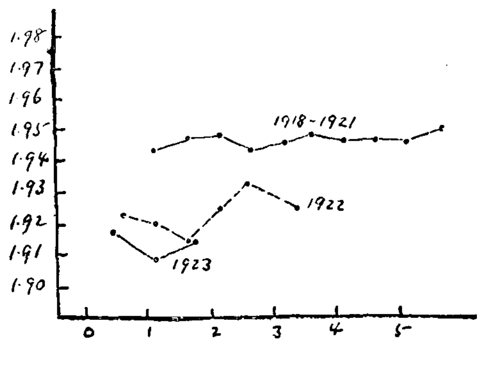


Fig. 10.



affecting the decided diminutions of the mean values of both solar constant and the flocculi area of the past few years.

Issei Yamamoto.

Harvard College Observatory,
Cambridge, Massachusetts, U. S. A.

February 28, 1924.

APPENDIX II.

On the Relation Between Sun-spots and the Solar Constants.[1]

Since 1921, we have a new series of sun-spot observations which are being made by Mr. Katué Misawa, Suwa, Nagano-ken. His programme is to observe sun-spots daily, making sketches of the solar disc with his 8–cm. telescope, visually, with a power of x83, and counting numbers of the spots and their groups. So that his works are quite similar to those of Zürich observers which are yielding the well known "relative numbers" of sun-spots for past several decades. The weather of Suwa, however, is much more uniform than that of Zürich according to Mr. Misawa's records of past years: and the distribution of numbers of days of solar observations all around the year is so uniform that a new series of "relative numbers" of sun-spots, computed by the writer recently, seems to give the more reliable data for the solar activity than from any other series.

Some weeks ago, the writer tried to find, if any, some relation between the sun-spot relative numbers from Misawa's observations and the series of observed solar constants from the Smithsonian Institution of Washington, D. C. The materials of the latter series are those given by C. G. Abbot, to the writer in 1923 during his staying at Mt. Wilson Observatory, and their dates of observations comprise the interval: 1918 July to 1923 May. Consequently the writer has taken up those materials in the present study which are from 1921 October to 1923 May, the interval being in common in both of these solar observations. All the investigations have been statistic, the treatments[2] of the materials being quite similar to that case in which the writer sought any relation between the areas of calcium flocculi and the solar constants in 1923.

In the first step, the whole material was divided into several groups according to definite intervals of the sun-spot relative numbers, and the mean values were obtained. The following table gives the results:

Table I.

Interval of Relative No.	0–9	10–19	20–29	30–39	40–49	50≦
Mean Value of Solar Const.	1·921	1·922	1·928	1·939	1·936	1·930
Mean Value of Relative No.	0·0	13·2	24·9	35·2	44·2	61·4
No. of Days	160	114	43	16	17	12

Similarly the whole materials were divided according to definite intervals of the solar constants, and mean values were obtained as tabulated below:

Table II.

Interval of Solar Const.	≦1·899	1·900 –1·909	1·910 –1·919	1·920 –1·929	1·930 –1·939	1·940 –1·949	1·959 –1·959	1·960≦
Mean Value of Solar Const.	1·884	1·906	1·914	1·925	1·934	1·944	1·955	1·965
Mean Value of Relative No.	6·8	8·7	12·5	11·1	14·6	18·1	16·7	17·4
No. of Days	37	42	71	61	62	49	18	21

Mean values of both of these two Tables have been plotted in Fig. 1, in which the small circles represent the values from Table I, and the crosses similarly those from Table II.

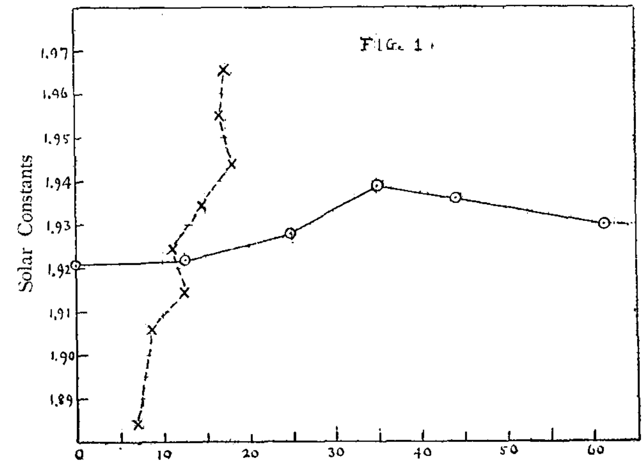
In Fig. 1, *some* kinds of correlations are suggested between the two series. To get a more definite results, the writer divided the whole interval of time into three parts, as:

1) 1921 October to 1922 March,
2) 1922 April to September,
3) 1922 October to 1923 May.

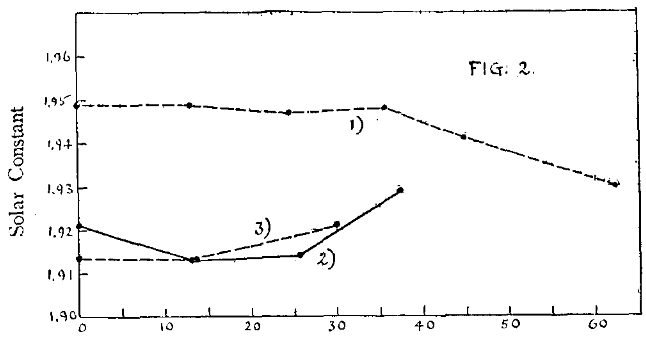
And, for each of these three intervals, the computations of obtaining mean values have been accomplished quite similarly as in the former cases. These results are summarised in Table III below:

Table III.

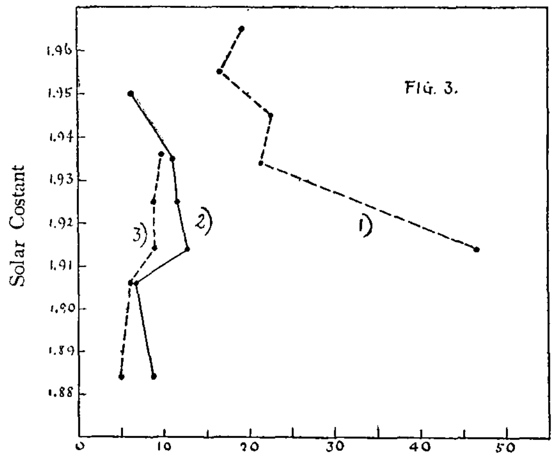
<table>
<tr><th>Epoch</th><th>0–9</th><th>10–19</th><th>20–29</th><th>30–39</th><th>40–49</th><th>50≦</th></tr>
<tr><td>1)</td><td>1·949
0·0
22</td><td>1·949
13·0
32</td><td>1·947
24·5
16</td><td>1·948
35·7
9</td><td>1·941
44·8
11</td><td>1·930
62·3
11</td></tr>
<tr><td>2)</td><td>1·921
0·0
59</td><td>1·913
13·0
37</td><td>1·914
25·5
15</td><td colspan="2">1·929
37·4
10</td><td>—
—
0</td></tr>
<tr><td>3)</td><td>1·914
0·0
79</td><td>1·913
13·4
48</td><td colspan="4">1·921
30·0
16</td></tr>
</table>



Sun-Spot Relative Number from Misawa's Observations.



Sun-Spot Relative Number from Misawa's Observations.



Sun-Spot Relative Number from Misawa's Obs.

For each epoch in the Table, the first row gives the mean solar constant, the second row the mean relative number, and the third row the number of days included.

Table IV.

<table>
<tr><th>Epoch</th><th>≦1·899</th><th>1·900
–1·909</th><th>1·910
–1·919</th><th>1·920
–1·929</th><th>1·930
–1·939</th><th>1·940
–1·949</th><th>1·950
–1·959</th><th>1·960≦</th></tr>
<tr><td>1)</td><td>—
—
0</td><td colspan="3">1·914
46·6
8</td><td>1·934
21·4
22</td><td>1·945
23·2
33</td><td>1·955
16·7
18</td><td>1·965
19·3
19</td></tr>
<tr><td>2)</td><td>1·884
8·8
18</td><td>1·906
6·6
14</td><td>1·914
12·8
27</td><td>1·925
11·6
25</td><td>1·935
11·2
34</td><td colspan="3">1·950
6·2
13</td></tr>
<tr><td>3)</td><td>1·884
5·0
19</td><td>1·906
6·2
26</td><td>1·915
9·0
40</td><td>1·925
8·9
34</td><td colspan="2">1·936
9·9
21</td><td>—
—
0</td><td>—
—
0</td></tr>
</table>

The structure of this Table IV is quite similar to that of Table III. The results of these Tables are plotted in Fig. 2 and Fig. 3 respectively.

It is now clear that statistically speaking there is practically no relation between the sun-spot relative numbers and the solar constants, as seen in these Figures, in so far as our materials are concerned. This is the same conclusion as the writer obtained in 1923 for any apparent relation between the solar constant and the solar activity represented in the calcium flocculi on the disc.

Issei Yamamoto.

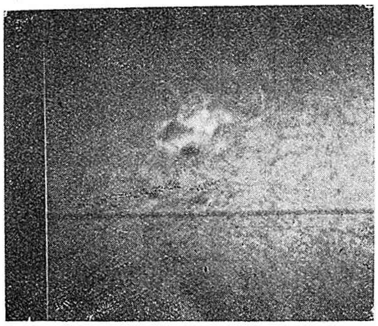
Kyoto University Observatory,
December 20, 1926.

1 This paper is one of the contributions by the writer to the 3rd. Pan-Pacific Science Congress, held at Tokyo in 1926, and read at the Sectional Meeting on Nov. 2, 1926.

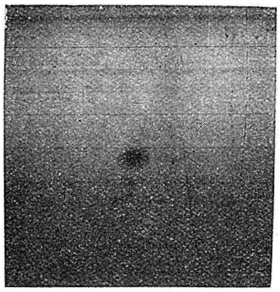
2 The daily values of the sun-spot relative numbers have been computed from the BULLETINs and THE HEAVENS of the Society of Astronomical Friends, Kyoto.

Plate IV.

Mt. Wilson Sun-spot No. 1884, on July 27, 1921, in *full development.*



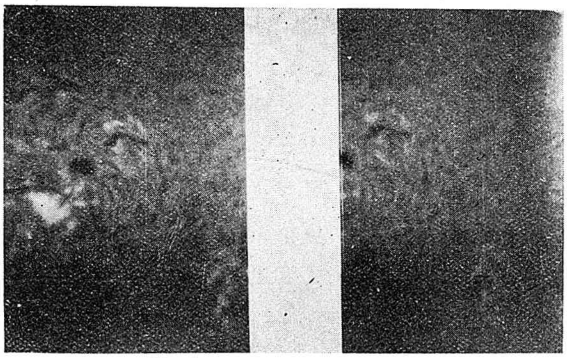
Hα image.



Direct image.

Plate V.

Mt. Wilson Sun-spot No. 1904, on Sept. 19, 1921,
Heat effects just in *balance,*

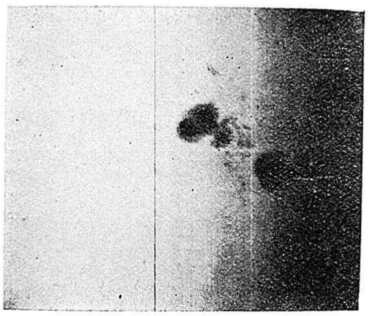


Both are Hα images.

Plate VI.

Mt. Wilson Sun-spot No. 1842, on May 14, 1921; *decaying.*

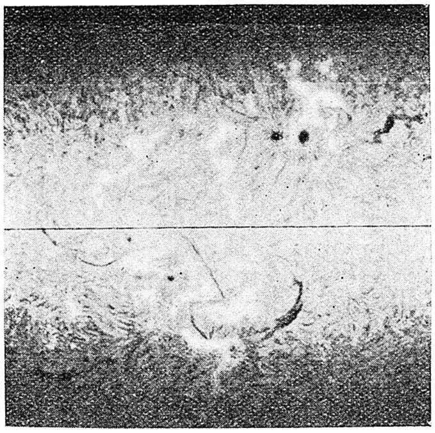
Hα image.



Direct image.

Plate VII.

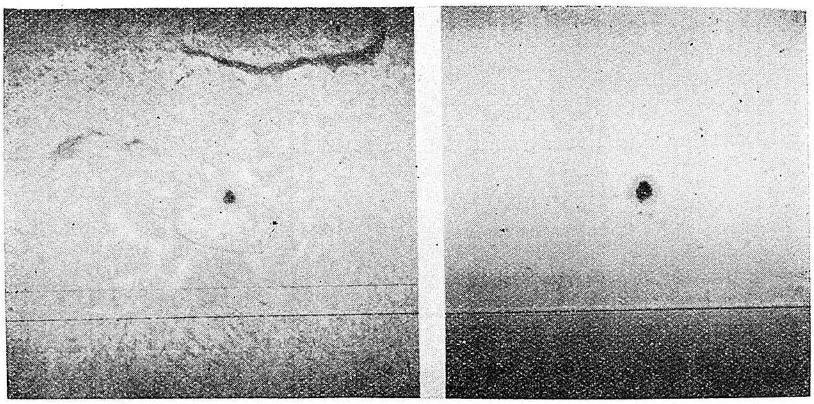
Mt. Wilson Sun-spot No. 1869, on July 7, 1921; in *decay*.



Hα image.

Plate VIII.

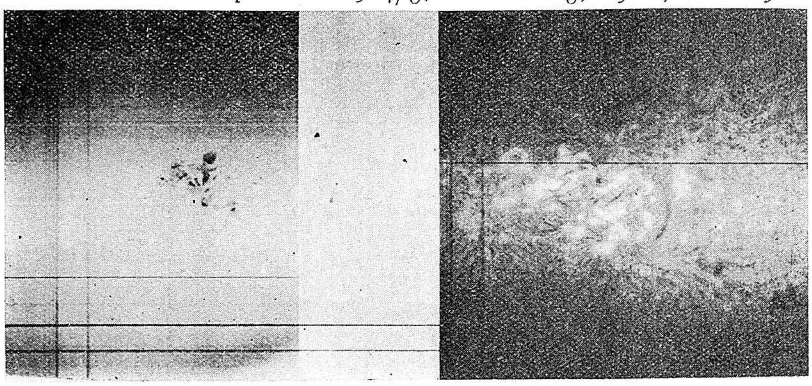
Mt. Wilson Sun-spot No. 1917, on Nov. 18, 1921; *decaying*.



Hα image. Direct image.

Plate IX.

Mt. Wilson Sun-spot No. 1924/5, on Dec. 15, 1921; in *decay*.



Hα image. Direct image.