SMITHSONIAN MISCELLANEOUS COLLECTIONS
VOLUME 95, NUMBER 23

Roebling Fund

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The Lord Baltimore Press
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In the Zeitschrift fur Meteorologie for October 1936, Fuessner has presented evidence which convinced him that the correction factors K and K′ given in association with silver-disk pyrheliometers are inapplicable, and better omitted. If this were true, it would overthrow the results of 25 years of observing, as published in the Annals of the Astrophysical Observatory, and in my recent papers on the dependence of weather on variations of solar radiation.[1]

The following facts contradict Fuessner's conclusion:

1. If the corrections had been omitted in reducing pyrheliometry at Montezuma, Chile, with silver-disk pyrheliometers S. I. 30 and S. I. 31, certain notable changes would have occurred in the solar-constant values reported in table 31, volume 5, Annals of the Astrophysical Observatory. To fix ideas I will first refer to these Annals, volume 5, pages 69, 211, and 213. From these references we note that in the months of August and November, 1929 and 1930, the average temperature of the air at 8 o'clock a. m. (which can have differed but little from that at which the pyrheliometers were read) was higher by 15°1 F. in 1929 and by 12°0 F. in 1930 in November than in August. Transforming these differences to Centigrade and performing the appropriate computations, it appears that the omission of the correction factors would have produced a change in the relative values of the mean solar-constant numbers for these two months of approximately 0.019 calorie in 1929, and 0.016 calorie in 1930. The actual monthly means of the solar-constant values as given on pages 211 and 213 for Montezuma observations were 1.931 and 1.936 in the year 1929, and 1.945 and 1.944 in the year 1930. To speak approximately, the published difference of only 0.005 calorie in 1929 would have become 0.024 calorie, and the published difference of only 0.001 calorie in 1930 would have become 0.015 calorie if the silver-disk pyrheliometer corrections had been omitted.

[1] Smithsonian Miscellaneous Collections, vol. 94, no. 10, 1935; vol. 95, nos. 12, 15, 19, 1936.

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Again, referring to page 252, Annals, volume 5, consider the third line of the first table. The average yearly range from winter to summer of the published mean solar-constant values observed at Montezuma in the period of 10 years from 1921 to 1930 is only from 1.9397 calories (the 10-year mean, June to August) to 1.9398 (the 10-year mean, December to February). If the silver-disk pyrheliometer correction factors were omitted, we see from page 69, and from the

Table 1

Group A

Dates		1935 June 23	June 26	July 13	Aug. 8	Aug. 9	Aug. 16	Aug. 17		Mean Diff.
Mean Bulb Temps. C.	Montezuma...	19°.5	16°.8	17°.3	18°.9	21°.3	18°.4	16°.2		
	St. Katherine.	24°.0	22°.9	22°.2	29°.0	28°.3	26°.8	28°.4		
	Difference....	− 4°.5	− 6°.1	− 4°.0	−10°.1	− 7°.0	+ 8°.4	−12°.2		− 7°.6
Solar Const.	Montezuma...	42 S−	37 S−	44 S	44 S	43 S−	48 S−	32 S−		
	St. Katherine.	41 S	43 S	35 S−	43 S−	43 S−	45 S−	46 S		
Montez. minus St. Kath.	Actual.......	+ 1	− 4	+ 0	+ 1	0	+ 3	−14		− 1
	Without correction..	+11	+ 9	+19	+23	+15	+21	+12		+16

Group B

Dates		1934 Dec. 5	Dec. 17	1935 Jan. 2	Jan. 6	Jan. 10	Feb. 15	Feb. 22	Nov. 15	
Mean Bulb Temps. C.	Montezuma...	24°.7	24°.1	20°.7	21°.3	23°.9	23°.2	24°.6	23°.1	
	St. Katherine.	13°.4	14°.2	6°.3	10°.4	14°.2	12°.1	10°.0	15°.9	
	Difference....	+11°.3	+ 9°.9	+14°.4	+10.°9	+ 9°.7	+11°.1	+14°.6	+ 7°.2	+11°.1
Solar Const.	Montezuma...	51 S−	56 S−	46 S−	49 S−	42 S	49 S−	42 S−	53 S−	
	St. Katherine.	46 S	50 S	48 S−	46 S−	35 S−	42 S−	52 S−	45 S	
Montez. minus St. Kath.	Actual.......	+ 5	+ 6	− 2	+ 3	+ 7	+ 7	−10	+ 8	+ 3
	Without correction..	−19	−15	−33	−20	−14	−17	−41	−7	−21

figures just given above, that for the 10-year averages instead of a yearly range of 0.0001 calorie (or 5/1000 percent) the solar-constant values would have shown an approximate average yearly range from winter to summer of about 0.0180 calorie (or almost an entire 1 percent).

These facts alone show strongly indirect evidence that it is very improbable that the application of the silver-disk correction factors can properly be omitted.

2. We have now two first-rate solar stations, Montezuma and St. Katherine, which lie in opposite hemispheres. Summer at the one comes during the winter at the other. My colleague, L. B. Aldrich, has collected for me groups of solar-constant values of two kinds (table 1). In the one kind, group A, it was winter at Montezuma and summer at St. Katherine. In the other kind, group B, it was summer at Montezuma and winter at St. Katherine. We shall now see what the actual mean values of the solar constant were found to be at the two stations and what they would have been found to be if the silver-disk pyrheliometer correction factors had been omitted. The solar-constant values given are all to be understood as prefixed with 1.9. Thus for 42 read 1.942. They are not absolutely final values, as we are still engaged in removing small sources of error before final publication, but they are the best we now have.

From these typical good days it is seen that with an average temperature difference between group A and group B of $-18^\circ.7$, the actual mean difference of solar-constant values was -0.004 calorie, or 2/10 percent. Had the pyrheliometer corrections been omitted it would have been $+0.037$ calorie, or 2 percent, a discrepancy 10 times as large.

3. The correction factors K and K′ to the silver-disk pyrheliometry were not guessed at. As regards K, they were the results of observation, as regards K′, of well-accepted principles of exact thermometry.

As for the factor K:

In the years 1910 and 1911, L. B. Aldrich and the writer compared silver-disk pyrheliometers S. I. 1, S. I. 2, S. I. 3, S. I. 4, A. P. O. 8, and A. P. O. IV on several different days with temperatures ranging from 11° C. to 43°.5 C. The instruments were repeatedly interchanged as regards temperature. I will omit details, as I shall give below a later comparison made in the same way.

A general summary of all of these experiments of the years 1910 and 1911 is as follows:

Table 2

Comparisons of pyrheliometers	Number	Value of K	Assumed weight
S. I. 1 with A. P. O. 8	11	0.00111	2
S. I. 2 " " "	10	0.00132	2
S. I. 3 " " "	10	0.00104	3 [a]
S. I. 4 " " "	10	0.00034	1/2 [a]
A. P. O. IV with A. P. O. 8	9	0.00108	2
	Weighted mean	0.00109	
	Adopted value	0.0011	

[a] The higher weight given S. I. 3 with A. P. O. 8, and the lower weight given S. I. 4 with A. P. O. 8, depended principally on the wide temperature differences with the former pair, and the narrow temperature differences which happened to have prevailed with the latter pair.

As for the factor K′:

When exposure to the sun drives mercury into the capillary of the thermometer, the length of the column of newly appearing mercury depends on the temperature prevailing in the thermometer stem. The coefficient of linear expansion of mercury in a capillary of the glass used in the thermometer may be taken as 0.00014 per degree Centigrade. The rise of temperature of the pyrheliometer is therefore corrected to what it would have been at a stem temperature of 20° C., namely, by the corrected temperature rise multiplied by $0.00014(20° - T)$.

4. The indirect and direct evidence I have thus far brought forward seems to me more weighty than that which moved Fuessner to his conclusion. For his observations involved the peculiarities of several other types of pyrheliometers and were made in a high latitude at rather low sun. Yet since, if sustained, Fuessner's conclusion invalidates nearly the whole program of the Smithsonian Astrophysical Observatory for the past 25 years, I have felt it to be necessary to redetermine the factor K from new observations. For this purpose I directed Messrs. Zodtner and Greeley, both highly skilled observers of long experience, now operating our station at Table Mountain, California, to make numerous direct comparisons of silver-disk pyrheliometers A. P. O. 10 and A. P. O. 12, using pendulum beats to fix the times of observing. Their program is as follows:

Observing in a warm room with opened window with one pyrheliometer, and immediately outside in winter's cold with the other, a series of absolutely simultaneous comparisons is made. Time signals for both observers were given by a pendulum. Then, without removing the instruments, they are allowed to return to nearly the temperatures of their respective surroundings, and a second comparison is made with exchanged observers. Then, on a second day, or later in the same day, with the instruments exchanged, so that that which was warm has now become cold, and that which was cold has now become warm, the same program is repeated. In this way the instruments and the observers were exchanged again and again, until satisfactory results had been obtained. These observations were made in good sky conditions with fairly high sun at the latitude 34° North.

As the matter is of importance to support the accuracy of the last 25 years of work of the Astrophysical Observatory, I give the results in some detail. In the following table the readings marked R represent the corrected rise of temperature of the pyrheliometer after proper corrections are applied for irregularity of the bore of the stem and for reducing the temperature of the stem to 20° C.

TABLE 3

A. P. O. 12 Bulb temp. T	A. P. O. 12 Corrected R	A. P. O. 10 Bulb temp. T	A. P. O. 10 Corrected R	ΔT	ΔR	ΔΔT	ΔΔR	K
Jan. 21, 1937. F. A. G. reading A. P. O. 12, H. H. Z. reading A. P. O. 10.								
10°8	4.373	−1°6	4.591	−12°4	0.218			
14.8	4.369	+1.3	4.583	−13.5	0.214			
17.1	4.370	+2.5	4.611	−14.6	0.241			
17.4	4.361	+1.4	4.625	−16.0	0.244			
Jan. 26, 1937. F. A. G. reading A. P. O. 12, H. H. Z. reading A. P. O. 10.								
6.3	4.307	14.0	4.398	7.7	0.091	−20.1	0.127	−0.00140
9.1	4.312	18.5	4.437	9.4	0.125	−22.9	0.089	−0.00086
10.4	4.317	22.0	4.442	11.6	0.125	−26.2	0.116	−0.00098
11.0	4.312	24.6	4.438	13.6	0.126	−29.6	0.118	−0.00091
Jan. 21, 1937. H. H. Z. reading A. P. O. 12, F. A. G. reading A. P. O. 10.								
17.9	4.337	1.3	4.583	−16.6	0.246			
17.9	4.326	0.7	4.568	−17.2	0.242			
18.9	4.430 ?	1.7	4.588	−17.2	0.158 ?			
19.3	4.394	2.3	4.604	−17.0	0.210			
Jan. 26, 1937. H. H. Z. reading A. P. O. 12, F. A. G. reading A. P. O. 10.								
7.8	4.352	28.3	4.426	20.5	0.074	−37.1	0.172	−0.00103
9.5	4.363	31.8	4.398	22.3	0.035	−39.5	0.207	−0.00117
10.2	4.368	34.4	4.392	24.2	0.024	−41.4	0.134 ?	−0.00067 ? [a]
10.5	4.348	36.4	4.404	25.9	0.056	−42.9	0.154	−0.00080
Jan. 26, 1937. H. H. Z. reading A. P. O. 12, F. A. G. reading A. P. O. 10.								
13.8	4.456	26.9	4.353	13.1	−0.103			
19.3	4.335	26.2	4.368	6.9	+0.033			
23.2	4.324	24.9	4.375	1.7	0.051			
25.9	4.277	23.7	4.397	−2.2	0.120			
28.1	4.205	22.8	4.320	−5.3	0.115			
Jan. 27, 1937. H. H. Z. reading A. P. O. 12, F. A. G. reading A. P. O. 10.								
24.3	4.256	19.2	4.407	−5.1	0.151	18.2	−0.254	−0.00320 [a]
26.8	4.265	19.1	4.387	−7.7	0.122	14.6	−0.089	−0.00139
28.6	4.252	18.9	4.403	−9.7	0.151	11.4	−0.100	−0.00201 [a]
29.9	4.241	18.7	4.394	−11.2	0.153	9.0	−0.033	−0.00108
30.3	4.214	18.5	4.389	−11.8	0.175	6.5	−0.060	−0.00121
Jan. 26, 1937. F. A. G. reading A. P. O. 12, H. H. Z. reading A. P. O. 10.								
28.1	4.075	17.0	4.237	−11.1	0.162			
30.6	4.071	18.3	4.237	−12.3	0.166			
31.9	3.983	18.6	4.224	−13.3	0.241			
33.0	3.944	17.4	4.141	−15.6	0.197			
Feb. 1, 1937. F. A. G. reading A. P. O. 12, H. H. Z. reading A. P. O. 10.								
10.2	4.456	17.8	4.498	7.6	0.042	−18.7	0.120	−0.00147
10.7	4.401	24.1	4.508	13.4	0.107	−25.7	0.059	−0.00053 [a]
12.6	4.381	28.4	4.485	15.8	0.104	−29.1	0.137	−0.00108
13.4	4.406	31.4	4.496	18.0	0.090	−33.6	0.107	−0.00073
					General mean (13 values)			−0.00109

[a] These 4 values omitted from the mean. Their mean is −0.00160.

The reader will notice that by the method of reduction adopted, whereby for every determination the same instrument is read both warm and cool by the same observer, and the results thus obtained are subtracted, personal equation is eliminated and it is not necessary to know the reduction factors applicable to the instruments compared. The result K=0.00109 is identical with that found by Abbot and Aldrich 25 years ago, and indicates no desirable correction to the published preferred value, K=0.0011.

5. Although our coefficient as heretofore published appears to be applicable to the measurements of the 11 silver-disk pyrheliometers referred to in this paper, some one may raise the question as to whether it is applicable to the instrument S. I. 12 at Potsdam which was employed by Fuessner. Inasmuch as all of the pyrheliometers we have prepared and sent out from the Smithsonian Institution are made of similar materials, and with their receivers of identical sizes, it is highly improbable that the Potsdam pyrheliometer is exceptional.

But there is a further check on this question. In October 1931 the writer carried silver-disk pyrheliometer S. I. 5_{bis} to Potsdam, and at 2 separate times involving a considerable range of temperatures, comparisons were made between it and the Potsdam instrument S. I. 12. The results were uncommonly harmonious, as both instruments were reduced with the usual value of the temperature coefficient K. Hence we may believe that as concerns temperature these two instruments, S. I. 5_{bis} and S. I. 12, are alike. But in 1932 and 1934, silver-disk pyrheliometer S. I. 5_{bis} was carefully compared with the new water-flow double-chamber standard pyrheliometer No. 5 on Mount Wilson. These comparisons involved a range of temperature from 26° to 46° C. We were unable to detect any differences in results showing the influence of this large range in temperatures. Had the coefficient K been omitted, as recommended by Fuessner, a progressive range of 2.2 percent would have appeared. Hence we may be sure that S. I. 5_{bis} is no exception in temperature behavior to the 11 others referred to in this paper, and the Potsdam comparison indicates that the instrument S. I. 12 used in Fuessner's investigations behaved similarly.

Conclusion.—I do not think it devolves on me to suggest what conditions of instruments or observation may have led Fuessner to the false conclusion he has published that the temperature coefficients should be omitted from reductions of measurements with the silver-disk pyrheliometers. I feel sure that if he had reflected that such a change would destroy all of the conclusions on solar variability and its consequences which have come from the work of the Astrophysical

Observatory for 25 years, he would have been kind enough to have consulted me privately before publishing his conclusion. The prolonged hurtful influence of such an important erroneous publication in the literature can never be overtaken by any subsequent correction. However, copies of the present paper will be sent to all owners of silver-disk pyrheliometers, and to many other individuals and institutions likely to be interested.

I must add that since the work published by Fuessner on the absolute scale of pyrheliometry is certainly vitiated so far as it depends on his preferred reduction of the silver-disk pyrheliometer observations, and was moreover of a character that permitted so erroneous a conclusion to be derived as that which he has published, I cannot but feel that its findings as to absolute pyrheliometry must be taken with great reserve. It would be very desirable indeed if a direct comparison could be made at Mount Wilson between the Smithsonian water-flow double-chamber pyrheliometer No. 5, and the standard pyrheliometer which was employed by Fuessner.