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AREQUIPA PYRHELIOMETRY

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AREQUIPA PYRHELIOMETRY

By C. G. ABBOT[1]

In 1910 the Committee on Solar Radiation of the International Union for Cooperation in Solar Research recommended that regular observations of the intensity of solar radiation should be undertaken at additional stations in relatively cloudless regions far removed from existing stations. Prof. E. C. Pickering thereupon offered to undertake such observations at the Arequipa, Peru, station of the Harvard College Observatory if suitable apparatus should be furnished. In conversation between Messrs. Pickering and Abbot it appeared inexpedient to undertake a complete spectrobolometric program for the determination of the solar constant of radiation, but pyrheliometric observations were proposed whenever weather should permit.

By authority of the Secretary of the Smithsonian Institution, a silver disk pyrheliometer was lent for the purpose. This unfortunately was broken in transportation, and much time was lost owing to the delays of communication, so that it was not until the summer of 1912 that silver disk pyrheliometer S. I. 17 arrived at Arequipa. This instrument also was damaged in transportation, by loss of mercury from the cavity in the silver disk. But this defect was skillfully repaired by Señor J. E. Muniz.

It is probable that this alteration involved some slight change in the constant of the instrument, but probably not more than 1 per cent. Until we obtain further knowledge we may therefore retain the value of the constant as stated in "Smithsonian Pyrheliometry Revised," namely, 0.3635.

Individual measurements were made at Arequipa in the manner described in the publication just cited. The general plan of the work, as proposed by Mr. Abbot, was to secure measurements of the pyrheliometer and psychrometer at highest sun, and also at a solar zenith distance of about 70°, corresponding to three times the path in air which obtains at zenith sun. Some delay occurred in making these requirements fully understood at Arequipa, and it is to be

[1] Published by the Smithsonian Institution by request of Director E. C. Pickering of the Harvard College Observatory.

regretted that it has not generally proved practicable in connection with other duties for the observers to secure measurements with the air mass as great as 3.

At Prof. Pickering's desire the observations are reduced and published by the Smithsonian Institution. They were made at Arequipa mainly by Dr. Leon Campbell, and in part by H. Perrine. Computations are mainly by L. B. Aldrich. The position of Arequipa is: Long. $4^h\ 46^m\ 11.73^s$ W., Lat. 16° 22′ 28″ S. Alt., 2,451 meters.

Nothing would be gained by making a series of pyrheliometer measurements at a station no higher than Arequipa if such a series did not throw light on the variability of the sun or on the variability of the transparency of the earth's atmosphere. Two kinds of solar variability are thought to exist. One is associated with that general solar activity which is indicated by faculæ, sun spots, and other visible solar features. This type of variability may be expected to march in rough correlation with the eleven year sun spot cycle. Another type of solar variability appears to be of short irregular intervals in its fluctuations, which are to be measured by days or months rather than by years.

As for the variations of atmospheric transparency, we need not consider those caused by ordinary cloudiness. Pyrheliometer measurements are made only when the sky around the sun is cloudless. Water vapor and dust are the two variable elements which principally affect the atmospheric transmission of solar radiation. Water vapor is effective in two ways: it absorbs radiation of certain wave-lengths, particularly in the infra-red spectrum; and it associates itself with dust to produce haze which scatters the solar radiation of all wave-lengths, thus increasing sky light at the expense of direct sun light.

At so high a station as Arequipa, dust, except as associated with water vapor to form haze, is generally not very effective to diminish solar radiation. But after forest fires or great volcanic eruptions it may be of very great influence.

The hindrance of solar rays by the atmosphere is of course dependent on the length of path of the solar beam therein. For zenith distances (Z) less than 70° the length of atmospheric path is closely proportional to secant Z. Suppose one could observe the solar radiation outside the atmosphere, and also at the earth's surface at zenith distances whose secants were 1, 2, and 3. Let the four values of the intensity of radiation be c_0, c_1, c_2, c_3, respectively. Let the fractions $\frac{c_1}{c_0}$, $\frac{c_2}{c_1}$, $\frac{c_3}{c_2}$, be denoted by a_1, a_2, a_3, respectively. These values may be called the atmospheric transmission coefficients at the given station for the first, second, and third air masses. As shown by Forbes and many subsequent writers, $a_1 < a_2 < a_3$, when, as with the pyrheliometer, a complex beam including many wave-lengths is observed.

Confining ourselves altogether in treating of atmospheric transparency to the consideration of the quantity a_2 for the station Arequipa, as we shall do in this paper, we propose to investigate its dependence on the amount of atmospheric humidity, and on the season of the year. We hope that the observations may be continued long enough to give good correlation factors in these respects, so that in future years abnormal changes like those caused by volcanoes will reveal themselves, and their climatic influences may be studied. Remarks on the influence of the dust from the Katmai eruption of 1912 will appear below.

A second object of the work is to connect by empirical formulæ the values of intensity of solar radiation, atmospheric transmission, and humidity as observed at Arequipa with the values of the solar constant of radiation outside the atmosphere determined by the spectro-bolometer at Mount Wilson. Thus it is hoped to employ Arequipa observations to indicate variations of solar emission of radiation.

No sufficient object to justify printing all Arequipa pyrheliometer values seems to exist. We therefore abridge the results as shown in the following table. Generally observations were secured with secant *Z* values as small as 1.3, and often as small as 1.05. To give the best possible comparable values of pyrheliometer measurements, we have interpolated the values for air mass 1.2.[1] In addition we give the values for 1.0 and 2.0 air masses whenever this can be done with fair certainty. From these latter values come the transmission coefficients a_2. The humidity was determined sometimes by swinging wet and dry thermometers, sometimes by the hydrograph. We have compared results by the two methods, and have expressed all in terms of pressure of aqueous vapor in millimeters of mercury. The values given in the table are the mean values for the interval of time covered by the pyrheliometer measurements of each day. The letters *A*, *M*, and *P* signify morning, noon, and afternoon, respectively. In the two final columns, after the date and the initials of observers and remarks, are given empirical determinations of the solar constant of radiation, of which more will be stated hereafter.

[1] We shall use the term "air mass" in this paper as the equivalent of secant *Z*, taking no acount of barometric pressure.

TABLE I—*Arequipa Pyrheliometry*

Date	No. of values read	Calories at air masses			Mean humidity mm.	Trans-mission coefficient a_2	Remarks	Observer	Solar constant	
		1.2	1	2					Formula I	Formula II
1912										
Aug. 13 A. ...	15	1.410	.....	.....	.....	.....	Sky variable.	L. C.	.....	.....
P. ...	10	1.422	.....	.....	.....	.....	Sky variable.	L. C., H. P.	.....	.....
15 A. ...	8	1.434	1.474	1.273	.....	.864	Sky clear.	L. C.	.....	.....
P. ...	20	1.452	1.493	1.290	.....	.865	Sky clear.	L. C., H. P.	.....	.....
16 A. ...	6	1.440	.....	.....	.....	.....	Windy.	L. C., H. P.	.....	.....
P. ...	15	1.456	1.518	1.210	.....	.797	Sky clear.	L. C., H. P.	.....	.....
17 P. ...	15	1.417	1.470	1.200	.....	.817	Sky 0-1.	L. C., H. P.	.....	.....
19 A. ...	6	1.533	.....	.....	.....	.....	Sky 2-1.	L. C., H. P.	.....	.....
P. ...	6	1.570	.....	.....	.....	.....	Windy, slight haze.	L. C., H. P.	.....	.....
20 A. ...	4	1.465	.....	.....	.....	.....	Haze, sky 1-2.	L. C., H. P.	.....	.....
P. ...	7	1.440	.....	.....	.....	.....	Clouds very near.	L. C., H. P.	.....	.....
22 A. ...	6	1.503	.....	.....	.....	.....	Sky 2-3, sun clear.	L. C., H. P.	.....	.....
P. ...	10	1.500	1.532	1.368	.....	.894	Sky 2-3, sun clear.	L. C., H. P.	.....	.....
23 A. ...	5	1.463	.....	.....	.....	.....	Sky clear, 1-2.	L. C., H. P.	.....	.....
P. ...	6	1.483	.....	.....	.....	.....	Sky clear, 1-2.	L. C., H. P.	.....	.....
24 A. ...	6	1.484	.....	.....	.....	.....	Windy, sky 2.	L. C., H. P.	.....	.....
P. ...	2	1.467	.....	.....	.....	.....	Sky 2.	L. C., H. P.	.....	.....
28 A. ...	3	1.540	.....	.....	.....	.....	Sky 0.	L. C.	.....	.....
P. ...	6	1.540	.....	.....	.....	.....	Windy, sky 0.	H. P.	.....	.....
29 A. ...	5	1.540	.....	.....	.....	.....	Sky 0.	L. C., H. P.	.....	.....
P. ...	5	1.540	.....	.....	.....	.....	Sky 0.	L. C., H. P.	.....	.....
30 A. ...	4	1.535	.....	.....	.....	.....	Sky 0.	L. C.	.....	.....
P. ...	4	1.518	.....	.....	.....	.....	Sky 0, windy.	L. C.	.....	.....
31 A. ...	4	1.497	.....	.....	.....	.....	Sky 0.	L. C., H. P.	.....	.....
P. ...	6	1.517	.....	.....	.....	.....	Sky 0, windy.	H. P.	.....	.....
Sept. 1 A. ...	2	1.493	.....	.....	.....	.....	Sky 0, windy.	L. C.	.....	.....
2 A. ...	6	1.504	1.557	1.300	.....	.835	Sky 0.	L. C.	.....	.....
P. ...	2	1.497	.....	.....	.....	.....	Sky 0.	L. C.	.....	.....
3 A. ...	3	1.512	.....	.....	.....	.....	Sky 0.	L. C.	.....	.....
P. ...	4	1.512	.....	.....	.....	.....	Sky 0, windy.	L. C.	.....	.....

TABLE I—*Arequipa Pyrheliometry* (Continued)

Date	No. of values read.	Calories at air masses 1.2	1	2	Mean humidity mm.	Trans-mission coefficient a_2	Remarks	Observer	Solar constant Formula I	Formula II
Sept. 4 A. ...	3	1.488	.....	.....	.....	.....	Sky 0-1.	L. C.	.....	.....
P. ...	4	1.488	.....	.....	.....	.....	Sky 1.	L. C.	.....	.....
5 A. ...	2	1.450	.....	.....	.....	.....	....	L. C.	.....	.....
P. ...	5	1.450	.....	.....	.....	.....	Sky 2.	H. P., L. C.	.....	.....
6 A. ...	2	1.498	.....	.....	.....	.....	Sky 1.	L. C.	.....	.....
P. ...	4	1.498	.....	.....	.....	.....	Sky 1.	L. C.	.....	.....
7 A. ...	2	.....	.....	.....	.....	.....	Sky 4.	H. P.	.....	.....
P. ...	4	1.520	.....	.....	.....	.....	Sky 3.	H. P.	.....	.....
8 A. ...	2	1.462	.....	.....	.....	.....	Windy, sky 2.	L. C.	.....	.....
P. ...	4	1.462	.....	.....	.....	.....	Windy, sky 2.	L. C.	.....	.....
9 A. ...	4	1.490	.....	.....	.....	.....	Sky 1.	L. C.	.....	.....
P. ...	4	1.490	.....	.....	.....	.....	Sky 1.	L. C., H. P.	.....	.....
10 P. ...	6	1.537	.....	.....	.....	.....	Sky 0.	L. C.	.....	.....
11 P. ...	6	1.448	.....	.....	.....	.....	Sky 1-2.	H. P., L. C.	.....	.....
12 P. ...	6	1.495	.....	.....	.....	.....	Sky 0.	L. C.	.....	.....
13 A. ...	6	1.512	.....	.....	.....	.....	Sky 1, hazy.	L. C.	.....	.....
14 P. ...	5	1.522	.....	.....	.....	.....	Sky 0.	L. C.	.....	.....
15 A. ...	6	1.522	.....	.....	.....	.....	Sky 0.	L. C.	.....	.....
16 A. ...	6	1.495	.....	.....	.....	.....	Sky 0.	L. C.	.....	.....
17 A. ...	6	1.480	.....	.....	.....	.....	Sky clear.	L. C.	.....	.....
18 A. ...	5	1.486	.....	.....	.....	.....	Sky 0, windy.	L. C.	.....	.....
19 A. ...	6	1.468	.....	.....	.....	.....	Sky 2.	L. C.	.....	.....
20 A. ...	6	1.494	.....	.....	.....	.....	Sky 5, clear near sun.	L. C.	.....	.....
22 A. ...	6	1.480	.....	.....	.....	.....	Sky 4, clear near sun.	L. C.	.....	.....
24 A. ...	8	1.423	1.483	1.194	.....	.806	Sky 1-2.	L. C.	.....	.....
25 A. ...	7	1.412	.....	.....	.....	.....	Sky 2.	L. C.	.....	.....
27 A. ...	4	1.457	.....	.....	.....	.....	Sky 3, sky variable.	L. C.	.....	.....
30 A. ...	6	1.522	.....	.....	.....	.....	Sky 2.	L. C.	.....	.....
Oct. 1 A. & P.	10	1.513	.....	.....	.....	.....	Sky 0, P. M. better.	L. C.	.....	.....
2 A. ...	5	1.513	.....	.....	.....	.....	Sky 1.	L. C.	.....	.....
3 M. .	4	1.571	.....	.....	.....	.....	Sky scattered cirri, but thin.	L. C.	.....	.....

TABLE 1—*Arequipa Pyrheliometry* (Continued)

Date	No. of values read	Calories at air masses			Mean humidity mm.	Transmission coefficient a_2	Remarks	Observer	Solar constant	
		1.2	1	2					Formula I	Formula II
Oct. 6 M.	5	1.503	.....	.....	.....	.....	Sky 4.	L. C.	.....	.....
8 A.	10	1.540	.....	.....	.....	.....	Sky 1-2.	L. C.	.....	.....
P.	12	1.540	.....	.....	.....	.....	Sky 1, hazy.	L. C.	.....	.....
9 A.	33	1.536	1.561	1.436	.....	.920	Sky 0-1-2, hazy.	L. C.	.....	.....
P.	20	1.497	1.541	1.316	.....	.854	Sky 0-1, slight haze.	L. C.	.....	.....
10 A.	11	1.552	1.581	1.438	.....	.910	Sky 0.	L. C.	.....	.....
11 A.	9	1.583	.....	.....	.....	.....	Sky 0, exceptionally clear.	L. C.	.....	.....
12 A.	6	1.609	.....	.....	.....	.....	Exceptionally clear.	L. C.	.....	.....
13 M.	6	1.586	.....	.....	.....	.....	Sky 1.	L. C.	.....	.....
14 A.	5	1.614	.....	.....	.....	.....	Sky very clear.	L. C.	.....	.....
15 A.	8	1.600	.....	.....	.....	.....	Sky very clear.	L. C.	.....	.....
16 M.	5	1.577	.....	.....	.....	.....	Sky 0.	L. C.	.....	.....
17 M.	7	1.624	.....	.....	.....	.....	Sky 0.	H. P., L. C.	.....	.....
18 A.	5	1.560	.....	.....	.....	.....	Sky 1.	L. C.	.....	.....
19 A.	10	1.578	.....	.....	.....	.....	Sky 2-1.	H. P., L. C.	.....	.....
20 M.	5	1.549	.....	.....	.....	.....	Sky 0-1.	L. C.	.....	.....
21 A.	22	1.561	1.590	1.440	.....	.906	Sky 0.	L. C.	.....	.....
P.	8	1.516	1.595?	1.200?	.....	.755?	Sky 0, then windy and dust in air.	L. C.	.....	.....
22 M.	5	1.564	.....	.....	.....	.....	Sky 1.	L. C.	.....	.....
23 M.	5	1.550	.....	.....	.....	.....	Sky 0, hazy near horizon.	L. C.	.....	.....
24 M.	5	1.562	.....	.....	.....	.....	Sky 4.	H. P.	.....	.....
Nov. 4 P.	5	1.540	.....	.....	.....	.....	Sky 1, sun clear.	L. C.	.....	.....
9 A.	5	1.521	.....	.....	.....	.....	Sky 2.	L. C.	.....	.....
18 M.	5	1.529	.....	.....	.....	.....	Sky 2.	H. P.	.....	.....
19 M.	5	1.585	.....	.....	.....	.....	Sky 4.	H. P.	.....	.....
20 M.	5	1.570	.....	.....	.....	.....	Sky 0, slight haze.	L. C.	.....	.....
21 M.	5	1.527	.....	.....	.....	.....	Sky 0.	L. C.	.....	.....
25 A.	6	1.554	.....	.....	3.00	.....	Sky 1.	L. C.	1.87	.....

TABLE I—*Arequipa Pyrheliometry* (Continued)

Date	No. of values read	Calories at air masses 1.2	1	2	Mean humidity mm.	Transmission coefficient a_2	Remarks	Observer	Solar constant Formula I	Formula II
Dec. 4 A. ...	6	1.528	.....	.....	6.76	.....	Sky 2.	L. C.	1.94	.....
6 A. ...	4	1.534	.....	.....	8.19	.....	Sky 3.	L. C.	1.98	.....
11 A. ...	12	1.490	1.546	1.270	6.88	.821	Sky 2.	L. C.	1.90	1.92
12 A. ...	10	1.555	1.583	1.443	8.04	.912	Sky 0-1.	L. C.	2.00	1.96
P. ...	4	1.542	1.603	1.300	(8.00)	.811	Sky 4.	H. P.	1.99	2.03
15 A. ...	8	1.470	.....	.....	5.79	.....	Sky 3-4, then clouds.	H. P.	1.85	.....
1913										
Jan. 3 A. ...	6	1.443	1.470	1.334	8.26	.907	Sky 3-5, then clouds.	L. C.	1.86	1.82
4 A. ...	10	1.390	1.450	1.143	10.20	.788	Sky 4, sun clear.	L. C.	1.82	1.91
6 A. ...	12	1.526	1.571	1.349	8.64	.859	Sky 3-2-1.	L. C.	1.98	1.99
8 A. ...	4	1.500	.....	.....	8.33	.....	Sky 3.	H. P.	1.94	.....
10 A. ...	6	1.486	.....	.....	9.32	.....	Sky 2.	L. C.	1.93	.....
Feb. 4 P. ...	4	1.464	.....	.....	9.65	.....	Sky 1, windy.	L. C.	1.92	.....
Mar. 24 A. ...	16	1.321	1.362	1.150	8.00	.845	Sky 2-2-3, hazy.	L. C.	1.75	.....
Apr. 1 A. ...	10	1.387	1.427	1.230	7.90	.862	Sky 2, then 5.	L. C.	1.84	1.84
2 A. ...	10	1.393	1.450	1.172	7.25	.808	Sky 3.	L. C.	1.84	1.88
7 A. ...	12	1.430	1.478	1.237	8.90	.836	Sky 0.	L. C.	1.92	1.96
9 A. ...	10	1.394	1.431	1.243	8.75	.869	Sky 4-5, then cloudy.	L. C.	1.87	1.87
25 P. ...	10	1.439	1.474	1.298	5.07	.881	Sky 1.	L. C.	1.88	1.90
30 P. ...	2	1.430	.....	.....	(3.5)?	.....	Sky 2, then clouds.	L. C.	1.80?	.....
May 1 A. ...	6	1.330	1.371	1.160	(3.7)?	.846	Sky 1, then clouds.	L. C.	1.70?	.....
4 A. ...	12	1.518	1.568	1.320	3.90	.842	Sky 0.	L. C.	1.94	1.96
5 A. ...	12	1.508	1.530	1.419	3.80	.927	Sky 0.	L. C.	1.92	1.88
6 P. ...	12	1.525	1.571	1.342	4.72	.854	Sky 0.	L. C.	1.98	1.98
7 P. ...	8	1.473	1.510	1.321	5.99	.875	Sky 2.	L. C.	1.95	1.92
8 P. ...	12	1.480	1.515	1.346	4.61	.889	Sky 2.	L. C.	1.92	1.89
10 A. ...	12	1.494	.....	.....	3.78	.....	Sky 2.	L. C.	1.90	.....
11 A. ...	12	1.506	1.543	1.353	4.47	.877	Sky 2.	L. C.	1.95	1.94
13 A. ...	12	1.465	1.510	1.283	5.48	.850	Sky 2-1.	L. C.	1.94	1.93
21 A. ...	8	1.473	.....	.....	5.27	.....	Sky gen. clear.	L. C.	1.94	.....

TABLE I—*Arequipa Pyrheliometry* (Continued)

Date	No. of values read	Calories at air masses 1.2	1	2	Mean humidity mm.	Trans-mission coefficient a_2	Remarks	Observer	Solar constant Formula I	Formula II
May 23 A. ...	5	1.463	.....	.....	(3.00)	.....	Sky 2.	L. C.	1.84?	.....
24 A. ...	8	1.490	1.510	1.417	2.74	.939	Sky clear.	L. C.	1.86	1.83
June 2 A. ...	8	1.497	.....	.....	3.12	.....	Sky 1.	L. C.	1.90	.....
3 P. ...	6	1.560	1.598	1.408	2.74	.881	Sky clear.	L. C.	1.95	1.97
4 P. ...	10	1.583	1.630	1.393	4.00	.855	Sky 1.	L. C.	2.04	2.05
13 P. ...	4	1.468	.....	.....	4.79	.....	Sky 1, then clouds.	L. C.	1.93	.....
14 A. ...	6	1.403	1.453	1.203	4.22	.829	Sky 3, windy.	L. C.	1.84	1.86
15 A. ...	4	1.416	1.454	1.260	3.81	.868	Sky ?	L. C., H. P.	1.84	1.84
16 P. ...	6	1.434	1.469	1.297	5.72	.883	Sky 2, hazy.	L. C.	1.92	1.89
17 P. ...	6	1.489	1.527	1.338	4.56	.875	Sky 4, then clear.	L. C.	1.95	1.94
18 P. ...	4	1.497	1.530	1.367	3.76	.894	Sky 0.	L. C.	1.94	1.92
19 P. ...	4	1.483	1.513	1.356	4.42	.896	Sky 0.	L. C.	1.94	1.91
24 P. ...	4	1.597	1.635	1.440	3.30	.882	Sky 0, some haze.	L. C.	2.04	2.03
25 P. ...	4	1.567	1.613	1.380	2.23	.856	Sky 0.	L. C.	1.94	2.00
26 P. ...	4	1.540	1.578	1.398	3.04	.886	Sky 0.	L. C.	1.96	1.98
27 A. ...	6	1.522	1.550	1.410	2.85	.910	Sky 1, windy and dusty.	L. C.	1.92	1.91
28 A. ...	4	1.460	1.485	1.357	3.07	.915	Sky 2, hazy from near volcano.	L. C.	1.86	1.84
July 1 A. ...	4	1.460	1.498	1.312	4.20	.875	Hazy.	L. C.	1.91	1.90
2 P. ...	4	1.505	1.550	1.326	3.00	.856	Sky 1.	L. C.	1.91	1.94
3 M. .	2	1.397	.....	.....	5.38	.....	Sky 1, windy.	L. C.	1.86	.....
7 P. ...	4	1.480	1.512	1.352	2.70	.895	Sky clear.	L. C.	1.86	1.87
8 P. ...	4	1.491	1.520	1.371	2.25	.902	Sky clear.	L. C.	1.85	1.87
13 P. ...	2	1.463	.....	.....	2.20	.....	Sky 0.	L. C.	1.82	.....
14 P. ...	4	1.476	1.510	1.339	2.55	.887	Sky 0.	L. C.	1.85	1.87
15 P. ...	4	1.486	1.560	1.192	2.05	.764	Sky 1, hazy.	H. P., L. C.	1.83	1.97
17 A.&P.	6	.....	.....	.....	2.50	.....	Sky 1-0.	L. C.	.....	.....
18 P. ...	4	1.504	1.530	1.400	3.00	.915	Sky 0.	L. C.	1.91	1.87
19 A. ...	6	1.451	1.479	1.345	3.00	.909	Sky 1, windy.	L. C.	1.85	1.83
20 A. ...	2	.....	.....	.....	2.68	.....	Sky 2, then clouds.	L. C.	.....	1.89

TABLE 1—*Arequipa Pyrheliometry* (Continued)

Date	No. of values read	Calories at air masses			Mean humidity mm.	Transmission coefficient a_2	Remarks	Observer	Solar constant	
		1.2	1	2					Formula I	Formula II
July 22 P. ...	4	1.450	1.491	1.282	4.01	.860	Sky 1, clear.	L. C.	1.89	1.83
25 P. ...	4	1.436	1.470	1.298	2.91	.883	Sky 1.	L. C.	1.82	.....
26 P. ...	4	1.452	1.490	1.300	2.95	.873	Sky 1.	L. C.	1.85	1.86
27 P. ...	2	1.474	.....	.....	3.53	.....	Sky 1, then clouds.	L. C.	1.90	.....
29 P. ...	6	1.511	1.550	1.357	3.44	.876	Sky 0.	L. C.	1.94	1.94
30 P. ...	4	1.520	1.563	1.347	3.08	.862	Sky clear.	L. C.	1.93	1.95
31 P. ...	4	1.432	1.463	1.310	2.95	.897	Sky 1.	L. C.	1.82	1.82
Aug. 4 P. ...	4	1.540	1.586	1.340	3.55	.845	Sky clear.	L. C.	1.98	2.01
5 P. ...	4	1.550	1.590	1.408	2.94	.886	Sky 2-1.	L. C.	1.95	.....
6 P. ...	4	1.481	1.524	1.309	3.14	.859	Sky clear.	L. C., H. P.	1.88	1.90
7 P. ...	4	1.518	1.565	1.333	2.65	.852	Sky clear.	L. C.	1.90	.....
8 P. ...	4	1.334	1.380	1.155	3.30	.837	Very hazy and dusty	L. C.	1.70	.....
12 P. ...	4	1.457	1.496	1.297	4.25	.867	Sky 1, sun clear.	L. C	1.89	1.89
13 P. ...	2	1.403	.....	.....	3.79	.....	Sky 3, then clouds.	L. C.	1.81	.....
14 P. ...	4	1.428	1.467	1.254	3.60	.854	Sky 2, clouds near.	L. C.	1.83	1.85
15 P. ...	4	1.439	1.477	1.279	3.96	.866	Sky 1.	L. C.	1.85	1.85
16 A. ...	4	1.390?	.....	.....	5.78	.....	Sky 2.	C. W.	1.84?	.....
17 A. ...	4	1.348	1.392	1.168	4.57	.839	Sky 6.	C. W.	1.76	1.77
18 P. ...	4	1.500	1.530	1.361	6.05	.890	Sky 0.	H. P.	1.99	1.96
21 P. ...	2	1.568	.....	.....	1.60(?)	.....	Sky 3, then clouds.	L. C.	1.86	.....
22 P. ...	2	1.503	.....	.....	3.11	.....	Sky 8.	?	1.88	.....
25 P. ...	2	1.452	.....	.....	5.20	.....	Sky 1.	L. C.	1.90	.....
26 P. ...	4	1.442	1.493	1.227	4.16	.822	Sky 1.	L. C.	1.85	1.88
27 P. ...	4	1.427	1.469	1.262	5.14	.859	Sky 1.	L. C.	1.86	1.86
28 P. ...	2	1.423	.....	.....	5.58	.....	Sky 3.	L. C.	1.87	.....
30 P. ...	2	1.483	.....	.....	6.25	.....	Sky 3.	L. C.	1.96	.....
Sept. 1 A. ...	4	1.438	1.495	1.206	4.46	.808	Sky 1.	L. C.	1.85	1.89
2 P. ...	4	1.452	1.510	1.247	4.05	.826	Sky 1.	L. C.	1.85	1.88
3 P. ...	4	1.525	1.579	1.306	4.56	.827	Sky clear.	L. C., H. P.	1.96	2.00
4 P. ...	4	1.495	1.523	1.373	4.30	.902	Sky 0-1.	L. C.	1.91	1.89
8 P. ...	4	1.528	1.570	1.363	3.91	.869	Sky 0.	L. C.	1.94	1.95

TABLE 1—*Arequipa Pyrheliometry* (Continued)

Date	No. of values read.	Calories at air masses			Mean humidity mm.	Transmission coefficient a_2	Remarks	Observer	Solar constant	
		1.2	1	2					Formula I	Formula II
Sept. 9 P. ...	4	1.500	1.567	1.224	4.31	.781	Sky 0, then hazy and very dusty.	L. C.	1.92	1.99
10 P. ...	4	1.452	1.498	1.278	3.87	.853	Sky 2.	L. C.	1.84	1.84
12 P. ...	2	1.474	.....	.....	3.81	.....	Sky 1.	L. C.	1.86	.....
17 P. ...	4	1.514	1.547	1.384	3.75	.894	Sky 0.	L. C.	1.91	1.89
18 P. ...	4	1.483	1.537	1.270	3.91	.827	Sky 0.	L. C.	1.88	1.91
21 P. ...	2	1.402	.....	.....	3.79	.....	Sky 1.	L. C.	1.77	.....
22 P. ...	4	1.499	1.535	1.357	4.74	.884	Sky 1-0.	L. C.	1.92	1.90
23 P. ...	4	1.543	1.588	1.357	4.64	.854	Sky 0.	L. C.	1.98	1.98
26 P. ...	4	1.406	1.447	1.249	6.41	.864	Sky 1, clear.	L. C.	1.84	1.83
27 P. ...	4	1.440	1.485	1.261	6.93	.849	Sky 1.	L. C.	1.89	1.90
28 P. ...	4	1.515	1.563	1.324	7.12	.847	Sky 1, clear.	L. C.	2.00	2.00
29 P. ...	4	1.500	1.535	1.356	6.67	.883	Sky 0-1.	H. P.	1.97	1.93
30 P. ...	4	1.447	1.498	1.238	6.41	.826	Sky 1, very windy.	H. P., L. C.	1.89	1.91
Oct. 1 P. ...	4	1.435	1.500	1.178	5.25	.785	Sky 2.	L. C.	1.84	1.90
2 P. ...	6	1.471	1.510	1.305	4.70	.864	Sky (?).	H. P., C. W.	1.88	1.87
3 P. ...	4	1.443	1.485	1.273	5.08	.857	Sky 1.	L. C.	1.85	1.85
4 P. ...	4	1.438	1.488	1.245	5.43	.836	Sky 1, clear, windy.	L. C.	1.86	1.86
6 P. ...	4	1.480	1.530	1.280	4.97	.836	Sky 1.	L. C.	1.89	1.90
18 P. ...	4	1.440	.....	.....	6.64	.....	Sky 5-4.	H. P., L. C.	1.87	.....
20 P. ...	2	1.418	.....	.....	6.68	.....	Sky (?).	H. P.	1.84	.....
21 A. ...	2	1.302	.....	.....	5.54	.....	Sky 4, variable.	L. C.	1.66	.....
22 A. ...	2	1.408	.....	.....	5.91	.....	Sky 5.	L. C.	1.81	.....
23 P. ...	2	1.330	.....	.....	7.31	.....	Sky 3.	L. C.	1.73	.....
25 A. ...	4	1.458	.....	.....	7.71	.....	Sky 1-2.	L. C.	1.90	.....
29 A. ...	4	1.403	.....	.....	6.55	.....	Sky 2.	L. C.	1.81	.....
31 A. ...	4	1.496	1.563	1.225	6.18	.780	Sky 2.	L. C.	1.92	1.98
Nov. 1 P. ...	2	1.535	.....	.....	5.07	.....	Sky 2.	L. C.	1.94	.....
8 A. ...	2	1.495	.....	.....	5.44	.....	Sky 2.	L. C.	1.89	.....
14 P. ...	2	1.470	.....	.....	5.80	.....	Sky 5, windy.	H. P.	1.87	.....
16 A. ...	2	1.468	.....	.....	6.86	.....	Sky 4.	L. C.	1.88	.....

TABLE I—*Arequipa Pyrheliometry* (Continued)

Date	No. of values read	Calories at air masses			Mean humidity mm.	Transmission coefficient a_2	Remarks	Observer	Solar constant	
		1.2	1	2					Formula I	Formula II
Nov. 17 A. ...	4	1.429	.....	.....	8.50	.....	Sky 4-6.	L. C.	1.86	.....
18 A. ...	4	1.479	.....	.....	6.54	.....	Sky 4-3.	L. C.	1.89	.....
25 A. ...	2	1.560	.....	.....	7.61	.....	Sky 2.	L. C.	2.01	.....
26 A. ...	4	1.525	.....	.....	7.82	.....	Sky 1-3, windy.	L. C., H. P.	1.97	.....
27 A. ...	6	1.507	1.563	1.277	6.55	.817	Sky 1-2.	L. C.	1.92	1.95
28 P. ...	4	1.502	1.551	1.300	6.50	.838	Sky 3.	L. C.	1.92	1.93
29 A. ...	4	1.530	.....	.....	6.48	.....	Sky clear 3, windy.	L. C., H. P.	1.95	.....
30 P. ...	4	1.538	1.577	1.380	7.27	.875	Sky 4-3.	L. C.	1.98	1.96
Dec. 1 A.&P.	6	1.570	1.613	1.389	5.78	.861	Sky 0-1.	L. C.	1.98	1.96
2 A.&P.	6	1.565	1.607	1.397	5.00	.869	Sky 0.	L. C., H. P.	1.95	1.93
3 P. ...	4	1.515	1.569	1.303	6.02	.830	Sky 2-3, very windy.	L. C.	1.91	1.93
11 A.&P.	6	1.550	1.609	1.307	5.70	.812	Sky clear, 2.	L. C.	1.95	1.98
12 A.&P.	6	1.521	1.597	1.228	5.00	.768	Sky 2, clear.	L. C.	1.89	1.96
13 P. ...	2	1.487	.....	.....	7.56	.....	Sky 4.	L. C.	1.91	.....
14 A.&P.	4	1.515	.....	.....	6.78	.....	Sky 1-2.	L. C.	1.93	.....
17 A. ...	4	1.471	.....	.....	7.88	.....	Sky 3, windy.	L. C.	1.89	.....
19 P. ...	2	1.507	.....	.....	6.58	.....	Sky 5, windy.	H. P.	1.92	.....
20 A.&P.	4	1.520	.....	.....	11.18	.....	Sky 1, windy.	H. P.	2.01	.....
21 A.&P.	4	1.540?	.....	.....	12.70	.....	Sky 1-3, windy.	L. C., H. P.	2.05?	.....
23 A. ...	2	1.465	.....	.....	8.20	.....	Sun clear.	H. P.	1.89	.....
28 A.&P.	8	1.490	1.547	1.262	7.77	.816	Sky 2-4-3, windy.	H. P., L. C.	1.92	1.95
29 A.&P.	4	1.532	.....	.....	5.98	.....	Sky 0-1.	H. P.	1.92	.....
30 A.&P.	6	1.521	1.570	1.323	6.42	.843	Sky 2-3, windy.	C. W., H. P.	1.93	1.93
1914										
Jan. 2 A.&P.	6	1.506	.....	.....	8.01	.....	Sky 1-0-2.	H. P., C. W.	1.94	.....
3 A.&P.	6	1.560?	1.627?	1.300?	5.96	.799	Sky 1-4, very windy.	C. W., H. P.	1.97?	2.01
6 A. ...	6	1.473	1.518	1.297	6.00	.854	Sky 6-5-5.	L. C., C. W., H. P.	1.86	1.85
10 A. ...	2	1.496	.....	.....	9.57	.....	Sky 6.	H. P.	1.95	.....
11 A. ...	4	1.520	.....	.....	8.29	.....	Sky 4-3.	H. P., L. C.	1.96	.....

TABLE 1—*Arequipa Pyrheliometry* (Continued)

Date	No. of values read	Calories at air masses 1.2	1	2	Mean humidity mm.	Transmission coefficient a_2	Remarks	Observer	Solar constant Formula I	Formula II
Jan. 12 A. & P.	6	1.465	1.515	1.260	5.31(?)	.832	Sky 0-2-4, windy.	H. P.	1.83?	1.84
15 A.	8	1.574	1.615	1.410	6.36	.873	Sky clear, windy.	L. C.	2.00	1.97
20 A.	2	1.427	.....	.....	8.30	.....	Sky 6.	L. C.	1.84	.....
21 A.	4	1.461	1.512	1.259	9.23	.833	Sky 1-2.	L. C.	1.90	1.94
29 A.	4	1.503	1.537	1.376	5.95	.....	Sky 3.	L. C.	1.89	.....
30 A.	2	1.460	.....	.....	7.90	.....	Sky 4.	L. C.	1.88	.....
Feb. 2 A.	3	1.420	1.450	1.303	9.42	.889	Sky 4-5.	L. C.	1.86	1.85
9 A.	2	1.455	.....	.....	9.99	.....	Sky 4.	L. C.	1.91	.....
12 A.	4	1.455	.....	.....	10.27	.....	Sky 5-4.	H. P., L. C.	1.92	.....
13 A.	6	1.484	.....	.....	10.27	.....	Sky 5, then clearer.	L. C.	1.96	.....
14 A.	4	1.470	.....	.....	9.74	.....	Sky 4-3.	L. C.	1.93	.....
15 A.	4	1.468	.....	.....	9.19	.....	Sky 2-4.	H. P.	1.92	.....
16 A.	4	1.440	1.500	1.260	9.72	.840	Sky 3-2.	L. C.	1.90	1.94
18 A.	4	1.456	1.500	1.282	10.95	.855	Sky 4-6.	L. C.	1.94	1.98
19 A.	2	.....	.....	.....	10.11	.....	Sky 3.	L. C.	.....	.....
23 A.	4	1.520?	.....	.....	7.71	.....	Sky 1.	L. C.	1.98?	.....
24 A.	4	1.480	.....	.....	8.87	.....	Sky 1.	L. C.	1.94	.....
27 A.	2	1.450	.....	.....	9.09	.....	Sky 5.	L. C.	1.92	.....
Mar. 3 A.	4	1.511	.....	.....	7.64	.....	Sky 5-3.	L. C.	1.97	.....
5 A.	4	1.560	.....	.....	13.08	.....	Sky 5.	L. C.	2.11	.....
6 A.	6	1.500	1.537	1.344	7.39	.874	Sky 4-3-2.	L. C.	1.96	1.94
7 A.	4	1.539	1.578	1.383	.816	.876	Sky 2.	L. C.	2.03	2.01
10 A.	4	1.440	1.470	1.320	8.16	.898	Sky 2.	L. C.	1.84	1.87
15 A.	4	1.454	1.473	1.377	8.57	.935	Sky clear, 1.	L. C.	1.92	1.86
16 A.	4	1.482	1.532	1.288	8.07	.841	Sky clear.	L. C.	1.96	1.98
18 A.	6	1.440	1.460	1.360	8.25	.931	Sky 2.	L. C.	1.91	1.85
19 A.	2	.....	.....	.....	8.74	.....	Sky 2.	L. C.	.....	.....
22 P.	2	1.428	.....	.....	9.05	.....	Sky 3.	L. C.	1.91	.....
25 A.	4	1.438	.....	.....	9.27	.....	Sky 2.	L. C.	1.92	.....
26 A.	4	1.427	1.468	1.270	8.93	.865	Sky 4-6.	H. P.	1.91	1.90
27 A.	4	1.459	1.502	1.285	4.87	.855	Sky 2.	L. C.	1.87	1.86

TABLE 1—*Arequipa Pyrheliometry* (Continued)

Date	No. of values read	Calories at air masses 1.2	1	2	Mean humidity mm.	Trans-mission coefficient a_2	Remarks	Observer	Solar constant Formula I	Formula II
Mar. 28 A. ...	4	1.473	1.505	1.340	8.28	.890	Sky 2-3.	L. C.	1.96	1.94
30 A. ...	8	1.465	1.495	1.343	8.02	.897	Sky 3-2.	L. C.	1.95	1.92
31 A.&P.	6	1.440	.....	.....	7.48	.....	Sky 2-2-5.	L. C.	1.90	.....
Apr. 4 A. ...	6	1.453	1.480	1.344	6.60	.908	Sky hazy, 2-2-3.	L. C., H. P.	1.91	1.86
5 A.&P.	10	1.489	1.525	1.344	6.48	.882	Sky 3-0-0-1-1.	L. C., H. P.	1.95	1.92
6 A. ...	4	1.487	1.510	1.392	6.29	.922	Sky 0.	H. P.	1.95	1.89
7 P. ...	2	1.480	.....	.....	7.84	.....	Sky 2.	L. C.	1.97	.....
8 A. ...	4	1.488	1.517	1.386	6.22	.914	Sky 3.	H. P., L. C.	1.95	1.90
10 A. ...	4	1.500	1.548	1.310	6.48	.846	Sky 2.	L. C.	1.97	1.97
11 A. ...	5	1.442	1.484	1.280	7.33	.867	Sky 1-1-4.	L. C., H. P.	1.91	1.90
12 A. ...	4	1.492	.....	.....	5.70	.....	Sky 4-3.	H. P.	1.94	.....
14 P. ...	4	1.479	1.554	1.177	(6.00)?	.....	Sky 2-1.	L. C., H. P.	(1.93)?	.....
15 A.&P.	4	.....	.....	.....	7.65	.....	Sky 2-2.	H. P., L. C.	.....	.....
16 P. ...	2	1.494?	.....	.....	(6.00)?	.....	Sky 1.	?	(1.95)?	.....
17 P. ...	4	1.454	1.477	1.368	7.35	.926	Sky 1-2, windy.	L. C., H. P.	1.93	1.87
22 P. ...	4	1.507	1.547	1.350	(6.00)?	.872	Sky 0.	H. P.	(1.98)?	1.96
25 A. ...	4	1.510	.....	.....	5.33	.....	Sky 0.	H. P., L. C.	1.97	.....
26 P. ...	4	1.522	1.573	1.315	6.03	.836	Sky 0.	L. C.	2.00	2.01
May 4 P. ...	4	1.430	1.496	1.180	7.21	.....	Sky 2-5, very windy and dusty.	L. C., H. P.	1.92	.....
5 P. ...	2	1.440?	.....	.....	8.49	.....	Sky 3.	H. P.	1.95?	.....
6 P. ...	2	1.473?	.....	.....	7.57	.....	Sky 2.	H. P.	1.98?	.....
7 P. ...	4	1.456	1.490	1.320	6.27	.886	Sky 3-5, windy.	L. C.	1.93	1.91
11 A. ...	4	1.434	1.470	1.290	6.48	.878	Sky 1.	L. C.	1.92	1.89
12 P. ...	4	1.474	.....	.....	(6.00)?	.....	Sky (?)	L. C.	(1.96)?	.....
13*	....	.....	.....	.....	.....	.....	......	......	.....	.....
June 12 P. ...	2	1.460?	.....	.....	5.62	.....	Sky 3.	L. C.	1.95?	.....
16 P. ...	4	1.547	1.588	1.380	3.75	.869	Sky 0, windy.	H. P.	2.00	2.00
18 P. ...	4	1.421	1.441	1.352	(4.66)?	.937	Sky 1, hazy, windy.	L. C., H. P.	(1.87)?	1.81
19 A.&P.	4	1.472	.....	.....	4.54	.....	Sky 2-3.	H. P.	1.93	.....

* Pyr. sent to be overhauled if necessary.

TABLE I—*Arequipa Pyrheliometry* (Continued)

Date	No. of values read	Calories at air masses			Mean humidity mm.	Trans-mission coefficient a_2	Remarks	Observer	Solar constant	
		1.2	1	2					Formula I	Formula II
June 20 A. ...	4	1.580	.....	.....	4.92	.....	Sky clear.	L. C.	2.08	.....
21 A. ...	4	1.486	1.514	1.373	4.40	.907	Sky clear.	L. C.	1.95	1.91
22 A. ...	4	1.497	.....	.....	3.90	.....	Sky 1.	L. C.	1.94	.....
23 A. ...	4	1.504	1.532	1.397	(3.38)?	.912	Sky 0, very clear.	L. C., H. P.	(1.93)?	1.90
24 A. ...	4	1.502	1.543	1.343	4.06	.870	Sky clear.	L. C.	1.96	1.95
28 A. ...	4	1.538	.....	.....	5.76	.....	Sky 1.	L. C.	2.05	.....
29 P. ...	4	1.454	1.472	1.352	4.54	.918	Sky 0, hazy near horizon.	H. P., L. C.	1.91	1.87
July 7 P. ...	2	1.445?	.....	.....	4.38	.....	Sky 2.	L. C.	1.89?	.....
8 A. & P.	6	1.505?	.....	.....	5.05	.....	Sky gen. clear, some haze.	L. C.	1.99?	.....
9 A. & P.	6	1.489	1.543	1.265	4.22	.820	Sky clear.	H. P.	1.94	1.98
10 A. ...	4	1.446	1.493	1.255	6.04	.813	Sky 2.	H. P., L. C.	1.94	1.97
11 A. ...	6	1.448	1.485	1.302	4.97	.877	Sky 3.	H. P.	1.92	1.90
13 A. ...	4	1.500	1.543	1.323	4.61	.858	Sky clear, but hazy.	L. C.	1.97	1.97
14 A. ...	4	1.532	1.590	1.310	4.25	.824	Sky clear.	L. C.	2.00	2.03
15 A. ...	4	1.499	1.547	1.305	4.02	.844	Sky 0, hazy.	H. P.	1.95	1.97
16 A ...	4	1.498	1.580	1.173	4.15	.....	Sky hazy, growing clearer.	L. C.	1.96	.....
17 A. ...	4	1.480	1.564	1.147	4.76	.....	Sky 1.	H. P.	1.95	.....
18 A. ...	4	1.443	1.471	1.335	5.55	.907	Sky clear.	L. C.	1.93	1.88
20 A. ...	4	1.549	1.555	1.527	2.33	.982	Sky clear.	L. C.	1.93	1.88
21 A. ...	4	1.521	1.585	1.264	2.87	.798	Sky hazy.	H. P.	1.93	2.00
22 A. ...	4	1.544	1.597	1.340	3.83	.839	Sky clear.	L. C.	2.00	2.02
23 A. ...	4	1.527	1.580	1.312	3.59	.830	Sky 3, windy.	H. P.	1.97	2.00
24 A. ...	4	1.550	1.600	1.347	3.49	.842	Sky 0.	L. C.	1.99	2.02
25 A. ...	4	1.556	1.590	1.423	2.85	.895	Sky 0.	H. P., L. C.	1.97	1.97
26 A. ...	4	1.544	1.635	1.180	2.70	.....	Sky hazy.	H. P.	1.94	.....
27 A. ...	2	1.543?	.....	.....	3.18	.....	Sky clear.	L. C.	1.97?	.....
28 A. ...	4	1.563	1.602	1.410	2.50	.880	Sky clear.	H. P.	1.96	1.98
29 A. ...	4	1.611	1.674	1.360	1.84	.812	Sky clear.	L. C.	1.96	2.08

TABLE I—*Arequipa Pyrheliometry* (Continued)

Date	No. of values read	Calories at air masses 1.2	1	2	Mean humidity mm.	Trans-mission coefficient a_2	Remarks	Observer	Solar constant Formula I	Formula II
July 31 A. ...	4	1.508	1.648	.....	3.13	.....	Sky 3.	H. P.	1.92	.....
Aug. 3 P. ...	2	1.488	.....	.....	3.79	.....	Sky 1.	H. P.	1.93	.....
4 A. ...	4	1.528	1.553	1.437	3.32	.925	Sky 0.	H. P.	1.95	1.92
5 A. ...	4	1.547	.....	.....	5.99	.....	Sky 0.	H. P., L. C.	2.06	.....
6 A. ...	4	1.528	.....	.....	3.48	.....	Sky 0, but hazy and windy.	H. P.	1.95	.....
7 A. ...	6	1.523	.....	.....	4.71	.....	Sky clear, 1.	L. C.	1.99	.....
8 A. ...	4	1.497	.....	.....	3.07	.....	Sky 1.	L. C.	1.90	.....
11 A. ...	4	1.504	.....	.....	4.13	.....	Sky 0.	H. P.	1.95	.....
12 A. ...	4	1.593	.....	.....	4.50	.....	Sky clear.	L. C.	2.08	.....
14 A. & P.	8	1.510	1.552	1.338	4.61	.862	Sky clear, hazy and windy.	H. P.	1.98	1.97
15 P. ...	4	1.514	1.550	1.387	4.24	.895	Sky clear, 1.	L. C.	1.96	1.93
18 P. ...	4	1.567	1.602	1.426	5.28	.890	Sky exceptionally clear.	L. C.	2.06	2.02
19 P. ...	4	1.540	1.585	1.360	3.51	.858	Sky very clear, windy.	L. C., H. P.	1.96	2.00
20 P. ...	4	1.530	1.569	1.375	3.49	.876	Sky clear.	H. P., L. C.	1.94	1.93
21 P. ...	4	1.479	1.499	1.397	3.67	.931	Sky 2-1, windy.	H. P., L. C.	1.88	1.83
22 P. ...	4	1.529	1.569	1.373	3.12	.875	Sky clear, windy.	L. C.	1.92	1.93
24 P. ...	2	1.494	.....	.....	4.49	.....	Sky 2.	L. C.	1.93	.....
25 P. ...	3	1.437	.....	.....	4.14	.....	Sky 2.	H. P.	1.84	.....
28 P. ...	4	1.508	1.541	1.370	5.39	.889	Sky 1.	L. C.	1.98	1.94
Sept. 2 P. ...	2	1.475	.....	.....	3.82	.....	Sky 2, windy.	H. P.	1.87	.....
7 P. ...	4	1.446	1.494	1.260	(4.00)?	.843	Sky 4.	L. C., H. P.	(1.84)?	1.86
8 P. ...	2	1.438	.....	.....	6.16	.....	Sky 2.	H. P.	1.90	.....
9 P. ...	2	.....	.....	.....	5.66	.....	Sky 5.	H. P.	.....	.....
11 P. ...	2	1.587?	.....	.....	4.77	.....	Sky 2, windy.	L. C.	2.04?	.....
12 P. ...	6	1.560	1.604	1.378	3.45	.859	Sky 0, windy.	L. C., H. P.	1.95	1.96
14 P. ...	2	.....	.....	.....	4.89	.....	Sky 2.	H. P.	.....	.....
15 P. ...	2	1.560	.....	.....	4.01	.....	Sky 2.	L. C.	1.97	.....

TABLE 1—*Arequipa Pyrheliometry* (Continued)

Date	No. of values read	Calories at air masses 1.2	1	2	Mean humidity mm.	Trans-mission coefficient a_2	Remarks	Observer	Solar constant Formula I	Formula II
Sept. 16 P. ...	4	1.540	1.580	1.383	3.67	.875	Sky clear, windy.	H. P.	1.94	1.93
17 P. ...	4	1.548	1.594	1.368	3.98	.858	Sky 1.	L. C.	1.96	1.96
18 P. ...	4	1.488	1.519	1.366	(4.00)	.899	Sky 3, clear, windy.	H. P.	(1.89)	1.86
26 P. ...	4	1.531	1.580	1.337	4.65	.846	Sky 0-1.	L. C., H. P.	1.95	1.96
27 P. ...	4	1.544	1.591	1.360	5.69	.855	Sky clear, windy.	L. C., H. P.	2.00	1.99
28 P. ...	2	1.520	.....	.....	5.50	.....	Sky 3.	H. P.	1.96	.....
29 P. ...	4	1.538	1.582	1.364	5.54	.862	Sky clear, 1, windy.	L. C., H. P.	1.99	1.98
Oct. 4 P. ...	4	1.500	1.581	1.178	4.87	.....	Sky clear.	L. C., H. P.	1.92	.....
9 P. ...	4	1.523	1.592	1.251	5.02	.787	Sky 1.	L. C.	1.94	2.02
10 P. ...	4	1.470	1.500	1.349	4.83	.899	Sky clear.	L. C., H. P.	1.87	1.84
11 P. ...	2	1.500	.....	.....	4.75	.....	Sky clear, 1.	L. C.	1.91	.....
15 P. ...	4	1.573	1.615	1.400	5.21	.867	Sky clear.	L. C., H. P.	2.00	1.99
16 P. ...	4	1.566	1.609	1.370	4.61	.851	Sky clear.	H. P.	1.97	1.98
19 P. ...	2	1.557?	.....	.....	4.75	.....	Sky clear, windy.	L. C.	1.97?	.....
20 P. ...	4	1.563	1.616	1.349	5.19	.835	Sky clear.	L. C., H. P.	1.99	2.00
21 P. ...	2	1.543	.....	.....	5.45	.....	Sky 4, windy.	H. P.	1.97	.....
22 P. ...	4	1.511	1.565	1.302	5.24	.832	Sky clear, very windy.	L. C., H. P.	1.92	1.94
23 A. ...	6	1.590?	.....	.....	3.63	.....	Sky clear.	L. C.	1.97?	.....
24 A. ...	4	1.578	.....	.....	4.18	.....	Sky clear.	L. C., H. P.	1.97	.....
25 A. ...	4	1.562	.....	.....	4.18	.....	Sky clear.	L. C., H. P.	1.94	.....
26 A. ...	4	1.527	.....	.....	4.50	.....	Somewhat hazy.	L. C.	1.91	.....
27 A. ...	2	1.618	.....	.....	(4.50)	.....	Somewhat hazy.	L. C.	(2.03)	.....
28 P. ...	4	1.560	1.617	1.335	3.79	.826	Sky clear.	L. C.	1.93	1.96
29 P. ...	2	1.531	.....	.....	4.50	.....	Sky clear, windy.	L. C.	1.92	.....
30 A. ...	2	1.568	.....	.....	3.65	.....	Sky clear, windy.	L. C.	1.93	.....
31 A. ...	4	1.555	.....	.....	4.26	.....	Clear but hazy, windy.	L. C.	1.94	.....
Nov. 1 P. ...	4	1.507	1.574	1.234	4.95	.784	Sky clear, windy.	L. C.	1.90	1.96
3 P. ...	4	1.514	1.559	1.343	4.37	.861	Sky clear, windy.	L. C.	1.89	1.89
9 P. ...	2	1.564	.....	.....	(4.40)?	.....	Sky clear.	L. C.	(1.94)?	.....

TABLE 1—*Arequipa Pyrheliometry* (Continued)

Date	No. of values read	Calories at air masses			Mean humidity mm.	Trans-mission coefficient a_2	Remarks	Observer	Solar constant	
		1.2	1	2					Formula I	Formula II
Nov. 10 P. ...	4	1.549	1.596	1.363	5.31	.854	Sky clear.	L. C.	1.96	1.95
11 P. ...	2	1.550	.....	.....	4.81	.....	Sky 1, windy.	L. C.	1.94	.....
12 A. ...	4	1.555	.....	.....	4.50	.....	Sky clear.	L. C.	1.94	.....
24 P. ...	4	1.466	1.524	1.330	5.52	.873	Sky 1, windy.	H. P.	1.85	1.83
Dec. 7 P. ...	4	1.481	1.528	1.296	6.98	.848	Sky 4.	H. P.	1.89	1.89
12 A. & P.	6	1.547	1.592	1.364	6.64	.857	Sky 3-2.	H. P.	1.97	1.96
16 P. ...	2	1.544	.....	.....	5.80	.....	Sky 3.	H. P.	1.94	.....
17 P. ...	2	1.550	.....	.....	5.84	.....	Sky 3, windy.	H. P.	1.95	.....
19 A. ...	4	1.592	.....	.....	5.18	.....	Sky clear.	H. P., L. C.	1.99	.....
20 P. ...	2	1.594	.....	.....	4.50?	.....	Sky clear.	L. C.	1.97?	.....
24 A. ...	2	1.500	.....	.....	(5.50)?	.....	Sky 2.	L. C.	(1.88)?	.....
31 A. ...	2	1.543	.....	.....	6.65	.....	Sky clear.	L. C.	1.96	.....
1915										
Jan. 14 A. ...	4	1.535	.....	.....	6.47	.....	Sky 2.	L. C., H. P.	1.95	.....
15 A. ...	4	1.550	.....	.....	4.34	.....	Sky 2.	H. P.	1.90	.....
20 A. ...	4	1.485	.....	.....	4.76	.....	Sky 2.	L. C., H. P.	1.84	.....
Feb. 2 A. ...	4	1.475	.....	.....	8.98	.....	Sky 2.	L. C., H. P.	1.92	.....
9 A. ...	4	1.470	1.493	1.370	7.67	.917	Sky 3-5.	L. C., H. P.	1.90	1.85
10 A. ...	4	1.489	.....	.....	7.85	.....	Sky gen. clear, 3.	L. C., H. P.	1.93	.....
11 A. ...	4	1.478	.....	.....	9.49	.....	Sky 3-5.	H. P.	1.94	.....
Mar. 8 P. ...	4	1.526	1.554	1.411	(7.00)?	.908	Sky 1.	L. C., H. P.	(1.99)?	1.94
17 A. ...	4	1.430	1.465	1.297	8.52	.886	Sky 1.	L. C.	1.90	1.88
20 A. ...	6	1.480	1.520	1.328	7.29	.874	Sky 2.	L. C.	1.94	1.93
21 A. ...	4	1.460?	.....	.....	5.48	.....	Sky 1.	L. C.	1.88	.....
25 A. ...	6	1.518	1.560	1.353	(8.50)?	.867	Sky 1-0-0.	L. C.	(2.01)?	2.01
26 P. ...	4	1.517	.....	.....	9.55	.....	Sky clear.	L. C.	2.04	.....
27 P. ...	4	1.522	1.562	1.360	9.14	.870	Sky clear.	L. C.	2.04	2.04

TABLE 2—*Monthly Mean Values*

	Month		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1912	Radiation	$e_{1\cdot2}$	....	....	....	....	....	....	....	1.487	1.487	1.558	1.547	1.520
	Transmission	a_2	....	....	....	....	....	....	....	.847	(.821)	.869	....	(.848)
	Vapor pressure	p	....	....	....	....	....	....	....	....	....	....	3.00	7.28
*	Solar constant	e_0	....	....	....	....	....	....	....	(1.93)	(1.91)	(1.98)	(1.97)	1.94
			....	....	....	....	....	....	....	....	....	....	....	1.97
	Number days	n	....	....	....	....	....	....	....	13	25	21	7	8
1913		$e_{1\cdot2}$	1.469	(1.464)	(1.321)	1.412	1.478	1.501	1.470	1.457	1.478	1.425	1.503	1.518
		a_2	(.821)	....	(.845)	.851	.878	.879	.875	.856	.848	.826	(.843)	.831
		p	8.95	(9.65)	(8.00)	6.89	4.29	3.71	3.07	4.56	4.87	6.00	6.70	7.24
		e_0	1.91	....	....	1.86	1.92	1.94	1.87	1.88	1.90	1.86	1.92	1.93
			1.91	....	....	1.89	1.92	1.93	1.89	1.89	1.92	1.89	1.95	1.95
		n	5	1	1	6	12	15	17	19	18	13	12	15
1914		$e_{1\cdot2}$	1.495	1.463	1.470	1.485	1.451	1.496	1.514	1.516	1.521	1.542	1.529	1.544
		a_2	.838	(.861)	.886	.886	(.882)	.902	.855	.889	.862	.842	.843	....
		p	7.35	9.61	8.35	6.49	7.00	4.50	3.83	4.16	4.65	4.58	4.83	5.89
		e_0	1.91	1.91	1.93	1.95	1.94	1.96	1.95	1.96	1.94	1.95	1.92	1.94
			1.92	1.92	1.91	1.92	(1.90)	1.91	1.98	1.94	1.94	1.96	1.91	1.93
		n	11	11	15	14	6	11	22	18	13	19	7	8
1915		$e_{1\cdot2}$	1.523	1.478	1.493	....	....	....	....	....	....	....	....	....
		a_2	....	(.917)	.881	....	....	....	....	....	....	....	....	....
		p	5.19	8.50	7.93	....	....	....	....	....	....	....	....	....
		e_0	(1.90)	(1.92)	1.97	....	....	....	....	....	....	....	....	....
			....	(1.85)	1.96	....	....	....	....	....	....	....	....	....
		n	3	4	7	....	....	....	....	....	....	....	....	....
	Weighted mean	$e_{1\cdot2}$	1.493	1.467	1.475	1.463	1.469	1.499	1.495	1.486	1.492	1.512	1.522	1.526
	values	a_2	.832	(.880)	.878	.870	.880	.885	.865	.865	.850	.845	.843	.835
	all years	p	7.42	9.58	8.28	6.60	5.20	4.05	3.48	4.36	4.77	5.15	6.00	6.80
	Total days	n	19	16	23	20	18	26	39	50	56	53	26	28
	Weighted mean value for mean solar distance	$e_{1\cdot2}$	1.448	1.434	1.462	1.474	1.502	1.547	1.543	1.521	1.511	1.500	1.488	1.480

* Computed by formulæ I and II as given below.

We now give in Table 2 mean monthly values of the intensity of solar radiation ($e_{1.2}$) at air mass 1. 2, the transmission coefficient a_2, the pressure of aqueous vapor p, and the empirical solar constant values e_0, of which more is said below. The table gives also the number of days on which radiation was observed. This considerably exceeds the number of days on which the atmospheric transmission could be determined. Monthly means based on very meager data are indicated by parentheses.

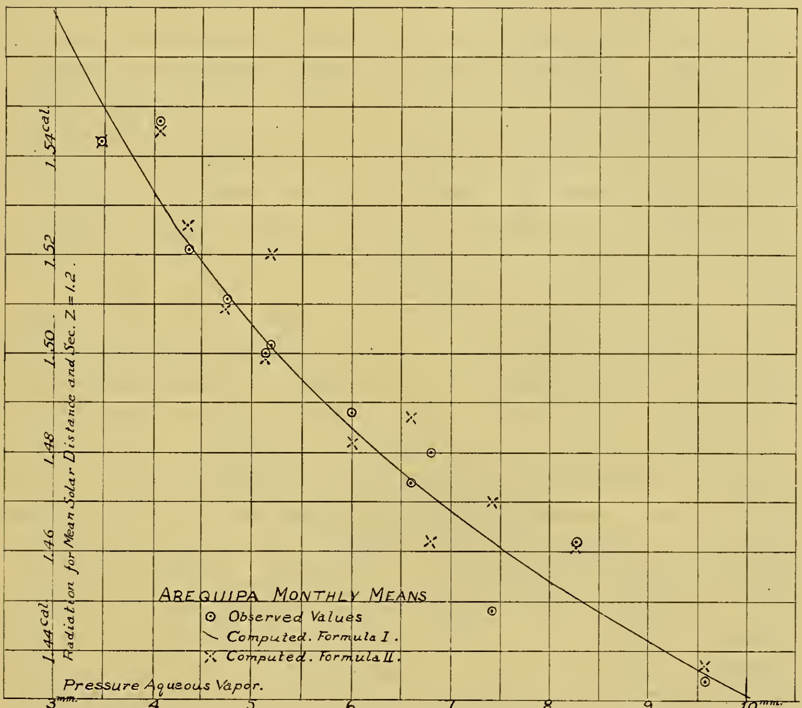

FIG. 1.

General mean: Of $e_{1.2} = 1.496$; of $a_2 = .860$; of $p = 5.97$.

Examination of the foregoing table fails to indicate any notable abnormalities covering considerable periods. In other words nothing appears to lead us to suppose that these were not normal years for Arequipa (unless as regards the *number* of clear days, on which we say nothing). This is especially interesting, for in the northern hemisphere the year 1912 was notable for the great decrease in direct solar radiation received at the earth's surface, and of atmospheric transparency, which speedily followed the volcanic eruption of Mt. Katmai in June of that year. Remnants of this volcanic dust still remained distinguishable by pyrheliometry in the United States up to near the end of the year 1913. No indication of its presence above Arequipa in either 1912 or 1913 seems to be shown. The volcanic dust from Katmai, though general in the northern hemisphere, seems not to have crossed the equator.

In the last line of the table the mean monthly radiation values for the whole period of observation have been reduced to what they would have been if the sun's distance had remained uniform at its mean value. The close connection between solar radiation at the earth's surface, and atmospheric humidity is brought out graphically in fig. 1. Ordinates are mean monthly values of $e_{1.2}$ reduced to mean solar distance, abscissæ are corresponding mean monthly values of water vapor pressure (p). The smoothness of the curve defined by these points is remarkable. It is perhaps to be ascribed to the great altitude and inland location of Arequipa. Apparently the degree of atmospheric humidity at the earth's surface there is a good index of the total quantity of humidity existing between the station and the limit of the atmosphere.

It is obvious, of course, that fluctuations of atmospheric transmission coefficients must also produce their effects on the observed intensity of solar radiation at the station. Such fluctuations are of two kinds: First, those associated with changes of water vapor. Second, those associated with changes of dustiness, such as those produced in the northern hemisphere by the Katmai eruption. The influence on the solar radiation of fluctuations of the first type, which are a function of the humidity, may be generally (for a high-level station like Arequipa) much greater than those associated with dust alone. But it might well be expected that for certain months of the year the dust fluctuations would be by no means negligible. However, restricting our thought to a high-level station like Arequipa, and remembering the powerful true absorption produced in the infra-red spectrum by water vapor, and the large changes in this true absorption attending changes of humidity when the humidity and air mass are both small, it is easy to see after all why the observed radiation at $M=1.2$ at Arequipa seems to be so well represented as a function of water vapor alone. For both the true absorption and a large proportion of the variable elements of the general scattering are functions of water vapor. Compared to these, the variable scattering produced by dry dust alone is generally small.

In figure 2 the radiation, $e_{1.}$ (not reduced to mean solar distance), the vapor pressure, p, and the transmission, a_2, are all given as functions of the time of the year.

The data of figure 1 have been represented by the following two formulæ, one expressing the radiation $e_{1.2}$ (reduced to mean solar distance) as a function of vapor pressure, p, alone, the other as a function of vapor pressure, p, and transmission a_2:

Formula I. $e^{corr}_{1.2} = 0.981 + \frac{0.75}{p^{0.222}}$

Formula II. $e^{corr}_{1.2} = 1.50 + (5.25 - p)0.19 + (a_2 - 0.85)0.63$

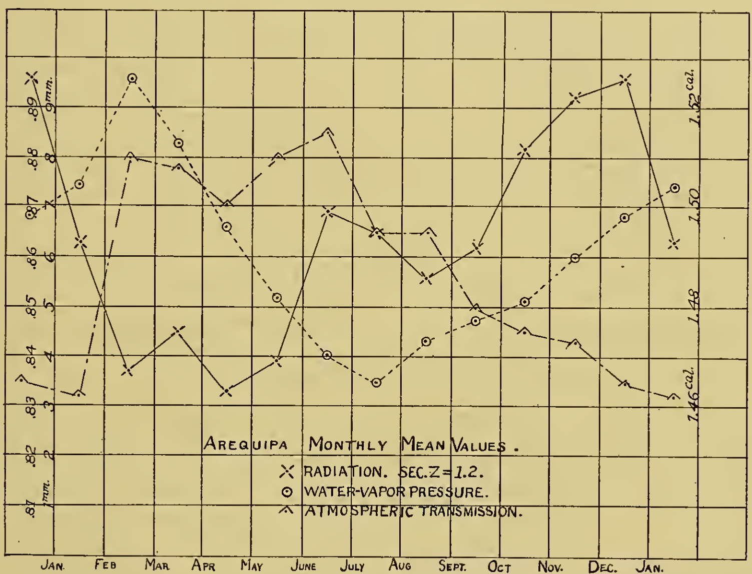

FIG. 2.

We now come to a very interesting application of these formulæ. During the period of about four years covered by the Arequipa observations, we may assign as the mean value of the solar constant of radiation outside the atmosphere 1.93 calories per sq. cm. per min. Dividing by this value we have the following empirical formulæ for obtaining from Arequipa daily observations values of the solar constant of radiation:

Formula I. $e_0 = \frac{e^{corr}_{1.2}}{0.508 + \frac{0.389}{p^{0.222}}}$.

Formula II. $e_0 = \frac{e^{corr}_{1.2}}{0.777 + (5.25 - p)0.01 + (a_2 - 0.85)0.33}$.

During the years 1913 and 1914 the solar constant was determined at Mount Wilson by spectro-bolometric observations on some of the days when these formulæ are applicable to Arequipa observations. From 34 comparisons of Arequipa and Mount Wilson solar constant values, the average deviation of individual days is about 2.5 per cent. Omitting 5 days when unusually great discrepancies occurred, owing to poor sky at one station or the other, the average deviation is only 2 per cent.

Under the circumstances it seemed unreasonable to hope that for individual days the empirically derived solar constant results from Arequipa observations would be of sufficient accuracy to show the short-period fluctuations of the solar constant. It might reasonably be expected, however, that monthly mean values would seldom differ by more than 1 per cent from the values obtained in corresponding months at Mount Wilson. Thus a new confirmation of the variability of the sun in its longer periods may be hoped for from pyrheliometry and psychrometry at Arequipa alone. This hope seems to be confirmed by the following Table 3. Both Arequipa values (formulæ I and II) are given, but the number of days relates to the first method values, which are more numerous.

Table 3—*Monthly Mean Solar Constant Values*

Month	1913 July	Aug.	Sept.	Oct.	Nov.	1914 June	July	Aug.	Sept.	Oct.
Arequipa (I)	1.87	1.89	1.90	1.86	1.92	1.96	1.95	1.96	1.94	....
Arequipa (II)	1.89	1.89	1.92	1.89	....	1.91	1.98	1.94	1.94	....
No. days	17	18	18	11	12	11	22	18	13	....
Mount Wilson	1.925	1.931	1.920	1.874	1.876	1.952	1.956	1.964	1.943	....
No. days	3	18	25	24	5	14	14	22	18	....

The comparisons of July and November, 1913, have little weight because of the small number of days observed at Mount Wilson. Apart from these months only one, August, 1913, shows a difference of more than 1 per cent between Arequipa and Mount Wilson. Both stations agree in showing the interesting result that the solar constant was decidedly higher in 1914 than in 1913.

With the word of caution that individual day's values may often be in error by as much as 5 per cent, and on the average by as much as 2 per cent, we have included in Table 1 two columns giving the daily solar constant values determined from Arequipa pyrheliometry by means of formulæ I and II. Table 2 gives the mean monthly solar constant values by formulæ I and II. Months for which no values of vapor pressures are available are supplied by taking the mean monthly vapor pressures for these months for several years as given in Table 2. Such solar constant values are given in parentheses.

Finally the 29 days with solar constant values available for favorable comparison between Mount Wilson and Arequipa have been divided into two groups of high and low values respectively, as indicated by Mount Wilson work. The mean values are as follows:

Station	Group I	No. days	Group II	No. days.	Group I–Group II
Mount Wilson	1.954	15	1.893	14	0.061
Arequipa { Formula I	1.936	15	1.900	14	0.036
Arequipa { Formula II	1.943	13	1.907	14	0.036

The days selected are these:

Group I. { 1913. Aug. 5, 12, 18; Sept. 2, 3, 9, 17, 18, 22.
1914. June 16, 23, 24; July 17, 23, 28.

Group II. { 1913. Aug. 4, 6, 15; Sept. 4, 8, 10, 26, 27, 29, 30; Oct. 1, 6, 31.
1914. June 21.

This comparison, so far as it has weight, evidently tends to confirm the existence of short-period irregular solar variations, discovered by other investigations.

SUMMARY.—Observations with the silver disk pyrheliometer and nearly simultaneous measurements of atmospheric humidity have been made since August, 1912, at Arequipa, Peru, at the station of the Harvard College Observatory.

From these observations have been determined values of the solar radiation at Arequipa corresponding with secant Z equal to 1.0, 1.2, and 2.0; values of pressure of aqueous vapor, and values of the diminution of radiation attending the passage of the sun from the zenith distance whose secant is 1.0 to that whose secant is 2.0.

Owing to other occupations the observers have generally made these observations when the sun was within 60° of the zenith. On this account determinations of atmospheric transparency are not always possible, and are of less weight than other data given.

The results are collected to give monthly mean values. These show a remarkably close connection between radiation and vapor pressure. Advantage is taken of this close correlation to determine by empirical formulæ values of the solar constant of radiation. These empirical values agree quite as well as could be expected with values obtained at Mount Wilson, California, by complete spectrobolometric and pyrheliometric measurements combined. The Are-

quipa results confirm the variability of the sun, both from year to year and from day to day, shown by investigations at Mount Wilson and elsewhere.

It seems probable that from observations similar to those at Arequipa, if conducted at eight or ten favorable stations of high level in various parts of the world, the variations of the sun could be determined almost or quite as certainly as from two stations equipped for complete spectro-bolometric determinations of the solar constant.

The Arequipa results indicate that the volcanic dust which was general in the atmosphere in the northern hemisphere for more than a year after the volcanic eruption of Mt. Katmai, Alaska, in June, 1912, did not influence the transparency of the atmosphere in Peru.