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MEASUREMENTS OF SOLAR RADIATION INTENSITY AND DETERMINATIONS OF ITS DEPLETION BY THE ATMOSPHERE

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[Weather Bureau, Washington, D. C., February 25, 1930]

This paper is intended as a supplement to one on the same subjects that was published in this REVIEW, **55**: 155–169, April, 1927. It is based principally on replies to a circular letter dated December 1, 1927, addressed to 30 heads of observatories or meteorological services, and requesting corrections and additions to the lists of pyrheliometric stations and the pyrheliometric data published in the earlier paper.

The replies received have resulted in the addition of 11 stations to the list of those measuring and publishing the total radiation (direct + diffuse) received on a horizontal surface, and of 4 stations that include in this measurement direct solar radiation only.

Forty stations have been added to the list of those measuring and publishing the intensity of direct solar radiation at normal incidence, but of these eight are stations in Union of Socialist Soviet Republics whose publications are not available to me.

A considerable number of stations previously listed have published additional data or summaries. These include all with station numbers less than 18 in Tables 1 and 2, and less than 100 in Tables 6, 7, and 8.

CORRECTIONS AND ADDITIONS TO PREVIOUSLY PUBLISHED DATA

The following corrections should be made in the data published in the REVIEW above cited:

Table 1: Toronto, period, blank; should be August, 1911–September, 1916.

Table 6:
- Batavia, altitude should be 15 meters.
- Innsbruck, longitude should be 11° 24′ E.
- La Quiaca, latitude should be 20° 06′ S; longitude should be 65° 36′ W; altitude should be 3,462 meters.
- Mount Czarnohora, Worchta should be Worochta.
- Pangerango, latitude should be 6° 45′ S; longitude should be 106° 58′ E.
- Pariš, latitude should be 48° 48′ N.
- Sonnblick, longitude should be 12° 57′ E.
- Ursanova should be Ursynov.
- Zakopane, Austria, should be Poland.

Table 8:
- Jungfraujoch, Stein, M. Edward, should be Stenz, Edward.
- Paris, Bureau Central Meteorologique de France, 1907–1914, should be 1907–1924.
- Mémoires, 1907–1914, should be 1907–1924.

TABLE 1.—*Stations which obtain records of the total radiation received on a horizontal surface from the sun and sky*

Station	Latitude	Longitude	Altitude	Period	Instruments
	° ′	° ′	*Meters*		
(1) Lincoln, Nebr.	40 50 N	96 41 W	381	July, 1915–December, 1929.	Callendar.
(2) Madison, Wis.	43 05 N	89 23 W	308	April, 1911–December, 1929.	Do.
(3) Chicago, Ill.	41 47 N	87 35 W	210	September, 1923–December, 1929.	Weather Bureau thermoelectric.
(5) Washington, D. C.	38 56 N	77 05 W	137	November, 1914–October, 1922.	Callendar.
			126	November, 1922–December, 1929.	Weather Bureau thermoelectric.
(6) New York, N.Y. (Central Park Observatory.)	40 46 N	73 58 W	48	April, 1924–December, 1929.	Do.
(11) Davos Platz, Switzerland.	46 48 N	9 49 E	1,600	January, 1922–December, 1927.	Davos pyrheliograph.
(14) Stockholm, Sweden.	59 21 N	18 04 E	44	July, 1922–June, 1927.	Ångström.[1]
(15) Sloutzk (Pavlovsk, Union of Socialist Soviet Republics.	59 41 N	30 29 E	40	January, 1926–December, 1928.	Crova-Sloutzk;[1] Savinoff.
(18) La Jolla, Calif.	32 50 N	117 15 W	26	July, 1928 and November, 1928–December, 1929.	Weather Bureau thermoelectric.
(19 Pasadena, Calif.	34 15 N	118 17 W	246	1926–1928	Do.
(20) Fresno, Calif.	36 43 N	119 49 W	26	October, 1928–December, 1929.	Moll-Engelhard.
(21) Twin Falls, Idaho.	42 29 N	114 25 W	1,300	January, 1927–December, 1929.	Weather Bureau thermoelectric.
(22) Gainesville, Fla.	29 39 N	82 21 W	71	October, 1929–January, 1930.	Moll-Richard.
(23) Pittsburgh, Pa.	40 26 N	80 00 W	341	Dec. 24, 1929–Jan. 28, 1930.	Weather Bureau thermoelectric.
(24) Muottas-Muraigl.	46 32 N	9 53 E	2,456	July 21–Aug. 2, Oct. 2–14, 1923; Jan. 20–27, Mar. 8–13, 1924.	Ångström pyranometer.
(25) Zugspitze, Germany.	47 25 N	10 59 E	2,962	August, 1926–July 1927.	Do.
(26) Theodosia, Union of Socialist Soviet Republics.	45 02 N	35 24 E	15	March, 1926–December, 1928.	Crova-Sloutzk,[1] Savinoff.
(27) Kislovodsk, Union of Socialist Soviet Republics.	43 54 N	42 42 E	850	July–December, 1928.	Do.[1]
(28) Mount Elbrus, Union of Socialist Soviet Republics.	43 17 N	40 12 E	3,200	Aug. 10–19, 1926	Do.[1]

[1] Radiation records as recorded have been reduced to the Smithsonian pyrheliometric scale of 1913 by multiplying by 1.035.

TABLE 1.—*Stations which obtain records of the total radiation received on a horizontal surface from the sun and sky*—Continued

Station	Latitude	Longitude	Altitude	Period	Instruments
	° ′	° ′	*Meters*		
(29) Paris, France (Parc St. Maur).	48 48 N	2 29 E	50	1926	Moll thermopile; Richard register. (For cloudless skies.)
(30) Tiflis, Union of Socialist Soviet Republics.	41 43 N	44 48 E	421	June–August, 1927	Å. Mi.,[1] Crova-Sloutzk.
(31) Tashkent, Union of Socialist Soviet Republics.	41 20 N	69 18 E	475	1926–1928	Å. Crova.[1]
(32) Irkutsk, Union of Socialist Soviet Republics.	52 16 N	104 19 E	467	1928	Å.[1] Crova-Sloutzk-Linke.

[1] Radiation records as recorded have been reduced to the Smithsonian pyrheliometric scale of 1913 by multiplying by 1.035.

TABLE 2.—*Sources of data given in Tables 3, 4, and 5*

(1) LINCOLN.
KIMBALL, HERBERT, H. 1916–1929. Solar and Sky Radiation Measurements. Mo. Wea. Rev., **44**: 178. Monthly thereafter.

(2) MADISON.
KIMBALL, HERBERT H., and MILLER, ERIC R. 1916. The Total Radiation Received on a Horizontal Surface from the Sun and Sky at Madison, Wis. Mo. Wea. Rev., **44**: 180.
KIMBALL, HERBERT H. 1916–1929. Solar and Sky Radiation Measurements. Mo. Wea. Rev., **44**: 179. Monthly thereafter.

(3) CHICAGO.
KIMBALL, HERBERT H. 1923–1929. Solar and Sky Radiation Measurements. Mo. Wea. Rev., **51**: 533. Monthly thereafter.

(5) WASHINGTON.
KIMBALL, HERBERT, H. 1915–1929. The Total Radiation Received on a Horizontal Surface at Washington, D. C. Mo. Wea. Rev. **43**: 100–111. Monthly thereafter.

(6) NEW YORK.
KIMBALL, HERBERT H. 1924–1929. Solar and Sky Radiation Measurements. Mo. Wea. Rev., **52**: 225. Monthly thereafter.

(11) DAVOS.
DORNO, C. 1928. Tägliche und Säkulare Schwenkungen du Sonnenstrahlung im Davos.

(14) STOCKHOLM.
ÅNGSTRÖM, ANDERS. 1928. Recording Solar Radiation. Meddelanden från Statens Meteorologisk-Hydrografiska Anstalt. Band 4, No. 3.

(15) SLOUTZK.
KALITIN, N. N. Bulletin de la Commission Actinométrique permanente de l'Observatoiré Géophysique Central, 1925–1928.
Rates of solar energy according to observations effected at the Magnetic-Meteorological Observatory Sloutzk (Pavlovsk). Recuéil de Géophysik. Tome VI, Fascule 1.

(18) LA JOLLA.
RICHARDSON, BURT. 1929. See Solar Observations. Mo. Wea. Rev., **57**: 300. Monthly thereafter.

(19) PASADENA.
RICHARDSON, BURT. 1929. See Solar Observations. Mo. Wea. Rev., **57**: 300.

(20) FRESNO.
KIMBALL, H. H. Solar Observations. Mo. Wea. Rev. **57**: 26. Monthly thereafter.

(21) TWIN FALLS.
KIMBALL, H. H. 1927. Solar Observations. Mo. Wea. Rev. **55**: 29. Monthly thereafter.

(22) GAINESVILLE.
KIMBALL, H. H. 1930. Solar Observations. Mo. Wea. Rev. **58**: 26.

TABLE 2.—*Sources of data given in Tables 3, 4, and 5*—Continued.

(23) PITTSBURGH.
KIMBALL, H. H. 1930. Solar Observations. Mo. Wea. Rev. **58**: 26.

(24) MUOTTAS-MURAIGL.
DORNO, C. 1927. Grundzüge des Klimas von Muottas-Muraigl. (Oberengadin.)

(25) ZUGSPITZE.
LIPP, HERMANN. 1928. Beiträge zum Strahlungsklima der Zugspitze. Deutschen Meteorologischen Jahrbuch für Bayern.

(26) THEODOSIA.
KALITIN, N. N. 1927–1929. Bulletin de la Commission Actinométrique permanente de la Observatoiré Géophysique Central, 1926–1928.

(27) KISLOVODSK.
KALITIN, N. N. 1929. Bulletin de la Commission Actinométrique permanente de la Observatoiré Géophysique Central, 1928, 2–3.

(28) MOUNT ELBRUS.
KALITIN, N. N. 1928. Solar, Diffused and Terrestrial Radiation According to Observations Effected on Mount Elbrus. Jr. Geophysics and Meteorology. 3. N°. 3. 195–209. (Reprint.)

(29) PARIS.
BRAZIER, C. E. 1926. Observations et Travaux Actinométriques effectuis à l'Observatoire du Parc Saint-Maur pendant l'anne 1926. Annales, Institut de Physique du Globe de l'Université de Paris. VI., 121.

(30) TIFLIS.
Mossidse, Schalva. Aktinometrische Beobachungen am Geophysikalischen Observatorium Georgiens zu Tiflis. Aktinometrischer Monatsbericht, 1928, No. 1. (Georgien and Russian text with German abstract.)

(31) TASHKENT.
KALITIN, N. N. 1926–1928. Bulletin de la Commission Actinométrique permanente de l'Observatoire Géophysique Central.

(32) IRKUTSK.
KALITIN, N. N. 1928. Bulletin de la Commission Actinométrique permanente de l'Observatoiré Géophysique Central.

NEW DATA

Vertical component of solar radiation.—Table 3 gives monthly averages of daily totals of solar radiation received on a horizontal surface, (1) including both that received directly from the sun and that received diffusely from the sky; (2) the component received directly from the sun; and (3) the component received diffusely from the sky. These daily totals are obtained by means of instruments that make a continuous record of the intensity of the solar radiation that falls upon their receiving surfaces. In most cases the instrument records (1), the intensity of the total radiation (direct + diffuse). An increasing number of stations are now recording continuously the intensity of direct solar radiation at normal incidence. The vertical component of this intensity gives (2), above, and the difference between (1) and (2) gives (3), the intensity of the diffuse solar radiation received on a horizontal surface.

This latter measurement may be made by an instrument that will give the total (direct + diffuse) radiation, by interposing a screen between its receiving surface and the sun. It includes radiation received from both clear and cloudy skies.

Table 4 gives smoothed weekly averages of the total solar radiation (direct + diffuse) received on a horizontal surface. The averages have been smoothed by the well-known smoothing formula,

$$\frac{a+2b+c}{4}.$$

TABLE 3.—*Monthly averages of daily totals of solar radiation received on a horizontal surface (gram-calories per square centimeter)*

	January	February	March	April	May	June	July	August	September	October	November	December
Pasadena [1]	302	383	427	532	568	512	582	568	490	400	365	316
Pittsburgh [1]	95											
Davos [1]	186	286	358	381	470	454	487	524	585	346	232	176
Muottas-Muraigl [1]	[2] 284		[3] 500				[4] 805			[5] 456		
Zugspitze [1]	130	234	325	424	473	562	433	509	368	277	160	106
Stockholm: [1]												
1922–1927	25	73	181	295	344	416	422	310	209	110	47	22
1905–1926 [6]	29	75	186	295	422	450	414	319	218	107	49	22
Direct solar [7]	11	39	105	219	318	347	328	232	147	50	12	3
Diffuse solar [8]	18	36	81	76	104	103	86	87	71	57	37	19
Sloutzk [1]	25	70	194	269	341	389	445	296	176	69	19	11
Direct [7]	9	25	113	130	194	226	311	184	104	30	4	3
Diffuse [8]	16	45	81	129	147	163	134	112	72	39	15	8
Theodosia [1]	76	108	195	282	433	534	549	442	338	215	113	56
Direct [7]			117		312	451	408		284	143	34	9
Diffuse [8]			78		121	83	141		54	72	79	47
Kislovodsk [1]			310	357	377	393	483		264	240	193	65
Direct [7]			169	181	236	255	372				132	37
Diffuse [8]			141	176	141	138	111				61	28
Mount Elbrus: [1]												
Clear sky								697				
Cloudy sky								304				
Paris: [7]												
Clear sky	110	180	305	475	560	580	570	500	390	275	135	95
Average sky	24	56	104	190	269	273	279	260	172	77	32	18
Tiflis [7]						430	372	379				
Tashkent [7]	65	119	186	293	332	541	522	511	387	225	124	58
Irkutsk [7]	28	97	204	260	285	334	345	272	172	118	35	28

[1] Total radiation (direct + diffuse).
[2] For Jan. 20–27.
[3] For Mar. 8–13.
[4] For July 23–Aug. 2.
[5] For Oct. 2–14.
[6] Computed.
[7] Vertical component of direct.
[8] Vertical component of diffuse.

TABLE 4.—*Weekly means of daily total solar radiation (direct + diffuse) received on a horizontal surface (gram-calories per square centimeter)*

Week	Washington	Madison	Lincoln	Chicago	New York	Twin Falls	Fresno	Gainesville	La Jolla
Jan. 4	151	138	185	79	107	176	123	310	272
Jan. 11	156	148	192	80	106	183	134	256	264
Jan. 18	164	164	202	88	115	191	190	222	248
Jan. 25	181	182	215	100	140	180	235		257
Feb. 1	196	196	233	106	141	188	257		260
Feb. 8	207	210	257	110	139	238	308		268
Feb. 15	227	230	284	127	138	267	363		310
Feb. 22	256	255	310	160	174	257	398		361
Mar. 1	288	280	338	189	234	249	397		376
Mar. 8	313	299	356	196	267	258	368		344
Mar. 15	332	316	377	208	262	286	391		322
Mar. 22	348	335	397	222	256	268	470		378
Mar. 29	362	358	407	238	270	258	510		417
Apr. 5	382	380	413	276	309	349	512		446
Apr. 12	400	397	421	304	332	422	554		456
Apr. 19	413	410	442	306	334	455	595		424
Apr. 26	426	428	469	319	346	529	639		473
May 3	444	450	480	355	355	604	691		508
May 10	457	465	487	377	362	639	677		488
May 17	466	474	515	384	375	710	656		
May 24	482	482	528	402	396	734	696		
May 31	492	493	522	420	411	693	706		
June 7	493	505	528	421	412	657	667		
June 14	490	509	536	412	408	664	684		489
June 21	490	520	560	414	399	712	731		509
June 28	499	533	586	436	402	710	734		517
July 5	499	534	583	449	410	709	727		530
July 12	485	526	572	432	405	726	728		546
July 19	478	512	562	415	402	715	710		515
July 26	470	490	543	396	397	681	690		429
Aug. 2	452	469	521	366	370	648	678		427
Aug. 9	437	454	504	356	346	638	647		442
Aug. 16	428	443	495	362	331	617	609		454
Aug. 23	421	430	485	368	314	591	602		453
Aug. 30	405	404	462	357	317	569	601		400
Sept. 6	385	370	428	315	289	544	575		289
Sept. 13	366	347	405	284	308	520	516		232
Sept. 20	354	335	373	267	274	496	467		288
Sept. 27	338	298	349	234	244	464	459		368
Oct. 4	321	270	323	208	247	429	444		364
Oct. 11	300	247	307	190	247	407	414	428	294
Oct. 18	276	224	294	171	198	390	379	448	252
Oct. 25	259	204	269	154	188	351	335	423	248
Nov. 1	240	184	241	136	171	292	305	354	237
Nov. 8	219	162	221	114	144	232	290	344	240
Nov. 15	197	143	206	99	124	184	269	338	255
Nov. 22	177	131	198	92	116	152	241	274	272
Nov. 29	160	126	187	80	108	143	208	272	291
Dec. 6	147	121	172	72	101	136	174	307	290
Dec. 13	141	118	165	68	96	122	159	275	287
Dec. 20	141	122	170	72	99	130	150	263	280
Dec. 27 [1]	144	129	179	79	104	159	137	317	262

[1] 8-day period.

Table 5 gives the annual totals of solar radiation (direct + diffuse) received on a horizontal surface. They are expressed in both gram-calories per square centimeter and in kilowatt-hours per square dekameter. The latter values are included for the reason that the general public is more familiar with electrical than with heat units. They are obtained from the former by multiplying by the factor 1.161.

TABLE 5.—*Annual totals of solar radiation received on a horizontal surface (direct + diffuse)*

Stations	Gr. cal./cm.²	Kilowatt-hours
Pasadena, Calif.	165416	192048
Fresno, Calif.	169691	197011
Twin Falls, Idaho	153613	178345
Lincoln, Nebr.	136346	158298
Madison, Wis.	118744	137862
Chicago, Ill.	90260	104792
Washington, D. C.	121641	141225
New York, N. Y.	94801	110064
Stockholm, Sweden	[1] 77486	[1] 89838
	[2] 78851	
Davos Platz, Switzerland	130657	151693
Zugspitze, Germany	122125	141786
Sloutzk, Union of Socialist Soviet Republics	69497	80686
Theodosie, Union of Socialist Soviet Republics	102007	118430
Direct solar radiation only		
Paris, France:		
Average day	53227	61797
Clear day	125693	145930
Tashkent, Union of Socialist Soviet Republics	102105	118544
Irkutsk, Union of Socialist Soviet Republics	64208	74545

[1] Instrumental record, 1922–27.
[2] Computed from relation between recorded amount and degree of cloudiness.

Solar radiation intensity at normal incidence.—In Table 6, under "Instruments," the following abbreviations have been employed:

Å = Ångström electrical compensation pyrheliometer.
Ma. = Marvin electrical resistance pyrheliometer.
S. I. = Smithsonian silver-disk pyrheliometer.
M. G. = Moll pyrheliometer as modified by Gorczyński.
Mi. = Michelson bimetallic pyrheliometer.

Table 7 summarizes the measurements of solar radiation intensity at normal incidence. In the column headed "Data" the symbols have the following significance:

A_m = intensity after the solar rays have passed through air mass m, where unit air mass is the atmosphere passed through with the sun in the zenith; and in general

$$m = \frac{\text{atmospheric refraction in seconds}}{58.36'' \times \sin Z (Z = \text{sun's zenith distance})}$$

A_{max} = mean of daily maximum intensities.
a = atmospheric transmission.

Numerical subscripts designate the values of m for which values of A or a are given. Thus,
A_2 = radiation intensity when m = 2.

$a_{0-1} = \frac{A_1}{A_0}$, or the transmission when the sun is in the zenith.

a_{2-3} = atmospheric transmission indicated by $\frac{A_3}{A_2}$

Table 8 gives the sources of the data summarized in Table 7.

It will be noted that the values of A_2 in Table 7 are higher in winter than in summer. This is partly due to the fact that the earth's radius vector reaches its maximum value in early July and its minimum in early January, and partly to the fact that the atmosphere contains much less water vapor in winter than in summer.

TABLE 6.—*List of pyrheliometric stations*

Station	Latitude	Longitude	Altitude	Period	Instrument
	° ′	° ′	*Meters*		
(100) Antibes, France	43 34 N	7 7 E	35	July, 1914–March, 1916	Crova.
(101) Antrea, Finland	61 00 N	29 14 E	15	June–August, 1922–23	Å., Mi. (S. I. scale).
(102) Ariana, Tunis	36 49 N	7 57 E	10	July, 1924–June, 1927	Richard-Moll.
(103) Baku, Union of Socialist Soviet Republics.	40 22 N	49 50 E	14	October, 1922	Michelson actinograph.
(104) Borovoy, Samara, Union Socialist Soviet Republics.	53 00 N	52 03 E	82	1906–1918	Viola-Saveliev, Mi.
(15) Davos, Switzerland	46 48 N	9 49 E	1,600	1907–1927 (new summary)	Å., Mi. (reduced to S. I. standard).
(17) Eskdalemuir, Scotland	55 19 N	3 12 W	244	1922–1926 (continuation)	Å.[1]
(24) Fresno, Calif	36 43 N	119 49 W	110	October, 1928	S. I.
(105) Giewont, Poland	49 15 N	20 00 E	1,900	Aug. 31, 1926	M. G.
(106) Golodnaya Steppe, Union Socialist Soviet Republics.	40 25 N	68 45 E	320	1914–15	Mi.
(107) Helsingfors, Finland	60 10 N	24 57 E	40	June, 1922–December, 1923	Å, Mi. (S. I. scale).
(108) Irkutsk, Union Socialist Soviet Republics	52 16 N	104 19 E	470	(*a*) 1913–1927; (*b*) 1928	Å.,[1] Crova, Mi.
(109) Jokkmokk, Sweden	66 36 N	19 51 E	255	June 29, 1927	M. G., Å.[1]
(110) Jungfruskar, Finland	60 9 N	21 5 E	20	July, 1922	Å., Mi. (S. I. scale).
(34) Katharinenburg (Sverdlovsk), Union of Socialist Republics.	56 50 N	60 38 E	280	1915–16	Mi., Å.,[1] Crova actinograph.
(35) Kew Obs'y. Eng	51 28 N	0 18 W	6	1922–1926 (continuation)	Å.[1]
(111) Khanga, Algeria	34 49 N	6 43 E	253	June 17, 1877	Violle.
(36) Kief, Union of Socialist Soviet Republics	50 27 N	30 30 E	183	1888–1893, 1920–1928	Violle, Crova actinograph, Chowolson. Mi.
(112) Kislovodsk, Union of Socialist Soviet Republics.	43 54 N	42 42 E	850	May–December, 1928	Å., [1] Crova.
(113) Koursk, Union of Socialist Soviet Republics.	51 45 N	36 12 E	250	May, 1925–December, 1928	Mi.
(114) Laghouat, Algeria	33 48 N	2 55 E	750	July 12–13, 1877	Violle.
(42) Leningrad, Union of Socialist Soviet Republics.	59 56 N	30 16 E	5	1915–16, 1918, 1923–24, 1926–1928	Mi., Mi.-Marten, Chwolson.
(43) Lincoln, Nebr	40 50 N	96 41 W	373	1926–1928 (continuation)	Ma.
(115) Lötschenlücke (Berne), Switzerland	46 28 N	7 57 E	3,240	August, 1926	Mi. (S. I. scale).
(116) Lysina, Poland	49 46 N	20 4 E	912	April, 1923	Mi. (S. I. scale).
(45) Madison, Wis	43 05 N	89 23 W	297	1926–1928 (continued)	Ma.
(49) Mont Blanc, France	45 49 N	6 52 E	4,810	Aug. 16, 1875	Violle.
			3,050	Aug. 17, 1875	
			1,200	Aug. 16–17, 1875	
(117) Montana (Wallis), Switzerland	46 19 N	7 28 E	1,515	August, 1926	Mi. (S. I. scale).
(52) Montpellier, France	43 37 N	3 53 E	44	1875–1877	Crova.
				December, 1911–July, 1914	A?[1]
(53) Moscow, Union of Socialist Soviet Republics.	55 50 N	37 33 E	165	(*a*) 1909 to date; (*b*) 1914–1924	Mi., Å., Crova, S. I.
(118) Mount Elbrus (Krugozor), Union of Socialist Soviet Republics.	43 17 N	40 12 E	3,200	Aug. 8–20, 1926	Å.,[1] Savinoff.
(119) Mount Evans, Greenland	66 51 N	50 50 W	394	September, 1927–April, 1928	Moll. (S. I. scale).
			76–550	August, 1927	
(120) Muottas-Muraigl	46 32 N	9 53 E	2,456	July–August, 1923; October–January, 1923–24; March–June, 1924.	Mi., S. I.
(121) Oura-Tiube, Union of Socialist Soviet Republics.	39 55 N	69 00 E	1,040	January, 1907	Å.
(63) Paris, Parc St. Maur	48 48 N	2 29 E	50	1924–1926	Å., Mi., S. I.
(67) Potsdam, Germany	52 23 N	12 4 E	106	1907–1923	Å., Mi., S. I.
(122) Repetek, Union of Socialist Soviet Republics.	38 35 N	63 10 E	185	April, May, September, October, 1925	Mi.
(123) Rovaniemi, Finland	66 29 N	25 44 E	200	June, 1923	Å., Mi. (S. I. scale).
(124) Schbreiberhau (Reisengeberge), Germany	50 50 N	15 32 E	700	April, 1923; January, 1926	Mi.
(125) Sebastopol, Union of Socialist Soviet Republics.	44 36 N	33 32 E	12	1925	Mi., Crova.
(64) Sloutzk (Pavlovsk), Union of Socialist Soviet Republics.	59 41 N	30 29 E	30	January, 1926–December, 1928	Mi., Å.[1]
126) Smokovek, Czechoslovakia	49 8 N	20 13 E	1,015	1923–1926	Bimetallic, Å.[1]
(127) Stolzalpe, Austria	47 08 N	14 12 E	1,160	Aug. 10–17, 1925	Å.[1]
(128) Swinica, Poland	49 15 N	20 00 E	2,306	Sept. 1, 1926	M. G.
(75) Tashkent, Union of Socialist Soviet Republics.	41 20 N	60 18 E	480	1926–1928	Mi., A.[1]
(129) Tacubaya, Mexico	19 24 N	99 12 W	2,309	1911–1915	Å., S. I.
(130) Tagrait, Algeria	34 49 N	6 43 E	993	June 17, 1877	Violle.
(131) Tchimigan, Union of Socialist Soviet Republics.	70 km. NE Tashkent		1,400	June–July, 1923	Mi.
			1,980	July–August, 1925	
			3,200		
(81) Theodosia, Union of Socialist Soviet Republics.	45 02 N	35 24 E	15	February, 1926–December, 1928	Mi., Å.[1]
				June–August, 1927	Crova-Savinov actinograph.
(132) Tiflis, Union of Socialist Soviet Republics	41 43 N	44 48 E	420	September, 1913–December, 1915; June–August, 1927; January–December, 1928.	Å.,[1] Mi.
(133) Tomsk, Union of Socialist Soviet Republics	56 30 N	84 58 E	124	March to May, October to November, 1901	Viol Saveliev.
(134) Touggourt, Algeria	33 09 N	6 02 E	--------	March–April, 1924	Mi., S. I.
(135) Vienna, Austria	48 15 N	16 22 E	203	March, 1904–September, 1906	A.[1]
(136) Vladivostok, Union of Socialist Soviet Republics.	43 07 N	133 55 E	50	January–December, 1928	Å.[1] Crova, Viole-Saveliev.
(88) Warsaw, Poland	52 13 N	21 01 E	138	1919–1922	Mi., Å, S. I.
	52 13 N	21 03 E	86	1923–1928	M. G.
(89) Washington, D. C	38 56 N	72 05 W	127	1914–1928	Ma.
(137) Yalta, Union of Socialist Soviet Republics	44 30 N	34 11 E	100	June–September, 1926; May–September, 1927	Mi.
(90) Zakopane, Poland	49 17 N	19 58 E	833	Aug. 28–Sept. 15, 1926	M. G.
(138) Zaleszczyki, Poland	48 39 N	25 44 E	190	Jan. 10–Sept. 21, 1924	M. G., Å. (S. I. scale).
(139) Zugspitze, Germany	47 25 N	10 59 E	2,962	Aug., 1926–July, 1927	S. I., Å., Mi.
(91) Atlantic Ocean	North Seas		--------	Apr. 5–May 2; July 15–Aug. 15, 1923	Universal actinometer of Hartman & Braun, Frankfurt a Main.
Hamburg to Buenos Aires and return	Off Spanish coast; NE. trades; off Cape Verde Islands, calm zone, SE. trades.				

[1] Radiation records as recorded have been reduced to the Smithsonian pyrheliometric scale of 1913 by multiplying by 1.035.

TABLE 6.—*List of pyrheliometric stations*—Continued

Station	Latitude	Longitude	Altitude	Period	Instrument
	°	°			
Atlantic Ocean	39 N	10 W		Aug. 30, 1925	Ångström pyrheliometer standardized by comparison with Smithsonian silver-disk pyrheliometer.
NE. trades	26 N	16 W		Sept. 2, 1925	
Do	22 N	18 W		Sept. 3, 1925	
Calm zone	16 N	22 W		Sept. 4, 1925	
SE. trades	2 N	29 W		Sept. 7, 1925	
Do	3 S	32 W		Sept. 8, 1925	
Do	8 S	38 W		Sept. 9, 1925	
Do	13 S	38 W		Oct. 2, 1925	
Do	9 S	35 W		Oct. 3, 1925	
Do	5 S	33 W		Oct. 4, 1925	
Do	0	30 W		Oct. 5, 1925	
NE. trades	24 N	18 W		Oct. 10, 1925	
Do	29 N	16 W		Oct. 11, 1925	
	42 N	9 W		Oct. 14, 1925	
Atlantic Ocean	43.5 N	4.0 W		Apr. 22, 1928	Moll, S. I.
	43.5 N	9.0 W		Apr. 23, 1928	
	38.5 N	25.0 W		Apr. 25, 1928	
	37.0 N	31.0 W		Apr. 26, 1928	
	34.5 N	40.0 W		Apr. 27, 1928	
	33.0 N	47.0 W		Apr. 28, 1928	
	31.0 N	56.0 W		Apr. 29, 1928	
	27.5 N	70.0 W		May 1, 1928	
	26.0 N	77.0 W		May 2, 1928	

TABLE 7.—*Monthly means of solar radiation and atmospheric transmission*

Station	January	February	March	April	May	June	July	August	September	October	November	December
Tacubaya (129):												
A_m(max)	1.66	1.62	1.54	1.54	1.52	1.54	1.51	1.53	1.57	1.60	1.57	1.63
A_m	1.41	1.46	1.40	1.39	1.42	1.45	1.39	1.44	1.45	1.45	1.43	1.44
m	1.31	1.18	1.07	1.02	1.00	1.01	1.00	1.01	1.05	1.13	1.27	1.36
a_{0-1}	----	----	----	----	.75	.77	.74	.76	----	----	----	----
Fresno (24):												
A_2	----	----	----	----	----	----	----	----	----	1.14	----	----
a_{2-3}	----	----	----	----	----	----	----	----	----	.82	----	----
a_{0-1}	----	----	----	----	----	----	----	----	----	.72	----	----
Lincoln (43):												
A_2	1.40	1.37	1.25	1.20	1.12	1.10	1.07	1.07	1.17	1.20	1.36	1.38
a_{2-3}	.84	.86	.87	.82	.84	.84	.83	.83	.85	.91	.88	.87
a_{0-1}	----	----	----	.75	.73	.72	.71	.69	.73	.76	----	----
Madison (45):												
A_2	1.36	1.37	1.30	1.22	1.11	1.10	1.03	1.10	1.16	1.19	1.31	1.32
a_{2-3}	.90	.88	.91	.89	.86	.87	.87	.86	.88	.88	.88	.93
a_{0-1}	----	----	----	.74	.72	.71	.68	.69	.71	.72	----	----
Washington (89):												
A_2	1.23	1.18	1.14	1.09	.98	.91	.94	.96	1.05	1.10	1.18	1.23
a_{2-3}	.83	.82	.83	.83	.81	.82	.82	.84	.83	.86	.85	.84
a_{0-1}	----	----	.71	.71	.68	.65	.63	.64	.69	.72	----	----
Paris (Parc St. Maur) (63):												
A_m(max)	1.08	1.32	1.37	1.43	1.35	1.39	1.39	1.37	1.38	1.27	1.19	1.18
m_{max}	3.15	1.90	1.61	1.31	1.19	1.30	1.24	1.24	1.59	1.98	2.94	3.08
A_m	.87	1.05	1.16	1.20	1.21	1.16	1.19	1.21	1.19	1.07	.96	.78
m	3.19	2.20	1.69	1.37	1.21	1.20	1.18	1.28	1.54	1.83	2.78	3.49
Antibes (100):												
$A_{m=2.55}$	1.32	1.32	1.20	1.08	.98	1.01	1.05	1.00	1.04	1.10	1.30	1.29
A_m	1.34	1.40	1.38	1.35	1.36	1.36	1.41	1.34	1.36	1.31	1.31	1.26
m	2.32	1.80	1.42	1.20	1.10	1.06	1.08	1.15	1.31	1.64	2.14	2.54
A_2	1.43	1.38	1.32	1.23	1.12	1.20	1.17	1.07	1.12	1.22	1.41	1.41
a_{2-3}	.82	.91	.83	.86	.83	.80	.86	.89	.83	.83	.89	.87
Montpellier (52):												
A_m	1.24	1.20	1.34	1.34	1.24	1.12	1.20	----	1.20	1.26	1.15	1.23
m	2.63	2.13	1.39	1.22	1.10	1.06	1.08	----	1.32	1.76	2.40	2.82
A_m	.99	1.29	1.30	1.31	1.30	1.29	1.26	----	----	1.17	1.15	1.02
m	2.32	1.80	1.42	1.20	1.10	1.07	1.08	----	----	1.64	2.18	2.54
A_2	----	1.27	1.00	1.24	1.06	1.09	.79	----	----	1.11	1.20	1.21
a_{2-3}	----	.84	.81	.83	.81	.85	.70	----	----	.79	.85	.88
a_{0-1}	----	.76	.70	.70	.70	.73	.68	----	----	.73	.74	----
Mont Blanc Summit (49)—												
$A_{m=1.26}$	----	----	----	----	----	----	----	2.39	----	----	----	----
Grands-Mulets—												
$A_{m=1.26}$	----	----	----	----	----	----	----	2.26	----	----	----	----
Glacier der Bossont:												
$A_{m=1.26}$	----	----	----	----	----	----	----	2.02	----	----	----	----
$a_{(4,810-1,200}$ meters)	----	----	----	----	----	----	----	.88	----	----	----	----
$a_{(3,050-1,200}$ meters)	----	----	----	----	----	----	----	.92	----	----	----	----
Khanga (111)—												
$A_{m=1.28}$	----	----	----	----	----	1.60	----	----	----	----	----	----
Laghouat (114)—												
A_2	----	----	----	----	----	----	1.52	----	----	----	----	----
a_{2-3}	----	----	----	----	----	----	.85	----	----	----	----	----
a_{0-1}	----	----	----	----	----	----	.80	----	----	----	----	----
Tagrait (130)—												
$A_{m=1.28}$	----	----	----	----	----	1.75	----	----	----	----	----	----
A_2	----	----	----	----	----	1.55	----	----	----	----	----	----
a_{2-3}	----	----	----	----	----	.87	----	----	----	----	----	----
a_{0-1}	----	----	----	----	----	.83	----	----	----	----	----	----
Touggourt (134)—												
A_2	----	----	1.19	1.18	----	----	----	----	----	----	----	----
a_{2-3}	----	----	.87	.85	----	----	----	----	----	----	----	----
a_{0-1}	----	----	.74	.72	----	----	----	----	----	----	----	----

TABLE 7.—*Monthly means of solar radiation and atmospheric transmission*—Continued

Station	January	February	March	April	May	June	July	August	September	October	November	December
Ariana (102)—												
A_2	1.28	1.29	1.18	1.19	1.13	1.10	1.11	0.99	0.91	1.14	1.29	1.33
a_{2-3}	.83	.83	.80	.81	.84	.84	.83	.79	.79	.84	.86	.86
a_{0-1}	.78	.79	.78	.79	.75	.75	.75	.70	.66	.74	.78	.78
Vienna (135):												
A_2	.90	----	----	.94	----	----	.81	----	----	.87	----	----
a_{2-3}	.86	----	----	.78	----	----	.82	----	----	.85	----	----
a_{0-1}	.60	----	----	.59	----	----	.57	----	----	----	----	----
Stolzalpe (127):												
A_2	----	----	----	----	----	----	----	1.24	----	----	----	----
a_{2-3}	----	----	----	----	----	----	----	.87	----	----	----	----
a_{0-1}	----	----	----	----	----	----	----	.79	----	----	----	----
Davos (15):												
A_2	1.42	1.38	1.31	1.33	1.25	1.21	1.22	1.29	1.31	1.33	1.35	1.43
a_{2-3}	.85	.86	.82	.88	.92	.93	.93	.88	.89	.89	.87	.82
a_{0-1}	.84	.83	.81	.81	.79	.78	.75	.78	.79	.81	.82	----
Muottas-Muraigl (120):												
A_2	1.57	----	1.47	----	----	1.27	1.34	----	----	1.47	----	----
a_{2-3}	.92	----	.90	----	----	.90	.90	----	----	.92	----	----
a_{0-1}	----	----	.84	----	----	.78	.82	----	----	.86	----	----
Lötschenlücke (115):												
A_2	----	----	----	----	----	----	----	1.35	----	----	----	----
a_{2-3}	----	----	----	----	----	----	----	.91	----	----	----	----
a_{0-1}	----	----	----	----	----	----	----	.83	----	----	----	----
Montana (117):												
A_2	----	----	----	----	----	----	----	1.28	----	----	----	----
a_{2-3}	----	----	----	----	----	----	----	.88	----	----	----	----
a_{0-1}	----	----	----	----	----	----	----	.80	----	----	----	----
Zugspitze (139):												
A_2	1.56	1.59	1.55	1.49	1.42	1.41	1.42	1.44	1.47	1.53	1.63	1.51
a_{2-3}	.94	.94	.92	.91	.91	.92	.90	.90	.92	.92	.90	.95
a_{0-1}	----	.85	.86	.85	.84	.83	.85	.85	.85	.82	----	----
Eskdalemuir (17):												
A_m	.89	1.02	1.15	1.17	1.26	1.20	1.25	1.20	1.19	1.14	.89	.85
m	4.14	2.70	1.83	1.43	1.24	1.18	1.20	1.33	1.63	2.29	3.55	4.98
Kew (35):												
A_m	.70	.94	.97	1.01	1.05	1.06	1.03	1.06	1.00	.95	.74	.90
m	3.28	2.31	1.69	1.33	1.18	1.13	1.15	1.26	1.50	2.02	2.90	3.77
Potsdam (67):												
A_2	----	1.18	1.08	1.13	1.07	1.06	.99	.98	1.13	1.19	----	----
A_3	1.09	1.05	.94	.93	.90	.89	.80	.77	.93	1.01	.96	1.10
a_{2-3}	----	.89	.87	.82	.84	.84	.81	.79	.82	.85	----	----
a_{0-1}	----	----	.63	.70	.70	.70	.65	.64	.71	----	----	----
Schreiberhau (124):												
A_2	----	1.37	1.31	1.21	1.12	1.19	1.12	1.23	1.26	1.39	1.38	----
A_3	1.37	1.25	1.13	.98	.85	.98	.92	1.13	1.18	1.24	1.28	1.30
a_{2-3}	----	.91	.87	.81	.76	.83	.82	.92	.93	.89	.92	----
a_{0-1}	----	----	.80	.78	.78	.76	.76	.74	.79	.80	.76	----
Smokovek (126):												
A_2	1.48	1.42	1.40	1.30	1.18	1.21	1.18	1.18	1.32	1.38	1.31	----
A_4	1.21	1.17	1.03	.92	.83	.93	.92	.88	1.06	1.09	1.20	1.19
a_{2-3}	.90	.91	.86	.86	.82	.88	.88	.84	.91	.89	.97	----
a_{0-10}	----	----	.83	.77	.75	.75	.74	.73	.73	.74	----	----
Lysina (116):												
A_2	----	----	----	1.18	----	----	----	----	----	----	----	----
a_{2-3}	----	----	----	.87	----	----	----	----	----	----	----	----
a_{0-1}	----	----	----	.73	----	----	----	----	----	----	----	----
Giewont (105):												
A_2	----	----	----	----	----	----	----	1.50	----	----	----	----
a_{2-3}	----	----	----	----	----	----	----	.97	----	----	----	----
a_{0-1}	----	----	----	----	----	----	----	.86	----	----	----	----

TABLE 7.—*Monthly means of solar radiation and atmospheric transmission*—Continued

Station	January	February	March	April	May	June	July	August	September	October	November	December
Swinica (128):												
A_2									1.54			
a_{2-3}									.94			
a_{0-1}									.86			
Warsaw (88):												
A_{max}	0.98	1.14	1.21	1.24	1.22	1.22	1.22	1.21	1.14	1.11	1.02	0.91
m	3.47	2.50	1.87	1.46	1.34	1.33	1.24	1.40	1.69	2.18	3.07	4.45
$A_{abs.max}$	1.21	1.42	1.43	1.43	1.42	1.38	1.37	1.40	1.39	1.40	1.34	1.26
m	3.24	2.22	1.79	1.34	1.30	1.28	1.39	1.28	1.29	1.78	2.56	3.66
Zakopane (90):												
A_2	1.29			1.20					1.18			
a_{2-3}	.91			.84					.90			
a_{0-1}				.79					.78			
Zaleszczyki (138):												
A_2									1.25			
a_{2-3}									.88			
a_{0-1}									.75			
Helsingfors (107):												
A_2		1.19		1.24		1.16		1.24		1.26		
$A_{m=4}$		1.01		.97		.93		.99		1.03		
$A_{m=5.6}$												.86
a_{2-3}		.92		.87		.89		.89		.91		
a_{0-1}		.65		.74		.69		.76		.70		
Antrea (101):												
A_2						1.17	1.21	1.26				
A_4						.96	.91	.98				
a_{2-3}						.90	.86	.87				
a_{0-1}						.74	.77	.75				
Jungfruskär (110):												
A_2							1.24					
A_4							.94					
a_{2-3}							.87					
a_{0-1}							.75					
Rovaniemi (123):												
A_2						1.19						
A_4						.93						
a_{2-3}						.88						
a_{0-1}						.76						
Jokkmokk (109):												
A_2						.98						
a_{2-3}						.82						
Mount Evans (119):												
A_m		1.25	1.51	1.36					1.31	1.25		
m		5.0	2.5	2.5					2.5	3.5		
A_2		1.51	1.54	1.43				[1] 1.22	1.36	1.45		
a_{2-3}		.90	.92	.90				.88	.91	.91		
a_{0-1}			.87	.82				.73	.79			
Leningrad [2] (42).												
Sloutzk (64a):												
A_5	.94	.99	.87	.81	.78	.80	.74	.72	.83	.97	.99	
A_2			1.31	1.25	1.15	1.18	1.13	1.08	1.26	1.41		
a_{2-3}			.90	.87	.87	.86	.86	.86	.89	.84		
a_{0-1}			.75	.75	.69	.73	.70	.68	.81			
Sloutzk (64b):												
A_5	.95	.91	.85	.77	.73	.70	.66	.70	.74	.83	.93	.93
A_2		1.31	1.27	1.20	1.13	1.09	1.07	1.15	1.18	1.28		
a_{2-3}		.89	.86	.85	.85	.85	.83	.84	.85	.84		
a_{0-1}			.80	.79	.77	.76	.74	.76	.76			
Koursk (113):												
A_4	1.09	1.02	1.06	.83	.87	.80	.80	.87	.76	1.05	1.14	
A_2		1.35	1.35	1.16	1.14	1.12	1.03	1.07	1.16	1.31		
a_{2-3}		.86	.88	.84	.88	.85	.85	.85	.85	.87		
a_{0-1}			.79	.72	.69	.69	.66	.70	.75	.80		
Moscow (53):												
$A_{abs\ max}$	1.13	1.38	1.44	1.44	1.53	1.40	1.40	1.41	1.39	1.29	1.21	1.11
Kief [2] (36).												
Sevastopol [2] (125).												
Theodosia (81):												
A_3	1.03	1.12	.92	.86	.88	.88	.83	.88	.92	1.02	1.00	1.14
A_2	1.15	1.16	1.08	1.02	1.05	1.05	1.04	1.05	1.11	1.17	1.07	
a_{2-3}	.90		.86	.84	.83	.83	.79	.83	.83	.88	.94	
a_{0-1}			.64	.66	.71	.72	.72	.68	.70	.70		
Tiflis (132):												
A_m	1.26	1.29	1.34	1.32	1.42	1.36	1.32	1.34	1.30	1.27	1.27	1.19
m	2.10	1.74	1.44	1.18	1.09	1.05	1.07	1.13	1.27	1.51	1.97	2.33
$A_{2.37}$	1.20	1.17	1.14	1.03	1.11	1.05	.98	1.05	1.08	1.13	1.19	1.20
A_2	1.32	1.28	1.31	1.18	1.19	1.10	1.12	1.15	1.22	1.27	1.18	1.27
a_{2-3}	.85	.89	.87	.89	.83	.85	.83	.85	.86	.88	.89	.90
a_{0-1}	.80	.77	.76	.72	.75	.74	.74	.74	.78	.75	.68	
Mount Elbrus (118):												
A_2								1.38				
a_{2-3}								.89				
a_{0-1}								.87				
Kislovodsk (112):												
A_2					1.23	1.21	1.16	1.19	1.23	1.31	1.33	
a_{2-3}					.86	.86	.86	.86	.87	.89	.87	
a_{0-1}					.78	.76	.73	.76	.74	.73		
Baku [2] (103).												
Tomsk (133):												
A_m			1.29	1.32	1.29					1.16	.99	
m			1.74	1.46	1.28					2.77	4.28	
Yalta [2] (134).												
Borovoy [2] (104).												
Katherinenburg (34):												
A_m	.93										1.09	.79
m	4.0										4.0	6.0

[1] Within 30 miles east from Mount Evans.
[2] Not found in U. S. Weather Bureau library.

TABLE 7.—*Monthly means of solar radiation and atmospheric transmission*—Continued

Station	January	February	March	April	May	June	July	August	September	October	November	December
Katherinenburg (34)—Contd.												
A_2		1.34	1.28	1.21	1.16	1.13	1.04	1.20	1.20	1.31		
a_{2-3}		.87	.87	.88	.87	.83	.83	.85	.88	.90		
a_{0-1}				.78	.74	.73	.72	.74				
Golodnoya Steppe [2] (106).												
Oura Tiube [2] (121).												
Repetek [2] (122).												
Tashkent (75):												
A_3	1.22	1.27	1.15	1.05	1.02	.94	.92	.99	1.02	1.07	1.23	1.28
A_2	1.44	1.41	1.31	1.24	1.18	1.10	1.09	1.15	1.20	1.21	1.34	1.45
a_{2-3}	.85	.90	.85	.84	.87	.85	.84	.86	.86	.88	.92	.89
a_{0-1}		.80	.82	.81	.73	.72	.72	.71	.73	.71	.74	
Tchimigan [2] (131).												
Irkutsk (108b):												
A_4	.82	.96	.98	.90	.99	.91	.85	.86	.96	.86	.84	.91
A_2	1.34	1.39	1.24	1.21	1.28	1.14	1.08	1.16	1.23	1.12		
a_{2-3}	.77	.83	.89	.84	.86	.89	.89	.86	.89	.88		
a_{0-1}			.71	.75	.77	.67	.70	.72	.72			
Vladivostock (136):												
A_3	1.30	1.18	1.17	.96	.85	.90	.99	.94	1.07			
A_2	1.52	1.34	1.37	1.25	1.13	1.12	1.15	1.14	1.22			
a_{2-3}	.85	.88	.85	.81	.76	.82	.86	.83	.87			
a_{0-1}		.77	.83	.82	.77	.74	.73	.74	.75			
Atlantic Ocean (91):												
North Sea—				[3]								
A_2				1.09								
a_{2-3}				.81								
a_{0-1}				.71								
Off Spanish coast—												
A_2				1.07								
a_{2-3}				.82								
a_{0-1}				.69								
N. E. trades—												
A_2				1.16								
a_{2-3}				.84								
a_{0-1}				.74								
Off Cape Verd. I.—												
A_2				.76								
a_{2-3}				.70								
a_{0-1}				.60								
Calm Zone—												
A_2				.97								
a_{2-3}				.88								
a_{0-1}				.67								
S. E. trades—												
A_2				1.15								
a_{2-3}				.87								
a_{0-1}				.74								
Off Portugal—												
$A_{3.5}$								.89				
N. E. trades—												
A_2									.79			
a_{2-3}									.73			
a_{0-1}									.59			
N. E. trades—												
A_1									1.06			
a_{0-1}									.57			
Calm Zone—												
A_2									.75			
a_{2-3}									.71			
a_{0-1}									.58			
S. E. trades—												
A_1									1.25			
a_{0-1}									.66			
S. E. trades—												
A_1									1.24			
a_{0-1}									.65			
S. E. trades—												
A_1									1.28			
a_{0-1}									.67			
S. E. trades—												
A_1										1.36		
a_{0-1}										.70		
S. E. trades—												
$A_{1.2}$										1.26		
S. E. trades—												
A_1										1.34		
a_{0-1}										.69		
S. E. trades—												
A_2										1.11		
a_{2-3}										.86		
a_{0-1}										.68		
N. E. trades—												
A_2										1.18		
a_{2-3}										.89		
a_{0-1}										.75		
N. E. trades—												
A_2										1.19		
a_{2-3}										.87		
a_{0-1}										.72		
Coast of Spain—												
A_2										1.26		
a_{2-3}										.89		
a_{0-1}										.69		

[2] Not found in U. S. Weather Bureau library.
[3] See dates in Table 6.

TABLE 7.—*Monthly means of solar radiation and atmospheric transmission*—Continued

Station	January	February	March	April	May	June	July	August	September	October	November	December
North Atlantic Ocean:												
Bay of Biscay—												
$A_{1.17}$	----	----	----	1.33	----	----	----	----	----	----	----	----
Off Spain—												
$A_{1.17}$	----	----	----	1.35	----	----	----	----	----	----	----	----
Off Azores—												
$A_{1.10}$	----	----	----	1.37	----	----	----	----	----	----	----	----
S. Temperate—												
$A_{1.09}$	----	----	----	1.33	----	----	----	----	----	----	----	----
S. Temperate—												
$A_{1.08}$	----	----	----	1.32	----	----	----	----	----	----	----	----
S. Temperate—												
$A_{1.06}$	----	----	----	1.29	----	----	----	----	----	----	----	----
S. Temperate—												
$A_{1.04}$	----	----	----	1.24	----	----	----	----	----	----	----	----
S. Temperate—												
$A_{1.03}$	----	----	----	----	1.22	----	----	----	----	----	----	----
Off Bahama I.—												
$A_{1.03}$	----	----	----	----	1.19	----	----	----	----	----	----	----

TABLE 8.—*Source of pyrheliometric data*

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TABLE 8.—*Source of pyrheliometric data*—Continued

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TABLE 8.—*Source of pyrheliometric data*—Continued

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TABLE 8.—*Source of pyrheliometric data*—Continued

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NOTE.—After this paper had been submitted for publication the following was received: "Tabellen der Intensität der Sonnenstrahlung in Mittel-Europa," Heft 1, Januar, 1930. Zusammengestellt vom Meteorologisch-Magnetischen Observatorium Potsdam. It summarizes pyrheliometric observations for January, 1930, for the following stations: Breslau-Krietern; Davos; Karlsruhe; Potsdam; Schömberg b. Wildbad i. Württemberg; Serfaus, Tirol (Ob. Inntal); Taunus-Feldberg; Wien; Wyk auf Föhr.

ATMOSPHERIC DEPLETION OF SOLAR RADIATION

Figure 1 is similar to Figure 3 in the paper of April, 1927, except that it has been extended to cover a greater range of atmospheric water vapor (depth of water, W, that would be obtained if all the water vapor in the atmosphere were precipitated). Full details of the construction and use of the table are given in the earlier paper.

In Table 9 are given values of a_{0-1} taken from Table 7, and a_{0-2} computed from $\frac{A_2R^2}{A_o}$ where R is the earth's radius vector in terms of its mean value, and $A_o = 1.940$ gr. cal. per min. per sq. cm., the mean value of Abbot's determinations of the solar constant. There are also given values of a_{0-1} and a_{0-2} for dust-free air that have been obtained by interpolation between curves 9 to 13 of Figure 1.

In using these curves it is necessary to remember that unit air mass on the air-mass scale of this figure represents a *dry-air-pressure* of 760 mm. The dry-air pressure at a station is represented by $m = B - e$, where B is the station barometric pressure and e is the water-vapor pressure. Therefore unit air mass for the station, m', will fall at $\frac{B-e}{760}$ on the air mass scale of the figure.

For stations at or near sea level it is not necessary to consider this small deviation from standard air mass. In the computations for Table 9 unit air mass for Madison, Wis., falls at about 0.96 on the air-mass scale of Figure 1; for Lincoln, Nebr., at about 0.95, and for Davos, Switzerland, at 0.82. At any point on curves 9 to 15, inclusive, Figure 1, the water-vapor content of the atmosphere through which the sun's rays pass is represented by $m'W=\frac{B-e}{760}W$, where W has the value assigned to it for the respective curves.

TABLE 9.—*Depletion of solar radiation by atmospheric dust*

WASHINGTON, D. C.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P (mm.)	754	753	752	751	750	750	750	751	753	753	753	754
W (mm.)	6.0	6.1	8.2	11.1	17.6	28.9	33.1	31.7	24.5	16.4	10.0	6.9
a_{0-1}:												
(Pyr.)	-----	-----	.71	.71	.68	.65	.63	.64	.69	.72	-----	-----
Dust-free air	-----	-----	.81	.80	.77	.74	.72	.72	.75	.78	-----	-----
Dust depletion	-----	-----	.10	.09	.09	.09	.09	.08	.06	.06	-----	-----
a_{0-2}:												
(Pyr.)	.61	.59	.58	.57	.52	.48	.50	.51	.54	.56	.59	.61
Dust-free air	.74	.74	.71	.70	.67	.61	.60	.60	.63	.67	.71	.73
Dust depletion	.13	.15	.13	.13	.15	.13	.10	.09	.09	.11	.12	.12

MADISON, WIS.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P (mm.)	736	737	736	735	735	736	736	737	737	737	737	737
W (mm.)	3.8	4.0	6.3	9.3	13.8	25.6	28.5	26.0	19.9	13.0	8.1	3.9
a_{0-1}:												
(Pyr.)	-----	-----	-----	.74	.72	.71	.68	.69	.71	.72	-----	-----
Dust-free air	-----	-----	-----	.80	.78	.75	.74	.75	.77	.79	-----	-----
Dust depletion	-----	-----	-----	.06	.06	.04	.06	.06	.06	.07	-----	-----
a_{0-2}:												
(Pyr.)	.68	.69	.66	.63	.58	.58	.55	.58	.60	.61	.66	.65
Dust-free air	.76	.76	.74	.72	.69	.68	.62	.63	.66	.70	.73	.76
Dust depletion	.08	.07	.08	.09	.11	.10	.07	.05	.06	.09	.07	.11

LINCOLN, NEBR.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P (mm.)	732	732	730	729	728	728	729	729	730	730	731	731
W (mm.)	5.1	5.7	7.7	11.6	16.1	28.2	30.7	29.5	21.0	11.8	8.7	6.0
a_{0-1}:												
(Pyr)	-----	-----	-----	.75	.73	.72	.71	.69	.73	.76	-----	-----
Dust-free air	-----	-----	-----	.80	.78	.74	.74	.73	.76	.80	-----	-----
Dust depletion	-----	-----	-----	.05	.05	.02	.03	.04	.03	.04	-----	-----
a_{0-2}:												
(Pyr.)	.70	.69	.64	.62	.59	.58	.57	.56	.61	.61	.68	.68
Dust-free air	.74	.74	.73	.70	.68	.62	.61	.61	.65	.70	.72	.74
Dust depletion	.04	.05	.09	.08	.09	.04	.04	.05	.04	.09	.04	.06

DAVOS, SWITZERLAND

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
P (mm.)	625	626	627	628	629	630	630	629	628	627	626	625
W (mm.)	4.5	5.2	5.9	8.1	10.5	13.6	15.6	15.5	13.1	9.1	6.7	5.0
a_{0-1}:												
(Pyr.)	-----	-----	.81	.81	.79	.78	.75	.78	.79	-----	-----	-----
Dust-free air	-----	-----	.84	.82	.81	.80	.79	.79	.80	-----	-----	-----
Dust depletion	-----	-----	.03	.01	.02	.02	.04	.01	.01	-----	-----	-----
a_{0-2}:												
(Pyr.)	.71	.69	.67	.69	.66	.64	.65	.68	.68	.68	.68	.70
Dust-free air	.77	.76	.76	.74	.72	.70	.69	.69	.71	.73	.75	.76
Dust depletion	.06	.07	.09	.05	.06	.06	.04	.01	.03	.05	.07	.06

Depletion by atmospheric dust.—The difference between the values of a_{0-1}, or a_{0-2} as given by pyrheliometric readings and the corresponding values as computed for dust-free air by means of Figure 1 represents the depletion of solar radiation by atmospheric dust. It will be noted in Table 9 that the depletion by dust diminishes with an increase of altitude. Measurements made at the Astrophysical Observatory of the Smithsonian Institution at Calama, Chile, altitude 2,250 meters, indicates that with the sun in the zenith in the driest part of the year the depletion of solar radiation by atmospheric dust amounts to only about 3 per cent of the solar constant, and that during the remainder of the year it is inappreciable.

In connection with the construction of Figure 1 it was necessary to determine the intensity of solar radiation in different parts of the spectrum both for dry air and for air containing different amounts of water vapor. The determinations were made for sea-level conditions, B=760 mm., and also for the height of Calama, Chile, B=582 mm., $m'=\frac{582}{760}=0.766$. Having determined these intensities, it is a simple matter to compute the relative energy in the solar spectrum between different wave-length limits. For dust-free air at an altitude of 2,250 meters the results are given in Table 10, and for dust-free air at sea level, in Table 11 (A). In both tables the second column also, gives the distribution of energy outside the atmosphere.

TABLE 10.—*Percentage of total energy in different parts of solar spectrum outside the atmosphere (m=0) and with a dust-free atmosphere at the altitude of Calama, Chile ($m'=\frac{582}{760}=0.766$); also depletion by atmospheric dust (depletion in total spectrum=10 per cent of solar constant)*

	Energy distribution				Depletion by dust		
Air mass (m')	0	0.766	0.766	0.766	0.766	0.766	0.766
Water-vapor content of atmosphere (cm.)	0	0	.42	1.28	0	.42	1.28
Place in spectrum	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Below 0.346μ	3.1	1.8	1.7	1.5	29.1	30.4	31.9
0.346–0.405μ	5.0	3.8	4.0	4.1	23.6	24.8	26.0
0.405–0.704μ	40.1	39.5	42.3	43.6	14.9	15.6	16.4
Above 0.704μ	51.8	54.9	52.0	50.8	7.0	7.1	7.1
Total	100.0	100.0	100.0	100.0	-------	-------	-------
Percentage of solar constant	100.0	93.5	86.0	81.2	10.0	10.0	10.0

TABLE 11

(A) PERCENTAGE OF TOTAL ENERGY IN DIFFERENT PARTS OF SOLAR SPECTRUM AFTER DEPLETION BY DUST-FREE AIR

Solar zenith distance	0°					60°				75.7°			
Air mass	0	1				2				4			
Water-vapor content of atmosphere (cm.)	----	0.0	1.0	2.0	3.0	0.0	1.0	2.0	3.0	0.0	1.0	2.0	3.0
Place in spectrum	%	%	%	%	%	%	%	%	%	%	%	%	%
Below 0.346μ	3.1	1.3	1.2	1.0	0.7	0.6	0.5	0.3	0.1	0.2	0.1	0.06	0.02
0.346–0.405μ	5.0	3.5	3.8	3.7	3.6	2.4	2.7	2.5	2.3	1.1	1.2	1.07	1.00
0.405–0.704μ	40.1	39.3	43.3	44.2	44.9	37.6	42.3	43.4	44.2	34.0	39.7	40.4	40.9
Above 0.704μ	51.8	55.9	51.7	51.1	50.8	59.4	54.5	53.8	53.4	64.7	59.0	58.5	58.1
Total spectrum	100	100	100	100	100	100	100	100	100	100	100	100	100
Percentage of solar constant	100	90.4	80.3	76.3	73.1	84.2	69.2	65.9	61.1	75.8	58.8	51.7	45.8

(B) DEPLETION OF ENERGY BY ATMOSPHERIC DUST (TOTAL DEPLETION=10 PER CENT OF SOLAR CONSTANT)

Below 0.346μ	30.3	32.7	34.4	35.7	32.4	40.9	41.8	43.3	41.5	48.7	56.4	63.5
0.346–0.405μ	24.6	26.7	27.9	29.0	26.5	31.8	33.7	34.9	33.2	39.1	45.2	50.2
0.405–0.704μ	15.5	16.8	17.5	18.3	18.1	19.7	20.9	21.6	20.4	25.0	27.5	30.5
Above 0.701μ	6.4	7.3	7.8	8.2	6.9	9.0	9.5	11.2	8.7	11.2	13.2	15.2

(C) TOTAL DEPLETION=10 PER CENT OF INTENSITY OF DUST-FREE AIR

Below 0.346μ	27.4	26.3	26.2	26.1	27.3	29.2	27.5	26.5	31.5	28.6	29.2	29.1
0.346–0.405μ	22.2	21.4	21.3	21.2	22.3	22.7	22.2	21.3	25.2	23.0	23.4	23.0
0.405–0.704μ	14.0	13.5	13.4	13.4	15.2	14.0	13.8	13.2	15.5	14.7	14.2	14.0
Above 0.704μ	5.8	5.9	6.0	6.0	5.8	6.2	6.3	6.8	6.6	6.6	6.8	7.0

Angström[1] has recently shown that the depletion of solar radiation by atmospheric dust may be expressed by the equation $\gamma=\frac{\sigma}{\lambda^{\alpha}}$. He has also found that under normal conditions the value of α departs but little from 1.28, although following the eruption of Katmai Volcano in 1912 its value was reduced about one-half. I have applied this equation to the intensities of solar radiation at different wave lengths after depletion by dust-free air, including the absorption by ozone, water vapor and other gases of the atmosphere. Table 10 and Table 11 (B) give the resulting percentages of depletion by atmospheric dust, computed for a depletion in the total spectrum amounting to 10 per cent of the solar constant. For any other percentage of depletion, as x, the percentage given in the tables must be multiplied by $\frac{x}{10}$. At Davos, in April, August and September, $m'=\frac{616}{760}=0.811$, the depletion by atmospheric dust amounts to only 1 per cent, and interpolation between Table 10 and Table 11 (B) indicates that the depletion in the different spectral regions, beginning with the shortest wave length, would be about 3.1, 2.5, 1.6, and 0.7 per cent, respectively.

On the other hand, at Washington in September, with the sun 60° from the zenith (m=2), an atmospheric water-vapor content of 2.45 cm., and a depletion by atmospheric dust of 9 per cent, the percentage depletions obtained from table 11 (B) for the different spectral regions are, respectively, 38.2, 31.0, 18.1, and 9.3.

The corresponding intensities in these spectral bands may be obtained from Tables 11 (A) and 11 (B) as follows:

Intensity below $0.346\mu=0.002\ (1.94\times0.637)(1-0.382)=0.0015$.

Intensity between 0.346μ and $0.405\mu=0.24(1.94\times0.637)(1-0.310)=0.0205$.

Intensity between 0.405μ and $0.704\mu=0.438(1.94\times0.637)(1-0.181)=0.4433$.

Intensity above $0.704\mu=0.536(1.94\times0.637)(1-0.093)=0.6008$.

Intensity in total solar spectrum with earth at mean solar distance=1.0663.

Intensity reduced to mean solar distance for September$=\frac{1.0663}{R^2}$ $=1.055$ gram calories per minute per square centimeter, or practically the same as in Table 7.

It must be understood that the above computation of intensities in different parts of the spectrum are for average conditions only, and take no account of the effect of variations in the ozone content of the atmosphere with both time and place, or of possible variations in the distribution of energy in the spectrum of solar radiation before it enters the earth's atmosphere. Therefore they can not take the place of careful measurements, and only serve to indicate approximately how much energy is to be expected in different spectral regions under different atmospheric conditions. The variations in the ozone content of the atmosphere must exert a marked effect upon the amount of solar energy of wave lengths below 0.346μ that reaches the surface of the earth.

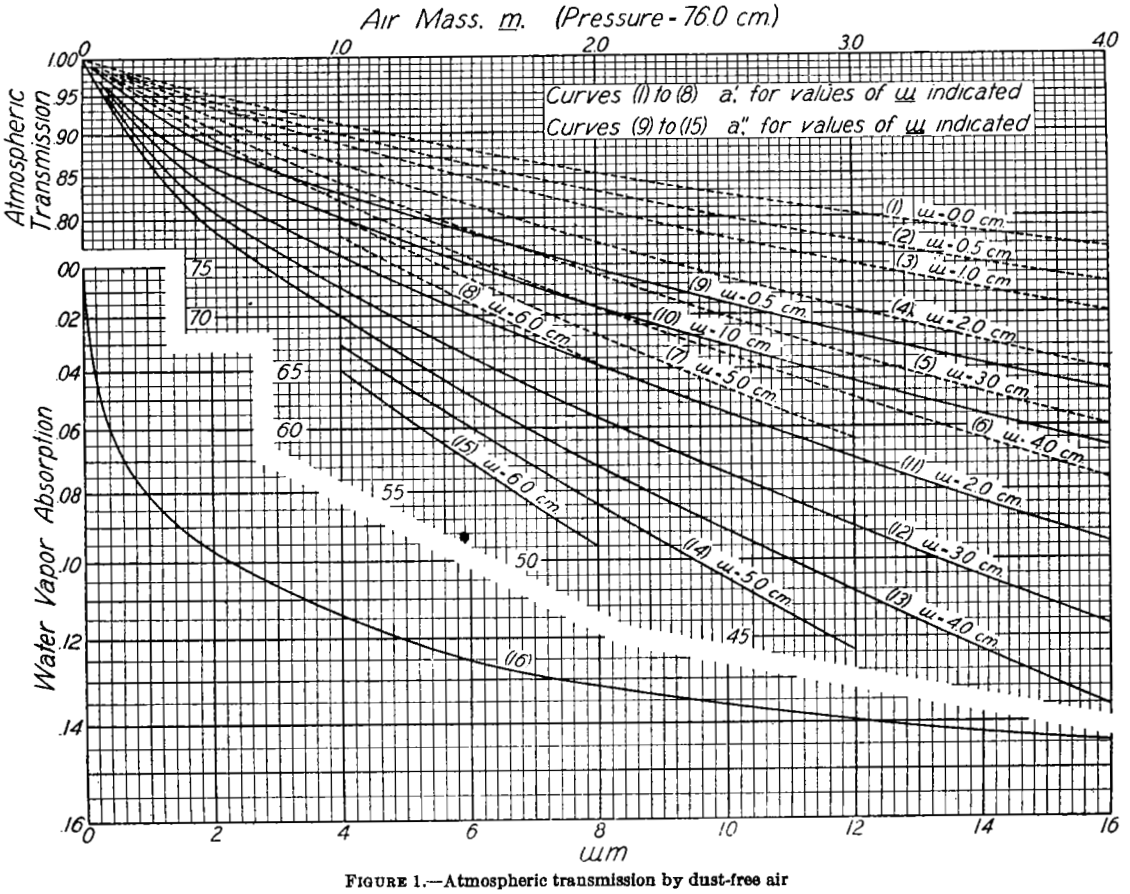

FIGURE 1.—Atmospheric transmission by dust-free air

[1] Ångström, Anders. On the atmospheric transmission of solar radiation and on dust in the air. Geografiska Annaler, 1929, H. 2.