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THE BRIGHTNESS OF THE SKY

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INTRODUCTION

It was planned to send an expedition from the Smithsonian Institution to Argentina or Chile in the early summer of 1917, for the purpose of making daily observations on the solar constant of radiation similar to those which have been made for fourteen summers past at the station of the Smithsonian Astrophysical Observatory on Mt. Wilson, California. Accordingly, much of the apparatus was boxed ready for shipment to Chile early in 1917. Owing to war conditions, however, it was thought best to defer sending the expedition to a foreign country, and a location was selected on the slope of Hump Mountain, near Elk Park, North Carolina.

From all available reports, this locality, it was thought, might be expected to furnish two hundred clear days per year. It was selected because of this fact, and also because it had a sufficient elevation, was at a great distance from Mt. Wilson (insuring different local weather conditions at the two stations), and because of its easy access.

Bolometric observations were begun at Hump Mountain on June 17, 1917. But it soon became evident that there was too much cloudiness and rainfall to render it suitable for a permanent solar constant station. However, the expedition possessed an instrument for which the varying conditions of Hump Mountain were just suited, this instrument being the pyranometer, recently perfected at the Smithsonian Astrophysical Observatory, and described in detail in two former publications of the Institution (Smithsonian Miscellaneous Collections, Vol. 66, Nos. 7 and 11). Accordingly, a considerable amount of work was done with the pyranometer during the expedition's stay at Hump Mountain, which lasted until April, 1918, when it prepared to go to Chile.

The present paper is a description of these various lines of observation. It is thought best not to burden the reader with the many pages of observations which were taken, therefore an effort will be made to condense as much as possible without omitting important details.

STATION AND APPARATUS

The station was located at an elevation of 4,800 feet above sea level, on the eastern slope of Hump Mountain. The very heavy winds prevailing at certain seasons made it impossible to select a site near the summit, which rises to an altitude of about 5,500 feet. The latitude was 36° 08′ N. and longitude 82° 0′ W.

Most of the sky radiation observations were made with the instrument resting on a level platform erected on the roof of the observatory, in order to eliminate the building as an obstruction. Being located below the summit of the mountain, a certain small percentage of the sky was cut off, but this was accurately measured by means of a theodolite and found to be 5.1 per cent of the total hemisphere. The mountain cut off an angle of 13.0° measured vertically at its highest point.

The galvanometer, ammeter, resistances and battery were located in the room beneath, the first two mentioned being mounted on a pier made of large boxes filled with stones.

A brief description of the pyranometer and the auxiliary apparatus may be of interest here. The pyranometer consists essentially of two blackened strips of manganin of exactly the same horizontal dimensions, but one strip about ten times as thick as the other. These strips, which are exposed to an entire hemisphere of radiation, are insulated and carefully soldered to copper blocks at each end. Very sensitive tellurium-platinum thermo-elements are joined in series with each other and are set across and underneath the two strips and separated from them by thin waxed paper. The thermo-element leads pass to the galvanometer, but for convenience in obtaining suitable deflections, three different resistance combinations are included in series. The manganin strips attached to the copper bars are connected in parallel, but with proper resistances included, so that the heating current applied divides in exactly the proper proportion to cause the same heating effect in both strips. When the shutter is opened to admit radiation, since the blackened strips have the same horizontal dimensions, the same quantity of heat is imparted to each, but the thicker strip conducts its heat to the ends the more readily and so a difference in temperature at the thermo-elements produces an electric current which deflects the galvanometer. When the shutter is closed a current is sent through the strips, so as to cause about an equal deflection of the galvanometer thus indicating a heating effect equal to that produced by the radiation. This current is measured in a carefully calibrated milli-ammeter, and from the ratio of the nearly equal deflections (first swings) and the known current and the constant of the instrument the calories per square centimeter per minute striking the strips as radiation, can be readily computed by the following formula:

$$\text{Calories}=K\,\frac{d_r}{d_c}\,c^2$$

where K=constant of the instrument, d_r and d_c=deflections of galvanometer produced by the radiation and current respectively, and c=current corrected by the calibration curve of the milli-ammeter.

For work in day time, a hollow hemispherical screen of ultra-violet crown glass is placed over the strips to prevent the exchange of long wave length radiation between the strips and the sky. That this admits practically all solar wave lengths of any importance will be shown later in the paper. The transmission of this screen is about 0.92 but the instrument is calibrated with it over the strips so the value of K presupposes its use.

For day work the instrument can be used in four ways, when it is in a horizontal position: (1) with no shade of any kind, to measure total sky radiation, or if the sun be present, total sun and sky radiation; (2) a small circular polished metal screen can be interposed to shade the strips from the sun but allowing the sky radiation to strike the strips; (3) zones of metal, shading various sections of the sky can also be used; (4) an enclosing hood can be slipped on which admits only solar radiation when its small shutter is opened. This hood and also the shade mentioned in (2) may be adjusted to follow the sun.

To determine the value of K, the instrument is used carefully leveled with the hood mentioned in (4) upon it. A series of observations is then taken on the sun, simultaneously with readings of a pyrheliometer, or preferably a pair of pyrheliometers. A set of observations of the altitude of the sun, or of time, are kept, in order to construct an air-mass-time curve. "Air mass" is approximately the secant of the zenith distance, but if taken by the altitude method, the refraction correction must be included. Since the pyranometer strips lie in a horizontal position, while the pyrheliometer points directly at the sun, the air mass is a factor in the formula for obtaining the constant K, which is as follows:

$$K=\frac{\text{pyrheliometer calories}}{c^2/d_c\times d_r\times\text{air mass}}$$

where c, d_r and d_c are the same as used before. $\frac{c^2}{d_c}$ should be practically constant and an average of all the values of this quantity is used.

In order to show the good agreement of values of K obtained by this method a set of observations will be included.

HUMP MOUNTAIN, AUGUST 26, 1919

Hour angle	Zero	Reading	Deflection	Current	Correction factor	$\frac{c^2}{d_c}$	Air mass	Pyrheliometer calories	K
—2:52:15	1.97	16.05	14.08	....	.....	......	1.413	1.462	2.093
51	1.97	15.42	13.45	.691	.9944	.03510	.....	.....	.....
50	1.97	16.15	14.18	....	.....	......	1.404	1.460	2.090
49	1.96	16.13	14.17	.710	.9945	.03518	.....	.....	.....
48	1.94	16.21	14.27	....	.....	......	1.396	1.448	2.072
47	1.96	16.13	14.17	.710	.9945	.03518	.....	.....	.....
46	1.94	16.39?	14.45?	....	.....	......	1.387	1.445	2.054?
45	1.95	16.18	14.23	.711	.9945	.03513	.....	.....	.....
44	1.93	16.39	14.46	....	.....	......	1.379	1.457	2.083
43	1.95	16.95	15.00	.732	.9946	.03534	.....	.....	.....
42	1.95	16.51	14.56	....	.....	......	1.371	1.462	2.087
41	1.94	16.42	14.48	.719	.9945	.03531	.....	.....	.....
40	1.92	16.55	14.63	....	.....	......	1.363	1.465	2.092
39	1.93	16.87	14.94	.725	.9946	.03480	.....	.....	.....
38	1.91	16.63	14.72	....	.....	......	1.356	1.469	2.099
37	1.92	16.79	14.87	.723	.9946	.03478	.....	.....	.....
36	1.91	16.70	14.79	....	.....	......	1.348	1.469	2.100
35	1.92	16.50	14.58	.727?	.9946	.03586?	.....	.....	.....
34	1.91	16.72	14.81	....	.....	......	1.341	1.461	2.097
33	1.90	16.72	14.82	.722	.9946	.03480	.....	.....	.....
32	1.88	17.00	15.12	....	.....	......	1.333	1.468	2.076
31	1.89	16.40	14.51	.718	.9945	.03514	.....	.....	.....
30	1.88	17.06	15.18	....	.....	......	1.326	1.460	2.069
29	1.89	20.00	18.81	.800?	.9948	.03367?	.....	.....	.....
28	1.89	17.11	15.22	....	.....	......	1.321	1.471	2.086
27	1.91	19.30	17.39	.786	.9948	.03516	.....	.....	.....
26	1.91	17.24	15.33	....	.....	......	1.313	1.465	2.074
25	1.91	17.08	15.17	.732	.9946	.03494	.....	.....	.....
24	1.91	17.34	15.43	....	.....	......	1.306	1.465	2.071
23	1.92	17.61	15.69	.745	.9947	.03500	.....	.....	.....
22	1.91	17.50	15.59	....	.....	......	1.301	1.468	2.064
21	1.92	17.51	15.59	.743	.9947	.03504	.....	.....	.....
20	1.91	17.49	15.58	....	.....	......	1.294	1.474	2.083
19	1.93	17.38	15.45	.740	.9946	.03506	.....	.....	.....
				Mean $\frac{c^2}{dc}$ =		.03508		Mean =	2.083

In obtaining the means the values at —2:46:15, —2:35:15 and —2:29:15 were omitted, as the readings were questionable.

Calibrations were made every few weeks, and up to December 20, 1917, the value of K was always found to be about 2.08. The instrument was taken to Washington the latter part of December to have an overhauling, and after that the constant was either 2.11 or 2.12. But it plainly shows that the constant does not vary appreciably, if the instrument has reasonable care. The slight change in December was probably caused by the blackening of the surfaces of the manganin strips being altered a very little.

SENSITIVENESS OF PYRANOMETER

In March, 1918, at the Hump Mountain Observatory an investigation was made of the sensitiveness of the pyranometer to different wave lengths. To do this, the regular bolometric apparatus was employed, except that in place of the bolometer and battery, the pyranometer was used to measure the heat of the various parts of the spectrum, and its indications were recorded as on a regular bolographic plate. The thermo-elements were joined directly to the very sensitive galvanometer, used in bolographic work. (As a matter of precaution shunts were first put in the circuit to prevent any possible injury to the galvanometer.) A circular piece of black paper with a slit 0.40 mm. wide, and cut just to fit within the glass hemisphere, was placed over the blackened strips and at right angles to them. Then the glass hemisphere was placed in position. Outside of this was placed a black metal diaphragm, and finally the sun hood mentioned above under (4). Thus there was practically no chance for stray radiation to reach the strips, especially since all the apparatus was installed in a dark room with black paper lined walls.

A brief description of the remainder of the spectrobolometric apparatus employed for this test will be given. The sun's rays strike a two-mirror coelostat and are reflected into the building, first passing through the revolving sector to cut down the intensity of radiation in a fixed and known ratio. Then they pass through the slit, and about eight feet distant, through the prism. The spectrum is reflected by a plane speculum metal mirror on to a concave speculum mirror, which brings the spectrum to a focus at the plane of the pyranometer strips. (The strips lie in a vertical plane in this observation, with their longitudinal direction horizontal, and crossed at the center by the paper slit, which allows only rays of nearly the same wave length to strike the strips at one time.) The spectrum is moved across the paper slit, when the prism is rotated by a worm gearing. This gearing is connected to the plate carrier clock in such a manner that as the photographic plate descends the prism is slowly rotated, causing the spectrum to advance from infra-red toward ultra-violet across the blackened strips. The thermo-couple of the pyranometer causes the galvanometer needle to deflect, and this reflects a beam from an auxiliary source on to the photographic plate so that the spot deflection is at right angles to the direction of motion of the plate, thus automatically tracing an energy curve on the plate.

The observations were made from about wave length 2.2μ in the infra-red, to 0.33μ in the ultra-violet. Three curves were run on the plate, the first two being with the pyranometer, and the third with the regular bolometer. During the first curve the spectroscope slit was opened 1.37 mm., during the second 2.85 mm. and during the regular bolograph 0.35 mm. The time of run was 7 m., 20 s. Sectors were changed at four places in the run in order to give a good deflection and not allow the curve to leave the plate. The last section in the ultra-violet was run with full intensity of solar beam.

Of course it could not be expected that much definition could be obtained with a slit of such width, but an examination of the plate will show that the various wave lengths are recorded in about their true magnitude, through practically the entire range of the spectrum where there is an appreciable amount of energy. It also shows that the glass hemisphere employed transmits these waves in about their true relation. By making due allowance for sector, slit widths, and width and height of paper diaphragm as compared with the bolometer and corresponding deflections for equal wave lengths on the plates, it is seen that the pyranometer is approximately one-fourth as sensitive as the bolometer.

SKY RADIATION MEASUREMENTS

Practically all pyranometer observations made at Hump Mountain were taken with the instrument resting on the roof platform—as heretofore mentioned. As stated before, there was approximately 5.1 per cent of the total area of the hemsiphere cut off by the hill to the west, but as this all lies next to the horizon from whence the rays strike the pyranometer strips at a very unfavorable angle, and since as will be shown later, the hill itself offers radiation to help offset that cut off from the sky, it is perhaps well within the general accuracy of the results to ignore the hill entirely.

Observations on clear skies.—The major portion of the observations on the entire hemisphere of clear skies was made in connection with auxiliary curves to investigate the sky radiation during bolographs. These were run quite regularly with bolographs from August 18, 1917, to November 26, 1917. They were originally intended to offer a means of obtaining a very close approximation to the solar constant by constructing an empirical curve showing the relation between intensity of sky radiation, and the ratio of the true solar constant to the apparent value obtained by exterpolating the pyrheliometer values to zero air mass. Such a curve was found to be quite erratic and of no value for solar constant work, but the results obtained are quite interesting in themselves and a résumé will be given here.

Twenty-eight sets of observations were taken in all. In each of these the total sky calories (exclusive of the sun) were obtained at known air masses. Plots were made betwen sky calories and air masses, and similar plots between solar calories and air masses as obtained by the pyrheliometer. The areas underneath these respective curves were read between the limits of the air masses obtaining during the course of the bolograph. The ratio of these areas was plotted against the ratio of true to apparent solar constant. As stated above this investigation did not prove useful for solar constant determination.

The main interest attaching to these observations in the present discussion has to do with the general intensity of sky radiation and the effect of the altitude or air mass of the sun on the same. To best show the results obtained by these observations a table has been prepared giving the air mass (M) and zenith distance (Z) of the sun at a certain chosen point in each bolograph, the sky calories (H) at this air mass, the solar calories (S), the sum of solar and sky radiation on a horizontal surface, the ratio of solar radiation to sky radiation, and a general description of the character of weather prevailing during the bolographs. The column headed "Pyrh." gives the solar calories measured on a surface at right angles to the path of the beam, while S is the same reduced to a horizontal surface, or $S = \frac{\text{Pyrh.}}{M}$. The units in H, Pyrh., and S are calories per sq. cm. per min.

1917 Date	Bol. Grd.	M	Z	H	Pyrh.	S	$S+H$	S/H	Character of sky, etc,
Aug. 18	*VG*	4.89	78° 27′	.0501	1.037	0.212	.2621	4.23	Cloudless—hazy along horizon.
		4.17	76° 20′	.0544	1.100	0.264	.3184	4.85	
		3.34	72° 45′	.0587	1.149	0.344	.4027	5.86	
		2.69	68° 18′	.0638	1.263	0.470	.5338	7.37	
		2.03	60° 30′	.0758	1.342	0.661	.7368	8.72	
		1.30	39° 30′	.0974	1.421	1.093	1.1904	11.23	
25	*G+*	4.74	78° 05′	.0538	0.924	0.195	.2488	3.63	Blue near zenith—but haze low down. Increasing.
		4.03	75° 50′	.0579	1.023	0.254	.3119	4.39	
		3.36	72° 51′	.0628	1.126	0.335	.3978	5.34	
		2.73	68° 39′	.0689	1.231	0.451	.5199	6.55	
26	*E*	4.74	78° 05′	.0467	1.108	0.234	.2807	5.00	Very blue. Light haze near horizon.
		4.04	75° 52′	.0500	1.153	0.285	.3350	5.71	
		3.40	73° 03′	.0527	1.213	0.357	.4097	6.77	
		2.67	68° 09′	.0577	1.300	0.487	.5447	8.44	
		1.97	59° 30′	.0657	1.387	0.704	.7697	10.72	
		1.25	37° 00′	.....	1.481	1.184	.....	....	
28	*G*	4.75	78° 06′	.0692	0.717	0.151	.2202	2.18	Cloudless until IV but very hazy.
		4.00	75° 46′	.0795	0.807	0.202	.2815	2.54	
		3.29	72° 27′	.0906	0.907	0.276	.3666	3.04	
		2.65	68° 00′	.1053	1.003	0.379	.4843	3.59	
		1.97	59° 30′	.....	1.130	0.574	.....	....	
Sept. 12	*VG*	4.91	78° 30′	.0444	1.017	0.207	.2514	4.66	Very clear except low haze along horizon.
		4.09	76° 03′	.0511	1.119	0.274	.3251	5.36	
		3.33	72° 42′	.0569	1.188	0.357	.4139	6.27	
		2.71	68° 30′	.0624	1.267	0.467	.5294	7.49	
		2.02	60° 15′	.0703	1.354	0.670	.7403	9.54	
		1.31	40° 00′	.0874	1.497	1.142	1.2294	13.07	
13	*VG+*	4.84	78° 19′	.0429	1.137	0.235	.2779	5.48	Cloudless and little haze. Cirri after IV.
		4.12	76° 10′	.0471	1.195	0.290	.3371	6.16	
		3.31	72° 36′	.0547	1.285	0.389	.4437	7.11	
		2.65	68° 00′	.....	1.355	0.511	.....	....	
		1.98	59° 45′	.....	1.456	0.735	.....	....	
		1.32	40° 30′	.....	1.535	1.163	.....	....	

1917 Date	Bol. Grd.	*M*	*Z*	*H*	Pyrh.	*S*	*S+H*	*S/H*	Character of sky, etc.
Sept. 18	*E*	4.75	78° 06′	.0522	1.017	0.214	.2662	4.10	Clear except slight cirri and haze near horizon.
		4.07	75° 58′	.0568	1.084	0.266	.3228	4.69	
		3.36	72° 51′	.0620	1.159	0.345	.4070	5.56	
		2.71	68° 30′	.0672	1.242	0.458	.5252	6.82	
		2.03	60° 30′	.0755	1.347	0.664	.7395	8.79	
		1.30	39° 30′	.0895	1.472	1.132	1.2215	12.64	
26	*VG*	4.82	78° 17′	.0558	0.936	0.194	.2498	3.48	Cloudless but rather hazy. Fog in valley.
		4.11	76° 08′	.0615	1.004	0.244	.3055	3.97	
		3.35	72° 48′	.0677	1.097	0.327	.3947	4.84	
		2.72	68° 36′	.0756	1.187	0.436	.5116	5.77	
		2.11	61° 45′	.0859	1.274	0.604	.6899	7.03	
		1.35	42° 00′	.1039	1.385	1.026	1.1299	9.88	
Oct. 2	*VG*—	4.74	78° 05′	.0436	1.098	0.232	.2756	5.32	Cloudless. Little haze, but increasing.
		4.05	75° 54′	.0486	1.152	0.284	.3326	5.85	
		3.37	72° 54′	.0530	1.230	0.365	.4180	6.89	
		2.73	68° 39′	.0577	1.315	0.482	.5397	8.35	
		2.06	61° 00′	.0655	1.396	0.678	.7435	10.34	
		1.32	40° 30′	.0803	1.477	1.118	1.1983	13.93	
3	*VG*	3.38	72° 57′	.0609	1.203	0.356	.4169	5.84	Cirri over sun during I. Fairly hazy.
		2.91	70° 03′	.0631	1.260	0.433	.4961	6.86	
		2.41	65° 36′	.0666	1.335	0.554	.6206	8.32	
		1.87	57° 45′	.0745	1.415	0.757	.8315	10.15	
5	*VG*	4.94	78° 35′	.0477	0.973	0.197	.2447	4.13	Nearly cloudless, but quite hazy.
		4.20	76° 26′	.0518	1.055	0.251	.3028	4.85	
		3.45	73° 18′	.0574	1.172	0.340	.3974	5.92	
		2.80	69° 12′	.0631	1.216	0.434	.4971	6.88	
		2.05	60° 45′	.0733	1.333	0.650	.7233	8.87	
		1.36	42° 30′	.....	1.390	1.022	.....	....	
10	*VG*—	5.02	78° 47′	.0496	1.040	0.207	.2566	4.18	Nearly cloudless. Rather hazy. Fog rising.
		4.28	76° 42′	.0563	1.093	0.255	.3113	4.54	
		3.48	73° 27′	.0643	1.191	0.342	.4063	5.32	
		2.74	68° 42′	.0727	1.266	0.462	.5347	6.36	
		2.04	60° 38′	.0862	1.371	0.672	.7582	7.80	

1917 Date	Bol. Grd.	*M*	*Z*	*H*	Pyrh.	*S*	*S+H*	*S/H*	Character of sky, etc.
Oct. 13	*VG*	4.83	78° 18′	.0450	1.116	0.231	.2760	5.14	Cloudless except small cirri in S. E. Little haze.
		4.13	76° 12′	.0494	1.200	0.291	.3404	5.88	Very clear.
		3.29	72° 27′	.0549	1.295	0.394	.4489	7.17	
		2.71	68° 30′	.0589	1.357	0.501	.5599	8.51	
		2.03	60° 30′	.0659	1.447	0.713	.7789	10.81	
		1.39	44° 00′	.0782	1.522	1 095	1.1732	14.00	
14	*G*—	5.05	78° 50′	.0542	0.947	0.187	.2412	3.46	Little cirrus along horizon in S. E. Little haze.
		4.35	76° 56′	.0587	1.015	0.233	.2917	3.98	
		3.67	74° 23′	.0644	1.086	0.296	.3604	4.60	
		3.08	71° 12′	.0701	1.173	0.381	.4511	5.44	
		2.37	65° 12′	.0808	1.294	0.546	.6268	6.76	
		1.60	51° 15′	.1097	1.349	0.843	.9527	7.69	
15	*G*	4 94	78° 35′	.0578	0.906	0.183	.2408	3.17	Cloudless, but increasing streaky haze.
		4.21	76° 28′	.0671	0.951	0.226	.2931	3.37	
		3.53	73° 42′	.0750	1.035	0.293	.3680	3.91	
		2.75	68° 48′	.0832	1.155	0.420	.5032	5.05	
		2.01	60° 08′	.0944	1.286	0.640	.7344	6.78	
16	*VG*—	4.97	78° 39′	.0517	0.932	0.188	.2397	3.63	Small cumuli at horizon in E. Very hazy.
		4.30	76° 46′	.0566	0.986	0.229	.2856	4.05	
		3.51	73° 36′	.0664	1.085	0.309	.3754	4.66	
		2.77	69° 00′	.0782	1.183	0.427	.5052	5.46	
		2.04	60° 38′	.0937	1.276	0.626	.7197	6.68	
		1.42	45° 15′	.....	1.382	0.973	.....	....	
28	*G*	5.04	78° 49′	.0433	1.119	0.282	.2653	5.13	Cloudless, little haze. Sea of fog in valley.
		4.31	76° 48′	.0464	1.181	0.274	.3204	5.90	
		3.38	72° 57′	.0507	1.276	0.378	.4287	7.45	
		2.76	68° 54′	.0551	1.353	0.490	.5451	8.90	
		2.09	61° 23′	.0612	1.445	0.691	.7522	11.29	
		1.53	49° 15′	.0680	1.549	1.012	1.0800	15.02	Cloudless, but considerable low haze.
Nov. 4	*VG*—	5.06	78° 51′	.0447	1.097	0.217	.2617	4.85	
		4.35	76° 56′	.0481	1.164	0.268	.3161	5.57	
		3.53	73° 42′	.0523	1.242	0.352	.4043	6.73	
		2.83	69° 27′	.0571	1.335	0.472	.5291	8.26	
		2.17	62° 30′	.0631	1.418	0.653	.7161	10.36	
		1.61	51° 30′	.0713	1.527	0.948	1.0193	13.31	

1917 Date	Bol. Grd.	M	Z	H	Pyrh.	S	$S+H$	S/H	Character of sky, etc.
Nov. 5	G	4.99	78° 42′	.0471	1.136	0.228	.2751	4.84	Cloudless, but considerable low haze.
		4.36	76° 58′	.0516	1.192	0.273	.3246	5.30	
		3.58	73° 57′	.0566	1.231	0.344	.4006	6.08	
		2.86	69° 42′	.0625	1.326	0.464	.5265	7.42	
		2.18	62° 45′	.0707	1.426	0.654	.7247	9.25	
		1.62	52° 00′	.0799	1.513	0.934	1.0139	11.69	
7	VG	5.03	78° 48′	.0616	0.933	0.186	.2476	3.01	Cloudless, but very hazy. Haze uneven.
		4.33	76° 52′	.0679	1.005	0.232	.2999	3.42	
		3.59	74° 00′	.0744	1.097	0.306	.3804	4.11	
		2.93	70° 12′	.0817	1.213	0.414	.4957	5.07	
		2.18	62° 45′	.0909	1.320	0.606	.6969	6.66	
		1.64	52° 30′	.1042	1.431	0.873	.9772	8.38	
8	VG—	4.99	78° 42′	.0475	1.067	0.214	.2615	4.50	Cloudless, but haze rising and uneven.
		4.32	76° 50′	.0517	1.135	0.263	.3147	5.09	
		3.52	73° 39′	.0580	1.231	0.350	.4080	6.03	
		2.91	70° 03′	.0636	1.322	0.454	.5176	7.14	
		2.13	62° 00′	.0757	1.416	0.665	.7407	8.78	
		1.66	53° 00′	.0959	1.447	0.872	.9679	9.08	
9	G—	3.67	74° 23′	.0816	0.992	0.270	.3516	3.31	Cloudless, but streaky in S. and E. Increasing haze.
		3.12	71° 27′	.0870	1.080	0.348	.4350	4.00	
		2.49	66° 24′	.0913	1.200	0.482	.5733	5.28	
		1.67	53° 15′	.0950	1.432	0.857	.9520	9.02	
10	G—	5.05	78° 50′	.0674	0.816	0.162	.2294	2.40	Cloudless early, but increasing uneven haze.
		4.36	76° 58′	.0777	0.892	0.204	.2817	2.63	
		3.59	74° 00′	.0912	0.929	0.259	.3502	2.84	
		2.91	70° 03′	.1049	1.077	0.370	.4749	3.53	
		2.16	62° 23′	.1250	1.245	0.576	.7010	4.61	
		1.68	53° 30′	.1467	1.260	0.750	.8967	5.11	
11	G	5.16	79° 06′	.0584	0.933	0.181	.2394	3.10	Cloudless early. Increasing haze and cirri.
		4.49	77° 22′	.0647	1.004	0.224	.2887	3.46	
		3.75	74° 44′	.0721	1.075	0.287	.3591	3.98	
		3.21	72° 00′	.0800	1.177	0.367	.4470	4.58	
		2.63	67° 48′	.....	1.223	0.465	.....	....	

1917 Date	Bol. Grd.	*M*	*Z*	*H*	Pyrh.	*S*	*S+H*	*S/H*	Character of sky, etc.
Nov. 15	*G* —	5.07	78° 53′	.0543	1.023	0.202	.2563	3.72	Fog and cirri over horizon N. and E. Increasing haze.
		4.39	77° 04′	.0598	1.019	0.232	.2918	3.88	
		3.58	73° 57′	.0658	1.188	0.332	.3978	5.05	
		2.94	70° 15′	.0703	1.266	0.431	.5013	6.13	
		2.12	61° 53′	.0743	1.439	0.678	.7523	9.13	
		1.73	54° 45′	.0829	1.387	0.802	.8849	9.68	
17	*E* —	5.01	78° 45′	.0448	1.129	0.225	.2698	5.04	Cloudless, except slight cirri low in S. E. Very little haze.
		4.41	77° 08′	.0481	1.183	0.268	.3161	5.58	
		3.64	74° 15′	.0538	1.265	0.348	.4018	6.46	
		2.92	70° 06′	.0589	1.347	0.461	.5199	7.82	
		2.15	62° 15′	.0675	1.455	0.677	.7445	10.03	
		1.75	55° 15′	.0749	1.494	0.854	.9289	11.40	
18	*E*	5.05	78° 50′	.0465	1.127	0.223	.2695	4.80	Cloudless except faint cirri in S. E. Low haze.
		4.44	77° 12′	.0497	1.180	0.266	.3157	5.35	
		3.66	74° 20′	.0551	1.257	0.343	.3981	6.23	
		2.98	70° 30′	.0607	1.330	0.446	.5067	7.35	
		2.30	64° 15′	.0688	1.410	0.613	.6818	8.91	
		1.77	55° 30′	.0854	1.454	0.822	.9074	9.62	
26	*E* —	4.43	77° 10′	.0486	1.161	0.262	.3106	5.39	
		3.87	75° 14′	.0528	1.216	0.314	.3668	5.95	Cloudless. Some low haze in north.
		3.06	71° 06′	.0590	1.317	0.430	.4890	7.29	
		2.43	65° 48′	.0651	1.422	0.585	.6501	8.99	
		1.89	58° 00′	.0757	1.505	0.796	.8717	10.52	

If the logarithm of *H* be plotted against air mass in the six observations for each day, it will nearly always occur that the points for *I, II, III,* and *IV* will be practically in a straight line, while *V* and *VI* will be somewhat higher than the line, *VI* being considerably higher than *V*. There is no theoretical reason why this relation should hold exactly, but its approximate indications may prove convenient to the reader. The divergence of the two later observations may be partially due to two causes. (1) An increase of water vapor in the air late in the morning with attendant increase in haziness causes decrease of the intensity of direct sun light and increase of the intensity of scattered sky light. (2) Sky light is much stronger proportionately in the shorter wave lengths than sun light. The longer wave lengths have a very much higher transmission coefficient than the shorter ones—or in other words, the shorter ones increase much more rapidly with a decrease of air mass than the longer ones. Thus the sky light may tend to increase faster than the direct sun light at high sun.

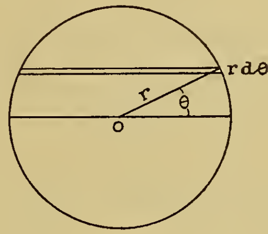

FIG. 1

The table shows that haze has a very marked effect in increasing sky radiation, and to a somewhat lesser extent in decreasing the solar radiation.

Sky radiation by zones.—In order to investigate the proportion of the sky radiation falling on a horizontal surface from various sections of the sky, two kinds of observations were made: (1) with thimbles placed over the pyranometer glass so as to divide the hemisphere into zones each 30° in width, and (2) with the thimble admitting a 60° cone of light, measuring the intensity of the ring concentric with the sun, and comparing it with cones of equal size and altitude, and located in azimuth 60°, 120°, 180°, respectively, from the sun, starting toward the east.

First will be discussed the horizontal zones, giving the theoretical intensity for an equal sky, and then the experimental results obtained under varying conditions.

Let O be taken as the point of observation.

Then the radius of the elementary zone $= r \cos\theta$, the circumference of the elementary zone $= 2\pi r \cos\theta$, the width of the elementary zone $= r\, d\theta$, and the area of the elementary zone $= 2\pi r^2 \cos\theta\, d\theta$. Call the horizontal intensity at the center O due to elementary zone $= dI$.

Then $dI = 2\pi r^2 \cos\theta \sin\theta\, d\theta$.

$$I = \int 2\pi r^2 \cos\theta \sin\theta\, d\theta.$$
$$= \pi r^2 \sin^2\theta.$$

(1) For the entire hemisphere (a_1 and a_2 in observations which follow) $I_0^{\pi/2} = \pi r^2$.

(2) From horizon to 30° altitude: $I_0^{\pi/6} = \frac{1}{4}\pi r^2$.

(3) From horizon to 60° altitude: $I_0^{\pi/3} = \frac{3}{4}\pi r^2$.

Hence in a sky in which every point sends radiation of equal intensity toward the point of observation the following intensities from the various 30° zones would be obtained in a horizontal surface at the point of observation.

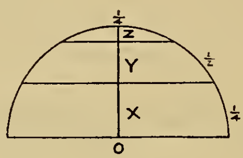

FIG. 2

For entire hemisphere (a_1 and a_2) $I_a = 1$.
For upper 60° zone (b) $I_b = 1 - \frac{1}{4} = \frac{3}{4}$.
For upper 30° zone (c) $I_c = 1 - \frac{3}{4} = \frac{1}{4}$.

In the following observations the values gotten with an entire hemisphere are called "a," those with the upper 60° open to radiation "b," and those with upper 30° open to radiation "c."

Call the horizontal intensity from the horizontal zones themselves x, y, and z, as shown in figure 2.

$$\text{Then } a = x + y + z$$
$$b = y + z$$
$$c = z;$$
$$\text{or } x = a - b$$
$$y = b - c$$
$$z = c.$$

In "equal sky" $x = \frac{1}{4}a$.
$y = \frac{1}{2}a$.
$z = \frac{1}{4}a$.

A sample set of observations will be given, followed by a table giving the results of all the zone observations taken. Usually the observations were begun with a full sky (a_1), then with the upper 60° (b), then the upper 30° (c), and finally another set with full sky (a_2). Since the sky radiation is continually changing, even with a clear sky, an average was taken of a_1 and a_2 when comparing with b and c. Several readings were taken at each position, these readings usually being one minute apart with a current compensation measurement on each of the half minutes. The glass hemisphere was used in all zone work.

The following set was taken on November 17, 1917, at Hump Mountain on a very clear sky but with some haze in the valley and along the horizon.

Hour angle	Zero	Reading	Deflection	Amps. current	Ammeter correction factor	c^2/d	Calories	Solar air mass	Solar altitude
(a_1)									
—1:50:30	4.08	6.18	2.10	....	....	....	.0696	2.05	29° 15′
	4.08	6.18	2.10	.185	....	.01583	....	....	....
49	4.28	6.40	2.12	....	....	....	.0703	2.04	29° 23′
	4.30	6.41	2.11	.185	....	.01575	....	....	....
48	4.38	6.49	2.11	....	....	....	.0699	2.03	29° 30′
	4.23	6.31	2.08	.184	.9856	.01581	....	....	....
47	4.14	6.25	2.11	....	....	....	.0699	2.02	29° 45′
	4.05	6.13	2.08	.184	.9856	.01581	....	....	....
						Mean	.0699		
(b)									
—1:44:30	4.13	5.51	1.38	....	....	....	.0457	2.01	29° 53′
	4.09	5.41	1.32	.147	....	.01592	....	....	....
43	4.08	5.48	1.40	....	....	....	.0464	2.01	29° 53′
	4.10	5.42	1.32	.148	....	.01614	...	....	....
42	4.12	5.53	1.41	....	....	....	.0467	2.00	30° 00′
	4.12	5.49	1.37	.148	....	.01555	....	....	....
41	4.29	5.67	1.38	....	....	....	.0457	2.00	30° 00′
	4.30	5.62	1.32	.148	....	.01614	....	....	....
40	4.39	5.79	1.40	....	....	....	.0464	2.00	30° 00′
	4.33	5.65	1.32	.148	....	.01614	....	....	....
						Mean	.0462		
(c)									
—1:37:30	4.18	4.61	0.43	....	....	....	.0142	1.98	30° 15′
	4.18	4.64	0.46	.089	....	.01717	....	....	....
36	4.10	4.61	0.51	....	....	....	.0169	1.97	30° 30′
	4.27	4.81	0.54	.089	....	.01463	....	....	....
35	4.30	4.75	0.45	....	....	....	.0149	1.97	30° 30′
	4.20	4.68	0.48	.089	....	.01646	....	....	....
34	4.00	4.48	0.48	....	....	....	.0159	1.96	30° 45′
	3.92	4.40	0.48	.089	....	.01646	....	....	....
33	3.82	4.29	0.47	....	....	....	.0156	1.96	30° 45′
	3.83	4.33	0.50	.090	....	.01616	....	....	....
						Mean	.0155		

Hour angle	Zero	Reading	Deflection	Amps. current	Ammeter correction factor	c^2/d	Calories	Solar air mass	Solar altitude
(a_2)									
—1:25:30	3.98	6.16	2.18	....	....	....	.0723	1.94	31° 00′
	4.03	6.15	2.12	.188	....	.01619	....	....	....
24	3.98	6.07	2.09	....	....	...	.0693	1.93	31° 15′
	3.77	6.03	2.26	.190	....	.01551	....	....	....
23	3.91	6.12	2.21	....	....	....	.0732	1.93	31° 15′
	3.98	6.20	2.22	.190	....	.01579	....	....	....
22	3.90	6.06	2.16	....	....	....	.0716	1.92	31° 23′
	4.01	6.29	2.28	.190	....	.01538	....	....	....
21	4.28	6.39	2.11	....	....	....	.0699	1.92	31° 23′
	4.07	6.30	2.23	.190	....	.01572	....	....	....
			Mean c^2/d (all)			.01593	Mean .0713		

SUMMARY.

$a = \frac{a_1 + a_2}{2}$ $\frac{.0699 + .0713}{2} = .0706$

$b = .0462$

$c = .0155$

$x = a - b = .0244$

$y = b - c = .0307$

$z = c =$ $.0155$

In "equal sky."

$x = 1/4\, a = .01765$

$y = 1/2\, a = .0353$

$z = 1/4\, a = .01765$

% $\frac{\text{True}}{\text{Equal}}$

$x = \frac{.0244}{.01765} = 138.3$

$y = \frac{.0307}{.0353} = 87.0$

$z = \frac{.0155}{.01765} = 87.8$

In the following table will be found the results obtained in the same manner as above for all the zone observations taken at Hump Mountain and a few taken at Calama, Chile. The latter station is located on the Atacama Desert in northern Chile at an elevation of 2,250 meters above sea level. The air in Calama is far dryer than on Hump Mountain but being on a large expanse of desert where rain scarcely ever falls, dust is of course more prevalent. There is in addition a sort of perpetual haze, which may have an origin in distant volcanoes of the Andes range.

Date	Hour angle start	Hour angle finish	Sun's alt. start	Sun's alt. finish	a $\frac{(a_1+a_2)}{2}$	b	c	Measured (M)			Equal sky (E)			% M/E			Weather and remarks
								x*	y*	z*	x*	y*	z*	x*	y*	z*	
Hump Mt. 1917			° ′	° ′													
Oct. 5	−2:53	−2:14	32 30	38 30	.0786	.0505	.0132	.0281	.0373	.0132	.0196	.0393	.0196	143.4	94.4	67.3	Cloudless but somewhat hazy.
" 5	−2:10	−1:54	39 00	41 00	.0840	.0535	.0147	.0315	.0388	.0147	.0210	.0420	.0210	149.9	92.4	70.0	" " " "
" 8	−1:05	−0:17	....	....	.2802	.1881	.0677	.0721	.1204	.0677	.0650	.1301	.0650	110.9	92.6	104.1	Very even low fog. (Average of two sets.)
" 13	−2:02	−1:38	37 15	40 30	.0732	.0446	.0126	.0286	.0320	.0126	.0183	.0366	.0183	156.3	87.4	68.8	Entirely clear sky.
" 13	+0:05	+0:18	46 00	46 00	.0762	.0517	.0146	.0245	.0371	.0146	.0190	.0381	.0190	128.9	97.4	76.9	Sky still cloudless.
" 13	+3:46	+4:04	21 00	17 45	.0552	.0340	.0103	.0212	.0237	.0103	.0138	.0276	.0138	153.6	85.9	74.6	" " "
" 17	−2:40	−2:19	31 22	34 30	.0982	.0596	.0154	.0386	.0442	.0154	.0245	.0491	.0246	157.6	90.0	62.6	Very hazy but cloudless.
" 28	−1:41	−1:20	35 30	37 15	.0644	.0388	.0090	.0256	.0298	.0090	.0161	.0322	.0161	159.0	92.6	55.9	Clear except haze on horizon comparatively dry.
Nov. 3	−0:54	−0:34	37 15	38 00	.0714	.0465	.0123	.0249	.0342	.0123	.0178	.0357	.0179	139.9	95.8	68.7	Clear except haze to 10° above horizon. Few patches of cirri.
" 3	+3:18	+3:38	....	....	.0605	.0377	.0103	.0228	.0274	.0103	.0151	.0303	.0151	151.0	90.5	68.2	Cloudless but somewhat hazy along horizon.
" 4	−2:21	−2:05	28 45	31 15	.0651	.0396	.0106	.0255	.0290	.0106	.0163	.0325	.0163	156.4	89.2	65.1	Cloudless but very hazy along horizon and in valley.
" 5	−2:01	−1:43	30 45	32 45	.0757	.0445	.0110	.0312	.0335	.0110	.0189	.0378	.0189	165.0	88.6	58.2	Cloudless but somewhat hazy along horizon.
" 6	−1:36	−1:14	33 07	35 00	.0801	.0480	.0140	.0321	.0340	.0140	.0200	.0401	.0200	160.5	84.8	70.0	Cloudless but quite hazy along horizon and in valley.
" 7	−2:17	−1:54	28 30	31 00	.0947	.0549	.0149	.0398	.0400	.0149	.0237	.0474	.0237	168.0	84.4	62.9	Cloudless but extremely hazy—some even above observatory.
" 15	−1:49	−1:24	29 52	32 07	.0763	.0519	.0157	.0244	.0362	.0157	.0191	.0382	.0191	127.7	94.8	82.2	Cloudless. Clear above but hazy along horizon.
" 15	+2:36	+3:03	23 54	20 24	.1248	.0746	.0148	.0502	.0598	.0148	.0312	.0624	.0312	160.9	95.8	47.5	Extremely hazy even above observatory. Grandfather Mt. hardly visible.
" 17	−1:51	−1:26	29 15	31 22	.0706	.0462	.0155	.0244	.0307	.0155	.0176	.0353	.0176	138.3	87.0	87.8	Very clear. Some low haze along horizon.
" 18	−2:04	−2:40	27 30	29 52	.0732	.0475	.0163	.0257	.0312	.0163	.0183	.0366	.0183	140.4	85.2	89.1	Cloudless and clear except near horizon in S. and E.
" 26	+1:10	+1:34	30 15	28 30	.0710	.0459	.0136	.0251	.0323	.0136	.0177	.0355	.0177	141.4	91.0	76.6	Quite clear except little low haze in S. and E.
Dec. 17	+1:41	+1:58	25 45	24 00	.0792	.0486	.0138	.0306	.0348	.0138	.0198	.0396	.0198	154.5	87.9	69.7	Very clear.
1918																	
Feb. 2	+2:44	+3:13	....	....	.1267	.0962	.0438	.0305	.0524	.0438	.0317	.0634	.0317	96.2	82.7	138.3	Even low fog. (Mean of 10 sets, changing zones each minute.)
" 10	+2:00	+2:20	32 07	29 45	.1131	.0679	.0173	.0452	.0506	.0173	.0283	.0566	.0283	159.7	89.4	61.1	Cloudless but sky somewhat gray.
" 11	−2:31	−2:13	28 15	30 30	.1074	.0746	.0241	.0328	.0505	.0241	.0268	.0537	.0268	122.1	94.1	89.8	Fairly clear. Cloudless. Air verydry.
" 23	+4:09	+4:21	15 38	13 50	.0510	.0303	.0099	.0207	.0204	.0099	.0127	.0255	.0127	162.3	80.0	77.6	Very clear sky.
" 28	−2:10	−1:48	36 00	38 45	.1162	.0680	.0180	.0482	.0500	.0180	.0291	.0581	.0290	165.7	86.1	62.1	Cloudless but hazy in valley to level of observatory.
" 28	+1:49	+2:13	39 15	36 00	.1793	.1089	.0269	.0704	.0820	.0269	.0448	.0896	.0448	157.1	91.5	60.0	Very hazy, even above observatory.
Mar. 8	−2:24	−2:00	36 45	40 15	.0784	.0454	.0136	.0330	.0318	.0136	.0196	.0392	.0196	168.4	81.2	69.4	Quite clear but some low haze.
Calama, Chile 1918			° ′	° ′													
July 21	−2:13	−1:27	36 15	42 00	.0708	.0466	.0182	.0240	.0286	.0182	.0177	.0354	.0177	135.6	80.8	102.8	Cloudless – but haze and dust in air.
" 31	+2:14	+2:35	....	....	.0687	.0408	.0135	.0279	.0273	.0135	.0172	.0343	.0172	162.2	79.6	78.5	Quite clear. Two small clouds low in S. E.
Aug. 1	+1:10	+1:30	....	....	.0707	.0451	.0152	.0256	.0299	.0152	.0177	.0353	.0177	144.6	84.7	85.8	Cloudless – quite clear.
" 29	−3:17	−3:02	....	....	.0896	.0534	.0160	.0362	.0374	.0160	.0224	.0448	.0224	161.7	83.5	71.4	Extremely hazy. Pyrheliometry low.
Sept. 7	−2:45	−2:19	40 15	45 00	.0734	.0485	.0147	.0249	.0338	.0147	.0183	.0367	.0183	136.0	92.2	80.3	Fairly clear – though some uniform haze.
" 14	−2:49	−2:28	40 45	45 00	.0717	.0461	.0152	.0256	.0309	.0152	.0179	.0358	.0179	143.0	86.3	84.9	Clear but hazy.
Oct. 28	+0:18	+0:45	....	....	.0974	.0685	.0277	.0288	.0408	.0277	.0243	.0487	.0243	118.5	83.8	113.9	Clear but gray sky.

*x, y, z, indicate lowest, middle, and upper 30° zones of sky, respectively.

By omitting the two fog observations (Oct. 8 and Feb. 2) and taking a general average of the twenty-four remaining Hump Mountain observations, the following values are obtained: $x=151.5$ per cent, $y=89.5$ per cent, and $z=69.7$ per cent, or approximately $x=150$ per cent, $y=90$ per cent, and $z=70$ per cent. In Calama, omitting the observations of July 21 and October 28, which differ much from the others, the averages of the five remaining values are $x=149.5$ per cent, $y=85.2$ per cent, and $z=80.2$ per cent. Thus it appears that in clear or somewhat hazy skies the radiation actually received on a horizontal surface, as compared with what would be received on a horizontal surface from an "equal" sky, shows the following percentages. First 30° zone above the horizon 150 per cent. Middle 30° zone 85 per cent to 90 per cent. Upper 30° zone 70 per cent to 80 per cent. From the two sets of observations taken in low and apparently even fog at Hump Mountain it appears that the middle zone has about a normal percentage but that the upper zone is much increased and the lower zone correspondingly decreased. This might be expected, however, since the fog particles are so dense in a horizontal line, while vertically the thickness is much less, and more radiation finds its way through the fog. The above ratios are undoubtedly affected very considerably by the sun's being in a particular zone at the time of observation, as will be shown under the discussions of the observations taken at different azimuths.

While the above ratios hold for the total amount of radiation received from the three 30° zones, it must not be inferred that equal areas of these zones in the various azimuths of the sky send out equal intensities. In order to investigate this phase of the subject another set of observations which we have termed "vertical zones" was carried on at Hump Mountain. To do this, the pyranometer was mounted bodily on an equatorial mounting such as is used for pyrheliometers. The threads where the equatorial mounting screws into its base, were left a little loose, and angles were marked off so that the whole apparatus could be revolved about a vertical axis through a known angle. The plane of the pyranometer strips was pointed exactly at right angles to the sun's beams, as determined by a spot of light. The metal thimble limiting exposure to a cone of light of 60° arc was placed over the glass hemisphere. In all cases the small disc to shade the direct rays of the sun was in place vertically above the strips, even where the instrument pointed to quarters of the sky away from the sun.

Method of observing.—First the instrument was pointed directly at the sun and one observation of the intensity made. The following minute, a similar observation was made at the same altitude but with the instrument revolved 60° in azimuth toward the east from the position of the sun in the first observation. Similarly the following minute 90°, and the next 120°, and the next 180°. These are termed respectively I, II, III, IV and V. Several sets were usually taken in this way, the azimuth and altitude being measured from the position of the sun at the beginning of each set. Then finally, the instrument was pointed vertically, and a few readings taken of the radiation of the same angular area directly overhead. The vertical readings are termed VI. Current compensation measurements were taken on the half minutes between sky readings. At first the set at 90° azimuth was not taken.

As in the case of the horizontal zones, a sample set of observations will be included, then a table of the results obtained on each day of such observations.

The sample set will be the first one taken February 11, 1918. The sky was quite clear and the air very dry for Hump Mountain, (about 35 per cent relative humidity) and the sky cloudless. The 90° set, or III, was omitted in this case.

February 11. 1918. Hump Mountain, N. C.

Hour angle	Air mass	Altitude	No.	Zero	Read.	Defl.	Current	c^2/d	Cal.
—1:05:00	1.64	37° 30′	I	12.42	14.35	1.93	....	....	.0658
				12.28	14.30	2.02	.183	.01610	....
04	"	"	II	12.30	13.32	1.02	....	....	.0358
				12.25	12.68	.43	.088	.01798	....
03	"	"	IV	12.09	12.57	.48	....	....	.0168
				11.96	12.41	.45	.088	.01718	....
02	"	"	V	11.82	12.23	.41	....	....	.0144
				11.68	12.13	.45	.088	.01718	....
—1:01	1.63	37° 45′	I	12.12	14.04	1.92	....	....	.0654
				12.06	14.05	1.99	.183	.01634	....
00	"	"	II	11.90	12.90	1.00	....	....	.0351
				11.97	12.44	.47	.088	.01645	....
0:58	"	"	IV	11.83	12.31	.48	....	....	.0168
				11.85	12.32	.47	.088	.01645	....
57	"	"	V	11.89	12.31	.42	....	....	.0147
				11.83	12.27	.44	.088	.01757	....
—0:56	1.62	38° 0′	I	12.00	13.96	1.96	....	....	.0668
				12.08	14.13	2.05	.183	.01587	....
55	"	"	II	11.97	13.00	1.03	....	....	.0361
				11.95	12.41	.46	.088	.01680	....
54	"	"	IV	11.73	12.14	.41	....	....	.0144
				11.51	11.98	.47	.088	.01645	....
53	"	"	V	11.43	11.87	.44	....	....	.0154
				11.40	11.98	.58	.088	.01333	....
—0:52	1.62	38° 0′	I	11.92	13.81	1.89	....	....	.0644
				11.92	13.94	2.02	.183	.01610	....
51	"	"	II	11.53	12.60	1.07	....	....	.0375
				11.30	11.71	.41	.088	(.01885)	....
50	1.61	38° 30′	IV	11.03	11.53	.50	....	....	.0175
				11.10	11.57	.47	.088	.01645	....
49	"	"	V	11.16	11.57	.41	....	....	.0144
				11.30	11.83	.53	.088	.01458	....
				POINTED VERTICALLY					
—0:45:00	1.60	....	VI	13.50	14.03	.53	....	....	.0186
				13.70	14.19	.49	.088	.01577	....
44	"	....		13.84	14.32	.48	....	....	.0168
				13.87	14.37	.50	.088	.01546	....
43	"	....		14.17	14.68	.51	....	....	.0179
				14.28	14.74	.46	.087	.01643	....

Av. c^2/d (large defl.) .01610
" " small " .01658

Averages		Ratio to I
I.	.0656	....
II.	.0361	55.0
IV.	.0164	25.0
V.	.0147	22.4
VI.	.0178	27.1

Date	Hour angle start	Hour angle finish	Approx. alt. start	Approx. alt. finish	Average calories I	II	III	IV	V	VI	Per cent of I II	III	IV	V	VI	Weather and remarks
1918																
Feb. 11	−1:05	−0:43	37° 30′	38° 30′	.0656	.0361	......	.0164	.0147	.0178	55.0	......	25.0	22.4	27.1	Fairly clear. Air dry. Brisk N. W. wind at intervals.
23	−2:22	−2:05	33 00	35 15	.0334	.0234	.0189	.0148	.0134	.0133	70.1	56.6	44.3	40.1	39.8	Clear. N. W. wind.
23	+3:35	+4:04	21 42	16 54	.0365	.0315	.0192	.0190	.0238	.0120	86.3	52.6	52.0	65.2	32.9	Clear. N. W. wind.
26	+2:06	+2:44	36 00	30 52	.0345	.0297	.0190	.0139	0146	.0129	86.1	55.1	40.3	42.2	37.4	Very clear. N. W. wind at interva's.
28	−2:34	−2:15	32 45	35 15	.0649	.0346	.0229	.0175	.0179	.0178	53.3	35.3	27.0	27.6	27.4	Cloudless but haze in valley and to level of observatory. Warmer.
28	+1:22	+1:44	42 00	40 00	.1238	.0782	.0455	.0289	.0230	.0318	63.2	36.7	23.3	18.6	25.7	Very hazy—even above observatory. Warm. Little wind.
Mar. 8	−2:47	−2:29	33 30	36 00	.0402	.0221	.0179	.0153	.0146	.0146	55.0	44.5	38.1	36.3	36.3	Quite clear but haze in valley. Little wind.

The following set was taken without the sun shaded off, i. e. I is the sum of sun plus sky as measured on a horizontal surface. All are taken without sun shade.

Feb. 23	+0:13	+0:23	44° 00′	43° 30′	1.607	.0304	.0210	.0155	.0127	......	1.9	1.3	1.0	0.8	....	Clear. N. W. wind.

The following set was taken in a fairly even and thick cloudy sky. Instrument pointed due south in I. Altitude not recorded but probably about 36°.

Mar. 23	−3:24	−2:49	?	?	.0483	.0536	.0539	.0485	.0353	......	111.0	112.0	100.0	73.0	....	Even and thick cloudy sky.

Summary of zone observations.—As might be expected, it is rather difficult to arrive at any very definite conclusions from observations of this character, owing to the many factors involved and the wide variation in these factors themselves. For instance the horizontal zones are a measure of the radiation from a strip of sky of uniform width and extending entirely around the sky, whereas the vertical zones are measures of circular areas of sky and varying in altitude. It is of course evident that the horizontal zones have not equal intensity per unit area in different azimuths of the sky, and also, as shown by the vertical zone observations, the zone in which the sun happens to be will show a larger sky radiation than it would were the intense sky radiation surrounding the sun not present. Hence the rough averages given immediately following the table of horizontal zone observations must not be regarded as very accurate if the sun and the ring of intense sky radiation surrounding it be all within one zone. But as a rough average, the values given are to be relied upon. There is even wider variation in the vertical zones, but it may be stated that if the sky be divided into four quadrants in azimuth, numbered 1, 2, 3, and 4, respectively, with the sun in the center of 1, then 2 and 4 will have an intensity of 50 to 80 per cent of 1, and 3 will have from 25 to 40 per cent of 1, under ordinary cloudless conditions of sky. The zenith region will show approximately 30 per cent of that surrounding the sun. These values are also dependent largely upon the condition of the sky, as regards haze, dust, smoke, etc., for the prevalence of all these impurities tends to increase the sky radiation in the zone, either horizontal or vertical, in which they are found. This is especially noticeable in the region immediately surrounding the sun, for with a clear blue sky, one can, by hiding the sun's disk, look practically up to the limb of the sun. On the other hand, if the sky be hazy, the glare is very intense, often several degrees from the sun's limb, and the eye can scarcely distinguish exactly where the sky leaves off and the sun's disk begins.

RADIATION FROM A CLEAR SKY AT 30° AND 19° SUN AT CALAMA

Quite an extensive set of observations have been taken at Calama on the radiation from cloudless skies with the sun exactly at air mass 2, or at an altitude of 30° above the horizon. A table follows which gives these results, with a description of the condition of the sky prevailing at the time.

Date	Calories from whole sky $M=2$	Character of sky
Dec. 23, 1918	.0814	Quite hazy.
" 27 "	.0858	" "
" 31 "	.0813	" "
Jan. 1, 1919	.0804	" "
" 2 "	.0795	Some haze.
" 11 "	.0752	Less haze than usual.
" 17 " p. m.	.0791	Hazy.
" 18 "	.0690	Considerably less haze than usual.
" 19 "	.0644	" " " " . Dry.
" 20 "	.0752	Some haze. Air quite humid.
" 21 "	.0799	Very hazy.
" 22 "	.0822	" "
" 23 "	.0852	" "
" 24 "	.0936	" "
" 25 "	.0977	Extremely hazy but cloudless.
Feb. 6 "	.0788	Hazy.
" 7 "	.0742	Some haze.
" 8 "	.0738	Quite hazy.
" 9 "	.0804	Very hazy and damp. Probably fog during night.
" 10 "	.0977	Extremely hazy and bright around sun.
" 13 "	.0906	Very hazy and some streakiness.
" 14 "	.0899	Very hazy and humid.
" 15 "	.1130	Extremely hazy.
" 17 "	.0748	Some haze.
" 18 "	.0686	" "
" 19 "	.0694	Less hazy than usual.
Mar. 17 "	.0983	Very hazy especially around sun.
" 18 "	.0739	Less hazy than usual.
" 19 "	.0786	Quite hazy.
" 21 "	.0874	" "
" 26 "	.0644	Quite clear. Some dust in air.
" 31 "	.0902	Quite hazy.
Apr. 1 "	.0825	Very hazy—quite humid.
" 2 "	.0747	Some haze.
" 3 "	.0872	Very hazy. Air very humid.
" 4 "	.0950	Very hazy and humid.
" 5 "	.0765	Quite hazy.
" 6 "	.0748	" "
" 7 "	.0720	" "
" 8 "	.0722	" "
" 9 "	.0662	Less hazy than usual.
" 10 "	.0690	Fairly hazy.
" 11 "	.0675	Some haze.
" 12 "	.0713	Quite hazy.
" 13 "	.0723	" "
" 14 "	.0678	Fairly hazy.
" 18 "	.0731	Quite hazy.
" 19 "	.0725	Quite hazy and some streakiness.
" 24 "	.0607	Less hazy than usual. Rather dusty.
" 25 "	.0641	Fairly hazy.
" 26 "	.0657	Quite hazy.
" 27 "	.0648	Rather hazy.
" 28 "	.0610	Some haze and dust.
" 29 "	.0640	Rather hazy.
" 30 "	.0656	" "
May 1 "	.0602	Some haze.
" 2 "	.0645	Rather hazy.
" 3 "	.0654	" "
" 4 "	.0623	Some haze and dust.
" 5 "	.0623	" " " "
" 9 "	.0634	Rather hazy.
" 10 "	.0668	Quite hazy—especially in east.
" 11 "	.0717	Very hazy.
" 12 "	.0710	Quite hazy.
Mean of 64 =	.0757	

Similar observations were made at air mass 3 (alt. about 19°) at Calama for a few weeks. The results follow in tabular form.

Date	Calories from whole sky $M=3$	Character of sky
Sept. 15, 1918	.0563	Hazy and a little thin cirrus.
" 16 "	.0534	Sky quite even, though somewhat hazy.
" 17 "	.0572	Considerable haze and dust.
" 18 "	.0573	Very hazy.
" 22 "	.0616	Quite hazy.
" 26 "	.0566	Rather hazy.
" 27 "	.0553	Some haze and smoke.
" 28 "	.0585	Very hazy, and streaky in east.
" 29 "	.0592	Quite hazy.
" 30 "	.0605	Very hazy.
Oct. 2 "	.0665	Quite hazy.
" 4 "	.0614	Rather hazy.
" 5 "	.0585	" "
" 6 "	.0585	" "
" 7 "	.0585	Fairly clear.
" 8 "	.0666	Very hazy.
" 9 "	.0611	Rather hazy.
" 10 "	.0595	Rather hazy and dusty.
" 15 "	.0594	Rather hazy.
" 16 "	.0686	Very hazy, misty and humid.
" 17 "	.0620	Quite hazy.
" 18 "	.0607	Hazy and some streakiness in east.
" 19 "	.0603	Quite hazy.
" 21 "	.0558	Some haze but sky quite uniform.
" 29 "	.0620	Some haze.
" 30 "	.0642	Rather hazy.
" 31 "	.0651	Quite hazy.
Nov. 1 "	.0580	Sky clear but some haze.
" 5 " p. m.	.0593	Quite hazy.
" 6 "	.0645	" "
" 7 "	.0637	Very hazy.
" 12 " a. m.	.0621	Rather hazy.
" 12 " p. m.	.0588	Sky clearer than in morning.
" 13 "	.0667	Quite hazy and some streakiness in east.
" 15 " p. m.	.0713	Quite hazy.
" 16 "	.0665	" "
" 17 "	.0703	Very hazy.
" 19 "	.0757	" "
" 20 "	.1085	Extremely hazy.
" 21 " p. m.	.0819	Very hazy.
" 22 "	.0683	Quite hazy.
" 25 "	.0818	Very hazy. Heavy dew during night.
" 27 " p. m.	.0646	Quite hazy.
" 29 " p. m.	.0616	Some haze.
" 30 "	.0657	Quite hazy and some streakiness.
Dec. 1 "	.0629	Quite hazy.
" 2 "	.0605	Rather hazy.
" 4 "	.0610	Less hazy than usual.
" 6 " p. m.	.0780	Very hazy.
" 7 "	.0726	Quite hazy.
" 11 "	.0644	Rather hazy.
Mean of 51 =	.0642	

Comparison of whole sky at M2 and M3.—By averaging 64 values at 30° sun and 51 values at 19° sun, it will be seen that increased sky radiation attends higher sun ; for approximately .0757 of a calorie is radiated by the whole sky at 30° sun and .0642 of a calorie at 19° sun. With a narrow zone of sky around the sun, the opposite is true—that is, the radiation decreases as the sun's altitude becomes greater. This is probably due to a clearing of the sky as the sun gets farther from the horizon. The radiation from the region next to the sun is much greater than for other equal areas of sky, as is shown by the vertical zone observations described in this paper. Hence as this region of greater intensity gets higher in the sky, its radiation falls more nearly vertical on a horizontal surface and this causes the total sky radiation to increase as the altitude of the sun increases.

On January 24, 1919, at Calama, a series of sky observations was made which may prove of some interest and illustrate what has just preceded. The sky was very hazy. Beginning with the sun at about 9° altitude, the measurements were alternated between the 30° zone arrangement pointed at the sun, but with the sun shaded off the strips, and the whole sky, the sun being again shaded off. Following are the results.

Mean hour angle	Sun's altitude	Calories in horizontal	Mean of x values	Character of sky
	(a) Zone around sun			
—5h 55m	9° 00′	.0456	3	Cloudless but very hazy. Light east wind.
	(b) Whole sky			
—5h 50m	9° 30′ (?)	.0535	3	Same as (a).
	(c) Zone around sun			
—5h 08m	18° 54′	.0350	3	Still very hazy—cloudless.
	(d) Whole sky			
—5h 03m	20° 00′	.0779	..	
	(e) Zone around sun			
—4h 18m	30° 00′	.0291	4	Still very hazy. Little wind.
	(f) Whole sky			
—4h 13m	31° 15′	.0936	4	
	(g) Zone around sun			
—2h 47m	50° 00′	.0250	4	Still quite hazy around sun.
	(h) Whole sky			
—2h 41m	53° 00′	.1166	4	

From the above it is seen that with a very hazy sky, with the sun ranging in altitude from 9° to 53° (the haze remaining practically constant), the radiation from the region near the sun's limb decreases 45 per cent, while the whole sky radiation increases 118 per cent.

OBSERVATIONS ON CLOUDED SKIES

As might well be expected, the observations made with the pyranometer on the radiation from cloudy skies, furnish a large range of values dependent upon the character of the clouds present in the sky, their position, and also the position of the sun with reference to the clouds. Quite a series of observations upon cloudy skies was taken at Hump Mountain, and under quite varying conditions. A résumé of these observations will be given and in most cases a brief statement as to the conditions obtaining at the time. Usually a mean of the values obtained will be included rather than the many pages of values as recorded. That is to say, the observations of each day will be divided into groups, of similar values in each group, and the mean given with the number of values entering into the mean.

Taking .0700 calories as a fair average of the intensity of the radiation on a horizontal surface from a cloudless sky at hour angles of the sun of 3 to 4, it will be seen that for cloudy skies the values are from four to nine fold for average clouds, and from one to four fold for very heavy clouds. Very often, just preceding the precipitation of rain, the radiation drops very considerably and very rapidly.

With low fog the observations unfortunately are few, but the indications are that the radiation is ten fold or more that of clear skies.

An average cloudy sky, if the clouds are not too thick, lets through about as much radiation (measured on a horizontal surface) as do the sun and a clear sky combined with the sun at an altitude of about 15°. The radiation from a low fog is about the same as from the sun and a clear sky at 30° sun.

Date	Hour angle	Mean of x values	Calories	
Aug. 6, 1917	$-1^h 32^m$	5	.596	Clouds fairly thick. Totally cloudy.
" " "	$-1^h 18^m$	5	.502	" " " " "
" " "	$-0^h 45^m$	10	.564	" " " " "
Aug. 16, 1917	$+4^h 28^m$	2	.507	Cloudy and partly foggy.
" " "	$+4^h 31^m$	3	.706	" " " "
Aug. 31, 1917	$-3^h 26^m$	4	.791	Heavy low fog. These are probably lower because of pyranometer glass coated with fog.
" " "	$-3^h 20^m$	6	.645	
Sept. 1, 1917	$-2^h 56^m$	4	.378	Fairly heavy clouds over whole sky, but sun faintly shining through spots at times.
" " "	$-2^h 44^m$	9	.247	
Sept. 22, 1917	$+1^h 38^m$	6	.202	Very heavy clouds and also low fog. It gradually grew darker, and just after the third set rain began to fall.
" " "	$+1^h 42^m$	3	.129	
" " "	$+1^h 45^m$	4	.072	
Sept. 29, 1917	$-1^h 35^m$	10	.326	Entirely cloudy sky. Clouds very high.
Dec. 3, 1917	$-2^h 28^m$	8	.308	Very cloudy sky. Clouds very even except along horizon. Began raining after last set.
" " "	$-2^h 43^m$	2	.180	
Jan. 19, 1918	$+1^h 32^m$	4	.456	Exceedingly hazy sky. Sun very dim. First and third sets are of the sky alone, and second and fourth of sun and sky—both measured on horizontal surface.
" " "	$+1^h 36^m$	5	.600	
" " "	$+1^h 42^m$	4	.461	
" " "	$+1^h 48^m$	5	.560	
Jan. 31, 1918	$+2^h 09^m$	10	.210	Sky covered with thin cirrus clouds through which sun shone. Sun shaded from strips.

RADIATION FROM HILL-SIDE

On February 23, 1918, an observation was made of a definite area of a hillside (approximately at right angles to the line of sight) covered with dry grass and leaves, and on which the sun was shining from an altitude of about 43°, directly back of the instrument. The vertical zone arrangement was used, but without the sun shade in place. An average of six very concordant values of the radiation from the hillside gives an intensity of .0546 calorie.

Immediately the instrument was pointed vertically, and a similar area of clear sky observed. The value in this case was .0169 calorie. This shows that the radiation outward from dry grass, etc., on which the sun is shining nearly vertically, at mid-day, is about three or four times that radiated by an equal area of clear zenith sky.

OBSERVATIONS AT DUSK

Two sets of observations have been taken to show the decrease of sky light at sunset. The first set was taken February 23, 1918, at Hump Mountain. Here an artificial sunset, so to speak, took place; for the mountain rose considerably above the observatory in the west, and the sun disappeared at an altitude of about +12°. The second set was taken December 10, 1918, at Calama, where the sun disappeared at an altitude of about −30 minutes. In both cases the whole sky was observed, with the sun shaded off and the glass screen on. Observations were begun sometime before sunset and were continued with some intervals until the galvanometer deflections were too small to read.

Results were as follows:

Hump Mountain, February 23, 1918

Sky cloudless, little haze, little wind.
Sun disappeared behind the hill .... $4^h : 30^m : 30^s$ H. A.
Time of sunset................................ $5^h : 31^m : 00^s$.

Hour angle	Altitude of sun	Calories	Hour angle	Altitude of sun	Calories
$+ 4^h : 09^m : 30^s$	15° 59′	0.0549	$5^h : 31^m : 30^s$	—0° 05′	.0111
10	15 47	.0539	32	0 16	.0098
11	15 35	.0522	33	0 27	.0091
$4^h : 26^m : 00^s$	12 42	.0484	$5^h : 37^m : 30^s$	1 13	.0064
27	12 30	.0478	38	1 24	.0057
28	12 18	.0488	39	1 36	.0051
29	12 06	.0481	40	1 47	.0040
30	11 54	.0468	41	1 58	.0034
31	11 42	.0468	42	2 10	.0031
32	11 30	.0445	43	2 21	.0031
33	11 18	.0448	44	2 32	.0027
34	11 06	.0451	45	2 43	.0017
35	10 55	.0445	46	2 54	.0017
36	10 43	.0445	47	3 06	.0011
			48	3 17	.0011
$5^h : 02^m : 30^s$	5 33	.0317	49	3 28	.00082
03	5 22	.0307	50	3 39	.00055
04	5 10	.0300	51	3 49	.00055
$5^h : 17^m : 30^s$	2 37	.0209			
18	2 26	.0206			
19	+2 15	.0199			

CALAMA, CHILE, DECEMBER 10, 1918

Sky cloudless, somewhat hazy, heavy wind at intervals.
Sun disappearing .... $6^h:42^m:00^s$ H. A.
Sun disappeared .... $44^m:18^s$.
True sunset (0° altitude) .... $40^m:20^s$.

Hour angle	Altitude of sun	Calories
$+4^h:42^m:45^s$	25° 20′	0.0878
43	25 06	.0881
44	24 53	.0871
45	24 40	.0874
46	24 26	.0871
$5^h:11^m:45^s$	18 57	.0741
12	18 44	.0693
13	18 31	.0683
14	18 18	.0693
15	18 05	.0683
$5^h:44^m:45^s$	11 43	.0553
45	11 30	.0536
46	11 18	.0536
47	11 05	.0536
$6^h:07^m:45^s$	6 47	.0382
08	6 35	.0386
09	6 23	.0375
10	6 10	.0372
11	5 58	.0369
$6^h:20^m:45^s$	4 05	.0278
21	3 53	.0275
22	3 41	.0262
23	3 28	.0252
24	3 16	.0242
25	3 04	.0235
$6^h:28^m:45^s$	2 26	.0202
29	2 14	.0195
30	2 02	.0195
31	1 50	.0175
32	1 37	.0172
33	1 25	.0172
34	1 13	.0152
35	1 01	.0142
36	0 49	.0139
37	0 37	.0129
38	0 25	.0119
39	0 13	.0113
40	+0 01	.0101
41	−0 11	.0091
42	0 23	.0085
43	0 34	.0078
44	0 46	.0068
45	0 58	.0059
46	1 09	.0052
47	1 21	.0038
48	1 33	.0035
50	1 57	.0029
51	2 09	.0023
52	2 21	.0021
53	2 33	.0012
$6^h:54^m:45^s$	−2 45	.0009
55	2 57	.0006
56	3 09	.0003
57	3 21	.0003
58	3 33	.0003
59	3 45	.0003

After the last observation in both places, although the rays had less than 1/100 the intensity of the average total mid-day sky radiation at Hump Mountain, or 1/200 at Calama; or less than 1/1000 of the strength of the solar rays reaching the earth, the ordinary small print of a newspaper was easily legible at arms length.

RADIATION UNDER TREES

During the autumn of 1917 some observations were taken at Hump Mountain in the shade of the trees on the mountainside. The object was to find out how much light passed the overgrowth and reached the ground. The extent of the work is limited, owing to the pressure of other matters.

On September 7 the pyranometer, with the auxiliary apparatus, was taken down the mountain side north of the observatory into a grove of beech and black birch. Observations were taken at five spots:

(*a*) In the shade of two large trees, no undergrowth within several feet;

(*b*) Under some rather thick saplings, partly shaded by higher trees, thin undergrowth;

(*c*) In a bed of ferns which covered the instrument, but with an open space directly above;

(*d*) In open space; trees all around; ferns and other vegetation somewhat above instrument toward south;

(*e*) Thick growth of saplings, considerable small vegetation on ground.

The sky, on this day, was cloudy and very variable. Observations had been taken on the whole sky and sun two hours before the instrument was moved to the grove, but after that the sky became nearly overcast. At the close, observations on the whole sky were taken, but there was so much variation that the readings were of little value.

A few days later, September 12, the observations were repeated, with a cloudless sky. With better conditions the readings showed far less variation among themselves than on the preceding days.

On October 2 a third set of observations was taken. The instrument was placed in the same five positions as before. This time the leaves were beginning to fall, and many that remained on the trees had turned yellow. The sky was cloudless and very clear.

Readings were taken mostly in groups of four or five. Below are the times for the middle of each group, the average calories for the group, an estimation of the total sky and sun radiation, and the ratio of the observed radiation under the trees to the estimated radiation above them. The estimated whole sky radiation is based, for September 7, on the observations taken on the tower, following those in the grove; for September 12, on solar observations by the pyrheliometer and total sky observations taken before the pyranometer was moved to the grove; for October 2, on pyrheliometer measurements taken at different air masses during the afternoon and total sky observations taken in the morning with the pyrheliometer, the sum of the two values at corresponding sun altitudes being used.

Place	Hour angle			Observed calories under trees			Estimated calories sun and sky			Ratio of observed to estimated		
	Sept. 7	Sept. 12	Oct. 2	Sept. 7	Sept. 12	Oct. 2	Sept.[1] 7	Sept. 12	Oct. 2	Sept. 7	Sept. 12	Oct. 2
a	$-1^h:18^m$	$-0^h:34^m$	$+2^h:00^m$	.0136	.0287	.0236	.38	1.28	1.02	.036	.022	.023
b	1 :10	0 :24	2 :09	.0145	.0197	.0138	.38	1.28	.94	.038	.015	.015
c	1 :01	0 :16	2 :17	.0156	.0140	.0083	.38	1.28	.89	.041	.011	.009
d	0 :50	0 :08	2 :26	.0619	.0498	....[3]	.38	1.28	.85	.163	.039	....
e	0 :34[2]	+0 :11	2 :38	.0144[2]	.0273	.0185	.38	1.28	.80	.038	.021	.023

[1] Sky nearly overcast. Sun appearing only occasionally during morning.
[2] There followed seven readings which showed a very rapid decrease of radiation.
[3] Direct sun on instrument.

Referring to the column of Ratios in the table above, we find a slight increase at *a* between September 12 and October 2. This is to be expected, for in this place the light was obstructed by high leaves, and many of these had fallen. For place *b* we find approximately the same ratio for both days, perhaps because the foliage of the saplings and undergrowth did not fall so early as that of the larger trees. The decrease in the ratio at *c* would follow an increase in the thickness of the ferns. At *e*, under saplings similar to those of *b*, a noticeable increase in the ratio occurred. This was very likely due to the absence of any shading by higher trees.

The results of these observations are meager, and of small reliability. Nevertheless, they suggest a field for wide and important research, concerning the necessary amount of light for various types of plants and at various stages in their development. The pyranometer, supplied perhaps with special colored screens for measuring different kinds of light, seems remarkably well suited to this purpose. It is hoped that a much more extensive investigation along this line may be undertaken.

SNOW OBSERVATIONS

Late in February, 1918, observations were taken to determine the reflecting power of snow. Part of the snow was gone at this time, as practically none had fallen since the first of the month, and there had been considerable rain. A suitable patch of snow was found, however, lying on a hillside sloping toward the northeast, not far from the observatory.

The procedure was as follows: The pyranometer, supplied with glass and thimble of 60° aperture, was mounted on an office stool and box, about four feet above the snow, and in such a manner that it could be alternately pointed at the sky and at such a point on the snow that the direct light and reflected light came from the same source. Care was taken to choose angles such that the cone of direct light included only sky and the reflected light came only from snow. The galvanometer was mounted on a tree about forty feet away and the ammeter and other apparatus was conveniently located nearby.

Observations were undertaken on two days, February 22 and 23. On the former the sky was very cloudy and snow was falling lightly, so that a thin film of fresh snow covered the patch of old snow. Readings were taken in sets of five except a set of four taken at the end with the instrument pointed at the zenith. Designating the sets alphabetically according to order, we observed as follows:

a Clouds in southeast, instrument elevated about +45°;

b Reflection of clouds of *a*, instruments elevated −25°;

c Same as *a;*

d Same as *b;*

e Instrument pointing on snow to southwest, so that direct and reflected rays would be in vertical plane;

f Clouds whose reflection was observed in *e;*

g Clouds in northeast, about 35° elevation;

h Clouds directly overhead.

Sets *g* and *h* were taken to give an idea of the comparative uniformity of the different parts of the sky.

On the following day there was a cloudless sky. This time light was observed coming from the sun and from the sky 30° around the sun. The day was fairly warm and the snow was melting slightly.

Ten sets of readings were taken, as follows:

a Sun and 30° sky around it;

b Snow, center about 4½ feet from instrument, giving most direct reflection, as shown by a mirror.

c Snow, about 30° east of *b* and 7 feet from instrument.

d Snow, about 30° west of *b* and 3½ feet from instrument.

e Snow, about in line with sun and 10 feet from instrument.

f Same as *a*.

g "Vertical zones," without sun shade (See Zone Observations).

h Snow, same as *e*.

i Mountain side covered with dry grass and leaves, sun almost directly behind instrument. Center of ground about 6 feet from instrument.

j Sky directly overhead. Strips shaded from sun by thimble.

There was an interval of about forty minutes between *f* and *g* in order to allow the taking of a bolograph.

Results of the observations are given below:

FEBRUARY 22.

Set	Hour angle	Mean calories
a	$-0^h:32^m:30^s$	.0300
b	25	.0212
c	17	.0424
d	− 09	.0231
e	+ 01	.0180
f	10	.0477
g	18	.0369
h	26	.0466

Ratios:

$b/a = .71$, $b/c = .50$, $d/c = .54$, $e/f = .38$.

The readings disagreed considerably among themselves, the sets on clouds being much less satisfactory in this respect than those on the snow, as will be seen by an inspection of sets *a*, *b*, and *g*, which were typical.

SETS

a		*b*		*g*	
Hour angle	Cal.	Hour angle	Cal.	Hour angle	Cal.
$-0^h:34^m:30^s$	.0307	$-0^h:27^m:30^s$	.0199	$+0^h:16^m:30^s$	.0343
33	.0291	26	.0199	17	.0496
32	.0323	25	.0206	18	.0294
31	.0310	24	.0225	19	.0366
30	.0271	23	.0229	20	.0346

The greater uniformity of the snow observations is probably due to the fact that the snow is comparatively a rough surface and a considerable proportion of the radiation came originally from portions of the sky very distant from the clouds observed directly; likewise, a large part of the radiation coming from the clouds in question, failed to reach the pyranometer, not being absorbed but reflected in other directions. Imagine, now, that the radiation from the clouds observed was reduced by one-half, while the rest of the sky remained the same. The effect observed from such a spot on the snow that a directly reflected ray from our clouds would strike the pyranometer, would, at the same time, be reduced not one-half but by one-half of that proportion which our clouds contributed to the whole radiation coming to the instrument from that spot on the snow. And though the radiation from the whole sky was far from uniform, the percentage of variation was probably considerably less than the percentage of variation in any particular portions of the sky.

With such wide ranges of variation definite results are out of the question. Nevertheless, it seems reasonable to state that from 50 to 60 per cent of the radiation from the clouds was reflected by the snow on this particular day.

February 23. Means of Sets

Set	Hour angle	Altitude of sun	Mean calories	Ratio to sun + 30° sky around
a	$-1^h:14^m:15^s$	40° 40′	1.5890	1.00
b	02 :00	41 42	.2033	.127
c	0 :53 :00	42 18	.2041	.128
d	46 :30	42 38	.1791	.112
e	38 :30	43 03	.2022	.126
f	— 31 :15	43 23	1.6100	1.00
h	+0 :29 :30	43 26	.2291	.143
i	40 :00	43 00	.0546	.035
j	50 :00	42 26	.0169	.010

Set a		Set b	
Hour angle	Calories	Hour angle	Calories
$-1^h:16^m:30^s$	1.588	$-1^h:04^m:00^s$	.2022
15	1.590	03	.2041
13	1.595	02	.2041
12	1.584	01	.2022
...	....	00	.2041

There was far better agreement among the readings than on the previous day, as will be seen by inspection of the results for *a* and *b*, which are typical.

It is remarkable that the ratio of the radiation measured from the snow is of the order of one-eighth the amount coming from the sun and a cone of sky 30° around it, while with the same cone, on the preceding day, the radiation from the snow was found to be rather more than one-half that coming from the clouds. This discrepancy can be accounted for as follows: On February 22 we observed a cone of light from a certain part of a totally cloudy sky and a similar cone from the snow such that a directly reflected beam from the center of the observed clouds would strike the surface of the strips normally. As stated above, a considerable portion of reflected light from the clouds observed was lost, but there was compensation from other parts of the sky. On the following day, however, we used sunlight and a cone of sky light 30° around it, so that compensation could come only from the rest of the sky, this outside radiation amounting perhaps to one-thirtieth, or possibly one-twentieth of that admitted by the thimble. Sets *b, c, d* and *e* show that the radiation from the snow was fairly uniform over a considerable area. Indeed, the highest readings are found in *c* where the instrument was pointed 30° east from the position of *b* in which the most direct reflections from the sun were measured; but this is probably because the snow of *c* was slightly cleaner than that of *b*. We can obtain an approximation, however, of the total radiation reflected to a point, by considering the effect if a whole hemisphere of snow were observed, or in other words, if no thimble were used, it being assumed that this were possible without the admission of the stray light. For if a ray coming from the sun is deflected a certain number of degrees west from the plane normal to the main snow surface and containing the sun, then at some other spot to the west of the first another ray is deflected by a snow crystal a corresponding number of degrees to the east of a normal plane containing the sun—or if in such a normal plane a certain ray makes a greater angle with the face of a crystal than with the main surface, another ray makes a correspondingly smaller angle with the face of another crystal; so that there is a general tendency toward compensation. The rays most directly reflected will be found the most effective, as they approach nearest to normal incidence on the pyranometer strips. We may now estimate the entire reflection by multiplying the results obtained with the thimble by 4 (the derivation of this ratio being given in the section on thimbles). Proceeding in this manner with sets *b, c, d, e,* and *h,* and adding 4 per cent to the sun and sky values, to allow for the portions of the sky not observed, we conclude that on the day in question about 50 per cent of the radiation coming from the sun and sky was reflected diffusely by the snow.

It seems very probable that considerably higher radiation would be obtained with snow that was freshly fallen. Unfortunately there was no appreciable fall of snow after this date, so that this opinion could not be confirmed.

SUMMARY

Quite an extensive set of observations was made at Hump Mountain, near Elk Park, North Carolina, from July, 1917 to April, 1918, with the pyranometer, an instrument constructed by the Smithsonian

Institution for the purpose of measuring radiation of various kinds. At Hump Mountain, measurements were made on the intensity of radiation from the sky, clear, hazy, cloudy, and foggy; the radiation under trees, plants, etc., snow reflection radiation, etc. In May, 1918, the instrument was taken to Calama, Chile, and other sky radiation measurements have been made there.

The pyranometer measures radiation by means of a delicate electric thermo-couple, which is heated by blackened manganin strips on which the radiation falls. The instrument is calibrated by means of a solar comparison with the pyrheliometer. The "constant" of the instrument is found to vary but little during long intervals.

Observations were made which showed that the pyranometer is a very sensitive instrument if joined to a delicate galvanometer, such as is used in bolometric work. The "bolograph" made with the pyranometer showed that it registers all wave lengths from 2.2μ to 0.33μ in their proper magnitude.

A table is given showing the relative intensity of the radiation from the whole sky (at air masses from 5.00 to 1.25) as compared with the simultaneous intensity of the solar beam as measured by the pyrheliometer, the latter being reduced to a horizontal surface. Intensities of total sky radiation for rather hazy though cloudless skies is given for air masses 3 and 2 for Calama, Chile.

The radiation from three horizontal zones of 30° width each, was investigated, during varying sky conditions. Also the intensity in various azimuths of the sky with a circular zone of 60° diameter. The position of the sun was taken as zero azimuth for each set and the other azimuths as well as the zenith region compared with it.

Observations were made on cloudy and foggy skies, and the intensity on a horizontal surface compared with the solar and clear sky radiation falling on a horizontal surface.

A brief investigation was made of a comparison of the radiation from a hillside covered with dry grass and weeds, and comparing it with an equal area of clear zenith sky.

Investigations were made both at Hump Mountain and Calama, regarding the diminution of radiation at dusk, and comparing it with solar intensity.

Observations were made of the intensity of radiation under trees and plants, showing roughly the amount of radiation needed by various plant growths.

Limited observations were made of the intensity of radiation reflected by snow, and comparing it with solar and sky radiation occurring at the time.