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A Mesoscale Radiation Study of the Cache Valley

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A MESOSCALE RADIATION STUDY OF THE CACHE VALLEY

by

Nolasco G. Baldazo

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Biometeorology

Approved:

[redacted]

UTAH STATE UNIVERSITY
Logan, Utah

1970

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To my wife Mila, daughters Gem (10½) and Ginggi (9) and sons Joe (7½) and Don Don (4½) this work is lovingly dedicated.

NG Baldazo
Nolasco G. Baldazo
College, Laguna
PHILIPPINES

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ABSTRACT

A MESOSCALE RADIATION STUDY OF THE CACHE VALLEY

by

Nolasco G. Baldazo, Master of Science

Utah State University, 1970

Major Professor: Dr. Inge Dirmhirn
Department: Soils and Meteorology

The radiation climate of Cache Valley was established from the continuous recordings of global and diffuse sky radiation at Utah State University campus from June 1968 to July 1969 and August 1968 to July 1969, respectively. The influence of topographic features during summer and winter conditions at seven representative locations running on an east-west direction across the valley were determined by making short term measurements on clear days.

A comparison of the clear day average global radiation on approximate dates of the same solar declination shows higher values during late winter and spring than the values during late summer and autumn. This is mainly the influence of the higher atmospheric water vapor during the warmer months. An interesting fact is, that not only the direct, but also the scattered radiation shows higher values during the spring months. This is caused by additional reflection from the snow-covered mountain slopes. In the curve showing the distribution of the diffuse sky radiation on completely cloudy days, the effect of the multiple reflection between the ground surface and the bases of clouds is very prominent in the period when there is snow on the ground.

sky radiation at Utah State University campus and to study the local influences of local topography on the receipt of global and diffuse sky radiation at various locations across the valley on an east-west direction by making short term measurements under summer and winter conditions.

In a mountain valley like Cache Valley, the difference in climate between the two opposite sides can largely be attributed to differences in the amounts of radiation received. This study was conducted on a scale where the incoming solar radiation may be influenced by topographic features.

REVIEW OF LITERATURE

The solar radiation reaching the earth's surface consists of two components: direct solar and diffuse sky radiation. The sum of these two components is termed as the global radiation. The amount and distribution of global radiation reaching a particular point on the earth's surface depends upon several factors such as latitude, altitude, and orientation of the place, condition of the atmosphere (turbidity and degree of cloudiness), obstructions due to local topography, and the kind of surface present (whether vegetation, snow or plain bare ground).

Solar constant

The rate at which the solar energy is received on a unit surface perpendicular to the sun's direction outside the gaseous atmosphere at the earth's mean distance from the sun is known as the solar constant. It is usually expressed in gram-calories per square centimeter per minute (gm-cal $cm^{-2}min^{-1}$) or milliwats per square centimeter (mW cm^{-2}).

The first direct measurement of solar constant was obtained on an aircraft at an altitude of 38,000 feet and the value so established is 1.936 ± 0.041 gm-cal $cm^{-2}min^{-1}$ (Thekaekara, 1968). Another direct measurement of the solar constant was obtained on a rocket aircraft at an altitude of about 82 kilometers and the value established is 1.952 gm-cal $cm^{-2}min^{-1}$ (Drummond et al., 1968, Drummond and Hickey, 1968). Both values obtained are about 2.5 percent lower than the estimate made by Johnson (1954).

Direct solar radiation

The basic formula for computing the amount of solar radiation I_o incident upon a horizontal surface at the top of the earth's atmosphere in time t is:

$$\frac{dI_o}{dt} = \frac{S_o}{r^2} \cos z \qquad (1)$$

where S_o is the solar constant, r the radius vector of the earth, and z the sun's zenith angle. The value of z for any given place and time may be computed from the relation:

$$\cos z = \cos\phi \cos\delta \cos\tau + \sin\phi \sin\delta \qquad (2)$$

where ϕ is the latitude, δ the sun's declination and τ the sun's hour angle.

The radiation that reaches the surface is attenuated exponentially by atmospheric gases and dusts according to wavelength. For example, the ultraviolet portion of the solar spectrum is absorbed by ozone in the stratosphere while the infrared by carbon dioxide and water vapor in the troposphere. In addition, there is also attenuation due to scattering by air molecules, water droplets, aerosols,and dusts. The complexities of the spectral adsorption and scattering fits a mathematical model of the type a^m in which a is the transmission coefficient for total radiation passing through the atmosphere and $m = \sec z$ is referred to as the optical air mass. The intensity of solar radiation received on a horizontal surface in time t is obtained by multiplying

Equation (1) by the atmospheric transmission a^{secz} to give:

$$\frac{dI}{dt} = \frac{S_o}{r^2} a^{secz} \cos z. \tag{3}$$

The optical air mass, secz, is the ratio of the actual path length through the atmosphere to the zenith path length and is therefore a function of latitude, declination, and hour angle of the sun (List, 1968).

Diffuse sky radiation

Part of the direct solar radiation scattered in the atmosphere on clear days reaches the earth's surface as diffuse sky radiation. The complex mechanism of scattering such as the Rayleigh and Mie scattering is discussed in most physics texts and is not appropriate to be dealt with in this paper.

The intensity of diffuse sky radiation in cloudless conditions decreases with height because the density of the air producing the scattering effect is less. In overcast conditions, this component increases strongly with height and is also influenced by the type of clouds. More details can be found in a study by Dirmhirn (1951) and Sauberer and Dirmhirn (1958). No other mountain range has been so thoroughly investigated from the plains to the summits as the Eastern Alps in Austria by the above investigators.

Relationship between direct and diffuse sky radiation

Direct solar radiation increases with height since the atmosphere, with its turbidity, scattering and absorbing properties, decreases in mass with height. In other words, the transmission coefficients are functions of the solar altitude, atmospheric water vapor, dust, ozone and any other radiation depleting factors.

At Mount Evans and Pikes Peak, Colorado, the diffuse sky radiation might not exceed 4 percent of the global, whereas in cities where soft coal is burned in quantity, the diffuse component might comprise 40 percent or even more in extreme cases (Hand, 1954).

A relationship between global and diffuse sky radiation according to the amount of cloudiness was shown by Sauberer and Dirmhirn (1958), and Hand (1947). Liu and Jordan (1960) derived an emperical equation for estimating the intensity of diffuse sky radiation on a horizontal surface under a cloudless atmosphere when the intensity of direct solar radiation at normal incidence is known.

Geographical distribution of solar radiation

Since solar radiation is not used in daily weather forecasting, its measurement in many synoptic stations of the Weather Bureau is not being undertaken. Besides the relatively higher cost of radiation instruments compared to other meteorological instruments, difficulty is encountered in their maintenance and calibration schedule. Today, there are less than 90 cooperative and Weather Bureau radiation stations in the United States for which data are published. Hand (1937) gave a historical review of the solar radiation investigations of the U. S. Weather Bureau.

In spite of the inadequacy of radiation data both in areal coverage, length of records, and quality of measurements, studies on the distribution of global radiation in this country were conducted by several investigators, among them are Fritz (1949), Fritz and MacDonald

(1949), Hand (1953), Bennett (1965), and Hall (1967). The lack of data was supplemented by estimating global radiation using emperical equations derived from relationships between insolation and the more commonly observed climatic elements, foremost among which is duration of bright sunshine. The first one to use this kind of a derived relationship was Angstrom (1924).

Maps showing the world-wide distribution of global radiation have been drawn by Black (1956), Landsberg (1961), and Budyko and Kondratiev (1964).

While the maps drawn showing the monthly mean daily insolation over the entire United States show the general radiation pattern, they do not show local variations which may be very large. It must be realized that any chart showing the distribution of global radiation over the country treats large areas only and that individual stations might vary as much as 100 percent or more from the surrounding areas (Hand, 1953).

INSTRUMENTS AND METHODS

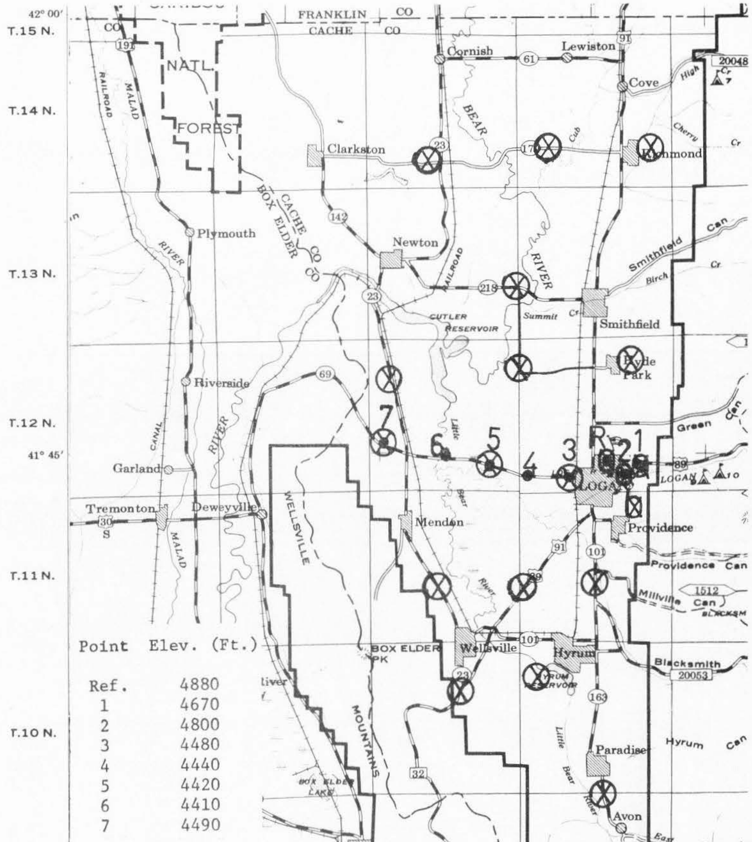
Location and duration of study

Radiation instruments were installed on the roof of the Forestry-Zoology Building at Utah State University campus (41°45'N; 111°50'W). This site offers an unobstructed view of the natural horizon and is readily accessible. Recorders were located in a laboratory room on the third floor of the building where a metal ladder was provided for climbing to the roof. Continuous measurements of global and diffuse sky radiation were obtained from these instruments from June 1968 to July 1969 and August 1968 to July 1969, respectively.

Short time measurements of global and diffuse sky radiation were made at seven points across Cache Valley on an east-west direction. Relative position in a north-south direction would not influence the intensity of solar radiation on a mescoscale basis except during sunrise and sunset due to differences in the horizon.

The measurements were made by placing a Star pyranometer properly levelled on top of the car. A recorder, powered by the car battery through an inverter, was used to record the output of the pyranometer. A 5- to 10-minute recording was made at each of the seven points by driving back and forth across the valley. This was repeated throughout the period between sunrise and sunset during clear days and during part of the day on a cloudy day.

The short time measurements were made on clear days when there was snow on the ground on March 24, 1969 and on June 30, 1969 when the snow was completely melted in the valley and in the mountains. The diffuse



Point	Elev. (Ft.)
Ref.	4880
1	4670
2	4800
3	4480
4	4440
5	4420
6	4410
7	4490

Figure 1. Map of Cache Valley showing the various locations where the natural horizons were determined ⊗ and Points 1 to 7 where short time measurements of global and diffuse sky radiation were made. R indicates the reference point where the continuous measurements were made.

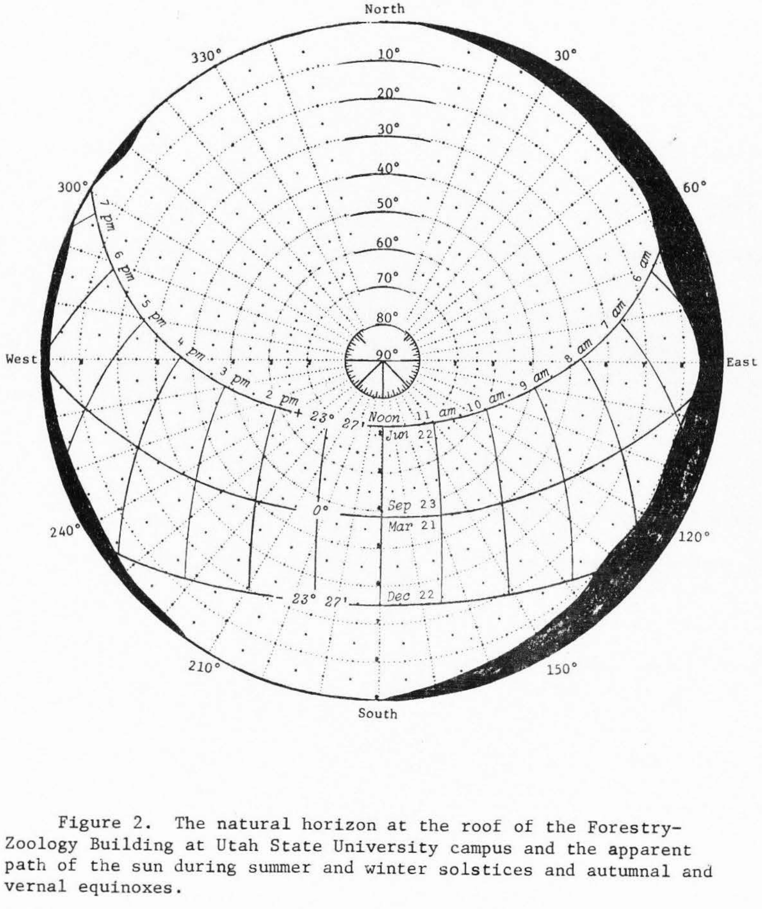


Figure 2. The natural horizon at the roof of the Forestry-Zoology Building at Utah State University campus and the apparent path of the sun during summer and winter solstices and autumnal and vernal equinoxes.

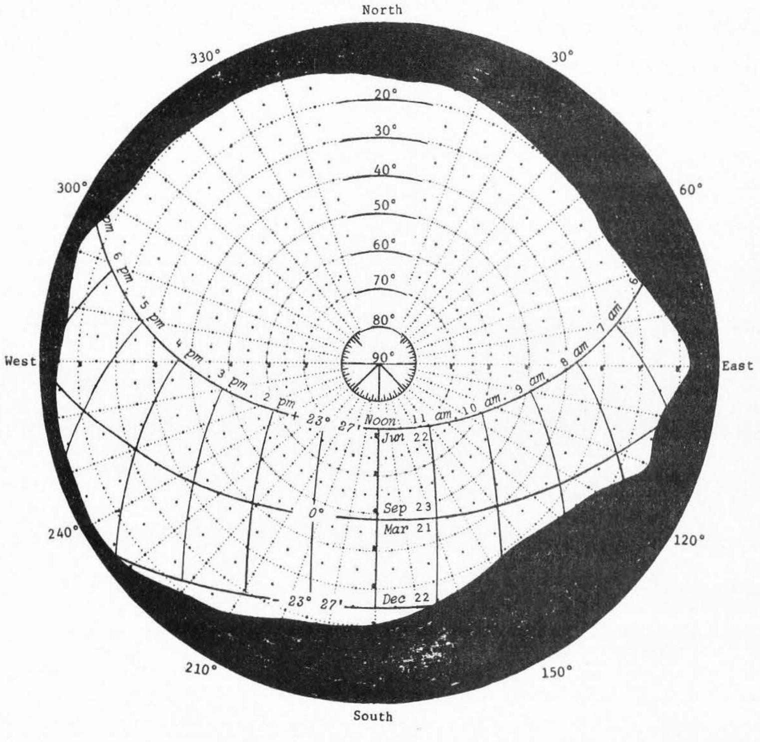


Figure 3. The natural horizon at Point 1 and the apparent path of the sun during summer and winter solstices and autumnal and vernal equinoxes.

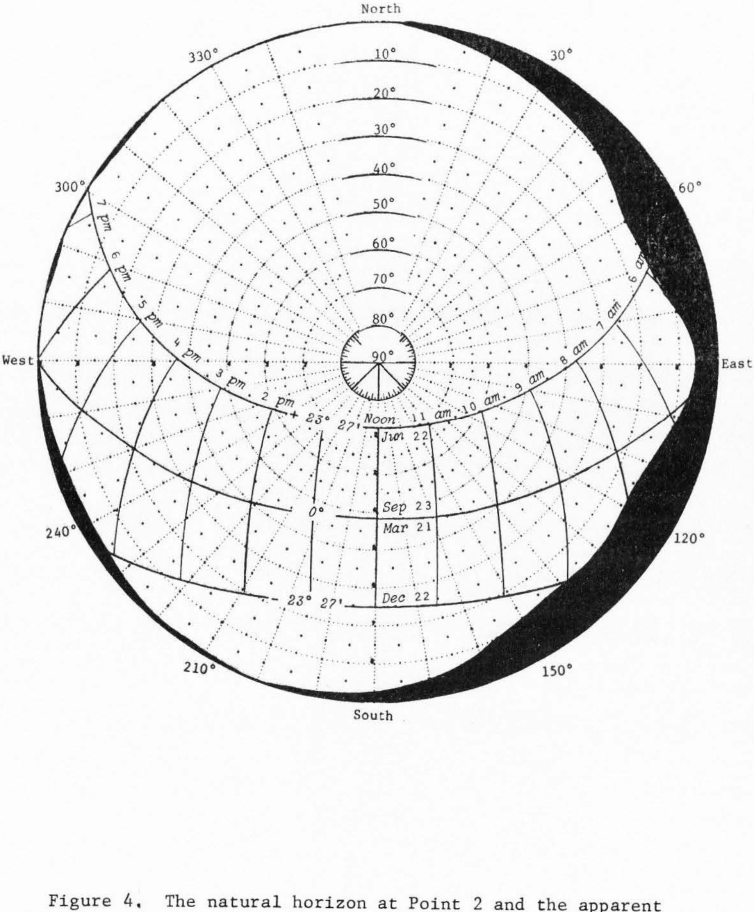


Figure 4. The natural horizon at Point 2 and the apparent path of the sun during summer and winter solstices and autumnal and vernal equinoxes.

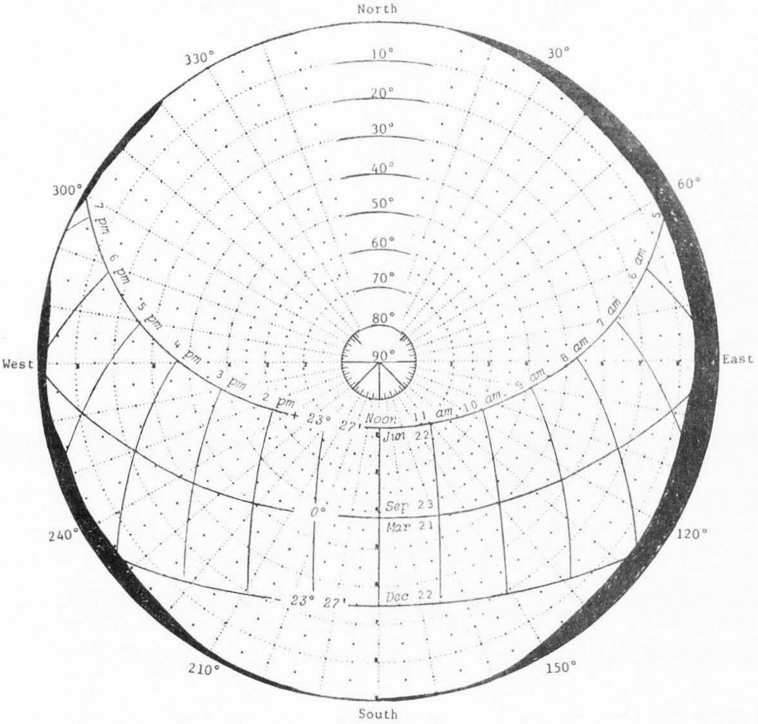


Figure 5. The natural horizon at Point 3 and the apparent path of the sun during summer and winter solstices and autumnal and vernal equinoxes.

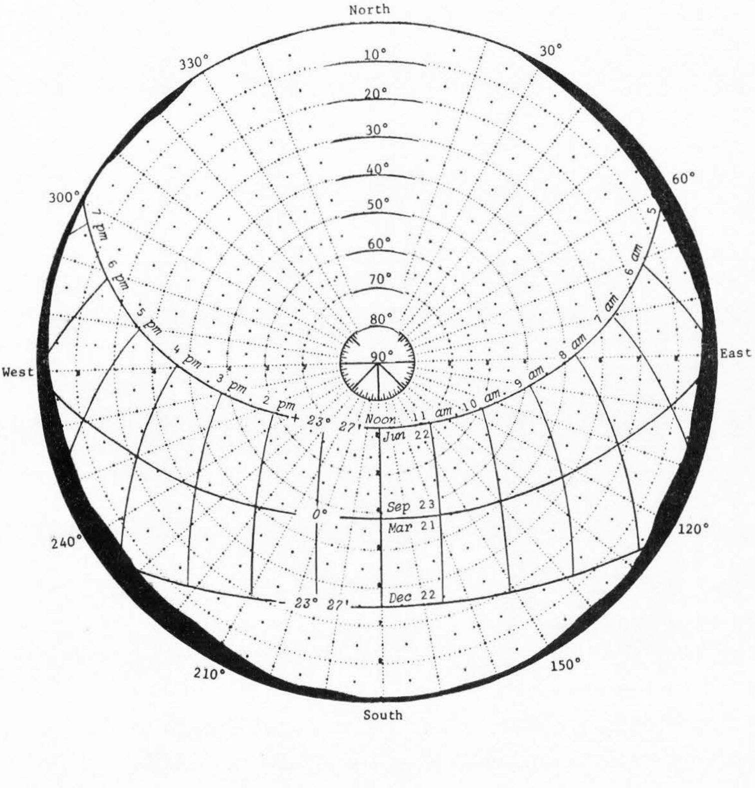


Figure 6. The natural horizon at Point 5 and the apparent path of the sun during summer and winter solstices and autumnal and vernal equinoxes.

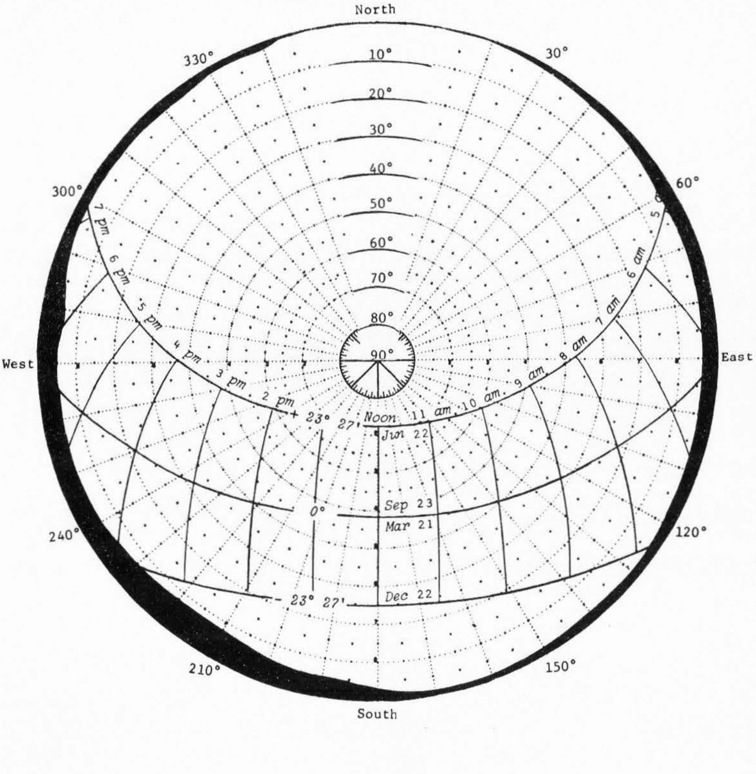


Figure 7. The natural horizon at Point 7 and the apparent path of the sun during summer and winter solstices and autumnal and vernal equinoxes.

Description of instruments

A Moll-Gorczynski and an Eppley pyranometer were used in the continuous measurements of global and diffuse sky radiation. A shadow band (also known as an occulting device) was used to shield the Eppley pyranometer from the direct solar radiation. A Star pyranometer was used in the short time measurements across the valley.

Moll-Gorczynski pyranometer. The receiver of the Moll-Gorczynski pyranometer (Figure 8) is a Moll thermopile consisting of alternate thin strips of manganin and constantan arranged in a zig-zag pattern forming a series of 14 thermojunctions which is approximately a square, 10 mm x 14 mm in diameter (Figure 8b). The strips are in thermal contact but electrically insulated from the copper plate which has a large thermal capacity. A black varnish of low thermal capacity fills the space between the strips and this results in a poor thermal contact so that each thermojunction can be treated separately as far as heat transfer is concerned. The thermopile is enclosed in two concentric glass hemispheres, 2 mm thick, and may be dismantled as shown in Figure 8c. A ring of synthetic rubber is inserted between the outer dome and the mounting which keeps the interior sealed airtight. The flat surface is maintained on a horizontal position and the solar radiation falling on it causes heat to be absorbed by the receiver. The heat absorbed is then transferred to the air by convection, to the copper plate by conduction, and to the surroundings by radiation. The effect of the double hemispherical glass dome is to reduce convective heat losses. A temperature gradient, between the center of the strip and its ends, results due to the greater thermal capacity of the supports and the copper plates. The central junctions

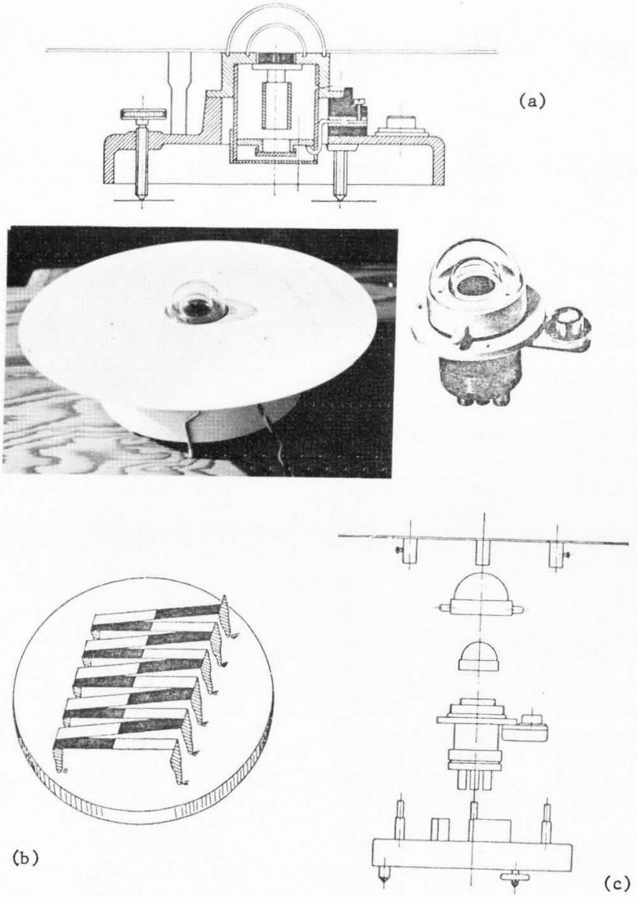
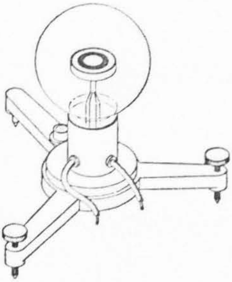


Figure 8. Moll-Gorczynski pyranometer (solarimeter). (a) Top: cross-sectional drawing. Bottom right: unmounted (from Robinson, 1966). **Bottom** left: mounted. (b) Moll thermopile (from Robinson, 1966.) (c) dismantled solarimeter (from Kipp and Zonen, Cat. No. cm 2 - cm 3).

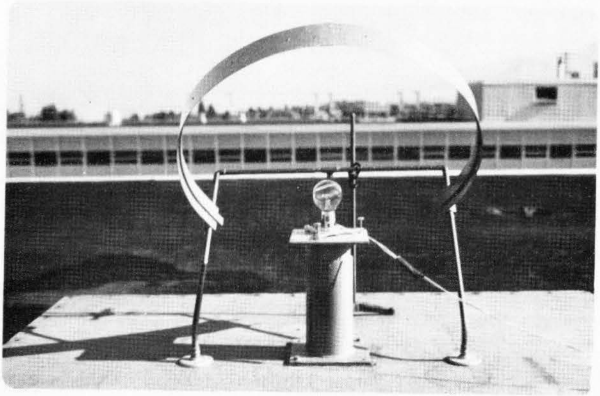
are the hot junctions and the ends of the thermopiles are the cold ones.

Gorczynski (1924) discussed the development and construction of the Moll-Gorczynski pyranometer which is now manufactured by Kipp and Zonen in Holland. This instrument is commonly used in Europe and according to Sellers (1965) is considered more accurate than the Eppley pyranometer which is the standard in the United States. The properties of the Moll-Gorczynski pyranometer was discussed by Robinson (1966) and also in IGY Instruction Manual, Part VI. Collins and Walton (1967) developed a thermistor compensation for this instrument which reduces the temperature coefficient considerably.

Eppley pyranometer (50-junction). The Eppley pyranometer (Figure 9a) was primarily designed for the measurement of intensity of solar radiation on a horizontal surface. Kimball and Hobbs (1923) discussed the development and construction of a similar instrument. The Eppley pyranometer is manufactured in the United States by Eppley Laboratory, Inc., Newport, Rhode Island. The receiving element consists of two thin and flat concentric silver rings. This is hermetically sealed in a lamp bulb of soda lime glass filled with dry air to prevent any condensation of water on its inner surface due to exposure to low temperature, which is an advantage over the Moll-Gorczynski pyranometer. The inner or hot ring is painted with lampblack and the outer or cold ring is smoked with magnesium oxide. A marked temperature difference results when the two rings are exposed to incoming solar radiation. The resulting current shows an electromotive force (emf) which is not strictly proportional to the difference between the temperature of the junctions attached to the black and the white



(a)



(b)

Figure 9. (a) The Eppley pyranometer. From Handbook of Meteorological Instruments, Part I. (British Meteorological Office, 1956). (b) Eppley pyranometer with shadow band.

rings, respectively, but the voltage is nearly proportional to the intensity of the received solar radiation. A complete description of this instrument is contained in the Eppley Bulletin No. 2.

MacDonald (1951) made several tests on the effect of temperature, angle of incidence, exposing the receiver on a vertical plane, a complete inversion from the horizontal, and the effect of a few water droplets on the glass on the response of the Eppley pyranometer. The tests showed that: (1) the output increased with decreasing ambient temperature; (2) the output varied with angle of incidence of collimated radiation; (3) the output decreased about 5 percent when the receiver was exposed in the vertical plane, but complete inversion from the horizontal had no significant effect; and (4) a few water droplets on the glass hemisphere did not influence output.

Woertz and Hand (1941) made tests using different techniques but analysis of their data indicates similar results except for one pyranometer. Other possible defects were pointed out such as: (1) the black and white rings not all in the same plane; (2) the black surface, especially, appears to be coated to a varying thickness; and (3) orientation may have small effect and therefore pyranometer should be oriented the same as during calibration.

Fuquay and Buettner (1957) also made laboratory investigations of some characteristics of the Eppley pyranometer. Experiments and theories were given to explain and show ways to avoid the following errors: (1) variable temperature coefficient; (2) variation of thermopile output with direction of gravity, and effect caused by internal air convection; (3) errors caused by radiation coming from the back side and being reflected by the glass cover; and (4) errors from specular reflectivity of the black receiver ring and the resulting deviation of response from the cosine law. According to Fuquay and Buettner, in its present form (i.e., present absorbing surface, single calibration constant, etc.), the Eppley pyranometer does not appear suitable for radiation measurements at high latitudes. For middle-latitude measurements, extensive calibration of the present units should considerably improve the accuracy of the instrument. Minor modifications of cover design and surface coatings could lead to a greatly improved instrument.

The shadow band was constructed to shield the pyranometer from direct solar radiation, thus the pyranometer detected only diffuse sky radiation. The shadow band was made of aluminum sheet and was 8 cm wide, 1.5 mm thick, and 180 cm long. The aluminum band was painted a dark gray to reduce possible reflection on the pyranometer. The shadow band was formed into an arc which has a diameter of about 81 cm and could be adjusted by sliding two clamps on two brass pipe legs mounted on a base screwed on the table. The legs are inclined in a south-north direction to an angle equal to the geographical latitude of Logan City by a vertical metal support fixed at the middle of the 71 cm crosspipe which joins the two legs on its upper ends. The Eppley pyranometer was fixed on a metal stand between the legs.

A similar device built by Hand (1946) for the U.S. Weather Bureau involves a ring arrangement. The ring has a radius of 20 inches and a cross-sectional diameter of 2 inches. The shading is modified in accordance with the date by a parallel displacement of the ring on a frame which is inclined to an angle equal to the geographical latitude of the station. This type of shadow band as well as the one used in this study involves a change in the distance between the receiver and the shadow band. Robinson (1955) describes an occulting device which ensures a fixed shading-receiver distance throughout the year.

Star pyranometer. Dirmhirn (1958) discussed in detail the development, construction, and operation of the Star pyranometer (Figure 10). The receiver consists of 32 small copper plates which are 0.05 mm thick and are alternately painted black and white. These are attached to two poorly conducting materials about 3 mm thick. The rings are mounted on a heat-insulating plate and spaced at a certain distance. The thermopile consists of manganin-constantan or copper-constantan junctions which are soldered to the plates. The junctions in thermal contact with the black plates are the hot junctions while those in contact with the white plates are the cold junctions. The receiver is covered by a polished glass hemisphere about 2 to 3 mm thick and is 7 cm in diameter.

Dirmhirn also showed that the effect of the short-wave radiation in the spectral range between 0.3 and 3 microns is nearly independent of the wavelength and that it can be measured according to the cosine law, up to 75° angles of incidence or better. It was also shown that the position of the Star pyranometer and the weather conditions do not influence the output. There is a direct proportionality between the amount of current and the intensity of the received solar radiation. The time of reaction until 99 percent of the output is reached is 20 seconds and the study showed that the accuracy is sufficiently high. This instrument is useful for momentary and continuous measurements of global and diffuse sky radiation as well as albedo. It was also tested in the

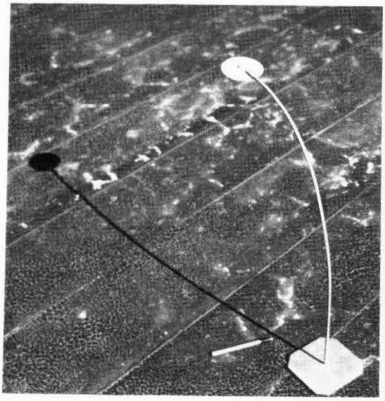
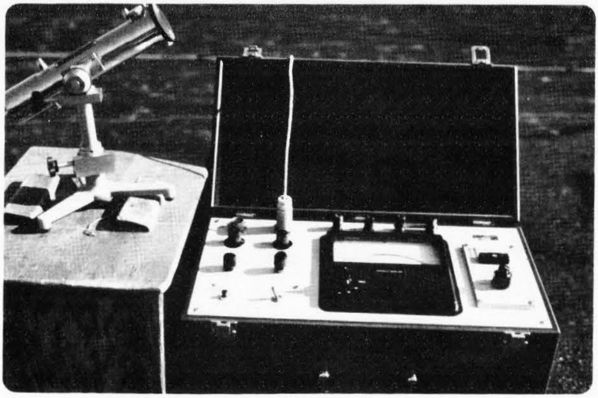


Figure 11. Shading disk.

Figure 10. Star pyranometer.



(a) (b)

Figure 12. (a) Angstrom compensation pyrheliometer. (b) Electronic galvanometer.

laboratory in the Department of Soils and Meteorology for temperature effect and was found to have no effect within the range -6 to 64 C.

Angstrom pyrhelimeter and calibration method. All the pyranometers used in this study were calibrated regularly with the use of the Angstrom compensation pyrheliometer (Figure 12a). In this instrument, a thin blackened shaded manganin strip is heated electrically until it is at the same temperature as a similar strip which is exposed to solar radiation. Under steady state condition, the energy used for heating is equal to the absorbed solar energy. The thermocouples on the back of the two strips are used to test for the equality of the temperature. These are connected in opposition through an electronic galvanometer (Figure 12b). The energy I of the direct solar radiation is calculated by means of the formula:

$$I = ki^2 \tag{4}$$

where i is the heating current in amperes and k, a dimensional and instrument constant typical of each Angstrom pyrheliometer. A complete description of this instrument may be obtained upon request from the Eppley Laboratory, Inc., Newport, Rhode Island.

During calibration, the global radiation is measured first and then the diffuse sky radiation by shading the pyranometer with a disk mounted at the end of a slender rod shown in Figure 11, held about a meter away. The shading disk has a diameter slightly greater than the diameter of the receiver. The vertical component of the direct solar radiation is then obtained by subtraction,

$$I \cos z = k(R_g - R_d) \tag{5}$$

where I is the observed direct solar radiation, z the sun's zenith angle which may be computed from Equation (2), R_g the pyranometer output without the shade and R_d the output in the shaded condition. The constant required for each pyranometer is k. The information obtained in all the calibrations made on the Moll-Gorczynski pyranometer which was used as the standard in this study are listed in Table 1.

Other methods of calibrating pyranometers are discussed by Hill (1966), Latimer (1964; 1966), and Drummond and Greer (1966).

Units, IPS and standard time for radiation

The unit used is the cal $cm^{-2}min^{-1}$ which is also specified by the World Meteorological Organization (WMO) and for totals of solar radiation, cal cm^{-2} per hour, day, month, and year as the case may be. In some meteorological services, the unit used is milliwat cm^{-2} (cal $cm^{-2}min^{-1}$ = 69.7 mW cm^{-2}). In some countries, a cal cm^{-2} is designated a langley and the corresponding unit of flux density is langley min^{-1}.

All the solar radiation measurements were referred to in what is known in some countries as Local Apparent Time (L. A. T.) and in others as True Solar Time (T. S. T.).

Care of instruments

The pyranometers used for continuous measurement of global and diffuse sky radiation were inspected at least once a day and additional times when necessary during the winter months, especially on days when there was snowfall. The glass hemispheres were wiped clean and dry and in the case of the Moll-Gorczynski pyranometer, whose outer glass

Table 1. Information on the calibrations made on the Moll-Gorczynski pyranometer using an Angstrom compensation pyrheliometer

Year and Month	Declination (degrees)	Solar angle (degrees)	Solar Radiation (Horizontal)		
			Angstrom I sin h	Moll-Gorczynski	
				Recorder	Deviation
	δ	h	gm-cal cm^{-2}	gm-cal cm^{-2}	%
1968					
July 26	+20° 30'	52° 23'	0.998	0.988	+1.1
28	+19° 00'	65° 22'	1.180	1.145	-3.0
Aug 12	+15° 00'	43° 46'	0.848	0.826	-2.6
29	+ 9° 39'	55° 02'	1.127	1.083	-3.7
Sep 5	+ 7° 07'	40° 45'	0.866	0.849	-2.0
24	- 0° 32'	46° 05'	0.969	0.952	-1.8
Oct 8	- 5° 35'	42° 34'	0.946	0.937	-1.0
17	-8° 58'	38° 58'	0.878	0.862	-1.8
1969					
Jan 10	-22° 04'	25° 56'	0.543	0.552	+1.7
Mar 11	- 4° 11'	41° 29'	0.897	0.890	+0.8
Apr 30	+14° 32'	59° 26'	1.192	1.180	-1.0
June 4	+22° 20'	69° 22'	1.270	1.243	-2.1
July 2	+23° 06'	73° 22'	1.330	1.295	-2.6
30	+18° 43'	64° 21'	1.173	1.151	-1.8
Aug 19	+13° 02'	60° 57'	1.150	1.120	-2.6
Sep 5	+ 7° 07'	55° 18'	1.120	1.102	-2.1
15	+ 3° 20'	51° 44'	1.012	0.992	-2.0
25	- 0° 32'	47° 23'	1.012	0.980	-3.0

hemisphere is not hermetically sealed, condensation inside the glass was always removed whenever present. Deposits of snow, frost or rime were removed carefully from the outer surface of the glass hemispheres during extremely cold mornings. The trace on the automatic recorders were marked when measurements were interrupted for cleaning the bulbs and for calibrations. When the records were evaluated, appropriate corrections were made. These problems were not encountered in the Star pyranometer in as much as it was only used for short time measurements on clear days where wiping the glass hemisphere clean and dry is enough.

Analysis of data

Continuous global and diffuse sky radiation. The global and diffuse sky radiation were analyzed on an hourly, daily, and monthly basis. The charts were removed from the respective recorders every Monday. The time was adjusted to the True Solar Time and the corrections made whenever necessary as regards to any possible interruptions previously mentioned including power failure. The hourly values were integrated using especially made mechanical integrators for both charts.

At the end of the period of study, 1 year and 2 months for the global radiation and 12 months for the diffuse sky radiation, the daily values were corrected based on the calibrations made. The corrections made on the global radiation were based on Figure 13. A different procedure was followed in determining the correction factor for correcting the diffuse sky radiation although calibrations were made on the Eppley pyranometer just the same.

The Eppley pyranometer was installed for a few days without the shadow band. Short period records (30-minutes) during completely cloudy

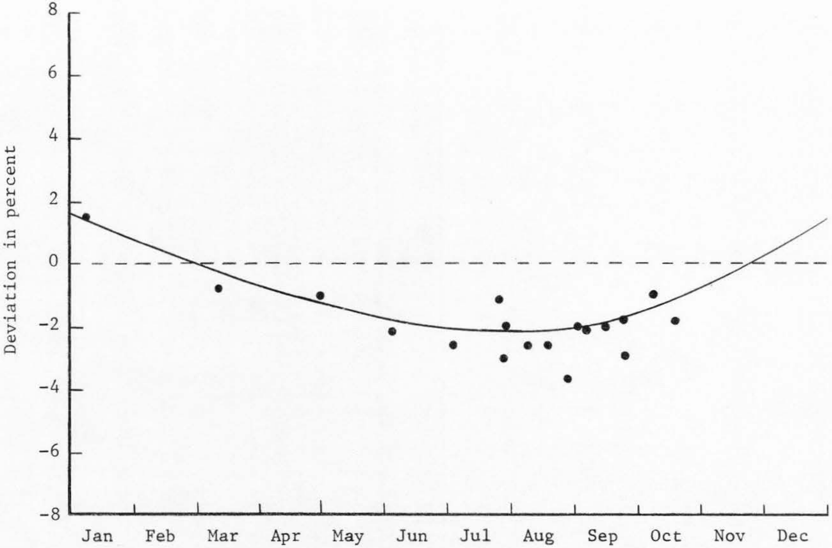


Figure 13. Deviations of the Moll-Gorczynski pyranometer from the Angstrom compensation pyrheliometer at calibration time.

days were compared to the Moll-Gorczynski record for the same period. Figure 14 indicates that no correction was necessary under this condition. When the shadow band was installed, short period values were again compared. A decrease of 9 percent was noted in the Eppley pyranometer output (Figure 15). Corrections on the daily values of diffuse sky radiation were therefore made based on this comparison.

Short-term global and diffuse sky radiation. The hourly march of the global radiation on a perfectly clear day under summer and winter conditions was established on all seven points selected in the valley. This was based on the short time measurements made at each point at certain intervals from sunrise to sunset on March 24, 1969 when there was snow on the ground and on June 30, 1969 when the snow was completely melted in the valley and in the mountains.

To avoid any discrepancy that may be due to the possible difference in the response of the pyranometer used in the valley and the one used at the reference point, comparisons were made at the reference point on the output of both instruments on a clear day. This was done as close as possible to the day the short time measurements were made, March 29, 1969 when there was snow on the ground and, July 4, 1969 when the snow was melted. Based on these comparisons, the measurements at the seven points were properly adjusted.

The diffuse sky radiation was measured during part of a completely cloudy day on June 24, 1969.

In all short time measurements, care was taken to synchronize the time, such that when comparisons were made, the accuracy with regards to the time was as close as possible to the nearest minute. The average for the period was always taken so that the error which may be due

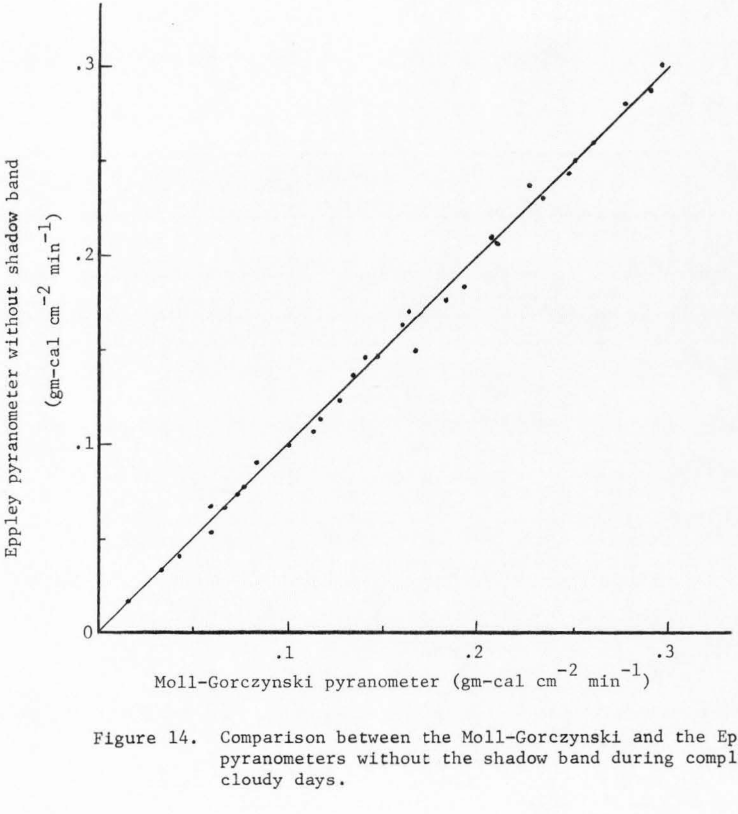


Figure 14. Comparison between the Moll-Gorczynski and the Eppley pyranometers without the shadow band during completely cloudy days.

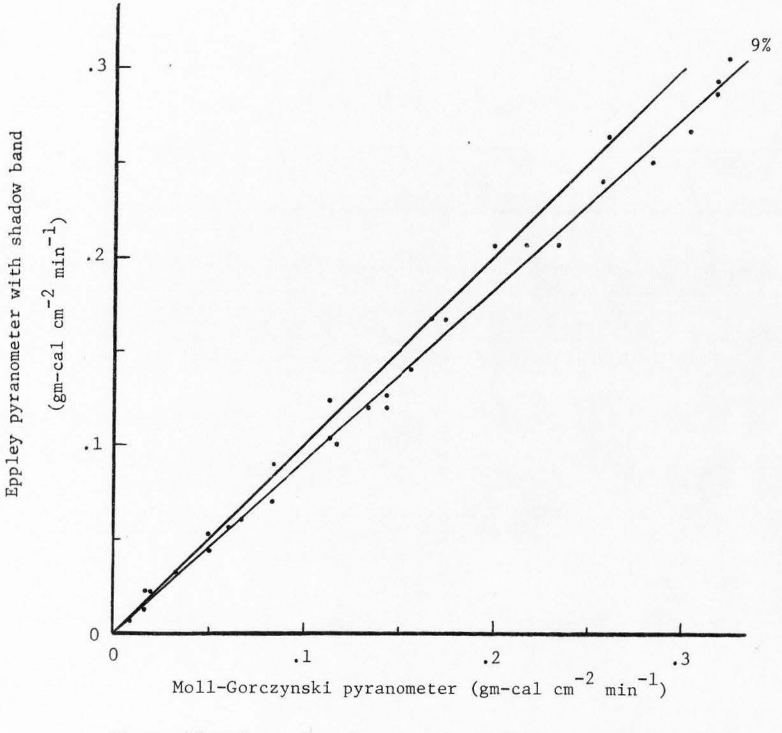


Figure 15. Comparison between the Moll-Gorczynski and the Eppley pyranometers with the shadow band during completely cloudy days.

to a difference in the time in the order of one minute or so was minimized.

RESULTS AND DISCUSSION

Continuous global and diffuse sky radiation

The actual daily and monthly totals of global and diffuse sky radiation are listed in Tables 2 and 3, while Figures 16 and 17 show their graphical distribution over the entire period of this study. These values reflect weather conditions during the period and can not be taken as climatic averages for the area. However, some implicit weather patterns can be deduced in Figure 16. Distinct depletion of the global radiation during certain days of the months are apparently a result of cloudiness associated with weather phenomena such as fronts and thunderstorms. The lower global radiation in these periods is usually associated with higher diffuse sky radiation, as for example, in August 1968 and June 1969 (Figures 16 and 17). During some days clouds reduced the amount of global radiation to as low as 14 percent of the possible.

In Figure 16 we could draw, without too much effort, a ceiling curve along the maximum daily values during the year. This maximum possible global radiation is a good means for comparison of a station with other locations. It also provides an idea of the maximum total energy which can be expected for the area by solar radiation processes. We will, therefore, discuss this maximum possible global radiation undisturbed by clouds.

Global and diffuse sky radiation (cloudless sky). Figure 18a shows the distribution of the global radiation based on the records on clear days. The intensity of solar radiation falling on a horizontal surface

University, Logan, Utah, June 1968 to July 1969

	1969						
	Jan	Feb	Mar	Apr	May	Jun	Jul
	105.8^{a}	172.3	210.0^{a}	552.7	464.2	775.2	772.6^{b}
a	108.5	234.4	300.4	572.7	636.6	716.2	779.2^{b}
	213.6	316.6^{b}	398.6	297.0	565.5	735.3	764.6
	56.8^{a}	311.8	446.2^{b}	582.3^{b}	601.8	740.4^{b}	777.6^{b}
	97.6^{a}	237.7	423.3	513.8	646.0	659.4	734.2
	196.4	90.3^{a}	320.0	213.3	698.1	618.0	718.3
	171.8	230.5	401.7	206.2^{a}	678.1	491.3	742.6
	200.1	330.9	465.6	316.4^{a}	697.8^{b}	602.3	745.9^{b}
	242.7	265.8	485.0	593.1^{b}	700.7^{b}	203.4	750.3^{b}
	213.4	268.3	502.6^{b}	575.7	705.3^{b}	730.9	749.2
a	82.7^{a}	299.9	498.5^{b}	573.9	587.0	564.8	689.8
	127.8	209.1	426.2	497.4	712.0	429.1	702.5
	88.7	226.2	507.5	219.8^{a}	651.7	667.0	680.0
a	60.2	219.4^{a}	509.9	514.7	700.9	381.0	518.8
a	159.1	155.8^{a}	497.4	157.2^{a}	519.8	305.9	709.4
a	103.5^{a}	167.1	491.1	454.1	737.3^{b}	606.4	719.3
	216.3	377.6	397.8	632.2	731.5^{b}	729.0	687.2
a	243.5	379.6	458.7	150.6^{a}	538.9	655.5	689.8
a	16.7^{a}	224.3^{a}	400.3	650.3	696.6	615.0	679.4
	17.9^{a}	230.8^{a}	536.7	648.3^{b}	644.0	401.9	672.8
	29.7^{a}	258.0	451.2	648.5	738.3^{b}	569.2	702.8
	39.5^{a}	344.9	538.1	549.0	750.8^{b}	477.4	659.9
a	198.3	285.5	284.4	640.3	741.5^{b}	237.5	442.9
	176.9	240.0	554.2^{b}	257.7	722.8	376.7	675.4
a	79.7^{a}	134.2^{a}	558.1^{b}	528.0	717.3	535.3	723.7^{b}
	82.4	289.2	549.1	482.3	695.3	528.1	706.3
a	206.3	339.4	480.0	681.9^{b}	743.4	537.7	610.9
a	145.7^{a}	418.5	565.0	664.0	765.6	762.5	473.1
	238.7		544.3	582.1	722.1	781.1^{b}	690.6^{b}
	221.8		505.7	712.0^{b}	566.7		670.3
	306.2		395.8		768.8		
	4448.3	7258.1	14103.4	14667.5	20846.4	17138.6	21166.6

Table 3. Actual diffuse sky radiation (gm-cal $cm^{-2}day^{-1}$), at Utah State University, Logan, Utah, August 1968 to July 1969

Day	1968					1969						
	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
1	143.5	78.7	62.4	98.1	140.1	105.8	172.3	210.0	139.4	277.8	135.5	92.3
2	261.3	186.3	51.4	109.1	113.6	108.5	226.4	249.6	106.4	198.3	161.6	80.3
3	159.4	99.3	50.6	109.0	146.2	62.6	66.2	209.7	155.3	292.5	145.0	98.8
4	124.6	91.0	140.8	60.5	117.4	56.8	134.5	88.8	79.5	250.3	80.9	120.8
5	117.9	54.1	63.4	139.0	96.9	97.6	185.4	147.8	238.2	183.7	151.8	139.1
6	90.2	79.2	226.3	72.8	59.1	118.9	90.3	302.3	167.4	130.3	163.4	211.5
7	159.1	140.4	172.0	154.9	110.4	116.0	225.1	215.5	206.2	128.5	303.2	128.1
8	188.0	81.1	66.4	120.8	104.2	77.9	79.8	167.8	284.4	110.2	236.6	109.1
9	238.1	102.3	71.6	85.6	117.1	76.4	203.5	127.5	94.1	101.6	177.8	99.2
10	103.9	153.4	97.7	48.1	128.4	76.8	141.2	79.2	100.5	93.3	167.9	92.3
11	117.6	208.0	158.6	133.3	73.3	82.7	198.8	83.3	91.7	262.8	213.3	111.8
12	149.9	96.5	146.8	36.1	153.6	120.6	203.5	231.8	212.6	107.3	250.6	124.3
13	245.1	172.9	70.4	94.9	80.8	86.4	221.6	109.1	219.8	218.8	256.0	113.8
14	223.9	172.1	45.1	50.7	110.2	60.2	219.4	93.6	271.4	160.7	214.6	149.8
15	172.1	150.5	158.8	45.3	108.2	95.5	145.3	175.8	157.2	213.0	270.9	217.5
16	252.9	197.5	146.9	92.8	89.5	103.5	158.9	180.3	194.0	90.8	288.7	101.8
17	149.4	139.6	50.5	109.5	117.5	70.0	125.8	241.3	105.5	100.8	345.5	101.9
18	194.9	63.0	62.4	134.6	119.5	59.1	117.6	197.4	150.6	270.3	192.3	169.0
19	222.7	97.9	49.0	77.2	131.4	16.7	218.8	312.4	93.0	166.9	202.1	185.1
20	197.1	79.3	62.1	75.3	114.4	17.9	218.9	96.6	82.5	195.7	229.0	120.6
21	208.1	192.1	52.5	108.9	124.9	29.7	235.1	245.9	90.6	84.4	243.8	146.4
22	107.4	248.1	167.1	29.6	78.6	37.9	193.7	121.4	138.2	78.4	266.3	111.0
23	136.9	67.0	81.0	63.2	81.7	167.2	217.0	233.4	131.4	80.5	324.8	129.9
24	112.4	54.0	51.6	114.9	90.6	166.8	218.4	72.2	176.4	101.2	191.7	270.1
25	68.2	49.7	56.2	111.2	104.7	79.7	134.2	77.0	211.7	137.0	257.7	136.1
26	121.9	61.0	61.3	56.3	112.2	42.0	221.4	95.4	248.3	177.6	287.7	81.4
27	128.0	147.3	62.0	101.8	135.3	140.7	203.1	218.8	84.9	117.9	239.4	109.1
28	137.3	153.9	42.7	118.1	88.9	145.7	113.6	132.0	121.9	102.0	232.9	160.2
29	57.6	64.6	62.1	58.6	139.0	141.5		78.8	184.5	134.0	173.5	222.6
30	52.0	135.8	62.2	106.8	106.8	191.7		171.9	79.2	321.9	85.1	84.9
31	57.0		164.7		127.0	99.8		205.9		102.5		112.0
SUM	4698.4	3616.6	2816.6	2717.0	3421.5	2849.7	4889.8	5172.5	4616.8	4991.0	6489.6	4130.8

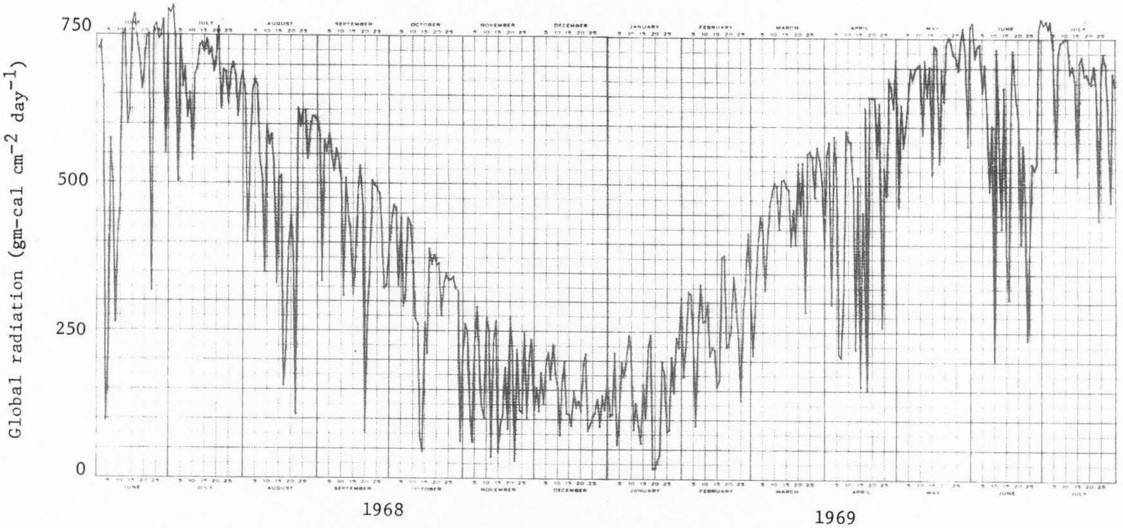


Figure 16. Actual global radiation June 1968 to July 1969 at Utah State University campus, Logan, Utah.

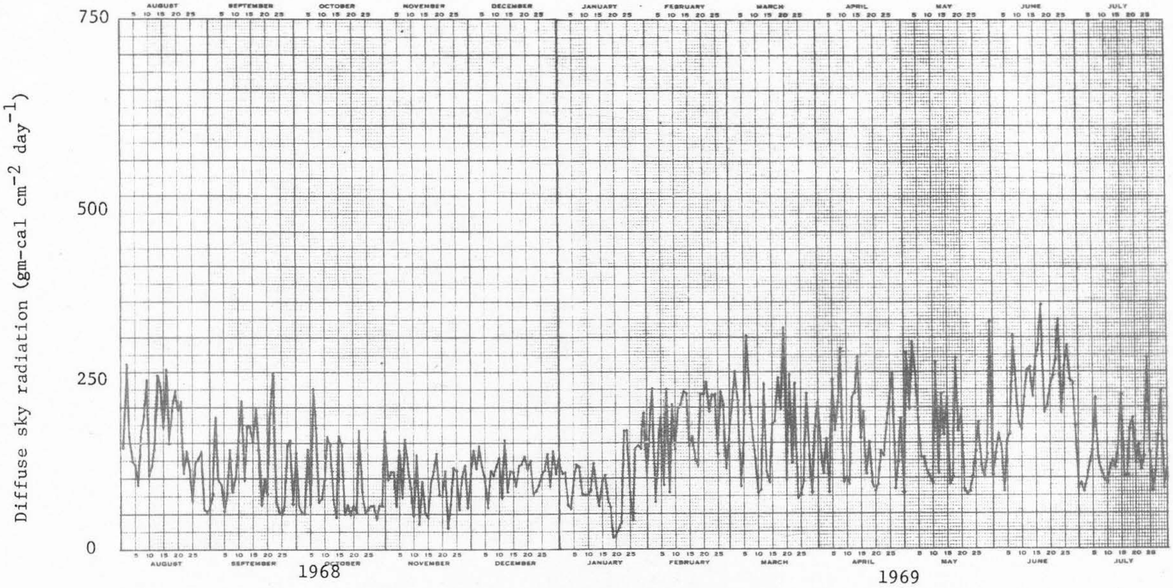


Figure 17. Actual diffuse sky radiation August 1968 to July 1969 at Utah State University campus, Logan, Utah.

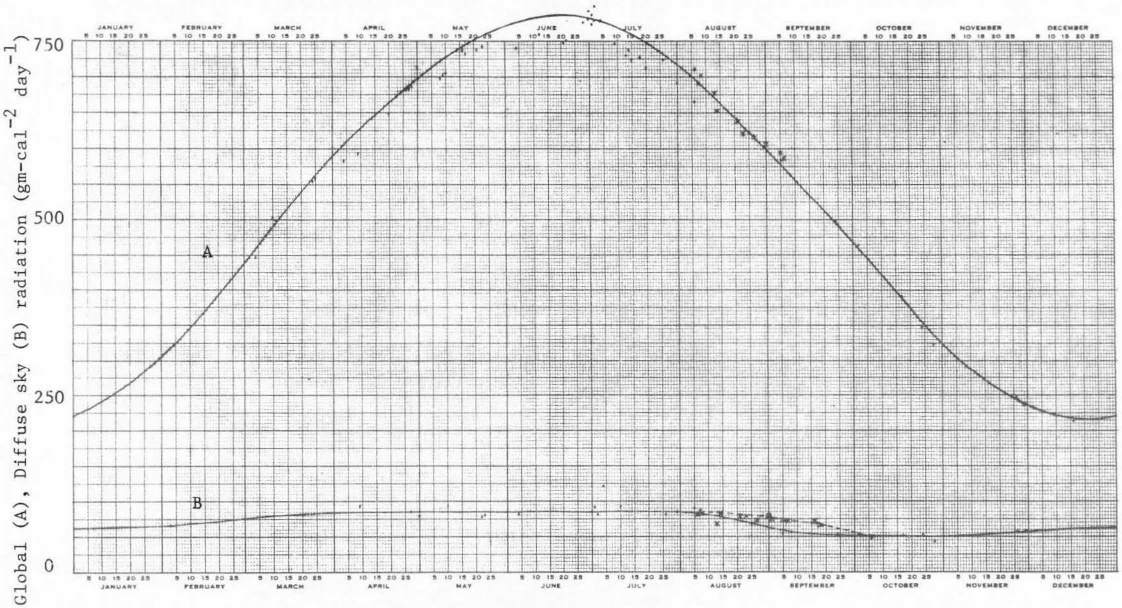


Figure 18. Average daily global (A) and diffuse sky (B) radiation on cloudless days, Utah State University, Logan, Utah.

on cloudless days does not vary much from year to year. The intensity is mainly influenced by astronomical factors, like the variation of the distance between the sun and the earth, solar declination, hour angle, and possibly the solar constant. Some physical factors, such as water vapor content and degree of contamination of the atmosphere and the albedo of the ground surface may also cause some variation from one year to the next. A study by Sauberer and Dirmhirn (1958) in Austria shows that the variation from the average global radiation established in this manner rarely exceeds 4 percent.

Under clear sky conditions, the extinction of the solar radiation due to the atmosphere depends upon the physical processes which affect the various regions of the solar spectrum. These effects are represented by the Rayleigh extinction coefficient (scattering by atmospheric molecules), the extinction coefficient which represents scattering by dusts (aerosols) and extinction coefficient which represents absorption, mainly by water vapor. Robinson (1966) presented a review of the relationships of the various extinction coefficients in empirical equations derived for computing global radiation.

A comparison of the global radiation on approximate dates of the same solar declination (Table 4) shows higher values during the relatively colder months of late winter and spring than during the warmer months of later summer and autumn. These values indicate the influence of the water vapor content of the atmosphere on the global radiation. Water vapor content of the air is a function of air temperature; thus there is a higher content in late summer and autumn. Because water vapor absorbs solar radiation the amount of global radiation is reduced during the period when the water vapor content of the air is highest. An interesting

Table 4. Average global radiation (gm-cal cm^{-2} day^{-1}) on approximate dates during clear days of the same solar declination

Declination	Approximate	Global radiation		Approximate	Global radiation	
(degrees)	date	Direct	Scattered	date	Direct	Scattered
+20	May 21	670	85	Jul 24	655	83
+15	May 1	615	85	Aug 12	596	78
+10	Apr 16	565	85	Aug 28	545	65
+ 5	Apr 3	519	83	Sep 10	499	56
0	Mar 21	463	82	Sep 23	448	52
- 5	Mar 8	402	78	Oct 6	390	50
-10	Feb 23	334	73	Oct 20	323	50
-15	Feb 9	274	68	Nov 3	261	51
-20	Jan 21	206	65	Nov 22	197	55

fact is, that not only the direct, but also the scattered component shows higher values during the spring months. This indicates that there exists still another effect, influencing mainly the diffuse sky radiation. In general we could expect a slightly higher diffuse component together with a reduced solar radiation due to higher water vapor content of the atmosphere. An explanation for the higher diffuse component of the global radiation is the closeness of the mountains and the reflected radiation from the slopes. During the spring months when these mountains are still snow-covered this additional reflection increases the scattered radiation more than during the fall months. Multiple reflection between snow and the atmosphere, however, though present during the months with snow on the ground, should not contribute to the higher global radiation by more than 1.5 percent (Bennett, 1965). This is reflected in Table 5 which shows the average daily value of the global radiation and its components, and the solar and scattered radiation in absolute values and in percent of the global radiation.

Figure 18b shows the annual variation of the diffuse component of global radiation on clear days. In this curve, a number of effects are apparent:

1. The dependance of the diffuse sky radiation on the amount of available solar radiation, which makes the maximum diffuse sky radiation coincide with the maximum solar radiation at mid-June.
2. The apparent strong effect of the snow cover, resulting in direct reflected radiation from the highly reflecting mountain slopes and some more increase by multiple reflection due to the immediate snow-covered environment.

Table 5. Average global, direct, and diffuse sky radiation (gm-cal cm^{-2} day^{-1}) during clear days on the 15th day of each month

Month	Global Radiation (gm-cal cm^{-2} day^{-1})	Direct Solar Radiation		Diffuse Sky Radiation	
		(gm-cal cm^{-2} day^{-1})	% of Global	(gm-cal cm^{-2} day^{-1})	% of Global
Jan	255	192	75.3	63	24.7
Feb	365	295	80.8	70	19.2
Mar	515	434	84.3	81	15.7
Apr	647	562	86.9	85	13.1
May	740	655	88.5	85	11.5
Jun	785	700	89.2	85	10.8
Jul	760	675	88.8	85	11.2
Aug	663	586	88.4	77	11.6
Sep	534	480	89.9	54	10.1
Oct	397	346	87.2	51	12.8
Nov	271	218	80.4	53	19.6
Dec	218	158	72.5	60	27.5
Average	512.5	441.8	86.2	70.8	13.8

3. Superimposed are the effects of the water vapor content of the atmosphere. This effect cannot be seen very clearly as it works in the opposite direction of the reflection, mentioned in 2.
4. A combined water vapor-aerosol effect can be seen in the highly different diffuse component during August of 1968 and 1969. In 1968, fronts passed the area from August 9 to 22, cleaning and cooling the atmosphere. The following clear days the scattering of radiation in the clean atmosphere was low. During 1969, July and August consisted of 16 clear days. Only a few scattered showers occurred, the atmosphere was consequently rich on aerosols, and scattering was higher. The differences amounted to approximately 15 cal $cm^{-2}day^{-1}$. This is about 23 percent of the average scattered radiation.

Global and diffuse sky radiation (cloudy days). Clouds are complex phenomena varying from thin transparent cirrus to thick (varying from a few hundred to several thousand meters) stratus, stratocumulus and dark cumulus (thunderstorm clouds); when present cloud cover may reduce the global radiation considerably for hours or even days. The reductions in the daily amounts of global and diffuse sky radiation are very prominent in Figures 16 and 17. The brightness of towering cumulus may also vary depending upon their position relative to the sun. Under partly cloudy conditions, when the sun is shining through the gaps in the clouds, high solar radiation values are found. The diffuse sky radiation is in general higher in cloudy weather than on clear days. More details on how cloud reflections give rise to high values of solar radiation at high altitude stations are given by Ives (1946) and Dirmhirn (1951).

When the sky is completely cloud-covered over the whole period of a day, climatic features can be deduced from the monthly distribution of global radiation such as the winter storms that give rise to the accumulation of snow on the ground, resulting in higher values of diffuse sky radiation due to multiple reflections between the snow and the bases of the clouds. Long periods of measurements are necessary for a more general interpretation of the effect of clouds on the radiation climate. However, even one year of record can give some indication of the more pronounced features of a particular radiation climate. The monthly variation of the global radiation for overcast days (Figure 19) is pronouncedly different from the expected curve which would have a maximum around June.

The amount of diffuse sky radiation on cloud-covered sky is greatly influenced by the density of clouds and also by the average albedo of large areas of the ground surface.

As previously mentioned, the diffuse sky radiation is in general higher in cloudy weather. Dirmhirn (1951) has shown that the intensity of diffuse sky radiation increases strongly with height in the case of an overcast sky. She also indicates then that the type of clouds present is important, since the bases of the clouds vary from a few hundred meters in the case of low clouds like stratus, stratocululus, and cumulus, to several thousand meters for high clouds like cirrus, cirrostratus, and cirrocumulus.

In a detailed study of the radiation climate of the Eastern Alps in Austria (Dirmhirn, 1951; Sauberer and Dirmhirn, 1958) it was shown that the diffuse sky radiation has a certain dependence on the altitude. However, this dependence is considerably disturbed by multiple reflection and reflection from the mountain slopes. They showed that at elevations of 200 to 3000 meters above sea level, the incoming radiation increases by 21 percent with clear sky and 160 percent with overcast sky, or about 1 and 4 percent, respectively, per 100 meters. The multiple reflection and scattering from clouds provide the main share in the increase of incoming radiation with height.

The albedo of the surface also influences the intensity of diffuse sky radiation. The increase is brought about mainly by multiple reflection between the ground surface and the cloud bases. Since the presence of snow on the ground increases the albedo, a corresponding increase in the scattered radiation also occurs. However, on cloudless days, this effect is not apparent in Figure 18b because of another effect. In spring, there is a greater increase in the diffuse sky radiation mainly due to the additional reflection from the mountain slopes which is still snow-covered. After the snow has melted, the relatively smaller increase in the scattered radiation contributed by reflection from the mountain slopes is complemented by an increase due to the greater water vapor content of the atmosphere. This resulted in about the same amount of diffuse sky radiation until early autumn.

In Figure 19, the increase in the diffuse sky radiation during cloud-covered sky due to multiple reflection effect is very prominent. The values are highest when there was snow on the ground in the valley and in the mountains in late winter and early spring and lowest in autumn when the surface was bare ground.

An analysis of the ten year winter data from five stations in the western United States shows that snow cover apparently produced an increase in the daily insolation of 1.5 percent with clear sky and 29.0 percent with overcast sky (Bennett, 1965).

On clear days, the distribution of the global and diffuse sky radiation in Figures 18a and 18b can be taken as climatic averages since it will not vary much from year to year. In this locality where the atmosphere is relatively clean and the effect of dust small, any variation of the transmission coefficients may be primarily due to a variation in the atmospheric water vapor as previously illustrated.

Under sky conditions not completely cloudless, the distribution of the global and diffuse sky radiation is very difficult to describe. However, we can say that the amount of global radiation received on a horizontal surface during a day is an indication of the degree of cloudiness whose variability is largely responsible for the observed diffuse sky radiation.

Short term global and diffuse sky radiation at various locations

The solar radiation received on the earth's surface on short distances in a mountain valley can vary considerably because of differences in the natural horizon and changes in the condition of the ground surface and the atmosphere brought about by the seasons.

Figures 20 to 26 show the hourly march of global radiation on a cloudless day on March 24, 1969 when there was snow on the ground at the seven points selected in the valley. The direction of the arrows indicate an increase (↑) or decrease (↓) as the case may be in the amount received compared to the reference point at the university campus. The hourly march of global radiation after all the snow in the valley and mountains melted is shown in Figures 27 to 33.

The decrease of the global radiation at solar noon and throughout the day in percent at seven locations are listed in Table 6. There was

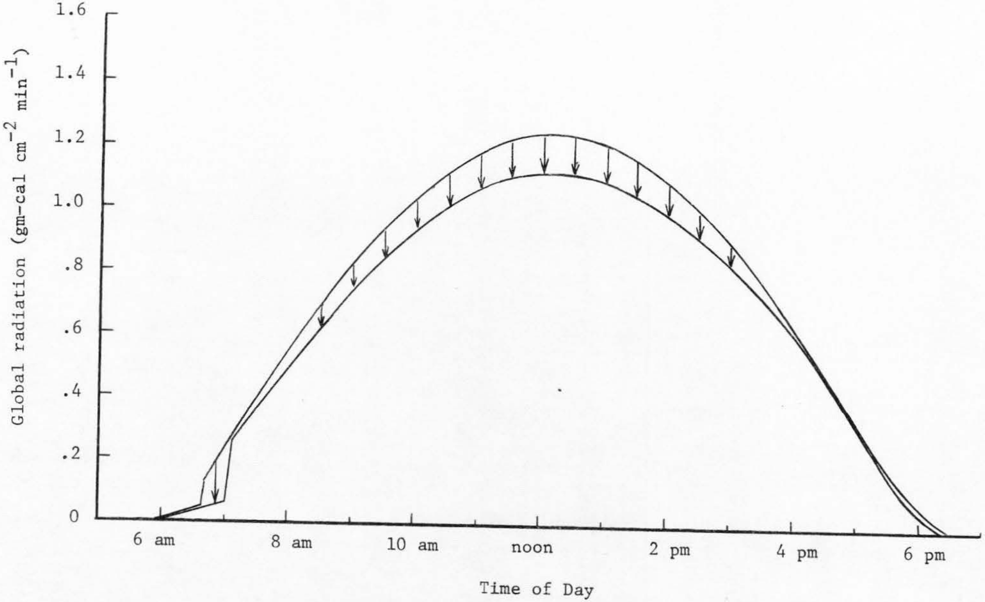


Figure 20. Global radiation at Point 1, arrows indicating decrease from reference point. Snow on the ground, March 24, 1969.

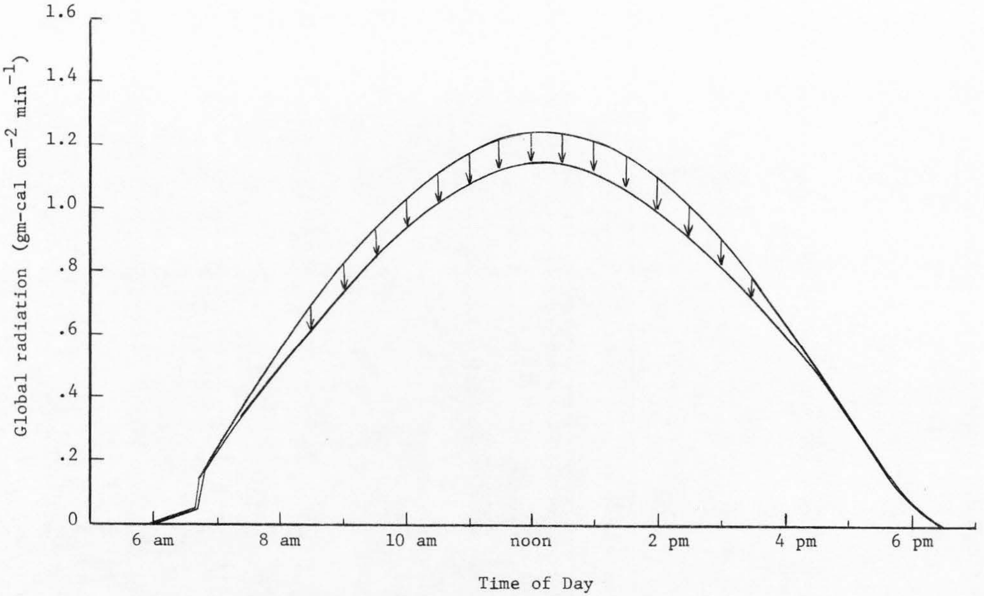


Figure 21. Global radiation at Point 2, arrows indicating decrease from reference point. Snow on the ground, March 24, 1969.

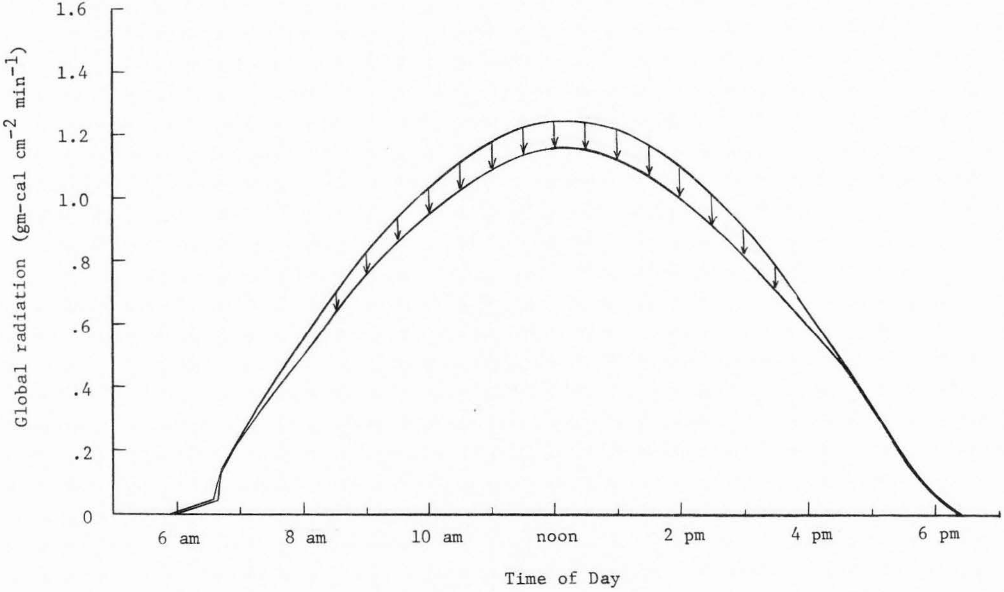


Figure 22. Global radiation at Point 3, arrows indicating decrease from reference point. Snow on the ground, March 24, 1969.

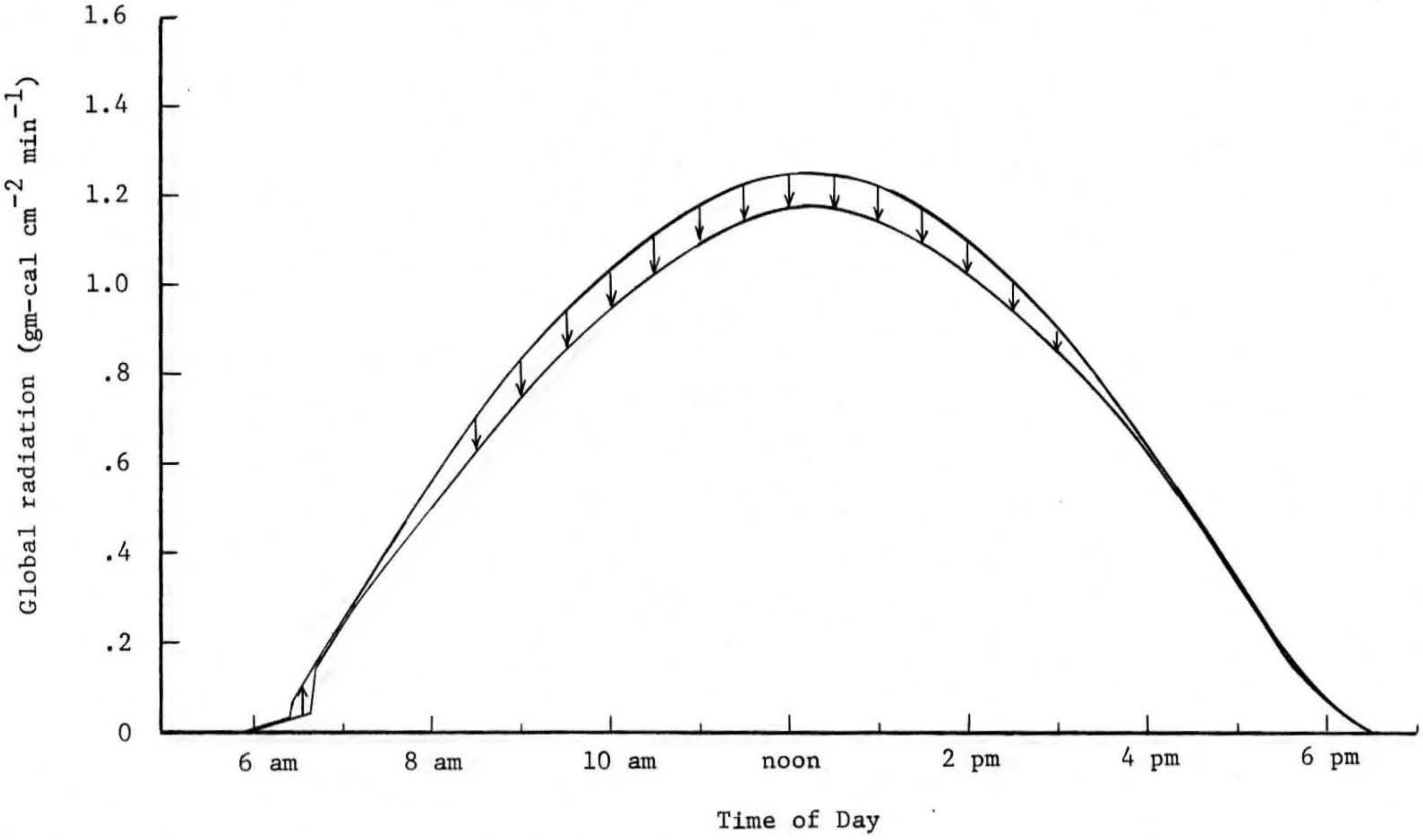


Figure 23. Global radiation at Point 4, arrows indicating increase or decrease from reference point. Snow on the ground, March 24, 1969.

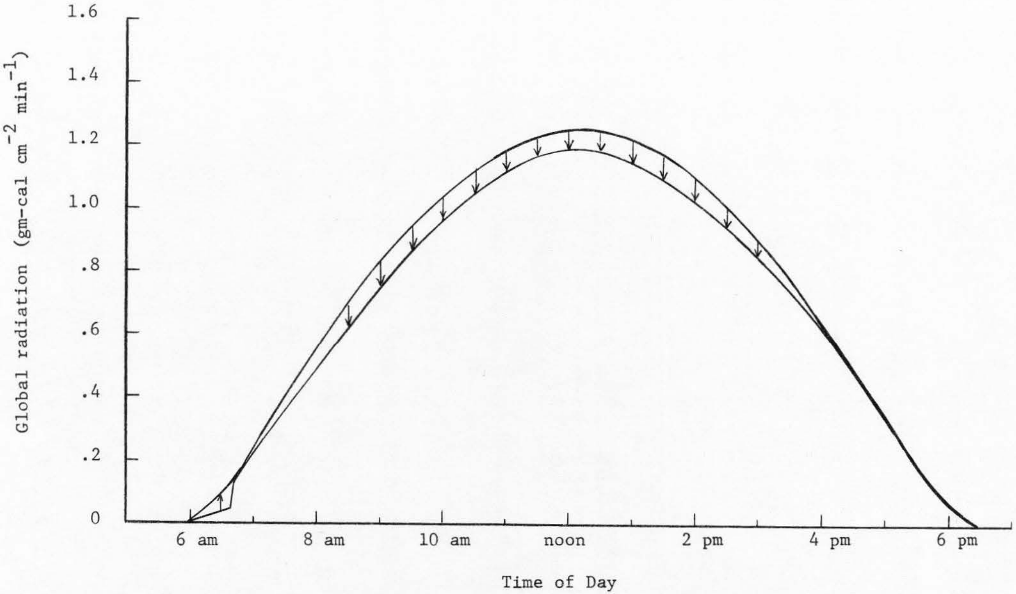


Figure 24. Global radiation at Point 5, arrows indicating increase or decrease from reference point. Snow on the ground, March 24, 1969.

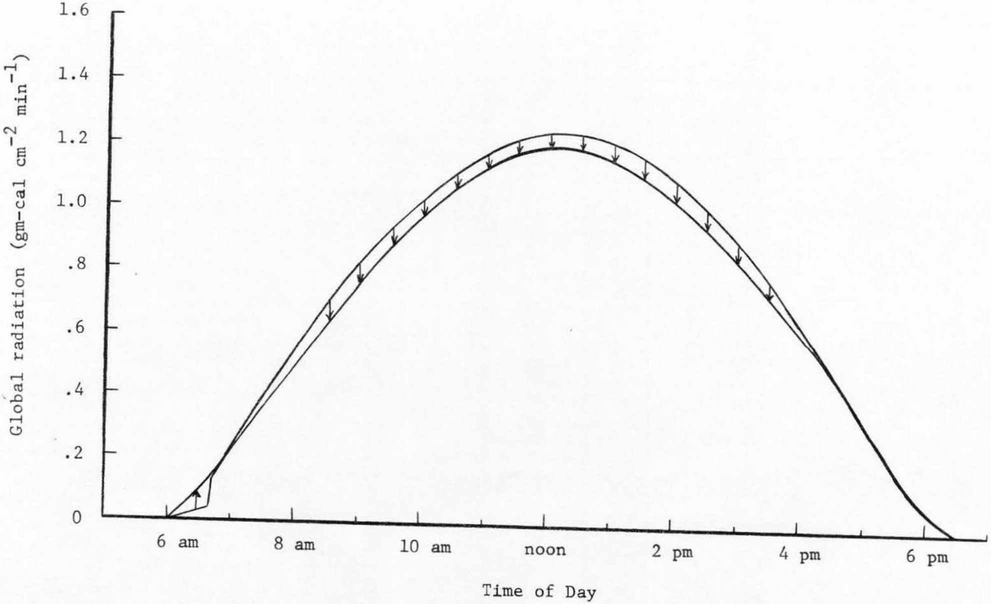


Figure 25. Global radiation at Point 6, arrows indicating increase or decrease from reference point. Snow on the ground, March 24, 1969.

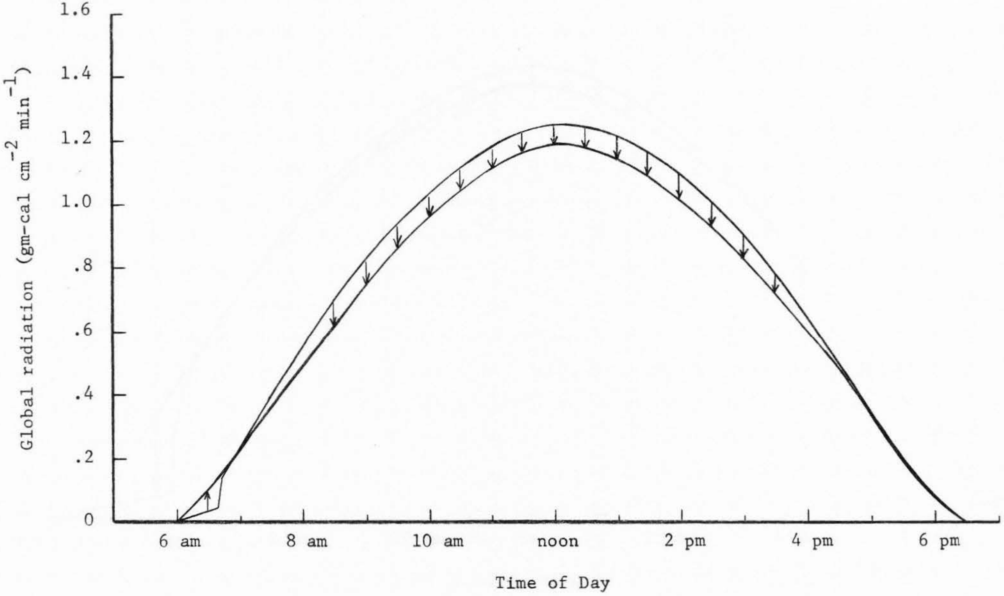


Figure 26. Global radiation at Point 7, arrows indicating increase or decrease from reference point. Snow on the ground, March 24, 1969.

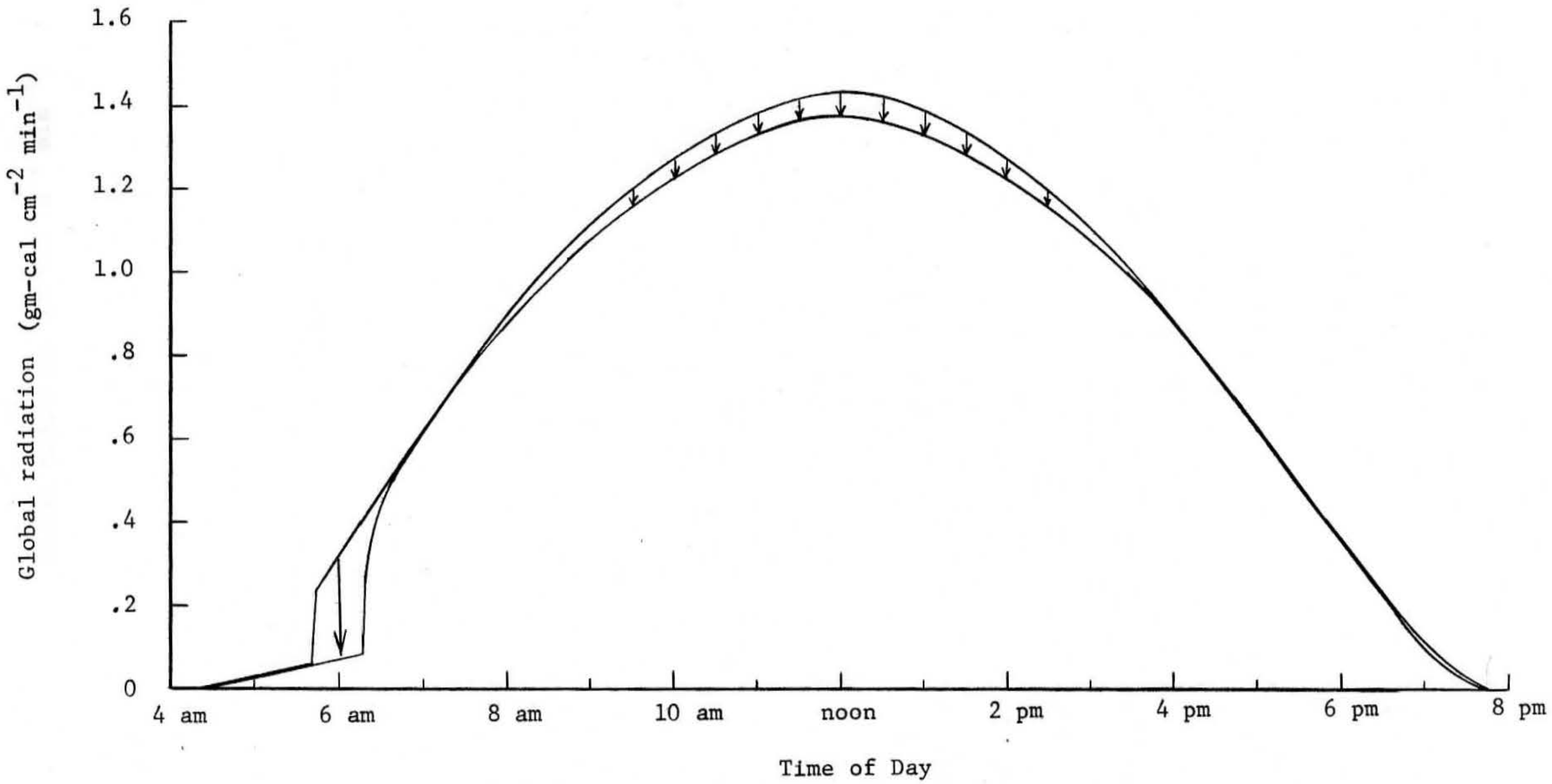


Figure 27. Global radiation at Point 1, arrows indicating decrease from reference point. No snow on the ground, June 30, 1969.

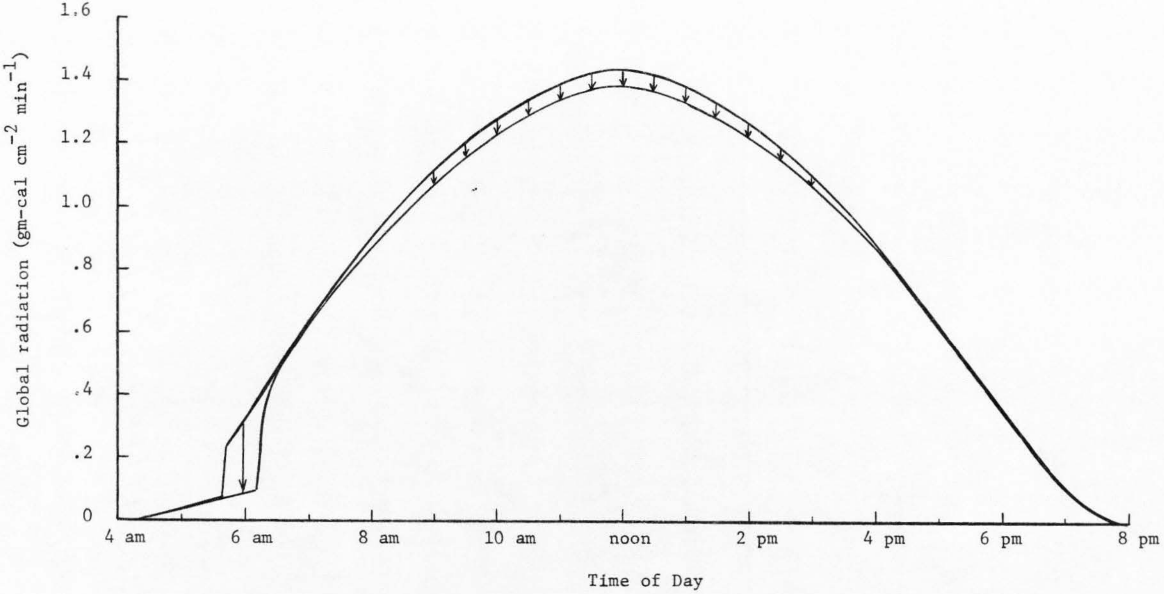


Figure 28. Global radiation at Point 2, arrows indicating decrease from reference point. No snow on the ground, June 30, 1969.

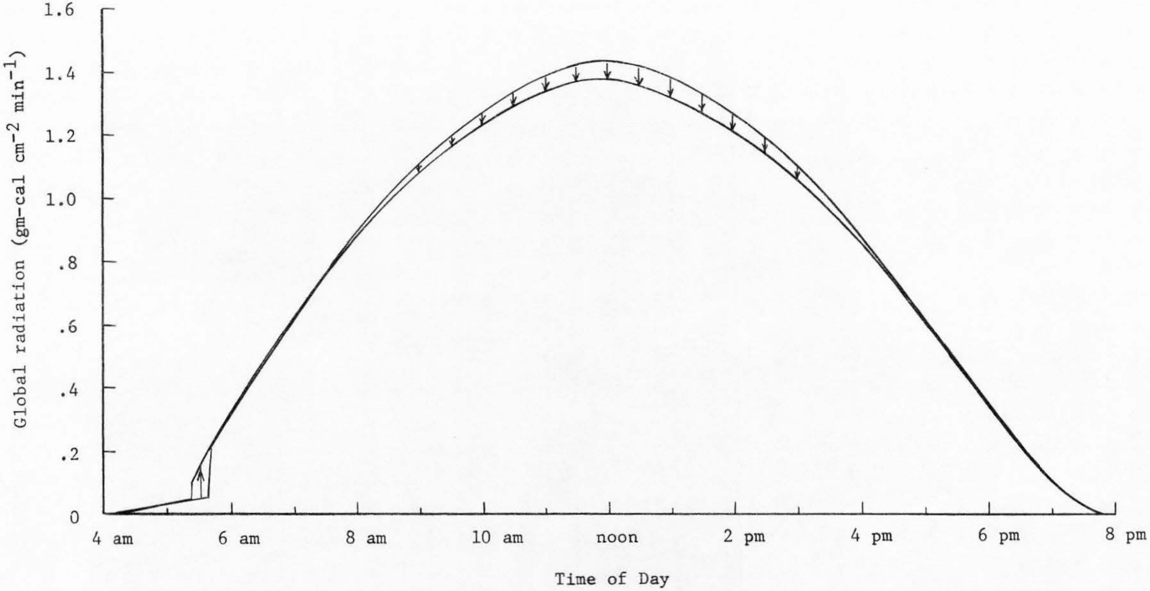


Figure 29. Global radiation at Point 3, arrows indicating increase or decrease from reference point. No snow on the ground, June 30, 1969.

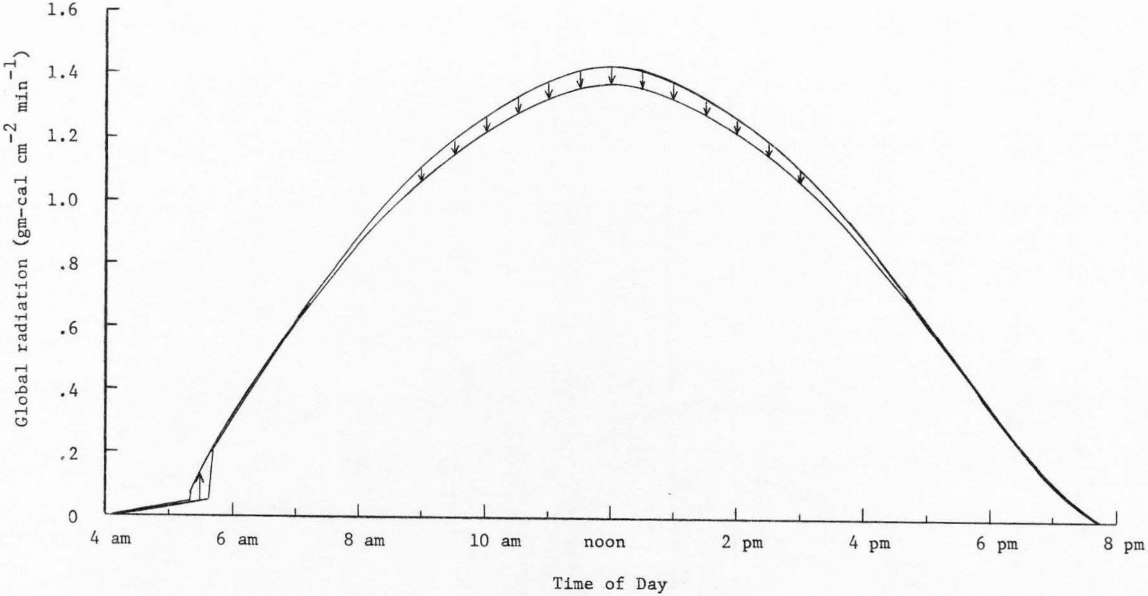


Figure 30. Global radiation at Point 4, arrows indicating increase or decrease from reference point. No snow on the ground, June 30, 1969.

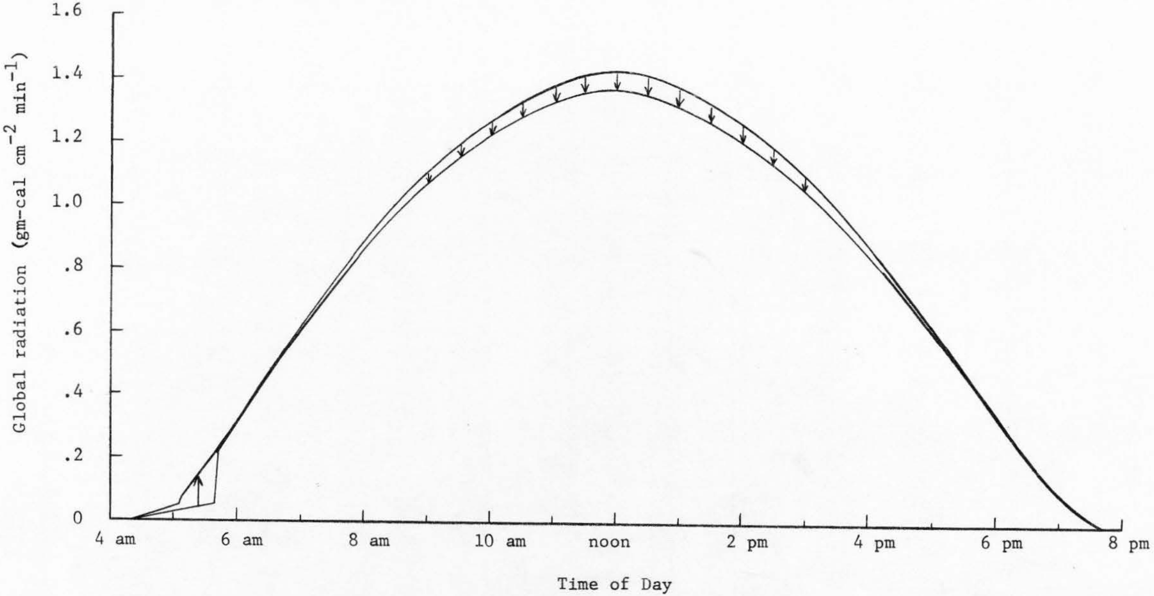


Figure 31. Global radiation at Point 5, arrows indicating increase or decrease from reference point. No snow on the ground, June 30, 1969.

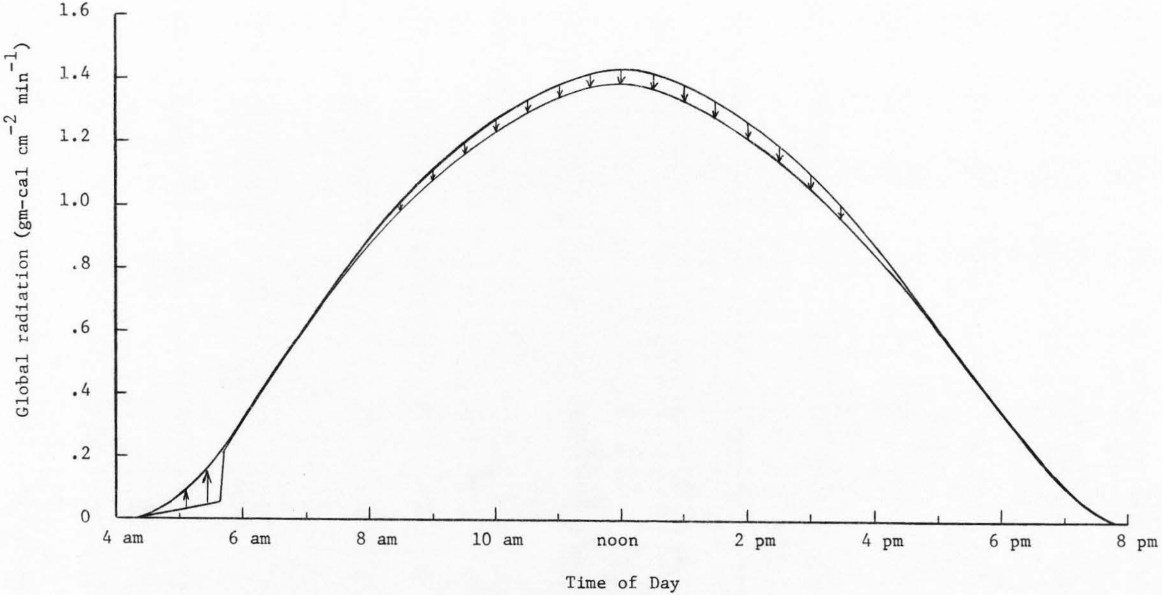


Figure 32. Global radiation at Point 6, arrows indicating increase or decrease from reference point. No snow on the ground, June 30, 1969.

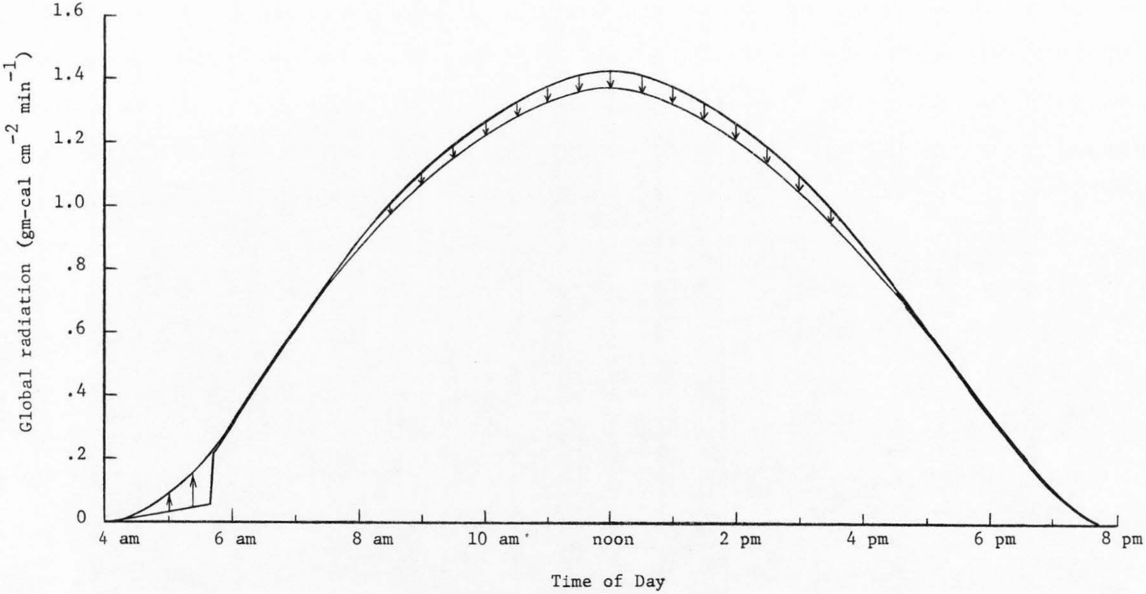


Figure 33. Global radiation at Point 7, arrows indicating increase or decrease from reference point. No snow on the ground, June 30, 1969.

Table 6. Decrease of global radiation (percent) received at the seven points in the valley compared to the amount received at the reference point during summer and winter

Points in the Valley	Snow on the ground March 24, 1969		No snow on the ground June 30, 1969	
	Noon	SR/SS[a]	Noon	SR/SS[a]
	%	%	%	%
1	10.7	9.5	4.2	4.6
2	9.2	8.6	3.5	4.6
3	6.5	7.7	3.5	3.0
4	5.5	6.6	3.5	3.0
5	4.5	6.6	3.5	3.0
6	3.5	5.2	2.5	2.6
7	4.5	5.5	3.5	3.0
Average	6.35	7.10	3.46	3.40

[a] SR/SS = Sunrise to Sunset

a decrease of 10.7 and 9.5 percent at solar noon and throughout the day, respectively, at Point 1 during winter and, likewise, a decrease of 4.2 and 4.6 percent at solar noon and throughout the day, respectively, during summer. The lowest decrease was at Point 6 which was 3.5 percent at solar noon and 5.2 percent throughout the day during winter and 2.5 percent at solar noon and 2.6 percent throughout the day during summer. The average decrease in all the locations are 6.4 percent at solar noon and 7.1 percent throughout the day with snow-covered ground with 3.5 and 3.4 percent at solar noon and throughout the day, respectively, after the snow melted.

The decrease in the intensity of the global radiation at the seven sites compared to the reference point may be due to the following factors: the natural horizon at Point 1 reduces the celestial dome by about 28 percent compared to only 8 percent at the reference point. There is not only a reduction of the direct component due to a later sunrise but also a reduction of the diffuse component due to the reduced sky. This seems to be the case also at Point 2 which is only a few hundred meters from Point 1 although higher in elevation by about 25 meters. During summer, the decrease is almost uniform except at Points 1 and 6. These may seem to indicate that the influence of the horizon becomes less significant other than at Point 1. At Point 6 which has the lowest elevation, reflections from the immediate environment and the mountains are greatest compared to the rest of the sites. This apparently accounts for the smaller difference.

The effect of terrain reflection would be to increase the diffuse radiation since the reflected radiation is in turn scattered by the atmospheric constituents and a fraction of this arrives at the surface again. It is likely that the effect of terrain reflection would not vary much from point to point except probably at Points 1 and 2 where the reduction due to a smaller sky counteracts the increase by terrain reflections. This would seem to indicate then, that in this study, at Points 3 to 7, the elevation would account for the greater portion of the difference. However, during winter, the non-uniform decrease at the seven points compared to the reference point may be partly due to the influence of the greater contamination of the atmosphere immediately above the residential area.

Another factor that may influence the intensity of global radiation at the various locations in the valley compared to the reference point is the fact that during the winter, radiation fog may be present in the valley and near the mountains early in the morning but not over the residential areas including the university campus. After the fog disappears there would be a higher water vapor content in the atmosphere over the valley compared to the reference point. Water vapor scattering may increase the diffuse component but reduces the direct component.

Figure 34 shows the ratio of short period (5- to 10-minute) diffuse sky radiation at the seven points to the values at the reference point on a completely cloudy day, June 24, 1969, as previously stated, the height of the bases and thickness of the clouds vary considerably and no definite conclusions or relations could be established with just a few observations. When this measurement was made it was observed that while the clouds close to Logan Canyon were very thick and dense, this was not so on the opposite side of the valley to the west. This is very evident in Figure 34 at Points 5, 6, and 7.

Under cloudy conditions in the valley, the radiation climate is

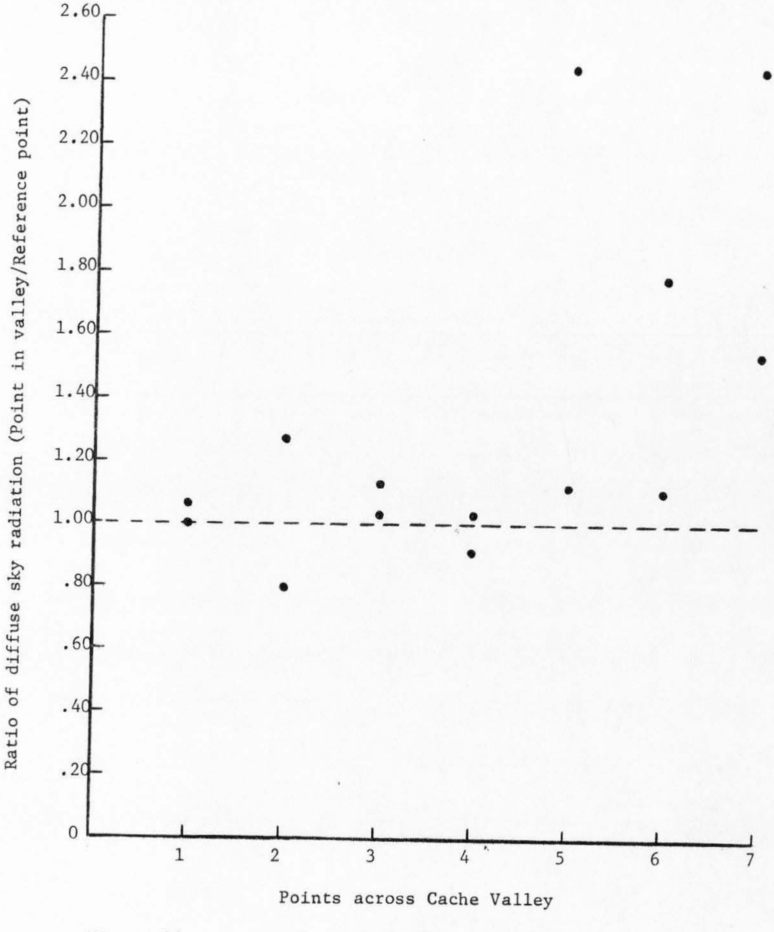


Figure 34. Two sample periods (5- to 10-minutes) of the ratio between diffuse sky radiation measured across the valley and the reference point on a completely cloudy day, June 24, 1969.

difficult to describe. The diffuse sky radiation is influenced not only by the density of clouds and albedo of the ground surface but also the elevation and location of the station with respect to the mountain range, especially to the east and west.

SUMMARY AND CONCLUSIONS

The radiation climate of Cache Valley was established from the continuous recordings of global and diffuse sky radiation at Utah State University campus from June 1968 to July 1969, and August 1968 to July 1969, respectively; and the short term measurements at seven points in the valley on an east-west direction on cloudless days on March 24 and June 30, 1969, and on a completely cloudy (overcast) day on June 24, 1969. A Moll-Gorczynski and an Eppley pyranometer were used in the continuous measurements. A shadow band was used to shield the Eppley pyranometer from the direct solar radiation; thus, the pyranometer detected only diffuse sky radiation. A Star pyranometer was used in the short term measurements. All the pyranometers were calibrated regularly with the use of the Angstrom compensation pyrheliometer. The daily global and the diffuse sky radiation were corrected based on the calibration of the Moll-Gorczynski solarimeter and on the comparisons between the short-period output of the Moll-Gorczynski solarimeter and the Eppley pyranometer with and without the shadow band for the same period, respectively.

A comparison of the clear day average global radiation on approximate dates of the same solar declination shows higher values during spring than the values during autumn. This is due to the higher atmospheric water vapor during the warmer months. An interesting fact is that the scattered radiation is also higher during the spring months. This is caused by the reflections from the snow-covered mountain slopes. During cloudy weather (overcast) condition, the higher values of global radiation in March and April were due to the multiple reflection between the snow and the bases of the clouds.

The influence of the topographic features during summer and winter were determined from the short term measurements on clear days at the seven locations across the valley. An average variation (decrease) of about 7 percent during winter and 3 percent during summer was experienced across the valley compared to the reference point where the continuous measurements were made. The global radiation on a completely cloudy day during summer was found to vary at the points on the opposite side of the valley to the west by as much as 144 percent.

The decrease in the intensity of solar radiation at Point 1 is due to the reduction of the celestial dome by about 28 percent which resulted in a depletion of the direct solar radiation due to a later sunrise and in the diffuse sky radiation due to a smaller sky. At Point 2, the decrease is due to the combined effect of lower elevation and greater obstruction of the natural horizon compared to the reference point. The decrease at Points 3 to 7 is mainly due to the influence of elevation during summer and to a small degree by the greater pollution of the air over the residential area and the prevalence of radiation fog over the valley and the mountains during winter. Under overcast conditions, the variation is mainly due to the difference in the density of the clouds on the opposite side of the valley on an east-west direction. When this measurement was made it was observed that while the clouds close to Logan Canyon were thick and dense, it was not so on the opposite side of the valley.

Recommendations

1. The continuous measurements of global and diffuse sky radiation should be carried on indefinitely for a number of years at the university campus to determine radiation climate and as a record of radiation conditions. While a general discription of the radiation climate can be made from these data based on a year's records, more valid information will be obtained from a longer period of observations. The global and diffuse sky radiation on clear days are not expected to vary much from year to year. However, the global radiation on overcast days are greatly influenced by the presence or absence of snow on the ground which vary from year to year and the thickness of clouds. Therefore, a longer period of observation is needed for a better picture of the global radiation on overcast days.
2. A sunshine duration recorder should be added to the measurements being made at the university campus. This instrument does not give information as to the type and amount of clouds that prevailed on a particular day, but a high degree of relationship between the global radiation and the duration of sunshine may be obtained after a few (5 to 10) years of observations since the amount of global radiation received on a horizontal surface during a day is an indication of the degree of cloudiness whose variability is largely responsible for the observed diffuse sky radiation.
3. Continuous measurements of global radiation in at least two other locations, one at the middle and the other at the opposite

side of the valley near Point 7, is recommended. The short term measurements made in this study on clear days during summer and winter conditions provide only a first information on the effect of topography on global radiation at the seven selected points. However, it was observed that, on certain days during the colder months in winter, there was fog in the valley early in the morning and sometimes throughout the day but none at all at the university campus. Under these conditions it is almost impossible to estimate the amount of global radiation at the various locations in the valley without continuous measurements. This indicates a characteristically different radiative environment with regard to the campus station.

4. The above recordings can also be used for an extensive study in order to get more information on the contribution of the shortwave radiation under cloudy sky conditions. The magnitudes of the components of global radiation are functions not only of cloud type and cloud amount but also of cloud distribution in the sky. Additional measurements have to be made throughout the valley both on an east-west and north-south direction. The result of the short term measurements of global radiation on an overcast day in this study indicates that the diffuse sky radiation on a completely cloudy day varies by as much as 144 percent from the reference point, even in a distance of only about 5 miles.

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