COMPUTATION AND INTERPRETATION OF INSOLATION TABLES FOR THE SURFACE OF MARS

by

William A. Schlosser, Raymond T. Greer and Vladimir Vand
Materials Research Laboratory and Department of Geochemistry and Mineralogy, The Pennsylvania State University, University Park, Pa.

Paper presented at the
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Washington, D. C.

April 10, 1968

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ABSTRACT

Computation of the Insolation Tables for the amount of sunlight received per square centimeter at any position of the planet's surface and at any time of orbit for the planet Mars has been programmed for the IBM 7074 computer. The values represent an extension and modification of previous work on insolation curves which had been compiled before the Mariner IV results concerning the atmosphere of Mars were known. These new computed values have been applied to predict extra-terrestrial atmosphere circulation patterns since the seasonal storage of insolation is small on Mars, and as a consequence the latitudinal gradient of ground temperature and the differential heating of the air should both vary seasonally on Mars in the same way as the effective insolation.

Profiles and contour plots of computed insolation values taken from the Tables compare favorably with changes in color patterns observed during the Martian year, suggesting that many of the striking Martian features depend on clearance and deposition of yellow dust which is influenced by the diurnal pattern of winds on Mars. The effect of a mountain range anchoring a zone of anticyclones which would contribute to the shape of the maria is indicated for the region 30° south latitude

and 130° west longitude; the suspected anticyclones increase with size starting with small ones at Phaethontis, and increasing in size in the order of: Electris, Eridania, Ausonia, Hellas, Naochis, Argyre I, and Ogygis Regio.

SUMMARY

Computation of the Insolation Tables for the amount of sunlight received per square centimeter at any position on the planet's surface and at any time of orbit for the planet Mars, have been programmed for the IBM 7074 computer. The Tables represent an extension of Mintz's work on insolation curves[1] and their application to extraterrestrial weather calculations. Because of the interest in predicting not only the seasonal but the daily patterns on Mars, the Tables give values for application to specific theories and models.

METHODS

For purposes of versatility and rapid computation, an IBM 7074 computer was utilized for the calculations of the following:

A. The radial distance of Mars from the sun,

B. The inclination of the axis of the planet to the plane of its orbit, and

C. The heat received by any specific square centimeter of the planet's surface.

To calculate the amount of heat energy received on the surface of Mars for any particular time of the day and of the year, it is necessary to evaluate both the radial distance, R, and the angle, L_s, that the planet makes as it travels in its orbit around the sun. The angle, θ, which is a constant for any given year, must also be determined. A diagram of these parameters is shown in Figure 1.

A. Radial Distance of Mars from the Sun

The relationship between the angle, E, described by the planet as it moves along its orbital path and the time of the year, is given by Kepler's equation,

$$E - e \sin E = \frac{2\pi}{P}(T) \tag{1}$$

where E is the eccentric anomaly,

P is the time required for a full orbital revolution of the planet,

T is the number of days since perihelion,

and e is the eccentricity of the planet's orbit.

The mean anomaly, M, equals the right hand side of equation (1) or $M = \frac{2\pi T}{P}$

where P is the complete period (687 days) of the Martian orbit around the sun,

and T is any particular time of the year.

Therefore, given M, an equation is required to express E in terms of M. Once the value of E is determined (for any time of the year, T), the radius vector from the planet to the sun and the angle L_s follow from the equation of the ellipse. Knowing L_s yields the inclination of the planet's axis to the orbit.

The calculation of E(M) proceeds as follows:

$$M = E - e \sin E$$

$$\sin E = E - \frac{E^3}{3!} + \frac{E^5}{5!} - \dots .$$

therefore

$$M = E - eE + \frac{eE^3}{3!} - \frac{eE^5}{5!} \tag{2}$$

Now E(M) may be of the form

$$E(M) = aM + bM^3 + cM^5 \ldots. \tag{3}$$

where a, b, and c are constants to be determined.

Substituting Eq. (3) into Eq. (2), and neglecting higher order terms yields:

$$M = (1-e)(aM + bM^3 + cM^5) + \frac{e}{3!}(a^3M^3 + 3a^2bM^5) - \frac{e}{5!}a^5M^5$$

and equating like powers of M to determine the constants a, c, and c gives the following:

$$a = \frac{1}{1-e} \tag{3a}$$

$$b = -\frac{e}{3!(1-e)^4} \tag{3b}$$

$$c = \frac{9e^2+e}{5!(1-e)^7} \tag{3c}$$

This alters Eq. (3) to the following:

$$E(M) = \frac{M}{1-e} - \frac{eM^3}{3!(1-e)^4} + \frac{(9e^2 + e)M^5}{5!(1-e)^7} \tag{4}$$

At this point, using the binomial expansion for $\frac{1}{(1-e)^n}$ yields:

$$E(M) = (1 + e + e^2 + e^3)M - \frac{e}{3!}(1 + 4e + 10e^2 + 20e^3)M^3$$

$$+ \frac{e}{5!}(1 + 16e + 91e^2)M^5 \tag{5}$$

Rearranging the terms of Eq. (5) in terms of series of sine of multiple angles, we obtain a Fourier series expansion:

$$E(M) = M + e \sin M + \frac{1}{2} e^2 \sin 2M + \ldots \tag{6}$$

and since $e \ll 1$, all of the higher terms can be neglected.

Referring to Figure 1, the radius, R is described by the equation[2]:

$$R = a(1 - e \cos E) \tag{6a}$$

where a is the distance in A.U. from the sun to the vertex of the orbit.

Substituting Eq. (6) into Eq. (6a) completes the derivation yielding the radial distance of the planet from the sun at any given time of the year.

B. Inclination of the Axis of the Planet to the Plane of its Orbit

Having determined E as a function of M, it is possible to define a new angle, γ (see Figure 1), as a function of E. From the equation of the ellipse[2],

$$\tan\left(\frac{\gamma}{2}\right) = \sqrt{\frac{1+e}{1-e}}\ \tan\left(\frac{E}{2}\right)$$

or,

$$\gamma = 2 \text{ arc } \tan\left[\sqrt{\frac{1+e}{1-e}}\ \tan\left(\frac{E}{2}\right)\right] \tag{7}$$

The angle, L_s, can be found from the geometry of the ellipse. By inspection:

$$L_s = \gamma - 113.44° \tag{8}$$

The angle of inclination of the planet's axis to its orbit, D_s, is given by the following relationship:

$$D_s = \sin(L_s) \tag{9}$$

Eq. (9) was obtained by inspecting tables[3] of D_s and L_s. In Eq. (8), 113.44° is the optimized value obtained by running a computer program that calculates the radius vector. This calculated value was compared to the radius vector in the Ephemeris and the value of θ was varied slightly to obtain minimum error. Everything else was constant.

By substituting Eq. (6), (7), and (8) into Eq. (9), the angle of the planet's axis to its orbit, D_s, may be calculated as a function of the time of the Martian year.

C. Heat Received by a Square Centimeter of the Planet's Surface

The amount of heat received from the sun by a square centimeter of the planet's surface, at normal incidence to the sun's rays, will be proportional to the inverse square of the radial distance of the planet to the sun. That is:

$$S = \frac{K}{R^2} \tag{10}$$

where K is a constant,

S is the amount of heat incident on the square centimeter,

and R is the radial distance of the planet to the sun.

The value of the solar constant, S, is 2.00 small cal. per min. on one sq. cm., and represents the amount of the sun's energy received on a square centimeter of a black body surface incident to the sun's rays and located at a distance of 1.0 A.U. away from the sun.

From Eq. (10),

$$K = SR^2 = 2880.0 \frac{\text{cal. A.U.}^2}{\text{day cm}^2}$$

The greatest amount of energy received by the planet, $S_{(max)}$, will occur when the planet is in its perihelion. Since the time, T, is zero at the perihelion, the eccentric anomaly must also be zero from Eq. (6). Eq. (6a) now reduces to the form:

$$R = a(1 - e) = 1.521\ (1.0 - 0.0934) = 1.3789\ \text{A.U.}$$

therefore

$$S_{(max)} = 1514.6 \frac{cal.}{cm^2 \; day}$$

Since Mars is not a black body, it will not absorb all of the sun's energy; the value of the albedo of Mars used here is $A = 0.26$. Therefore the effective insolation on the surface of Mars (perpendicular to sunlight) is

$$S(1 - A)_{(max)} = 1120.8 \frac{cal.}{cm^2 \; day}$$

at perihelion.

Because the planet is assumed to be spherical, a general point at the surface will not have normal incidence of the incoming rays of the sun. From consideration of Figure 2 and the rules of spherical geometry, this fact can be accommodated. The actual computer program does not calculate R; it calculates R^2/a^2 where "a" is the distance in A.U. from the sun (at the focal point of the Martian orbit) to the vertex of the Martian orbit. To take this into account, $S(1 - A)_{(max)}$ is changed to W in the computer program, where

$$W = \left(\frac{R^2}{a^2}\right) S \; (1 - A)_{(max)} = 928 \frac{cal.}{cm^2 \; day}$$

The amount of energy received by a square centimeter of surface, as it makes a revolution about its axis, will be given by

$$S(1 - A) = W\left(\frac{a^2}{R^2}\right) [\cos(D_s + 90°) \cos (90° - \text{latitude})$$

$$+ \sin(D_s + 90°) \sin (90° - \text{latitude}) \cos(2\pi t)] \qquad (11)$$

RESULTS

The values of the amount of heat energy received on the surface of Mars for any particular Martian time of the day and time of the year are listed in Table 1. January 1^{st} was taken as the day that the winter solstice occurs in the southern hemisphere. This is the time that the inclination of the planet is most negative. Knowing this fact, the mean anomaly can be calculated and from this the time of the year (T) can be found. For these calculations, the winter solstice occurs 38 days past the perihelion. Also, the length of the Martian day is taken as being 24 Martian hours, thus the calculations are started at midnight or at a point on the Martian sphere directly opposite the noontime sun. Arbitrarily, the names of 12 equal Martian months are taken from the names of analogous earth months, and are considered in terms of four seasons.

Figure 3a shows the daily noon, mean, and midnight effective insolation on Mars, [S(1-A)], at the time of the northern hemisphere winter solstice ("January 1^{st}"), when A = 0.26. From the northern hemisphere pole to 65° latitude there is no insolation; from this latitude the mean daily insolation rises to its maximum at the pole of the southern hemisphere. The noontime insolation has its maximum at 25° latitude of the southern hemisphere. From -65° latitude to the pole of the southern hemisphere there is some insolation at midnight. These variations can be followed in Figures 3b - 3ℓ as the seasons change. The values used in constructing Figures 3-5 were taken from Table 1.

Figures 4 and 5 permit a comparison of the daily and noon effective insolation patterns with the propagation and extent of darkening phenomenon[4-6] observed on the Martian surface. In general, the surface temperature of Mars will follow the effective insolation [S(1-A)] both seasonally and diurnally since most of the energy is absorbed by the ground and the seasonal storage of insolation is small.

Latitude and longitude measures of many points during the last 50 years show no appreciable change of position of the "coastlines" and other prominent markings on the planet. The only variations are in the intensity of coloring. Overall, there is strong meteorological evidence that the dark markings are primary and light markings are secondary.[7,8] The light and dark prominent features form bands. The most prominent dark band is located just south of the equator between about 0° and -30° latitude. The northern hemisphere is light between 0° and 60° latitude, and the southern hemisphere between -30° and -60° latitude. Both polar areas above ±60° latitude are dark again, except for brilliantly white polar caps which change in extent and disappear according to season.

The general circulation is made up of the mean conditions over a long period. On Mars, wind is considered an important, effective agent of transportation and surface modification. The insolation plots for latitude and heliocentric longitude indicate remarkable agreement with the expected general trends of Martian darkening phenomenon that could be associated with the planetary circulation pattern.

Acknowledgments

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FIGURE CAPTIONS

Figure 1. Schematic Orbit of Mars Around the Sun.

Figure 2. Geometric Representation of Angular Relationships for a cm^2 Area on the Martian Surface.

Figure 3. Profiles of the Effective Insolation Received During Each of 12 Equal Martian Months Identified by the Names of Analogous Earth Months.

(a) Insolation Received on January 1^{st}

(b) Insolation Received on February 1^{st}

(c) Insolation Received on March 1^{st}

(d) Insolation Received on April 1^{st}

(e) Insolation Received on May 1^{st}

(f) Insolation Received on June 1^{st}

(g) Insolation Received on July 1^{st}

(h) Insolation Received on August 1^{st}

(i) Insolation Received on September 1^{st}

(j) Insolation Received on October 1^{st}

(k) Insolation Received on November 1^{st}

(ℓ) Insolation Received on December 1^{st}

Figure 4. Daily Average Insolation Values Plotted to Indicate Trends which may be Responsible for Generating the General Planetary Circulation Pattern.

(a) Composite of the Daily Average Insolation Profiles for the 12 Martian Months.

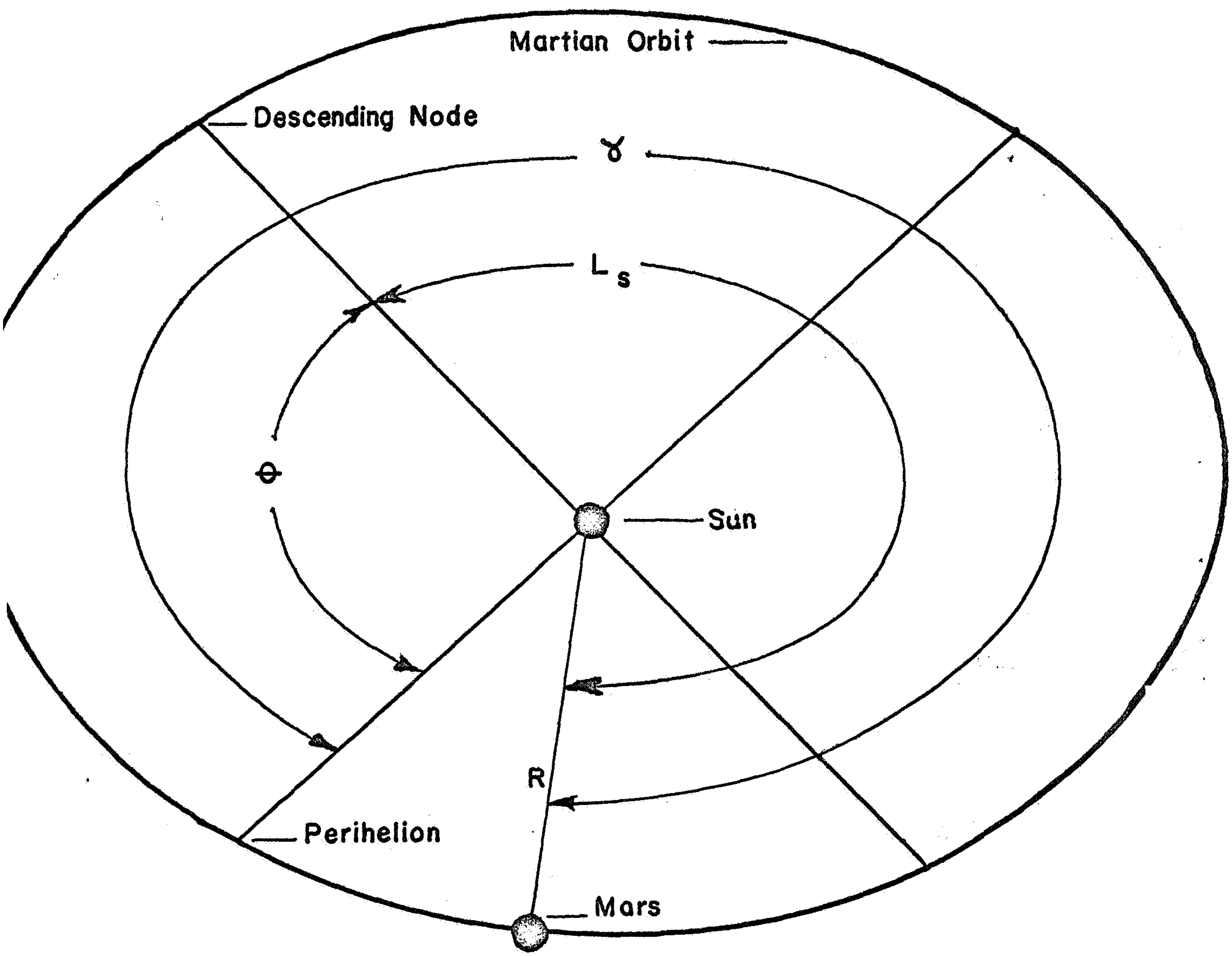
(b) Contour Plot Utilizing the Same Insolation Values for -90° to +90° Latitude vs. the 12 Martian Months.

Figure 5. Noon Insolation Values

(a) Composite of the Noon Insolation Profiles

(b) Contour Display of the Same Values.

Figure I. Schematic Orbit of Mars Around the Sun



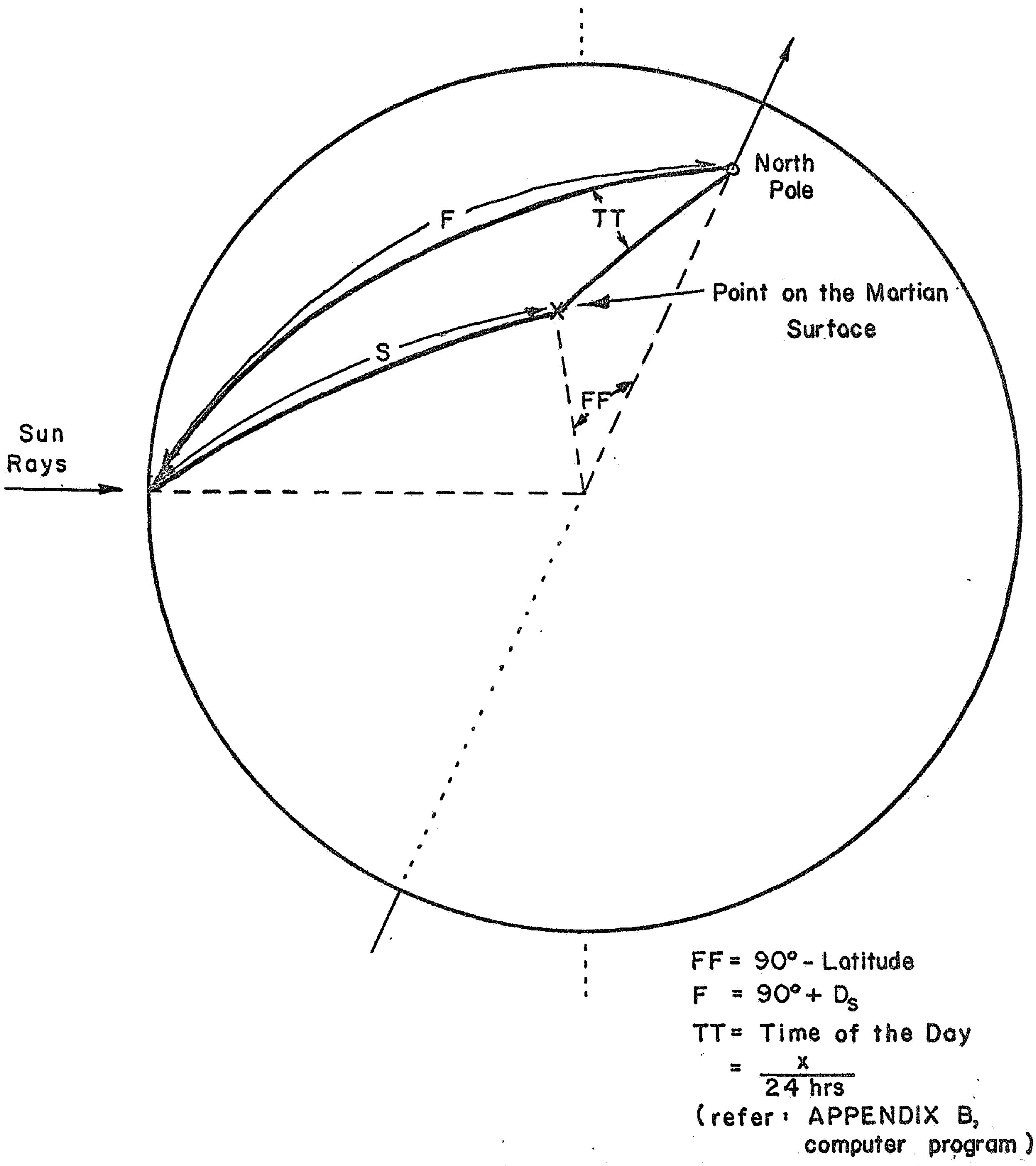


Figure 2. Geometric Representation of Angular Relationships for a 1 cm^2 Area on the Martian Surface

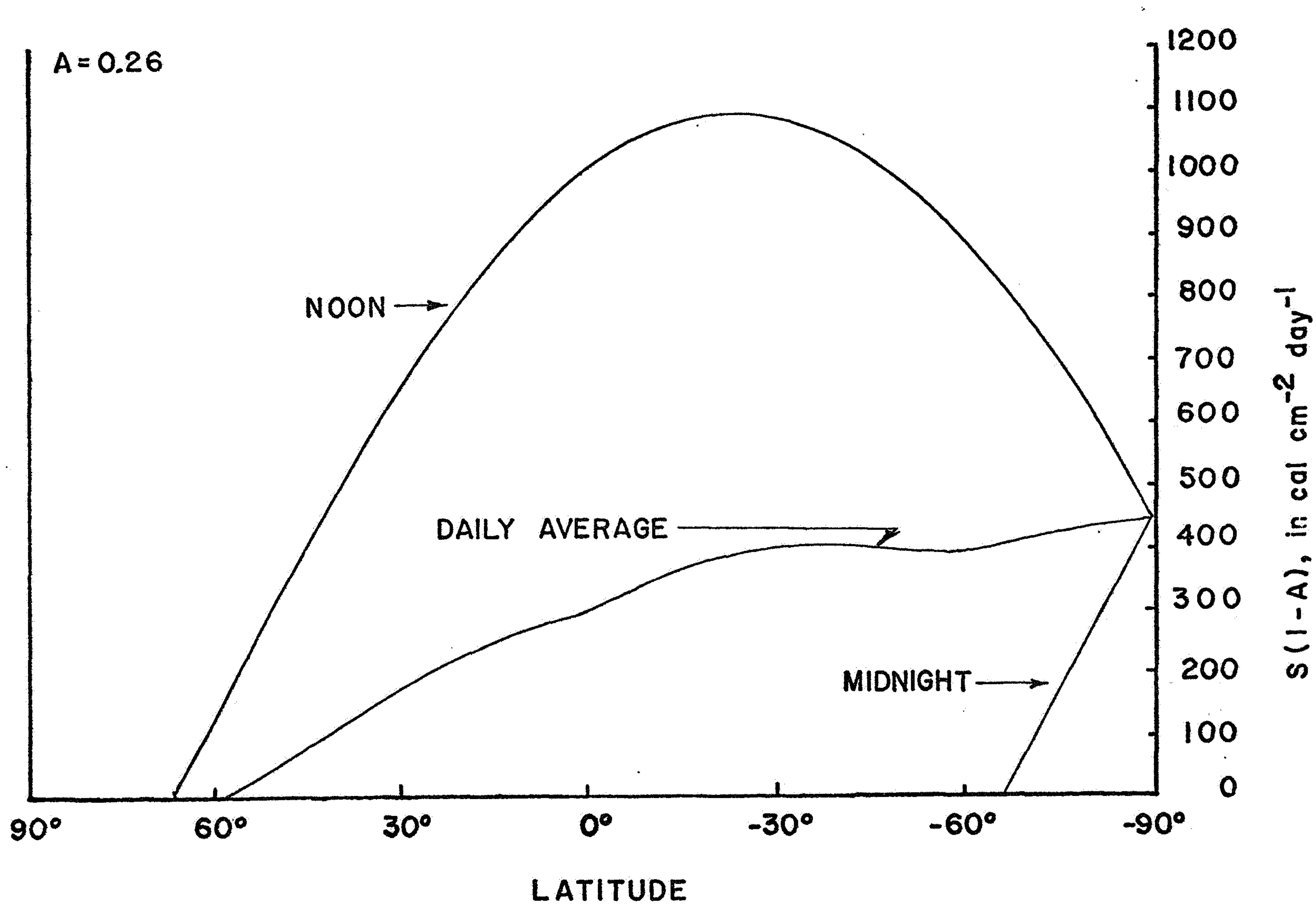


Figure 3a. Insolation Received on "January 1st"

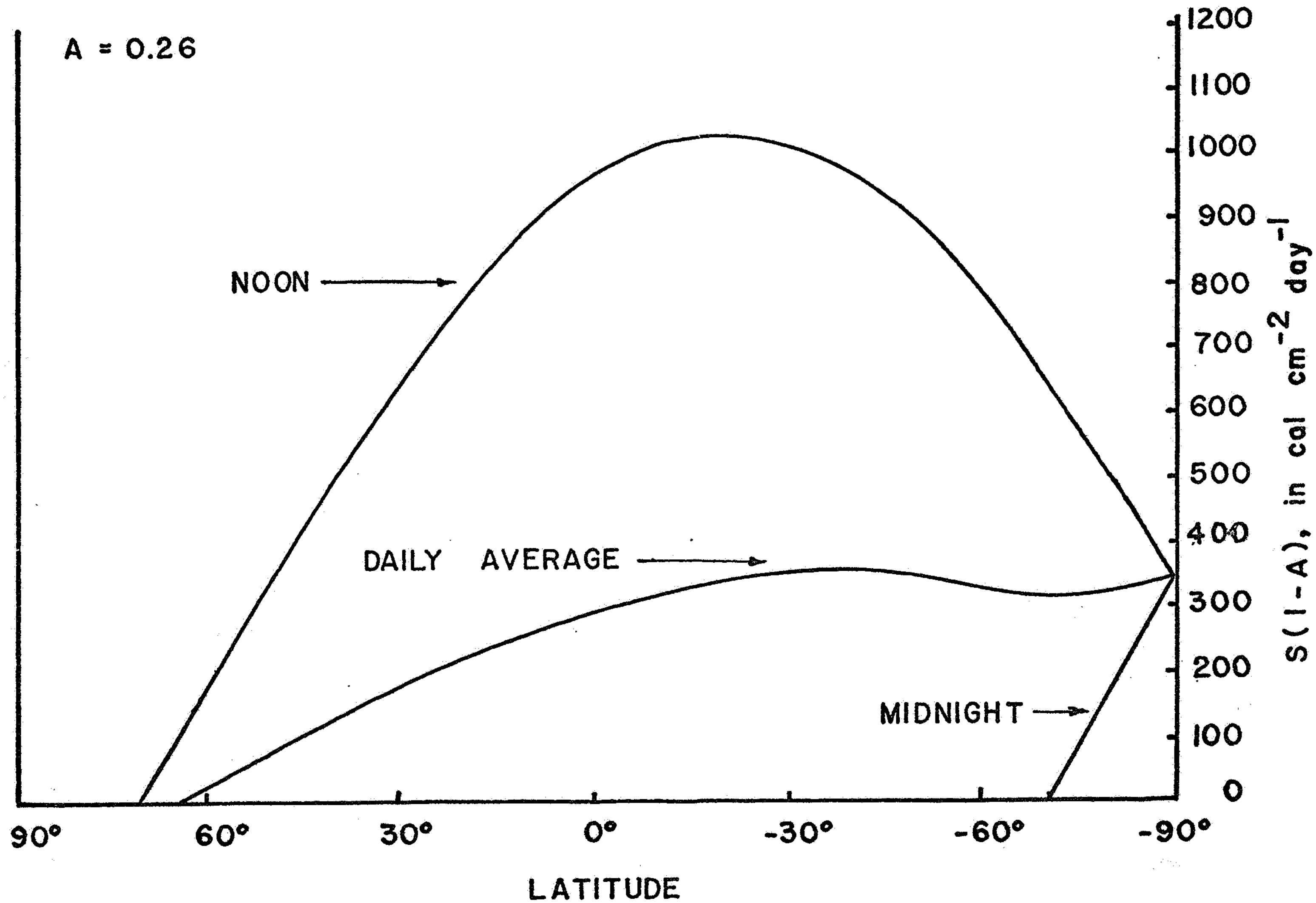


Figure 3b. Insolation Received on "February 1st"

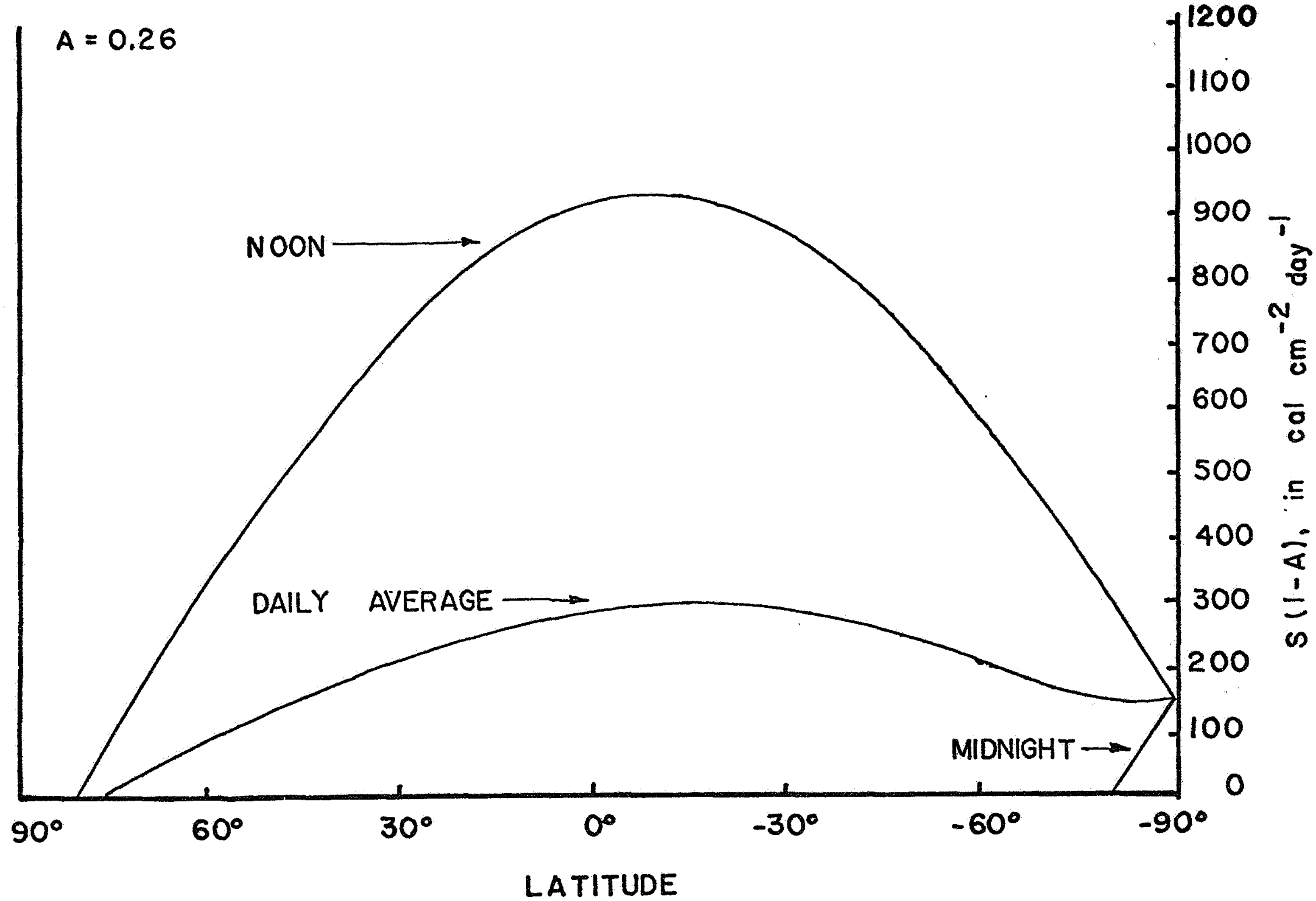


Figure 3c. Insolation Received on "March 1st"

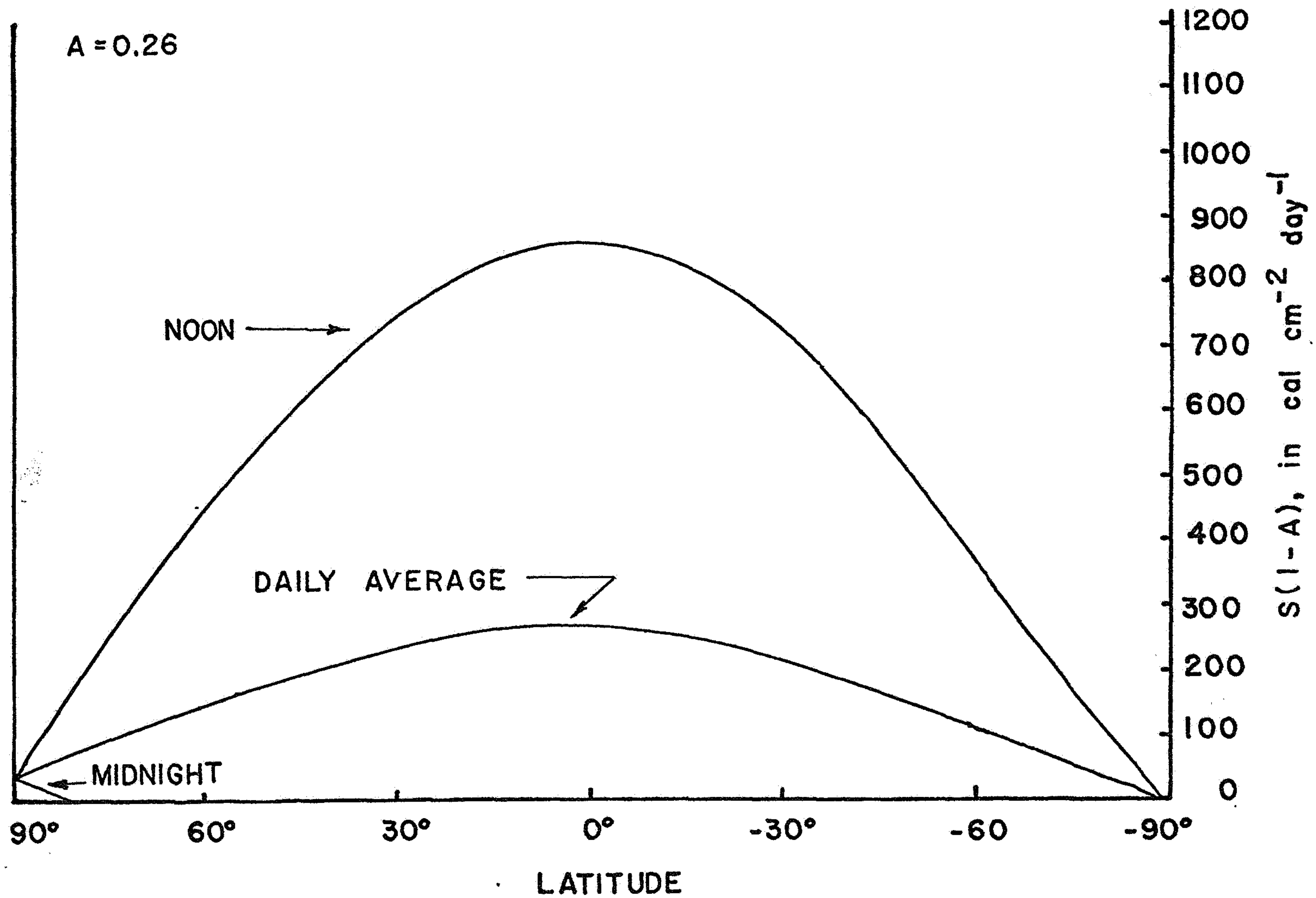


Figure 3d. Insolation Received on "April 1st"

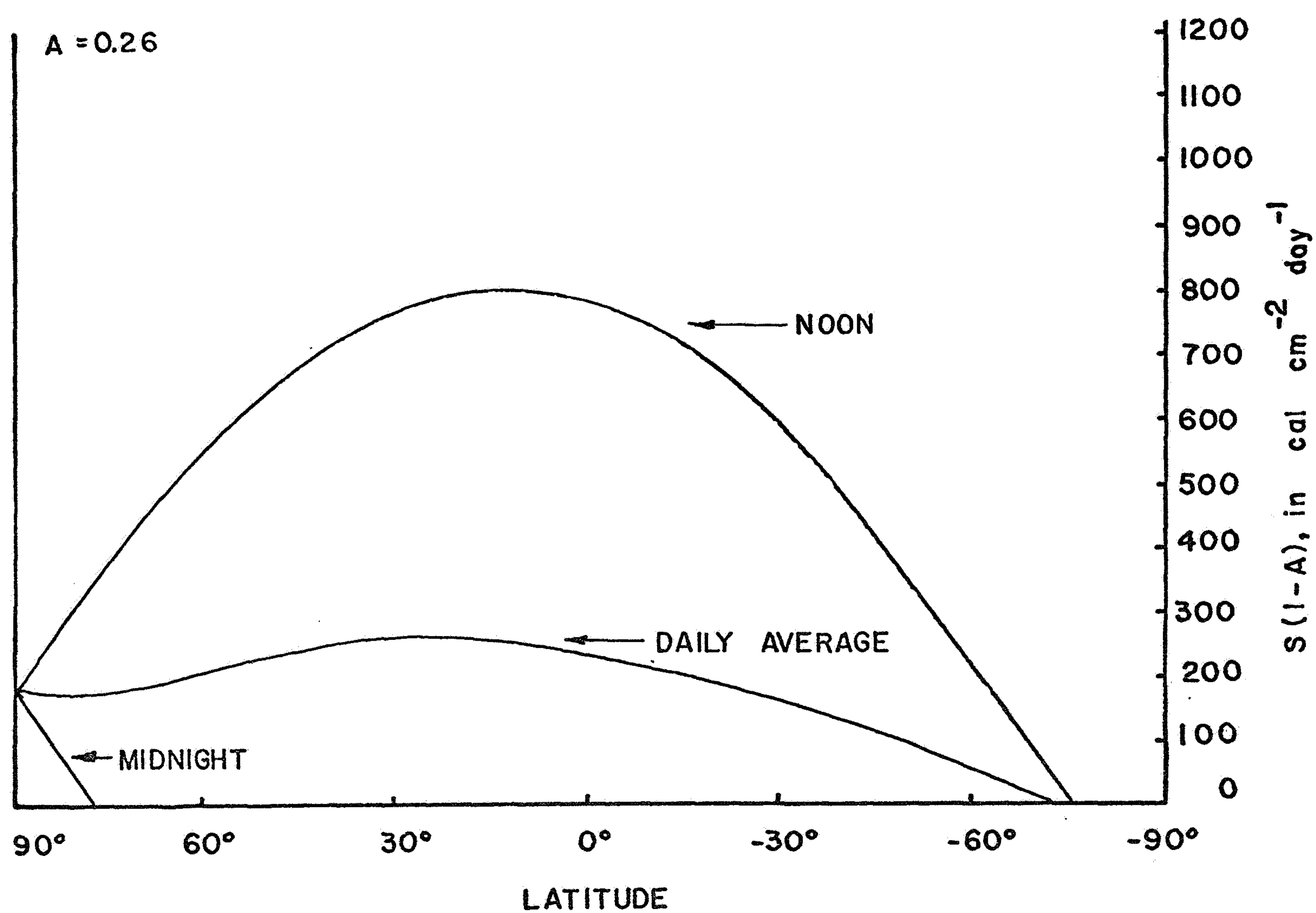


Figure 3e. Insolation Received on "May 1st"

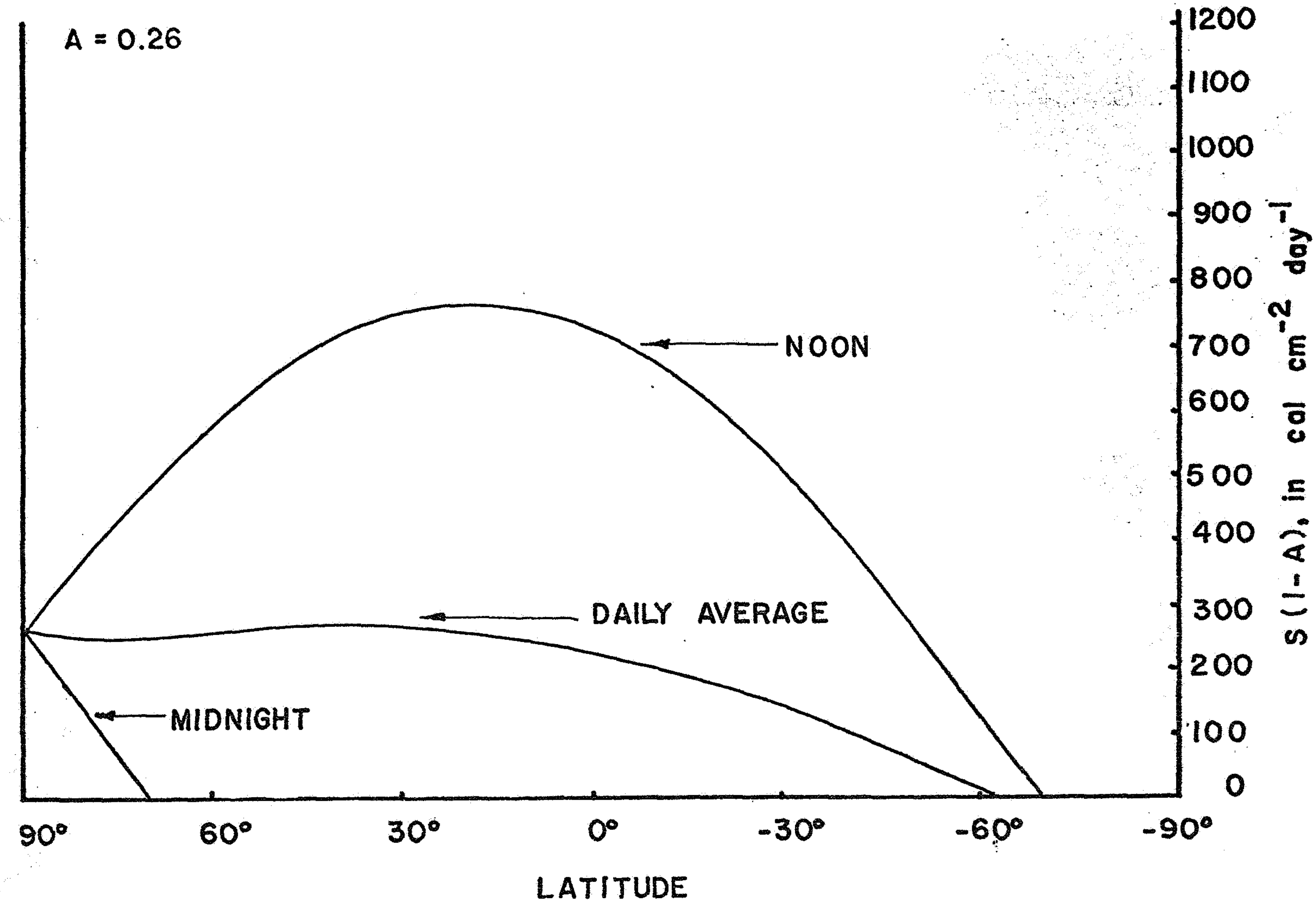


Figure 3f. Insolation Received on "June 1st"

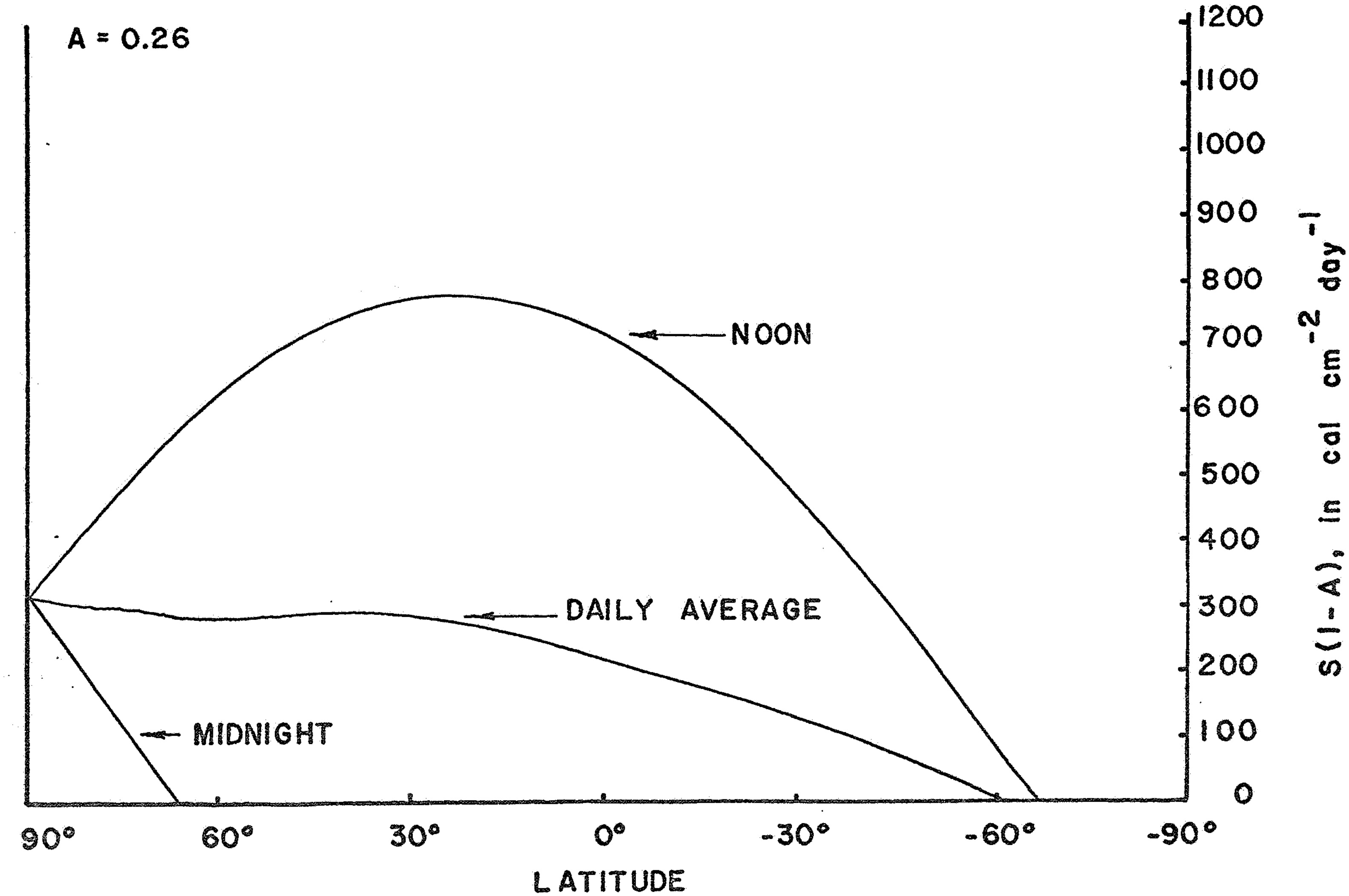


Figure 3g. Insolation Received on "July 1st"

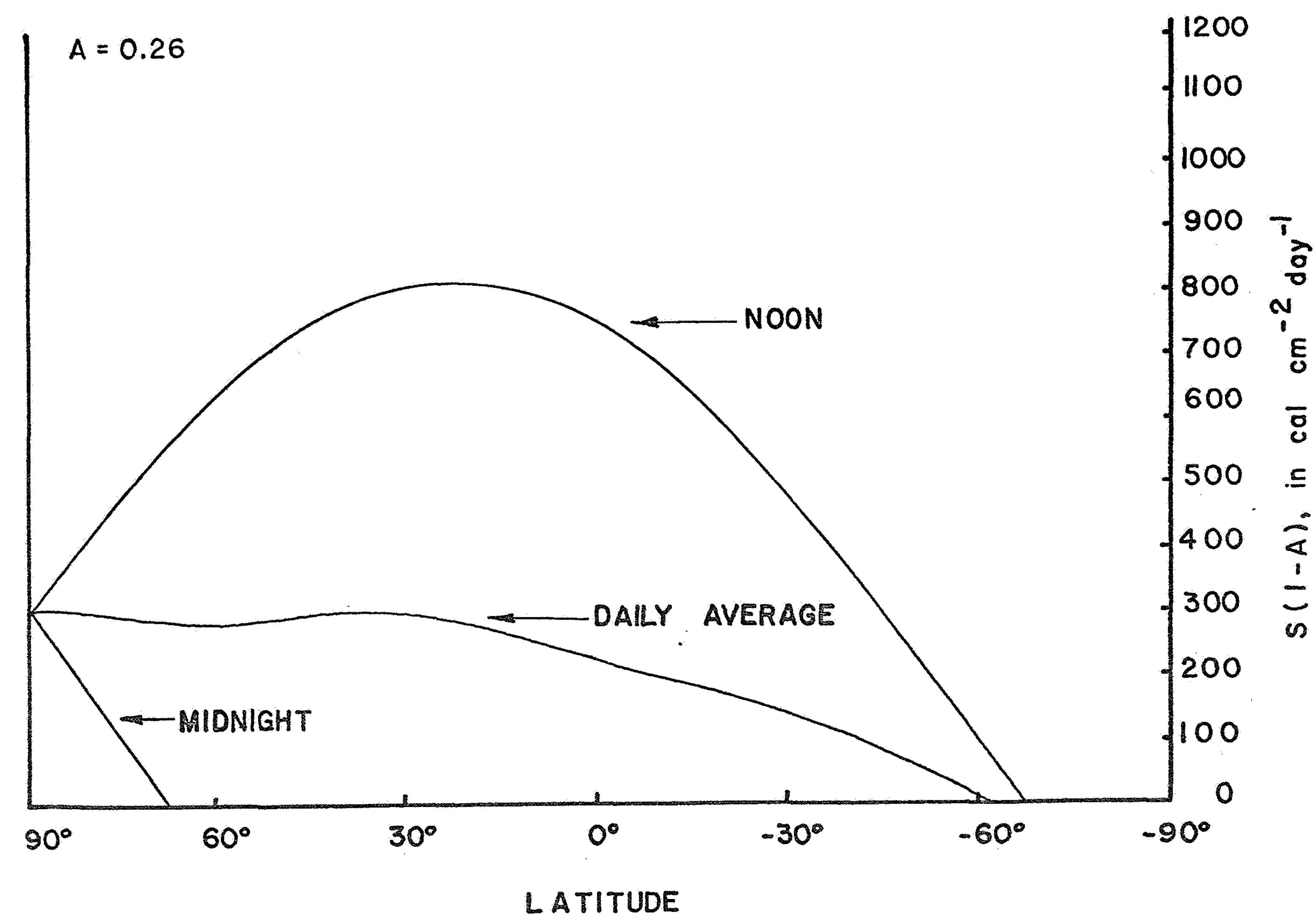


Figure 3h. Insolation Received on "August 1st"

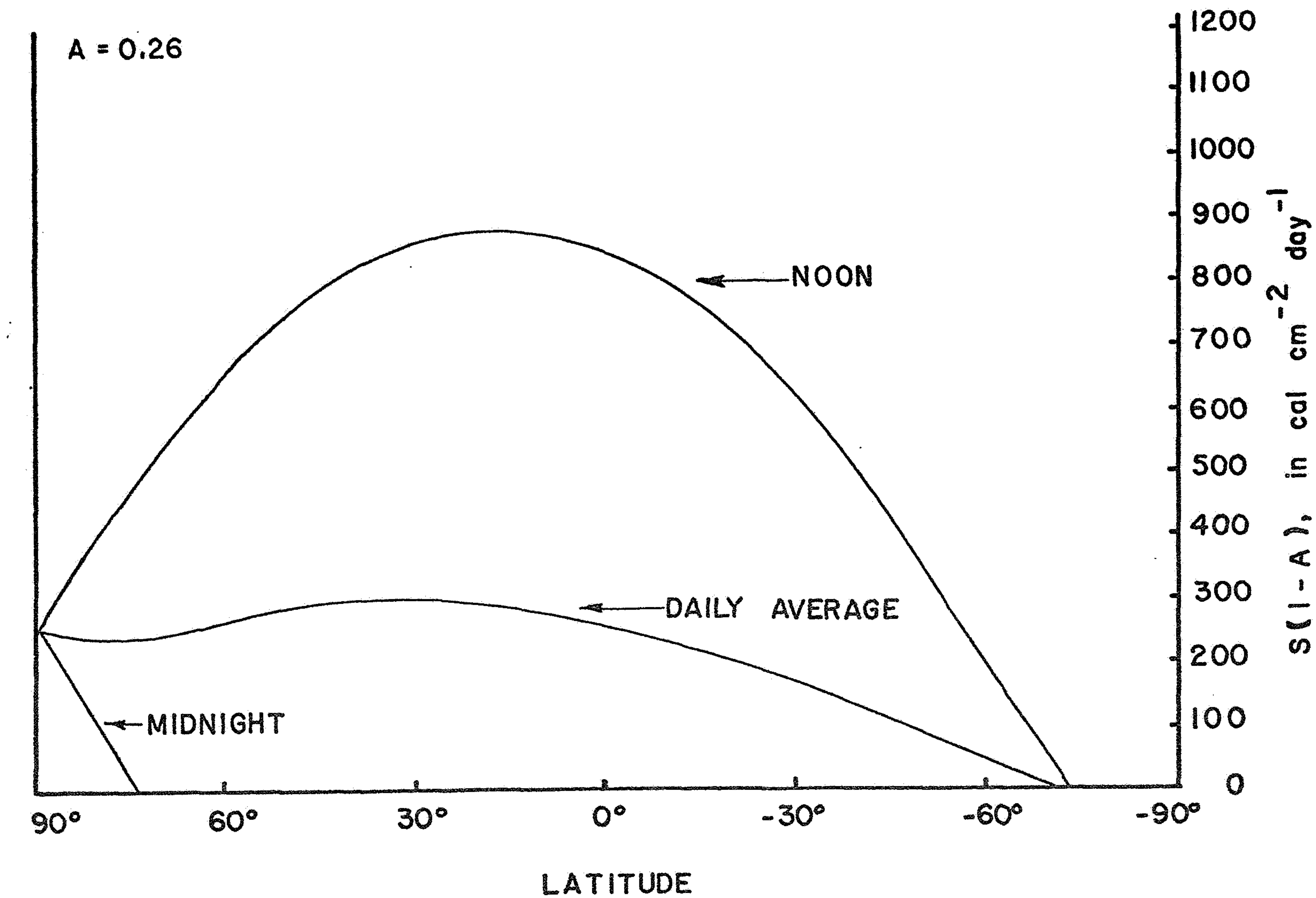


Figure 31. Insolation Received on "September 1st"

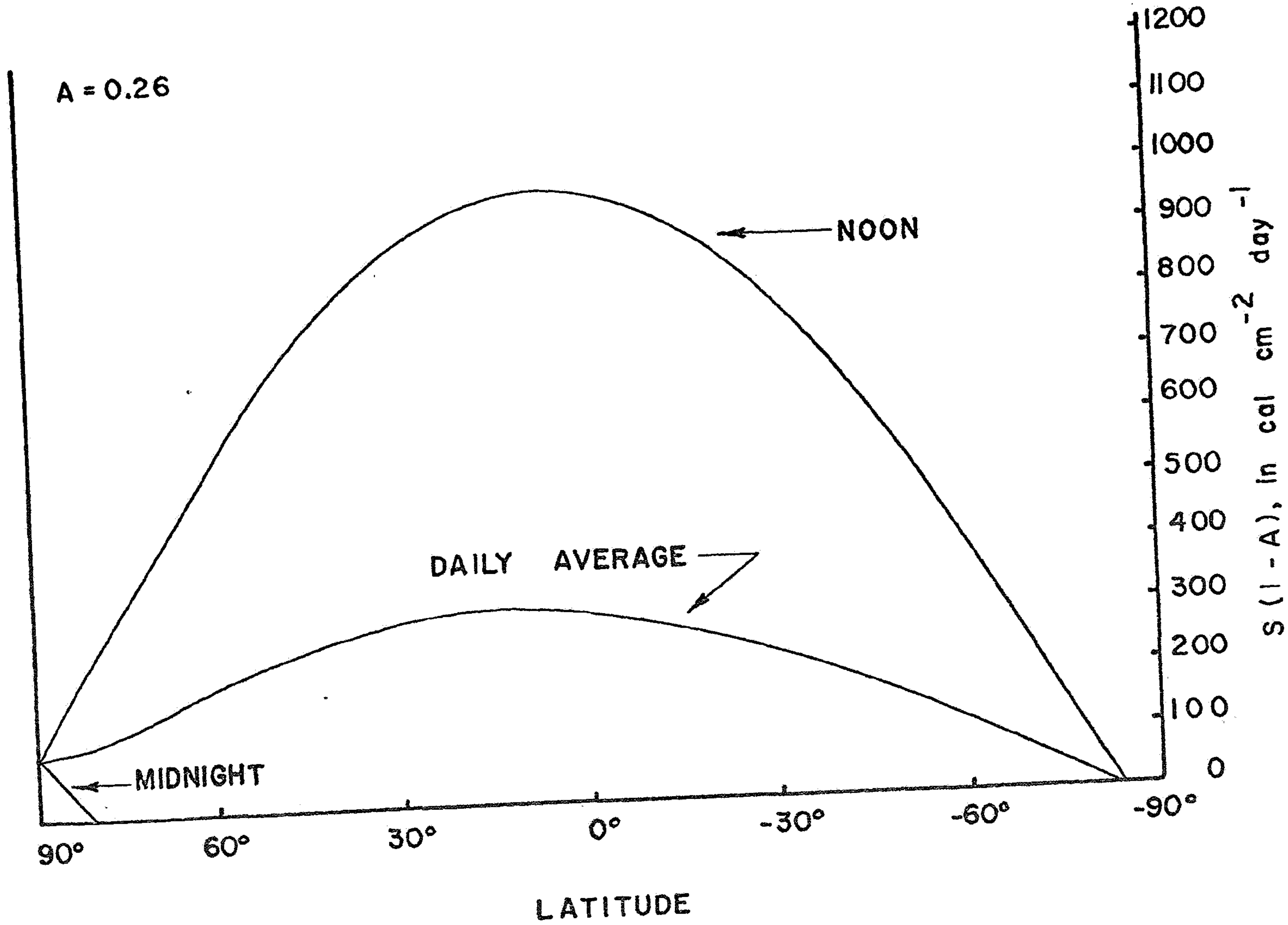


Figure 3j. Insolation Received on "October 1st"

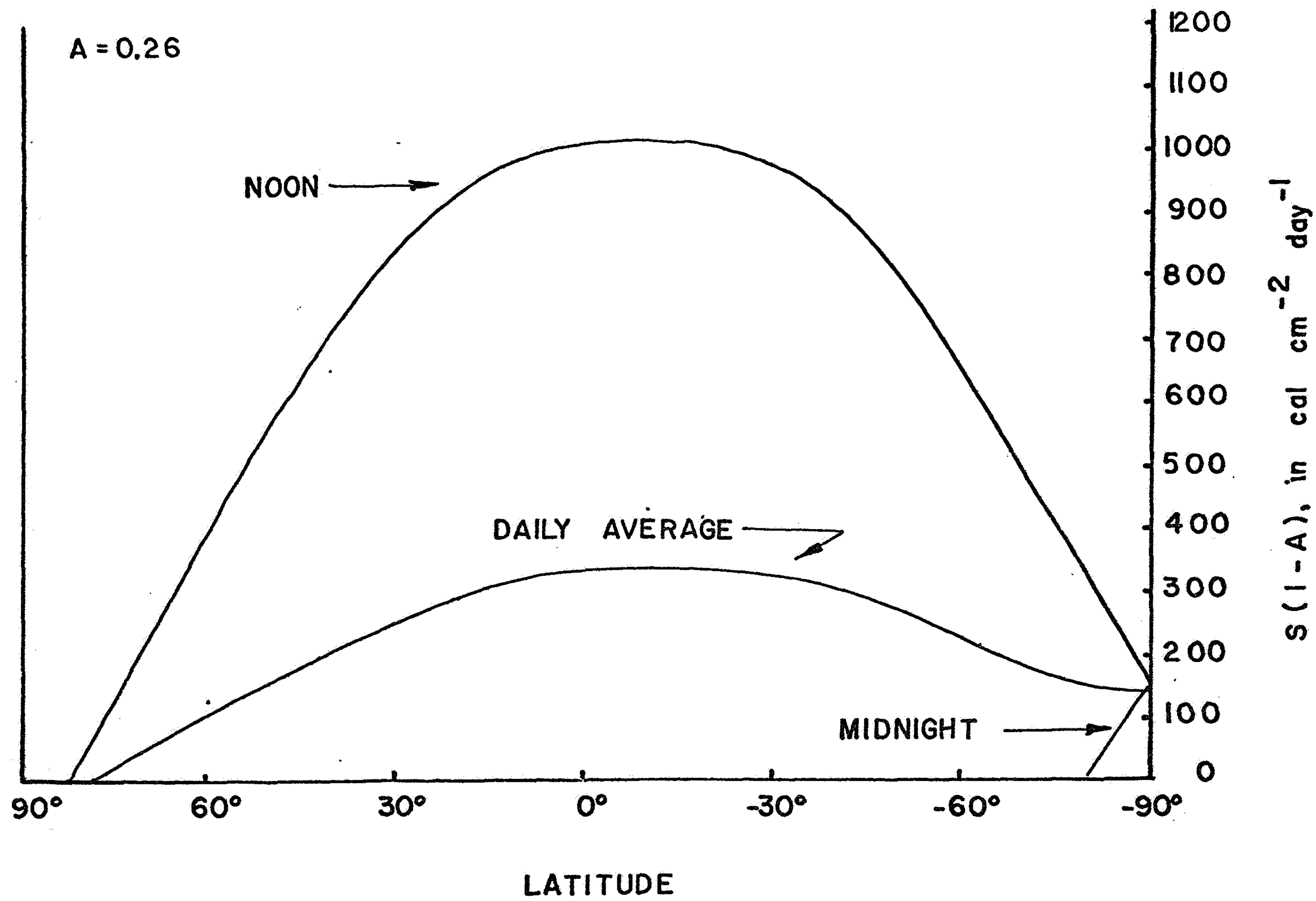


Figure 3k. Insolation Received on "November 1st"

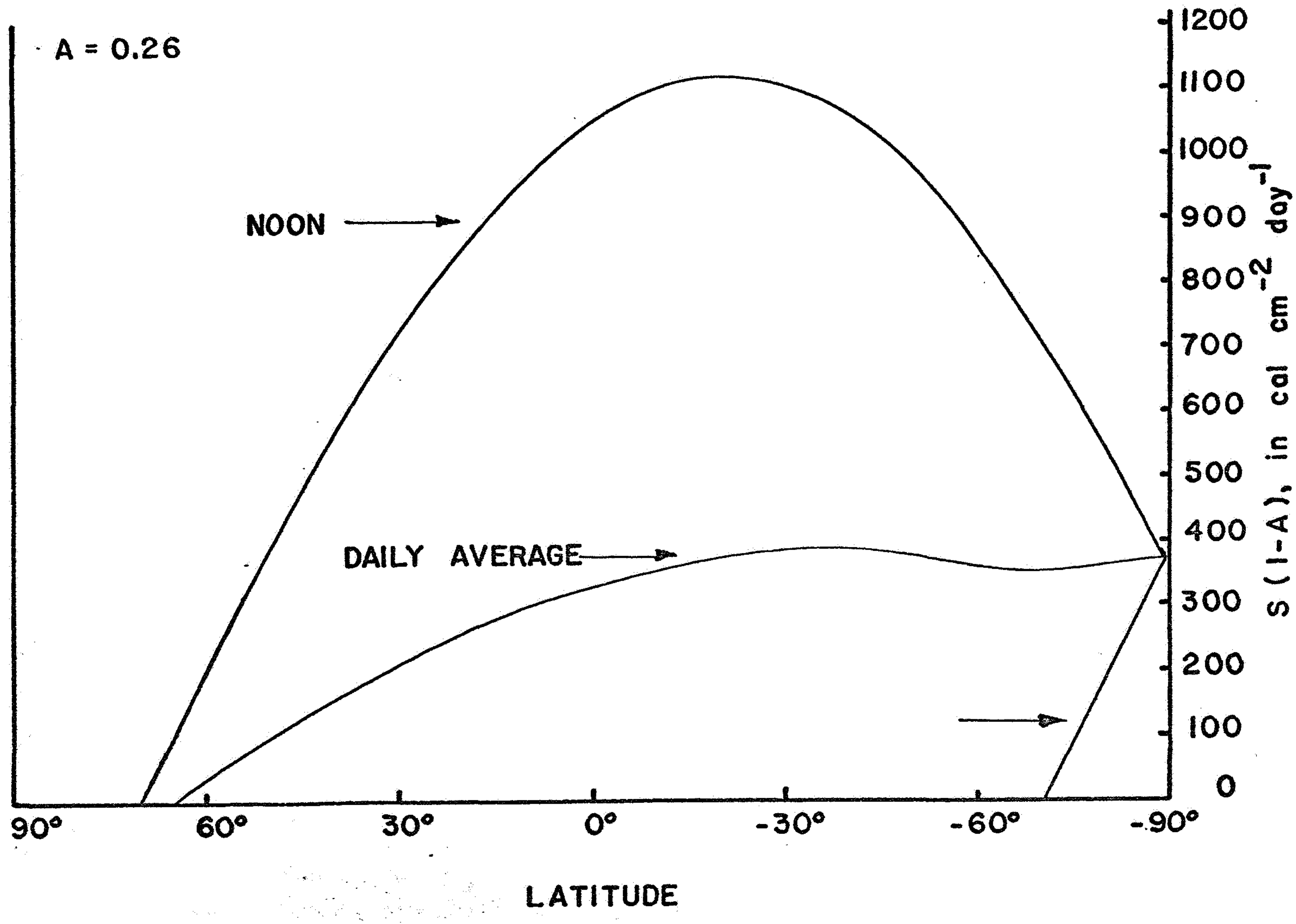


Figure 31. Insolation Received on "December 1st"

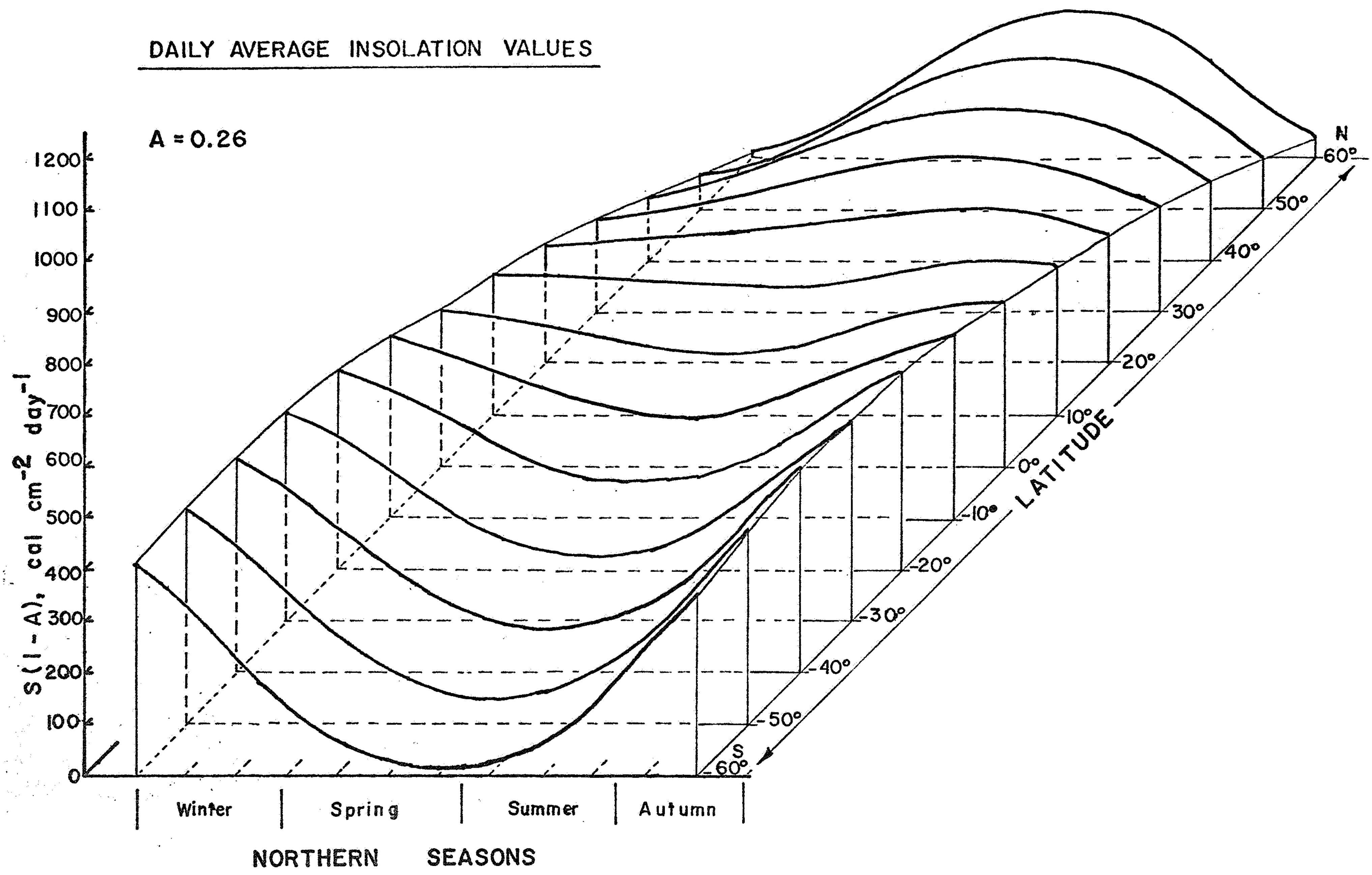


Figure 4a. Composite of the Daily Average Insolation Profiles for the 12 Martian Months

DAILY AVERAGE INSOLATION

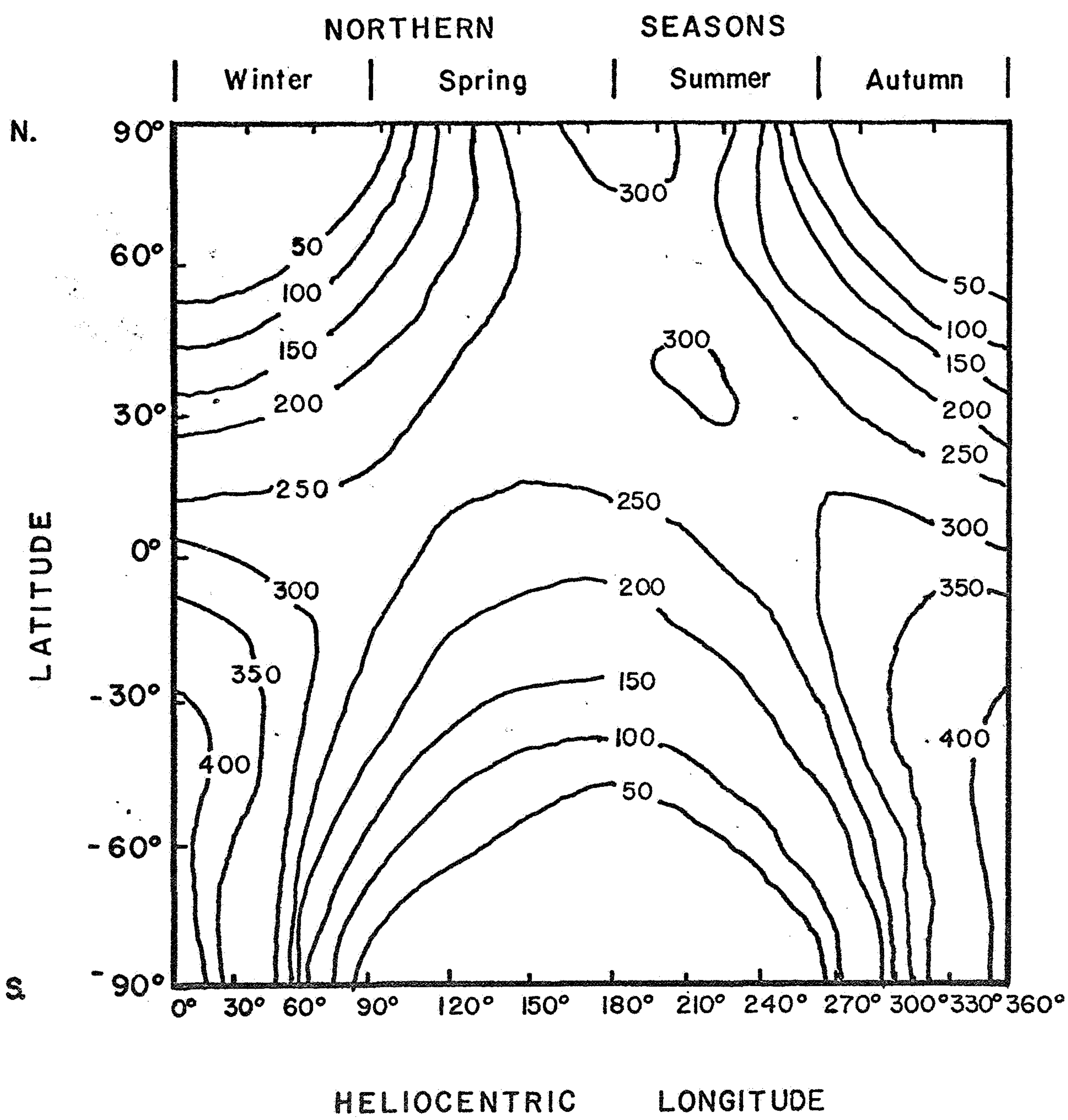


Figure 4b. Contour Plot Utilizing the Same Insolation Values for Latitude vs Martian Months

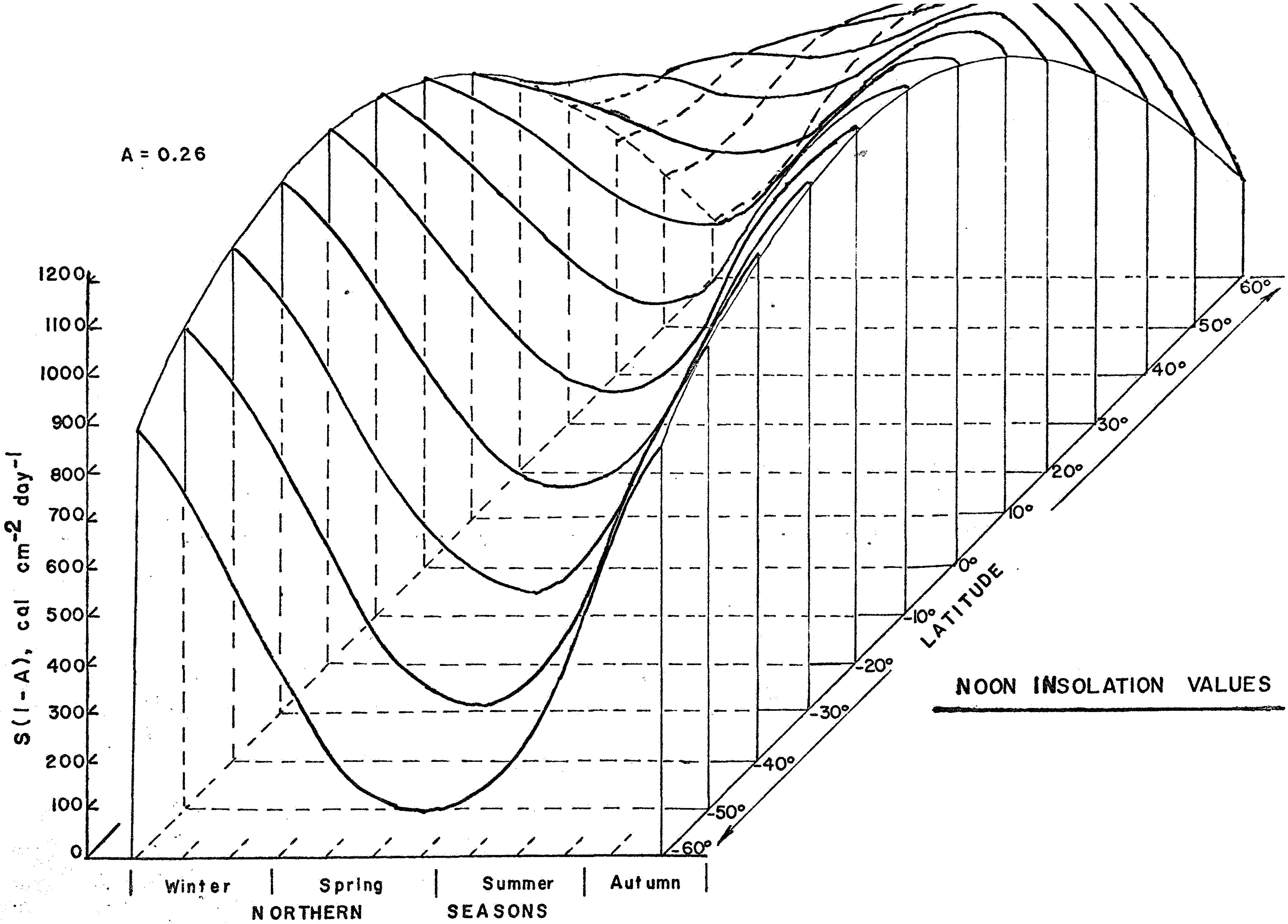


Figure 5a. Composite of the Noon Insolation Profiles

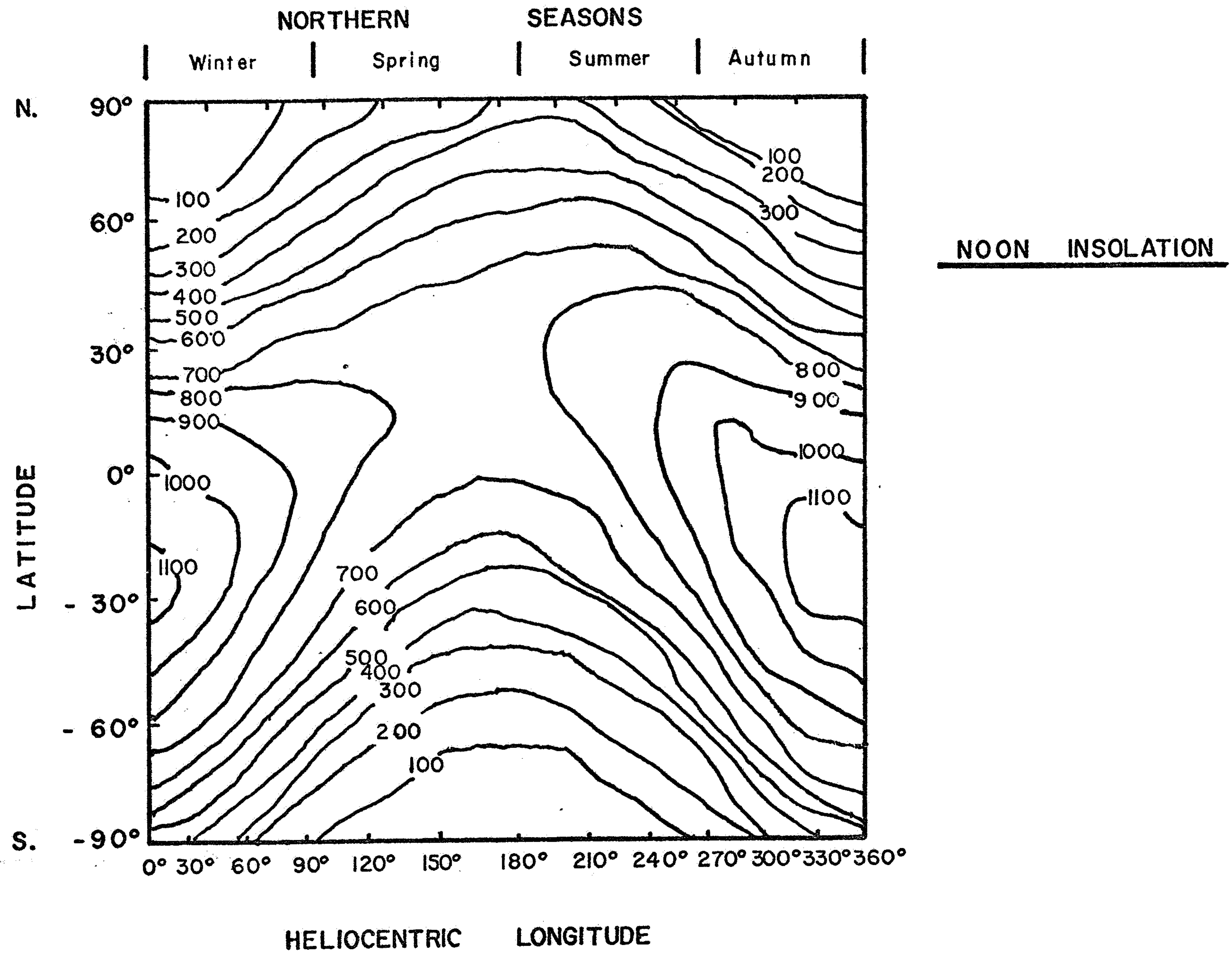


Figure 5b. Contour Display of the Same Values

TABLE CAPTION

Diurnal and Daily Average Effective Insolation Values Computed for the First Day of Each of 12 Equal Martian Months.

INSOLATION RECEIVED ON JANUARY 1st

DISTANCE TO SUN 1.3883 A.U.

INCLINATION OF AXIS 23.99 DEGREES

TIME (HRS.) LATITUDE	DAILY AVERAGE	0.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0
90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60.0	14.6	0.0	0.0	0.0	0.0	116.5	0.0	0.0	0.0
50.0	67.2	0.0	0.0	0.0	115.5	306.8	115.5	0.0	0.0
40.0	125.9	0.0	0.0	0.0	259.8	487.9	259.8	0.0	0.0
30.0	180.8	0.0	0.0	0.0	396.3	654.1	396.3	0.0	0.0
20.0	230.2	0.0	0.0	0.0	520.6	800.4	520.6	0.0	0.0
10.0	272.6	0.0	0.0	0.0	629.2	922.4	629.2	0.0	0.0
0.0	306.7	0.0	0.0	0.0	718.7	1016.4	718.7	0.0	0.0
- 10.0	351.1	0.0	0.0	78.5	786.3	1079.5	786.3	78.5	0.0
- 20.0	384.9	0.0	0.0	154.7	830.0	1109.8	830.0	154.7	0.0
- 30.0	407.0	0.0	0.0	226.1	848.5	1106.3	848.5	226.1	0.0
- 40.0	416.7	0.0	0.0	290.7	841.3	1069.3	841.3	290.7	0.0
- 50.0	413.7	0.0	0.0	346.5	808.4	999.8	808.4	346.5	0.0
- 60.0	406.3	0.0	32.4	391.7	751.0	899.9	751.0	391.7	32.4
- 70.0	425.0	77.4	179.2	425.0	670.8	772.6	670.8	425.0	179.2
- 80.0	445.4	268.9	320.6	445.4	570.2	621.9	570.2	445.4	320.6
- 90.0	452.3	452.3	452.3	452.3	452.3	452.3	452.3	452.3	452.3

INSOLATION RECEIVED ON FEBRUARY 1st

DISTANCE TO SUN 1.4371 A.U.

INCLINATION OF AXIS 19.58 DEGREES

TIME (HRS.) / LATITUDE	DAILY AVERAGE	0.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0
90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70.0	0.9	0.0	0.0	0.0	0.0	7.6	0.0	0.0	0.0
60.0	34.6	0.0	0.0	0.0	44.5	187.7	44.5	0.0	0.0
50.0	89.8	0.0	0.0	0.0	178.0	362.2	178.0	0.0	0.0
40.0	142.2	0.0	0.0	0.0	306.2	525.6	306.2	0.0	0.0
30.0	190.4	0.0	0.0	0.0	425.0	673.1	425.0	0.0	0.0
20.0	232.8	0.0	0.0	0.0	530.9	800.2	530.9	0.0	0.0
10.0	268.0	0.0	0.0	0.0	620.7	902.9	620.7	0.0	0.0
0.0	295.2	0.0	0.0	0.0	691.7	978.2	691.7	0.0	0.0
- 10.0	328.5	0.0	0.0	60.4	741.6	1023.7	741.6	60.4	0.0
- 20.0	351.8	0.0	0.0	119.0	769.0	1038.2	769.0	119.0	0.0
- 30.0	364.4	0.0	0.0	174.0	773.0	1021.1	773.0	174.0	0.0
- 40.0	365.9	0.0	0.0	223.7	753.5	973.0	753.5	223.7	0.0
- 50.0	356.3	0.0	0.0	266.6	711.2	895.3	711.2	266.6	0.0
- 60.0	335.9	0.0	0.0	301.4	647.2	790.4	647.2	301.4	0.0
- 70.0	327.9	0.0	90.4	327.0	563.5	661.5	573.5	327.0	90.4
- 80.0	342.7	172.8	222.6	342.7	462.8	512.5	462.8	342.7	222.6
- 90.0	348.0	348.0	348.0	348.0	348.0	348.0	348.0	348.0	348.0

INSOLATION RECEIVED ON MARCH 1st

DISTANCE TO SUN 1.5083 A.U.

INCLINATION OF AXIS 9.30 DEGREES

TIME (HRS.) LATITUDE	DAILY AVERAGE	0.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0
90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80.0	1.4	0.0	0.0	0.0	0.0	11.5	0.0	0.0	0.0
70.0	42.3	0.0	0.0	0.0	81.8	175.0	81.8	0.0	0.0
60.0	90.9	0.0	0.0	0.0	196.9	333.1	196.0	0.0	0.0
50.0	136.7	0.0	0.0	0.0	306.1	481.2	306.1	0.0	0.0
40.0	178.3	0.0	0.0	0.0	405.9	614.6	405.9	0.0	0.0
30.0	214.5	0.0	0.0	0.0	493.4	729.3	493.4	0.0	0.0
20.0	244.2	0.0	0.0	0.0	565.9	821.9	565.9	0.0	0.0
10.0	266.5	0.0	0.0	0.0	621.2	889.5	621.2	0.0	0.0
0.0	280.7	0.0	0.0	0.0	657.7	930.1	657.7	0.0	0.0
- 10.0	292.9	0.0	0.0	26.4	674.1	942.4	674.1	26.4	0.0
- 20.0	296.3	0.0	0.0	52.1	670.1	926.1	670.1	52.1	0.0
- 30.0	290.7	0.0	0.0	76.2	645.7	881.6	645.7	76.2	0.0
- 40.0	276.2	0.0	0.0	97.9	601.7	810.4	601.7	97.9	0.0
- 50.0	253.3	0.0	0.0	116.7	539.4	714.5	539.4	116.7	0.0
- 60.0	222.8	0.0	0.0	131.9	460.7	596.9	460.7	131.9	0.0
- 70.0	185.5	0.0	0.0	143.1	368.1	461.2	368.1	143.1	0.0
- 80.0	151.4	0.0	35.8	150.0	264.2	311.5	264.2	150.0	35.8
- 90.0	152.3	152.3	152.3	152.3	152.3	152.3	152.3	152.3	152.3

INSOLATION RECEIVED ON APRIL 1^{st}

DISTANCE TO SUN 1.5795 A.U.

INCLINATION OF AXIS -2.56 DEGREES

TIME (HRS.)		0.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0
LATITUDE	DAILY AVERAGE								
90.0	38.3	38.3	38.3	38.3	38.3	38.3	38.3	38.3	38.3
80.0	68.6	0.0	0.0	37.7	143.2	186.8	143.2	37.7	0.0
70.0	111.1	0.0	0.0	36.0	243.6	329.7	243.6	36.0	0.0
60.0	150.3	0.0	0.0	33.2	336.7	462.5	336.7	33.2	0.0
50.0	184.9	0.0	0.0	29.4	419.6	581.2	419.6	29.4	0.0
40.0	213.9	0.0	0.0	24.6	489.7	682.3	489.7	24.6	0.0
30.0	236.4	0.0	0.0	19.2	544.9	762.7	544.9	19.2	0.0
20.0	251.7	0.0	0.0	13.1	583.6	819.9	583.6	13.1	0.0
10.0	259.3	0.0	0.0	6.7	604.5	852.1	604.5	6.7	0.0
0.0	259.1	0.0	0.0	0.0	607.1	858.5	604.1	0.0	0.0
- 10.0	252.7	0.0	0.0	0.0	591.2	838.8	591.2	0.0	0.0
- 20.0	238.5	0.0	0.0	0.0	557.4	793.6	557.4	0.0	0.0
- 30.0	217.2	0.0	0.0	0.0	506.6	724.3	506.6	0.0	0.0
- 40.0	189.2	0.0	0.0	0.0	440.4	633.0	440.4	0.0	0.0
- 50.0	155.5	0.0	0.0	0.0	360.9	522.5	360.9	0.0	0.0
- 60.0	117.1	0.0	0.0	0.0	270.3	396.1	270.3	0.0	0.0
- 70.0	75.1	0.0	0.0	0.0	171.6	257.6	171.6	0.0	0.0
- 80.0	30.8	0.0	0.0	0.0	67.7	111.3	67.7	0.0	0.0
- 90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

INSOLATION RECEIVED ON MAY 1^{st}

DISTANCE TO SUN 1.6335 A.U.

INCLINATION OF AXIS -12.99 DEGREES

TIME (HRS.)		0.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0
LATITUDE	DAILY AVERAGE								
90.0	180.6	180.6	180.6	180.6	180.6	180.6	180.6	180.6	180.6
80.0	177.8	41.9	81.7	177.8	273.9	313.8	273.9	177.8	81.7
70.0	186.9	0.0	0.0	169.7	359.0	437.4	359.0	169.7	0.0
60.0	215.9	0.0	0.0	156.4	433.2	547.8	433.2	156.4	0.0
50.0	238.3	0.0	0.0	138.3	494.2	641.6	494.2	138.3	0.0
40.0	253.5	0.0	0.0	116.1	540.1	715.8	540.1	116.1	0.0
30.0	261.0	0.0	0.0	90.3	569.7	768.3	569.7	90.3	0.0
20.0	260.6	0.0	0.0	61.8	582.0	797.5	582.0	61.8	0.0
10.0	252.3	0.0	0.0	31.4	576.6	802.4	576.6	31.4	0.0
0.0	236.3	0.0	0.0	0.0	553.6	782.9	553.6	0.0	0.0
- 10.0	220.9	0.0	0.0	0.0	513.8	739.7	513.8	0.0	0.0
- 20.0	198.9	0.0	0.0	0.0	458.5	673.9	458.5	0.0	0.0
- 30.0	170.8	0.0	0.0	0.0	389.2	587.7	389.2	0.0	0.0
- 40.0	137.5	0.0	0.0	0.0	308.0	483.7	308.0	0.0	0.0
- 50.0	100.0	0.0	0.0	0.0	217.5	364.9	217.5	0.0	0.0
- 60.0	59.5	0.0	0.0	0.0	120.4	235.1	120.4	0.0	0.0
- 70.0	17.2	0.0	0.0	0.0	19.7	98.1	19.7	0.0	0.0
- 80.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- 90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

INSOLATION RECEIVED ON JUNE 1st

DISTANCE TO SUN 1.6601 A.U.

INCLINATION OF AXIS -20.38 DEGREES

TIME (HRS.)		0.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0
LATITUDE	DAILY AVERAGE								
90.0	270.9	270.9	270.9	270.9	270.9	270.9	270.9	270.9	270.9
80.0	266.8	140.1	177.2	266.8	356.3	393.4	356.3	266.8	177.2
70.0	254.5	5.1	78.2	254.5	430.9	504.0	430.9	254.5	78.2
60.0	256.7	0.0	0.0	234.6	492.4	599.2	492.4	234.6	0.0
50.0	271.2	0.0	0.0	207.5	539.0	676.3	539.0	207.5	0.0
40.0	277.4	0.0	0.0	174.1	569.1	732.8	569.1	174.1	0.0
30.0	275.2	0.0	0.0	135.4	582.0	767.0	582.0	135.4	0.0
20.0	264.7	0.0	0.0	92.6	577.2	777.9	577.2	92.6	0.0
10.0	246.1	0.0	0.0	47.0	554.9	765.2	554.9	47.0	0.0
0.0	220.1	0.0	0.0	0.0	515.7	729.3	515.7	0.0	0.0
- 10.0	199.1	0.0	0.0	0.0	460.8	671.1	460.8	0.0	0.0
- 20.0	172.1	0.0	0.0	0.0	391.9	592.6	391.9	0.0	0.0
- 30.0	139.8	0.0	0.0	0.0	311.1	496.1	311.1	0.0	0.0
- 40.0	103.3	0.0	0.0	0.0	220.9	384.5	220.9	0.0	0.0
- 50.0	63.6	0.0	0.0	0.0	124.0	261.3	124.0	0.0	0.0
- 60.0	22.1	0.0	0.0	0.0	23.2	130.0	23.2	0.0	0.0
- 70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- 80.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- 90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

INSOLATION RECEIVED ON JULY 1st

DISTANCE TO SUN 1.6548 A.U.

INCLINATION OF AXIS -23.82 DEGREES

TIME (HRS.)		0.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0
LATITUDE	DAILY AVERAGE								
90.0	316.2	316.2	316.2	316.2	316.2	316.2	316.2	316.2	316.2
80.0	311.4	187.0	223.5	311.4	399.4	435.8	399.4	311.4	223.5
70.0	297.1	52.2	123.9	297.1	470.4	542.1	470.4	297.1	123.9
60.0	284.4	0.0	20.6	273.9	527.1	632.0	527.1	273.9	20.6
50.0	290.3	0.0	0.0	242.2	567.8	702.6	567.8	242.2	0.0
40.0	292.6	0.0	0.0	203.3	591.2	751.9	591.2	203.3	0.0
30.0	286.0	0.0	0.0	158.1	596.7	778.4	596.7	158.1	0.0
20.0	270.7	0.0	0.0	108.1	584.1	781.2	584.1	108.1	0.0
10.0	247.2	0.0	0.0	54.9	553.7	760.3	553.7	54.9	0.0
0.0	216.1	0.0	0.0	0.0	506.5	716.2	506.5	0.0	0.0
- 10.0	192.3	0.0	0.0	0.0	443.9	650.5	443.9	0.0	0.0
- 20.0	162.6	0.0	0.0	0.0	367.8	564.9	367.8	0.0	0.0
- 30.0	127.9	0.0	0.0	0.0	280.5	462.2	280.5	0.0	0.0
- 40.0	89.4	0.0	0.0	0.0	184.7	345.4	184.7	0.0	0.0
- 50.0	48.1	0.0	0.0	0.0	83.3	218.2	83.3	0.0	0.0
- 60.0	10.5	0.0	0.0	0.0	0.0	84.3	0.0	0.0	0.0
- 70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- 80.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- 90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

INSOLATION RECEIVED ON AUGUST 1st

DISTANCE TO SUN 1.6185 A. U.

INCLINATION OF AXIS -22.70 DEGREES

TIME (HRS.)		0.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0
LATITUDE	DAILY AVERAGE								
90.0	315.8	315.8	315.8	315.8	315.8	315.8	315.8	315.8	315.8
80.0	311.0	179.9	218.3	311.0	403.8	442.2	403.8	311.0	218.3
70.0	296.8	38.5	114.2	296.8	479.4	555.0	479.4	296.8	114.2
60.0	286.5	0.0	6.6	273.5	540.5	651.1	540.5	273.5	6.6
50.0	297.7	0.0	0.0	241.9	585.1	727.3	585.1	241.9	0.0
40.0	301.4	0.0	0.0	203.0	612.0	781.4	612.0	203.0	0.0
30.0	296.0	0.0	0.0	157.9	620.3	811.8	620.3	157.9	0.0
20.0	281.6	0.0	0.0	108.0	609.7	817.6	609.7	108.0	0.0
10.0	258.7	0.0	0.0	54.8	580.7	798.5	580.7	54.8	0.0
0.0	227.9	0.0	0.0	0.0	533.9	755.1	533.9	0.0	0.0
- 10.0	203.8	0.0	0.0	0.0	471.0	688.8	471.0	0.0	0.0
- 20.0	173.6	0.0	0.0	0.0	393.7	601.5	393.7	0.0	0.0
- 30.0	138.1	0.0	0.0	0.0	304.5	496.0	304.5	0.0	0.0
- 40.0	98.4	0.0	0.0	0.0	206.0	375.4	206.0	0.0	0.0
- 50.0	55.7	0.0	0.0	0.0	101.3	243.4	101.3	0.0	0.0
- 60.0	13.0	0.0	0.0	0.0	0.0	104.0	0.0	0.0	0.0
- 70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- 80.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- 90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

INSOLATION RECEIVED ON SEPTEMBER 1st

DISTANCE TO SUN 1.5574 A.U.

INCLINATION OF AXIS -16.61 DEGREES

TIME (HRS.)		0.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0
LATITUDE	DAILY AVERAGE								
90.0	252.7	252.7	252.7	252.7	252.7	252.7	252.7	252.7	252.7
80.0	248.8	101.7	144.8	248.8	352.9	395.9	352.9	248.8	144.8
70.0	244.0	0.0	32.6	237.4	442.3	527.2	442.3	237.4	32.6
60.0	264.6	0.0	0.0	218.8	518.3	642.4	518.3	218.8	0.0
50.0	285.3	0.0	0.0	193.6	578.6	738.1	578.6	193.6	0.0
40.0	297.3	0.0	0.0	162.4	621.3	811.3	621.3	162.4	0.0
30.0	300.3	0.0	0.0	126.3	645.1	859.9	645.1	126.3	0.0
20.0	294.2	0.0	0.0	86.4	649.3	882.4	649.3	86.4	0.0
10.0	279.2	0.0	0.0	43.9	633.8	878.1	633.8	43.9	0.0
0.0	255.6	0.0	0.0	0.0	599.0	847.1	599.0	0.0	0.0
- 10.0	235.3	0.0	0.0	0.0	546.0	790.3	546.0	0.0	0.0
- 20.0	207.8	0.0	0.0	0.0	476.4	709.6	476.4	0.0	0.0
- 30.0	174.0	0.0	0.0	0.0	392.4	607.3	392.4	0.0	0.0
- 40.0	134.9	0.0	0.0	0.0	296.4	486.5	296.4	0.0	0.0
- 50.0	91.7	0.0	0.0	0.0	191.5	350.9	191.5	0.0	0.0
- 60.0	45.8	0.0	0.0	0.0	80.7	204.7	80.7	0.0	0.0
- 70.0	6.5	0.0	0.0	0.0	0.0	52.3	0.0	0.0	0.0
- 80.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- 90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

INSOLATION RECEIVED ON OCTOBER 1st

DISTANCE TO SUN 1.4839 A.U.

INCLINATION OF AXIS -5.79 DEGREES

TIME (HRS.)		0.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0
LATITUDE	DAILY AVERAGE								
90.0	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2	98.2
80.0	111.2	0.0	0.0	96.7	215.7	264.9	215.7	96.7	0.0
70.0	157.7	0.0	0.0	92.3	326.6	423.6	326.6	92.3	0.0
60.0	199.3	0.0	0.0	85.1	427.5	569.4	427.5	85.1	0.0
50.0	234.9	0.0	0.0	75.2	515.5	697.9	515.5	75.2	0.0
40.0	263.4	0.0	0.0	63.1	587.9	805.2	587.9	63.1	0.0
30.0	283.9	0.0	0.0	49.1	642.3	888.0	642.3	49.1	0.0
20.0	295.7	0.0	0.0	33.6	677.3	943.9	677.3	33.6	0.0
10.0	298.5	0.0	0.0	17.1	691.6	971.0	691.6	17.1	0.0
0.0	292.3	0.0	0.0	0.0	685.0	968.7	685.0	0.0	0.0
- 10.0	281.5	0.0	0.0	0.0	657.5	936.9	657.5	0.0	0.0
- 20.0	262.1	0.0	0.0	0.0	610.1	876.7	610.1	0.0	0.0
- 30.0	234.8	0.0	0.0	0.0	544.1	789.8	544.1	0.0	0.0
- 40.0	200.3	0.0	0.0	0.0	461.6	678.9	461.6	0.0	0.0
- 50.0	159.7	0.0	0.0	0.0	365.1	547.4	365.1	0.0	0.0
- 60.0	114.3	0.0	0.0	0.0	257.4	399.3	257.4	0.0	0.0
- 70.0	65.4	0.0	0.0	0.0	142.0	239.0	142.0	0.0	0.0
- 80.0	14.5	0.0	0.0	0.0	22.2	71.5	22.2	0.0	0.0
- 90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

INSOLATION RECEIVED ON NOVEMBER 1st

DISTANCE TO SUN 1.4175 A. U.

INCLINATION OF AXIS 7.79 DEGREES

TIME (HRS.) LATITUDE	DAILY AVERAGE	0.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0
90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80.0	5.1	0.0	0.0	0.0	0.0	41.2	0.0	0.0	0.0
70.0	58.2	0.0	0.0	0.0	119.8	225.7	119.8	0.0	0.0
60.0	112.6	0.0	0.0	0.0	248.6	403.4	248.6	0.0	0.0
50.0	163.5	0.0	0.0	0.0	369.8	568.8	369.8	0.0	0.0
40.0	209.6	0.0	0.0	0.0	479.7	716.9	479.7	0.0	0.0
30.0	249.2	0.0	0.0	0.0	575.1	843.3	575.1	0.0	0.0
20.0	281.3	0.0	0.0	0.0	653.0	944.0	653.0	0.0	0.0
10.0	304.8	0.0	0.0	0.0	711.1	1016.1	711.1	0.0	0.0
0.0	319.0	0.0	0.0	0.0	747.6	1057.2	747.6	0.0	0.0
- 10.0	329.9	0.0	0.0	25.1	761.3	1066.3	761.3	25.1	0.0
- 20.0	330.7	0.0	0.0	49.4	751.9	1042.9	751.9	49.4	0.0
- 30.0	321.5	0.0	0.0	72.3	719.7	987.9	719.7	72.3	0.0
- 40.0	302.5	0.0	0.0	92.9	665.5	902.8	665.6	92.9	0.0
- 50.0	274.3	0.0	0.0	110.8	591.3	790.3	591.3	110.8	0.0
- 60.0	237.8	0.0	0.0	125.2	499.0	653.8	499.0	125.2	0.0
- 70.0	194.0	0.0	0.0	135.9	391.5	497.5	391.5	135.9	0.0
- 80.0	147.5	0.0	12.6	142.4	272.2	326.0	272.2	142.4	12.6
- 90.0	144.6	144.6	144.6	144.6	144.6	144.6	144.6	144.6	144.6

INSOLATION RECEIVED ON DECEMBER 1st

DISTANCE TO SUN 1.3807 A. U.

INCLINATION OF AXIS 19.50 DEGREES

TIME (HRS.)		0.0	3.0	6.0	9.0	12.0	15.0	18.0	21.0
LATITUDE	DAILY AVERAGE								
90.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70.0	1.2	0.0	0.0	0.0	0.0	9.8	0.0	0.0	0.0
60.0	38.1	0.0	0.0	0.0	49.7	205.0	49.7	0.0	0.0
50.0	97.8	0.0	0.0	0.0	194.3	393.9	194.3	0.0	0.0
40.0	154.6	0.0	0.0	0.0	333.0	570.9	333.0	0.0	0.0
30.0	206.7	0.0	0.0	0.0	461.5	730.5	461.5	0.0	0.0
20.0	252.5	0.0	0.0	0.0	576.1	867.9	576.1	0.0	0.0
10.0	290.6	0.0	0.0	0.0	673.1	978.9	673.1	0.0	0.0
0.0	319.9	0.0	0.0	0.0	749.7	1060.2	749.7	0.0	0.0
- 10.0	355.8	0.0	0.0	65.2	803.5	1109.3	803.5	65.2	0.0
- 20.0	380.9	0.0	0.0	128.4	832.9	1124.7	832.9	128.4	0.0
- 30.0	394.4	0.0	0.0	187.7	836.9	1105.9	836.9	187.7	0.0
- 40.0	395.9	0.0	0.0	241.3	815.6	1053.5	815.6	241.3	0.0
- 50.0	385.4	0.0	0.0	287.6	769.5	969.1	769.5	287.6	0.0
- 60.0	363.2	0.0	0.0	325.1	699.9	855.2	699.9	325.1	0.0
- 70.0	354.0	0.0	96.4	352.8	609.2	715.4	609.2	352.8	96.4
- 80.0	369.7	185.6	239.5	369.7	499.9	553.8	499.9	369.7	239.5
- 90.0	375.4	375.4	375.4	375.4	375.4	375.4	375.4	375.4	375.4

APPENDIX A

FORTRAN Program

COMPILE RUN FORTRAN

```
C    TS=NUMBER OF DAYS TO JANUARY 1ST  (COUNTED FROM PERIHELION)
C    TINC=NUMBER OF DAYS THAT T WILL BE INCREMENTED
C    T=TIME OF THE YEAR (VARIABLE)
C    EE=ECCENTRICITY OF THE ORBIT
C    THAT=CONSTANT ANGLE, 113.44 DEGREES
C    W=HEAT RECEIVED AT PERIHELION
C    THIN=INCREMENT OF LATITUDE
C    N=NUMBER OF HEAT CALCULATIONS PER DAY PER LATITUDE
C    TTT=INTERVAL OF TIME BETWEEN HEAT CALCULATIONS  (N*TTT=24)
C    A=DIMENSION OF ORBIT
C    PHIM=MAXIMUM INCLINATION OF AXIS.
          DIMENSION H(100),XXT(30)
          READ 51,TS,TINC,EE,THAT,W,THIN
          READ 53,N,TTT,A,PHIM
          K=180.0/THIN+1.0
          PI=3.1416/2.0
          T=TS/687.0
          XHAT=THAT*3.1416/180.0
          DD=(1.0+EE)/(1.0-EE)
          ABC=SQRTF(DD)
          DO 14 II=1,12
          IF(II-1)1,1,101
     101  IF(II-2)2,2,102
     102  IF(II-3)3,3,103
     103  IF(II-4)4,4,104
     104  IF(II-5)5,5,105
     105  IF(II-6)6,6,106
     106  IF(II-7)7,7,107
     107  IF(II-8)8,8,108
     108  IF(II-9)9,9,109
     109  IF(II-10)10,10,110
     110  IF(II-11)11,11,111
     111  PRINT 212
          GO TO 900
      11  PRINT 211
          GO TO 900
      10  PRINT 210
          GO TO 900
       9  PRINT 209
          GO TO 900
       8  PRINT 208
          GO TO 900
       7  PRINT 207
          GO TO 900
       6  PRINT 206
          GO TO 900
       5  PRINT 205
          GO TO 900
       4  PRINT 204
          GO TO 900
       3  PRINT 203
          GO TO 900
       2  PRINT 202
          GO TO 900
       1  PRINT 201
```

```
900 XM=2.0*3.1416*T
    E=XM+EE*SINF(XM)+0.5*EE*EE*SINF(2.0*XM)
    U=1.0/(1.0-EE*COSF(E))
    Z=U*U
    ES=E/2.0
    PP=ABC*SINF(ES)/COSF(ES)
    GNU=2.0*ATANF(PP)
    SL=GNU=XHAT
    PHI=PHIM*SINF(SL)
    R=A*SQRTF(1.0/Z)
    PHIX=PHI*3.1416/180.0
    F=PI+PHIX
    THATA=PI
    XXT(L)=0.0
    DO 52 KK=2,N
    KKK=KK-1
52  XXT(KK)=XXT(KKK)+TTT
    PRINT 22,R
    PRINT 23,PHI
    PRINT 24,(XXT(KK),KK=1,N)
    PRINT 25
    PRINT 26
    DO 13 J=1,K
    TT=-12.0/24.0
    FF=PI-THATA
    HT=0.0
    DO 20 I=1,N
    SS=COSF(F)*COSF(FF)+SINF(F)*SINF(FF)*COSF(4.0*PI*TT)
16  H(I)=W*Z*SS
    IF(H(I))17,17,18
17  H(I)=0.0
18  TT=TT+TTT/24.0
    HT=HT+H(I)
20  CONTINUE
    CCCC=N
    HAVE=HT/CCCC
    THATAX=180.0*THATA/3.1416
    PRINT 44,THATAX,HAVE,(H(I),I=1,N)
13  THATA=THATA-(3.1416/180.0)*THIN
    T=T+TINC/687.0
14  CONTINUE
201 FORMAT(1H1,20X,34HINSOLATION RECEIVED ON JANUARY 1ST)
202 FORMAT(1H1,20X,35HINSOLATION RECEIVED ON FEBRUARY 1ST)
203 FORMAT(1H1,20X,32HINSOLATION RECEIVED ON MARCH 1ST)
204 FORMAT(1H1,20X,32HINSOLATION RECEIVED ON APRIL 1ST)
205 FORMAT(1H1,20X,30HINSOLATION RECEIVED ON MAY 1ST)
206 FORMAT(1H1,20X,31HINSOLATION RECEIVED ON JUNE 1ST)
207 FORMAT(1H1,20X,31HINSOLATION RECEIVED ON JULY 1ST)
208 FORMAT(1H1,20X,33HINSOLATION RECEIVED ON AUGUST 1ST)
209 FORMAT(1H1,20X,36HINSOLATION RECEIVED ON SEPTEMBER 1ST)
210 FORMAT(1H1,20X,34HINSOLATION RECEIVED ON OCTOBER 1ST)
211 FORMAT(1H1,20X,35HINSOLATION RECEIVED ON NOVEMBER 1ST)
212 FORMAT(1H1,20X,35HINSOLATION RECEIVED ON DECEMBER 1ST)
```

```
51 FORMAT(8F10.3)
53 FORMAT(I10,7F10.3)
22 FORMAT(1H0,10X,15HDISTANCE TO SUN,2X,F7.4,2X,4HA.U.)
23 FORMAT(1H0,10X,19HINCLINATION OF AXIS,2X,F6.2,2X,7HDEGREES)
24 FORMAT(1H0,10HTIME(HRS.),9X,9(F5.1,5X))
25 FORMAT(1H ,10X,5HDAILY)
26 FORMAT(1H ,8HLATITUDE,1X,7HAVERAGE)
44 FORMAT(1H ,F7.1,F8.1,1X,9(F8.1,2X))
   STOP
   END

+38.0     +57.25    +0.0934   +113.44   +928.0    +10.0
        8 ++3.0     +1.52     -23.99
```

APPENDIX B

FORTRAN Program: Comments

Symbol	Statement
TS -	Number of days to January 1st counted from the perihelion. January 1st is the day that the winter solstice occurs in the southern hemisphere. This is the time that the inclination of the planet is most negative. The inclination is called PHI in the program. This time corresponds to the time when L_S (called SL in the program) = 270°. With this information, the mean anomaly can be calculated, and from this time of the year, T, can be found. The winter solstice occurs 725 days into the orbit or 725-687 = 38.0 days past the perihelion.
TINC -	It was decided to make the Martian year have 12 months. The period of revolution = 687 days (Martian days) = earth days; therefore, each Martian month has 687/12 = +57.25 days/month = TINC. (T incremented)
T -	Time of the year (variable)
EE -	Eccentricity of the orbit = 0.0934
THAT -	is an angle (in degrees) that is described by the arc (θ) shown in Fig. 1. This number is a constant. The value of (THAT) used in the program was 113.44°.
W -	is the heat received at the perihelion = 928.0 cal/cm^2-day
THIN -	The increment of latitude = 10.0
N -	Number of heat calculations per day per latitude = 8.0
TTT -	Interval of time between heat calculations = 3.0 [such that N times TTT = 24].
A -	Dimension of orbit = 1.52
PHIM -	Maximum inclination of axis = -23.99

From the computer printout:

$K = \frac{18}{THIN} + 1$ This statement tells the computer how many lines of data are to be printed

$PI = \pi/2$

$T = TS/687$ This converts the starting time, in days, to a fractional part of the Martian year.

$XHAT = (THAT)\frac{\pi}{180.0}$ Converts (THAT) in degrees to radians

$DD = \frac{1+e}{1-e}$ where e is the eccentricity of the orbit

$ABC = \sqrt{\frac{1+e}{1-e}}$

900 $XM = 2\pi T$ This is the mean anomaly

$E = XM + e\sin(XM) + \frac{1}{2}e^2\sin(2XM)$ This is the eccentric anomaly and is Eq. (6) in the text.

$U = \frac{1}{1-e\cos(E)} = \frac{a}{R}$ (Eq. 6a in the text)

$Z = \frac{a^2}{R^2}$

a = distance in A.U. from the sun to the vertex of the orbit

R = radial distance of the planet to the sun

$ES = \frac{E}{2}$ Starting to compute γ (see Eq. (7))

$PP = \sqrt{\frac{1+e}{1-e}}\left(\frac{\sin(E/2)}{\cos(E/2)}\right) = \sqrt{\frac{1+e}{1-e}}\tan\left(\frac{E}{2}\right)$

$GNU = \gamma$ (Eq. (7)) $= 2\arctan\left[\sqrt{\frac{1+e}{1-e}}\tan\left(\frac{E}{2}\right)\right]$

$SL = GNU - XHAT$ This is Eq. (8).

$PHI = -PHIM\ SIN(SL)$ This is Eq. (9) where $PHI = D_S$ or the inclination of the planet's axis to the Martian orbit. PHIM is the maximum inclination. The minus sign comes from the face that the inclination (in the Ephemeris[3]) is measured from the sun instead of from the planet.

$R = a \frac{1}{z} = a \frac{r^2}{a^2} = r$ This is the radial distance of the planet to the sun.

$PHIX = PHI(\frac{\pi}{180})$ This converts the inclination to radians

$F = PI + PHIX$

$= \frac{\pi}{2} + PHIX$ Starting to compute angles of surfaces of the planet

$THATA = PI = \frac{\pi}{2}$ This is a variable (latitude) with an initial value of $\pi/2$ (starts at North Pole)

XXT(1) = 0 through PRINT 26 These statements just print the headings and labels on the printout

DO 13 J = 1,K Within this loop is contained all of the heat calculations for any given time (month) of the year

$TT = -\frac{12}{24}$ Assuming that the Martian day has 24 hours, the calculations are started at midnight or at a point on the Martian sphere directly opposite the noontime sun. TT is variable.

$FF = \frac{\pi}{2} - THETA$ (Refer Fig. 2)

SS = COS(S) (Refer Fig. 2)

HT = 0 This sets the accumulated heat received at any latitude during a Martian day equal to zero.

DO 20 I=1,N This loop within the first loop does all the heat calculations for any particular latitude.

$SS = COS(F)COS(FF)+sin(F)sin(FF)cos(2\pi TT)$ This is a relation of the sides and angles in a spherical triangle. The various angles are shown in Fig. 2. If SS is zero or negative this means that the particular part of the Martian surface is not receiving any sunlight and therefore cannot receive any heat. This is the reason for Statement 17 and the statement before it.

16 H(I) = (W) (Z) (SS) This is the actual heat computation.

W is the heat received at perihelion on a surface to the sun's rays. $W = (\frac{R^2}{a^2})S(1-A)_{max} = 928 \frac{cal}{cm^2\text{-day}}$. SS takes into account the fact that most surfaces are not to the sun's rays.

$Z = \frac{a^2}{r^2}$ This takes into account the fact that the amount of heat received varies as the inverse square of the planet's distance to the sun.

18 $TT = TT + \frac{TTT}{24}$ This statement increments the time of the day so a new calculation of the same latitude may be started.

HT = HT + H(I) This just adds up the heat from each calculation.

HAVE = HT/CCCC This averages the heat received:

$$\frac{\text{Total heat calculated during 24 hr.}}{\text{Number of calculations}}$$

THATAX = $(\frac{180}{\pi})$ THATA Converts THATA (radians) to degrees to be used for printout.

PRINT 44 This prints one line of data.

13 THATA = THATA - $(\frac{\pi}{180})$THIN This moves the latitude by the set increment. Calculations start from the North Pole and go to the South Pole. This is the end of the calculations for any given month.

$T = T + \frac{TINC}{687}$ This moves the program to a new month and a new set of heat calculations.