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Solar Radiation Incident on the Martian Surface

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Summary. Calculations indicate that the maximum daily solar radiation reaching the Martian surface is about 325 cal/cm^2 during southern hemisphere summer at latitude of about 40^o S. In the ultraviolet region of the spectrum, the radiation reaching the surface at wavelengths greater than 2800 Å is within 10% of the radiation incident on the atmosphere. There is significant extinction of radiation in the spectral region near 2500 Å in mid and high latitudes due to absorption of radiation by ozone; radiation reaching the surface may be reduced to one one-thousandth of that incident on the atmosphere during winter. Virtually no radiation of wavelengths less than 1900 Å reaches the surface because of absorption by the large column abundance of carbon dioxide. Daily and latitudinal distributions of radiation are presented for wavelengths of 3000, 2500 and 2000 Å.

Key words: Mars – Solar radiation

Introduction

The solar radiation reaching the surface of a planet for a given latitude and time depends upon the energy incident on the atmosphere, the amount of those gases and dust within the atmosphere that absorb the radiation, and the scattering of radiation by molecules, dust, and clouds. In addition the eccentricity of the planetary orbit, the inclination of the rotation axis to the ecliptic, and the revolution and rotation rate influence the spatial and temporal distribution of the radiation.

Mars is half again as far from the sun as the earth, so that the solar radiation incident on the Martian atmosphere is 43% of that incident on the earth's atmosphere. Thus the "solar constant" for Mars, i.e. the energy incident on one square centimeter at the mean distance of Mars from the sun is 0.83 calories/cm^2/min. On earth, as solar radiation traverses the atmosphere, about 19% is absorbed by water vapor and to a lesser extent by dust, ozone, and clouds. 20% is reflected back to space by clouds, while air molecules scatter 6%. Thus approximately 55% of the total solar radiation reaches

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the surface. The situation is much different on Mars. The column abundance[1] of the water vapor in the atmosphere is only 10^{-3} of that found in the terrestrial atmosphere; since water vapor is one of the primary absorbers of solar radiation ($\lambda > 0.7\mu m$), most will penetrate the Martian atmosphere and reach the surface for wavelengths longer than 3000 Å. Although there is thirty-five times as much carbon dioxide in the Martian atmosphere as on earth, carbon dioxide does not absorb solar radiation in the visible portion of the spectrum but only at wavelengths greater than about 1.5 μm where the amount of energy is small. Thus, molecular absorption of visible radiation in the clear atmosphere of Mars is not nearly so important as it is on earth.

As previously mentioned, air molecules scatter about 6% of the terrestrial radiation back to space. This scattering, known as Rayleigh scattering, depends on the atmospheric column density which is proportional to the air pressure at the surface of the planet. On Mars this is less than 10^{-2} of that on earth. Thus Rayleigh scattering of visible radiation on Mars is small, being less than 1% for wavelengths greater than 3500 Å. Rayleigh scattering does become more important at the shorter wavelengths since the scattering varies inversely as the fourth power of the wavelength.

Dust in a planetary atmosphere attenuates the solar radiation by both absorption and scattering. Dust amounts in both the Martian and terrestrial atmospheres are highly variable in both space and time. The attenuation is a function of wavelength and depends upon the aerosol number densities, size distributions and indices of refraction. In the earth's atmosphere, the extinction of visible solar radiation by aerosols is generally less than 20% (see e.g., Paltridge and Platt, 1976). Dust in the Martian atmosphere is highly variable. During the great dust storm of 1971, the optical depth[2] was 2 (Masursky, et al., 1972) corresponding to a transmission of radiation of only 15% For clear sky conditions, the optical depth is a few tenths.

Clouds in the terrestrial atmosphere obscure approximately 50% of the earth's surface and thus reflect much of the visible radiation back to space. Clouds also occur in the Martian atmosphere although they are not as extensive. They appear in the fall and winter seasons above latitudes of about 45° and are highly variable in both space and time. They sometimes appear as wave clouds but also as cloud layers which may be thick or quite diffuse (see e.g., Barth and Dick, 1974). The optical properties of these clouds are not known, and we have not attempted to include them in our calculations of the radiation reaching the surface. Thus one should keep in mind that our estimates of radiation at the Martian surface are somewhat large for wintertime, high latitude conditions.

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[1] The column abundance of a gas in an atmosphere is the amount in a column one square centimeter in cross section extending from the surface to the top of the atmosphere. Units may be grams of the gas (gms/cm^2) or the height of the column of that gas if reduced to standard temperature and pressure (e.g., μm-atm, or cm-atm).

[2] Optical depth (τ) is a measure of the extinction of radiation in an atmosphere. It is the product of the absorption or scattering cross section times the column abundance of the absorbing or scattering constituent. The transmission of radiation is $\exp(-\tau)$.

Distribution of Total Solar Radiation Incident on the Martian Surface

We show in Fig. 1 the total solar radiation reaching the Martian surface for clear sky conditions (optical depth of 0.35 which corresponds to a transmission of 70%). The methodology was given in a previous paper and will not be repeated here (Levine et al., 1977). The overall pattern of the radiation field on Mars is similar to that for earth since the angles of inclination of the axes of rotation are nearly the same. One should note however the asymmetry between the corresponding seasons; during southern hemisphere summer, the radiation is some 50% larger than that reaching the surface during northern hemisphere summer. This occurs because the orbital eccentricity of Mars is quite large, 0.093, and during southern hemisphere summer, Mars is closer to the sun than during northern hemisphere summer. During summer there is little variation in the incident radiation with latitude, the maximum occurring near 40° latitude. During winter the radiation decreases uniformly with increasing latitude. It is interesting to note that during northern hemisphere summer and winter, Mars receives about 55% as much radiation as does the earth at mid-latitudes, while for the southern hemispheres the percentages are about 84% and 53% for summer and winter, respectively. The larger terrestrial cloud cover compensates to some extent the smaller radiation incident on Mars because it is farther from the sun.

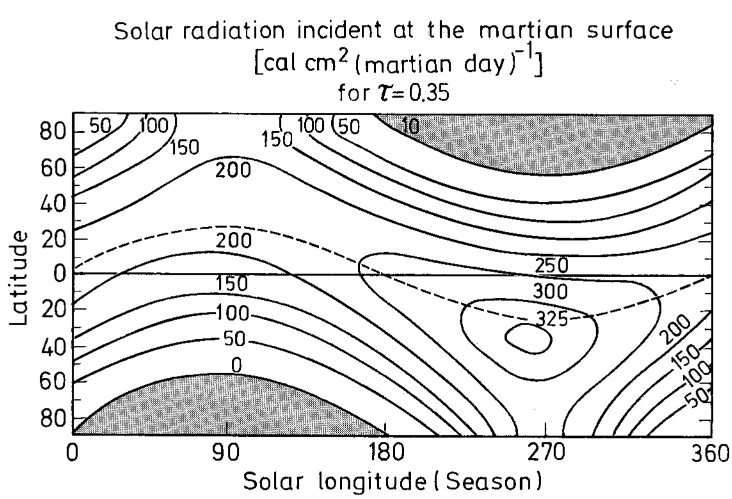

Fig. 1. Seasonal and latitudinal distribution of total solar radiation reaching the Martian surface. The optical depth $\tau = 0.35$ corresponds to an average transmission of 70%. The dashed line is the solar declination. Solar longitudes of 0°, 90°, 180°, and 270° correspond to northern hemisphere spring, summer, fall, and winter respectively. The Viking landers are at latitudes of 22.5° and 47.9° N

Ultraviolet Radiation Incident on the Martian Surface

The ultraviolet radiation reaching the surface of Mars is very much greater than that reaching the earth's surface and it has been speculated that this radiation may react with the Martian soils in as yet unknown ways. Ultraviolet radiation of wavelengths less than 3000 Å does not penetrate to the earth's surface because it is absorbed by molecular ozone and oxygen. For example, at 3000 Å only 4% of the radiation reaches the surface of earth while virtually none reaches the surface at 2000 Å. The ozone column abundance on Mars is highly variable but it can be as large as 60 μm-atm during high latitude winter conditions (Barth, 1974) which is still only 2% of that in the terrestrial atmosphere.

The methodology for calculation of the ultraviolet radiation reaching the surface is similar to that used by Levine et al. (1977). The radiation incident on the planet per unit area, per Martian day, per unit wavelength can be found by numerically integrating the following expression:

$$E = 2Sa^2/\omega r^2 \int_0^{h_o} (\cos h \cos \delta \cos \phi + \sin \delta \sin \phi) \times \exp(-\tau/(\cos h \cos \delta \cos \phi + \sin \delta \sin \phi))dh \quad (1)$$

where S is the ultraviolet radiation (energy/Å s) incident on the atmosphere when Mars is at its mean distance (a) of 1.524 A.U. from the sun, r is the instantaneous distance of Mars from the sun, ω is the angular speed of rotation of the planet, δ is the solar declination, ϕ is latitude, and h is the hour angle; h_o is the hour angle of sunrise. The optical depth τ includes Rayleigh scattering and absorption by carbon dioxide and ozone. We calculated the Rayleigh cross section to be $9.03 \times 10^{-12}/\lambda^4$ where λ is the wavelength in Angstroms. The ozone cross sections and solar flux incident on the atmosphere are from Ackerman (1971) and carbon dioxide cross sections are from Banks and Kockarts (1973).

We show in Fig. 2 the calculated ultraviolet radiation reaching Mars surface at 50° N latitude during spring and fall. Also included is the radiation incident on the atmosphere. The minimum in the radiation reaching the surface at 2550 Å is due to absorption by the Hartley band of ozone. On earth only 10^{-34} of this incident radiation reaches the surface, while on Mars the reduction is about 10^{-2}. These calculations were made for a Martian column abundance of 35μm-atm; for the maximum observed ozone amount (60μm-atm), the reduction in solar radiation would be about 10^{-3}. During the summer the column abundance is less than 3μm-atm in the polar regions (attenuation of 10%), while in equatorial regions no ozone has been measured during any season.

The second feature in Fig. 2 that one should note is that for wavelengths of 2000 Å and less, virtually no radiation reaches the Martian surface. This is due to absorption by carbon dioxide which comprises about 95% of the Martian atmosphere. Although the absorption cross section is only 5×10^{-23} cm^2 at 1950 Å, the large amount of carbon dioxide (column abundance of 2.3×10^{23} cm^{-2}) yields an optical depth of 11.5 so that only about 10^{-5} of the incident radiation reaches the surface. The absorption cross section increases to nearly 10^{-18} cm^2 in the spectral region of 1300 to 1500 Å (Banks and Kockarts, 1973). Below 1200 Å carbon dioxide will dissociate.

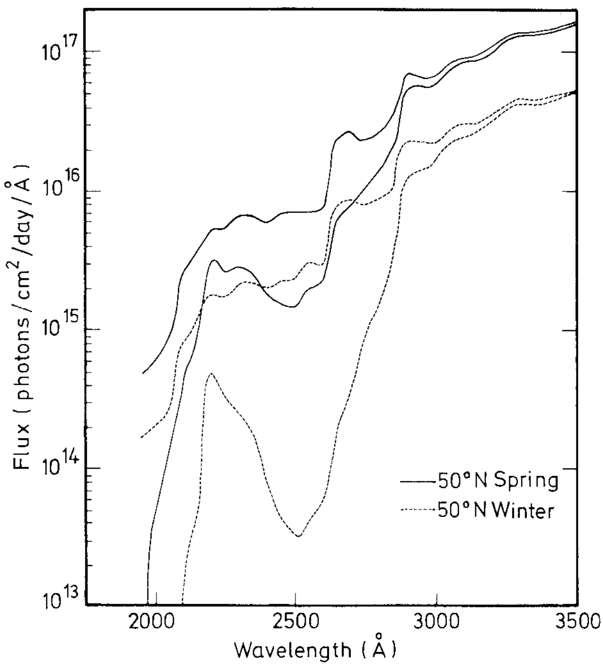

Fig. 2. A comparison of the radiation incident on the Martian atmosphere and at the surface for 50° N Spring and 50° N Winter. The uppermost curve for each season corresponds to the radiation incident on the atmosphere

The ionization edge occurs at 986 Å. Cross sections are about 10^{-17} cm^2. Thus carbon dioxide will shield the surface from any of this short wavelength radiation (Hudson, 1971).

Minor constituents in the Martian atmosphere will also absorb this short wavelength radiation but their contribution is negligible in comparison to the absorption by the large amount of carbon dioxide present. Water vapor absorption will occur beginning at wavelength about 1860 Å and reaching a maximum at 1450 Å with cross section of 5×10^{-18} cm^2. Molecular oxygen begins to absorb radiation at 2400 Å with cross section of 10^{-24} cm^2 but its column abundance is only about 10^{20} cm^{-2} so that the extinction of radiation at 2000-3000 Å is small.

Although scattering of radiation by the Martian air molecules (Rayleigh scattering) does contribute to the total extinction of ultraviolet radiation, the absorption by carbon dioxide dominates below about 2000 Å. The cross sections for both carbon dioxide absorption and Rayleigh scattering are equal (4×10^{-25} cm^2) at about 2200 Å. The extinction of ultraviolet radiation at 2500 Å for Rayleigh scattering is about 7% and is less than 1% at 3000 Å.

The variations of ultraviolet solar radiation with latitude reaching the surface at wavelengths 3000, 2500, and 2000 Å are shown in Figs. 3a, b, and c. At 3000 Å there is little atmospheric absorption and scattering so that the latitudinal distribution is similar to that of the solar radiation incident on the atmosphere. The photon flux

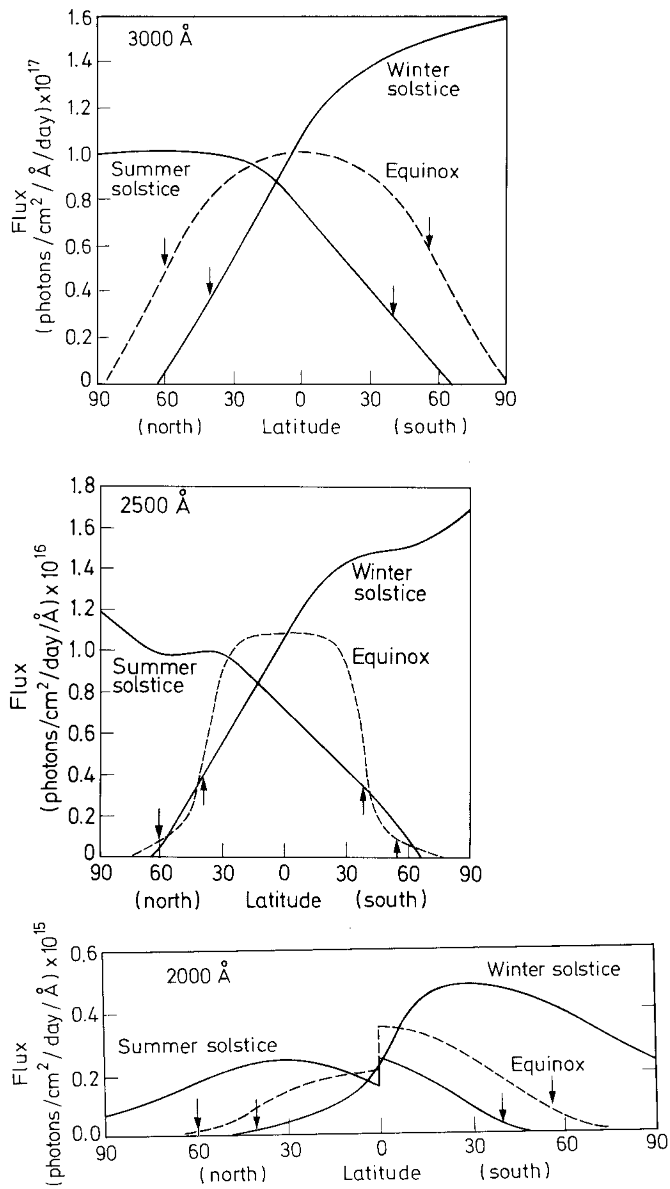

Fig. 3(a). Latitudinal distribution of daily solar radiation at 3000 Å reaching the Martian surface. The arrows refer to the edge of the polar hood; **(b).** Latitudinal distribution of daily solar radiation at 2500 Å reaching the Martian surface. The arrows refer to the edge of the polar hood; **(c).** Latitudinal distribution of daily solar radiation at 2000 Å reaching the Martian surface. The arrows refer to the edge of the polar hood is larger during southern hemisphere summer than during northern hemisphere summer, since Mars is closer to the sun during southern hemisphere summer. One should note that we have not considered reflection of radiation by the polar hood, the ice cloud that veils the polar cap, so that in polar latitudes the radiation shown is somewhat too high.

At 2500 Å (Fig. 3b) the photon flux is about one-tenth that at 3000 Å. The latitudinal distribution is somewhat different; there is enough absorption at 2500 Å so that now during the summer seasons the maximum in the radiation is beginning to shift toward lower latitudes. This is clearly seen in Fig. 3c where the absorption is so large that the maximum coincides with the solar declination. The discontinuity which appears at the equator results from our assumption that the surface pressure in the southern hemisphere is less than in the northern hemisphere. The mean surface elevation of the southern hemisphere is 4 km higher (Woiceshyn, 1974) than the elevation in the northern hemisphere and thus the pressure and carbon dioxide amount in the southern hemisphere are less, and more radiation reaches the surface. There is, of course, not an abrupt change in elevation across the equator and the radiation reaching the surface would not change as rapidly as shown in Figs. 3c and 4.

Finally we show the yearly photon flux for four wavelengths. At 3000 and 3500 Å there is about three times as much radiation reaching the surface near the equator than at the poles. The slight asymmetry is due to Mars being closer to the sun during

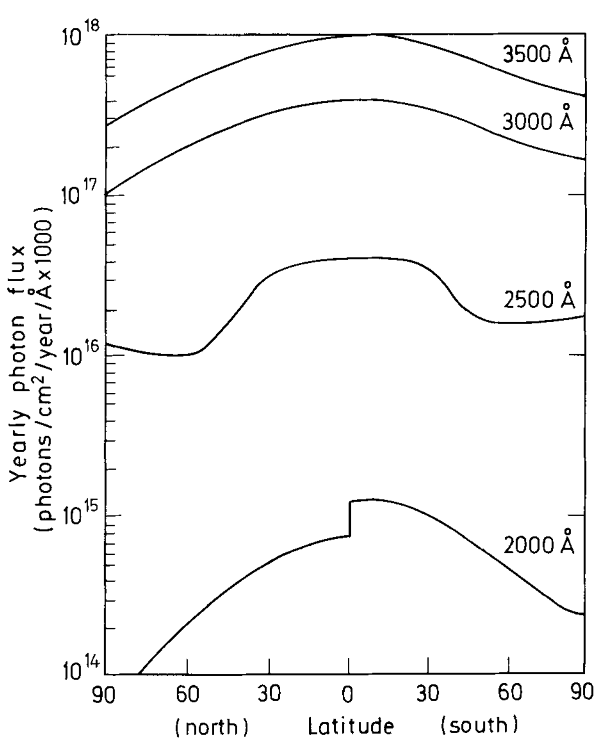

Fig. 4. Latitudinal distribution of yearly solar radiation incident on the Martian surface

southern hemisphere than during northern hemisphere summer. At 2500 Å, ozone absorbs the radiation at mid and high latitudes so that there is little latitudinal variation beyond about 45^{o} latitude. At 2000 Å, absorption by carbon dioxide dominates and there is more than an order of magnitude difference in the received radiation between equator and pole. For shorter wavelengths the photon flux would be negligibly small.

Thus we have shown that the total radiation incident on Mars surface, relative to the earth, is somewhat larger (10-20%) than one would expect by simply considering their relative distances from the sun. In the ultraviolet region of the spectrum from 2000 to 3000 Å, Mars surface receives much more radiation than does the earth. Below about 1900 Å, no radiation reaches the surface.

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