THE INFLUENCE OF GLOBAL DUST STORMS ON THE MEAN SEASONAL DAILY INSOLATIONS AT THE MARTIAN SURFACE

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Abstract. In this paper, we compare changes in the mean seasonal daily insolations at the Martian surface caused by global dust storms characterized by various atmospheric optical thickness (τ). The calculations, made for optical depths equal to 0, 0.1, 0.5, 1.0, 2.0, and 3.0, are based on the assumption of planet encircling storms lasting one season or one year. The variations in the latitudinal and seasonal surface insolation distributions are important, mainly at the poles where e.g. the mean annual and summer daily insolations decrease by nearly a factor of 3000 as τ goes from 0 to 3.0. At equatorial latitudes the corresponding loss is much smaller, reaching a value of approximately 40. Concerning the mean wintertime solar radiations it is found that the decrease is even more spectacular, especially at high latitudes.

1. Introduction

The solar radiation incident at the top of the atmosphere of Mars as a function of latitude (φ) and solar longitude ($\lambda_\odot$) and taking into account the currently adopted values of the eccentricity (e), the obliquity (ϵ) and the longitude of the perihelion (λ_p) has been computed and discussed by e.g. Vorob'yev and Monin (1975) and Levine *et al.* (1977). Variations in the insolation on the planet caused by periodic oscillations of the above mentioned dynamic parameters were presented by Murray *et al.* (1973), Ward (1974), and Van Hemelrijck (1983). Van Hemelrijck (1982a) studied also the influence of the oblateness on the solar energy input at the upper-boundary of Mars. Finally, the effect of atmospheric aerosols on the surface insolation has been investigated by Levine *et al.* (1977).

It should, however, be noted that in the latter work emphasis is placed on the daily insolation and on the mean annual daily insolation. In this short paper, we mainly accentuate the impact of global dust storms on the mean summer and winter daily insolations over the entire latitudinal interval.

Of all the global dust storms (also often called planetwide dust storms, great dust storms) listed in the literature, there exist only five well documented cases of planet-encircling storms on Mars; these were in 1956, 1971, 1973 and 2 in 1977 (Martin, 1984). They start as local dust storms, mostly during the southern hemisphere summer at subtropical latitudes and in favored regions. This is probably due to the fact that at this period the wind speeds reach their peak as the solar radiation is maximized at the perihelion passage of the planet. Although the dust optical thickness has typical values of no more than a few tenths, it was found that when local dust storms grow to global dimensions, the optical depth increases considerably and may attain values ranging from 3 to even 6. For more details about the great Martian dust storms we refer to Pollack *et al.* (1979), Pollack and Toon (1982), Toon *et al.* (1980), Zurek (1981, 1982) and Martin (1984).

In a first section, we briefly summarize some expressions needed for the calculation of the mean (annual, summer and winter) daily insolations incident on a planetary surface. Then, we discuss the results obtained with optical depths equal to 0, 0.1, 0.5, 1.0, 2.0, and 3.0.

2. Mean Daily Surface Insolation

In this work and for the northern hemisphere the summer period is arbitrary defined as running from vernal equinox over summer solstice to autumnal equinox and spanning a solar longitude of 180°; as a consequence, $\lambda_\odot = 180°$ and $\lambda_\odot = 360°$ represent the beginning and the end of the winter season. In the southern hemisphere, the solar longitude intervals (0–180°) and (180–360°) divide the year into astronomical winter and summer respectively.

The daily surface insolation may be expressed as (see e.g. Levine *et al.*, 1977)

$$I_{Ds} = [S_0 T(1 + e \cos W)^2 / \pi a_\odot^2 (1 - e^2)^2] \int_0^{h_0} \cos z \exp(-\tau \sec z)\, dh, \quad (1)$$

where S_0 is the solar constant at the mean Sun–Earth distance of 1 AU taken at 1.96 cal cm^{-2} (min)$^{-1}$ or 2822.4 cal cm^{-2} (day)$^{-1}$ (Wilson, 1982), T is the sidereal day, e is the eccentricity, W is the true anomaly, $a_\odot$ is the semi-major axis, h_0 is the local hour angle at sunset (or sunrise), z is the zenith angle and τ, as already mentioned, is the atmospheric optical thickness.

Furthermore, W and $\cos z$ can be calculated from the following well-known relationships

$$W = \lambda_\odot - \lambda_p \quad (2)$$

and

$$\cos z = \sin \varphi \sin \delta_\odot + \cos \varphi \cos \delta_\odot \sin h, \quad (3)$$

where the solar declination ($\delta_\odot$) is given by

$$\delta_\odot = \arcsin(\sin \epsilon \sin \lambda_\odot). \quad (4)$$

Finally, h_0 may be determined from expression (3) by the condition that at sunset (or sunrise) the zenith distance equals $\pi/2$. It follows that

$$h_0 = \arccos(-\tan \delta_\odot \tan \varphi) \quad (5)$$

if $|\varphi| < \pi/2 - |\delta_\odot|$.

In regions, where the Sun does not rise ($\varphi < -\pi/2 + \delta_\odot$ or $\varphi > \pi/2 + \delta_\odot$), we have $h_0 = 0$; in regions, where the Sun remains above the horizon all day ($\varphi > \pi/2 - \delta_\odot$ or $\varphi < -\pi/2 - \delta_\odot$), we may put $h_0 = \pi$. Note that Equation (1) has to be solved numerically.

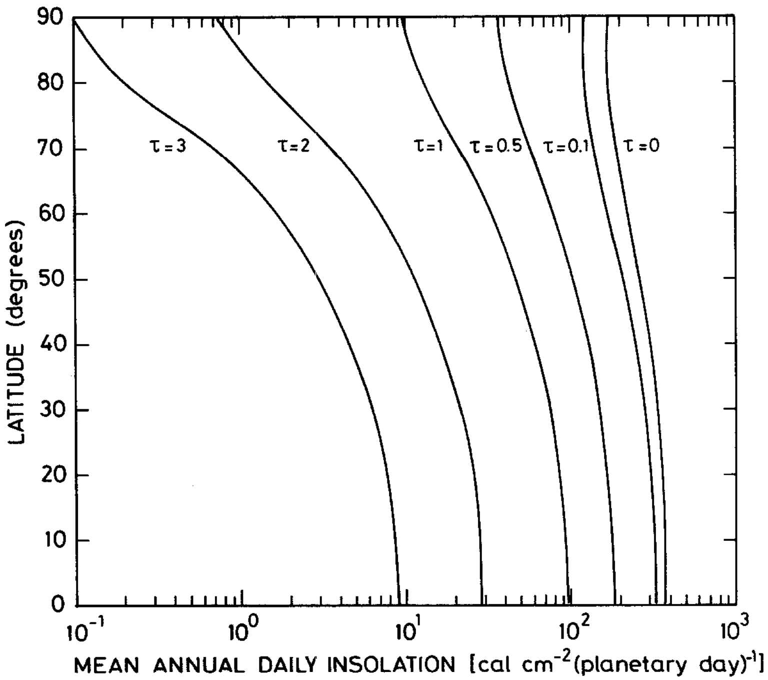

Fig. 1. Latitudinal variation of the mean annual daily insolation at the top of the atmosphere ($\tau = 0$) and at the surface of Mars ($\tau = 0.1$ to 3.0) and for the currently adopted values of the eccentricity, the obliquity and the longitude of the perihelion.

The mean (annual, summer or winter) daily surface insolations, hereafter denoted as $(\bar{I}_{Ds})_A$, $(\bar{I}_{Ds})_S$, and $(\bar{I}_{Ds})_W$ respectively, may be found by integrating numerically relation (1) within the appropriate time limits, yielding the total surface solar radiation over a year or over a season, and by dividing the obtained result by the tropical year (T_0) or by the corresponding length of the summer (T_S) or winter (T_W). For the calculation of T_S or T_W we refer to Van Hemelrijck (1982b).

In the following section, and as already mentioned in the introduction, we compare the mean solar radiations at the upper-boundary of Mars ($\tau = 0$) with the surface insolations for relatively clear sky conditions ($\tau = 0.1$ and 0.5) and with those characterized by atmospheric turbidities equal to 1.0, 2.0, and 3.0 respectively. Cases where $\tau > 3.0$ were not taken into account owing to the extremely small values of the solar energy falling on the Martian surface.

3. Discussion of the Distribution of the Solar Radiations

Figures 1, 2 and 3 illustrate respectively $(\bar{I}_{Ds})_A$, $(\bar{I}_{Ds})_S$, and $(\bar{I}_{Ds})_W$ as a function of latitude and optical thickness and for values of e, ϵ, and λ_p equal to 0.09339, 25°.2 and 248° (present values). The mean annual daily solar radiations being perfectly symmetric

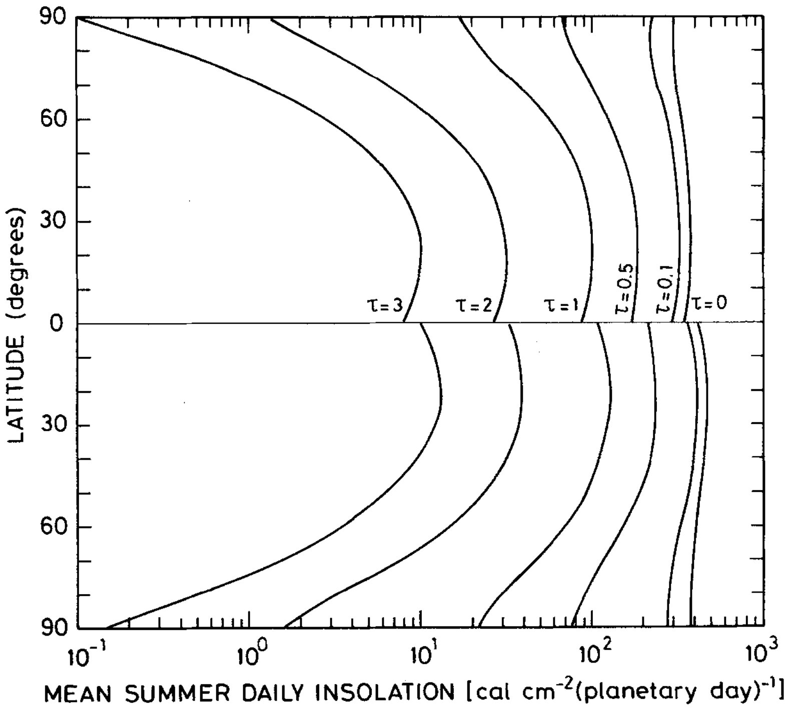

Fig. 2. Latitudinal variation of the mean summer daily insolation at the top of the atmosphere ($\tau = 0$) and at the surface of Mars ($\tau = 0.1$ to 3.0) and for the currently adopted values of the eccentricity, the obliquity and the longitude of the perihelion.

with respect to the equator, we only plotted the curves corresponding to the northern hemisphere. Furthermore, it is obvious that the non-coincidence at the equator of the curves representing the mean seasonal daily insolations (Figures 2 and 3) is due to the arbitrary chosen definition of the summer and winter in both hemispheres.

3.1. Mean Annual Daily Insolation

The mean annual daily solar radiations at the top of the atmosphere ($\tau = 0$) and at the surface of Mars for atmospheric optical thickness conditions $\tau = 0.1$, 0.35, and 2.0 are tabulated (from $\varphi = 0°$ to $\varphi = 85°$) in the paper by Levine *et al.* (1977). As mentioned by the authors, the mean annual daily insolation at the Martian poles decreases by more than a factor of 100 as τ increases from 0.1 to 2.0 during a great Martian dust storm. Moreover, the loss of solar radiation in going from the same minimum optical depth to e.g. $\tau = 3.0$ is even more spectacular as can be seen from Figure 1: the ratio of both insolations amounts to about 2000 as τ changes from 0.1 to 3.0. As τ goes from 0 to 3.0 the decrease of insolation attains values of approximately 3000.

The calculations also reveal that the rate of decrease of the radiation from the Sun is latitudinal dependent, reaching a minimum value at the equator. For $\varphi = 0°$ and when τ

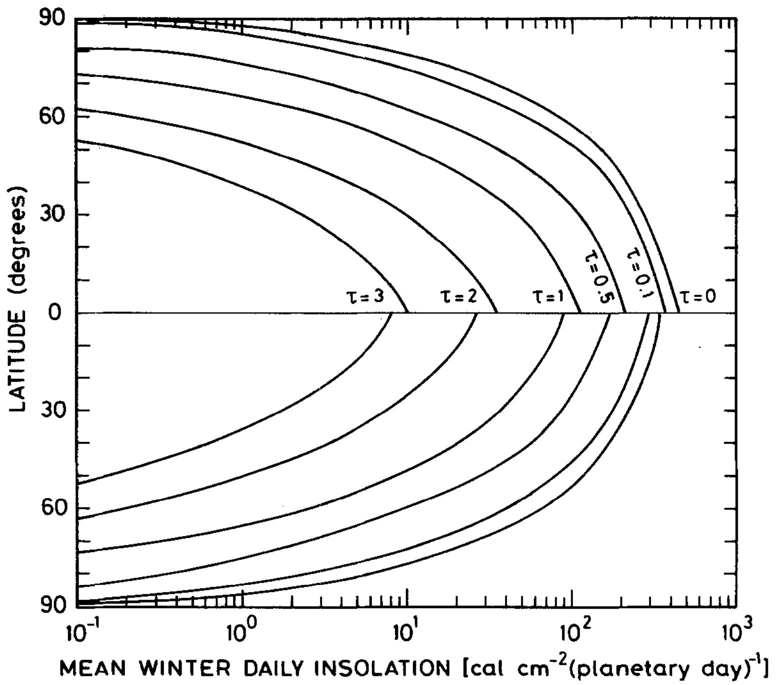

Fig. 3. Latitudinal variation of the mean winter daily insolation at the top of the atmosphere ($\tau = 0$) and at the surface of Mars ($\tau = 0.1$ to 3.0) and for the currently adopted values of the eccentricity, the obliquity and the longitude of the perihelion.

rises from 0.1 to 2.0 and 3.0, the mean annual daily surface insolation decreases with a factor of approximately 10 and 40 respectively, indicating that the attenuation of the average yearly incoming solar radiation is much higher at the poles than at the equator.

It is also evident that the reduction of the solar radiation from the $\tau = 0$ level is much more significative than the one obtained from an optical depth equal to 0.1; the difference is of the order of 15 and 40% at the equator and the poles respectively.

Figure 1 also clearly demonstrates that at equatorial latitudes and for constant values of τ, the solar energy input is only weakly dependent on φ.

3.2. Mean Summer Daily Insolation

The mean summer daily insolation for the six values of the atmospheric optical thickness is depicted in Figure 2. A striking difference with Figure 1 exists in that the distribution of the solar radiation curves is asymmetric with respect to the equator.

The rate of decrease of the mean summertime insolation as a function of latitude is practically similar to the loss of solar radiation averaged over a year.

When comparing Figure 1 with Figure 2 it is also obvious that $(\bar{I}_{Ds})_A$ increases over the entire latitudinal interval with decreasing φ, whereas the mean summer daily insolation $(\bar{I}_{Ds})_S$ reaches a minimum value between a latitude of about 30 ($\tau = 0$) and 20° ($\tau = 3.0$).

3.3. Mean Winter Daily Insolation

The mean wintertime insolation is given in Figure 3. Although at the equator the rate of absorption of the solar radiation by wind-blown dust is nearly equal to the one obtained in summer or over the year, it has been emphasized that at other latitudes the situation is obviously different in that the rate of decrease is much higher. For example, the mean summertime insolation at a latitude of 40° declines by a factor of about 1.2, 2, 4, 15, and 50 as τ enhances from 0 to 0.1, 0.5, 1.0, 2.0, and 3.0 respectively. For the mean winter daily insolations the corresponding values amount to about 1.3, 3, 8, 50, and more than 250.

As can be seen from Figure 3, $(\bar{I}_{Ds})_W$ is a monotonically decreasing function with a peak value at the equator and a minimum one equal to zero at both poles.

4. Concluding Remarks

This short study clearly demonstrates that the distribution of the Martian seasonal or yearly surface insolations can significantly be influenced by changes in the atmospheric optical thickness resulting from planet-encircling storms. It follows that the meteorology and the climatology of the planet Mars is strongly dependent upon those storms.

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