THE OBLATENESS EFFECT ON THE MEAN SEASONAL DAILY INSOLATIONS AT THE MARTIAN SURFACE DURING GLOBAL DUST STORMS

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Abstract. In this short paper, the combined effect of global dust storms and the oblateness on the mean seasonal daily insolations at the Martian surface is investigated. Due to the flattening, the mean summertime insolation is increased at equatorial and low latitudes, decreased at mid- and high latitudes. When comparing a spherical with an oblate planet Mars, it is found that the percentage differences of the mean summer daily insolations are dependent upon the optical depths (τ) considered. For an atmosphere without aerosols, the maximum percentage differences are respectively equal to + 0.05 and − 0.2%; at $\tau = 3.0$ the corresponding values amount to about 0.1 and 2%. In winter, the mean daily insolations are decreased over the entire latitudinal interval, where the maximum values are found at polar region latitudes; at e.g. a latitude of 85° the loss of solar energy enhances from 2 ($\tau = 0.0$) to more than 30% ($\tau = 3.0$). The mean annual daily insolation is maximally reduced by about 0.5 and 2% for optical thicknesses of 0.0 and 3.0, respectively.

1. Introduction

The oblateness effect on the solar radiation incident at the top of the atmosphere of Mars and the influence of global dust storms on the mean seasonal daily insolations at the Martian surface, the planet being considered as a sphere, have been separately studied in two papers by Van Hemelrijck (1982a, 1985).

It is found that for latitudes equatorward of the subsolar point, the mean summer daily insolation of an oblate planet Mars and for an optical depth (τ) equal to zero, is increased when compared to a spherical one, the rise being extremely small ($\sim 0.05\%$). At higher latitudes, there is a loss of insolation which is of most importance at mid-latitude regions ($\sim 0.2\%$). In winter, the mean daily insolation is reduced over the entire latitudinal interval reaching a peak value of 2% at high and polar region latitudes. Despite of the partial gain of the mean summertime insolation near the equator, the effect of the flattening can clearly be seen to reduce the daily insolation averaged over the year.

The calculations with regard to atmospheric aerosols were made for optical thicknesses equal to 0.0, 0.1, 0.5, 1.0, 2.0, and 3.0. The variations in the latitudinal and seasonal surface insolation distributions were 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 0.0 to 3.0. At equatorial latitudes, the corresponding loss is much smaller, attaining a value of approximately 40. Concerning the mean wintertime solar radiations it is found that the decrease is even more spectacular,

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especially at high latitudes. Similar calculations but for the mean annual daily solar radiations only, and for optical depths equal to 0.0, 0.1, 0.35, and 2.0 were made earlier by Levine *et al.* (1977) in the (0–85°) latitude region.

In this short paper, we investigate the oblateness effect on the mean (summer, winter and annual) daily insolations during global dust storms characterized by various optical depths. Our results are presented in three figures, illustrating the latitudinal variation of the percentage difference between the mean daily insolations with and without the effect of the flattening. Informations on dust storms may be found in e.g. Pollack *et al.* (1979), Pollack and Toon (1982), Toon *et al.* (1980), Zurek (1981, 1982), and Martin (1984).

In the following section, we briefly summarize some expressions used for the determination of the mean daily insolations incident on a planetary surface. Then we discuss the results obtained with different aerosol configurations.

2. Mean Daily Surface Insolations

First, it is to be emphasized that for the northern hemisphere, the summer is arbitrary defined as running from vernal equinox over summer solstice to autumnal equinox and spanning a solar longitude of 180°; the rest of the year is, as a consequence, taken as the winter period. In the southern hemisphere, the solar longitude intervals (0–180°) and (180–360°) divide the year into astronomical winter and summer, respectively. Secondly, our calculations are based on the assumption of planet encircling storms lasting one season or one year.

The daily insolation for a spherical planet may be expressed (see e.g. Levine *et al.*, 1977; Van Hemelrijck, 1985) as

$$I_D = (ST/\pi) \int_0^{h_0} \cos z \exp(-\tau \sec z)\, \mathrm{d}h, \tag{1}$$

with

$$S = S_0/r_\odot^2 \tag{2}$$

and

$$r_\odot = a_\odot\,(1 - e^2)/(1 + e \cos W), \tag{3}$$

where S_0 is the solar constant at the mean Sun–Earth distance of 1 AU taken at 1.96 cal cm^{-2} (min)$^{-1}$ (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 distance and τ, as mentioned earlier, is the atmospheric optical thickness.

Furthermore, W and z can be calculated from the following well-known relations

$$W = \lambda_\odot - \lambda_P \tag{4}$$

and

$$\cos z = \sin \phi' \sin \delta_\odot + \cos \phi' |\cos \delta_\odot \cos h, \tag{5}$$

where $\lambda_\odot$, λ_P, and ϕ' are, respectively, the solar longitude, the longitude of the planet's perihelion and the planetocentric latitude and where the solar declination ($\delta_\odot$) is given by

$$\delta_\odot = \sin^{-1} (\sin \epsilon \sin \lambda_\odot) \tag{6}$$

ϵ being the obliquity.

Finally, h_0 may be determined from expression (5) by the condition that at sunset (or sunrise) the zenith distance equals $\pi/2$. It follows that

$$h_0 = \cos^{-1} (-\tan \delta_\odot \tan \phi') \tag{7}$$

if $\quad |\phi'| < \pi/2 - |\delta_\odot|.$

In regions where the Sun does not rise, we have $h_0 = 0$; in regions where the Sun remains above the horizon all day, we may put $h_0 = \pi$.

The expression for the daily insolation of an oblate planet I_{DO} is similar to Equation (1) and is given by

$$I_{DO} = (ST/\pi) \int_0^{h_{00}} \cos Z \exp(-\tau \sec Z)\, \mathrm{d}h. \tag{8}$$

In (8), $\cos Z$ and h_{00} may be written respectively as

$$\cos Z = \cos v + \cos z\, (-\tan \phi' \cos z + \sin \delta_\odot \sec \phi') \sin v, \tag{9}$$

and

$$h_{00} = \cos^{-1} [-(1-f)^{-2} \tan \phi' \tan \delta_\odot]; \tag{10}$$

where v, the so-called angle of the vertical, is given by

$$v = \tan^{-1} [(1-f)^{-2} \tan \phi'] - \phi'; \tag{11}$$

f designating the flattening.

The mean (annual, summer or winter) daily surface insolations, hereafter denoted as $(\bar{I}_D)_A$, $(\bar{I}_D)_S$ and $(\bar{I}_D)_W$ (spherical planet) and $(\bar{I}_{DO})_A$, $(\bar{I}_{DO})_S$ and $(\bar{I}_{DO})_W$ (oblate planet) respectively, may be found by integrating numerically relation (1) or (8) within the appropriate time limits, yielding the total surface solar radiation over a year or a season and by dividing the obtained result by the tropical year T_0 (686.9 earth days) or by the corresponding length of the summer (T_S) or winter (T_W). For the calculation of T_S (381.3) or T_W (305.6) we refer to Van Hemelrijck (1982b).

TABLE I

Elements of the orbit of Mars

$a_{\odot}$	e	λ_P	ϵ	f	T
(AU)		(°)	(°)		(earth days)
1.524	0.09339	248	25.20	0.00515	1.02

Note that $(\bar{I}_D)_A$ and $(\bar{I}_{DO})_A$ may also be directly computed in terms of the mean seasonal daily insolations. Indeed, taking into account the numerical values of T_S, T_W and T_0, the average yearly insolations can, in a very good approximation, be written in the form

$$(\bar{I}_D)_A = 0.555\ (\bar{I}_D)_S + 0.445\ (\bar{I}_D)_W \tag{12}$$

and

$$(\bar{I}_{DO})_A = 0.555\ (\bar{I}_{DO})_S + 0.445\ (\bar{I}_{DO})_W. \tag{13}$$

The data for the parameters used in the calculations are listed in Table I.

3. Discussion of the Results

In Figure 1 the influence of the flattening on the mean summer daily insolation for various values of the optical thickness is plotted in terms of the percentage difference $100[(\bar{I}_{DO})_S - (\bar{I}_D)_S]/(\bar{I}_D)_S$ as a function of the planetocentric latitude. As already mentioned in the introduction peak values of the curve corresponding to clear sky conditions ($\tau = 0$) are equal to 0.05 and -0.2%. Those maximum values are attained at approximately $\phi' = 15°$ and 55°, respectively. Another interesting phenomenon is that for latitudes between the equator and the subsolar point, the mean summer daily insolation of Mars (or any outer planet), assumed as an oblate planet, is increased (Van Hemelrijck, 1982c, 1983; Brinkman and McGregor, 1979). Beyond the subsolar point, one observes a loss of solar energy.

Figure 1 clearly demonstrates that the rise or loss of the summertime solar radiation increases with increasing values of the atmospheric turbidity. For $\tau = 3.0$ the maximum values reach $+0.1$ and -1.9%, respectively. This means that in going from $\tau = 0.0$ to $\tau = 3.0$ the peak values enhance by a factor of approximately 2 and 10, respectively. It can also be seen that the latitude past which the mean summer daily insolations are decreasing due to the oblateness effect decreases with increasing optical depth. For $\tau = 0.0$, as stated earlier, this latitude is equal to the subsolar point; on the other hand, for $\tau = 3.0$ the intersection of the curve representing the percentage difference with the 0.0% level is moved to a latitude of about 18°. For $\phi' \simeq 15°$, the differences are nearly independent of τ. Finally, the point of maximum loss of insolation is a function of τ and varies from 55($\tau = 0.0$) to approximately 70° ($\tau = 3.0$).

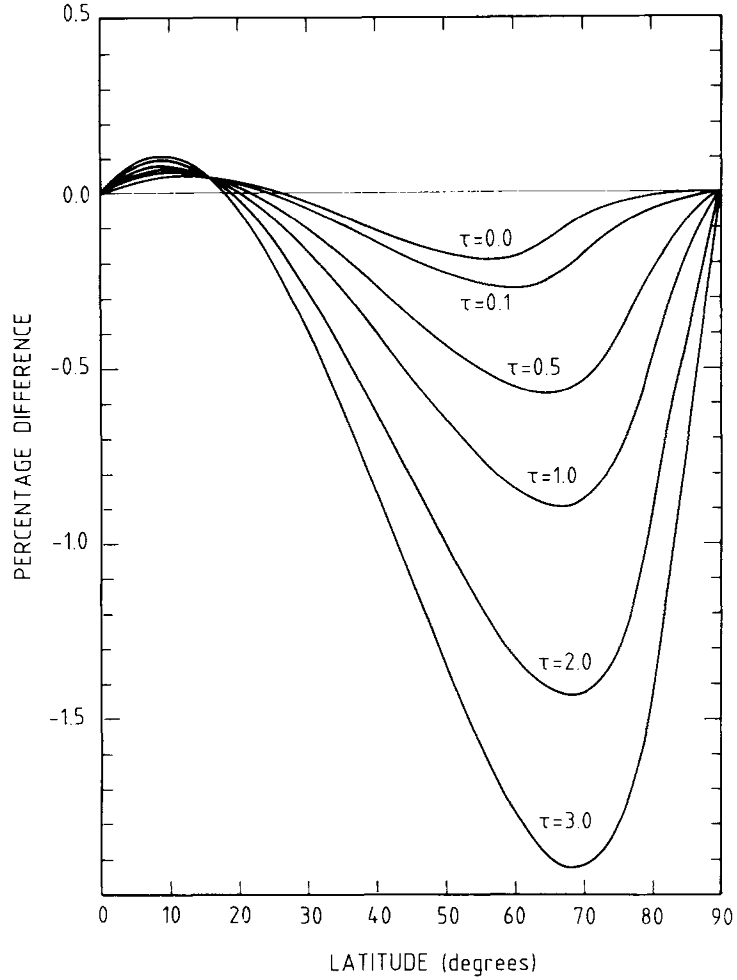

Fig. 1. The influence of the flattening on the mean summer daily insolation at the Martian surface for various values of the optical depth. The oblateness effect is plotted in terms of the percentage difference $100[(\bar{I}_{DO})_S - (\bar{I}_D)_S]/(\bar{I}_D)_S$ as a function of planetocentric latitude.

In winter, due to the flattening, the horizon plane is always tilted away from the Sun, causing both the cosine of the zenith angle and the length of the day to be reduced (Brinkman and McGregor, 1979; Van Hemelrijck, 1982c). It follows that the daily insolation and, consequently, the mean winter daily insolation is always decreased. This characteristic feature is obviously evident from Figure 2. The maximum decrease is found to be very close to the poles. For $\tau = 0.0$ it amounts to about 2%, whereas for an optical thickness of 3.0 the loss attains values as much as 30%. In Figure 2, the abscissa is cut off at a latitude of 85°. The reason for this limitation is to avoid an overloading of curves (or nearly straight lines) going to the 0.0% level in the (89–90°) latitudinal region.

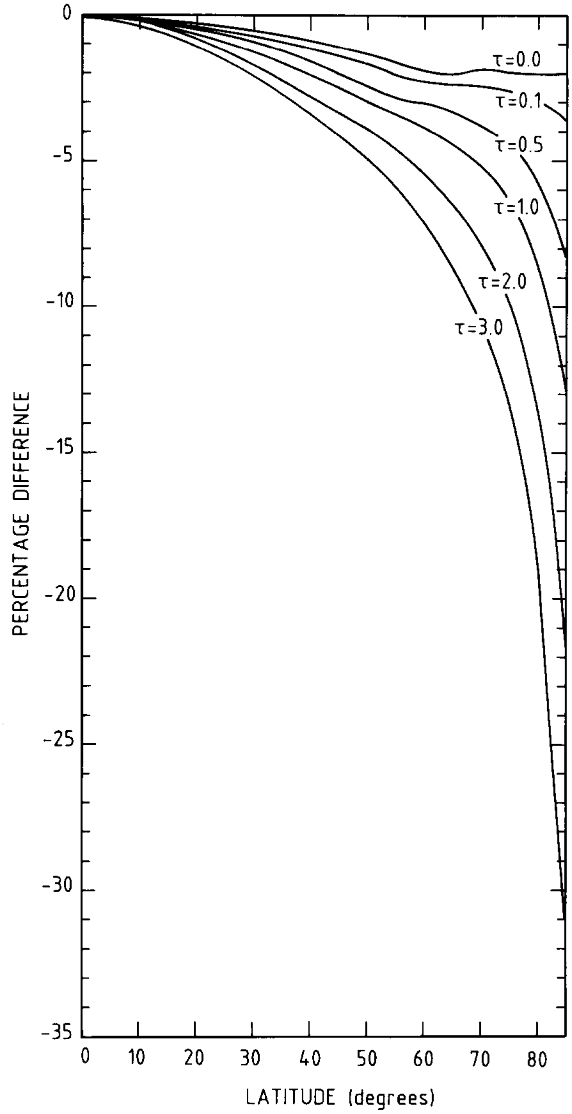

Fig. 2. The influence of the flattening on the mean winter daily insolation at the Martian surface for various values of the optical depth. The oblateness effect is plotted in terms of the percentage difference $100[(\bar{I}_{DO})_W - (\bar{I}_D)_W]/(\bar{I}_D)_W$ as a function of planetocentric latitude.

The partial gain of the mean summertime insolation in the neighborhood of the equator being considerably lower than the corresponding attenuation of the solar radiation in winter evidently results in a mean annual daily insolation which is reduced over the entire latitudinal interval as shown in Figure 3. It can be seen that the daily insolation averaged over a one year cycle is decreased by about 0.5% at mid-latitudes for an atmosphere without aerosols.

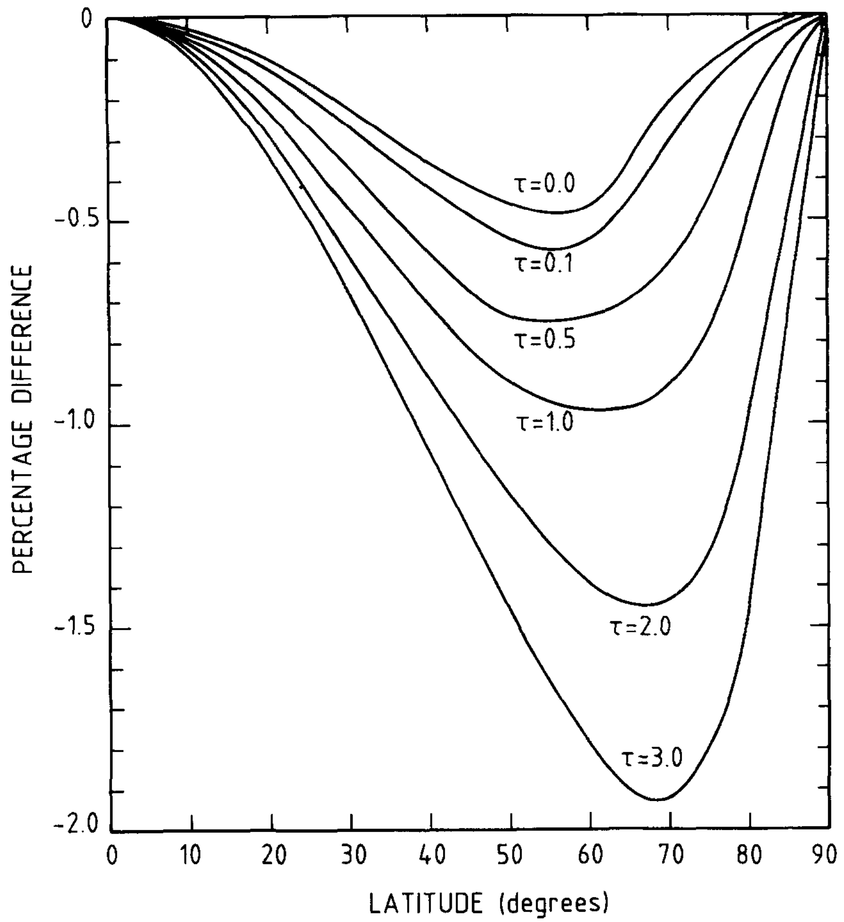

Fig. 3. The influence of the flattening on the mean annual daily insolation at the Martian surface for various values of the optical depth. The oblateness effect is plotted in terms of the percentage difference $100[(\bar{I}_{DP})_A - (\bar{I}_D)_A]/(\bar{I}_D)_A$ as a function of planetocentric latitude.

At higher optical thicknesses the percentage differences enhance, reaching a value of about 2% for $\tau = 3.0$. The point of maximum loss is also a function of τ and varies in nearly the same manner as is the case for the mean summer daily insolation.

In conclusion, this short study clearly demonstrates that the oblateness plays an important role in the determination of the mean daily insolations during global dust storms lasting one season or one year.

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