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The influence of global dust storms on the mean seasonal daily insolations at the martian surface

by

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FOREWORD

The paper "The influence of global dust storms on the mean seasonal daily insolations at the Martian surface" will be published in "The Moon and the Planets", 1984.

AVANT-PROPOS

L'article "The influence of global dust storms on the mean seasonal daily insolations at the Martian surface" sera publié dans "The Moon and the Planets", 1984.

VOORWOORD

De tekst "The influence of global dust storms on the mean seasonal daily insolations at the Martian surface" zal verschijnen in "The Moon and the Planets", 1984.

VORWORT

Der Text "The influence of global dust storms on the mean seasonal daily insolations at the Martian surface" wird in "The Moon and the Planets", 1984, herausgegeben werden.

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

by

E. VAN HEMELRIJCK

Abstract

In this short 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.

Résumé

Dans cet article, nous comparons les changements dans les insolations diurnes moyennes saisonnières à la surface de Mars dus à des tempêtes de poussière se caractérisant par diverses épaisseurs optiques atmosphériques (τ). Les calculs effectués pour des épaisseurs optiques égales à 0, 0.1, 0.5, 1.0, 2.0 et 3.0 impliquent l'hypothèse des tempêtes englobant la planète au cours d'une saison ou d'une année. Les changements dans les distributions de l'insolation à la surface en fonction de la latitude et de la saison sont importants, particulièrement aux pôles, où p.e. les insolations moyennes annuelles et journalières en été décroissent d'un facteur d'environ 3000 lorsque τ croît de 0 à 3.0. Aux latitudes équatoriales, la perte correspondante est beaucoup plus faible, atteignant une valeur approximative de 40. En ce qui concerne l'insolation journalière moyenne en hiver, la décroissance est encore plus importante, principalement aux latitudes élevées.

Samenvatting

In dit kort artikel vergelijken we veranderingen in de gemiddelde seizoens- dagelijkse zonnestraling invallend op het Marsoppervlak en die veroorzaakt worden door globale stofstormen waarvan de atmosferische optische dichtheid (τ) verschillende waarden kan aannemen. De berekeningen, voor optische dichtheden gelijk aan 0, 0.1, 0.5, 1.0, 2.0 en 3.0, zijn gesteund op de veronderstelling dat de stormen planeetomvattend zijn met een levensduur gelijk aan de lengte van een seizoen of een jaar. De veranderingen in de zonnestralingsverdelingen aan het oppervlak in functie van de breedte en het seizoen zijn belangrijk, vooral aan de polen, waar bv. de gemiddelde jaarlijkse en zomerse dagelijkse zonnestralingen verminderen met een factor van ongeveer 3000 als τ toeneemt van 0 tot 3.0. Op everaarsbreedte is het overeenkomstig verlies beduidend kleiner en bereikt een waarde van ongeveer 40. Wat betreft de gemiddelde winterse dagelijkse zonnestraling werd er gevonden dat de vermindering nog drastischer is vooral op grote breedten.

Zusammenfassung

In diesem kurzen Artikel vergleichen wir Veränderungen in der täglichen Durchschnittssonnenstrahlung während der Saisonen auf der Marsoberfläche die verursacht werden durch Staubsturmen wovon die atmosphärische optische Dicke (τ) verschiedene Werten kann annehmen. Die Berechnungen, für optische Dicken gleich an 0, 0.1, 0.5, 1.0, 2.0 und 3.0, sind basiert auf der Voraussetzung von Staubsturmen die der Planet umschliessen und die eine Saison oder ein Jahr dauern. Die Veränderungen in den Sonnenstrahlungsverteilungen an der Oberfläche mit Rücksicht auf der Breite un der Saison sind bedeutend, vornehmlich an den Polen, wo z.B. die Durchschnittssonnenstrahlung per Jahr und die täglichen Sonnenstrahlung im Sommer verminderen mit einem Faktor von ungefähr 3000 wenn τ erhöht von 0 bis 3.0. Auf Equatorialbreiten ist der übereinstimmende Verlust deutlich kleiner und erreicht ein Wert von ungefähr 40. Die Verminderung der täglichen Durchschnittssonnenstrahlung im Winter ist noch wichtiger, vornehmlich auf grossen Breiten.

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°) devide the year into astronomical winter and summer respectively.

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

$$I_{Ds} = [S_o T(1 + e\cos W)^2/\pi a_\odot^2 (1 - e^2)^2] \int_o^{h_o} \cos z \exp(- \tau \sec z)\, dh \qquad (1)$$

where S_o is the solar constant at the mean Sun-Earth distance of 1AU 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_o 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 cosz can be calculated from the following well-known relationships

$$W = \lambda_\odot - \lambda_P \qquad (2)$$

and

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

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

$$\delta_\odot = \arcsin (\sin \varepsilon \sin \lambda_\odot) \qquad (4)$$

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

$$h_o = \arccos (- \tan \delta_\odot \tan \varphi) \qquad (5)$$

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 $h_o = 0$; 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 $h_o = \pi$. Note that equation (1) has to be solved numerically.

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 be 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_o) 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 RADIATION

Figs. 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 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 (Figs. 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 Fig. 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.

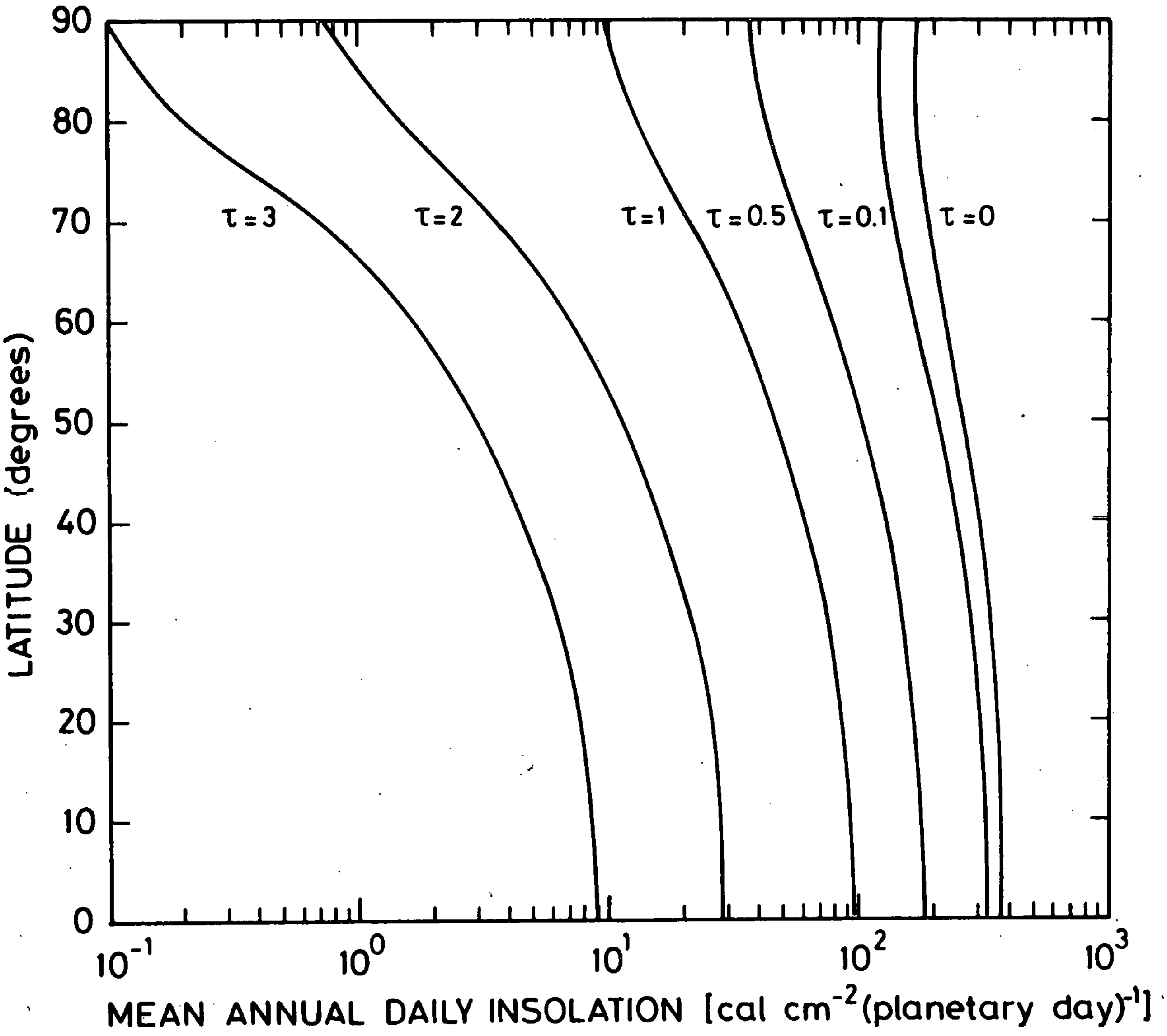

Fig. 1.- Latitudinal variation of the mean annual daily insolation at the top of the atmosphere ($\tau = 0$) and at the surface of Mars ($\tau = 0.1$ to 3.0) and for the currently adopted values of the eccentricity, the obliquity and the longitude of the perihelion.

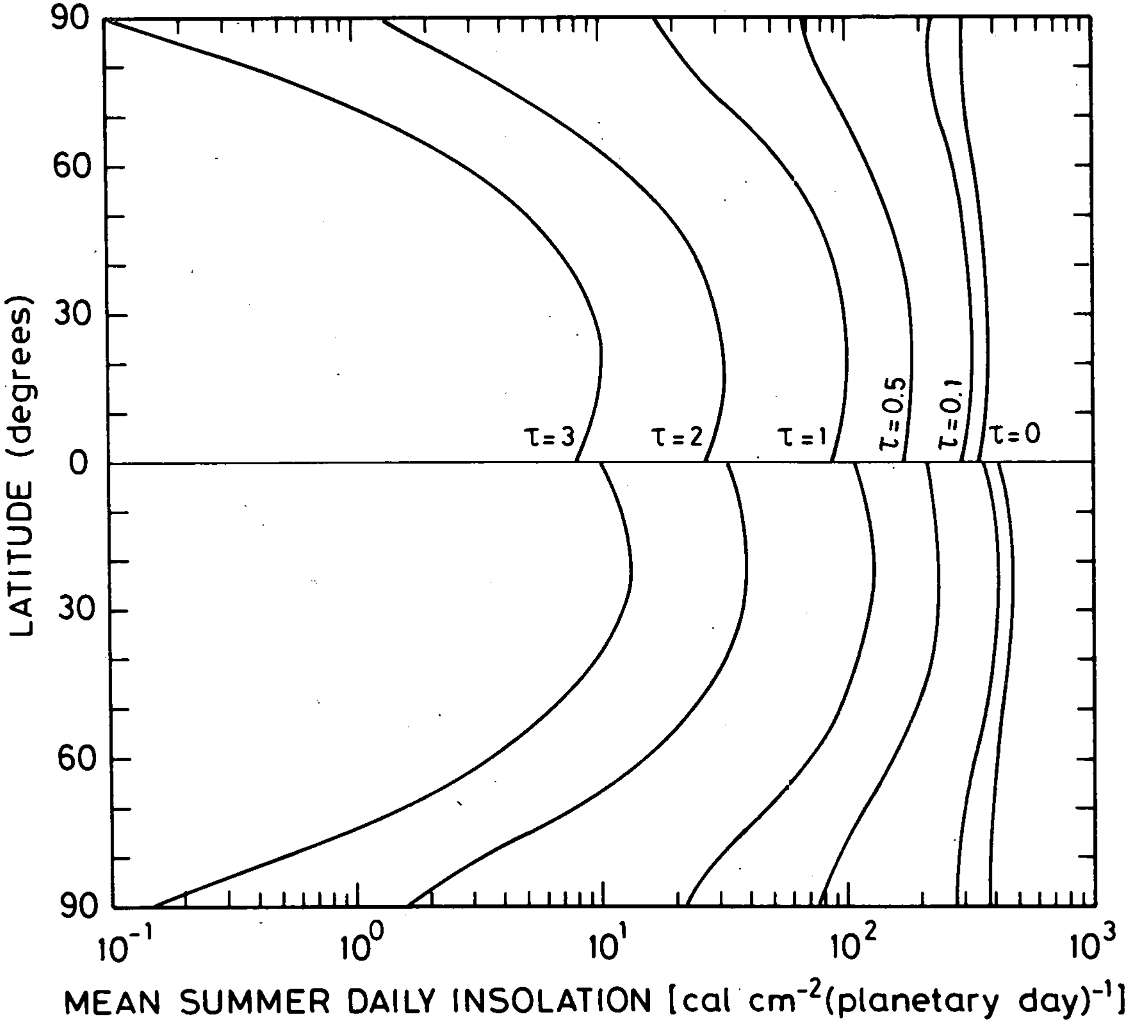

Fig. 2.- Latitudinal variation of the mean summer daily insolation at the top of the atmosphere ($\tau = 0$) and at the surface of Mars ($\tau = 0.1$ to 3.0) and for the currently adopted values of the eccentricity, the obliquity and the longitude of the perihelion.

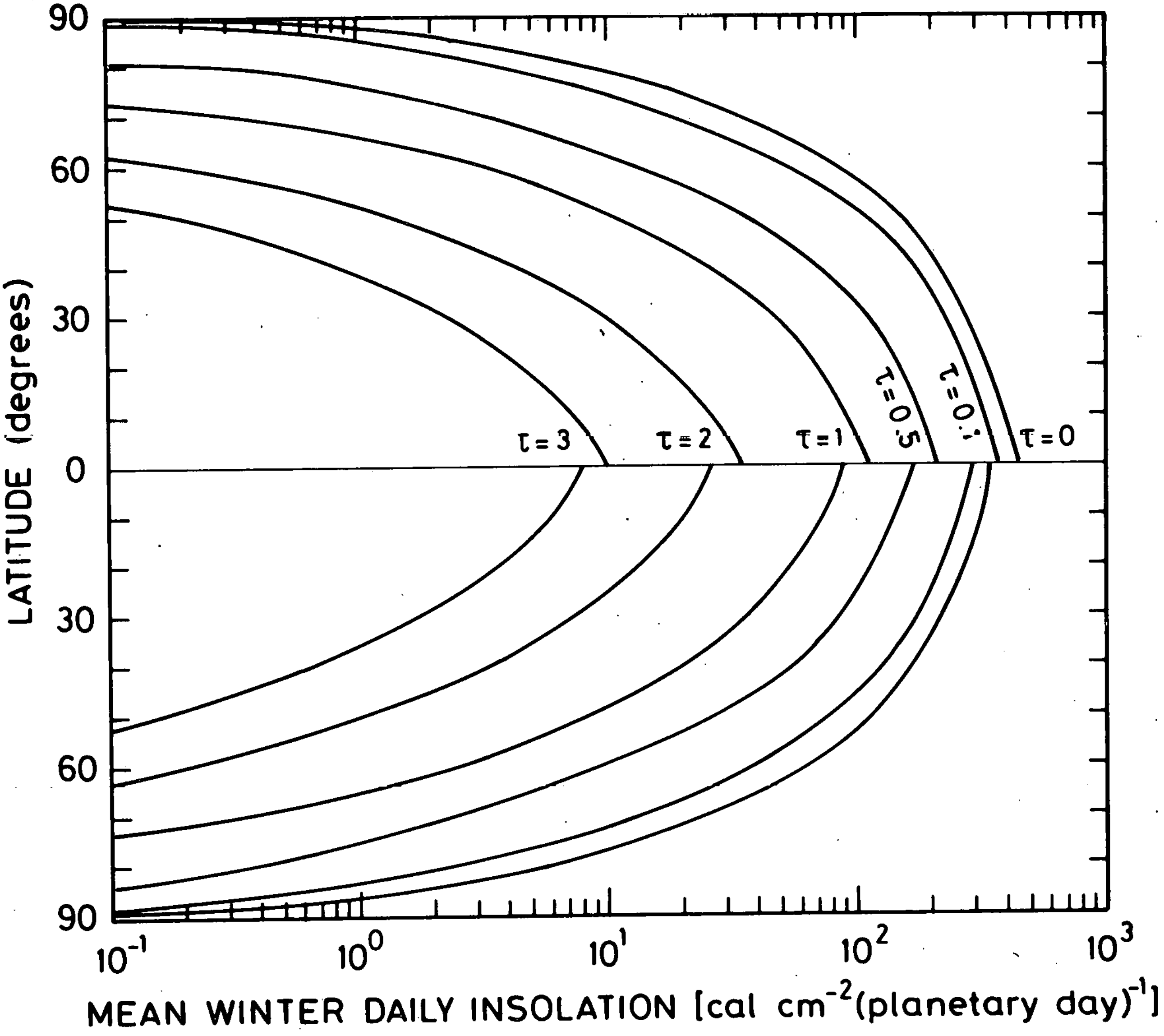

Fig. 3.- Latitudinal variation of the mean winter daily insolation at the top of the atmosphere ($\tau = 0$) and at the surface of Mars ($\tau = 0.1$ to 3.0) and for the currently adopted values of the eccentricity, the obliquity and the longitude of the perihelion.

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 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.

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

3.2. Mean summer daily insolation

The mean summer daily insolation for the six values of the atmospheric optical thickness is depicted in Fig. 2. A striking difference with Fig. 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 Fig. 1 with Fig. 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° ($\tau = 3$).

3.3. Mean winter daily insolation

The mean wintertime insolation is given in Fig. 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 to be 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 Fig. 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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