3. STUDY OF THE SOLAR RADIATION INCIDENT ON THE ATMOSPHERE OF THE INNER AND OUTER PLANETS OF THE SOLAR SYSTEM

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Between 1981 and 1987 we studied different aspects of the solar radiation incident on the atmosphere of the inner and outer planets of the solar system.

A formalism has been developed for the calculation of the insolation on the planets Mercury and Venus. For the first time, the daily insolation on those two slowly rotating planets has been analyzed in detail. Moreover, it has been found that, for Mercury, the instantaneous insolation and the daily insolation are strongly dependant upon the longitude difference between the meridian of a surface element and the meridian crossing the line of apsides at the perihelion passage of the planet.

Variations in the insolation on Mercury resulting from fluctuations of the orbital eccentricity ($0.11 \leq e \leq 0.24$) have also been investigated. Special attention was paid to the behaviour of the solar radiation distribution curves near sunrise and sunset which, at the so-called warm pole of Mercury (longitude: +/- 90°), occur as the planet goes through perihelion.[1,2] It has been proved that for eccentricities larger than about 0.194 there exist two very short periods of weak insolation on opposite sides of the Mercurian

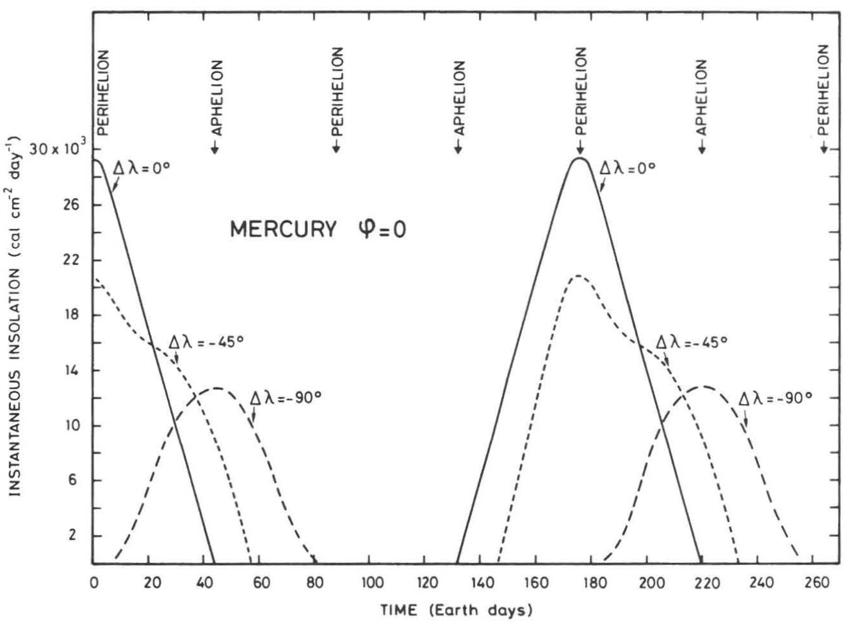

Figure 1 : Time variations of the instantaneous insolation at the top of the Mercurian atmosphere on fixed meridians characterized by the following specific numerical values of $\Delta\lambda$: 0, -45, and -90°. The curves are related to the equator ($\varphi = 0°$). Perihelion and aphelion passages are also illustrated.

surface that alternately point to the Sun at every perihelion passage. The critical value of the orbital eccentricity past which the Sun shortly sets after perihelion is near 0.213.

The daily solar radiation incident at the top of the atmospheres of the outer planets (Earth, Mars, Jupiter, Saturn, Uranus and Neptune), with and without the effect of the oblateness, was calculated as a function of season and latitude.[3,4] It was shown that for parts of the summer, the daily insolation of an oblate planet is slightly increased. In winter, the flattening effect results in a somewhat more extensive polar region, the solar energy input being always reduced. It is found that the mean summer daily insolation is scarcely increased between the equator and the subsolar point, but decreased poleward of the above mentioned limit. In winter, however, the mean daily insolation is always reduced. The partial gain of the mean summertime insolation being much smaller than the reduction during winter season evidently yields a mean annual daily insolation which is decreased.

Changes in the mean seasonal daily insolation at the top of the Martian atmosphere caused by significant large-scale variations in the eccentricity (e), the obliquity (ε) and the longitude of the perihelion (λp)[5,6,7,8] and, at the Martian surface, caused by global dust storms[9,10,11,12] characterized by various atmospheric optical thickness (τ) have been studied in detail. Although long-term periodic oscillations of the eccentricity and the longitude of the perihelion produce, respectively, very small or no variations in the

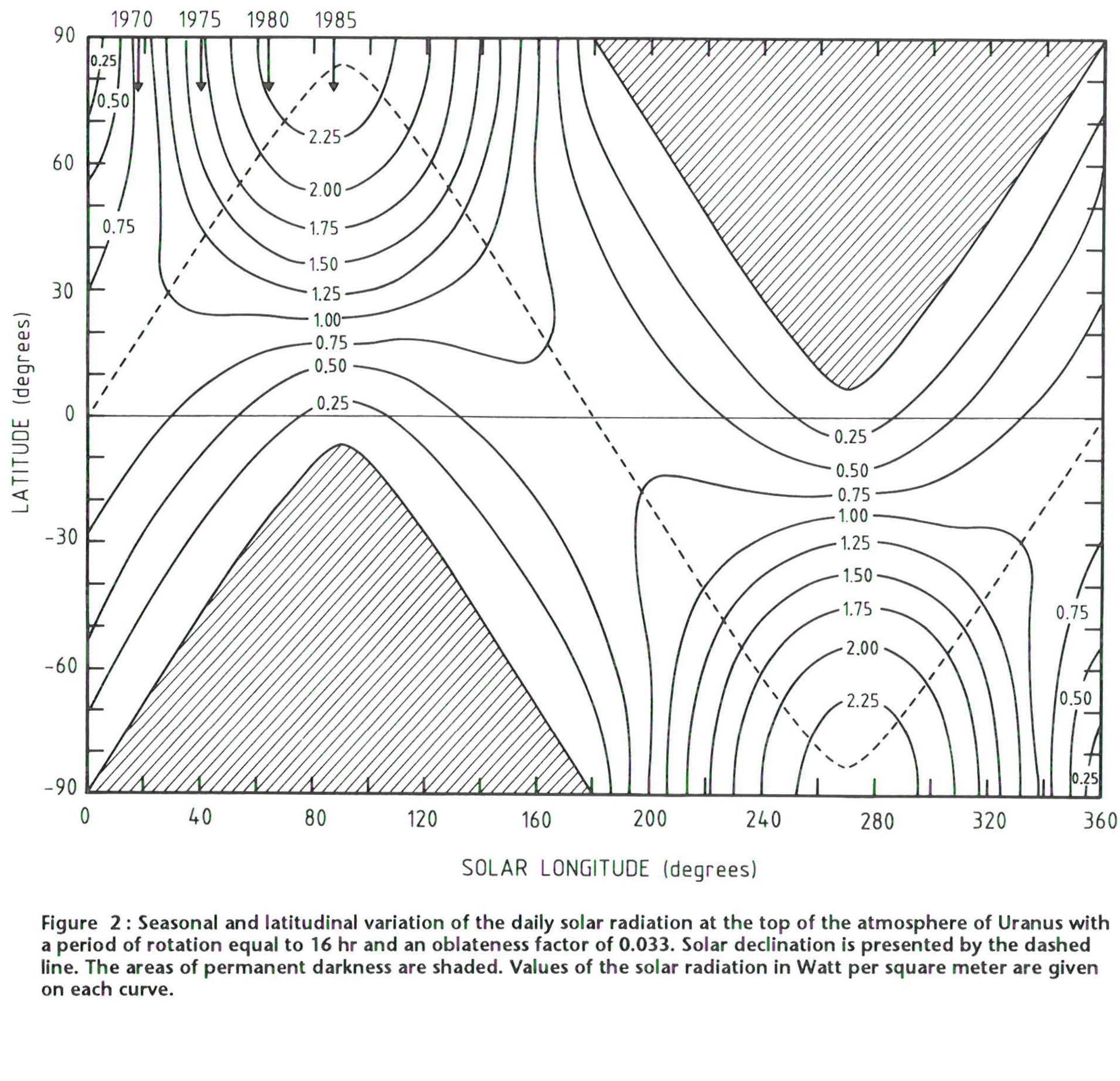

Figure 2 : Seasonal and latitudinal variation of the daily solar radiation at the top of the atmosphere of Uranus with a period of rotation equal to 16 hr and an oblateness factor of 0.033. Solar declination is presented by the dashed line. The areas of permanent darkness are shaded. Values of the solar radiation in Watt per square meter are given on each curve.

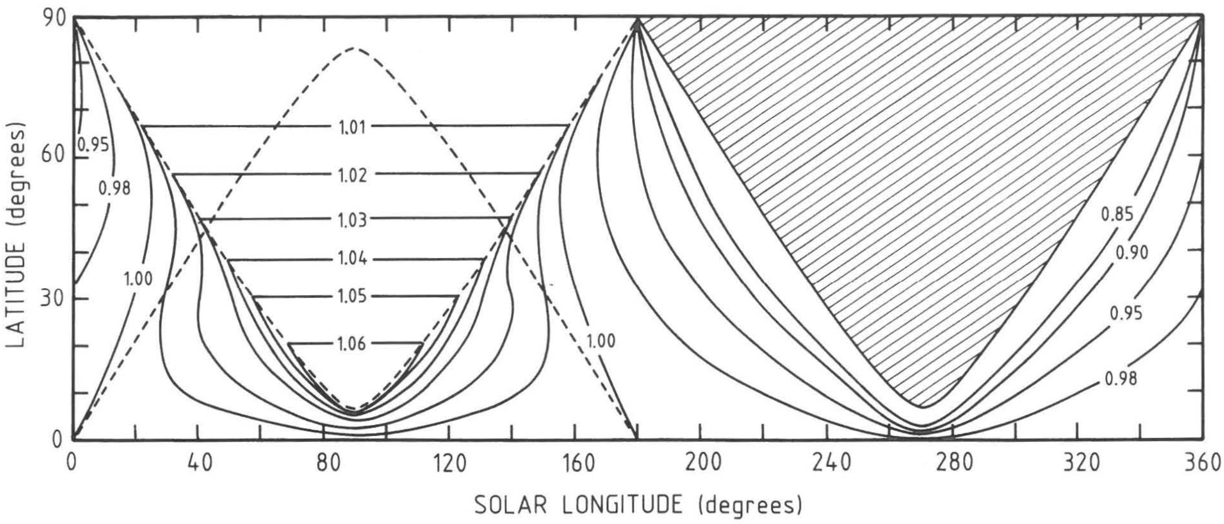

Figure 3 : Seasonal and latitudinal variation of the ratio of the daily solar radiation with and without the oblateness effect (f = 0.033) at the top of the atmosphere of Uranus. Values of the ratio of both insolations are given on each curve.

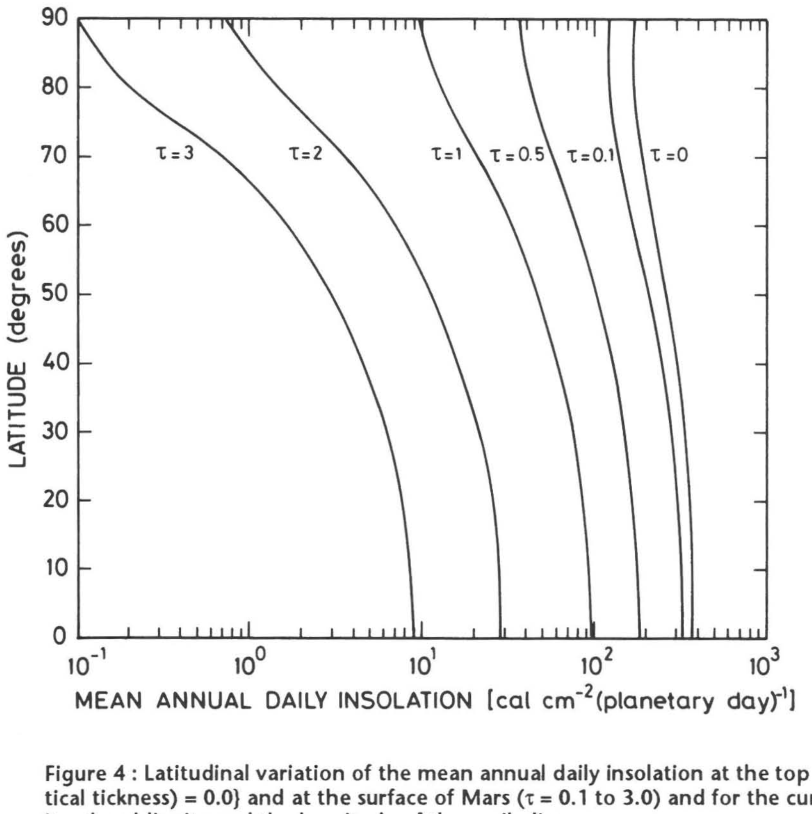

Figure 4 : Latitudinal variation of the mean annual daily insolation at the top of the atmosphere {τ (atmospheric optical tickness) = 0.0} and at the surface of Mars (τ = 0.1 to 3.0) and for the currently adopted values of the eccentricity, the obliquity and the longitude of the perihelion.

average yearly insolation, fluctuations of the above mentioned planetary data strongly effect the mean summer and winter daily insolations (15 to 20% over the entire latitude interval). Considering more particularly the variations in the obliquity, it is found that the summertime insolation experiences a nearly similar change as the mean annual daily insolation (a decrease of 7% at the equator and a more than twofold increase at the poles), whereas the corresponding mean winter daily insolation varies maximally by about 60% in the 60-80° latitude range.

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 the optical thickness goes from 0 tot 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.

In 1982, and this for the first time, we also presented calculations of the daily solar radiation incident at the top of Pluto's atmosphere and its variability with latitude and season and this for three fixed values of the obliquity (ε = 60, 75 and 90°)[13,14,15] cited in the literature and for the presently adopted values of the eccentricity and the longitude of the perihelion. From the two extreme values of the obliquity interval mentioned above it can be seen that at the time of the publication, the angle between the planet's spin axis and its orbit normal was very poorly determined. The obtained results, however, illustrated fairly well the sensitivity of Pluto's insolation changes in the obliquity.

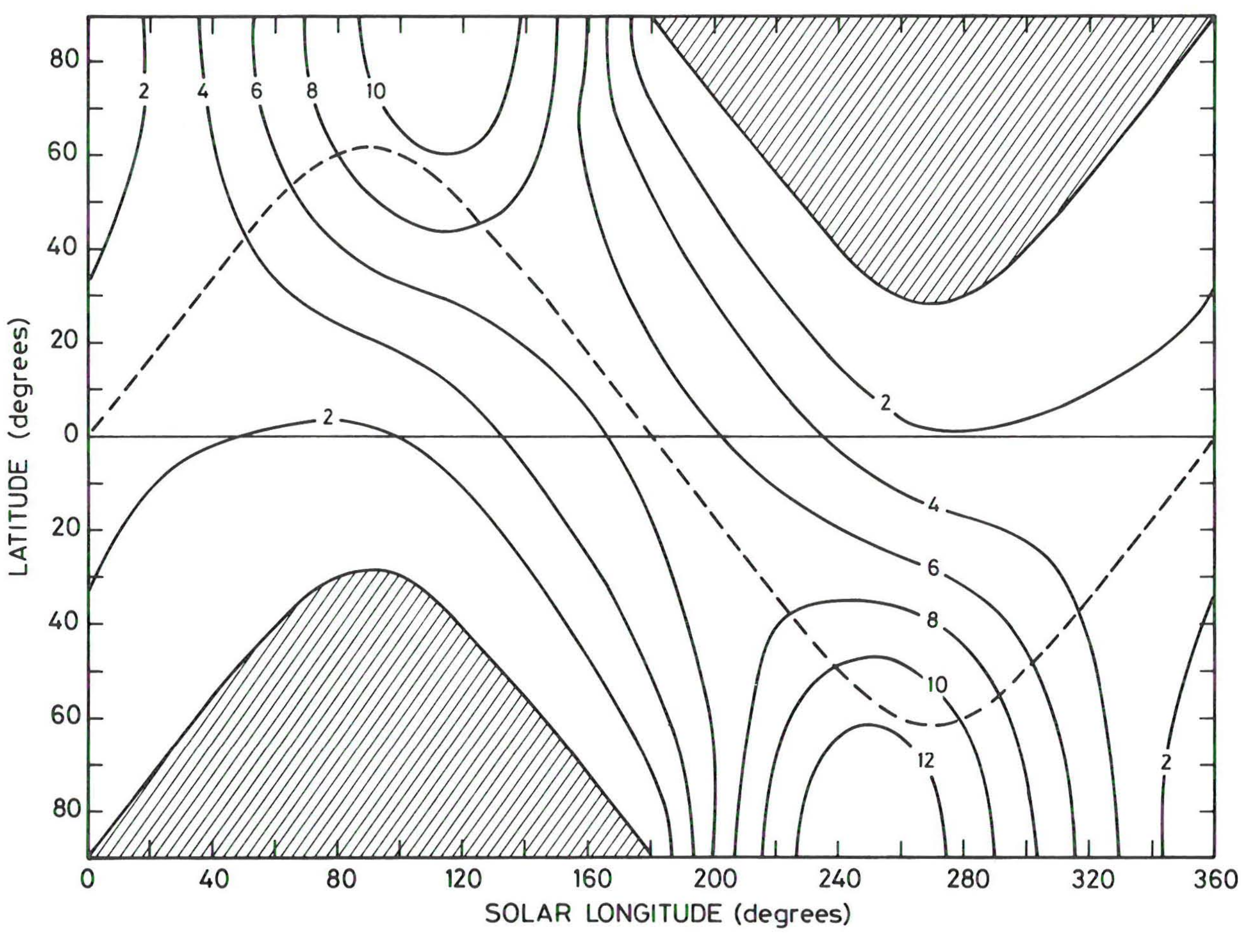

Figure 5 : Seasonal and latitudinal variation of the daily insolation (I_D) at the top of the atmosphere of Pluto at the epoch t = 0 (ε = 118.5°, e = 0.2446, λp = 191.7°) where t is the time in millions of years A.D. Values of I_D in cal cm^{-2} (planetary day)$^{-1}$ are given on each curve.

In 1983, the history of Pluto's obliquity was investigated[16] by numerical integration using analytic approximation. One founds that the obliquity varies between about 102° and about 126° over a time period of 3 million years, with a current pole position described by $\varepsilon = 118.5°$ implying that Pluto's rotation is slightly retrograde. Based on those data we reexamined variations in the insolation at Pluto corresponding to three epochs during the dynamical history of the planet. The calculations clearly demonstrate how the insolation at Pluto might considerably differ between the present-day epoch orbital configuration and alternatives in the past or in the future.

The daily solar radiation incident at the top of Saturn's atmosphere taking into account the shadow of the ring system was also calculated.[17,18,19] The study clearly demonstrated that the shadow of the ring system causes significant variations in both the planetary-wide distribution and the intensity of the daily insolation. The ring shadows decrease the daily solar radiation over much of the winter hemisphere mainly near the solstices (up to mid-latitudes). In the vicinity of the equinoxes the loss of solar energy is principally limited to equatorial and low latitude regions. Furthermore, it is obvious that the summer hemispheres are not affected by the rings. Concerning the mean winter and annual daily insolations it is found that the reduction reaches peak values of, respectively, 50 and 20% at a latitude of 20°.

Finally, the latitudinal and seasonal variation of the direct solar radiation incident at the top of the atmosphere of Uranus and Neptune has been recalculated by use of updated values for the period of axial rotation and the oblateness. Values for the solar radiation are given in Watt per square meter instead of the unit used in earlier papers (calories per square centimeter per planetary day). The solar radiation averaged over a season and a year as a function of planetocentric latitude has also been reviewed.

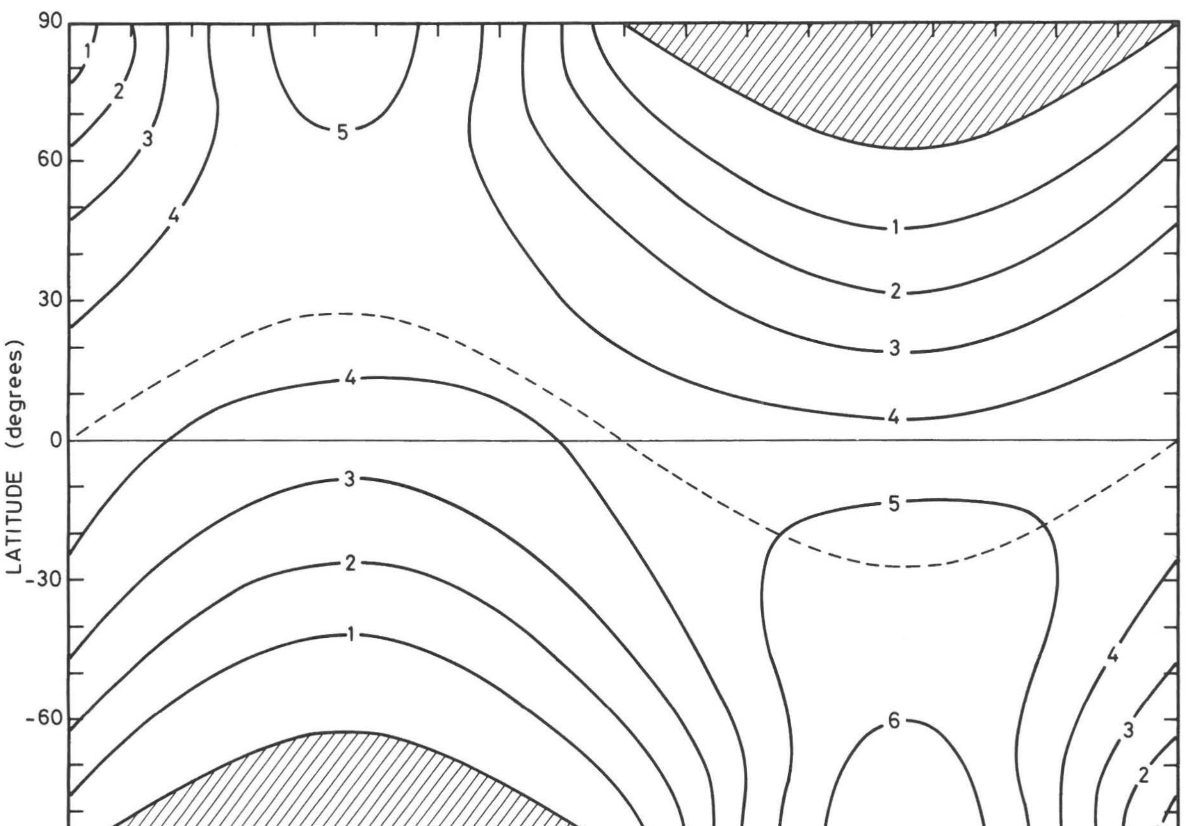

Figure 6 : Seasonal and latitudinal variation of the daily insolation at the top of the atmosphere of Saturn. The planet is assumed to be spherical and the shadow effect of the ring system is neglected. Values of the daily insolation in calories per square centimeter per Saturnian day are given on each curve.

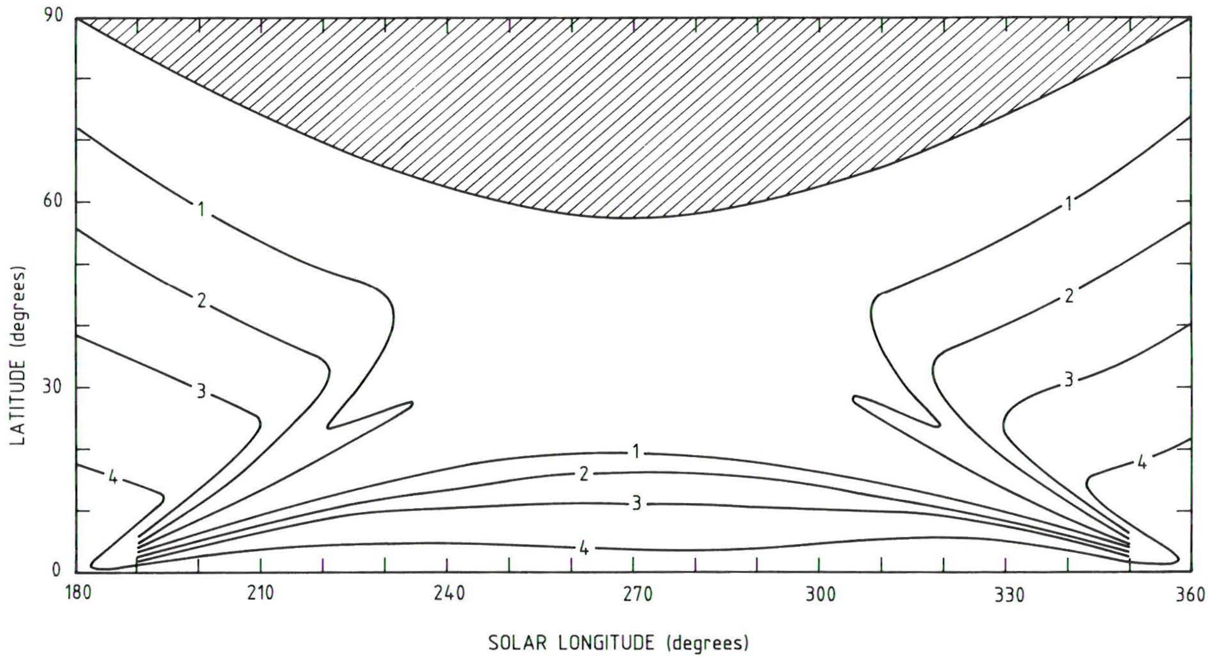

Figure 7 : Seasonal and latitudinal variation of the daily insolation ($I_{D_0}\tau$) at the top of the atmosphere of Saturn (northern winter hemisphere). Both the oblateness effect and the shadow of the ring system are taken into account.

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