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The Insolation at Pluto

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Calculations of the daily solar radiation incident at the top of Pluto's atmosphere and its variability with latitude and season and of the latitudinal variation of the mean annual daily insolation are presented. The large eccentricity of Pluto produces significant north–south seasonal asymmetries in the daily insolation. As for Uranus, having a similarly large obliquity, the equator receives less annual average energy than the poles.

1. INTRODUCTION

The upper-boundary insolation of the atmospheres of the outer planets, excluding Pluto, has been computed by, e.g., Vorob'yev and Monin (1975) and Levine *et al.* (1977). To the best of our knowledge, similar calculations for Pluto have never been published, mainly due to the fact that the angle between the planet's spin axis and its orbit normal (ϵ) is very poorly determined (Davies *et al.*, 1980).

In spite of the fact that the obliquity (ϵ) of Pluto is so questionable, we calculated the solar radiation incident on the planet for three fixed values of ϵ ranging from 60° (Andersson and Fix, 1973) over 75° (Golitsyn, 1979) to 90° (*Handbook of the British Astronomical Association,* 1981). The results illustrate the sensitivity of the daily and of the annual average insolation to changes in the obliquity.

First, we briefly discuss the calculation of the planetocentric longitude of Pluto's perihelion (λ_p). Then, the daily insolation and the mean annual daily insolation are considered.

For the methods of calculation we refer to Ward (1974), Vorob'yev and Monin (1975), Levine *et al.* (1977), Van Hemelrijck and Vercheval (1981), and Van Hemelrijck (1982a, b).

2. PLANETOCENTRIC LONGITUDE OF PLUTO'S PERIHELION

The position of perihelion (λ_p) for the planets in the solar system, except for Pluto, is given by Melbourne *et al.* (1968), Vorob'yev and Monin (1975), and Levine *et al.* (1977). It may be written in terms of the heliocentric longitude of the planet's perihelion (π_0) and the heliocentric longitude of the ascending node (Ω_0) as

$$\lambda_p = \pi_0 - \Omega_0 + \Lambda, \qquad (1)$$

where Λ is the planetocentric longitude of the ascending node altered by 180°. A detailed description of the procedure to calculate Λ is beyond the scope of the present work. However, Λ can be obtained from standard spherical trigonometric relationships (Vorob'yev and Monin, 1975). It is dependent upon several orbital and planetary data and can be expressed in the general form

$$\Lambda = f(i, \Omega_0, \pi_0, \epsilon, \epsilon_0, \alpha_0, \delta_0), \qquad (2)$$

where i, ϵ_0, α_0, and δ_0 are, respectively, the inclination to the ecliptic, the obliquity of the Earth's equator ($\epsilon_0 = 23^\circ\!.45$), and the right ascension and declination of Pluto's north pole. For the direction of the north pole, we adopted the recommended values published by the IAU Working Group on

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TABLE I

ADOPTED PLANETARY DATA FOR PLUTO

i^a (°)	$\Omega_0{}^a$ (°)	$\pi_0{}^a$ (°)	$\alpha_0{}^b$ (°)	$\delta_0{}^b$ (°)	$a_\odot{}^a$ (AU)	e^a	T^b (Earth days)	$T_0{}^c$ (Earth days)
17.14	109.51	222.50	305	5	39.72	0.2523	6.3867	90583

[a] Data drawn from Seidelmann *et al.* (1980).
[b] Data drawn from Davies *et al.* (1980).
[c] Data drawn from Golitsyn (1979).

cartographic coordinates and rotational elements of the planets and satellites (Davies *et al.*, 1980).

The adopted planetary data are given in Table I, where $a_\odot$, e, T, and T_0 signify, respectively, the semimajor axis, the eccentricity, the sidereal day, and the tropical year. The results of the calculations are represented in Table II, where one can also find the length of the seasons (T_S and T_W) for the three obliquities under consideration. It can be seen that λ_p is only weakly dependent on ϵ.

3. DISCUSSION OF CALCULATION

3.1. Daily Insolation

For the daily insolation, we followed the method adopted by Vorob'yev and Monin (1975) and Levine *et al.* (1977) in presenting our results in the form of a contour map giving the seasonal distribution in terms of the planetocentric longitude of the Sun taken to be 0° at the northern hemisphere vernal equinox. In addition, we included two figures showing the latitudinal variation of the daily insolation at the equator and the poles as a function of solar longitude. The isopleth for $\epsilon = 75°$ is illustrated in Fig. 1 and the equatorial and polar distributions are plotted in Figs. 2 and 3.

From the contour map and particularly from Figs. 2 and 3 it follows that the maximum solar radiation is incident at the poles with values of about 11 to 13 cal cm^{-2} (planetary day)$^{-1}$ (north pole) and 13.5 to 15.5 cal cm^{-2} (planetary day)$^{-1}$ (south pole). The maximum difference between the peak insolations attains approximately 20%; the north–south seasonal asymmetries are produced by the large eccentricity of Pluto's orbit. Moreover, it is found that over practically the entire Pluto year the polar insolation is greater than that at the equator.

The contour map and especially Fig. 3 reveal that the position of maximum solar radiation is shifted, by about 20°, from the position of summer solstices. This is due to the fact that the perihelion position ($\lambda_p \cong 190°$) is located approximately 80° from the south summer solstice. From Fig. 3 it can be seen that the maximum insolations occur near 110 and 250°.

It is easy to show that, at summer solstice, the polar daily insolation exceeds that of the equator for $\epsilon > 17.°7$ (all planets except Jupiter). For Pluto, the ratio of both insolations amounts to about 5.4, 11.7, and infinity (in this case the Sun does not rise at summer solstice), respectively, for obliquities equal to 60, 75, and 90°.

The global latitudinal redistribution caused mainly by the change in the obliquity is also illustrated in Figs. 2 and 3. It can be seen that the polar insolation increases with increasing obliquity, this gain being accompanied by a corresponding decrease of the equatorial solar radiation.

TABLE II

COMPUTED PLANETARY DATA FOR PLUTO

ϵ (°)	λ_p (°)	T_S (Earth days)	T_W (Earth days)
60	192.17	48,455	42,128
75	191.12	48,187	42,396
90	190.81	48,108	42,475

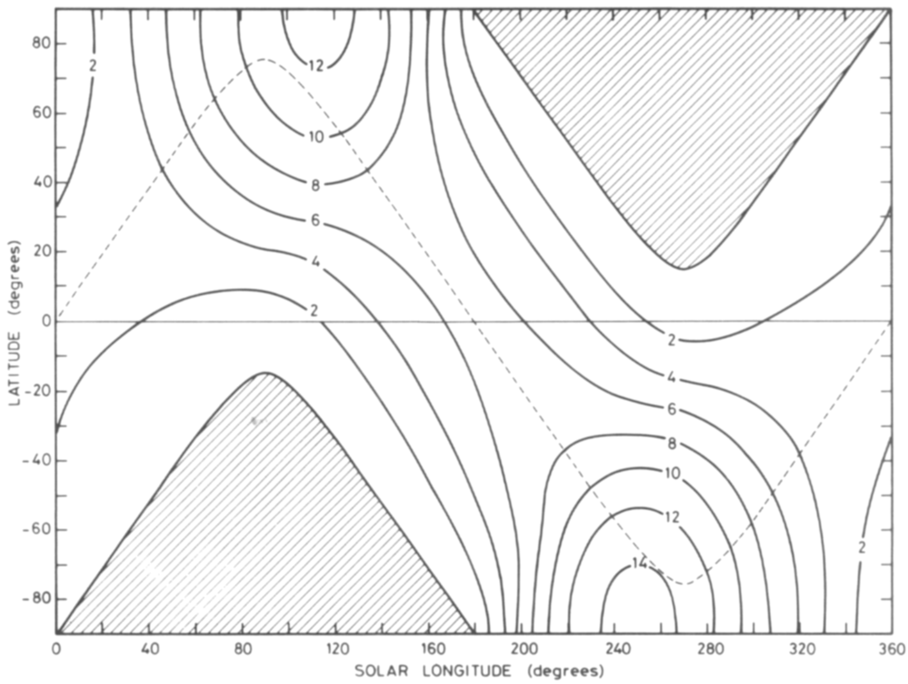

FIG. 1. Seasonal and latitudinal variation of the daily insolation at the top of the atmosphere of Pluto for an obliquity $\epsilon = 75°$. Solar declination is represented by the dashed line. The areas of permanent darkness are shaded. Values of the daily insolation, in cal cm^{-2} (planetary day)$^{-1}$, are given on each curve.

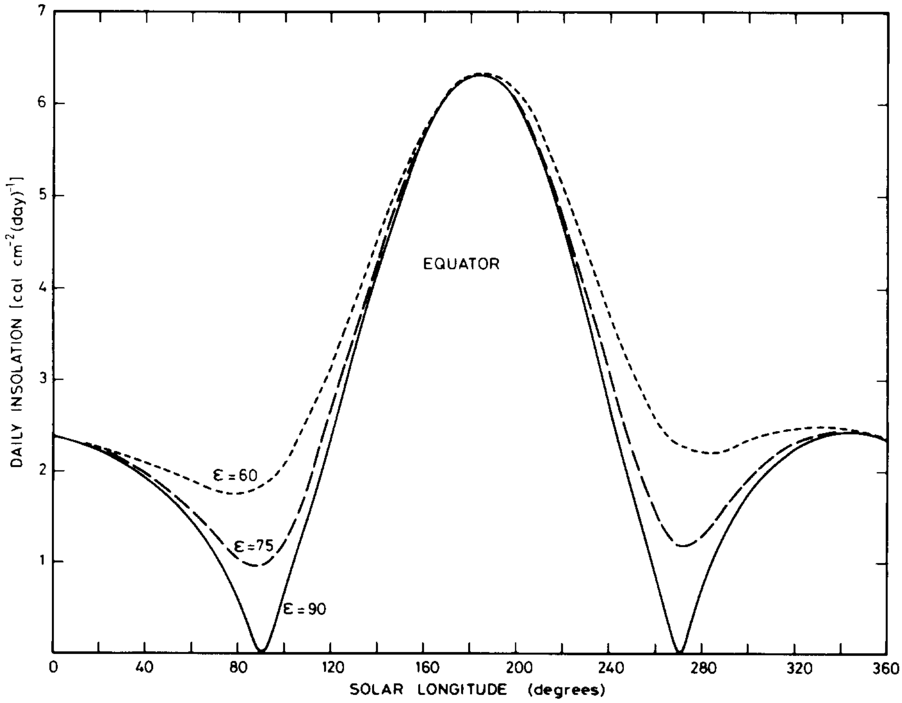

FIG. 2. Seasonal variation of the daily insolation at the equator of Pluto for various values of the obliquity.

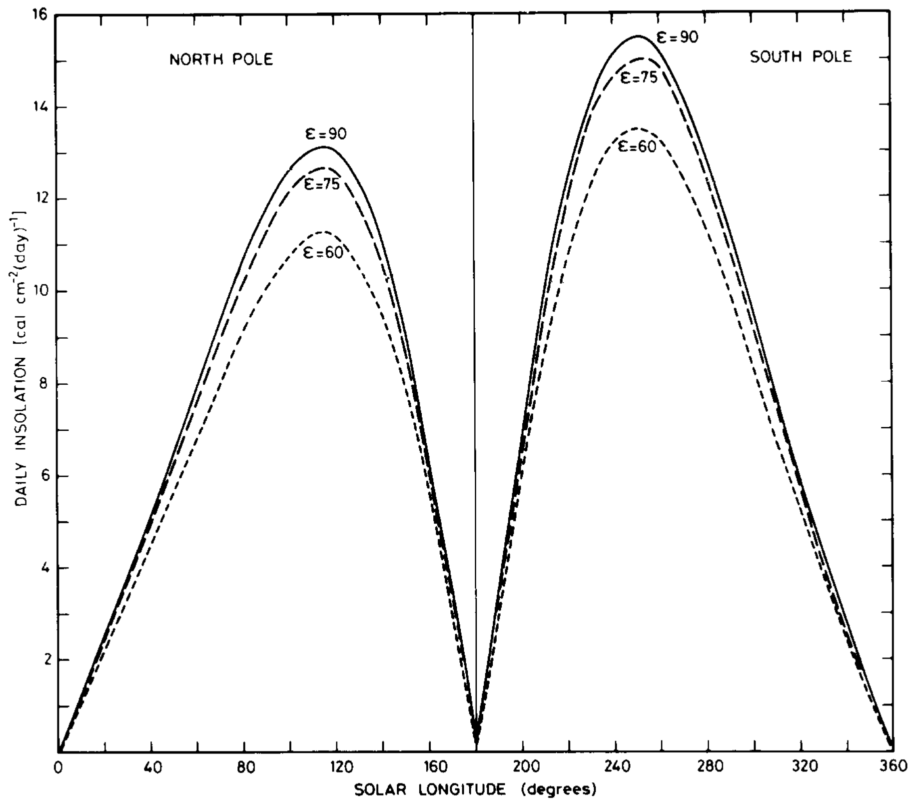

FIG. 3. Seasonal variation of the daily insolation at the poles of Pluto for various values of the obliquity.

Comparison of Fig. 1 with the isopleths for $\epsilon = 60$ and 90° (not represented in this paper) reveals that the general pattern of those three contour maps is only slightly different. In the solar longitude interval ($\pi/2$–$3\pi/2$) and especially at equatorial and midlatitudes the isocontours closely parallel the seasonal march of the Sun. In the region where the Sun does not set, the shape of the lines of constant daily insolation is roughly similar, although shifted with respect to the summer solstices, to the curve limiting the area of permanent sunlight. Furthermore, the isopleths illustrate that for nearly half the Pluto year some parts of the planet are in darkness. It is evident that the zone where the Sun does not rise increases with increasing obliquity.

Uranus and Pluto rotate lying practically on their sides in the orbital planes. In the polar regions the day and the night are approximately half a year long and the Sun is close to the zenith midway through the sunlit half of the year. Summer and winter are, roughly speaking, repeated twice a year in the equatorial region, the two seasons being substantially more temperate than in the polar regions. This phenomenon is demonstrated in Fig. 2 (contrast this diagram with Fig. 3).

3.2. Mean Annual Daily Insolation

The latitudinal variation of the mean daily insolation taken over a year is given in Fig. 4.

For the outer planets, there exists a critical obliquity ($\epsilon \cong 54°$) (Ward, 1974; Vorob'yev and Monin, 1975; Toon *et al.*, 1980) past which the equator receives less annual average energy than the poles. This situation is not only realized by Uranus but also by Pluto when assuming that ϵ is equal to or

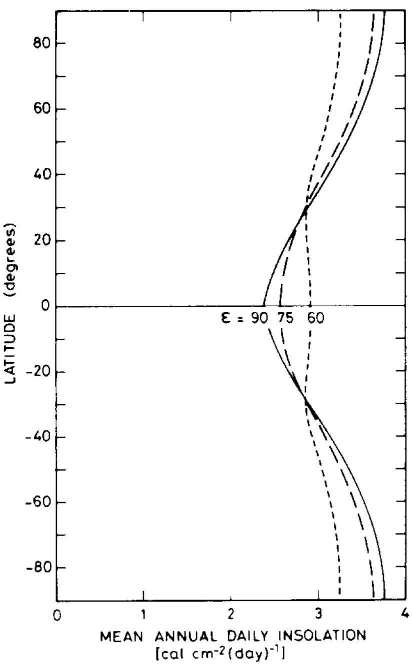

FIG. 4. Latitudinal variation of the mean annual daily insolation at the top of the atmosphere of Pluto for various values of the obliquity.

larger than 60°. This phenomenon is evident from Fig. 4. The ratio of both insolations amounts to about 0.9 (ϵ = 60°), 0.7 (ϵ = 75°), and 0.6 (ϵ = 90°).

From Fig. 3 it follows that the daily insolation at the south pole during summer solstice is appreciably higher than that of the north pole at its summer solstice. On the other hand, Fig. 4 indicates that the hemispheric seasonal asymmetry in the solar radiation disappears when averaging the incoming solar energy over the year. This is explained by observing that the length of the northern summer (T_S) (Table II) is longer than the length of the southern summer (T_W).

In conclusion, we believe the calculations presented in this work could help in studies of the radiation and energy budget of Pluto.

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