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## Latitude coverage of observations of the middle atmosphere by solar absorption spectrometry from a heliosynchronous orbit

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## FOREWORD

This article will be published in "ESA Journal".

## AVANT-PROPOS

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## VOORWOORD

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## VORWORT

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# LATITUDE COVERAGE OF OBSERVATIONS OF THE MIDDLE ATMOSPHERE BY SOLAR ABSORPTION SPECTROMETRY FROM A HELIOSYNCHRONOUS ORBIT

by

J. VERCHEVAL

## Abstract

The object of the present article is to analyse the conditions in which atmospheric measurements by solar absorption spectrometry could be performed from a space platform put on a heliosynchronous orbit. Those conditions, and particularly the annual coverage in latitude of the observations, essentially depend on the mean local time at the ascending node of the orbit.

## Résumé

L'objet de cet article est d'analyser les conditions dans lesquelles des mesures atmosphériques par spectrométrie d'absorption solaire pourraient être effectuées à partir d'une plate forme spatiale placée sur une orbite héliosynchrone. Ces conditions, et en particulier la couverture annuelle en latitude des observations, dépendent essentiellement du temps local moyen au noeud ascendant de l'orbite.

Samenvatting

Het doel van dit artikel is de voorwaarden te analyseren waarin atmosferische metingen door middel van zonneabsorptiespectrometrie zouden kunnen gedaan worden vanuit een ruimteplatform dat in een heliosynchrone baan geplaatst is. Die voorwaarden, en in het bijzonder de jaarlijkse zone van geografische breedten voor de waarnemingen, hangen hoofdzakelijk af van de gemiddelde plaatselijke tijd bij de klimmende knoop van de baan.

Zusammenfassung

Die Absicht dieses Artikels ist die Bedingungen zu analysieren worin atmosphärische Messungen durch Sonnenabsorptionspektrometrie würden getan können werden aus einer Raumplattform der in einer heliosynchronen Bahn gesetzt ist. Diese Bedingungen, und besonders das jährliche Gebiet der geographischen Breiten für den Beobachtungen hängen hauptsächlich von die mittlere lokale Zeit am aufsteigenden Knoten der Bahn ab.

## 1. INTRODUCTION

Measurements of atmospheric trace gases in the middle atmosphere were performed during the first Spacelab mission, on board the space shuttle from November 28 to December 8, 1983. The measuring method principle was absorption spectrometry, in the infrared, using the Sun as a light source during sunset or sunrise periods. Several descriptions of the instrumental set-up and the scientific programme have already been published [1-4]. A few thousand spectra were obtained during 18 solar occultation periods and the first results were highly significant [5-11]. The performance of such observations during occultation periods depends on the characteristics of the orbit and, in particular, on the orientation of its plane with respect to the direction of the sun. Moreover, the latitude coverage of the measurements also depends on these geometrical conditions.

As part of the American space station programme, a space platform could be set on a heliosynchronous orbit and the opportunity to conduct atmospheric measurements by absorption spectrometry from such an orbit cannot be neglected. For this reason, it is interesting to see what will be, for a heliosynchronous orbit, the possibilities for occultation and the resulting latitude coverage of the observations. This analysis is presented in this paper.

## 2. DESCRIPTION OF THE ORBIT

Due to the flattening of the Earth at the poles, a satellite orbit has a precession motion of its plane characterized by a linear variation of the right ascension of its ascending node ($\Omega$) with time. The rate of change of this orbital element, expressed in degrees per day, can be written as :

$$\frac{\Delta\Omega}{\Delta t} = - 9.97 \left(\frac{R_E}{a}\right)^{3.5} (1-e^2)^{-2} \cos i \qquad (1)$$

where $R_E$ denotes the equatorial radius of the Earth; a,e, and i are respectively the semi-major axis, the eccentricity and the inclination of the orbit.

A heliosynchronous orbit has the particularity to present a precession motion which counterbalances the mean apparent motion of the sun on the celestial sphere (0.98562 deg/day), in such a way that the Earth's regions are always overflown by the spacecraft at the same mean local times. The orbit which could be adopted would be circular at an altitude of 1000 kilometers with, therefore, an inclination of 99.4° as a consequence of relation (1).

## 3. CONDITION FOR OCCULTATION

The spectroscopic observation of the atmosphere is only possible when there is occultation of the sun by the earth as seen from the space platform. The possibilities of occultation mainly depend on the β angle which is defined as the angle between the solar vector (OA) and its projection into the orbit plane (OA'), taken as positive when the solar vector has a normal component to the orbital plane directed along the angular momentum vector of the platform (fig. 1). The points of the orbit corresponding to the beginning and the end of an occultation are fixed by two particular values $u_1$ and $u_2$ of the argument of latitude u which is an angle measured in the orbit plane from the ascending node N, positive in the direction of orbit travel. For a circular orbit with r as radius, it can be shown that for an observation at altitude z these values are given by [12]

$$\cos(u_1 - u_\odot) = \cos(u_2 - u_\odot) = -\frac{(R+z)}{r\cos\beta}\left[\frac{r^2}{(R+z)^2} - 1\right]^{1/2} \qquad (2)$$

where R is the Earth radius and $u_\odot$ is the argument of latitude of the projection of the solar vector on the orbit plane (fig. 1).

Therefore, occultation occurs if the condition

$$\frac{R + z}{r \cos \beta} \left( \frac{r^2}{(R + z)^2} - 1 \right)^{1/2} < 1$$

is satisfied. This condition becomes :

$$|\beta| < 90° - D$$

where D denotes the solar depression angle below the local horizontal plane given by

$$\cos D = \frac{R+z}{r}$$

For a heliosynchronous orbit at 1000 km, the depression angle at the beginning and the end of an occultation ($z=0$) is 30.2 degrees. Hence, the spectroscopic experiment will be feasible if

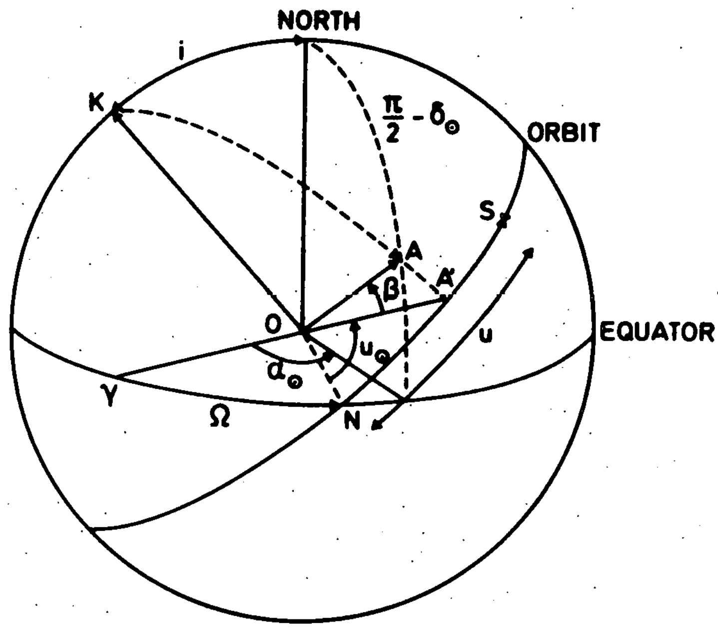
$$|\beta| < 59.8° \qquad (3)$$

If $|\beta|$ gets above this value, there will be no terminators (full sun orbit).

Considering the spherical triangle K North A in figure 1, the β-angle can be expressed in the form :

$$\sin \beta = \cos i \sin \delta_{\odot} + \sin i \cos \delta_{\odot} \sin (\Omega - \alpha_{\odot}) \qquad (4)$$

where $\alpha_{\odot}$ and $\delta_{\odot}$ denote the equatorial coordinates of the sun. The inclination i being fixed, the β-angle depends firstly on the declination of the sun $\delta_{\odot}$, and secondly on the difference $(\Omega - \alpha_{\odot})$ which is a function of launch time.




O CENTER OF THE EARTH
A SUN
S SPACELAB
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γ VERNAL POINT

Fig. 1.- Geometric aspect of the occultation problem.

For a heliosynchronous orbit, this difference ($\Omega - \alpha_\odot$) varies during the year as the equation of time since

$$\Omega - \alpha_\odot = (MLT)_N - 12h + E \quad (5)$$

where $(MLT)_N$ denotes the mean local time at the ascending node of the orbit (a constant fixed by the launch time).

The extreme values of the β-angle during one year are shown as a function of $(MLT)_N$ at the lower part of figure 2. It can be seen that for $(MLT)_N$ values between 4h and 8h or between 16h and 20h, the β-angle takes values which do not always satisfy condition (3) including, therefore, periods of time without occultation.

## 4. COVERAGE IN LATITUDE

By using formulas given in a previous work [12], the annual coverage in latitude of the measurements at the ground level, during sunrise and sunset, has been determined for different mean local times at the ascending node. The results are reported at the upper part of figure 2. It can be noted that the observations are mainly performed at high latitude in both hemispheres. The equatorial region is investigated only for $(MLT)_N$ values close to 4, 8, 16, and 20 hours, that is to say where the geometrical conditions give β-angles close to the limit of 59.8 degrees.

On the other hand, the coverages in latitude for sunrise (SR) and sunset (SS) are very similar if one considers the corresponding $(MLT)_N$ values linked by the following relation :

$$(MLT)_{N,SR} = 12h - (MLT)_{N,SS} \quad (6)$$

In particular, for $(MLT)_N$ values of 6 and 18 hours, the coverages in latitude at sunrise and sunset are overlapping and especially concern high latitudes.

ANNUAL COVERAGE IN LATITUDE FROM A HELIOSYNCHRONOUS ORBIT AT 1000 Km ALTITUDE

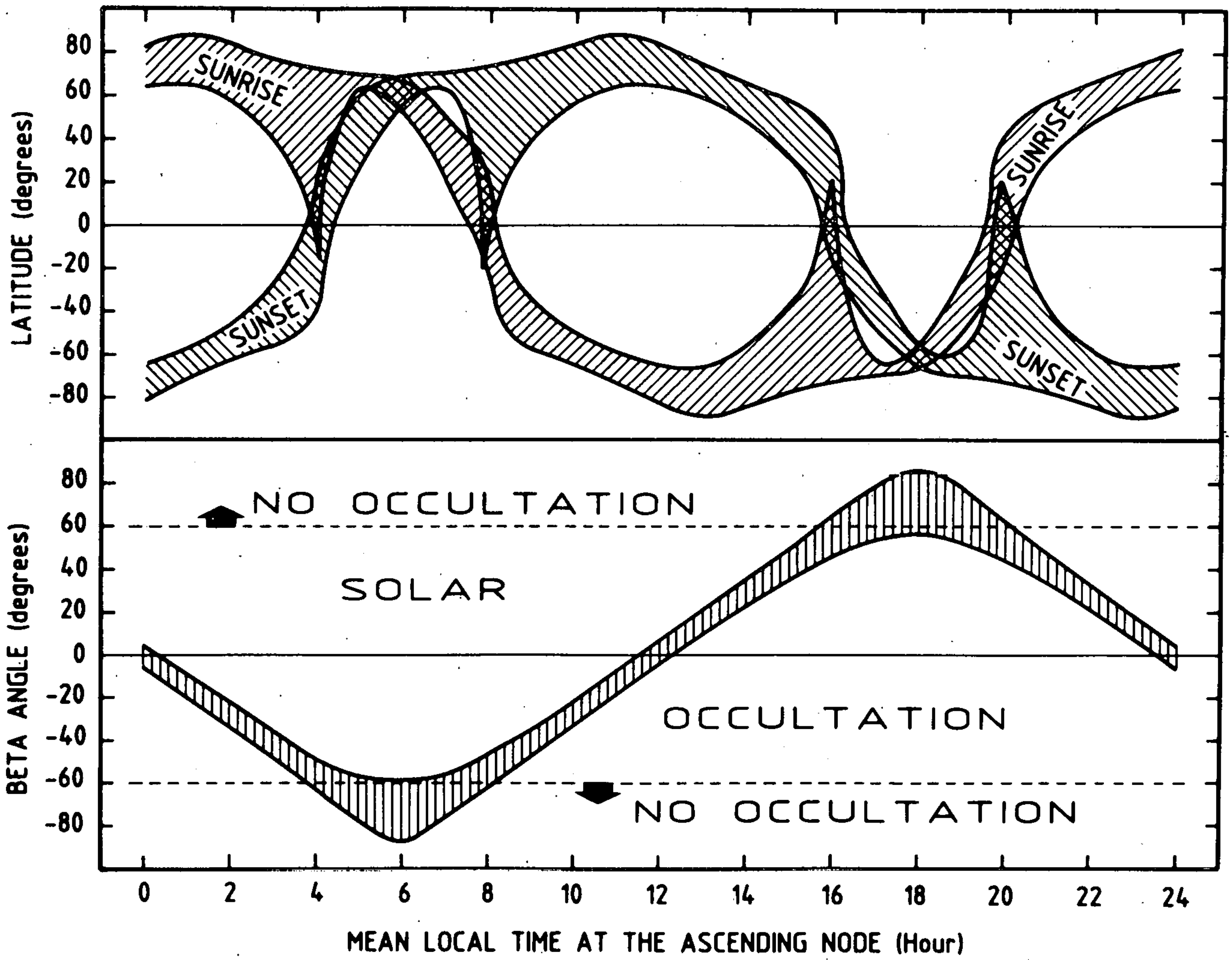


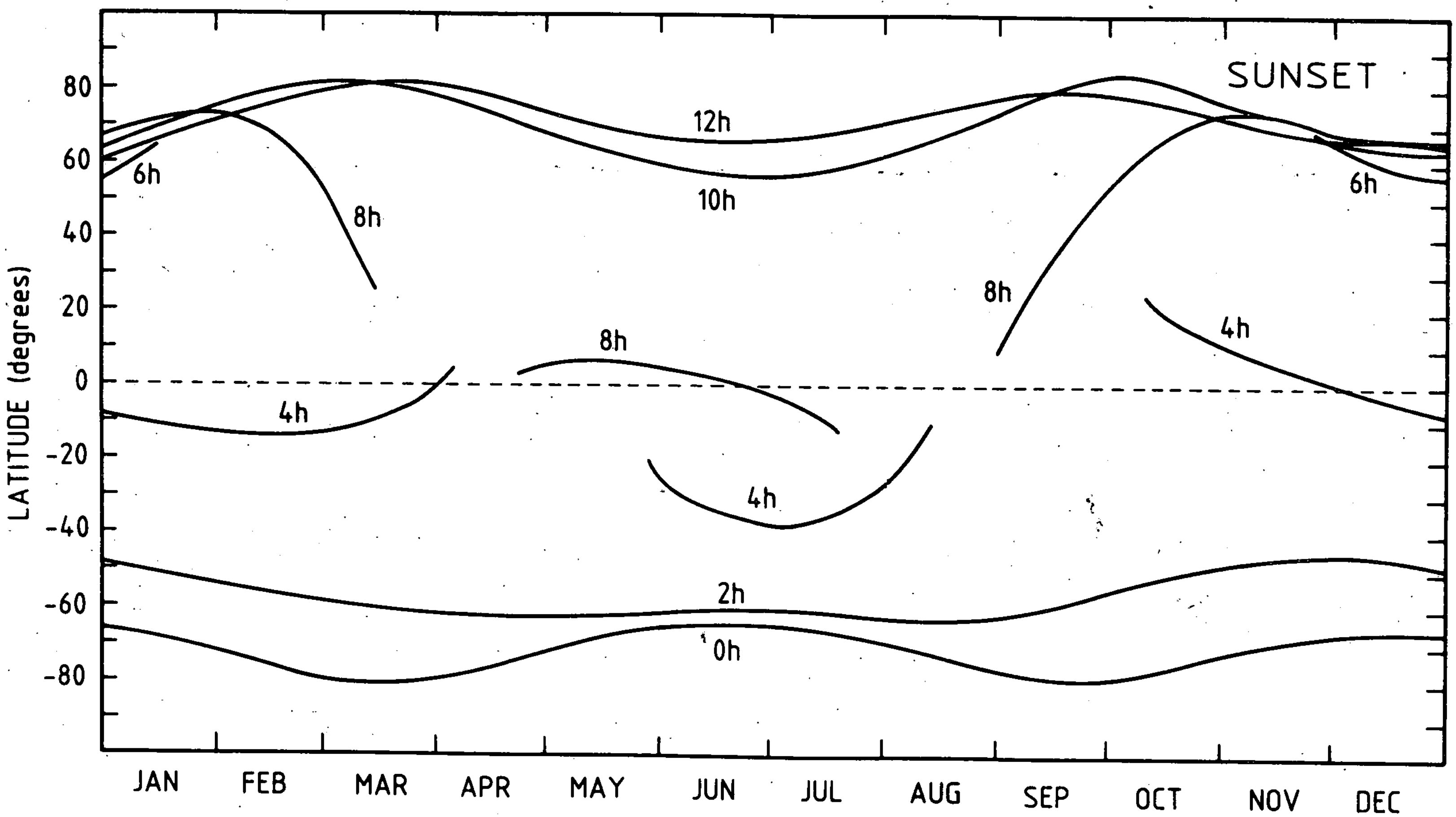

Fig. 2.- At the upper part : annual coverage in latitude from a heliosynchronous orbit at 1000 km in terms of the mean local time at the ascending node.
At the lower part : range of values of the β-angle during one year; occultations will occur for $|\beta| < 59.8$ degrees.

Figures 3 and 4 show the variation with time of the latitude of the observations during sunset and for different values of the mean local time at the ascending node. Figures 5 and 6 are referring to sunrise conditions. These four figures very well display the periods without occultation; the latter can rise up to 10,5 months for $(MLT)_N$ values of 6 and 18 hours. A comparison between sunset and sunrise conditions reveals that <u>for a particular day</u> of the year, relation (6) is not always reliable when the $(MLT)_N$ values are close to 4, 8, 16 and 20 hours. Indeed, for these particular values of $(MLT)_N$, combination of formulas (4) and (5) shows that β-angle can take values which give or not a possibility for occultation according to the values of the equation of time E. Figure 7 gives an illustration of this for the first three months of the year with $(MLT)_N$ taking 16h and 20h values. If the equation of time E is neglected, β-angle takes the same values for $(MLT)_N$ equal to 16 and 20 hours (curve 1). Taking into account the variation of E, β-angle values are either greater (curve 2) or lower (curve 3) than the limit value (59.8 degrees) between "occultation" and "no occultation" conditions.

On the other hand, the asymmetry of some of the curves between the two half-years is also due to the effect of the variation of the equation of time. More generally, this last effect has no practical influence when β-angle is far from its limit value.

## 5. CONCLUSION

Absorption spectrometry measurements of the Earth's atmosphere from a heliosynchronous orbit have an annual coverage in latitude which depends on the mean local time at the ascending node of the orbit. The high latitude regions in both hemispheres are mainly investigated. The coverage is extended to the equatorial region just for mean local times at the ascending node close to 4,8,16 and 20 hours. It is also for these particular cases that the equation of time plays a major role.




<u>Fig. 3.-</u> Coverage in latitude for various mean local times at the ascending node between 0 and 12 hours and for sunset conditions.

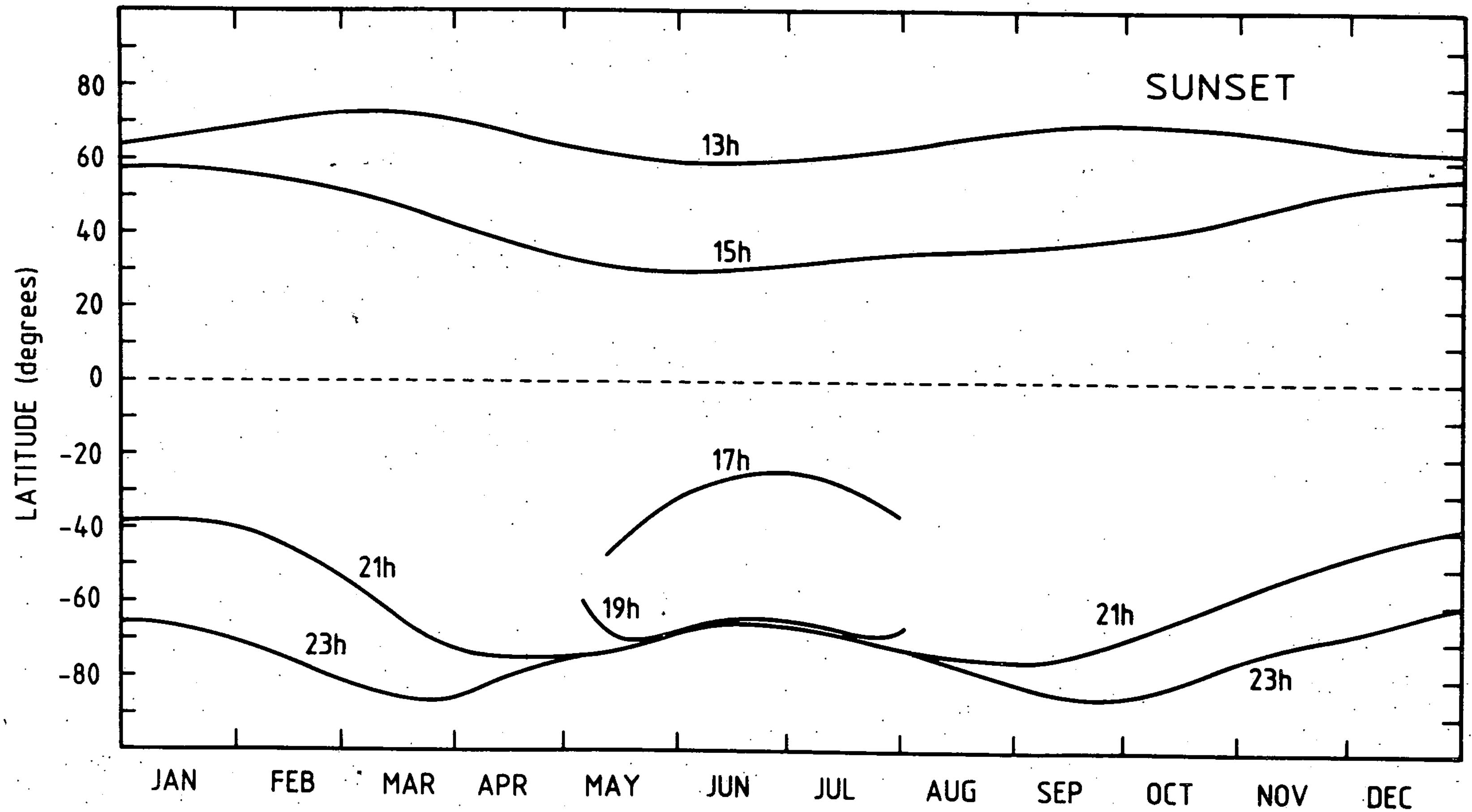



Fig. 4.- Coverage in latitude for various mean local times at the ascending node between 13 and 23 hours and for sunset conditions.

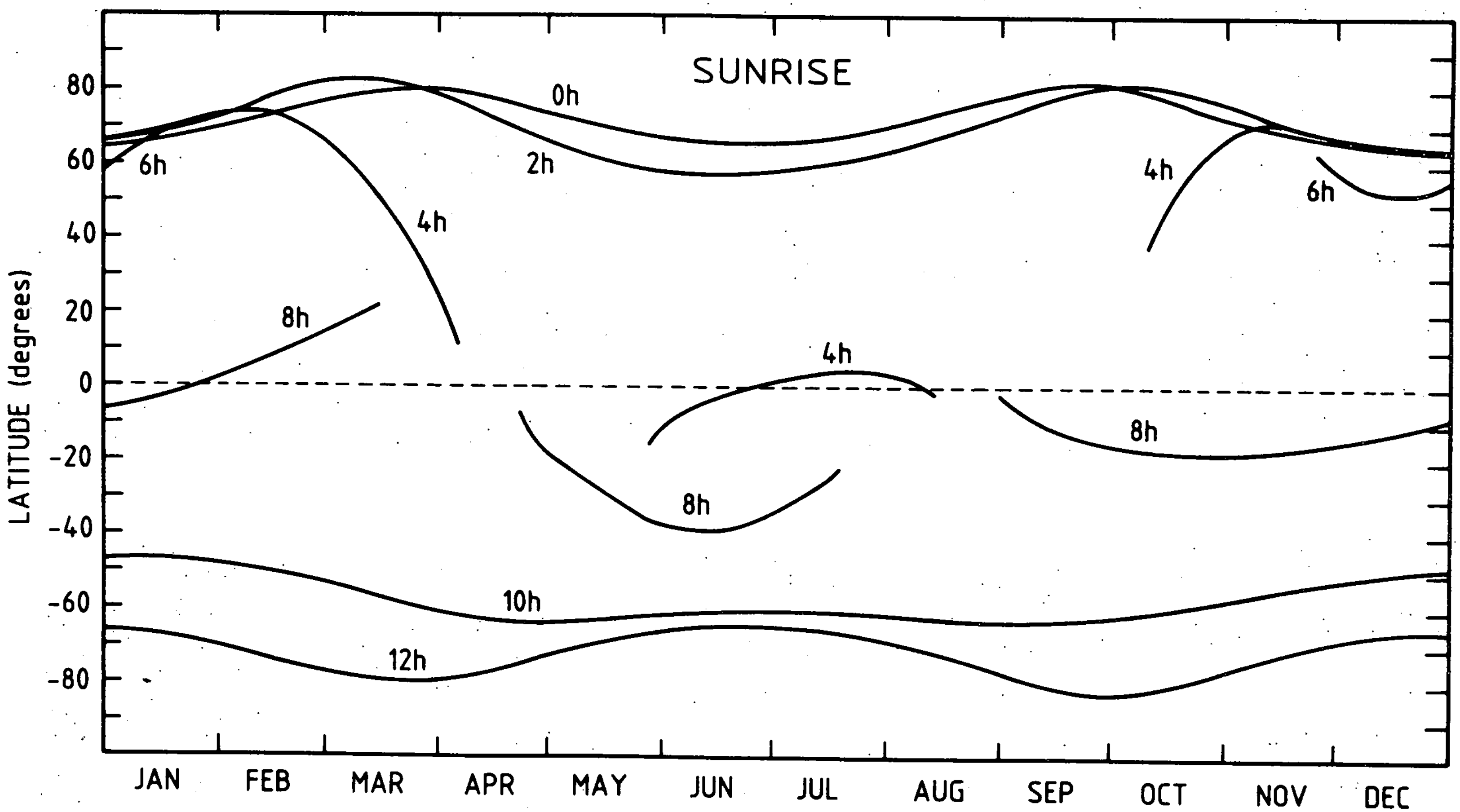



Fig. 5.- Coverage in latitude for various mean local times at the ascending node between 0 and 12 hours and for sunrise conditions.

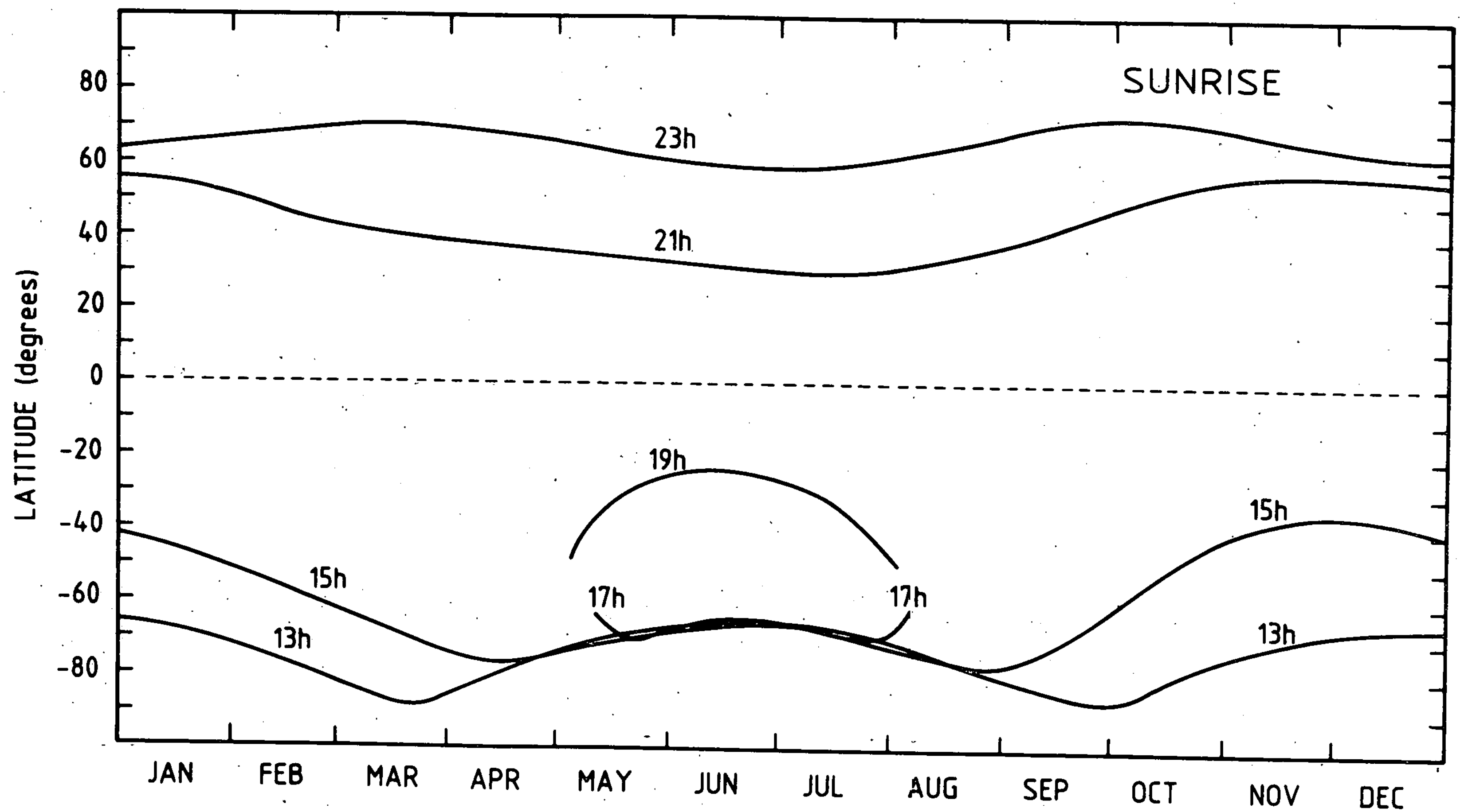



Fig. 6.- Coverage in latitude for various mean local times at the ascending node between 13 and 23 hours and for sunrise conditions.

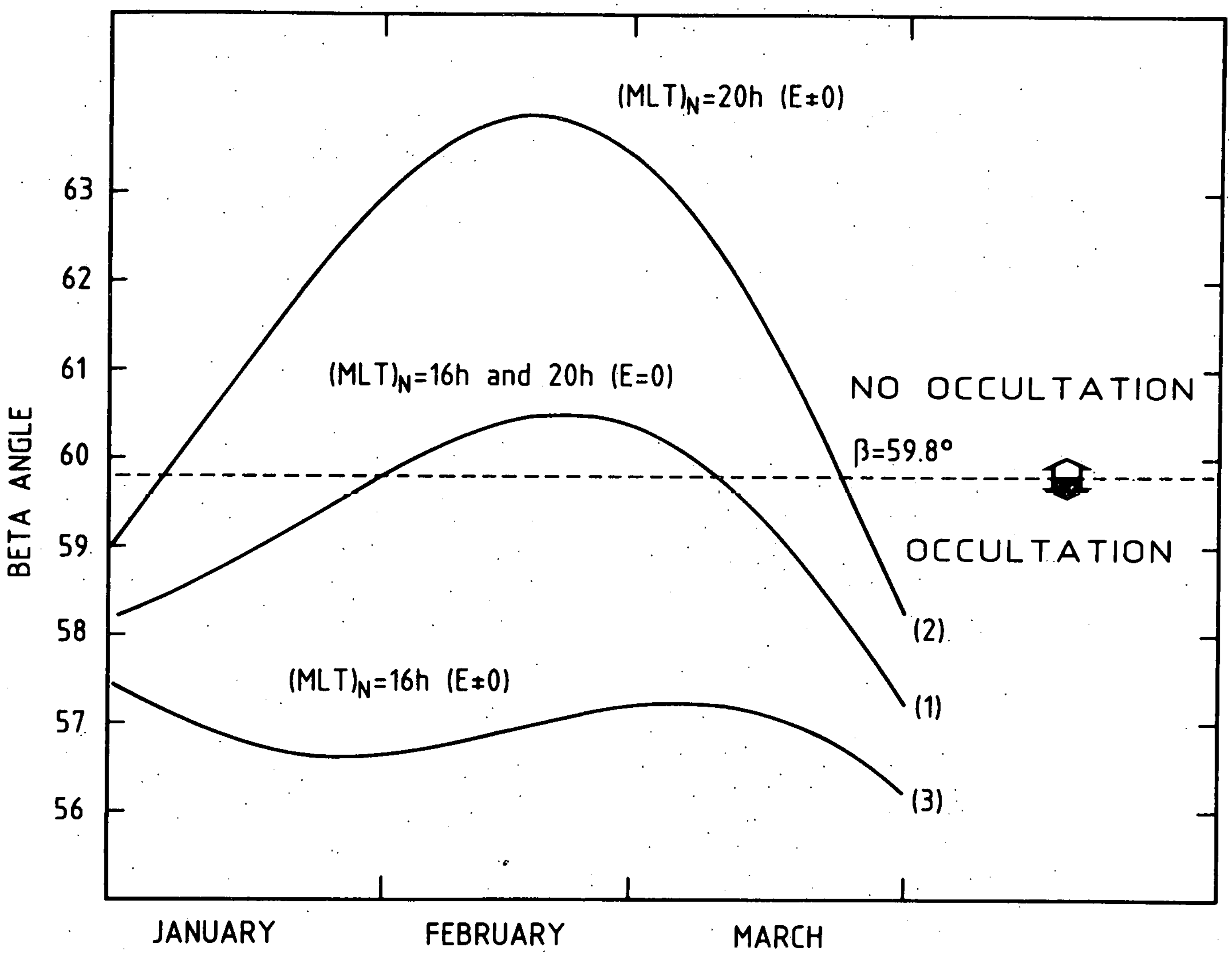



Fig. 7.- Effect of the equation of time on the β-angle for mean local times at the ascending node of 16 and 20 hours and for the first three months of the year.

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