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Latitude Coverage of Solar Absorption Spectrometry Observations of the Middle Atmosphere from a Heliosynchronous Orbit

Abstract The conditions under which atmospheric measurements by solar absorption spectrometry could be performed from a space platform in a heliosynchronous orbit are analysed. Those conditions, and particularly the annual latitudinal coverage of the observations, depend essentially on the mean local time at the ascending node of the orbit.

1. Introduction

Measurements of atmospheric trace gases in the middle atmosphere were performed during the first Spacelab mission between 28 November and 8 December 1983. The measuring technique was absorption spectrometry in the infrared, using the Sun as a light source at sunset or sunrise. Several descriptions of the instrument setup on that mission and the scientific programme conducted 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. The latitudinal coverage of the measurements also depends on these geometrical conditions.

As part of the US Space-Station Programme, a space platform could be put into a heliosynchronous orbit and the opportunity that this presents for conducting atmospheric measurements by absorption spectrometry cannot be neglected. This paper looks at the possibilities for occultation measurements from such a heliosynchronous orbit and the resulting latitudinal coverage of the observations.

2. Description of the orbit

Due to the flattening of the Earth at the poles, the plane of a satellite orbit precesses with a motion characterised by a linear variation in the right ascension of its ascending node (Ω) 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, and a, e, and i are the semi-major axis, the eccentricity and the inclination of the orbit, respectively.

A heliosynchronous orbit has the particular feature of a precession motion that counterbalances the mean apparent motion of the Sun on the celestial sphere (0.98562 deg/d) in such a way that particular regions of the Earth are always overflown by the spacecraft at the same mean local times. The orbit that could be adopted for the space platform would be circular at an altitude of 1000 km with, therefore, an inclination of 99.4° as a consequence of Equation 1.

3. Conditions for occultation

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 for occultation mainly depend on the angle β, 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 component normal 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 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 Reference 12 as

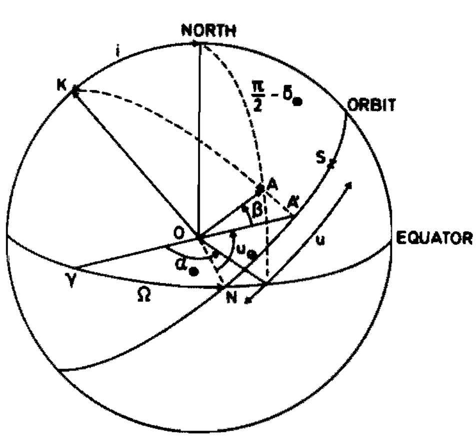

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Figure 1. Geometrical features of the occultation problem

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

where R is the Earth's radius and $u_\odot$ is the argument of latitude of the projection of the solar vector onto the orbital 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 end of an occultation ($z=0$) is 30.2°. Hence, the spectroscopic experiment will be feasible if

$$|\beta| < 59.8° \tag{3}$$

If $|\beta|$ goes 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

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

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.

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

$$\Omega - \alpha_{\odot} = (MLT)_N - 12\text{h} + E \tag{5}$$

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

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

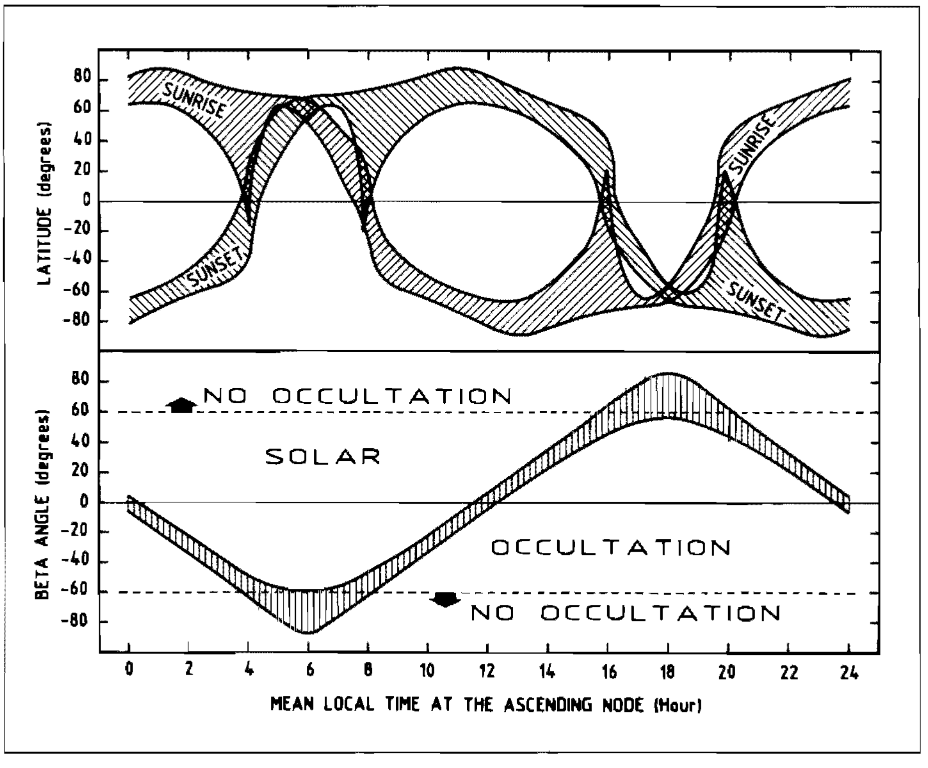

Figure 2. Upper part: annual latitudinal coverage from a heliosynchronous orbit at 1000 km altitude in terms of the mean local time at the ascending node.
Lower part: range of β-angle values over a one-year period; occultations will occur for $|\beta| < 59.8°$

4. Coverage in latitude

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

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

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

In particular, for $(MLT)_N$ values of 6 and 18 h, the coverages in latitude at sunrise and sunset overlap and are primarily at high latitudes.

Figures 3 and 4 show the variation with time of the latitude of the observations during sunset, for different values of the mean local time at the ascending node. Figures 5 and 6 refer to sunrise conditions. These four figures display the periods without occultation very well; the latter can be as long as 10.5 months for $(MLT)_N$ values of 6 and 18 h. A comparison of sunset and sunrise conditions reveals that, *for a particular day* of the year, Equation 6 is not always reliable when the $(MLT)_N$ values are close to 4, 8, 16 and 20 h. Indeed, for these particular values of $(MLT)_N$, combination of Equations 4 and 5 shows that the β-angle can take values that do or do not allow occultation depending on the values of the equation of time E. Figure 7 illustrates this for the first three months of the year, with $(MLT)_N$ taking values of 16 h and 20 h. If the equation of time E is neglected, the β-angle takes the same values for $(MLT)_N$ equal to 16 h and 20 h (curve 1). Taking into account the variation in E, the β-angle values are either greater (curve 2) or smaller (curve 3) than the limiting value of 59.8° between occultation and no-occultation conditions.

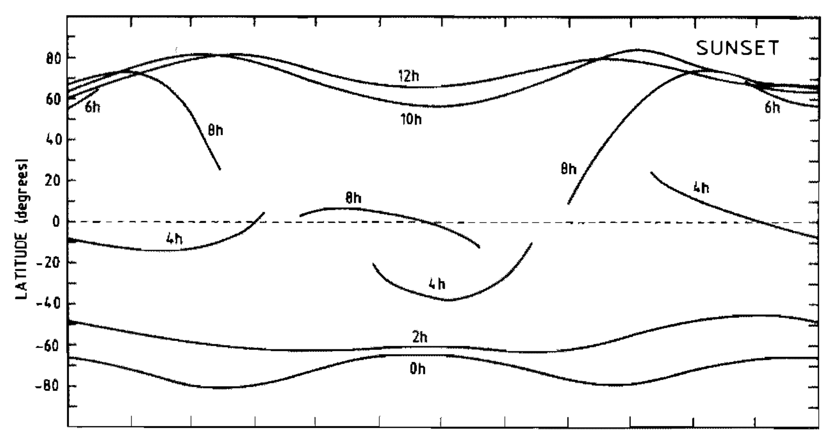

Figure 3. Latitude coverage for various mean local times at the ascending node between 0 and 12 h, for sunset conditions

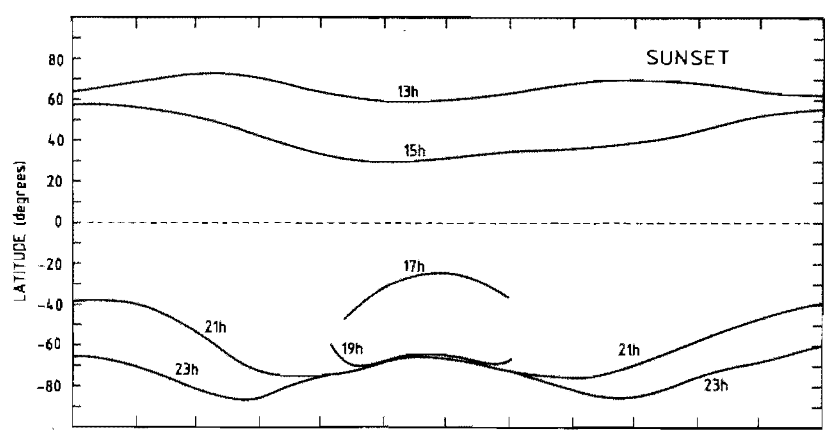

Figure 4. Latitude coverage for various mean local times at the ascending node between 13 and 23 h, for sunset conditions

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

5. Conclusion

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

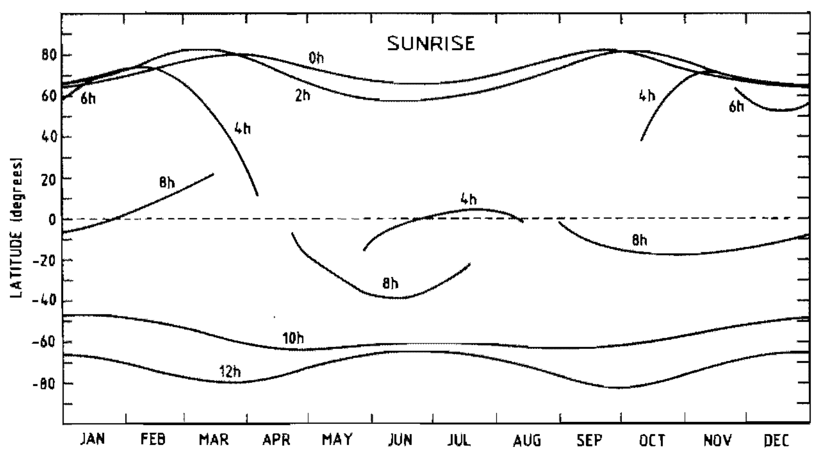

Figure 5. Latitude coverage for various mean local times at the ascending node between 0 and 12 h, for sunrise conditions

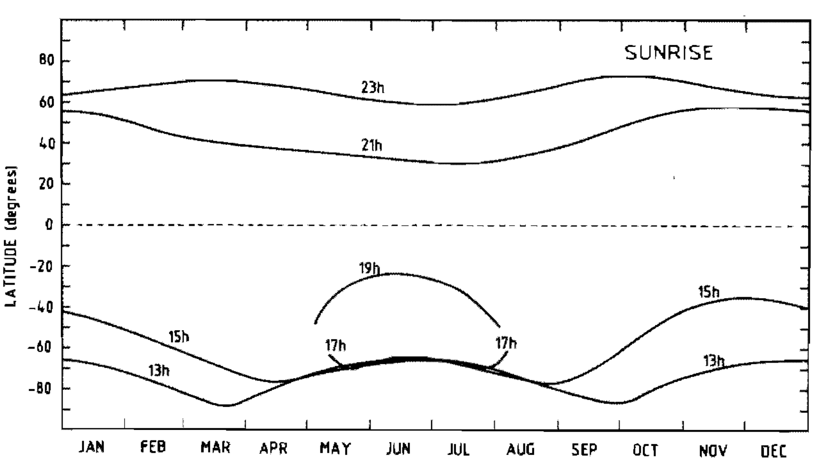

Figure 6. Latitude coverage for various mean local times at the ascending node between 13 and 23 h, for sunrise conditions

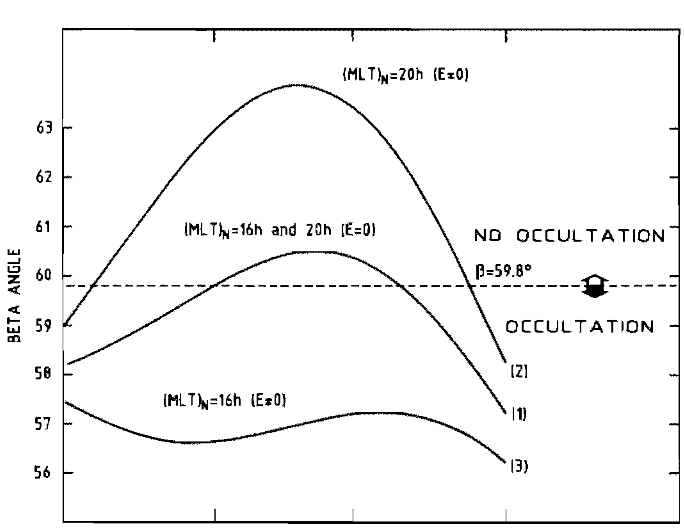

Figure 7. Effect of the time equation on the β-angle for mean local times at the ascending node of 16 and 20 h, for the first three months of the year

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