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NORTH-SOUTH ASYMMETRY IN A CLOSED MAGNETOSPHERE

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RESUMEN

Las observaciones –durante la fase anisotrópica de los eventos solares– de diferentes estructuras de flujo de radiación cósmica sobre el casquete polar Norte y el casquete polar Sur, se han tratado siempre de explicar suponiendo que existen diferentes topologías de interconexión de líneas del campo geomagnético con el campo magnético interplanetario en ambos hemisferios. El propósito de este trabajo es mostrar que esta asimetría Norte/Sur también puede presentarse en una magnetosfera cerrada debido tanto a la anisotropía misma del campo geomagnético, como a la presencia de una anisotropía del flujo de las partículas en el medio interplanetario, con una componente Norte o Sur respecto del ecuador geomagnético. Se analiza el evento del 24 de enero de 1969 y, se muestra que las predicciones teóricas basadas en los argumentos expuestos anteriormente coinciden satisfactoriamente con las observaciones.

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ABSTRACT

Observations –during anisotropic solar proton events– of a North-South asymmetry in flux structures over polar caps have been usually explained in terms of a difference in the topology of interconnected geomagnetic and interplanetary field lines in both hemispheres. The present work shows that a North-South asymmetry can exist also in a closed magnetosphere, in which case the flux profiles asymmetry is due to the N-S geomagnetic field asymmetry (this being stronger when the dipolar axis forms a large angle with the perpendicular to the solar wind flow direction) and to the presence of a northern (or southern) component of the interplanetary flux anisotropy with respect to the geomagnetic equator. The observations for the January 24, 1969 event are analyzed within the frame of arguments presented in this paper and the agreement with theoretical predictions is shown to be very satisfactory.

INTRODUCTION

The fact that during solar events different intensities of protons are observed over the northern and southern polar regions has been widely analized by many authors. (See fox example Krimigis and Van Allen, 1967; Reid and Sauer, 1967; Evans and Stone, 1969; Van Allen *et al.*, 1971, Domingo and Page, 1971 and Evans, 1973). This North-South flux asymmetry does not last the whole solar event but instead the intensities over both polar caps tend to become equal after a delay time which normaly ranges from several minutes to several hours.

At the present there seems to exist a general concensus that the observed North-South asymmetry is the result of different topologies of interconnection between geomagnetic and interplanetary field lines in the North and South hemispheres. The following mechanisms have been advanced to explain the North-South asymmetry as well as the delay: Evans (1973) assumes that particles arriving at both polar caps penetrate the magnetospheric cavity through two different and well localized regions at the tail boundary, which he names "windows", where the geomagnetic and the interplanetary field lines interconnect. The elbow of the interconection provides the turning mechanism that send the particles towards the earth. According to Evans, the windows lie approximately at 250 R_E and 1750 R_E downstream from the earth along the tail boundary. Whether the North or the South polar cap is connected to the nearest or the farthest windows depends on the conditions of the interplanetary magnetic field and mainly on its polarity. In this model, for convective solar events, the polar cap illuminated by particles coming from the nearest window is the first to present high intensity; the illumination of the other cap is delayed, that is, the proton flux intensity over this polar cap remains low, until the convected particles reach and enter the more distant window and move within the tail towards the earth. For the case of flare events the N/S asymmetry in the flux is assumed to be a consequence of a negative radial gradient of the intensity in the interplanetary proton flux and the delay time corresponds to the time that it takes the gradient to vanish.

Domingo and Page (1971) also claim that the North-South asymmetry in the illumination of polar caps by solar protons is due to different types of interconnection of field lines, but argue that the polarity of the interplanetary field is not sufficient to determine the interconnection of geomagnetic and interplanetary field lines and that the Northern or Southern directions of the interplanetary field must also be taken into account. In this model the interconnection of field lines will allow the direct access of solar protons to one of the polar caps —the one that first presents high intensity— while the access to the other is expected to be diffusive.

The purpose of this work is to show that there exist other factors that can induce North-South asymmetry in a closed magnetosphere without the interconnection of field lines. Such factors are of two different kinds: a) the asymmetry of the field in the magnetospheric cavity due to the intrinsic lack of symmetry of the internal field and also due to the North/South asymmetry of the external field caused by the tilt of the geomagnetic axis with respect to the solar wind flow, and b) the N/S asymmetry of the interplanetary flux. In the following sections both will be analized by means of an extensive study of propagation of particles performed by numerical integration of the equation of motion of the particles in a mathematical model of the geomagnetic field. The region of computation is limited by a model magnetopause which is a surface of revolution around the earth-sun line composed on the day side by a hemisphere of radius 13.9 R_E centered at -3.5 R_E. This surface extends on the night side into a truncated cone with 15.3° semiangle. In the tail, the integrations are carried out up to 20 R_E. From the computed trajectories, the expected latitudinal profiles of intensity over polar caps will be derived. The method for obtaining flux profiles is described in detail by Gall and Bravo (1974). In this method the peaks of intensity are assumed to be associated with an interplanetary flux anisotropy and are due to particles which enter the magnetosphere with directions lying within a 50° cone around the directions of the interplanetary anisotropy. The relative intensity between valleys and peaks is given by the ratio of anisotropy of the interplanetary flux and the shape of the profile is modulated by the solar proton flux spectrum which in this work is assumed to be $\epsilon^{-2.5}$. The exponent used corresponds to a typical value for solar protons; changes in the exponent of the spectrum does not modify the conclusions reached here.

THE ASYMMETRY OF THE MAGNETOSPHERIC FIELD AND THE N/S ASYMMETRY

1) Asymmetry of the Internal Field

Due to the lack of symmetry of the internal geomagnetic field one cannot expect to observed the same flux of particles of low energies (and hence sensitive to the non-symmetric part of the internal field) over the North and South polar caps. In order to test this effect an extensive study of propagation of particles with energies ranging between 3 MeV and 500 meV was made using the high simulation model of the internal field, namely a gaussian expansion with IGRF coefficients (Cain *et al.*, 1967); the expressions for external field used are those of Williams and Mead (1965) which are North/South symmetric and hence introduce no additonal asymmetry. (For details of the combined model used see Gall and Bravo, 1970). In this case the direction on anisotropy in the interplanetary medium was assumed to lie in the ecliptic along Parker's spiral (50° West of the Sun-Earth line), with a ratio of anisotropy (^{Imax}/Imin) equal to 2.

As can be seen from figure (1) the flux profiles expected over each polar cap for the above conditions differ considerably, and a North/South asymmetry is expected at all local time of observation. It was found that the differences are stronger for particles with energies below 100 MeV.

2) Asymmetry of the external field

The field of external origin, that is, the field due to the interaction of the solar wind with the geomagnetic internal field, is obviously dependent on the relative orientation of the geomagnetic axis with respect to the solar wind flow. Such a field should exhibit a North-South symmetry only when to dipole axis is perpendicular to the flux of the solar wind; that is for zero tilt angle. For all other tilt values a N/S asymmetry of the field is present and increases with the tilt angle.

For the study of the effect of the tilt on the relative illumination of the Northern and Southern polar caps, the Mead and Fairfield (1972) model was used with a dipolar representation of the internal field which obviously does not introduces additional asymmetries. Even when the Mead-Fairfield field lines flow-out for large tilt angles, this divergence does not affect the results obtained here because it lies out of the limits of the numerical integration region used in this work. In Figures (2) and (3) the computed profiles of intensity expected over both polar caps are shown for the cases of extreme values of the tilt angle namely ± 35°. As before, we assume the direction of the interplanetary anisotropy to lie in the ecliptic along Parker's spiral with a ratio of anisotropy of 2.

As the figures show the N/S asymmetry of the external field makes the profiles over one polar cap differ from the profiles over the other polar cap even for particles of energies higher than 500 MeV.

A NORTHERN OR SOUTHERN COMPONENT OF THE DIRECTION OF ANISOTROPY AND THE N/S ASYMMETRY

A North/South asymmetry in the illumination of polar caps by solar protons can also be induced by an Northern or Southern component –with respect to the geomagnetic equatorial plane– of the direction of the interplanetary anisotropy. To study the effect of such a component, the propagation of particles in the magnetosphere was analyzed with the help of the Mead and Fairfield model for zero tilt (when the Sun-Earth line lies on the geomagnetic equatorial plane) with a dipolar representation of the internal field; such a field is obviously N/S symmetric. Figures 4 and 5 show the theoretical profiles calculated for the case of a direction of anisotropy in the interplanetary medium along Parker's spiral but inclined 50° degree (North or South) to the ecliptic plane. Figure 4 corresponds to the case of a Northern component and Figure (5) to a Southern component; again an anisotropy ratio of 2 was assumed. As can be observed, a strong North-South asymmetry in the illumination of polar caps is induced by the presence of such components of the interplanetary anisotropy.

It is important to point out that a North or South component of the interplanetary flux with respect to the geomagnetic equatorial place exists even when the interplanetary flux lies entirely in the ecliptic plane. This is so because in general the geomagnetic equatorial plane does not coincide with the ecliptic. Obviously the relative Norther or Southern components are stronger during solstices when the tilt is larger.

Summarizing, the appearance of a N/S asymmetry in the illumination of polar caps by solar protons can well be explained in terms of a closed magnetosphere as a consequence of the situations mentioned before. We have discussed in this work the effect of various independent factor responsible for the N/S asymmetry but obviously in any actual observation many or all of these factors should be present, however, and hence the observed intensity profiles should result from combination of the ones presented here.

On the other hand, the intensity difference in the illumination profiles of both polar caps has been assumed, in the present study, to be due to differences in the flux intensity along different directions in the interplanetary medium. Therefore, any latitudinal structure, and hence also the N/S asymmetry will disappear when the interplanetary flux becomes isotropic. This means that the delay required to achieve the equal illumination of both polar caps should be related to the duration of the anisotropy and not to any specific magnetospheric configuration.

This conclusion agrees with the observations of Van Allen *et al.* (1971) who have reported that the ratio of the North and South intensities has been observed to be high early in the event, when a strong anisotropy in the interplanetary flux (with a southern component) existed, and dropped to 1 as the interplanetary flux became isotropic.

A COMPARISON WITH OBSERVATIONS

In order to test the validity of our results we will now compare the theoretical profiles with the experimental observations of the January 24, 1969 event for which all the required information about interplanetary flux characteristics is available. Figure 6 (a) shows the intensity profiles for protons of energies between 3.44 and 74 MeV as observed over both polar caps by INJUN 5. At the time of the observation both, the interplanetary field and the proton flux, has a strong southern component with θ ranging between $-40°$ and $-70°$. The ratio of southern to northern intensities was around 10.

The required theoretical intensity profiles were then obtained from calculation of orbits with TILT = $-30°$ at 6 H and 18 H MLT, assuming a direction of anisotropy forming 50° to the South of the ecliptic plane and a ratio of anisotropy of 10. These correspond to the conditions prevailing during the observations.

In Figure 6 (b) the theoretical profiles obtained are shown and a satisfactory agreement with the observations can be seen.

DISCUSSION AND CONCLUSIONS

The study presented here shows that the N/S asymmetry, generally accepted as a proof of interconnection of geomagnetic and interplanetary field lines, can also be explained satisfactorily in a closed magnetosphere.

This result invalidates the assumption that particles with energies of several MeV or higher penetrate the magnetosphere following adiabatically the interconnected lines. Moreover, it is quite possible that particles of such energies are not at all sensitive to the interconection of the magnetic lines.

Nevertheless, these results should not be taken as a proof of the non existence of interconnection. Indeed the causes presented here that produce the N/S asymmetry in a closed magnetosphere will also produced it in an open magnetosphere.

We must note, however, that since interconnection of magnetic fields is a dynamic process one hardly can expect it to be responsable of any long-lasting feature observed near the earth and hence such features must be treated in the frame of an average closed magnetosphere.

The conclusion derived from this work is that the N/S asymmetry is not a consequence of differences in the topology of interconection of field lines and that the search for such interconnection must be based on other kind of observations and with particles with energies below 1 MeV.

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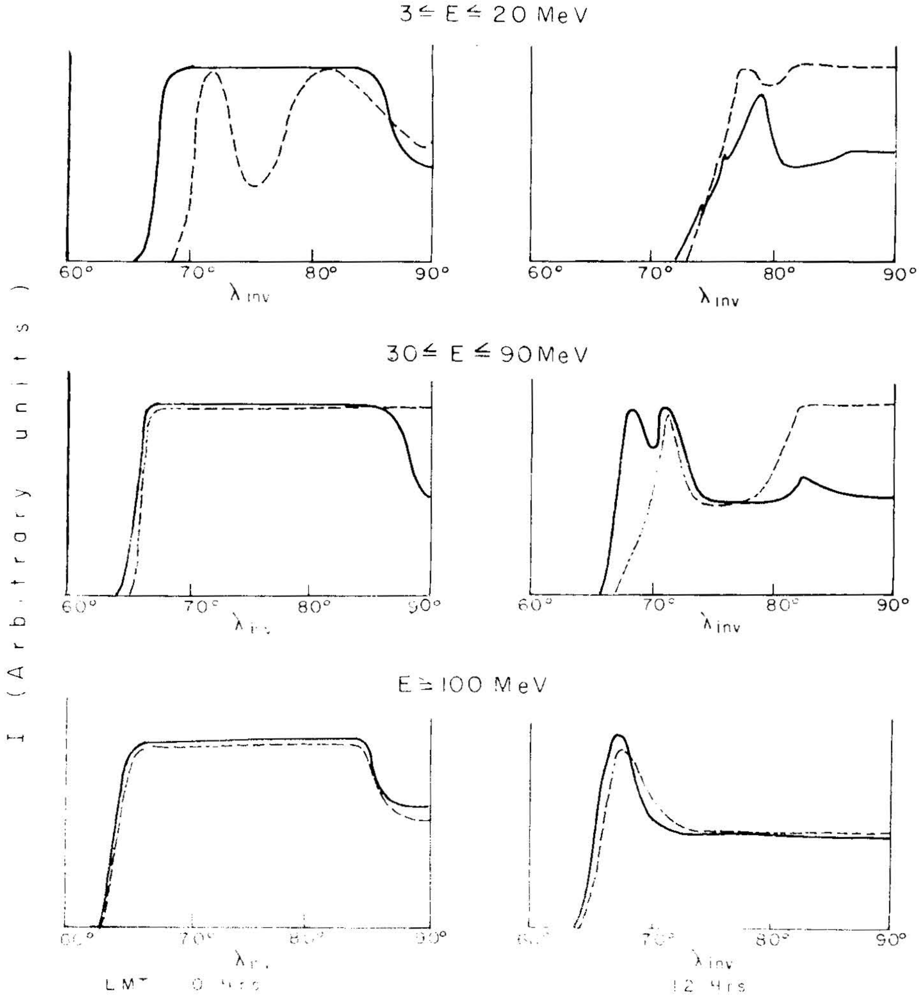

Figure 1. Theoretical proton intensity profiles over polar caps showing the expected N/S asymmetry as a consequence of the lack of symmetry in the internal field, for three different energy channels and for 0 and 12 hs of local magnetic time of observation. Solid and dashed lines corrrespond to the North and South polar cap respectively.

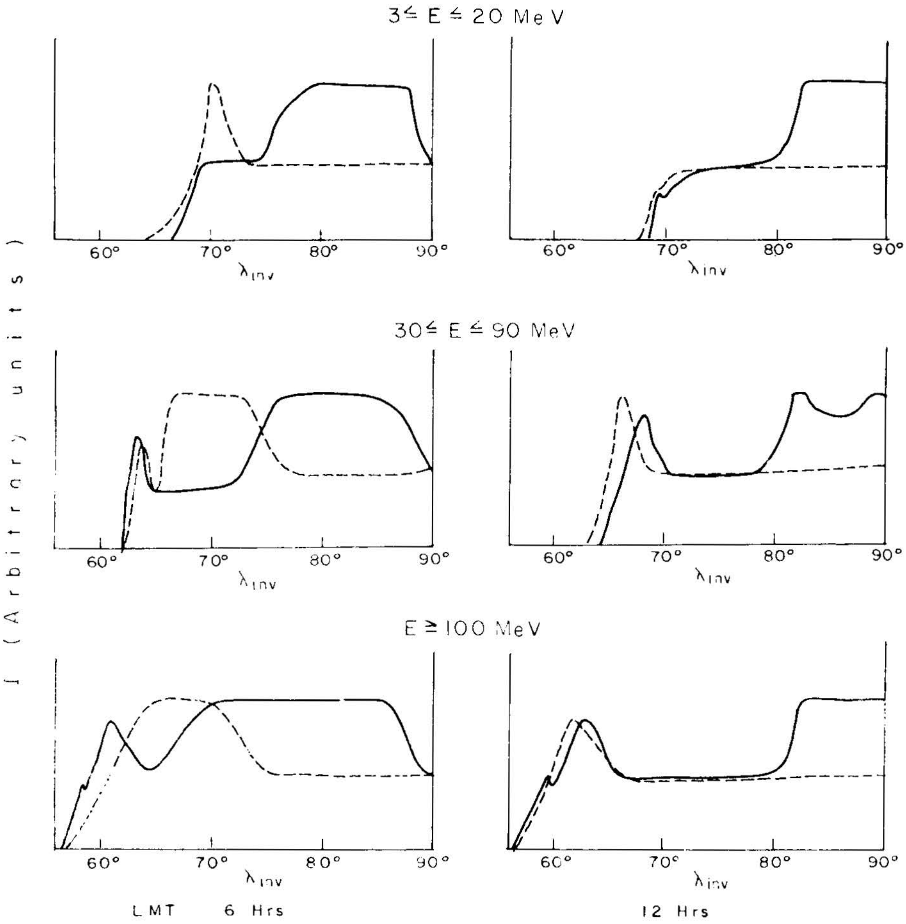

Figure 2. Theoretical proton intensity profiles over polar caps showing the expected N/S asymmetry as a consequence of the existence of a tilt angle of 35°. Solid line correspond to the North polar cap and dashed line to the South.

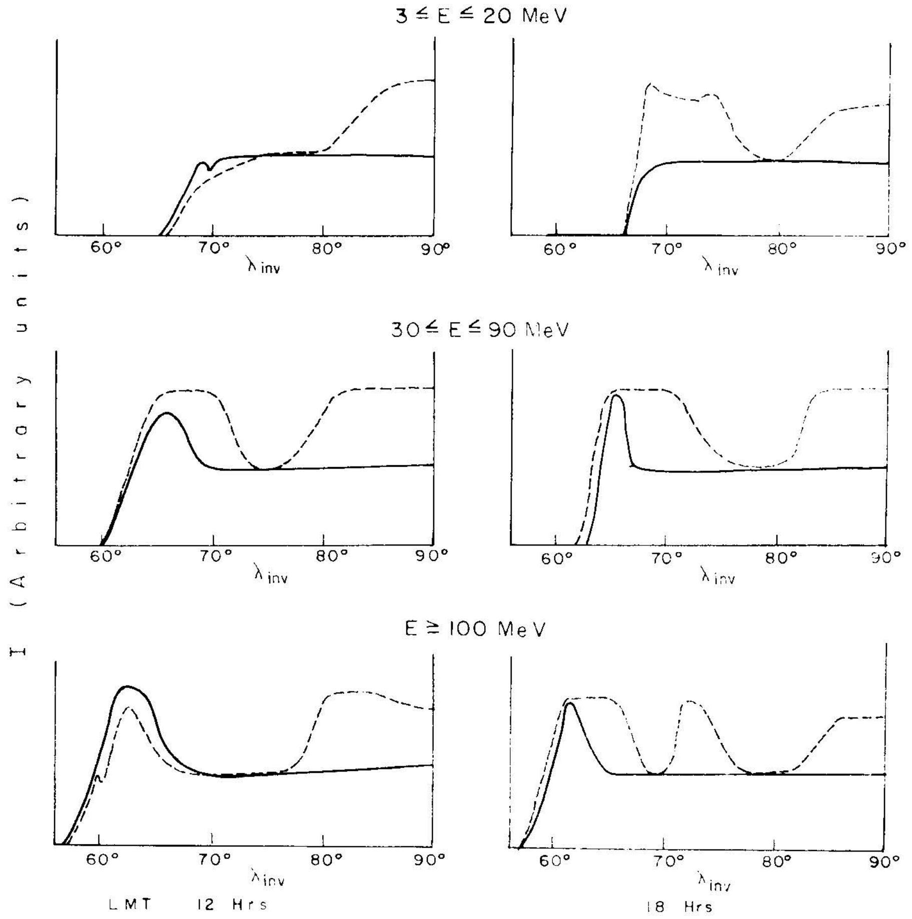

Figure 3. The same as figure 2 but for a tilt angle of −35°.

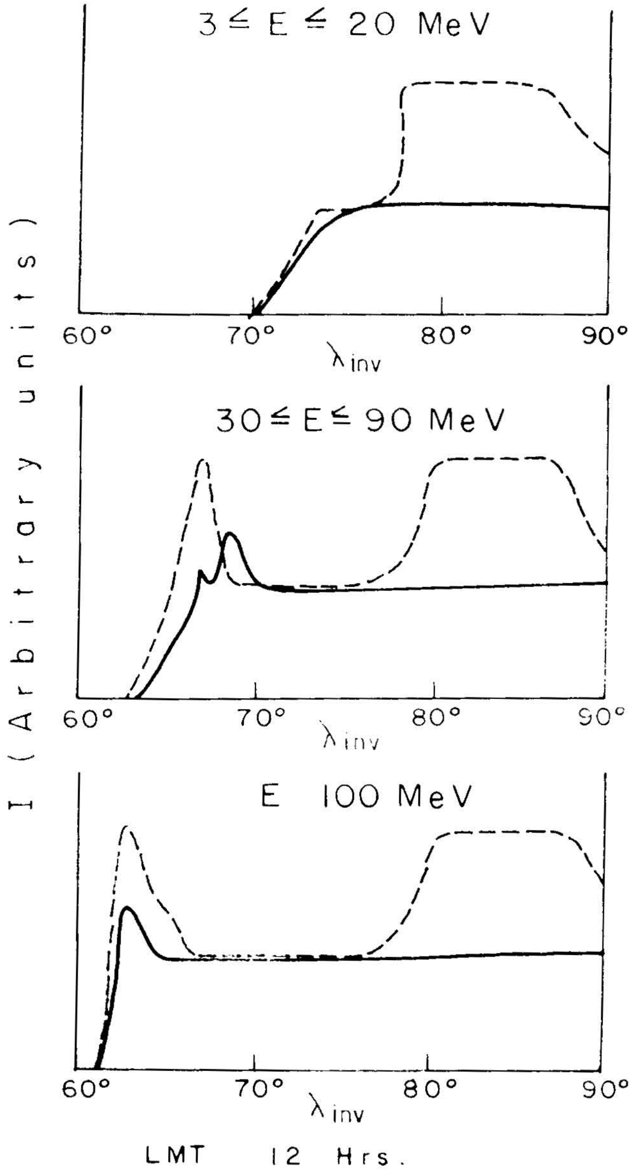

Figure 4. Theoretical proton intensity profiles over polar caps showing the expected N/S asymmetry as a consequence of a North component of the interplanetary flux. Solid lines correspond to the North polar cap and dashed line to the South.

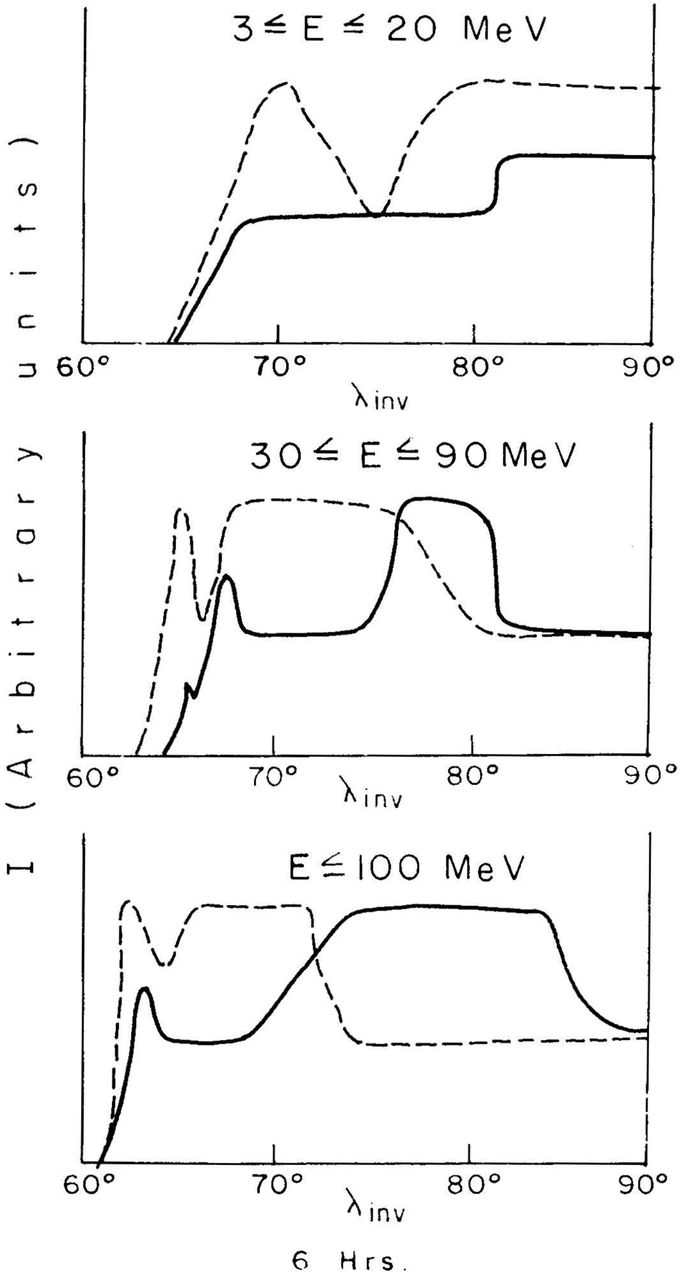

Figure 5. The same as Figure 4 but for a southern component of the interplanetary flux.

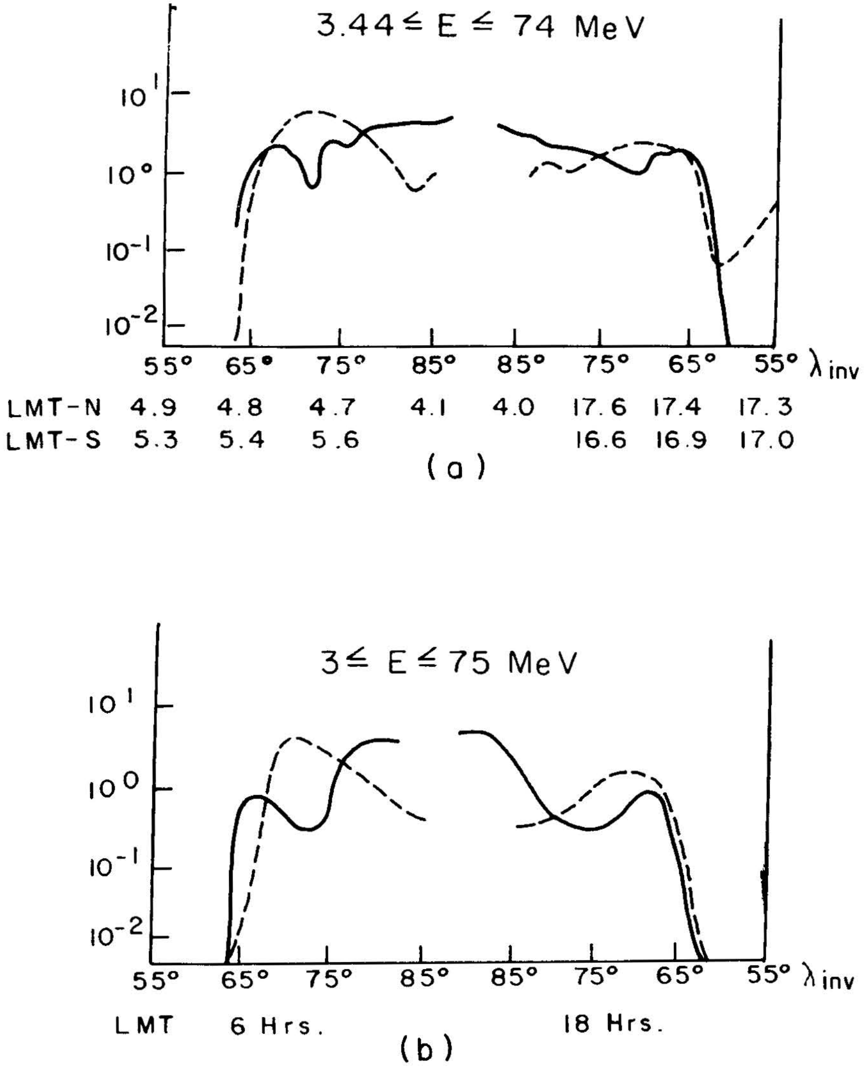

Figure 6. Comparison between the latitudinal profiles of proton intensity over the polar cap as observed by Van Allen *et al.*, 1971 (Fig. 6, Page 4270) in figure (a) and the theoretical profiles expected for this case. Following the arguments exposed in this work, in figure (b). Solid lines correspond to the North and dashed lines correspond to the South.

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