ANALYSIS OF THE GEOSTATIONARY ELECTRON ENVIRONMENT BASED ON LANL DATA

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1. INTRODUCTION

Data analysis and processing considered below is based on 5 geostationary satellites data from Los Alamos National Laboratory (LANL). The objective is to provide preliminary information for comparison with AE8 and creation of future updated/new electrons flux models for geostationary orbit including models of local time variation and standard deviation. Two different approaches are proposed:

- a conventional approach where the magnetic field B and L are computed with an internal field model only,
- a new approach consisting on the computation of B and L with an external field model.

2. PRELIMINARY ANALYSIS OF LANL DATA

2.1 General description of LANL data

LANL data sets from 1979 through to 1988 are available on six files ; each of which corresponds to a LANL satellite. LANL data is presented in hourly averages over the period of coverage and are already averaged over pitch angle ; they have been made available through NSSDC.

Table 1 summarises LANL data sets available for our purpose. The number of records is the number of valid records whereas the size refers to the total number of records (valid and invalid). The longitudes mentioned refer to the major values found ; the main value is underlined. As the satellite is drifting on orbit, we may have a few records giving other values of longitude. Furthermore, the time coverage may have some gaps with variable size. Figure 1 shows the LANL1 30-300 keV band flux versus local time.

2.2 Description of a LANL data record

Each hourly-averaged sample commences with a header of six fields of varying length followed by two sets of thirty-eight values. The six fields, read from left to right, signify spacecraft identification, EPM flag, LEM flag, date, universal time and spacecraft local time respectively. The first set of thirty-eight values corresponds to the integral band flux and the following set of values to the standard deviation of the integral band flux.

A set of values is divided into two energy classes. These are designated by LoE and HiE where :

LoE - lower energy electrons ranging 30 - 300 KeV with 6 energy bands : 30-300 KeV, 45-300 KeV, 65-300 KeV, 95-300 KeV, 140-300 KeV and 200-300 KeV

HiE - higher energy electrons ranging 200 - 2000 KeV with 6 energy bands : 200-2000 KeV, 300-2000 KeV, 400-2000 KeV, 900-2000 KeV and 1400-2000 KeV

3. OMNIDIRECTIONAL INTEGRAL SPECTRA

LANL data provide for the 12 energy bands, the number of particles per cm^2 per second per steradian with energy within this range. Each flux and standard deviation values is multiplied by 4π to obtain a number of particles per cm^2 per second (omnidirectional integral band flux). Following Cayton et al.'s work (Ref. 2), the omnidirectional integral flux denoted as J(>E) is represented by a double-Maxwellian distribution :

$$J(>E) = A \exp\left(-\frac{E}{E_a}\right) + C \exp\left(-\frac{E}{E_c}\right)$$

where A, C are constants and E_a, E_c are exponential gradients.

The four parameters A, C, E_a and E_c are obtained from the 12 electron energy channels using a least squares fitting technique. If $[E_i, E_{Ui}]$ is the i^{th} energy band and N_{ij} is the number of particles per cm^2 per second with energy within this range for local time bin j, then coefficients $A=A_{ij}$, $C=C_{ij}$, $E_a=E_{aij}$, $E_c=E_{cij}$ minimises the quantity

$$\sum_{i=1}^{12}\left(1 - \frac{A\,[\exp(-\frac{E_i}{E_a}) - \exp(-\frac{E_{Ui}}{E_a})] + C\,[\exp(-\frac{E_i}{E_c}) - \exp(-\frac{E_{Ui}}{E_c})]}{N_{ij}}\right)^2$$

Coefficients A, E_a, C and E_c are computed for each record.

4 ORGANISATION OF LANL DATA USING CONVENTIONAL APPROACH

4.1 Objectives

Conventional approach means using B-L coordinates system where the magnetic field B and the Mc-Ilwain's L value are computed by considering an internal magnetic field only. The objective is the construction of updated electron flux tables for geostationary orbits including updated local time variation model and a standard deviation model.

4.2 Mean integral spectra for the geostationary orbit

The methodology for calculating the mean integral spectrum is described below.

First, we compute the B-L value associated with each LANL record. As LANL data do not provide the exact position of the satellite, we fix for all records the altitude to 35786 km and the latitude to 0°. The longitude is calculated for each record from the universal time and local time.

Then, using standard geomagnetic coordinates conversion (e.g. programs SHELLC or BLXTRA, Ref. 1), we compute B and L for each record. The internal field model used is IGRF'85-120 terms coupled with the mean period of observations (e.g. for LANL1, BLTIME = 1981) and the McIlwain's magnetic moment value ($M = 0.311653$ Gauss.R_e^3).

Once all B-L records are available, we determine the B-L bins ; the extremal B and L values are $B_{min} = 0.00102$ Gauss, $B_{max} = 0.00118$ Gauss, $L_{min} = 6.5$ and $L_{max} = 7$. LANL1 B-L coverage is depicted on Figure 4.

4.2.2 Mean integral spectra for LANL B-L points

We fix a given epoch T and an energy level E. Typically, T represents a year from 1979 to 1988. We consider the previously defined B-L bins as well as the 24 local time bins [j, j+1[for j=0, 23. We sort data according to B, L and ϕ bins. For each bin, we calculate for every sample k the integral flux J_k relative to energy level E from coefficients A, E_a, C and E_c computed as explained in the former section. Then, we calculate the mean integral log-flux for that particular bin using the standard empirical formula

$$\mu = \log \bar{J} = \frac{1}{m} \sum_{k=1}^{m} \log J_k$$

where m is the number of samples. We obtain for B-L bins corresponding to LANL coverage, a mean electron integral flux for epoch T, energy level E and local time bins [j, j+1[for j=0, 23.

4.2.3 Mean integral spectra for any geostationary B-L point

We use a linear regression technique for computing the integral log-flux at any geostationary B-L points. This linear regression is justified by the fact that both B and L ranges are not too wide to be significant enough. We obtain the integral electron spectra for any energy level E for epochs 1979 to 1988, B-L points corresponding to the geostationary orbit. This integral electron flux is denoted as $J_T(>E,B,L,\phi)$. Averaging over local time yields the integral flux $J_T(>E,B,L)$.

4.2.4 Comparison with AE8

Comparison with the standard AE8 model is made for any geostationary longitude or B-L point. For longitude 225° E, the LANL flux is higher than the AE8 one. For the four other longitudes, it is lower for any energy between 30 and 2000 keV. Figure 2 shows the comparison between LANL and AE8 for longitude 300° E.

As a least squares plane is considered for fitting flux in the B-L plane, for L values below 6.70, the LANL flux will be higher than that computed with AE8. This conclusion emphasizes the fact that additional data analysis in the geostationary must be performed and that deeper comparison with existing or future data sets must be envisaged (e.g. METEOSAT, CRRES).

4.3 Update of local time variation for geostationary orbit

The transformation from geographical coordinates to B-L coordinates considering internal sources only has the effects of neglecting diurnal perturbations at high altitudes. This effect may be very significant.

Two models of local time variation corresponding to epochs 1964 (solar minimum) and 1967 (near solar maximum) exist in the AE4 model (Ref. 4). They have been incorporated into the AE8 model by C. Tranquille (Ref. 3).

AE4 local time variation models (variation with local time of flux levels from average flux levels) are described analytically by the formula

$$\Phi_T(E,L,\phi) = K_T(E,L)\, 10^{C_T(E,L) \cos \frac{\pi}{12} (\phi - \Omega_T(E,L))}$$

where:

- $\Omega_T(E,L)$ is the phase (constant and equal to 11 in these models)
- $K_T(E,L)$ and $C_T(E,L)$ are dimensionless ; $K_T(E,L)$ is a normalisation factor such that

$$\frac{1}{24} \int_0^{24} \Phi_T(E,L,\phi)\, d\phi = 1$$

LANL data are used to update coefficients C_T, K_T and Ω_T for the geostationary orbit at epochs T covered by LANL satellites keeping the same analytical expression for Φ_T but including a B dependence for these 3 coefficients.

We consider a certain epoch T, energy level E and B-L bin. We set $J = J_T(>E,B,L)$ and $J_i = J_T(>E,B,L,\phi_i)$ for $i = 0, 23$. We compute $\Phi_i = \frac{J_i}{J}$ and determine coefficients $C = C_T(E,B,L)$, $K = K_T(E,B,L)$ and $\Omega = \Omega_T(E,B,L)$ by solving the optimisation problem

$$\min \sum_{i=1}^{N} \left[1 - \frac{\log K + C \cos \frac{\pi}{12} (\phi_i - \Omega)}{\log \Phi_i} \right]^2$$

Comparison with AE4 models is shown on Figure 3.

4.4 Update of AE4 standard deviation model for geostationary orbit

4.4.1 Position of the problem

In AE3 and AE4 models, a standard deviation model was developed. It permits the calculation of probabilities that given flux levels will be exceeded. The model was developed assuming that the logarithm of the electron flux is normally distributed in time at any point in the outer zone.

In these models, the standard deviation $\sigma(E,L)$ of the distribution was taken to be constant with respect to B and local time ϕ because the data did not allow resolution of any variation with respect to these parameters. The standard deviation was found to be approximatively constant over epoch time as well. Sigma value $\sigma(E,L)$ is given for discrete values of E and L (Ref. 5, Table 5). Energy E varies from 0.04 to 1.5 MeV and L varies from 2.8 to 11.

Our objective is to build a standard deviation model σ valid for the geostationary orbit and depending on E, B, L and ϕ. With respect to AE4, L varies from 6.5 to 7 and B varies from 0.00102 and 0.00118 Gauss. This updated model will be denoted as $\sigma = \sigma(E,B,L,\phi)$.

4.4.2 Methodology

The classical way to proceed is that given in AE3 and AE4 (J.I. Vette, personal communication). We consider a given B-L-ϕ bin:

1 Collect daily (hourly for local time studies) observations

2 Obtain via fitting described in Section 3 the integral spectra and take this as a derived sample

3 Change the variable from J to $y = \log(J)$

4 For a given energy level E, proceed to compute the estimators of the mean and sigma values μ and σ by formulae

$$\mu = \frac{1}{M}\sum_{k=1}^{M} \log J_k \qquad \sigma^2 = \frac{1}{M-1}\sum_{k=1}^{M} (\log J_k - \mu)^2$$

where J_k denotes the k^{th} integral flux sample and M the number of samples.

This provides us with the standard deviation $\sigma(>E, B, L, \phi)$ which allows to consider the flux at mean plus one sigma or mean plus three sigma. Assuming the integral flux is log-normally distributed, we can calculate the threshold flux for given probability levels as for AE4 (Ref. 5, Table 7). Mean and standard deviation of the log-flux is depicted on Figure 6.

5. ORGANISATION OF LANL DATA USING AN EXTERNAL FIELD MODEL

5.1 Introduction

In opposite to the conventional approach described in the former section, LANL data are analysed with magnetic field B and Mc-Ilwain's value L computed with the Tsyganenko-89 external magnetic field model. The methodology is the same as in the conventional case. First, the B-L map is determined. Indeed, the coverage of LANL satellites in B-L coordinates is changed as B and L are not computed in the same manner. We compute K_p dependent spectra depending on epoch T, B and L and corresponding to four levels of magnetic activity K_p as defined below. Relative to the conventional approach, one observes larger variations in B and L. The extremal B and L values are B_{min} = 0.00094 Gauss, B_{max} = 0.00126 Gauss, L_{min} = 6.5 and L_{max} = 8.5. LANL1 B-L coverage is shown on Figure 5 ; comparison is made with conventional approach.

5.2 K_p dependent spectra for the geostationary orbit

Our objective is to derive electron spectra depending on the magnetic activity index K_p and including the local time variation of the field. We define 4 K_p ranges : $K_p < 2^+$ - quiet magnetic activity, $2^+ \leq K_p < 3^+$ - mean magnetic activity, $3^+ \leq K_p < 5^+$ - strong magnetic activity and $K_p \geq 5^+$ - magnetic substorm.

We average the flux in a B, L, K_p bin taking into account the magnetic activity via tri-hourly table of index K_p. The link is done via date and time. We obtain 4 averaged fluxes corresponding to the 4 ranges of magnetic activity mentioned above. As LANL data provide hourly average flux, the same tri-hourly average value of K_p correspond to 3 consecutive hourly average flux values.

The methodology is similar to that described in Section 4.2. We obtain a K_p-dependent integral electron flux organised in B-L coordinates for epoch 1979-1988. This model is denoted as $J_T(>E,B,L,K_p)$. Integral spectra for extremal K_p ranges is displayed on Figure 7 ; one observes that the flux corresponding to large K_p is smaller due to the compression of the magnetosphere during a geomagnetic substorm.

5.3 New standard deviation model

Our purpose is the creation of new tables of standard deviation σ for a geostationary orbit and for the epoch corresponding to LANL data depending on E, B, L and K_p. This model is denoted as $\sigma(>E,B,L,K_p)$. The methodology for computing σ is the same as that described in the conventional approach.

6. REFERENCES

[1] J. Borde et al., 'Development of improved models of the Earth's radiation environment - Data Analysis Report', MATRA ESPACE Technical Note S413/NT/44.90

[2] T.E. Cayton et al., 'Energetic electron components at geosynchronous orbit', Los Alamos publication

[3] C. Tranquille, 'TREP update to include electron flux local time variations', ESTEC Technical Note, reference WMA/CT/AE4/1, June 24, 1987

[4] C. Tranquille, 'Use of AE4 standard deviation model to obtain AE8 electron flux confidence levels', ESTEC Technical Note, reference WMA/CT/AE4/2, November 2, 1988

[5] J.I. Vette et al., 'Models of the trapped radiation environment: Volume III - Electrons at synchronous altitudes', NASA-SP-3024

[6] J.I. Vette et al., 'Problems in modelling the Earth's trapped radiation environment', NASA-TM-80447

[7] G. Wayne Singley and J.I. Vette, 'The AE4 model of the outer radiation zone electron environment', NSSDC 72-06, August 72

File name	Identificator	Nb of valid records	Size	Longitude(s)	Time coverage
LANL1.DAT	1976-059	16 421	11 442 blocks	290° E 325° E	03/01/79 - 27/06/83
LANL2.DAT	1977-007	31 911	22 081 blocks	70° E	03/01/79 - 30/06/83
LANL3.DAT	1979-053	21 550	15 070 blocks	225° E	22/06/79 - 25/05/85
LANL4.DAT	1981-025	27 840	19 194 blocks	225° E 290° E 70° E	27/03/81 - 30/03/85
LANL5.DAT	1982-019	42 308	40 204 blocks	325° E 290° E	21/03/82 - 27/07/87
LANL6.DAT	1984-037	31 629	21 773 blocks	70° E 225° E	24/04/84 - 31/10/88

Table 1 : LANL data sets synopsis

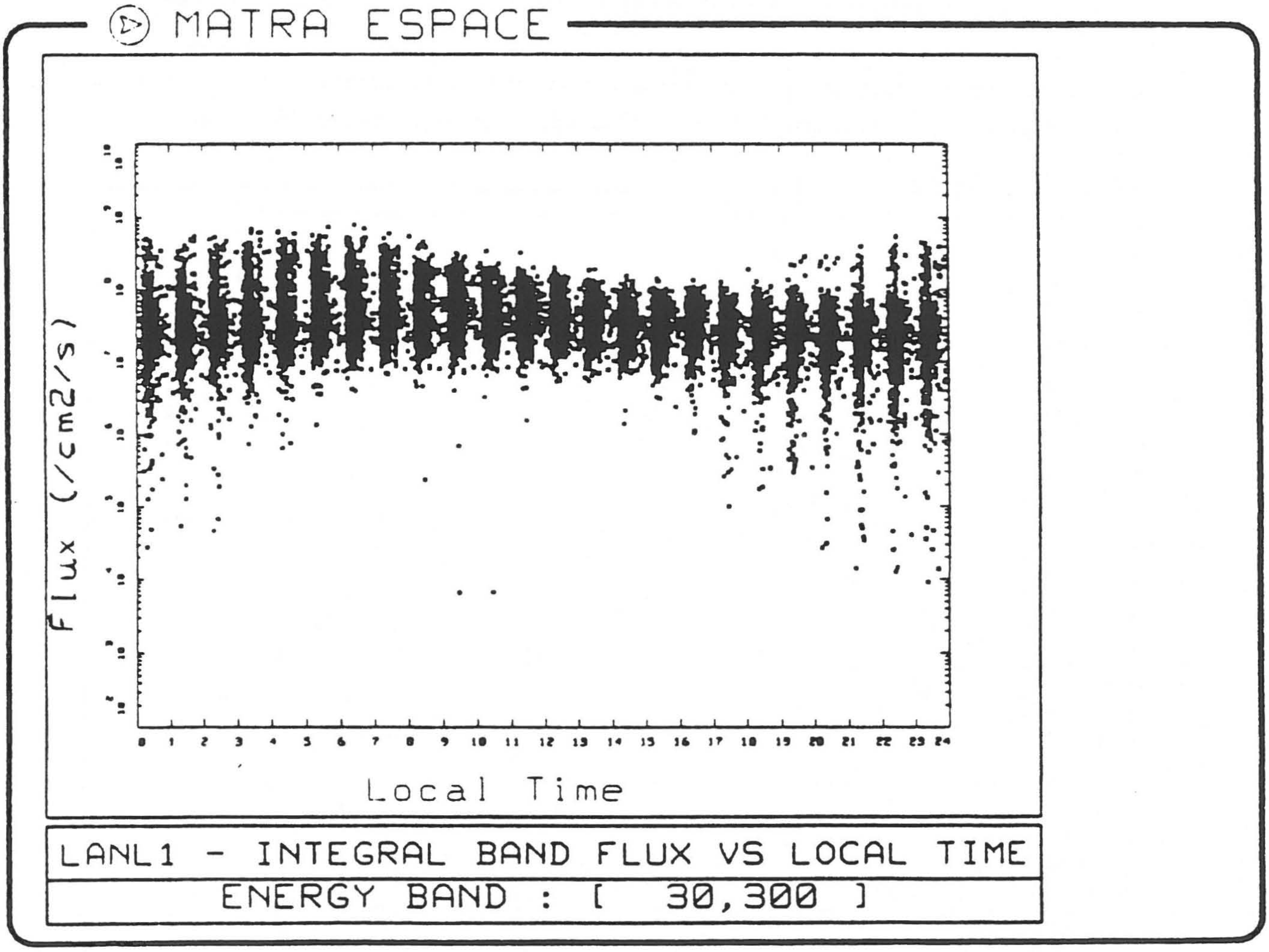

Figure 1 : LANL1 30-300 keV integral band flux versus local time

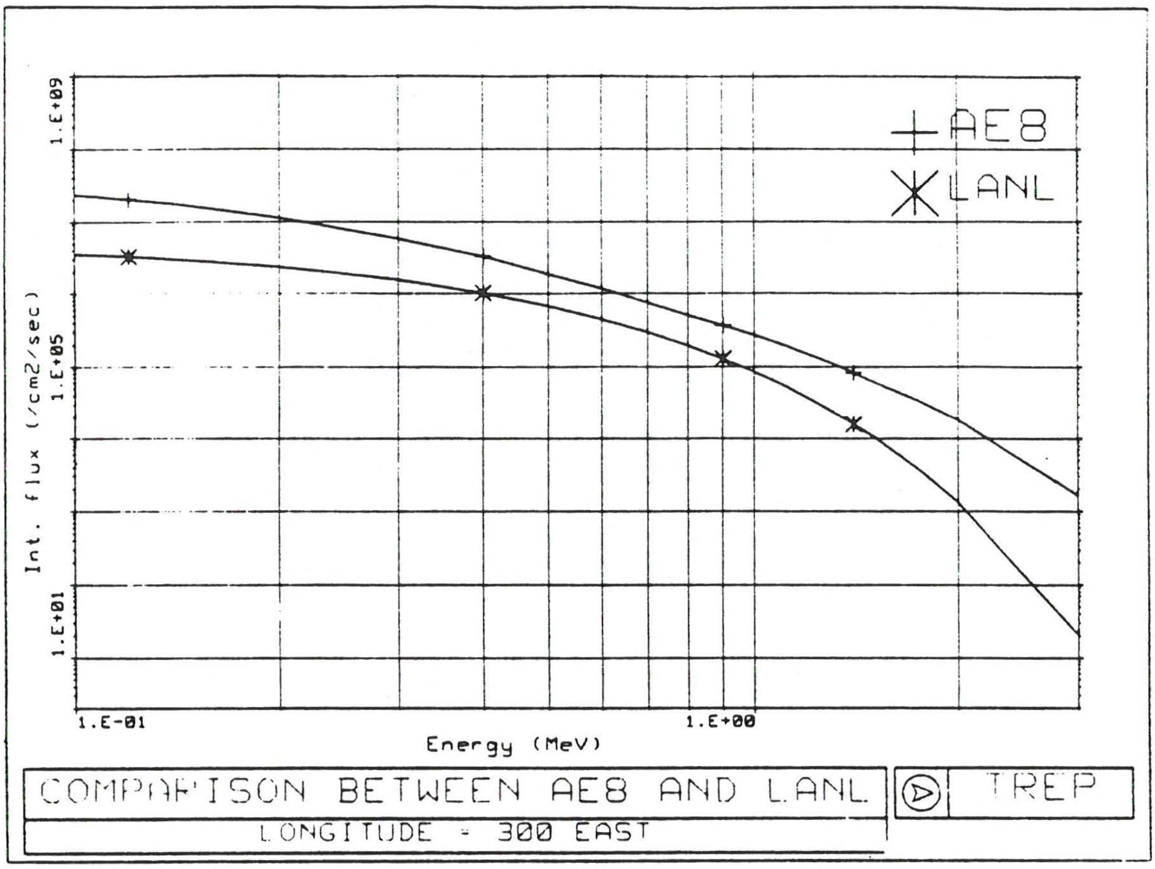

Figure 2 : Comparison between LANL and AE8 at longitude 300° East

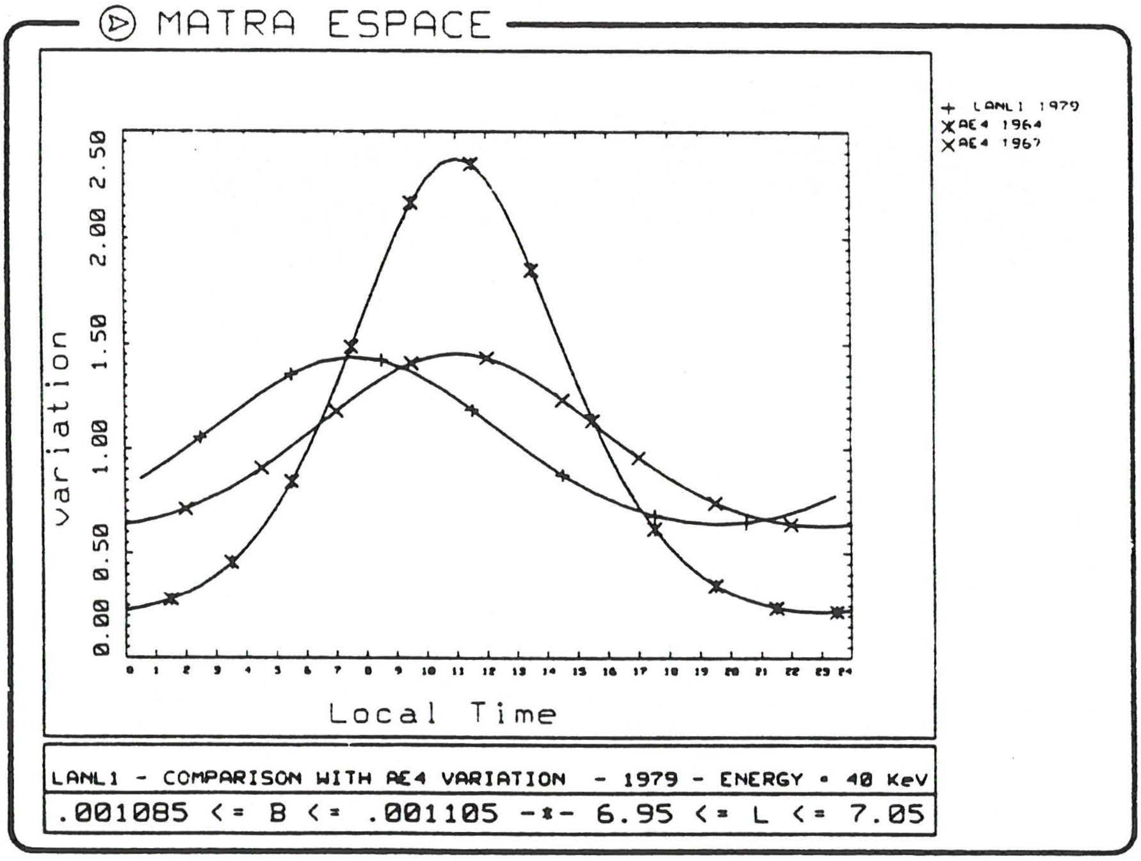

Figure 3 : Comparison between LANL and AE4 local time variation models

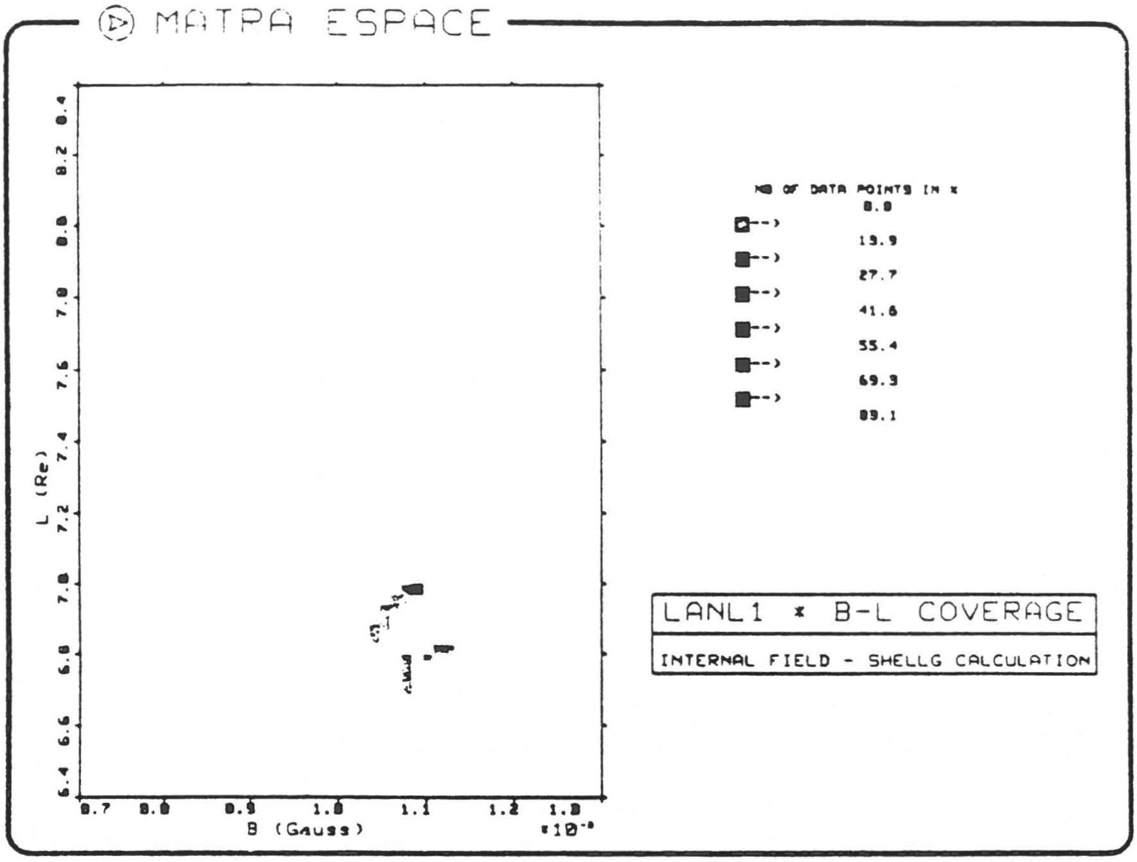

Figure 4 : LANL1 B-L coverage (conventional approach)

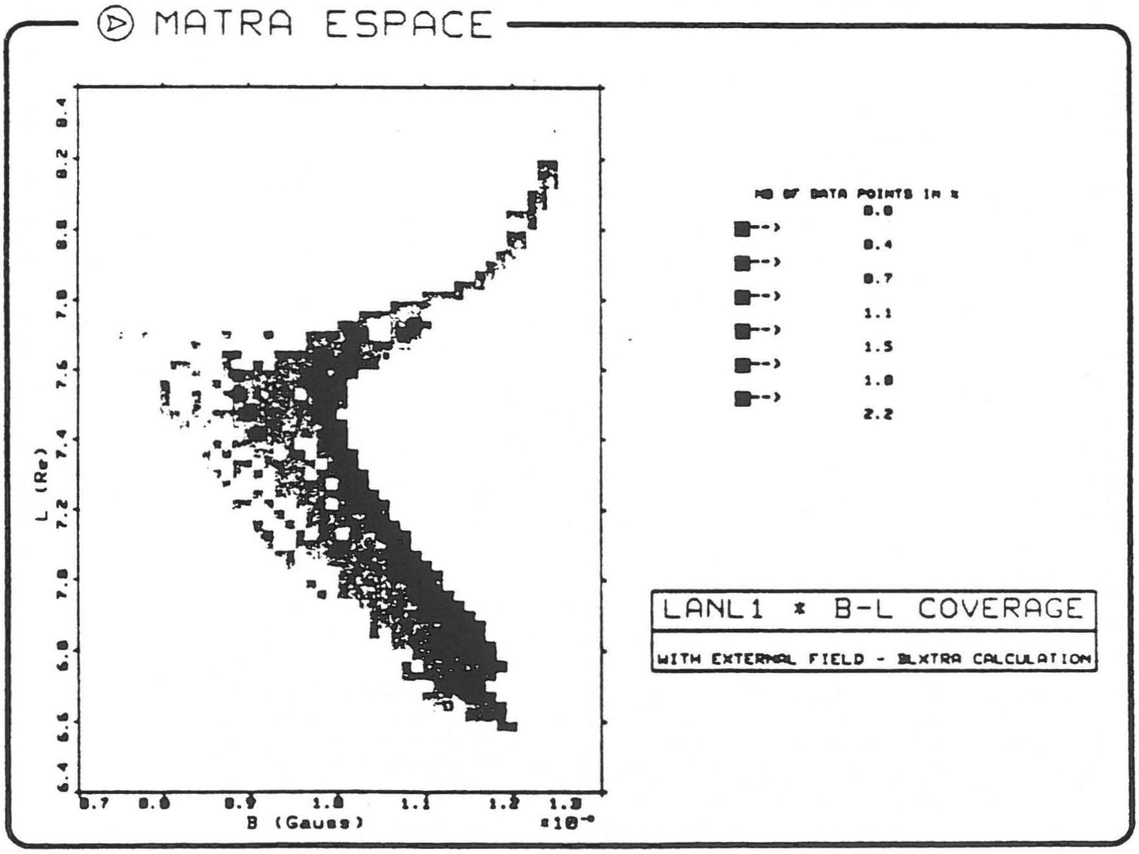

Figure 5 : LANL1 B-L coverage (with external field)

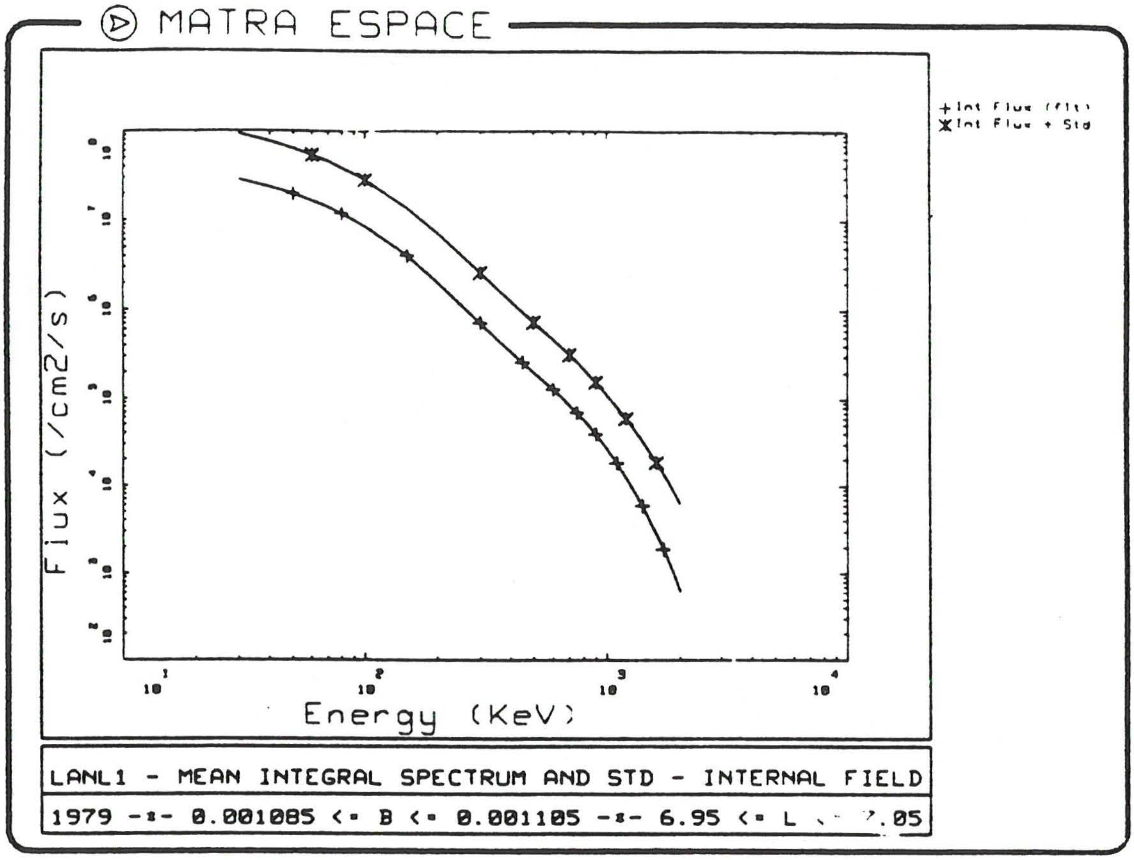

Figure 6 : Mean and standard deviation of the integral log-flux (conventional approach)

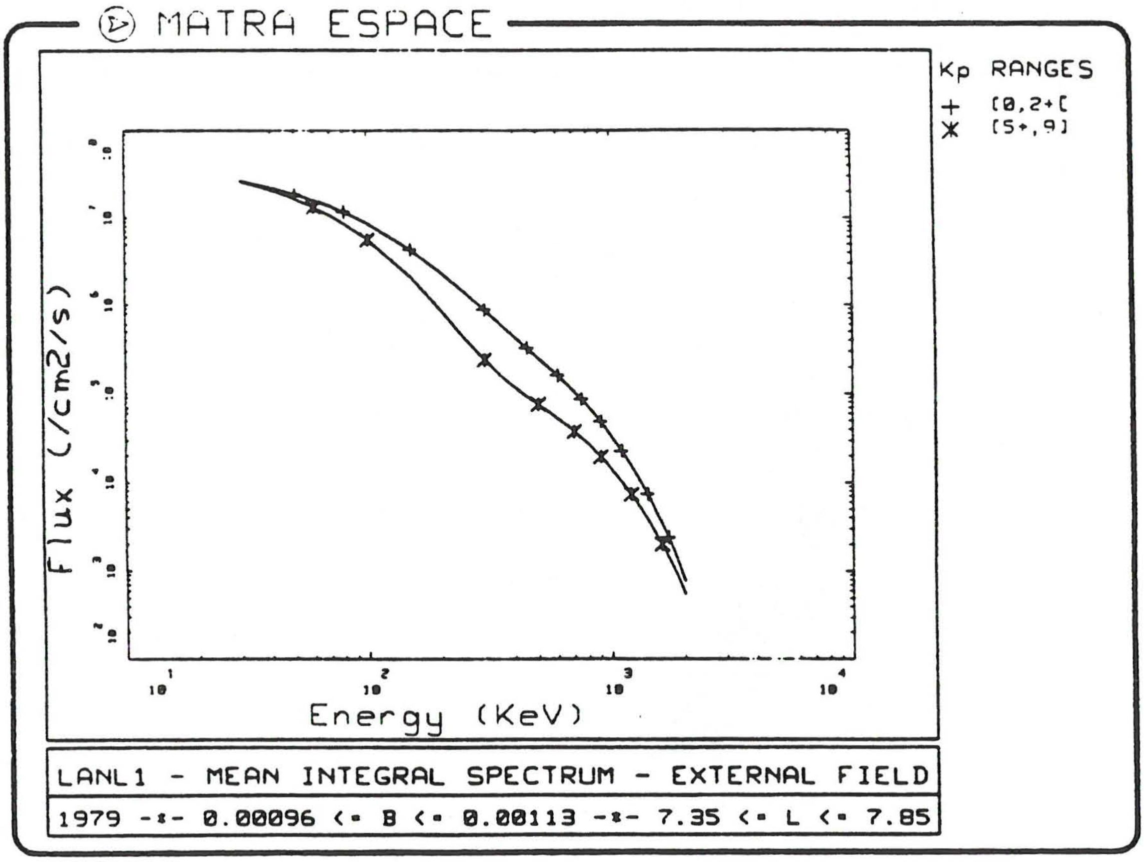

Figure 7 : Mean log-flux for extremal K_p ranges