ENHANCEMENTS OF DIFFERENTIAL FLUX OF ENERGETIC PARTICLES IN THE INNER MAGNETOSPHERE ASSOCIATED WITH A MAGNETIC STORM (EXTENDED ABSTRACT)

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We have been developing a computer simulation scheme for the energetic particles trapped in the Earth's magnetic field during a substorm. This paper is to study the enhancements of a directional differential flux of energetic particles revealled in the observational results by Explorer 45. Through our computer simulation, we can infer the distribution function in the plasma sheet as a source of the enhancements of energetic particles in the inner magnetosphere, $L \simeq 5$.

We assume in the magnetosphere the presence of the dipolar magnetic field and the electric fields consist of (1) large-scale convection field, (2) corotation field and (3) impulsive induced field due to dipolarization at a substorm onset as described below. The large-scale convection field is assumed to be of the Volland-Stern model (Volland, 1973; Stern, 1975), with its intensity depending on Kp indices (Maynard and Chen, 1975). We made following assumptions; (i) temporal variations of electromagnetic fields are so slow that the particle motion can be well approximated by its guiding center, (ii) the first and second adiabatic invariants (μ and J) are conserved, (iii) the particle motion generates no additional electromagnetic fields. With these assumptions, we calculated the bounce-average drift paths of the newly injected particles with arbitrary pitch angles in the equatorial plane (Ejiri, 1978).

Following Cladis and Francis (1985), we have derived a method to calculate the directional differential flux of bouncing energetic particles for the quantitative comparison with the measured differential flux. The distribution function of newly injected particles as a source is assumed to be approximately isotropic and Maxwellian. Total number of injected particles in a unit phase space volume, N_s, at the source point $(L_s, \phi_s(\text{MLT}))$ on the equatorial plane with an initial energy E_s and a sine of equatorial pitch angle y_s becomes

$$N_s = 4Re^3 L_s^2 \Delta L_s \Delta \phi_s \int_{y_s - \frac{1}{2}\Delta y_s}^{y_s + \frac{1}{2}\Delta y_s} \int_{E_s - \frac{1}{2}\Delta E_s}^{E_s + \frac{1}{2}\Delta E_s} \frac{n_s \sqrt{E_s}}{\sqrt{\pi} E_0^{3/2}} \exp\left(-\frac{E_s}{E_0}\right) F(y_s) y_s \, dy_s \, dE_s, \quad (1)$$

where Re, n_s and E_0 are radial distance from the center of the Earth, number density and temperature, respectively. ΔL_s can be obtained by radial drift velocity of the particle toward the Earth (dL/dt) at (L_s, ϕ_s) and calculation time step of the injection (Δt), *i.e.,*

$$\Delta L_s = \left(\frac{dL}{dt}\right)_{(L_s, \phi_s)} \Delta t. \tag{2}$$

The approximate formula of a function $F(y)$ is given by EJIRI (1978).

Total number of particles $N_{ijlm}|_T$ falling into a unit phase space volume, an energy range of $E_l - 1/2\Delta E_l$ to $E_l + 1/2\Delta E_l$ and a sine of pitch angle range of $y_m - 1/2\Delta y_m$ to $y_m + 1/2\Delta y_m$, at a point (L_i, ϕ_j) is obtained by summing up all the particles' contributions to that point after the elapsed time T. Then, the directional differential flux j_{ijlm} can be calculated as

$$j_{ijlm} = \frac{\sqrt{2E_l} N_{ijlm}|_T}{\int_{y_m - \frac{1}{2}\Delta y_m}^{y_m + \frac{1}{2}\Delta y_m} \int_{E_l - \frac{1}{2}\Delta E_l}^{E_l + \frac{1}{2}\Delta E_l} 8\pi R e L_i S \sqrt{m} F(y) y \, dy \, dE}, \tag{3}$$

where S is area of virtual plane detector in the equatorial plane and m is mass, respectively.

Figure 1 shows the calculated differential flux *versus* energy of the newly injected particles compared with Explorer 45 measurements (LONGANECKER and HOFFMAN, 1973; SMITH and HOFFMAN, 1974; EJIRI *et al.*, 1980) on February 13, 1972 during a main phase of a magnetic storm. A first substorm onset occurred at 1108 UT and the ion differential flux measured by Explorer 45 clearly began to enhance from 1145 UT of the energy of ~50 keV with dispersion signature. The background flux which may exist before the first substorm onset is seen in the energy range below 10 keV. In our simulation, particles are injected from $L = 8$ with longitudinal range 21 h$\leq$MLT$\leq$3 h,
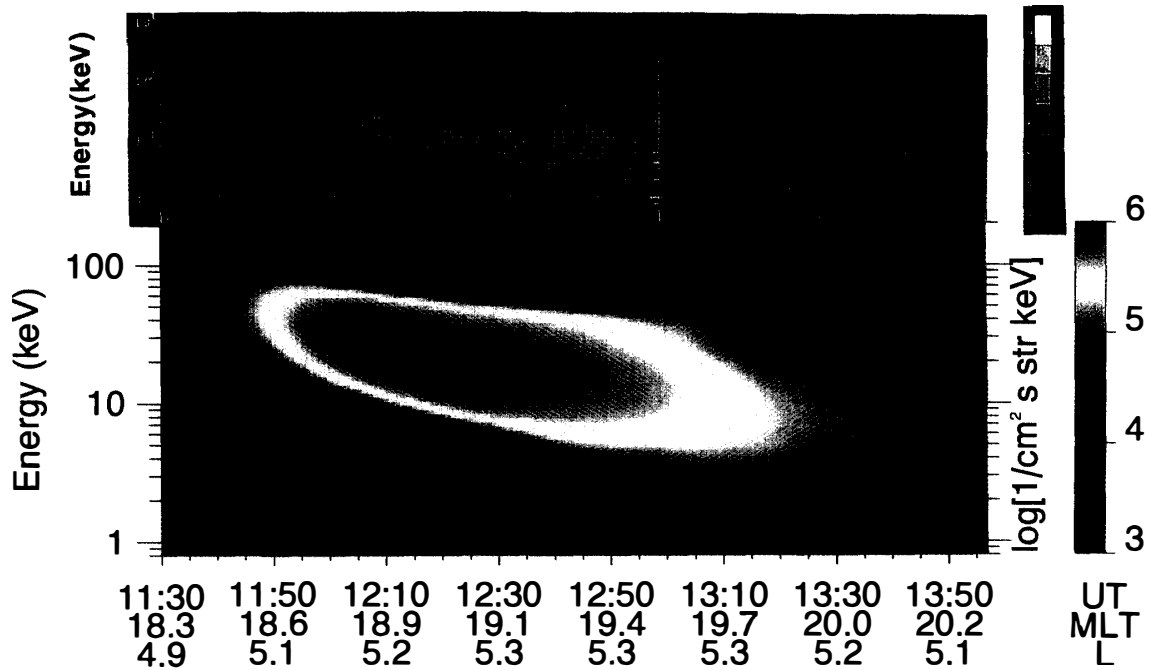

Fig. 1. Explorer 45 satellite observation (top) and calculation (bottom) for the energy-time spectra of ions of pitch angle 90° at 1130–1400 UT on February 13, 1972. Satellite locations are indicated at the bottom with MLT and L-value.

and the source distribution function is assumed to be isotropic Maxwellian with temperature 5 keV and number density 0.22 cm^{-3}. The source quantities, temperature and number density, were determined through trial and error, however the quantities are consistent with satellite observations (e.g., Baumjohann and Paschmann, 1989; Thomsen et al., 1996).

The induced dawn-dusk electric field due to dipolarization during the substorm onset is required to push the injected particles into the observed point ($L \simeq 5.2$, MLT $\simeq$ 19 h) within 37 min from the substorm onset time. We assumed the induced electric field E_i with a function of

$$E_i = E_{max} \exp\left(-\frac{(t-t_0)^2}{a}\right), \tag{4}$$

where E_{max}, t, t_0 and a are the maximum electric field, time, onset time and a factor of time scale, respectively. We found that the required electric field has a time scale of 6 min, maximum intensity of 10 mV/m and a portion of $L \geq 6.0$ and 21 h $\leq$ MLT $\leq$ 3 h. We could reproduce the characteristic dispersion signature by using our simulation under such source quantities and the induced electric field.

We can compare the enhanced differential flux quantitatively between calculation and observation in Fig. 2. From 1145 UT to 1200 UT the observed differential flux enhanced from 1.6×10^5 to 6.5×10^5 cm^2 s str keV for pitch angle 90° (solid lines) and from 7.6×10^4 to 4.2×10^5 cm^2 s str keV for pitch angle 30° (dotted lines) within the energy range of 30–60 keV. The calculated differential flux at the point ($L \simeq$
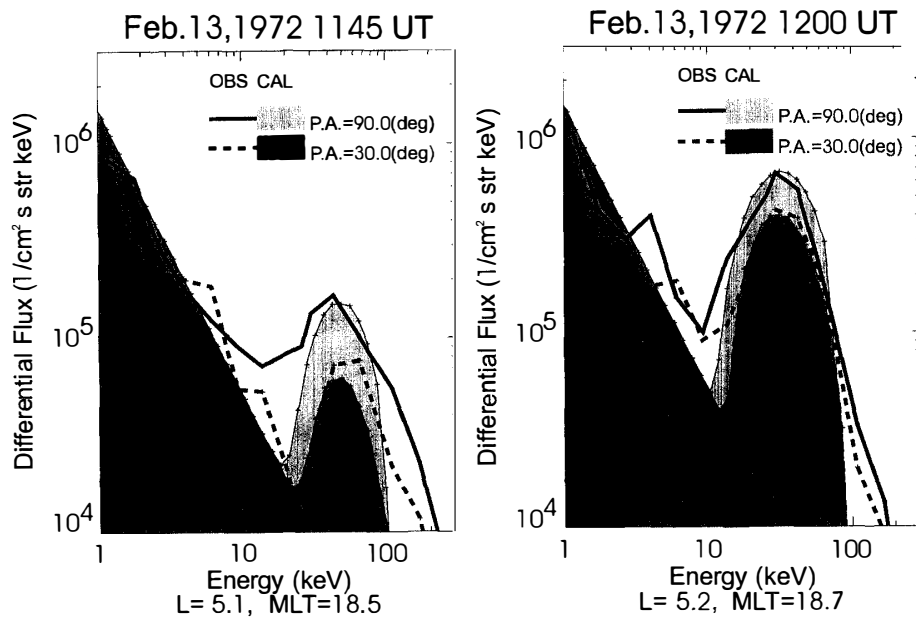

Fig. 2. *Calculated and observed differential flux of ions at 1145 UT (left) and 1200 UT (right) on February 13, 1972. Solid and dotted lines are observed flux of pitch angle 90° and 30°, respectively. Light and shaded painted regions are calculated flux of pitch angle 90° and 30°, respectively.*

5.2, MLT $\simeq$ 19 h) shows good agreement with the observation with respect to the peak energy and the absolute flux. Also we can demonstrate the anisotropy between pitch angles of 90° and 30° although the source distribution function is simply assumed to be isotropic.

Acknowledgments

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