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Polar Geophysical Institute

MODELLING OF THE AURORAL ELECTRON TRANSPORT AND ACCELERATION DURING THE BREAKUP

L.Lazutin *(Polar Geophysical Institute, Apatity, Russia)*

Abstract. Particle transport and acceleration during the transition between the magnetic field configurations corresponding to the situation before and after the breakup are simulated using *Tsyganenko* (1989) magnetic field model. Some modifications were introduced to create more realistic tailward magnetic field line stretching before the breakup. Modelling is restricted by particles conserving first and the second adiabatic invariants and to the midnight magnetosphere region with a closed field line configuration (5-15 Re). Combined effect of the radial enhanced convection in the inductive electric field and the radial component of magnetic drift results in particle acceleration, changes of position and pitch angle distribution. Following conclusions result from modelling: (1) electron acceleration is observed for all PA and starting positions with the preferential acceleration of the equatorial electrons. (2) electrons initially located at 5-9 Re are moving presumably tailward whereas more distant particles are transported earthward; (3) drift-shell splitting effect separate electrons with different energies; final position of the particles with smaller pitch angle is closer to the Earth; (4) pitch angles of the electrons increase during magnetic field dipolarization.

1. Introduction

From numerous experimental studies it is known, that during the auroral breakup the following effects are taking place among others in the vicinity of the geosinchronous orbit: (1) magnetic field configuration is changing from stretched tailward toward more dipolar, (2) auroral and radiation belts electron are accelerated in wide range of energies, and (3) radial earthward and tailward transport of particles were observed. Inductive electric field as a main source of trapped particles transport and acceleration was suggested (*Falthammar*, 1965, *Heikilla and Pellinen*, 1977)

Simulations of particle motion during substorms have been performed mostly for magnetotail region, because it was supposed to be the main breakup activity region (*Heikilla et al.*, 1979). For the closed dipollike field line geometry, particle earthward convection in enhanced electric field was studied by *Men'shutina and Pudovkin* (1971), *Kropotkin* (1977), *Yamamoto and Tamao* (1978).

Usually magnetic drift was supposed to be much less important in comparison with radial transport, which is true for the slowly varying magnetic field, but at the breakup dipolarization the magnetic field is changing radically for tens of seconds and magnetic drift deviation from the azimuthal direction might be essential. Present paper gives a brief description of modelling of energetic electron radial transport and acceleration as a result of combined magnetic and $\mathbf{E}\times\mathbf{B}$ drift in induced electric field.

Magnetic field configurations corresponding to the situation before and after the breakup are simulated using *Tsyganenko* (1989) magnetic field model with some modification introduced to create a more realistic tailward magnetic field line stretching before the breakup. The induced electric field was calculated from the vector potential. The magnitude obtained was comparable with the observed electric field during the breakup (*Aggson et al.*, 1983, *Shepherd et al.*, 1980), but the real structure of electric fields is much more complicated than the model one. Because of that we found important to confirm the reliability of the effects found in simulation by considerable variation of the introduced electric fields or particle energization.

2. Magnetic field models

Tsyganenko (1989) global magnetic field model reproduces statistical field for different Kp, as a consequence the short time prebreakup configuration with "taillike" stretched field lines is mixed with postbreakup active phase dipollike structures. Therefore we use "pure" Tsyganenko versions 1 and 4 as a final models, whereas to reproduce initial situation some changes in ring current coefficients have been made. Figure 1 present equatorial Bz component of the ring current and plasma sheet current contributions for two initial "taillike" models MD and ME, and two final ones - Ts1 and Ts4.

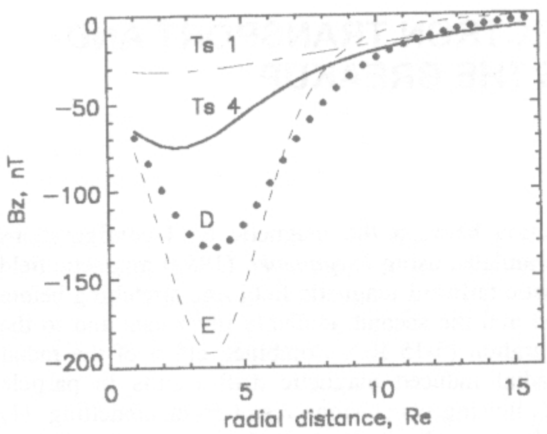

Figure 1. Bz-component of magnetic field of ring current and plasma sheet current for the models MD, ME, Ts1 and Ts4

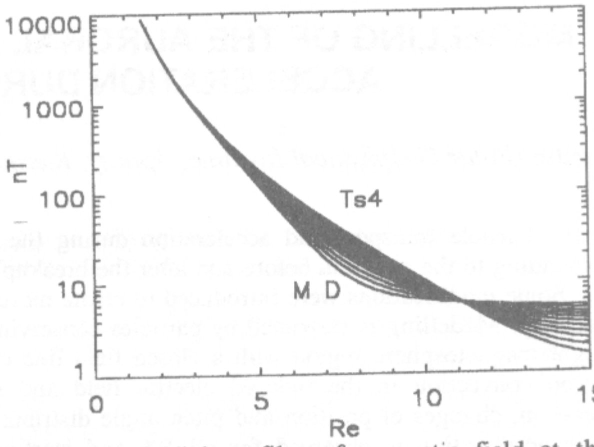

Figure 2. Radial profiles of magnetic field at the equator for 10 transition steps.

Most of calculations have been repeated for two pairs of models: for the transition from MD to Ts4 and from ME to Ts1. It was assumed, that particles remained during the process inside the sector around the midnight meridian with azimuthally uniform magnetic field. The duration of dipolarization was chosen equal to 10 s. For every 1 sec step magnetic field and particle parameters were calculated or extrapolated as illustrated by Figure 2. Real duration of the process might be greater, but in our case final results are independent of duration.

Different procedures were used to introduce induced electric field $\mathbf{E_i}$: in some cases it was postulated, in others it was calculated through the vector potential **A,** introduced in the *Tsyganenko* (1989) model (expressions 12-13). Figure 3 presents radial profiles of equatorial $\mathbf{E_i}$ for two magnetic field transitions. Electric field is directed duskward, producing eartward particle displacement.

Total electric field is equal to

$$E = -\frac{\partial A}{\partial t} - \nabla\Phi\,, \qquad (1)$$

where the first term is induced field and the second one is a polarisation field. Induced E-field has nonzero field-aligned component which will be compensated by free charges. Using the condition $[\mathbf{E}\times\mathbf{B}]=0$, *Delcourt et al.* (1990) calculated, that resulting decrease of the normal Ei component might be nearly 50%. The effect of it on the results of simulation will be investigated. Convective E-field is supposed to be less than $\mathbf{E_i}$.

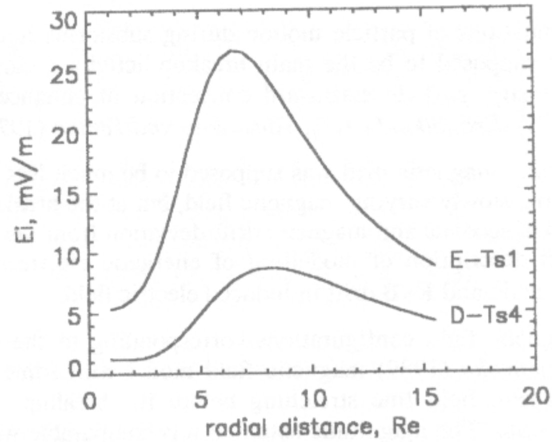

Figure 3 Induced E-field for two transitions from the "taillike" and "dipollike" configurations.

Drift velocity for the potential electric field

$$V = E \times B \qquad (2)$$

can not be directly applied in induced electric field case. It will be clear from the following consideration.

Let us suppose, that two particles are drifting earthward with equal drift velocity one in potential and other in equal induced electric field. Then the magnetic field will be growing faster along the drift trajectory of the second particle, because B is increasing with time. If the magnetic moments of both particles are conserved, which must be true, then they will aguire different accelerations in equal electric fields. Therefore our supposition that particles drift velocity in induced electric field is described by equation (2) was wrong. The difference between acceleration rates of our two particles will dissapear, if we will calculate induced ExB drift in a refference frame moving tailward along **W=const** trajectory.

This additional drift is similiar to the radial component of the magnetic drift in azimuthaly nonuniform magnetic field, and we will name it as induced magnetic drift.

Therefore total radial displacement will be described as **Vr=Vi+Vm** where **Vi** can be found from (2) and for the equatorial particles $\mathbf{V_m}$ is equal to:

$$V_m = \frac{\delta B}{\delta t}\frac{1}{gradB} \tag{3}$$

and in the region of positive **dB** it is directed tailward. For the field aligned particles V_{RM} can be found numerically from the condition **W**=0.

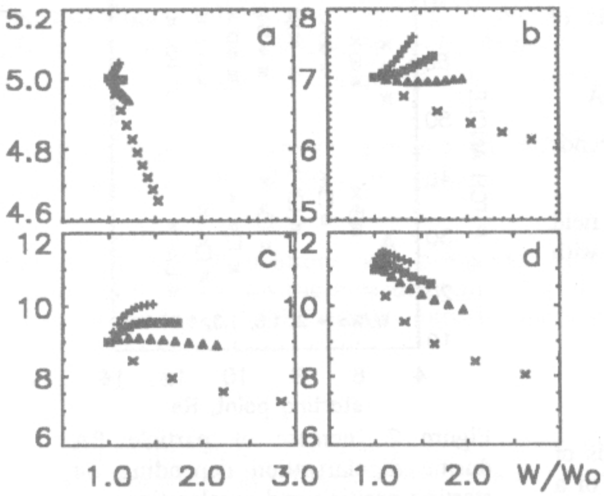

Figure 4. Radial transport versus acceleration rate for 90° electrons with four starting positions and four E_i values (10, 20 30 and 100 mV/m)

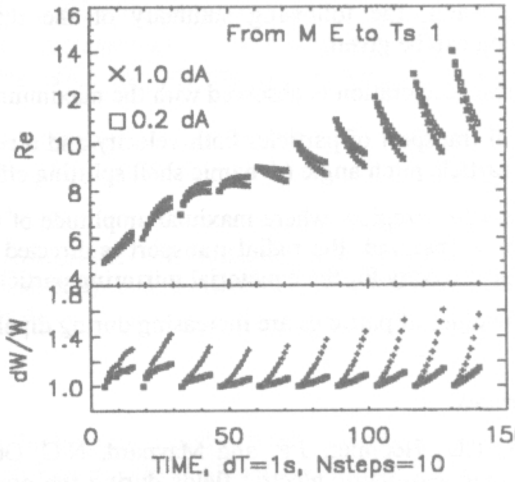

Figure 5 Radial transport and acceleration of 10 particles starting from 5 to 14 Re with two values of induced electric field.

3. Results and discussion

As a introductory step, let us consider results of modelling of movements of equatorial particles with several presumed values of $\mathbf{E_i}$ directed westward and independent of R. Results shown in Figure 4 reflect the concurrent influence of magnetic and **E×B** radial drift: particles are drifting tailward as soon as E_i-field is relatively small and the starting point is not close to the tail.

Figure 5 presents the results of modelling also for equatorial electrons, but for transformation ME - Ts1 and induced field calculated as shown by Figure 3 and the same field reduced by the factor of 5. Comparison shows that acceleration rate is decreasing with decrease of E_i, which is expected, but direction of the radial motion remains nearly the same: tailward in the active region (5-8 Re) and eartward at larger distances.

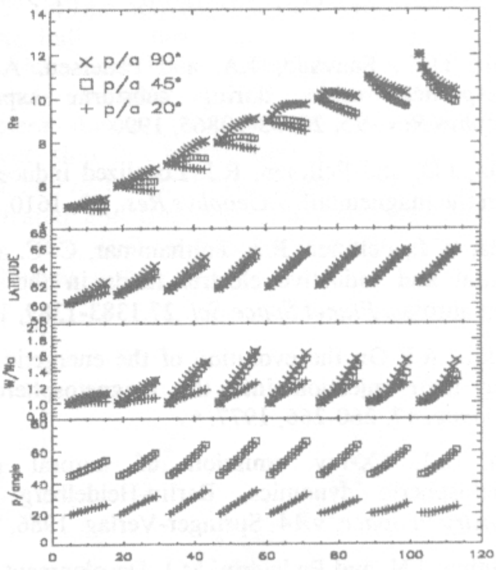

Figure 6 From top to bottom: radial transport of particles with initial PA 20°, 45° and 90°; latitudinal projection; increase of energy ; PA transformation.

Results of modelling for the transition MD - Ts4 and initial pitch angles 20°, 45° and 90° is shown in Figure 6. At the upper part simulation reveals dependence on the drift velocity and direction on the particle pitch angle, the effect predicted earlier (*Lazutin*, 1986) and named as dynamic shell splitting by analogy with drift shell splitting (*Roederer*, 1970). Projection of the particle drift into ionosphere shows that there poleward motion is dominating independently of the motions observed at the equator. Another remarkable effect is the increase of pitch angles, registered both for α=20° and 45° .

The behaviour of the particles during changes of the magnetic field can be investigated without intermediate calculations, if starting and final magnetic field model are known and two first adiabatic inveriants are conserved. Acceleration rate of the particle ,change of the position and pitch angle are related and we can found two parameters assuming that one of them is known. Figure 7 presents a results of such calculations for the transformation of pitch angles. It shows, that effect of the pitch angle increase is conserved even if zero increase of the particle energy is assumed.

The effect of the dynamical shell splitting might be sensitive to the correct choice of the induced E-field, which is difficult to make especially for field aligned particles. As shown by Figure 8, if we decrease the acceleration rate of 20° particles (and therefore reduce the associated induced field), the splitting effect, became smaller, but even with zero acceleration in active region shell splitting remains (the "diamonds" points on Fig 8).

In conclusion, the following summary of the main results of modelling can be given.

1. Particle acceleration is observed with the maximum at 90° PA.

2. Radial transport of particles both velocity and direction depends on the particle pitch angle (dynamic shell splitting effect).

3. In the active region, where maximal amplitude of magnetic field increase is observed, the radial transport is directed tailward with the bigger velocity for the equatorial mirroring particles.

4. Pitch angles of particles are increasing during dipolarization.

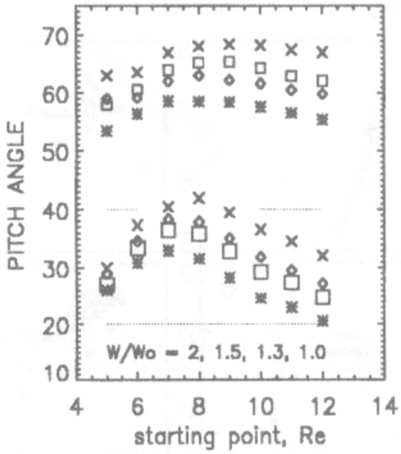

Figure 7 Increase of particle PA during dipolarization depending on starting position and acceleration rate (W/Wo=1 are the lowest points).

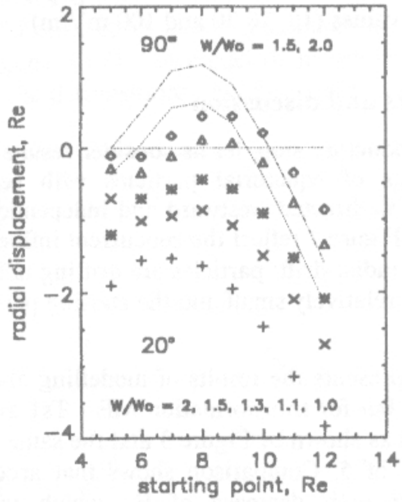

Figure 8 Radial displacement of the particles with PA 20° and 90°.

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