Inner Magnetosphere Modelling: Dependence on the Boundary Conditions in the Plasma Sheet

Natalia Yu. Ganushkina

(1) University of Michigan, Ann Arbor MI, USA/
(2) Finnish Meteorological Institute, Helsinki, Finland

This work was partly done during SPACECAST collaborative Project funded by the European Union Framework 7 programme

2012 GEM Workshop, 17 – 22 June 2012, Snowmass, CO, USA

Inner Magnetosphere Particle Transport and Acceleration Model (IMPTAM)

The inner magnetosphere particle transport and acceleration model:
- follows distributions of ions and electrons with arbitrary pitch angles
- from the plasma sheet to the inner L-shell regions
- with energies reaching up to hundreds of keVs
- in time-dependent magnetic and electric fields.
- distribution of particles is traced in the guiding center, or drift, approximation
  (motion of a charged particle as displacements of its guiding center,
  or the center of the circular Larmor orbit of a moving particle).

References:

1. Ganushkina, N. Yu., Pulkkinen, T. I., Fritz, T., Role of substorm-associated impulsive electric fields in the ring current development during storms, Ann. Geophys., 23, 579-591, 2005.

2. Ganushkina, N., Pulkkinen, T. I., Liemohn, M. and Milillo, A., Evolution of the proton ring current energy 670 distribution during April 21-25, 2001 storm, J. Geophys. Res., 111, A11S08, doi:10.1029/2006JA011609, 2006

3. Ganushkina, N. Yu., M. W. Liemohn, and T. I. Pulkkinen, Storm-time ring current: Model-dependent results, Ann. Geophys., 30, 177-202, 2012.

Inner Magnetosphere Particle Transport and Acceleration Model (1)

In order to follow the evolution of the particle **distribution function** f and particle **fluxes** in the inner magnetosphere dependent on the **position, time, energy, and pitch angl**e , it is necessary to specify:

(1) particle distribution at initial time at the model boundary;
(2) magnetic and electric fields everywhere dependent on time;
(3) drift velocities;
(3) all sources and losses of particles.

Transport of particles:

Drifts with velocities, radial and longitudinal, as sum of **ExB and magnetic drifts**

$$\mathrm{Vdrift} = \frac{\vec{E}\times\vec{B}}{B^2} + \frac{mv_\perp^2}{2qB^3}\left(\vec{B}\times\nabla B\right) + \frac{mv_{II}^2}{q}\frac{\vec{R}_c\times\vec{B}}{R_c^2 B^2}$$

1st and 2nd adiabatic invariants conserved.

Inner Magnetosphere Particle Transport and Acceleration Model (2)

Bounce-average drift velocity after averaging over one bounce of E×B and magnetic drift velocities

$$\langle v_0 \rangle = \frac{\mathbf{E}_0 \times \mathbf{B}_0}{B_0^2} + \frac{2p}{q\tau_b B_0} \nabla I \times e_0, \qquad I = \int_{S_m}^{S_m'} \left[1 - B(s)/B_m\right]^{1/2} ds,$$

Changes in the distribution function f (R, ϕ, t, E, α), where R and ϕ are the radial and azimuthal coordinates in the equatorial plane, respectively, t is the time, E is the particle energy, α is the particle pitch angle, and flux calculations using ***Liouville*'s theorem** taking into account **loss processes a**re obtained by:

$$\frac{df}{dt} = \frac{\partial f}{\partial \phi} \cdot V_\phi + \frac{\partial f}{\partial r} \cdot V_r + sources - losses$$

where V_ϕ and V_R are the azimuthal and radial components of the bounce-average drift velocity.

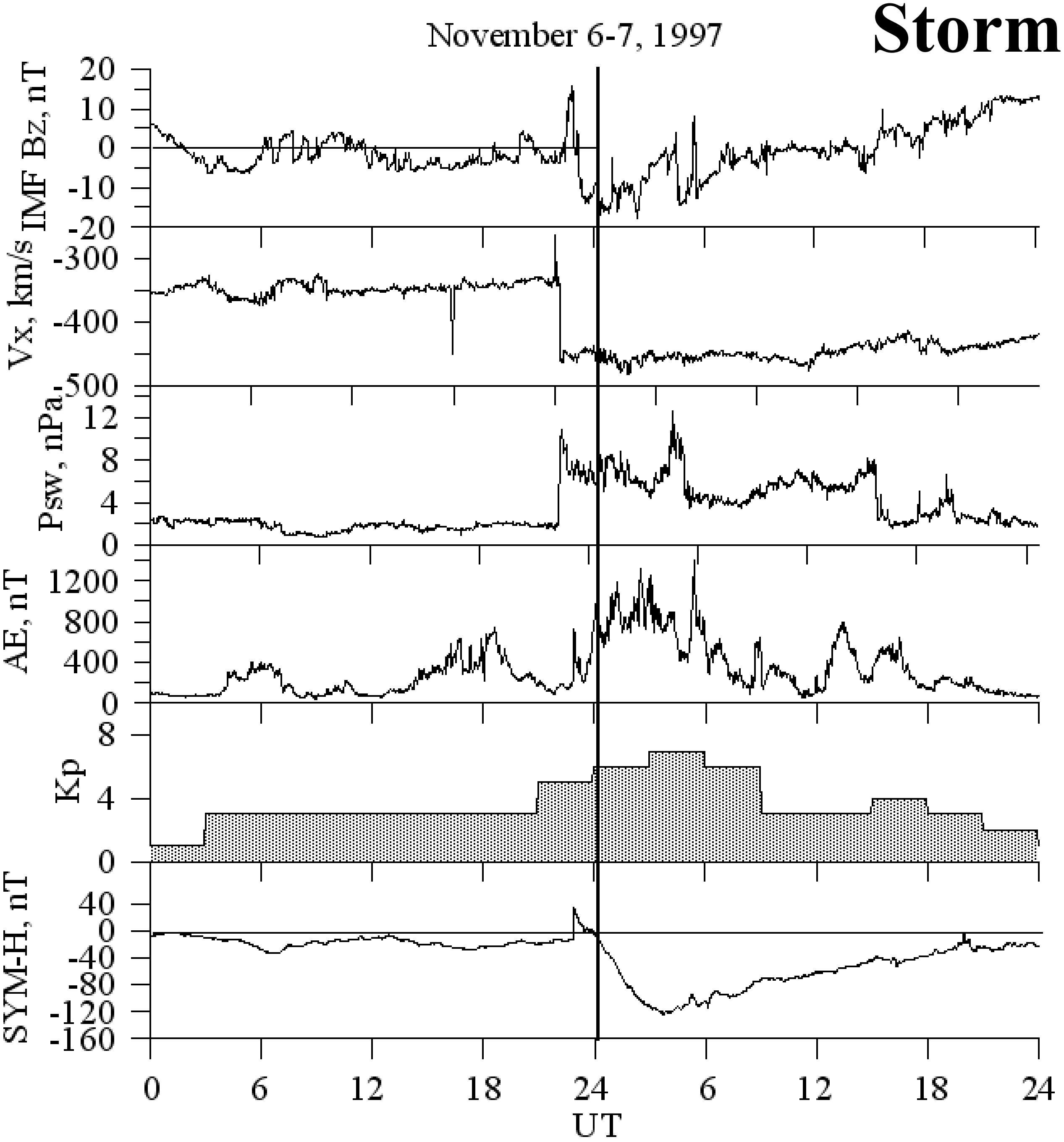
Inner Magnetosphere Particle Transport and Acceleration Model (5)

Boundary distribution: at any location from 6.6 to 10 Re
The particle distribution at the boundary is defined as a Maxwellian or kappa distribution function with parameters obtained from the empirical relations or from the observations during specific events.

Losses for ions:

- **charge exchange** with Hydrogen from geocorona;
- **Coulomb interaction** in dense thermal plasmas (plasmasphere);
- **convection outflow**, particle intersects the magnetopause and flows away along magnetosheath magnetic field lines.

Storm event


November 6-7, 1997
IMF Bz, nT
20
10
0
-10
-20
Vx, km/s
-300
-400
-500
Psw, nPa
12
8
4
0
AE, nT
1200
800
400
0
Kp
8
4
0
SYM-H, nT
40
0
-40
-80
-120
-160
0
6
12
18
24
6
12
18
24
UT

Models for Boundary Conditions

Initial distribution: empty magnetosphere

Boundary conditions:

(1) Maxwellian distribution at 6.6 Re with **n = 0.5 cm $^{-3}$ and T = 5 keV**;

(2) Kappa distribution at 6.6 Re with the observed parameters ($T_\perp$, $T_{||}$, n) by **LANL MPA and SOPA** at 1900-0500 MLT in the equatorial plane;

(3) **Empirical relation** between plasma sheet number density and solar wind number density $N_{ps} = 0.025 N_{sw} + 0.395$;

(4) Empirical model for plasma sheet parameters derived from **Geotail data by Tsyganenko and Mukai, 2003.**

Models for Magnetic and Electric Fields

Magnetic field models:
(1) dipole;

(2) Tsyganenko T89, Kp observed;

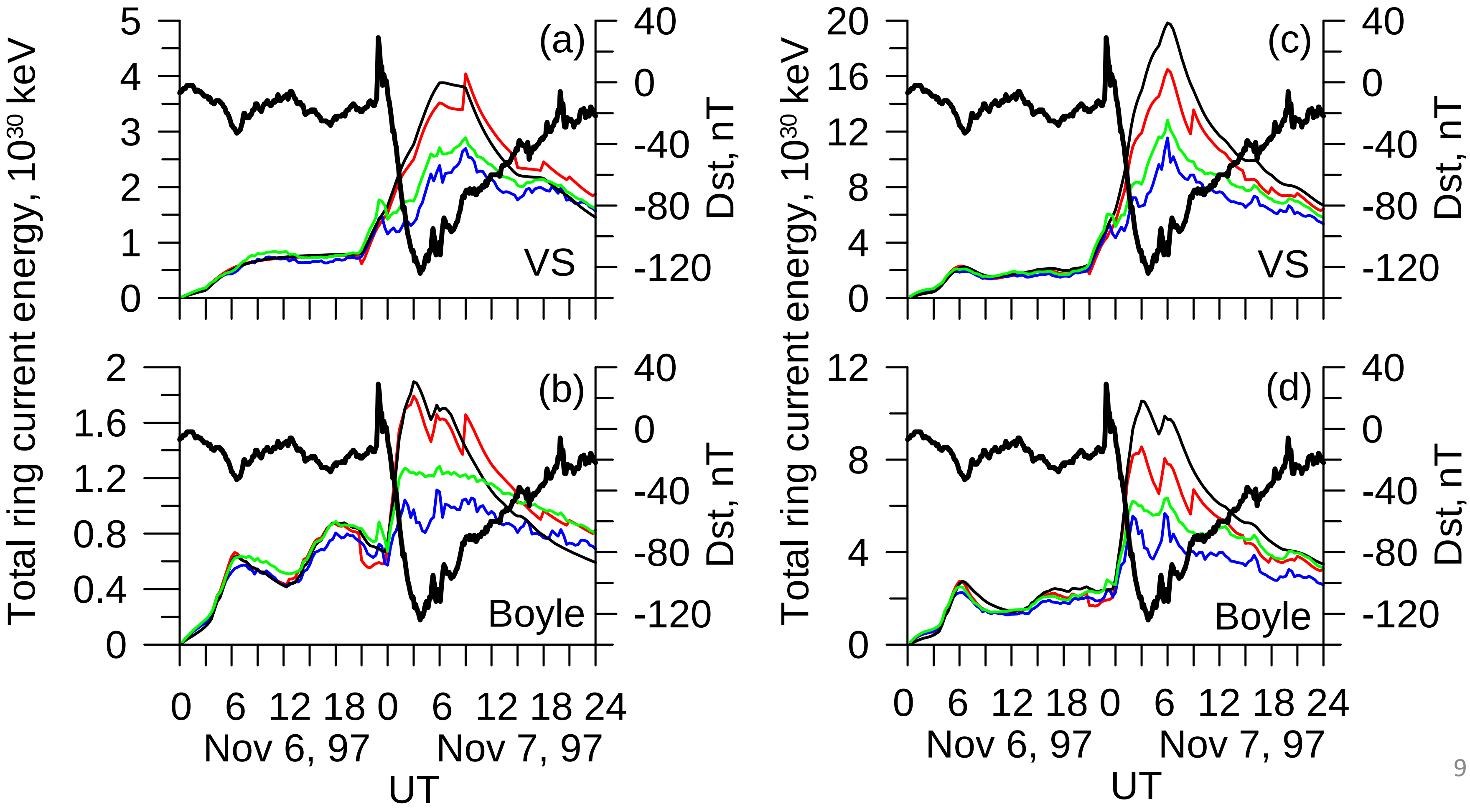
(3) Tsyganenko T96, Dst, Psw, IMF By and Bz, observed

(4) Tsyganenko TS04 (for storms) model, Dst, Psw, IMF By and Bz, observed, W1-W6 calculated from SW and IMF data.

Electric field models:
(1) Kp-dependent *Volland-Stern* convection electric field;

(2) *Boyle et al., 1997* polar cap potential dependent on SW and IMF parameters.

Ring current energy: November 6-7, 1997 storm, boundary at 6.6 Re



Maxwell at 6.6 Re,
n=0.5 cm^{-3}, T=5 keV

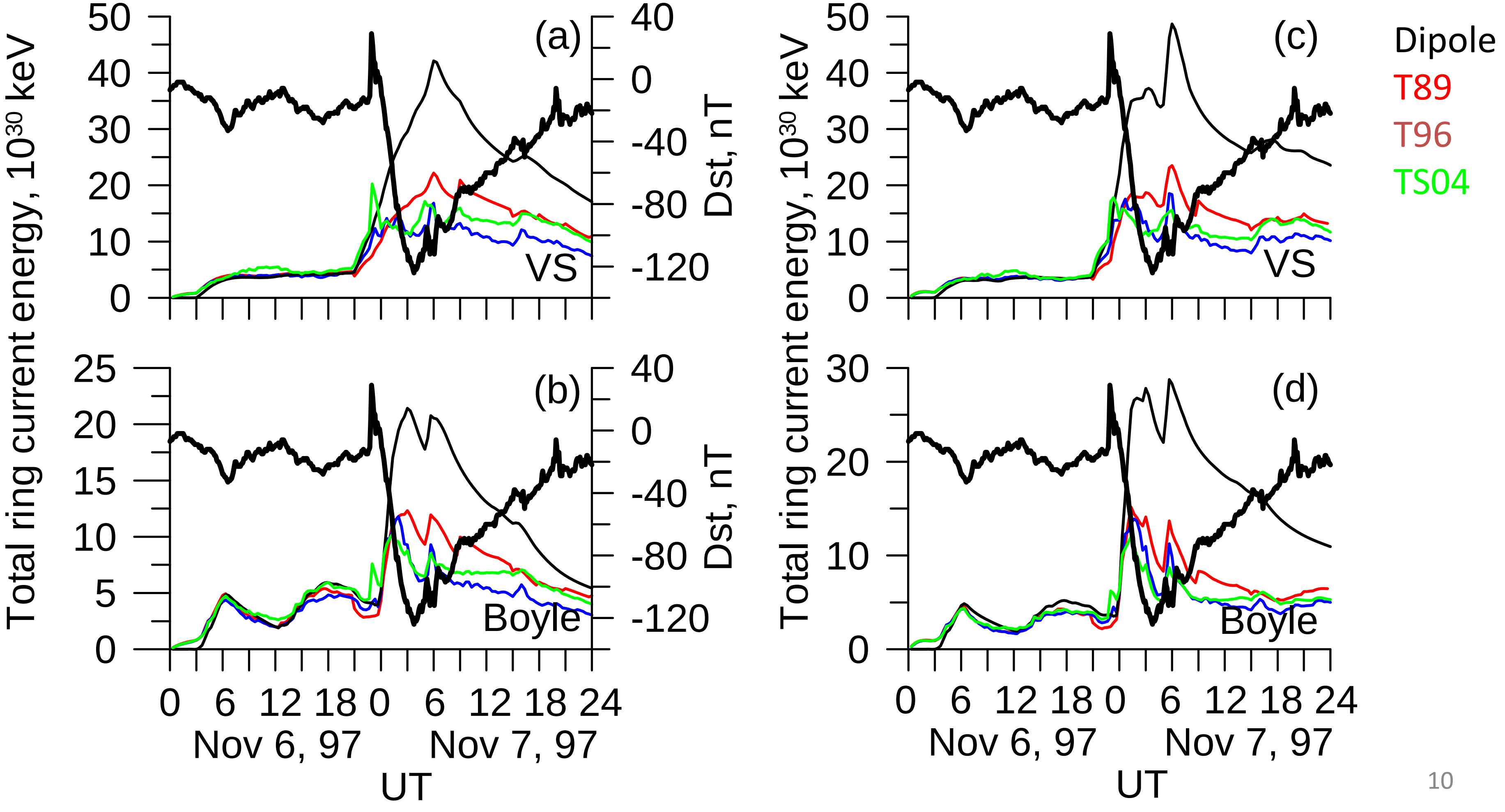
kappa at 6.6 Re,
n, $T_{||}$ and $T_{\perp}$ from LANL

Dipole
T89
T96
TS04

Ring current energy: November 6-7, 1997 storm, boundary at 10 Re

Maxwell at 10 Re, T= 5 keV,
n_{ps}=0.025n_{sw}+0.395

Maxwell at 10 Re, T and n from
Tsyganenko and Mukai (2003)



Ion species taken into account

1. **At 6.6 Re, LANL observations**

Scaling of the observed number density following *Young et al.*, 1982

$n(H+) = 0.34 * \exp(0.054 * Kp)$

$n(He+) = 0.0051 * \exp(0.0066 * F10.7)$

$n(O+) = 0.011 * \exp(0.24 * Kp + 0.011 * F10.7)$

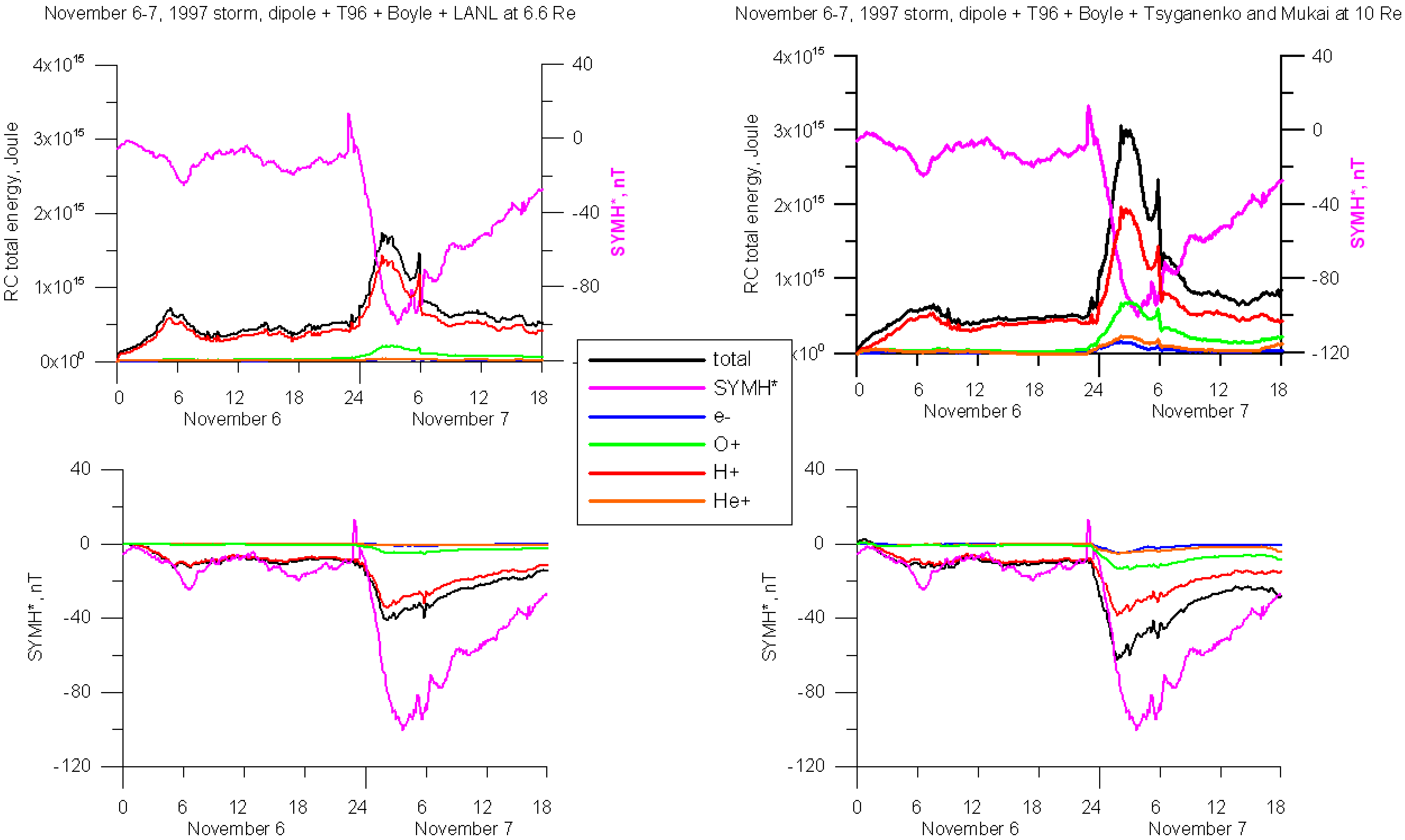
2. **At 10 Re, *Tsyganenko and Mukai* [2003] model**

Scaling of the observed number density following *Mouikis et al.*, 2010

$n(H+) = 0.19 * \exp(0.002 * F10.7 + 0.078 * (Kp - 1))$

$n(O+) = 0.002 * \exp(0.008 * F10.7 + 0.43 * (Kp - 1))$

Total ring current energy and Dst with ion species taken into account



November 6-7, 1997 storm, dipole + T96 + Boyle + LANL at 6.6 Re

November 6-7, 1997 storm, dipole + T96 + Boyle + Tsyganenko and Mukai at 10 Re

Summary

1. Different combinations of the magnetic and electric field models and boundary conditions result in very different modeled ring current, and, therefore, the physical conclusions based on simulation results can differ significantly.

2. A time-dependent model boundary outside of 6.6 RE gives a possibility to take into account the particles in the transition region (between dipole and stretched field lines) forming a partial ring current and near-Earth tail current in that region.

3. Tail current is very important for moderate storms.