Transport of the plasma sheet electrons to the geostationary distances

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Inner Magnetosphere Particle Transport and Acceleration Model (1)

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)

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.

Inner Magnetosphere Particle Transport and Acceleration Model (2)

-Changes in distribution function f and flux calculations for ions and electrons **with arbitrary pitch angles** using ***Liouville*'s theorem** taking into account **loss processes**.

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

- **Boundary distribution**: at any location from 6.6 to 10 Re
- **Transport of particles**:
  - -Drifts with velocities, radial and longitudinal, as sum of **ExB and magnetic drifts, 1**st and 2nd inv = const in **time-dependent magnetic and electric fields** with self-consistent magnetic field

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

$$\left\langle v_0 \right\rangle = \frac{\mathbf{E}_0 \times \mathbf{B}_0}{B_0^2} + \frac{2p}{q\tau_b B_0} \nabla I \times e_0,$$

$$I = \int_{S_m}^{S_m'} \left[1 - B(s)/B_m\right]^{1/2} ds,$$

Inner Magnetosphere Particle Transport and Acceleration Model (3)

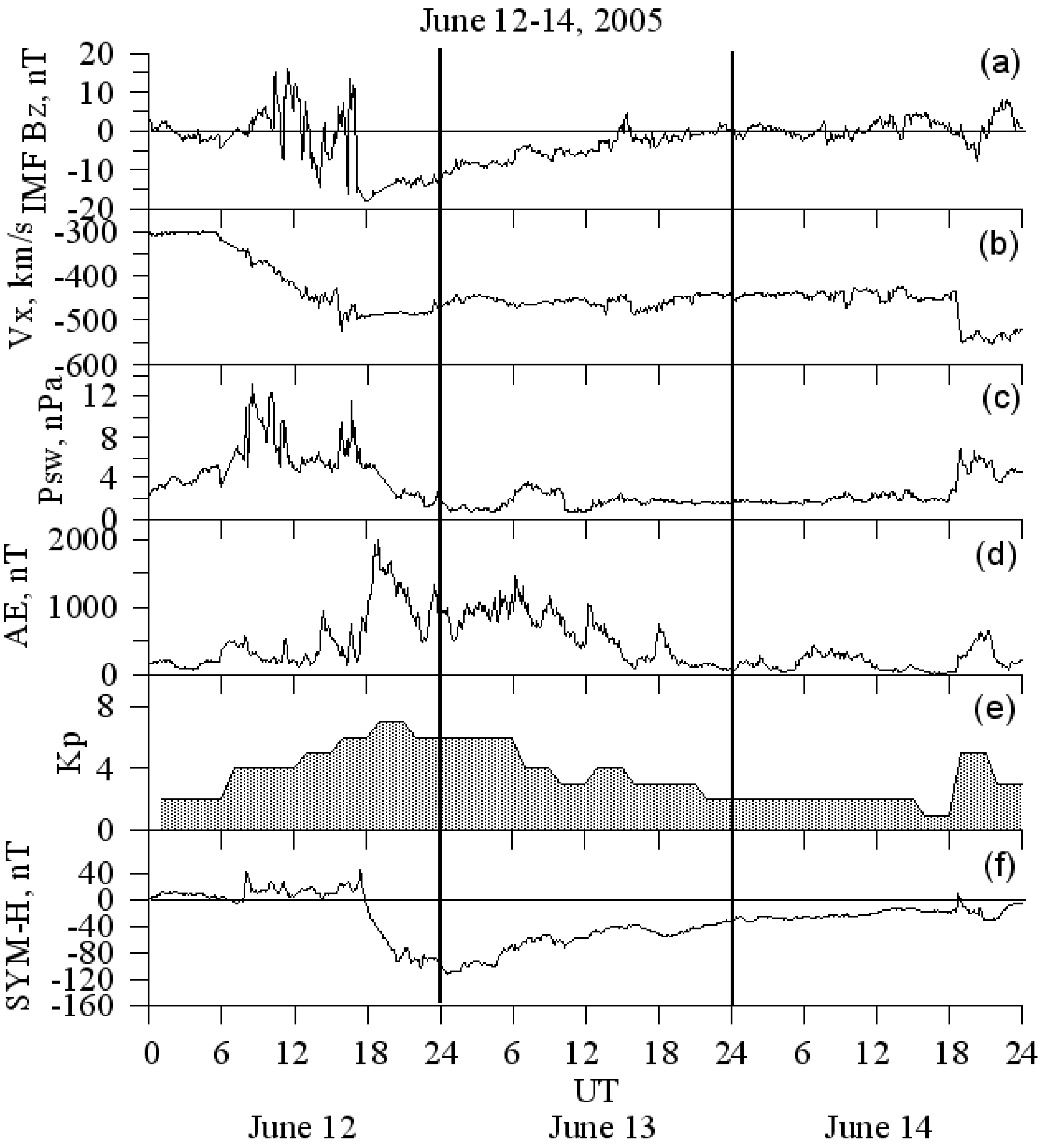
Losses for ions:

- **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.

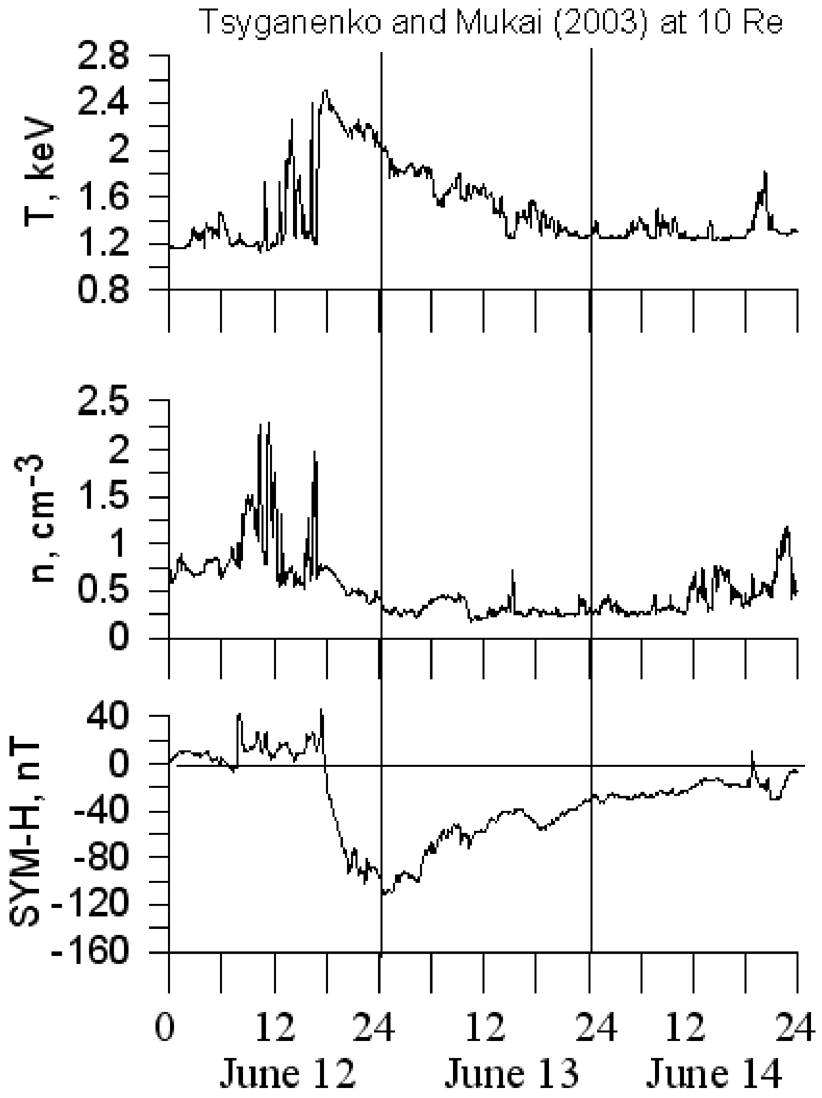
Losses for electrons:

- **Coulomb collisions** and loss to the atmosphere;
- **convection outflow**, particle intersects the magnetopause and flows away along magnetosheath magnetic field lines;
- scattering into the loss cone due to **pitch angle diffusion**.

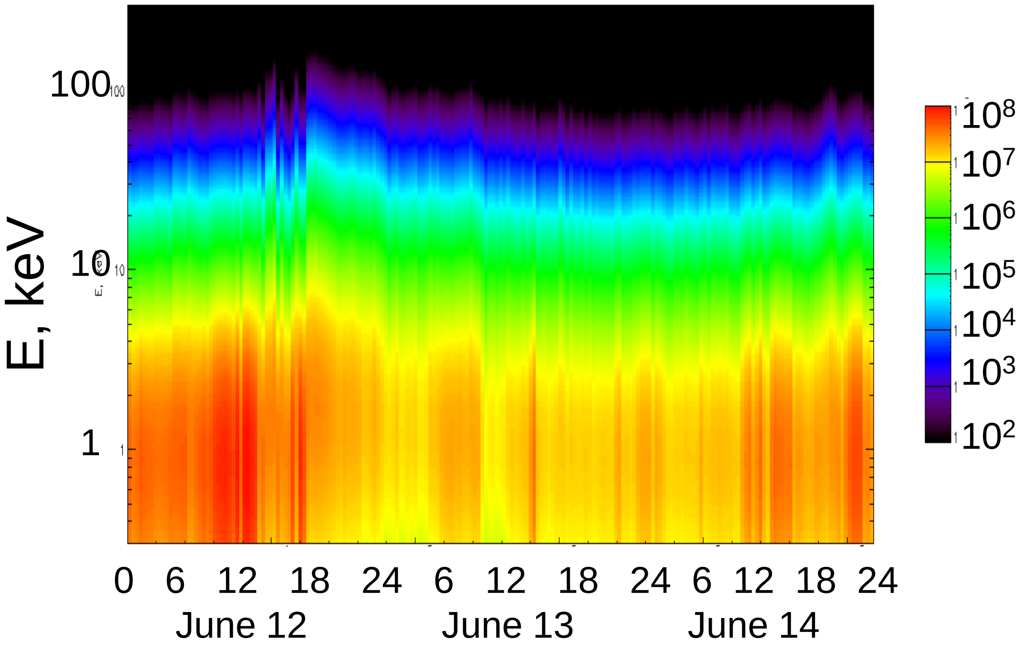
Storm event


June 12-14, 2005
IMF Bz, nT
20
10
0
-10
-20
(a)
Vx, km/s
-300
-400
-500
-600
(b)
Psw, nPa
12
8
4
0
(c)
AE, nT
2000
1000
0
(d)
Kp
8
4
0
(e)
SYM-H, nT
40
0
-40
-80
-120
-160
(f)
0
6
12
18
24
6
12
18
24
6
12
18
24
UT
June 12
June 13
June 14

Boundary conditions in the electron plasma sheet



Electron flux at the boundary at 10 Re



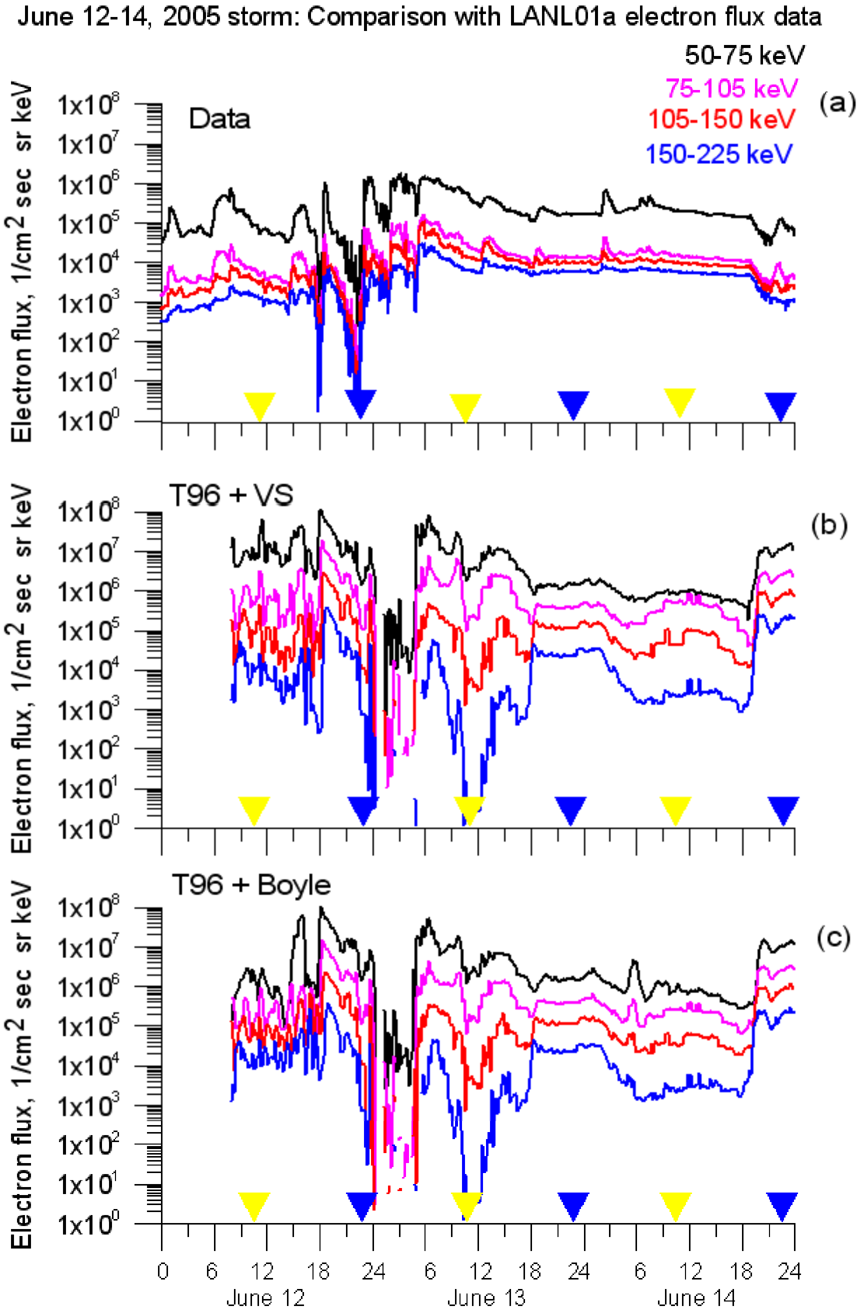
In *Tsyganenko and Mukai* (2003) model ne = ni and Te/Ti = 0.2

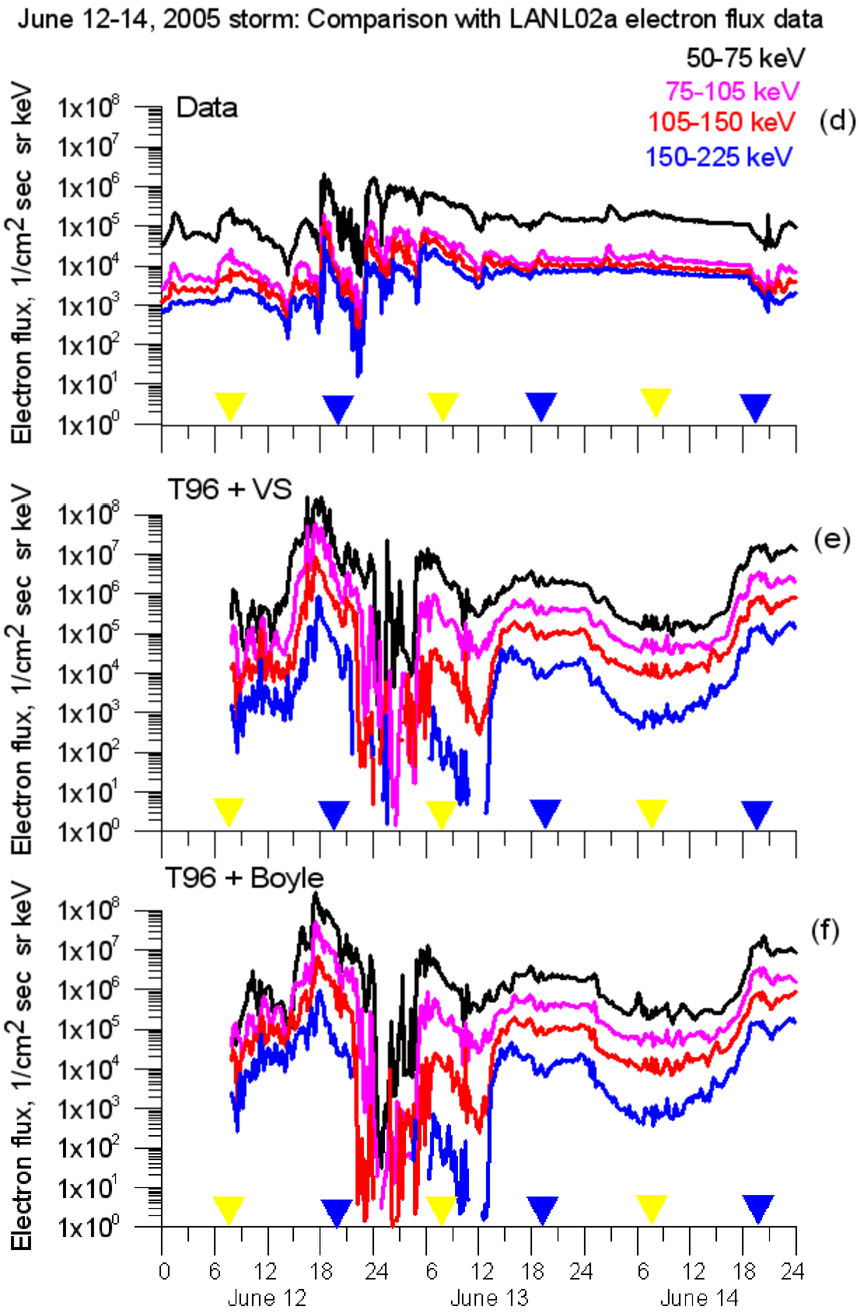
Combinations of models for IMPTAM for June 12-14, 2005 storm

No self-consistency (since realistic magnetic field models are used)

	Electric Field	Boundary conditions
dipole	Volland-Stern	Tsyganenko and Mukai, 2003
T89	Volland-Stern	Tsyganenko and Mukai, 2003
T96	Volland-Stern	Tsyganenko and Mukai, 2003
TS04	Volland-Stern	Tsyganenko and Mukai, 2003
dipole	Boyle et al., 1997	Tsyganenko and Mukai, 2003
T89	Boyle et al., 1997	Tsyganenko and Mukai, 2003
T96	Boyle et al., 1997	Tsyganenko and Mukai, 2003
TS04	Boyle et al., 1997	Tsyganenko and Mukai, 2003

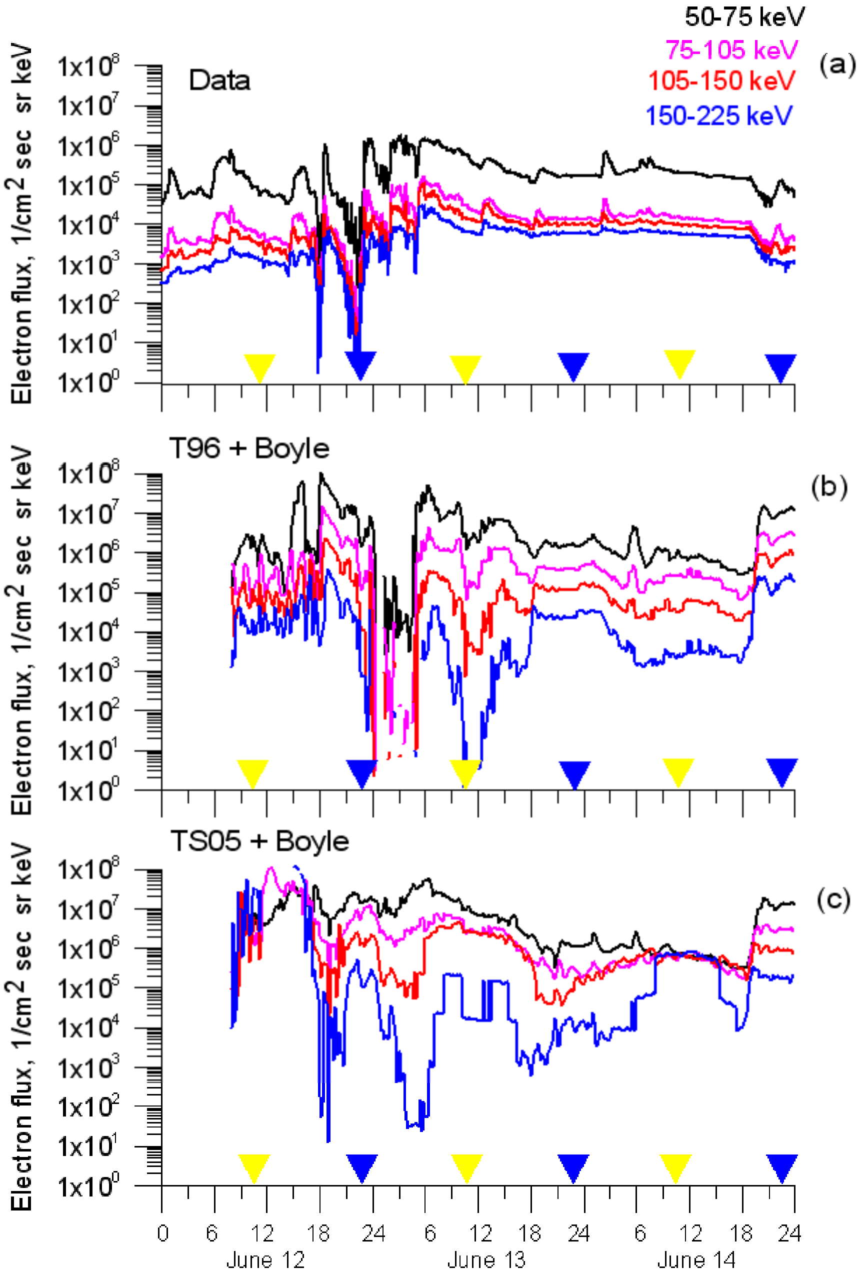
Electron fluxes at 6.6 Re: Electric field model choice


June 12-14, 2005 storm: Comparison with LANL01a electron flux data

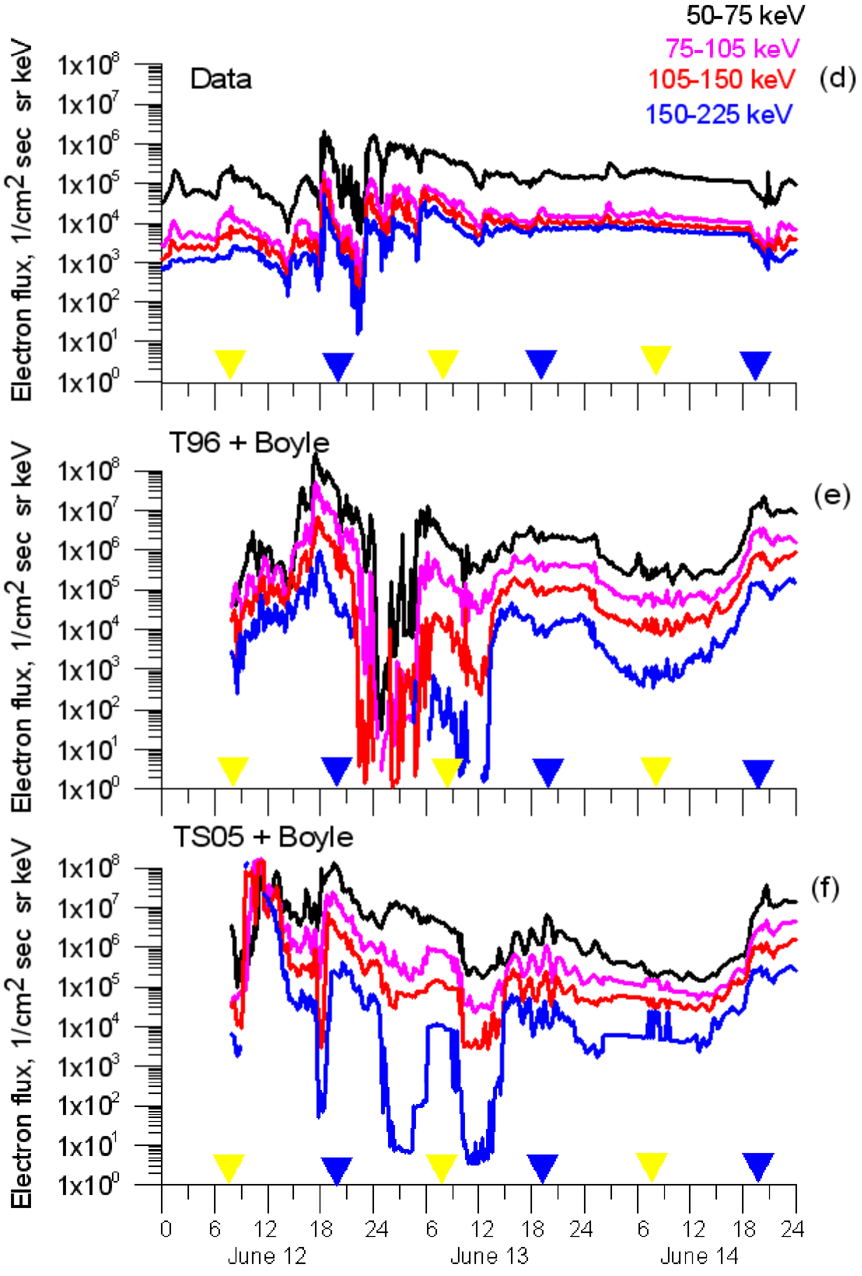

June 12-14, 2005 storm: Comparison with LANL02a electron flux data

Electron fluxes at 6.6 Re: Magnetic field model choice

June 12-14, 2005 storm: Comparison with LANL01a electron flux data



June 12-14, 2005 storm: Comparison with LANL02a electron flux data



Output from the simple modeling

Transport of plasma sheet electrons to from 10 Re in the plasma sheet to geostationary at 6.6 Re during storm times due the large-scale convection.

1. **Two orders of difference between the modeled electron fluxes and observed ones by LANL satellites are present**, which indicates that a **lower electron boundary condition and important loss processes** due to wave-particle interactions must be taken into account carefully.

2. Modeling with current version of IMPTAM and combination of models and boundary conditions used to model the electron fluxes were not sufficiently correct to be able to reproduce higher energy (150-225 keV) fluxes.

3. The choice of the large-scale convection electric field model does not significantly influence on the modeled electron fluxes.

Using the TS05 model for the background magnetic field instead of the T96 model resulted in the modeled electron fluxes much less close to the observed ones due to specific features of the TS05 model.

Inner Magnetosphere Particle Transport and Acceleration Model: Diffusion

Next **Radial diffusion** is applied (*Schulz and Lanzerotti*, 1974)

$$\frac{df}{dt} = L^2 \frac{\partial}{\partial L}\left(\frac{1}{L^2} D_{LL} \frac{\partial f}{\partial L} \right) - \frac{f}{\tau}$$

with diffusion coefficients D_{LL} (*Brautigam and Albert*, 2000)

$$D_{LL} = 10^{0.056 Kp - 9.325} L^{10}$$

And **Pitch- angle diffusion** by introducing electron lifetimes

1. by *Chen et al.* (2005) for strong diffusion and
   Shprits et al. (2007) for weak diffusion

2. By *Gu et al*. (2012) ”Parameterized lifetime of radiation belt electrons interacting with lower-band and upper-band oblique chorus waves”, submitted

Inner Magnetosphere Particle Transport and Acceleration Model: Electrons' Lifetimes (1)

Strong diffusion: $\tau_{sd} = \left(\frac{\gamma m_0}{p} \right) \left[\frac{2\Psi B_h}{1-\eta} \right]$

p is the particle momentum, γ is the ratio of relativistic mass to rest mass, Bh is the magnetic field at either foot point of field line, Ψ is the magnetic flux tube volume, η =0.25 backscatter coefficient (25% of electrons that will mirror at or below 0.02 Re are scattered back to flux tube instead of precipitating into atmosphere)

Weak diffusion: $\tau_{wd} = 4.8 \cdot 10^4 B_w^{-2} L^{-1} E^2, \quad B_w^2 = 2 \cdot 10^{2.5+0.18Kp}$

Bw is the local wave amplitude, E is kinetic energy in MeV

Inner Magnetosphere Particle Transport and Acceleration Model: Electrons’ Lifetimes (2)

Parametrization of electron lifetimes (1 keV – 2 MeV) due to chorus waves under different geomagnetic conditions

$$\tau(Kp) = 4 \cdot \tau \cdot (\frac{B_W}{B_W(Kp)})^2$$

$$\begin{cases} B_w(Kp) = B_w \cdot (2 \times 10^{0.73+0.91Kp})^{0.5} / 57.6, \;\; Kp \le 2+ \\ B_w(Kp) = B_w \cdot (2 \times 10^{02.5+0.18Kp})^{0.5} / 57.6, \;\; 2+ < Kp \le 6 \end{cases}$$

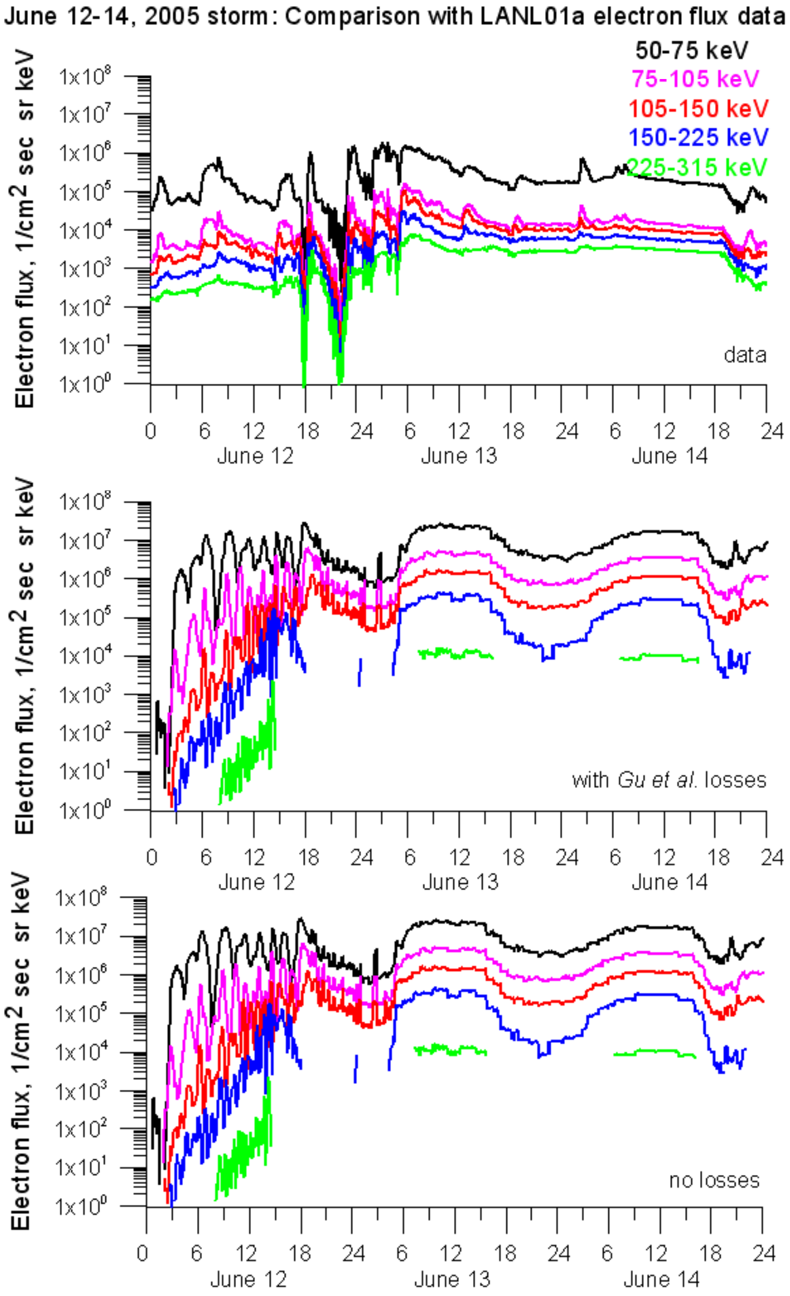
Kp<2+

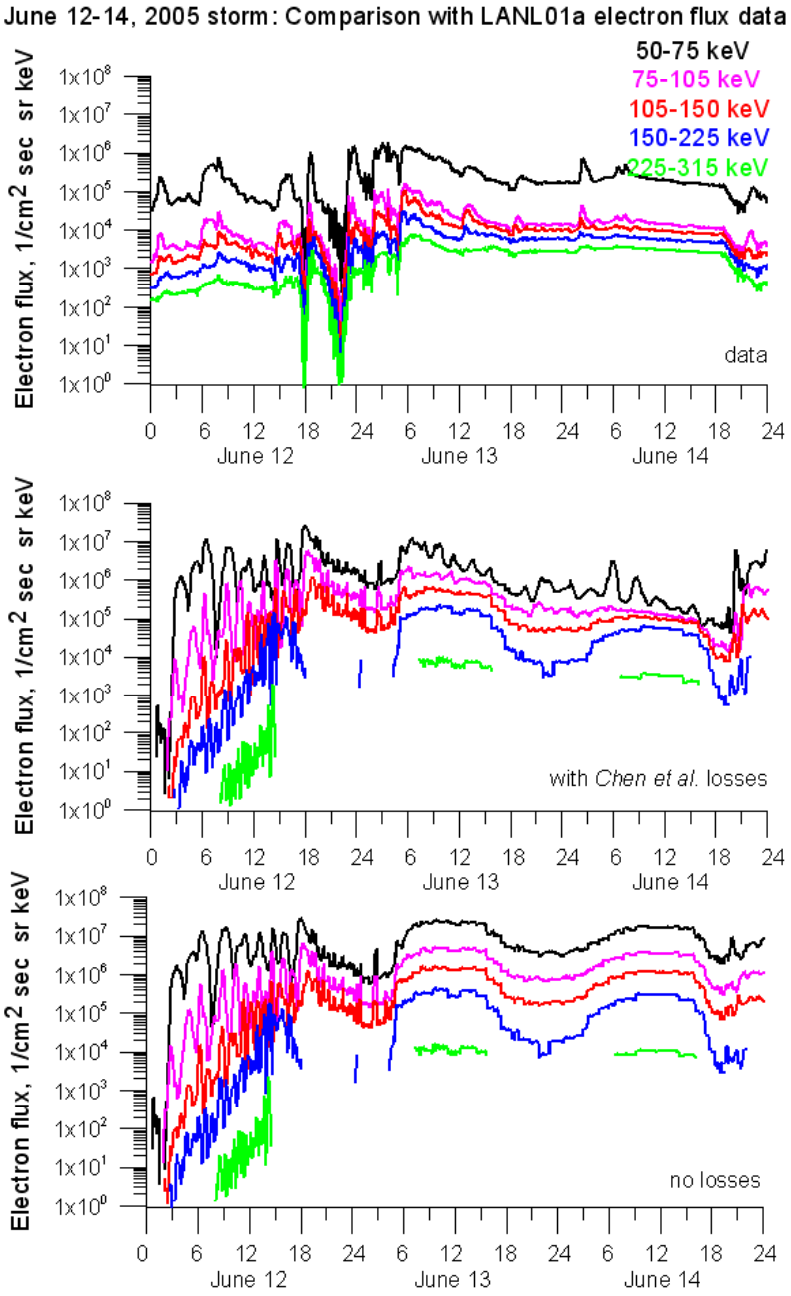
$$\tau(Kp) = 4 \cdot \tau \cdot \frac{B_w^2 \cdot 57.6^2}{B_w^2 \cdot \left(2 \cdot 10^{0.73+0.91Kp}\right)} = \frac{4 \cdot \tau \cdot 3317.76}{2 \cdot 10^{0.73+0.91Kp}} = \frac{\tau \cdot 6635.52}{10^{0.73+0.91Kp}}$$

2+<Kp<6

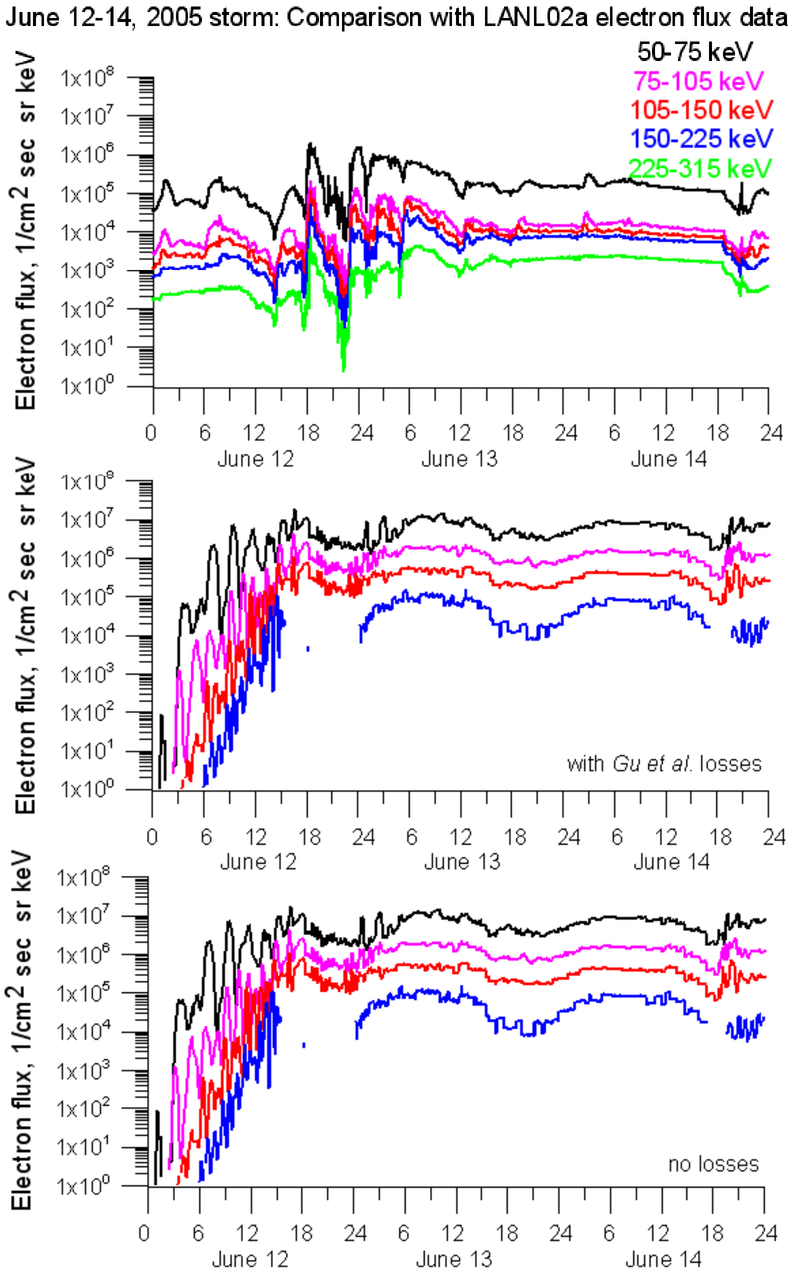
$$\tau(Kp) = 4 \cdot \tau \cdot \frac{B_w^2 \cdot 57.6^2}{B_w^2 \cdot \left(2 \cdot 10^{0.25+0.18Kp}\right)} = \frac{4 \cdot \tau \cdot 3317.76}{2 \cdot 10^{0.25+0.18Kp}} = \frac{\tau \cdot 6635.52}{10^{0.25+0.18Kp}}$$

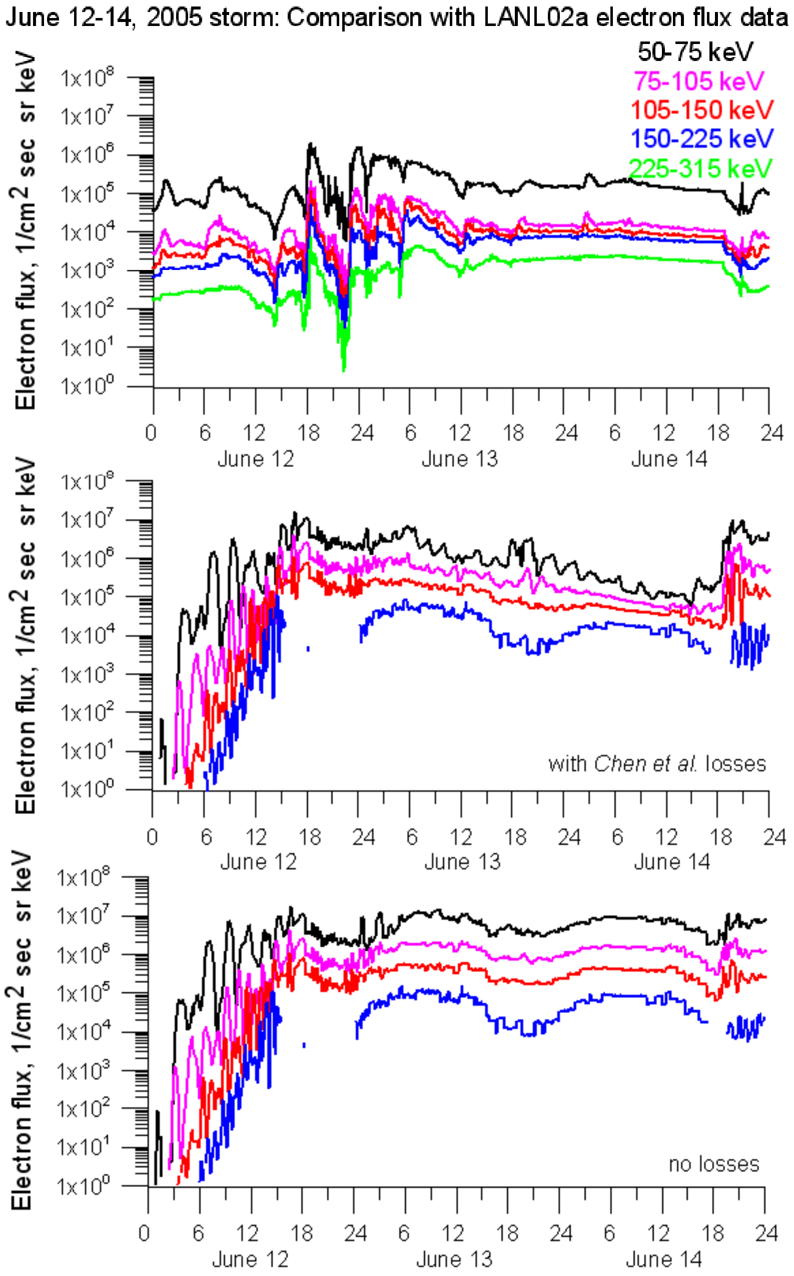
Electron fluxes at 6.6 Re: Losses or no losses



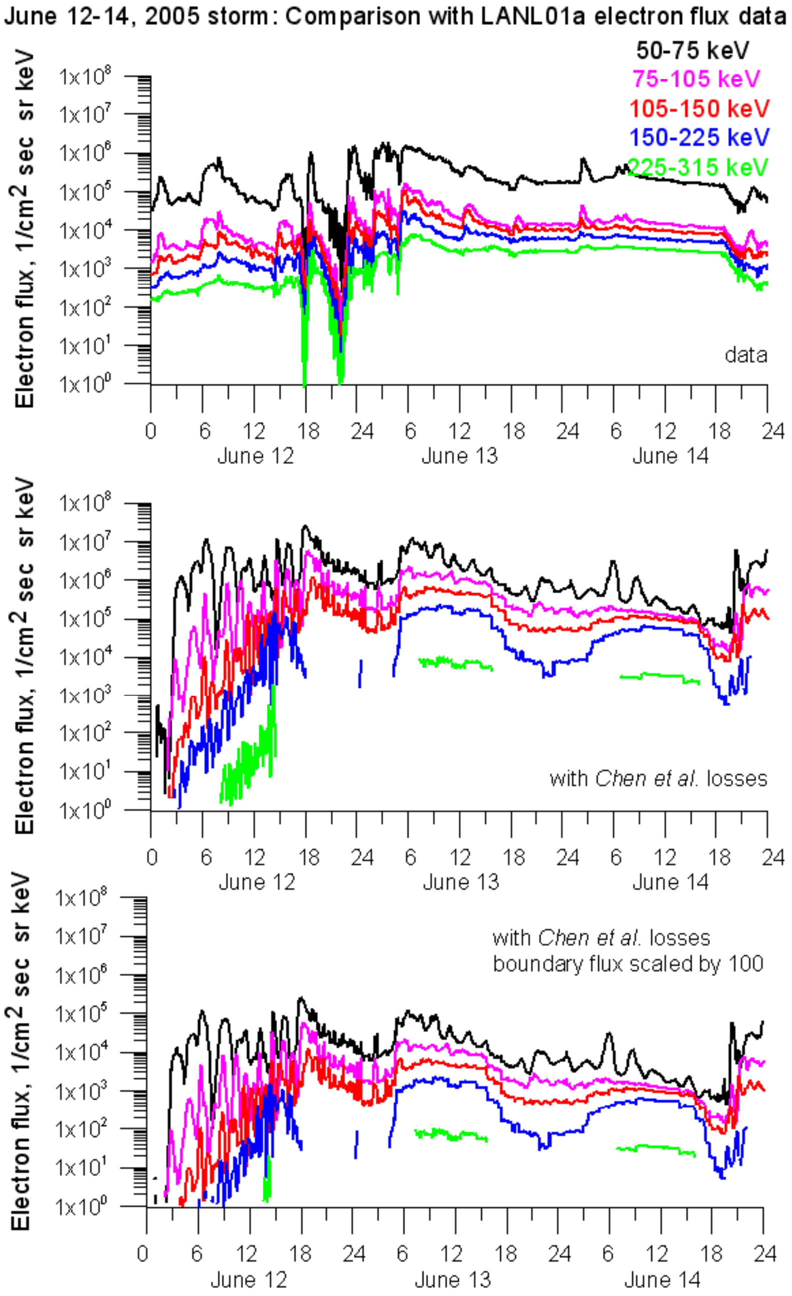


Electron fluxes at 6.6 Re: Losses or no losses





Electron fluxes at 6.6 Re: Scaling boundary conditions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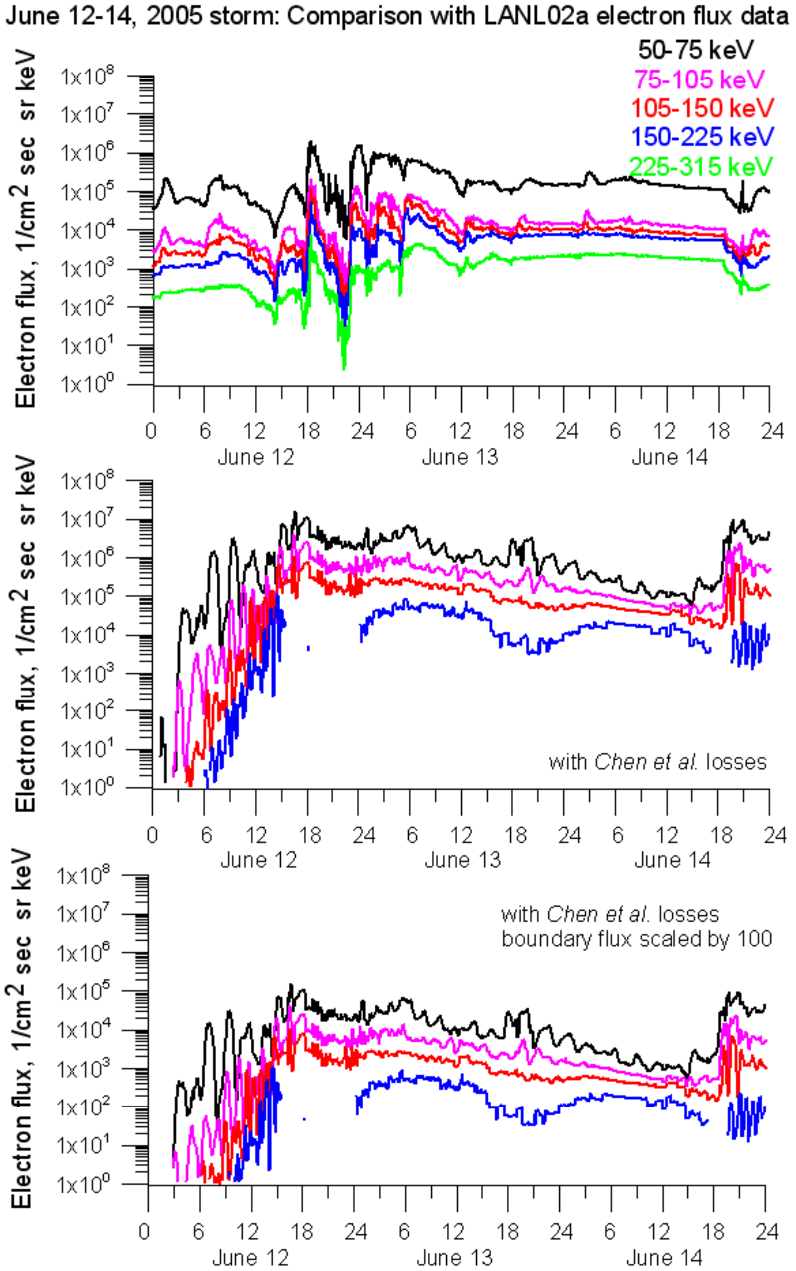
June 12-14, 2005 storm: Comparison with LANL02a electron flux data

Summary

- Transport of plasma sheet electrons from 10 Re to geostationary at 6.6 Re is mainly due to large-scale convection (*and substorm-associated fields*).

Previous results:

- *Electromagnetic pulses associated with substorm onsets bring slightly more Particles and energize them with appearance of 300 keV particles*

- *Simple model with fast moving pulses (distance from 10 to 6.6 Re in 5 minutes) in the plasma sheet used, need for further study*

- PA scattering may not be important. Reducing flux at 6.6 Re during recovery phase.

- **Main influencing factor is boundary conditions in the plasma sheet.** Scaling of boundary fluxes by factor of 100 resulted in reducing fluxes at 6.6 Re also by order of 100.