Initial results obtained with coupled OpenGGCM-CRCM with pressure and density feedback

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Outline

- OpenGGCM - CRCM merging, inputs, outputs
- Initial results - substorm plasma sheet pressure and temperature, FAC and ionospheric potential
- CRCM proton flux

OpenGGCM Coupled with CRCM – Inputs, Outputs

- CRCM runs on a separate processor (node) as a subroutine
- CRCM is called every 2 mins (or less)
- Feedback into OpenGGCM – the CRCM computed pressure and density are mapped back onto the MHD grid
- Fast – we should be able to use it in Space Weather prediction runs
- OpenGGCM grid resolution is important – lower resolution runs tend to produce higher CRCM particle flux
- Initial here runs are done with constant conductivity (and without CTIM)

CRCM Inputs (from OpenGGCM):

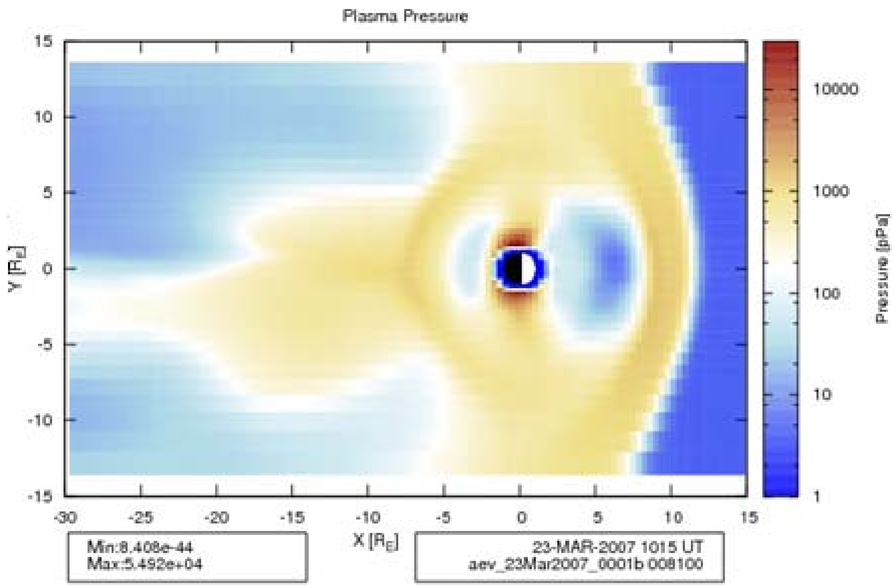
- Maximum possible number of points when tracing a field line (input)
- Number of field line tracing points for given latitude and MLT
- Field line trace points in SM coordinates [Re]
- Magnetic field magnitude [nT] in SM coords. at each field line trace point
- Mapping radius in the equatorial plane [Re] for each closed field line
- Local time location in the equatorial plane (hours from midnight)
- Magnetic field magnitude in the equatorial plane [nT]
- Flux tube volume [Re**3/Wb]
- Ionosphere potential, without corotation [V]
- Particle number density [1/m**3], mapped onto the ionosphere (input: MHD number density for CRCM to fill the boundary conditions; output: CRCM number density)
- Temperature [eV], mapped onto the ionosphere (input: MHD temperature for CRCM to fill the boundary conditions; output: CRCM temperature)

CRCM Feedback into OpenGGCM): Hot particle pressure and

OpenGGCM-CRCM Coupling

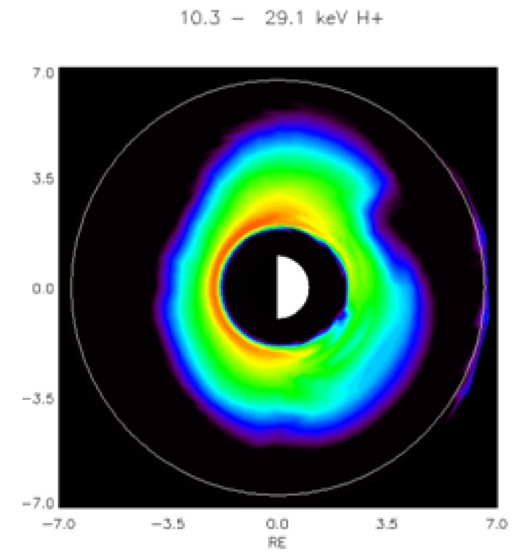
OpenGGCM cartesian MHD grid

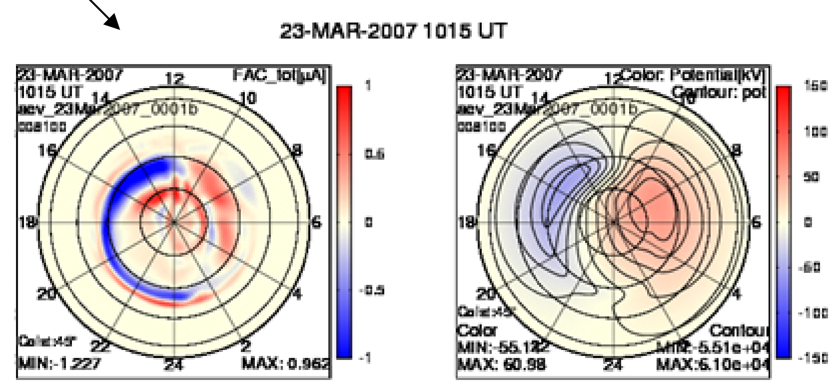
CRCM grid (MLT, Latitude)



Pot, B, Temp, N, FVT →

← pressure +density





23.03.2007 Substorm Event

THEMIS-B Data

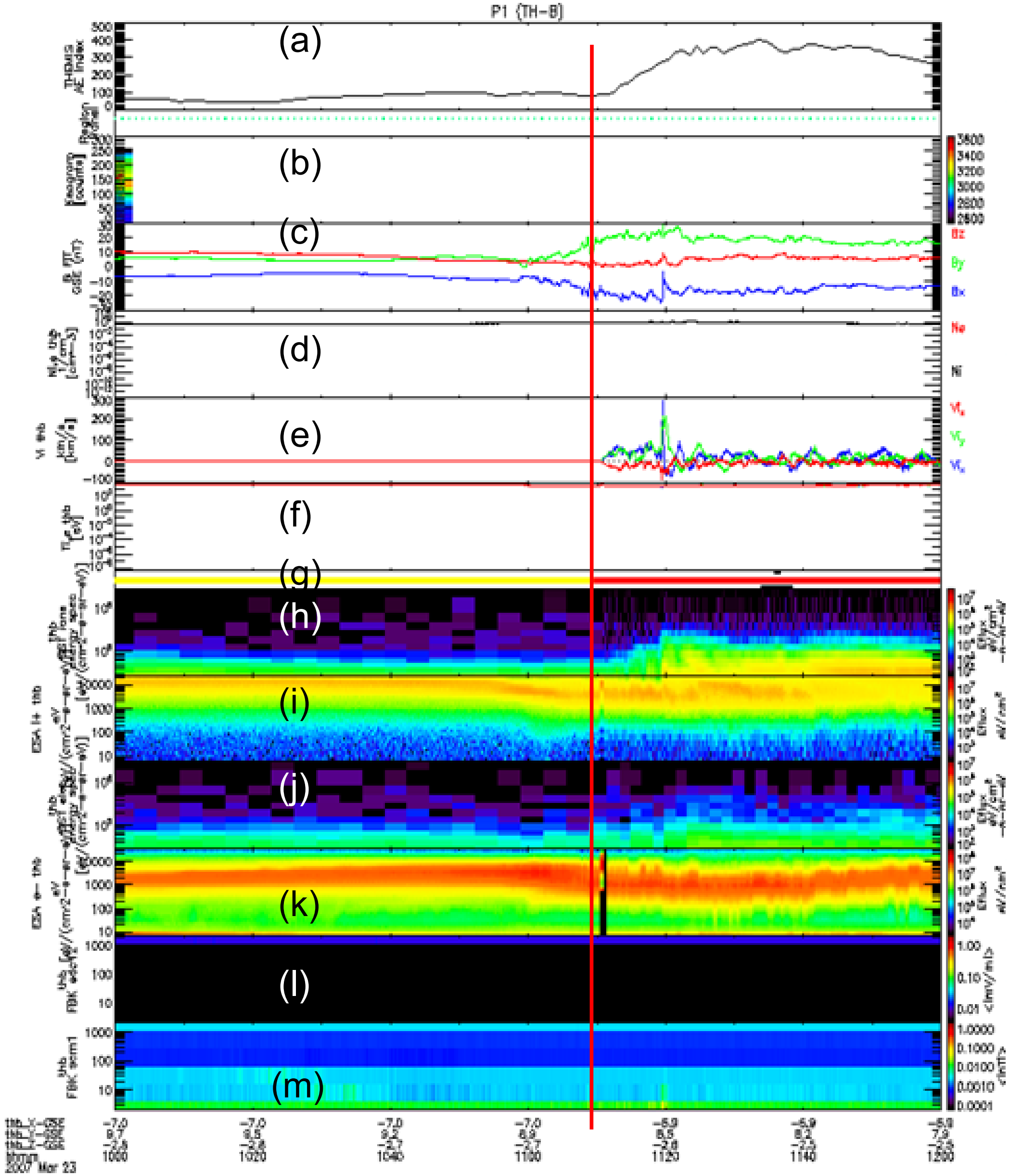


Figure: Summary plots from THEMIS Probe B on 23 March 2007 at 10:00 – 12:00 UT and THEMIS Probe E on 15 February 2009 at 00:00 – 06:00 UT: (a) THEMIS pseudo-AE index; (b) Keogram (north-south stripe of an All Sky Imager camera); (c) Magnetic field in GSE coordinates; (d) Ion and electron partial densities from the ESA instrument; (e) Ion partial flow velocity (ESA); (f) Ion and electron partial temperatures (ESA); (g) Bar indicating the data collection mode. Yellow: Slow Survey, Red: Fast Survey, Black line underneath: Particle Burst, Black line above: Wave Burst; (h) Ion omni-directional spectrum from the SST instrument; (i) Ion omni-directional spectrum (ESA); (j) and (k) electron spectra (SST, ESA); (l) on-board computed wave power spectrum at discrete filter-banks from the EFIinstrument; (m) on-board computed wave power spectrum from the SCM instrument. Satellite position in GSE coordinates is shown at the bottom. (http://themis.ssl.berkeley.edu)

OpenGGCM Solar Wind Input 23 March 2007

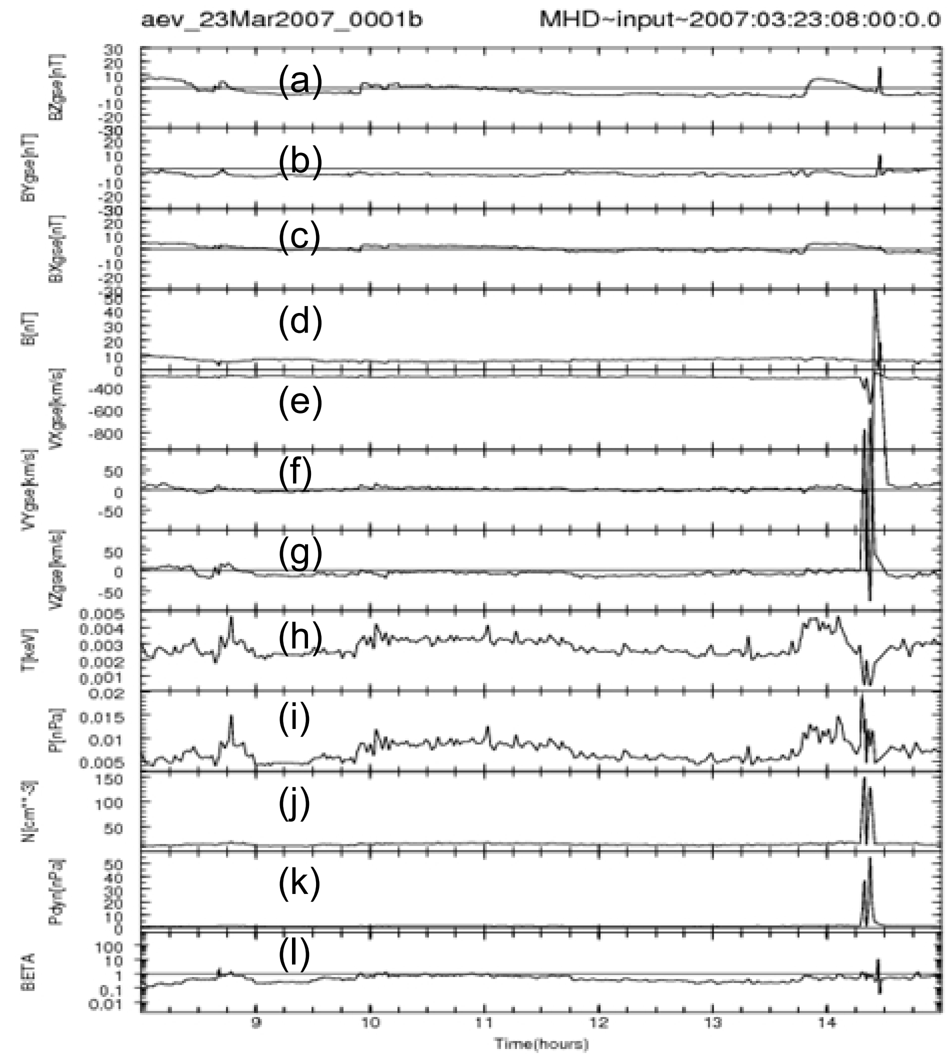


Figure: OpenGGCM input from the solar wind: (a), (b), and (c) are Bz, By, and Bx magnetic field components in GSE coordinates; (d) Total magnetic field; (e), (f), and (g) are Vx, Vy, and Vz in GSE; (h) SW Temperature; (I) SW pressure; (j) SW particle density; (k) SW dynamic pressure; (l) Beta.

Plasma Pressure: OpenGGCM-CRCM: 23.03.2007

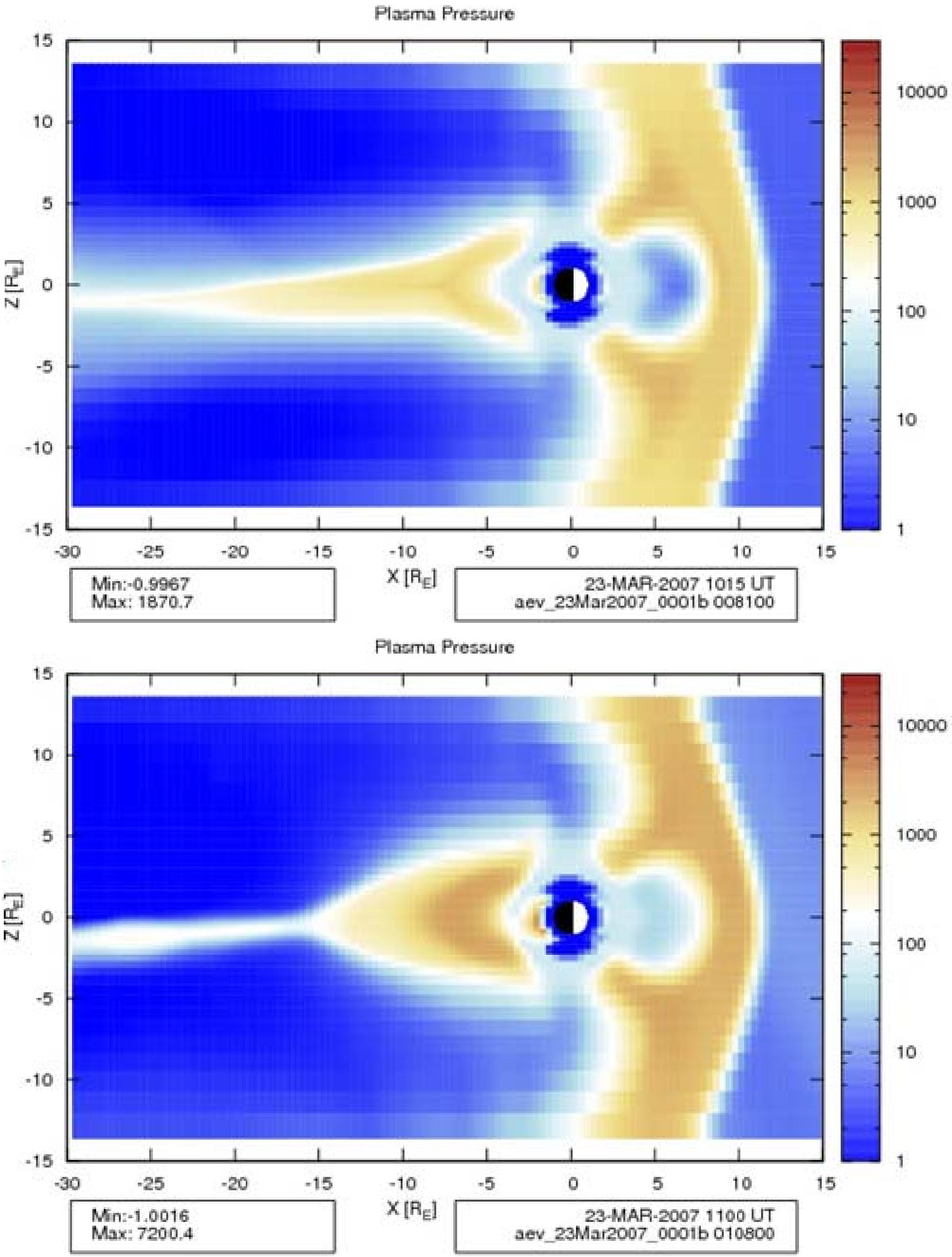


Figure: Plasma pressure [pPa] computed by coupled OpenGGCM-CRCM at two different times in the MHD XZ-plane. The ring current pressure is clearly visible at the night side.

Plasma Pressure: OpenGGCM: 23.03.2007

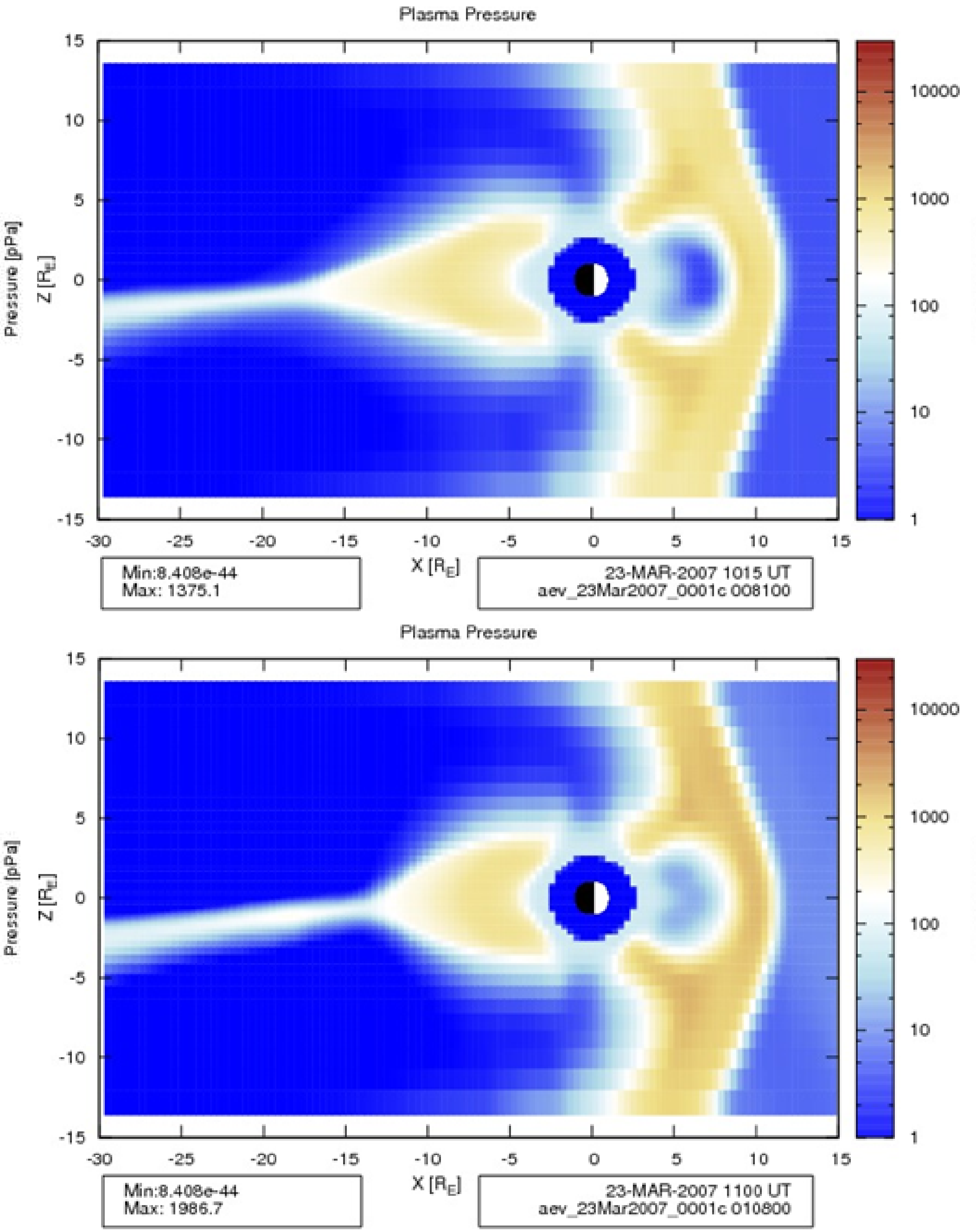
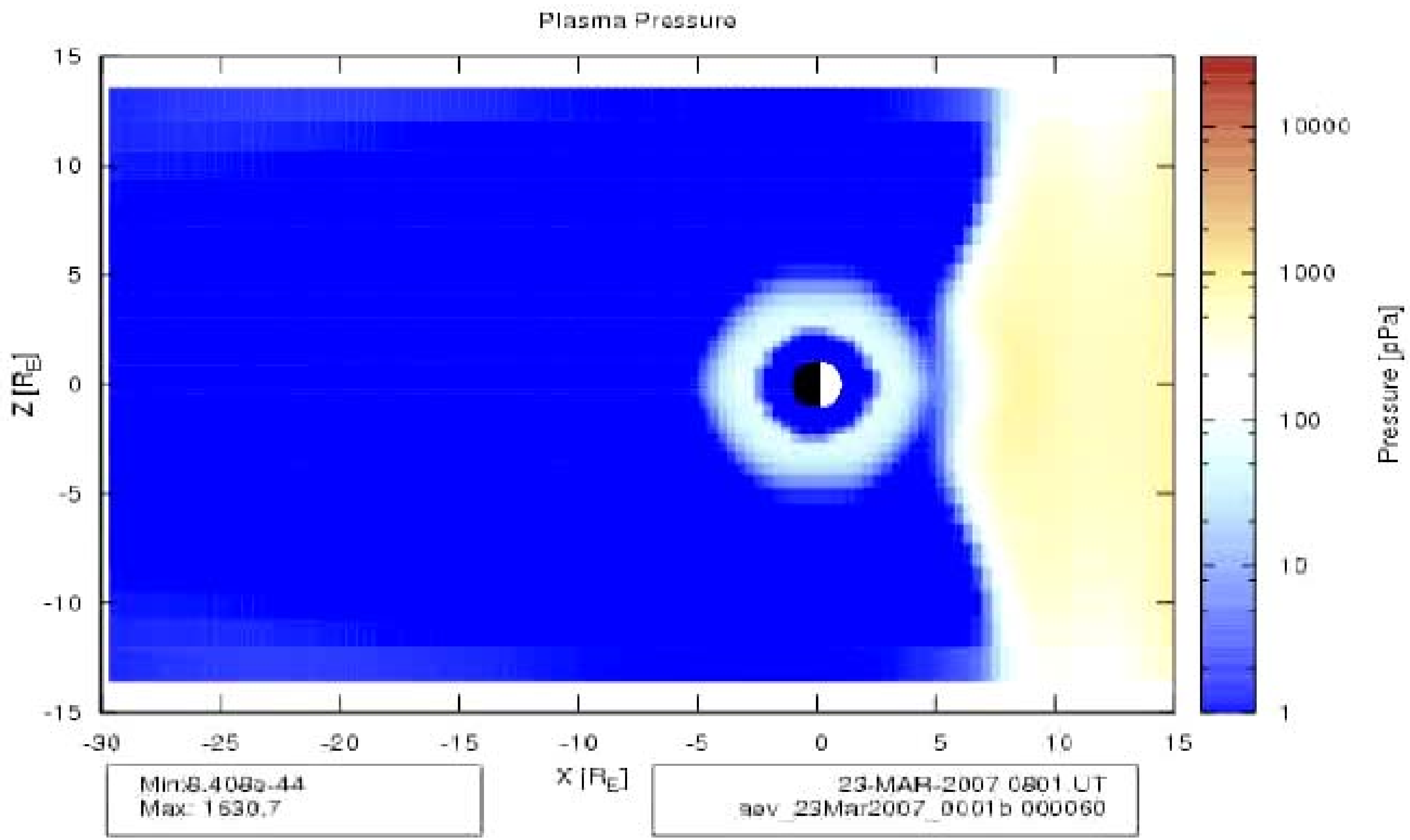


Figure: Plasma pressure [pPa] computed by OpenGGCM without CRCM at two different times in the MHD XZ-plane. There is no ring current pressure near the Earth.

Plasma Pressure: OpenGGCM-CRCM: 23.03.2007



Plasma Temperature: OpenGGCM-CRCM: 23.03.2007

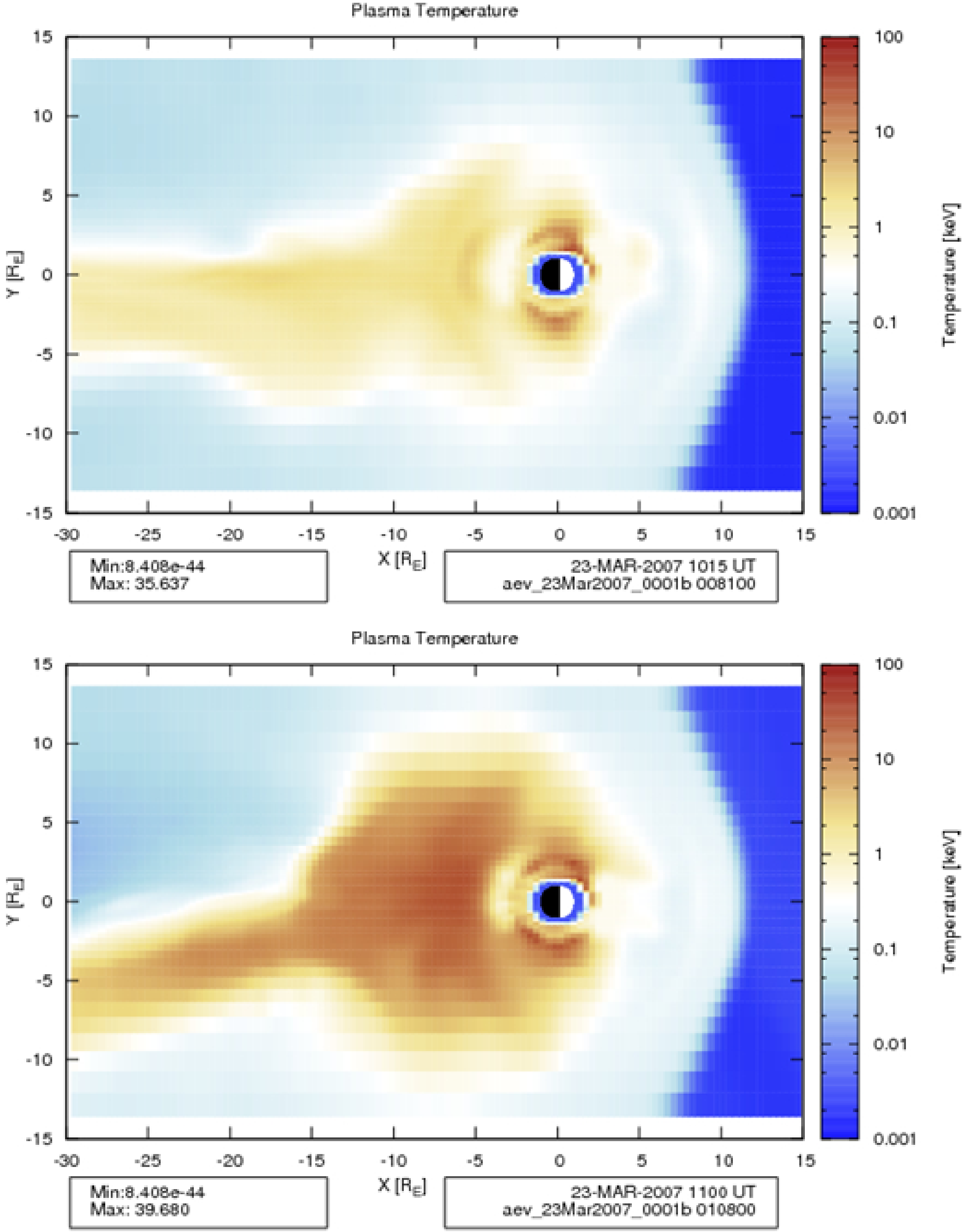


Figure: Plasma temperature [keV] computed by coupled OpenGGCM-CRCM at two different times in the MHD XY-plane. The "cut" at midnight in the ring current is due to the dipole tilt relative to the MHD XY-plane.

Plasma Temperature: OpenGGCM: 23.03.2007

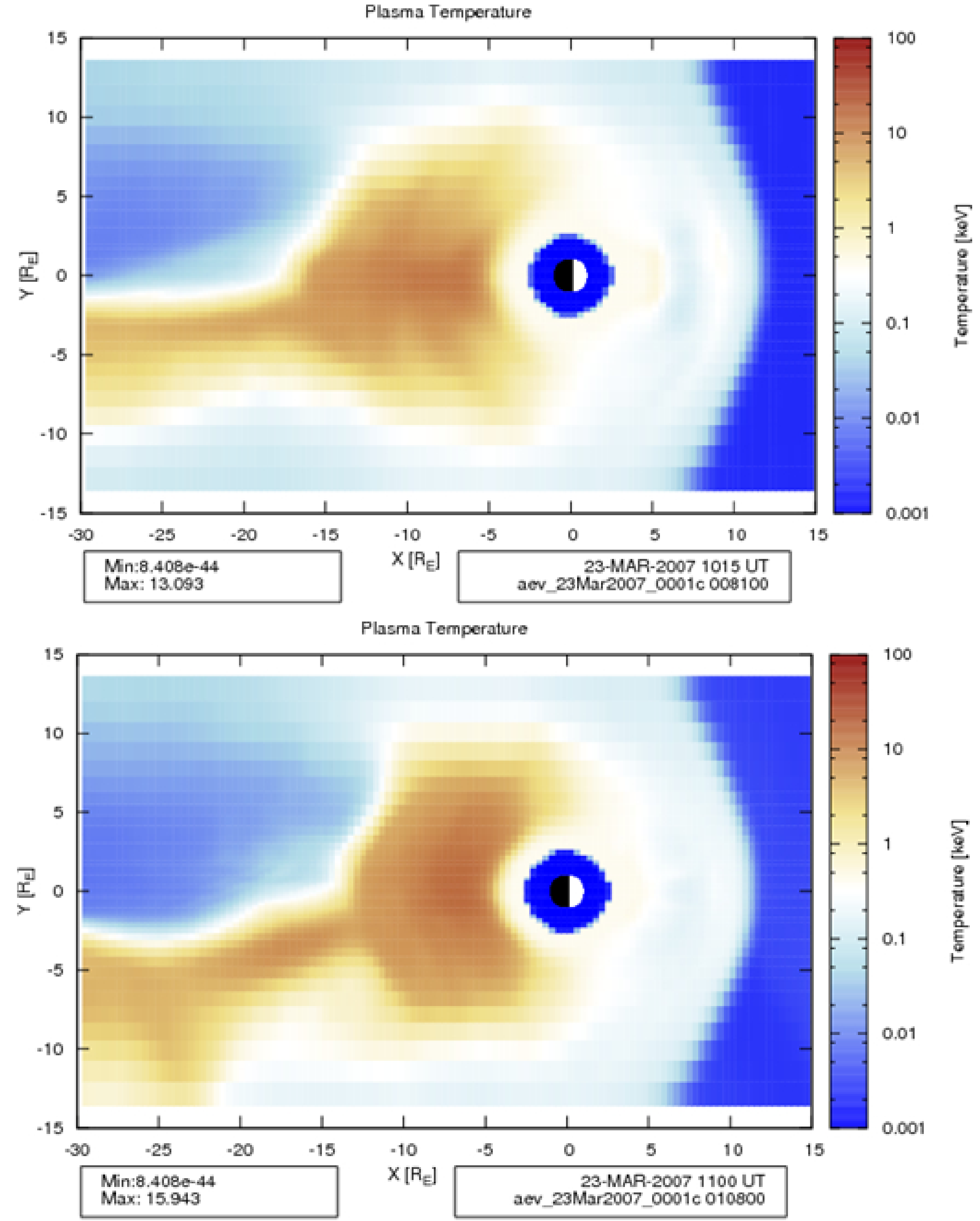
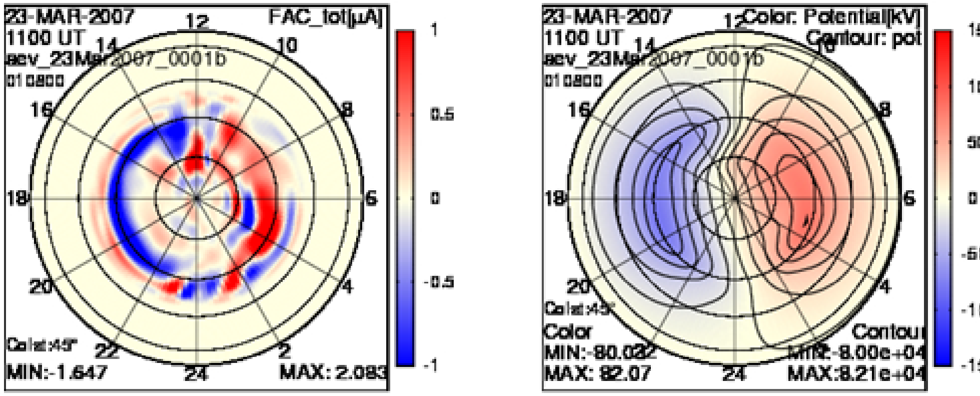


Figure: Plasma temperature [keV] computed by OpenGGCM without CRCM at two different times in the MHD XY-plane.

Computed Field Aligned Current and Potential

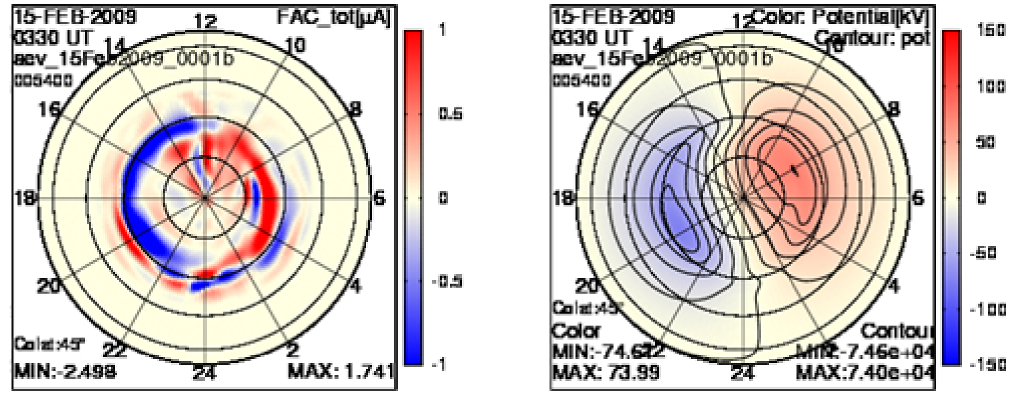
Field aligned current and ionospheric potential
with CRCM feedback

23-MAR-2007 1100 UT



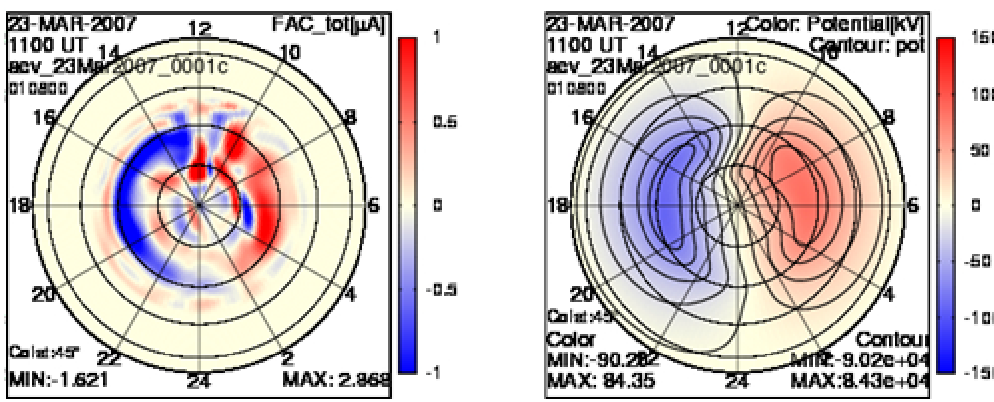
Field aligned current and ionospheric potential
with CRCM feedback

15-FEB-2009 0330 UT



Field aligned current and ionospheric potential with
no CRCM feedback

23-MAR-2007 1100 UT



Field aligned current and ionospheric potential with
no CRCM feedback

15-FEB-2009 0330 UT

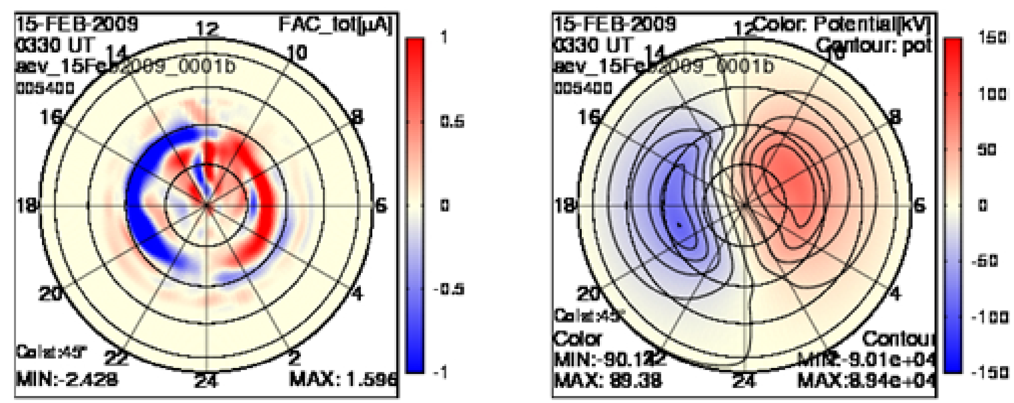


Figure: (Left) Total field aligned current in μA. (Right) Ionospheric potential in kV. The plots are at 11:00 UT. (Top) coupled OpenGGCM-CRCM via pressure feedback. (Bottom) OpenGGCM only without CRCM pressure feedback.

Figure: (Left) Total field aligned current in μA. (Right) Ionospheric potential in kV. The plots are at 11:00 UT. (Top) coupled OpenGGCM-CRCM via pressure feedback. (Bottom) OpenGGCM only without CRCM pressure feedback.

14.02.2008 THEMIS Event

THEMIS-E Data

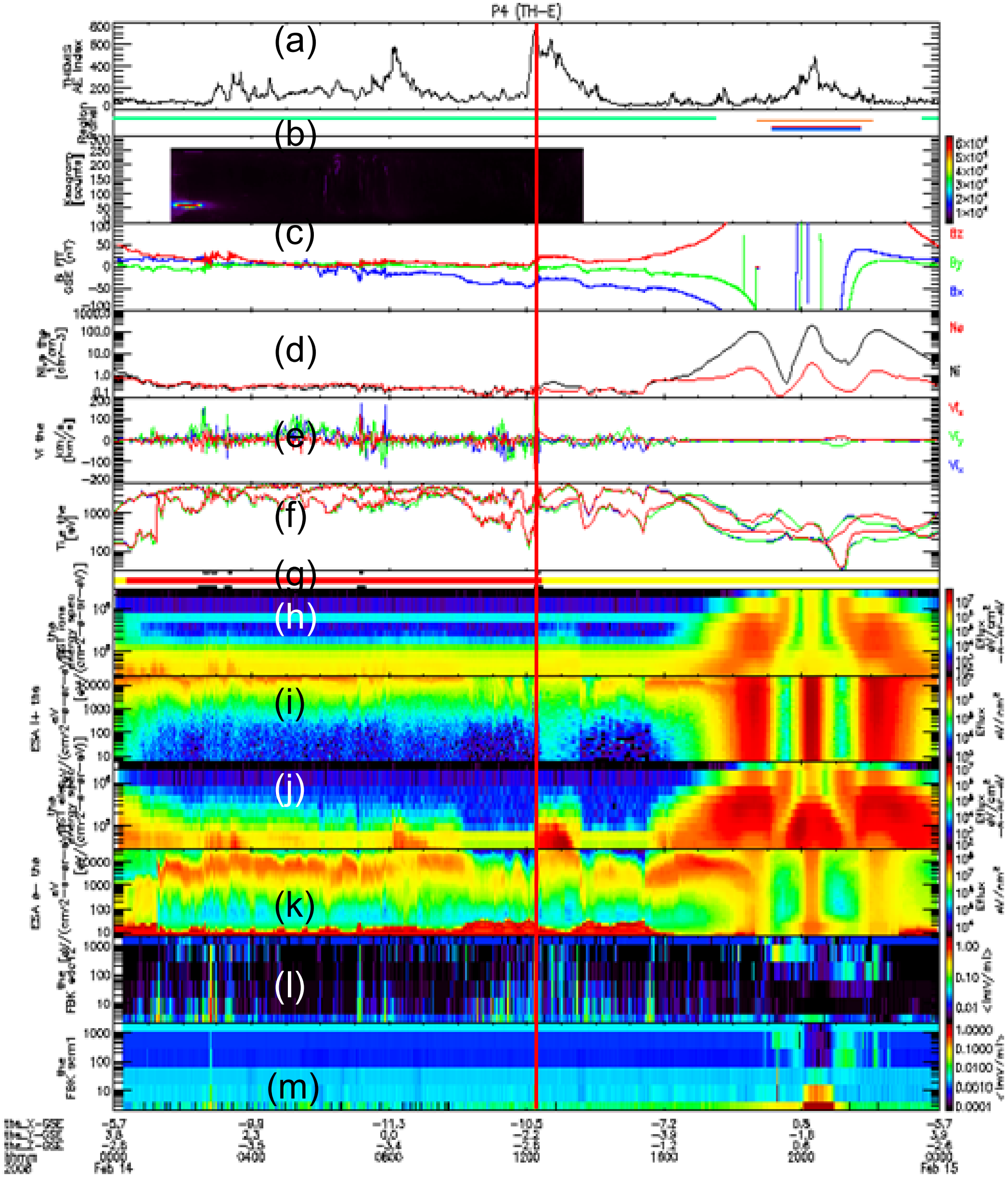


Figure: Summary plots from THEMIS Probe B on **23 March 2007** at 10:00 – 12:00 UT and THEMIS Probe E on **15 February 2009** at 00:00 – 06:00 UT: (a) THEMIS pseudo-AE index; (b) Keogram (north-south stripe of an All Sky Imager camera); (c) Magnetic field in GSE coordinates; (d) Ion and electron partial densities from the ESA instrument; (e) Ion partial flow velocity (ESA); (f) Ion and electron partial temperatures (ESA); (g) Bar indicating the data collection mode. Yellow: Slow Survey, Red: Fast Survey, Black line underneath: Particle Burst, Black line above: Wave Burst; (h) Ion omni-directional spectrum from the SST instrument; (i) Ion omni-directional spectrum (ESA); (j) and (k) electron spectra (SST, ESA); (l) on-board computed wave power spectrum at discrete filter-banks from the EFIinstrument; (m) on-board computed wave power spectrum from the SCM instrument. Satellite position in GSE coordinates is shown at the bottom. (http://themis.ssl.berkeley.edu)

OpenGGCM Solar Wind Input 14 Feb 2008

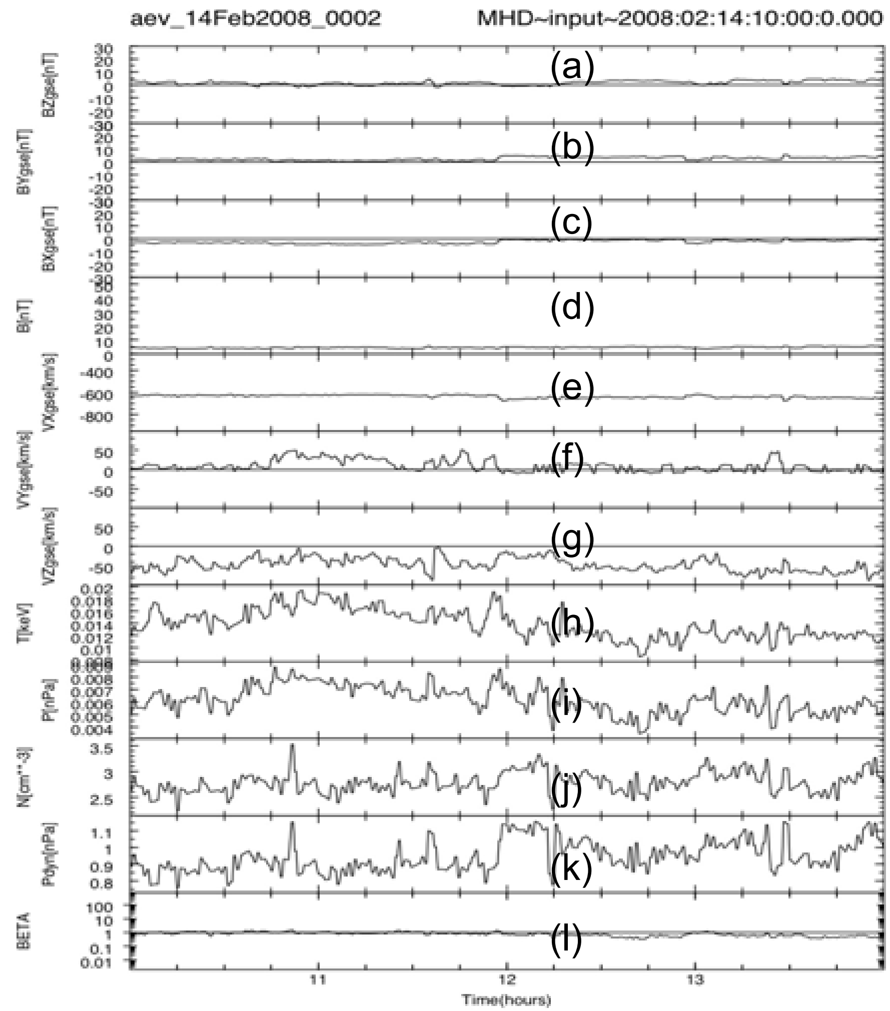


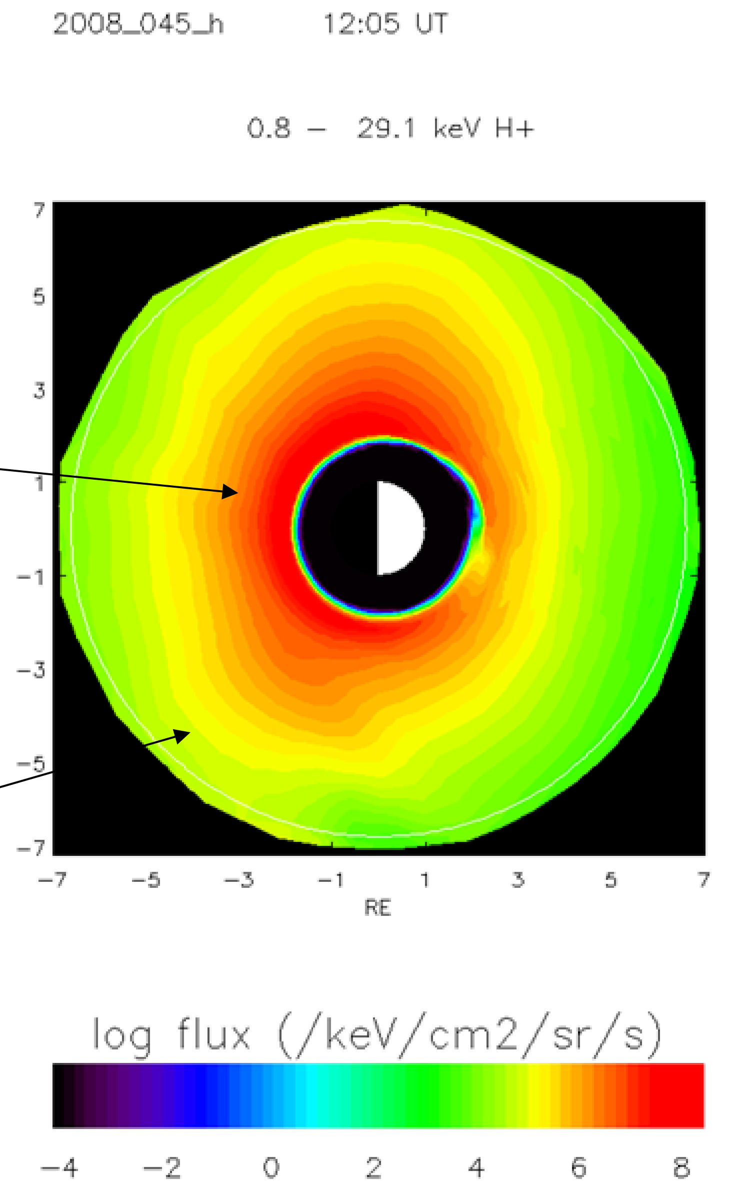
Figure: OpenGGCM input from the solar wind: (a), (b), and (c) are Bz, By, and Bx magnetic field components in GSE coordinates; (d) Total magnetic field; (e), (f), and (g) are Vx, Vy, and Vz in GSE; (h) SW Temperature; (I) SW pressure; (j) SW particle density; (k) SW dynamic pressure; (l) Beta.

CRCM H+ Flux (1-30keV) for the 14 Feb 2008 THEMIS Event

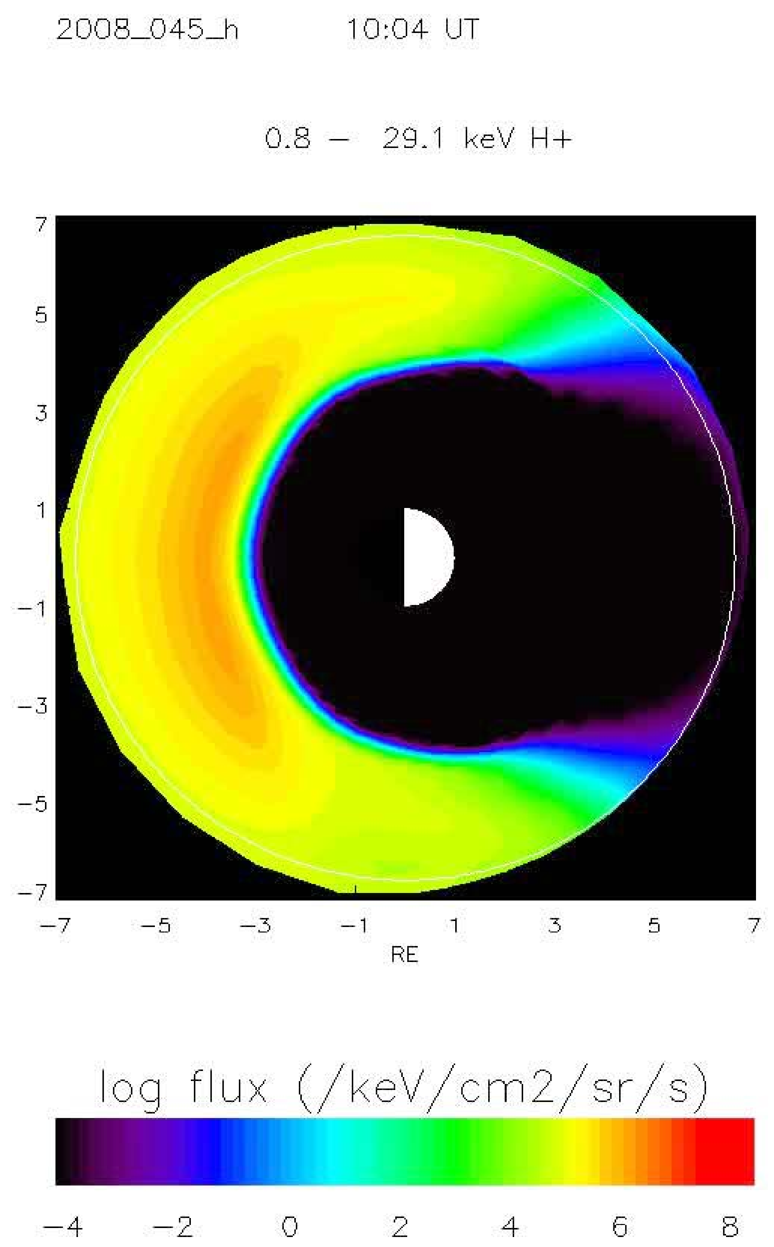
- Pressure and density feedback into OpenGGCM
- The CRCM boundary is 7 RE

- Flux is too close to Earth due to the constant conductivity used in the model – not enough shielding

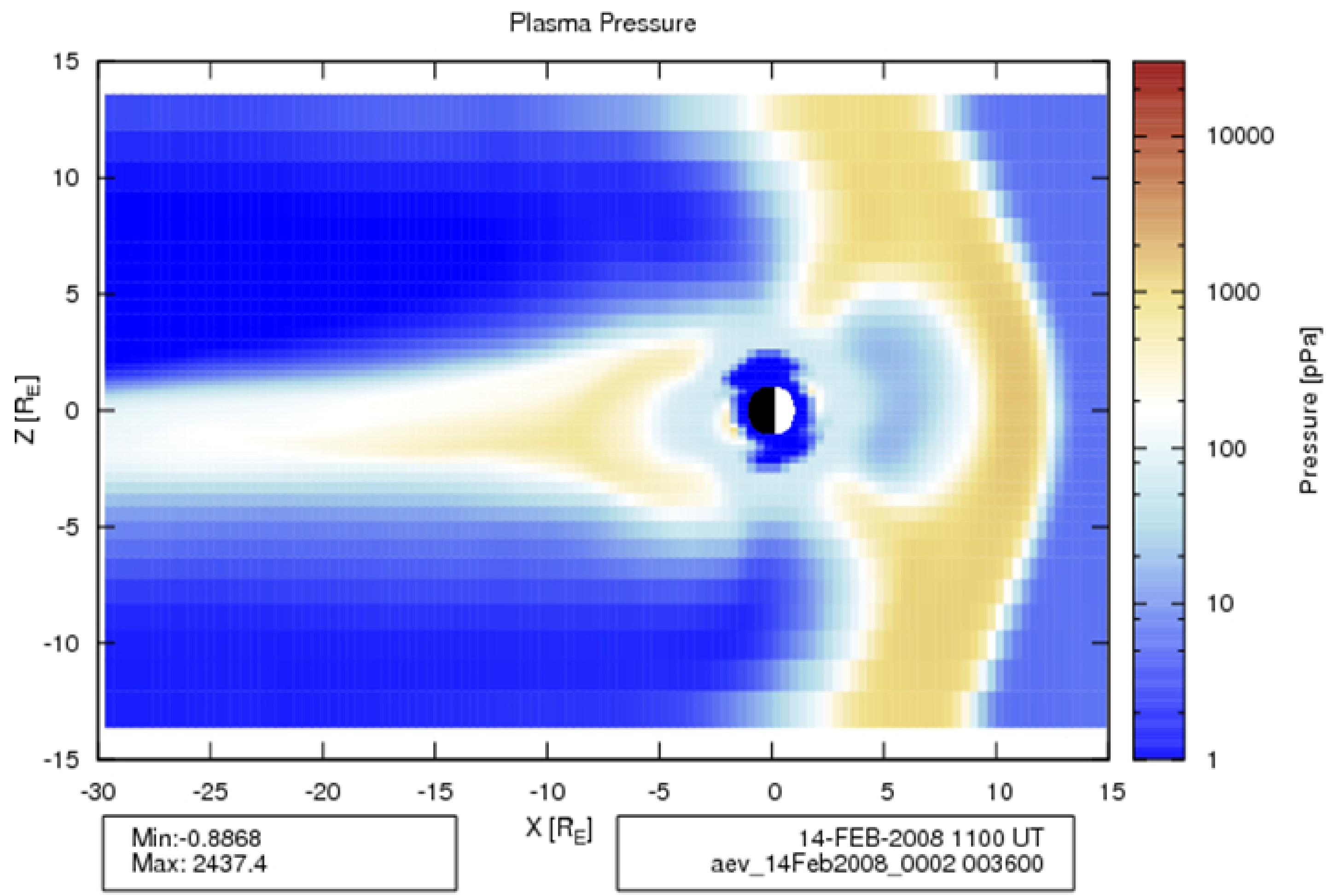
- We see particles entering the inner magnetosphere from the tail region



CRCM H+ Flux (1-30keV) for the 14 Feb 2008 THEMIS Event

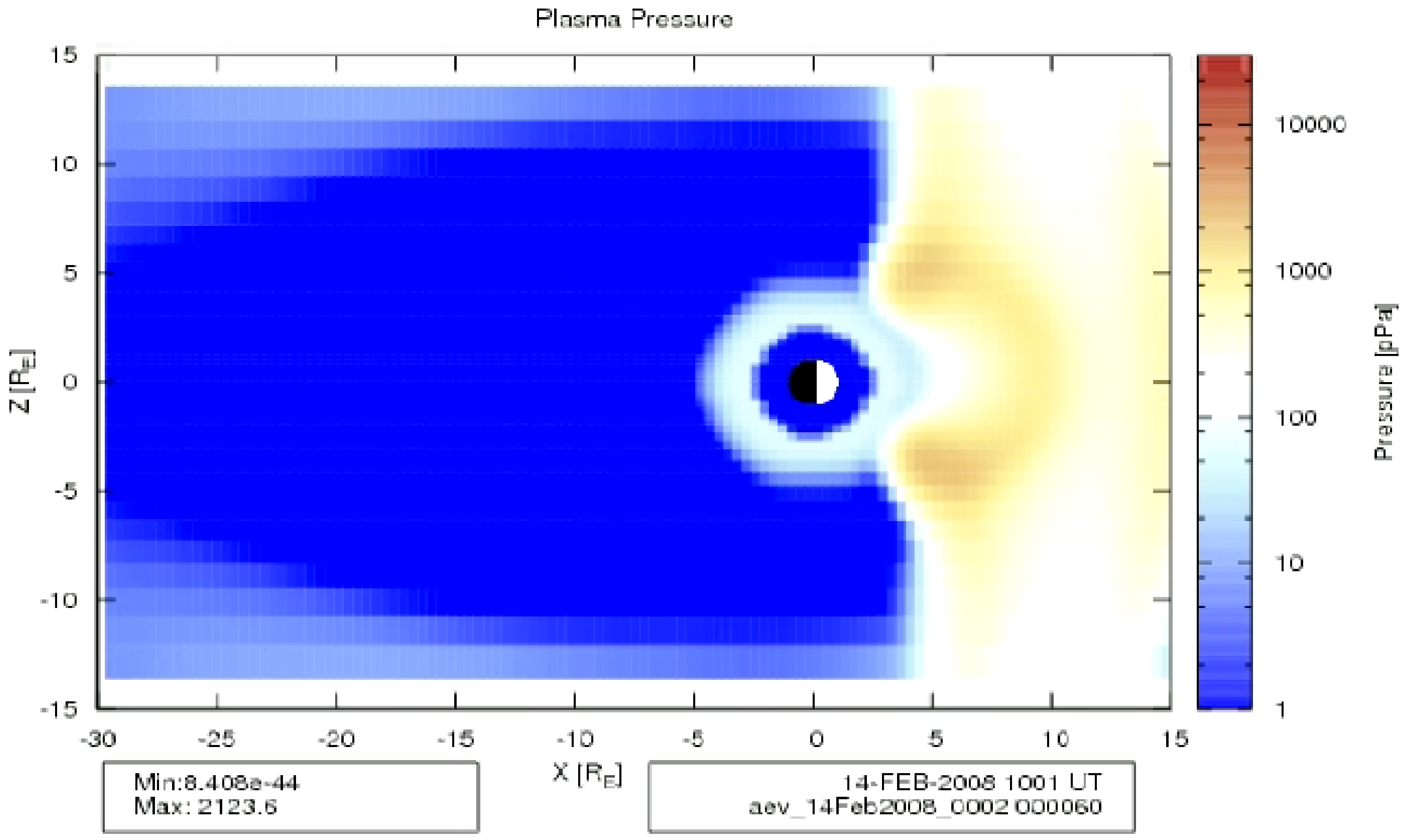


Plasma Pressure: OpenGGCM-CRCM: 14.02.2008



The position of the X-line is very dynamic (compared to standalone OpenGGCM) – it moves towards Earth close to onset and then moves away again.

Plasma Pressure: OpenGGCM-CRCM: 14.02.2008



Summary

- We have fully coupled OpenGGCM (global MHD model) with CRCM (ring current kinetic model) via pressure and density feedback. CRCM uses inputs from the global MHD model to calculate the plasma pressure and density close to Earth. Then the CRCM pressure and density are mapped back on the OpenGGCM MHD grid.
- We present initial simulations of the 23.03.2007, 14.02.2008, and 15.02.2009 substorm events observed by the THEMIS spacecraft.
- We see a significant increase in the plasma pressure and temperature close to Earth due to the ring current model (CRCM) feedback into the global MHD model (OpenGGCM).
- A more extended and enhanced near-Earth plasma sheet in the magnetotail is observed as a result from the CRCM feedback.
- The location of the X-line in magnetotail shifts further away from Earth when feedback from CRCM is included .
- Enhanced penetration of plasma into the inner magnetosphere is observed due to the increased density and pressure in the near-Earth magnetosphere with CRCM feedback.
- We observe a slight shielding effect, i.e., a reduced ionospheric potential when the CRCM feedback is turned on in comparison with the case of no ring current model feedback. The shielding is smaller than expected since the ionospheric conductance is kept constant for these initial runs.
- The MHD model self-consistently computes the field aligned currents, but does not fully reproduce the contribution of the ring current model to the inner magnetosphere current system in the case of CRCM feedback (need better conductance and may be better method of MHD FAC mapping).
- We present results for the computed CRCM 10-30 keV proton flux with and without feedback. We see a higher particle inflow into the ring current region in the case of a feedback. Due to the weak shielding effect, however, the ring current flux peak is located closer to Earth than observed.

FUTURE WORK: More tests with data comparison (realistic ionospheric conductance), CTIM, Collaborate further with CCMC, and (hopefully) get the whole thing coupled with a Sol. wind model for ring current predictions

(A. Glocer's talk on CRCM/RBE model)

Some Technical Details

Coding: Fortran, C, Perl, Python, bash scripts

Plotting Tools: Gnuplot (rocks!), Vizit, OpenDX, IDL

Hardware: Beowulf type cluster, 40-PS3 cluster, IBM 8-blade cluster (cell architecture)

CRCM Proton Flux 10-30 keV 23 March 2007

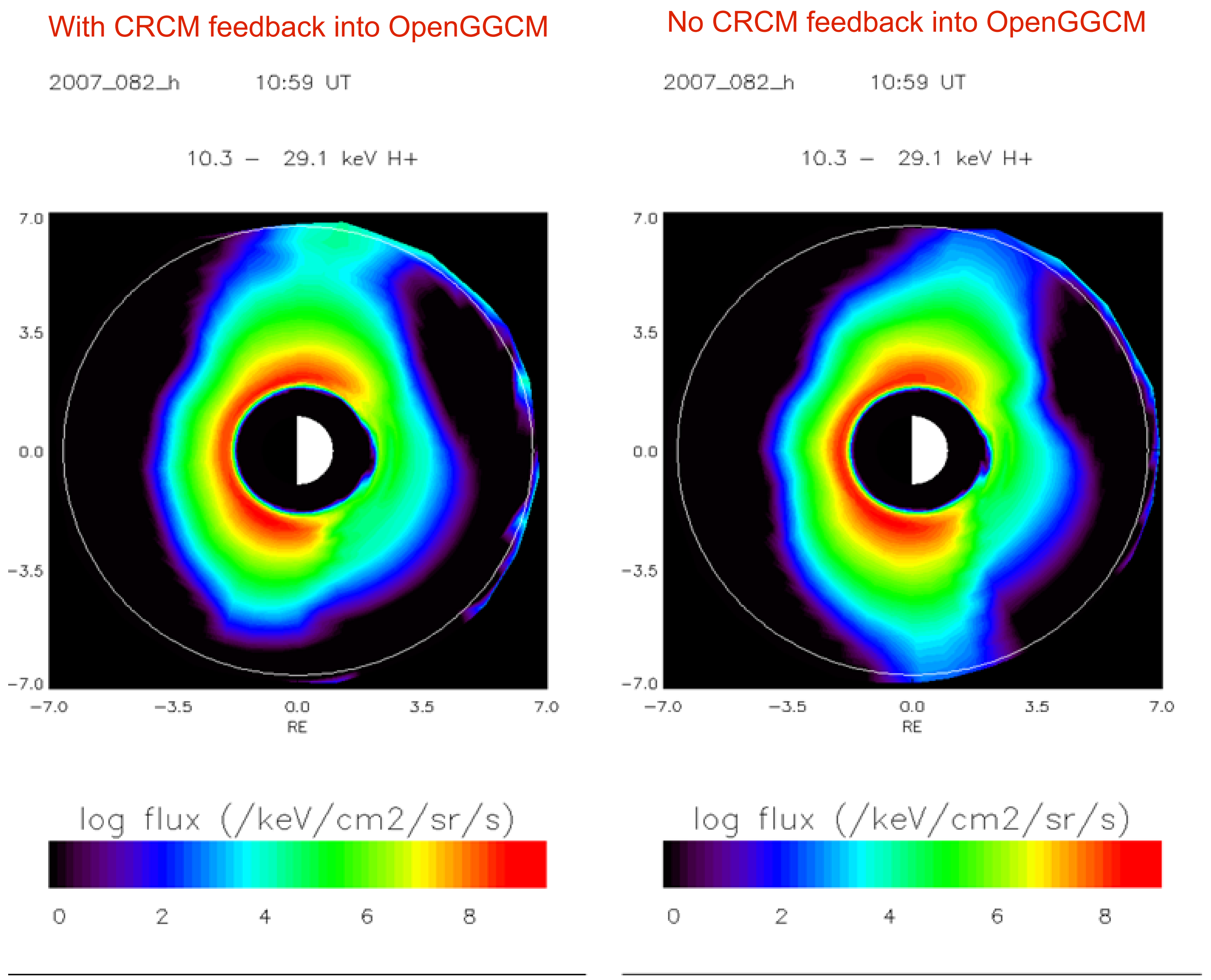


Figure: Proton flux (10-30 keV) computed by CRCM (left) with pressure feedback into OpenGGCM, and (right) without feedback (one way coupling) at 11:00 UT. When pressure feedback is implemented, more particles from the dusk-midnight side enter the ring current region.

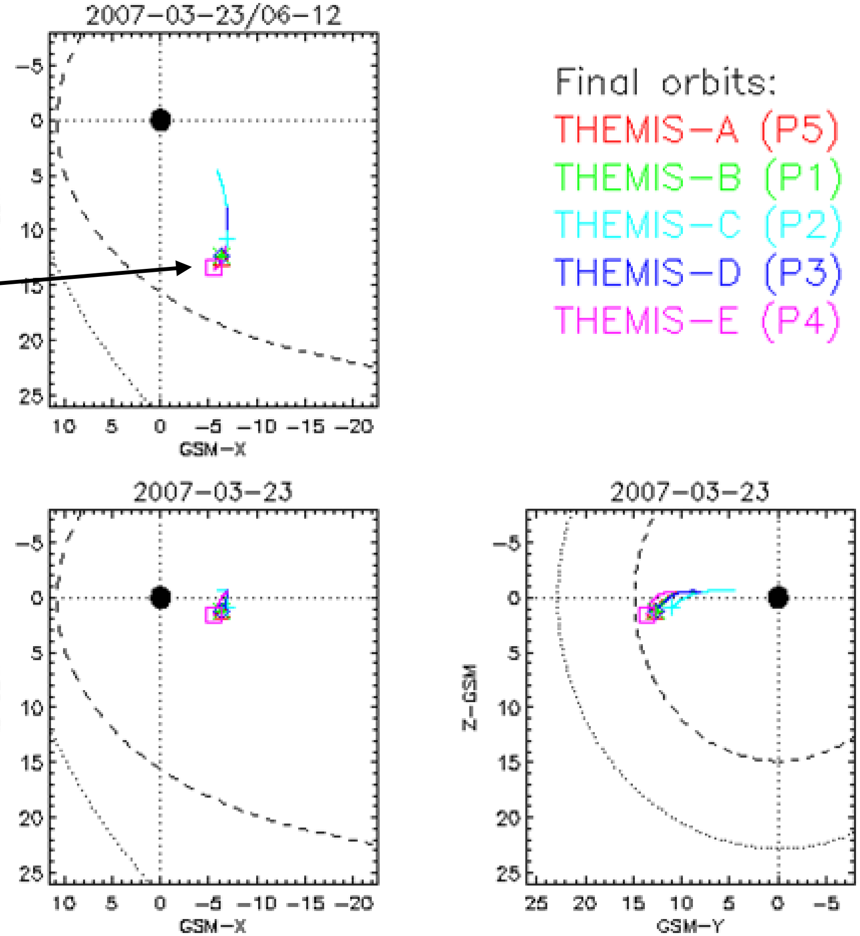
Figure: Summary plots from THEMIS Probe B on **23 March 2007** at 10:00 – 12:00 UT and THEMIS Probe E on **15 February 2009** at 00:00 – 06:00 UT: (a) THEMIS pseudo-AE index; (b) Keogram (north-south stripe of an All Sky Imager camera); (c) Magnetic field in GSE coordinates; (d) Ion and electron partial densities from the ESA instrument; (e) Ion partial flow velocity (ESA); (f) Ion and electron partial temperatures (ESA); (g) Bar indicating the data collection mode. Yellow: Slow Survey, Red: Fast Survey, Black line underneath: Particle Burst, Black line above: Wave Burst; (h) Ion omni-directional spectrum from the SST instrument; (i) Ion omni-directional spectrum (ESA); (j) and (k) electron spectra (SST, ESA); (l) on-board computed wave power spectrum at discrete filter-banks from the EFIinstrument; (m) on-board computed wave power spectrum from the SCM instrument. Satellite position in GSE coordinates is shown at the bottom. (http://themis.ssl.berkeley.edu)

Why do we select these events?

- 2007-03-23: A very well studied event (Angelopoulos et al. 2008), observed by ACE, WIND, and Cluster. Two substorms which later developed into a geomagnetic storm: the first substorm event occurred during the main phase of a moderate storm with *Dst* index of around -80 nT. The IMF was southward for about an hour prior to turning northward at around 11:08 UT.

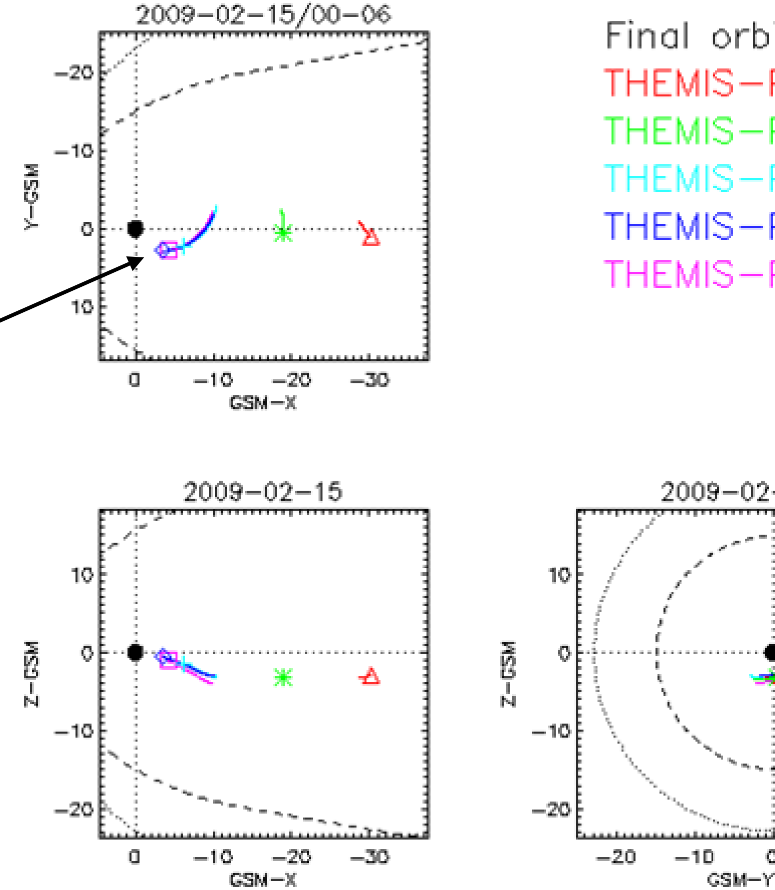
- 2009-02-15: The first substorm on that day is at around 03:12 UT from the ground Pi2 observations, while the all-sky camera observation shows that the aurora intensification and expansion phase starts at around 03:19 UT and then a second major onset at ~03:24 UT (ground magnetic observations). This was an isolated substorm event without any major dip in the *Dst* index.

THEMIS Orbits (GSM) 23 Mar 2007



THEMIS Orbits (GSM) 15 Feb 2009

~22 MLT



Plasma Density: OpenGGCM-CRCM: 23.03.2007

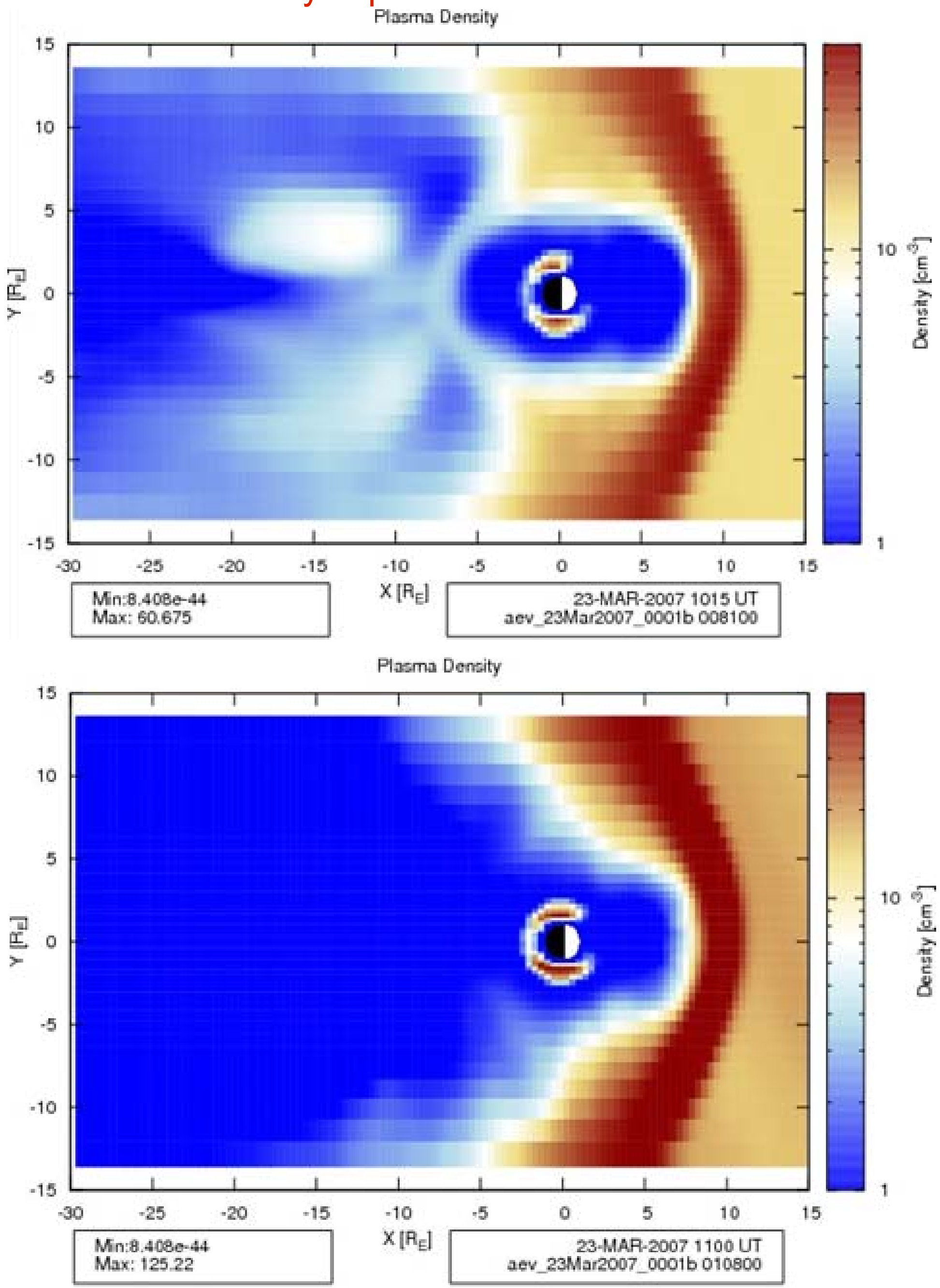


Figure: Plasma density [cm^{-3}] computed by coupled OpenGGCM-CRCM at two different times in the MHD YX-plane. Plasma from the tail region enters into the inner magnetosphere and the ring current density increases. The "cut" at midnight in the ring current is due to the dipole tilt relative to the MHD XY-plane.

Plasma Density: OpenGGCM: 23.03.2007

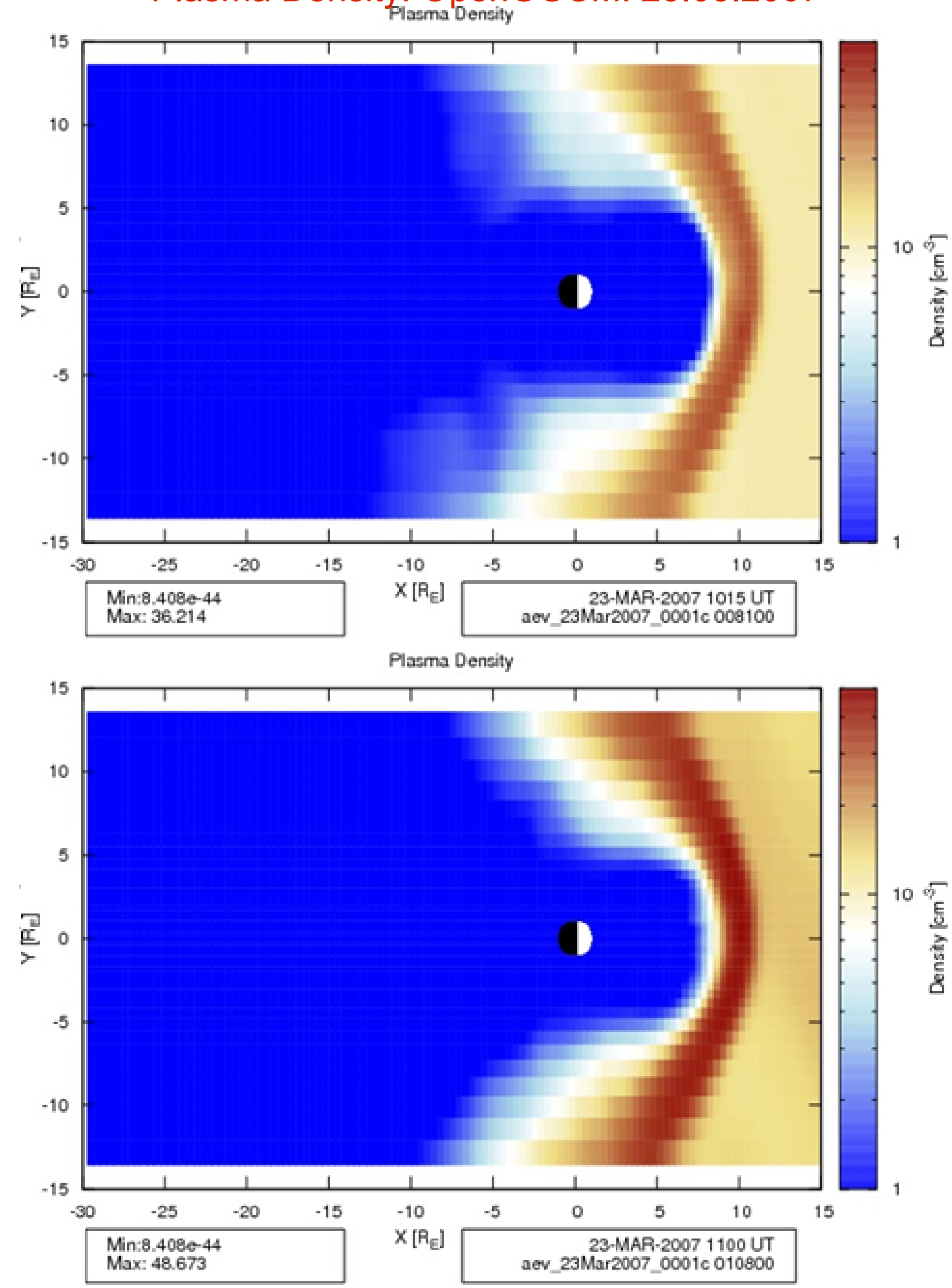
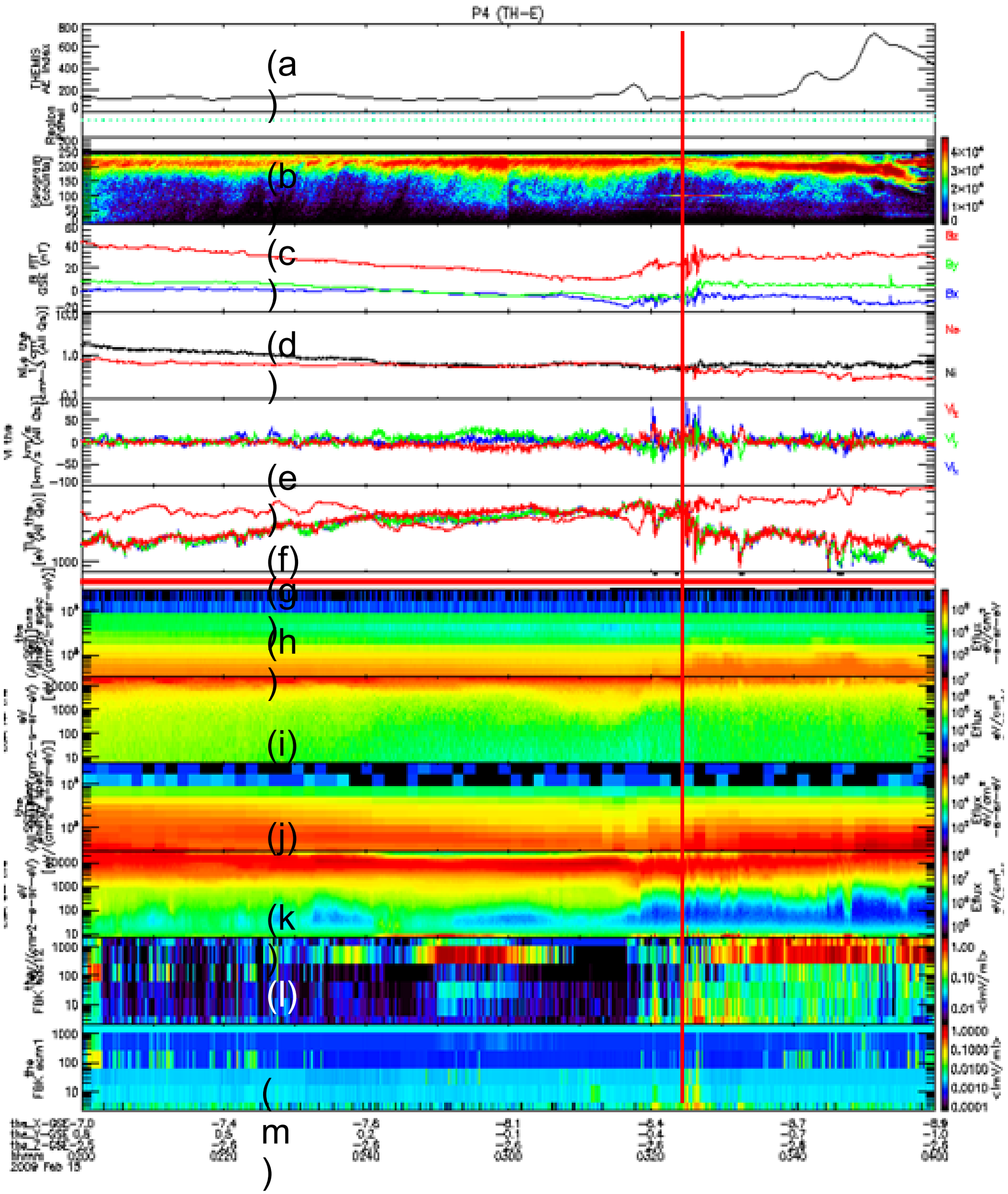


Figure: Plasma density [cm^{-3}] computed by OpenGGCM without CRCM at two different times in the MHD YX-plane. OpenGGCM alone underestimates the plasma density close to Earth.

15.02.2009 Substorm Event

THEMIS-E Data



OpenGGCM Solar Wind Input 15 February 2009

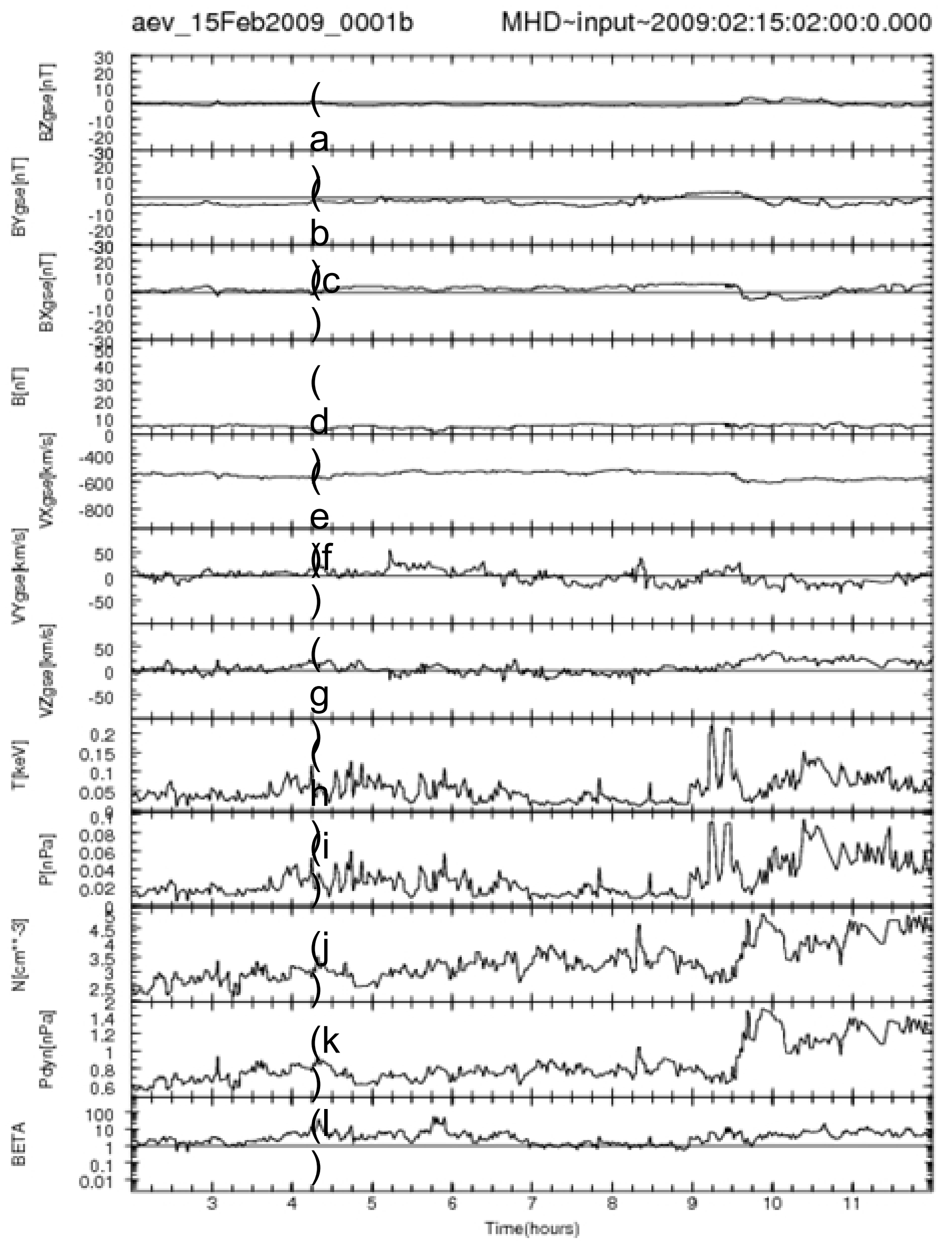
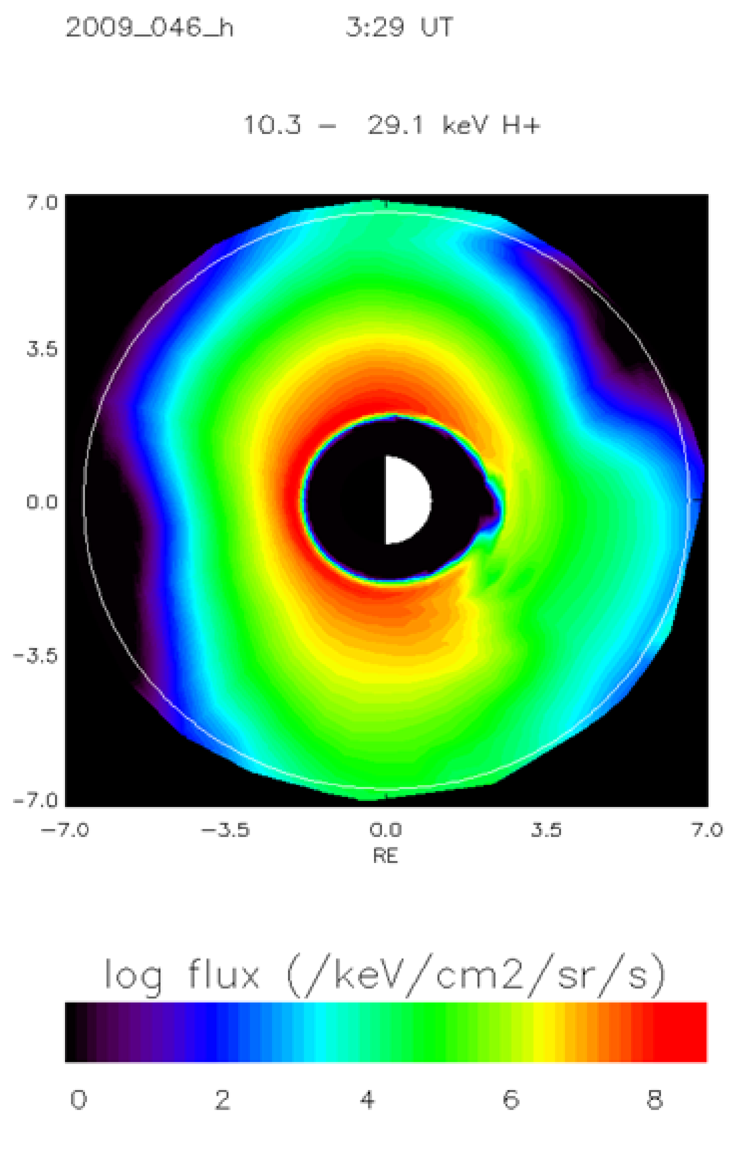


Figure: OpenGGCM input from the solar wind: (a), (b), and (c) are Bz, By, and Bx magnetic field components in GSE coordinates; (d) Total magnetic field; (e), (f), and (g) are Vx, Vy, and Vz in GSE; (h) SW Temperature; (I) SW pressure; (j) SW particle density; (k) SW dynamic pressure; (l) Beta.

CRCM Proton Flux 10-30 keV 15 February 2009

With CRCM feedback into OpenGGCM



No CRCM feedback into OpenGGCM

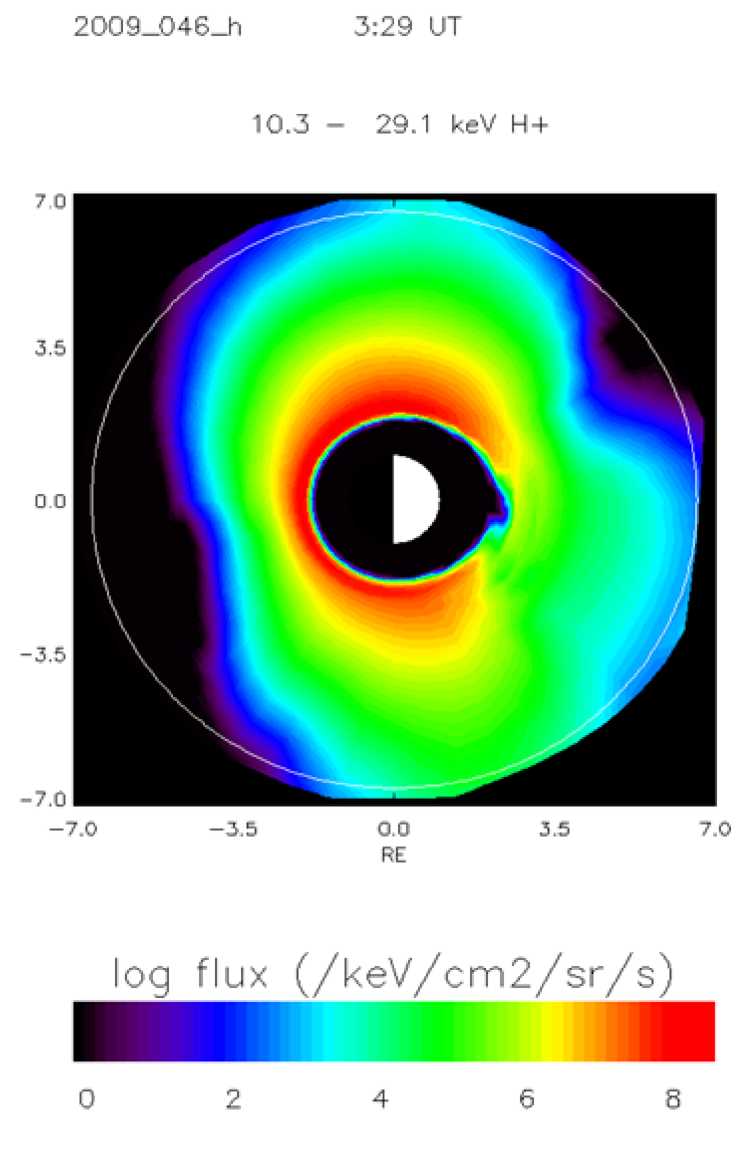


Figure: Proton flux (10-30 keV) computed by CRCM (left) with pressure feedback into OpenGGCM, and (right) without feedback (one way coupling) at 11:00 UT. When pressure feedback is implemented, the overall ring current particle population is slightly higher than the one in the case of no feedback.

Plasma Pressure: OpenGGCM-CRCM: 15.02.2009

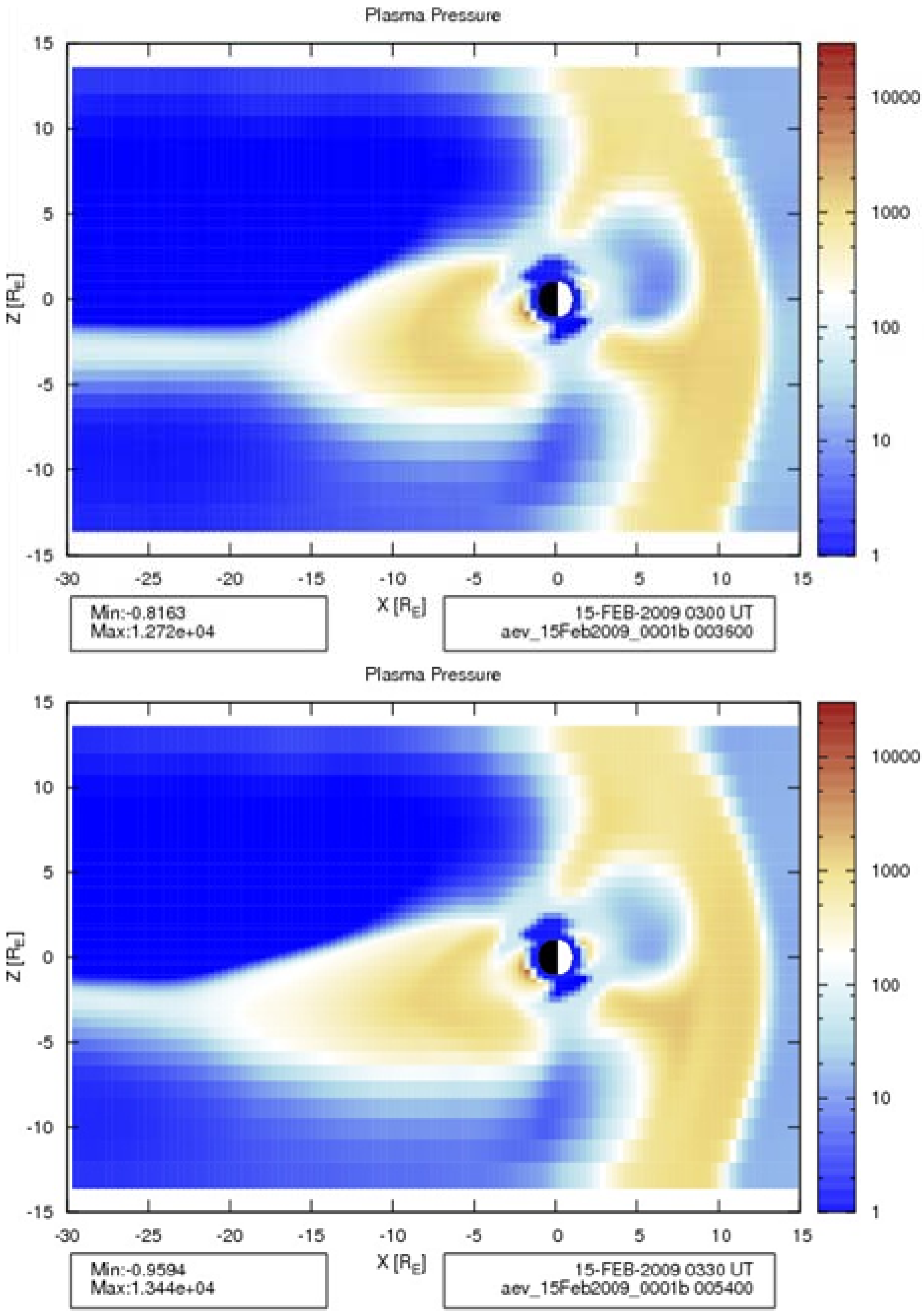


Figure: Plasma pressure [pPa] computed by coupled OpenGGCM-CRCM at two different times in the MHD XZ-plane. The ring current pressure is clearly visible at the night side.

Plasma Pressure: OpenGGCM: 15.02.2009

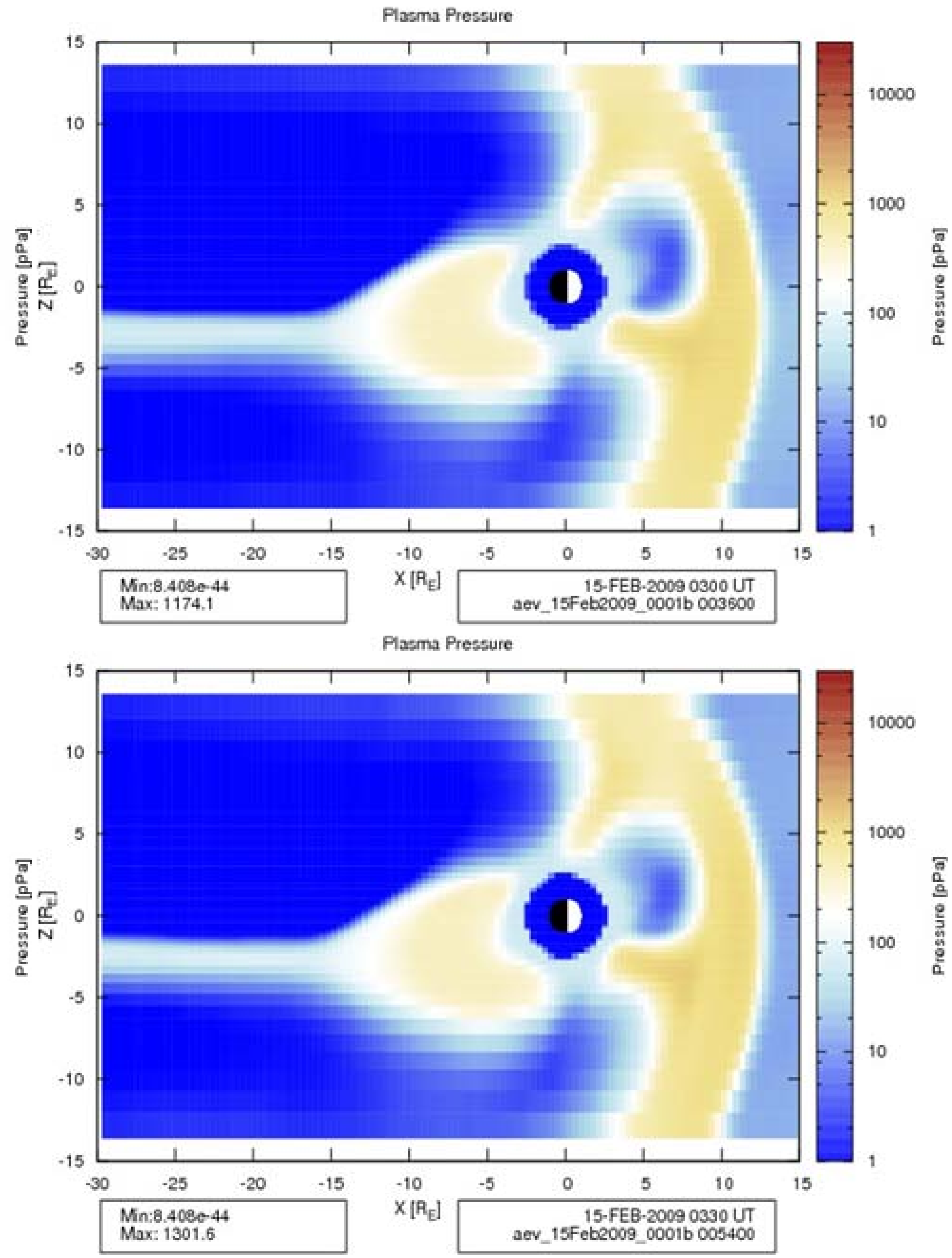


Figure: Plasma pressure [pPa] computed by OpenGGCM without CRCM at two different times in the MHD XZ-plane. The pressure at the night side is low due to the lack of ring current model.

Plasma Temperature: OpenGGCM-CRCM: 15.02.2009

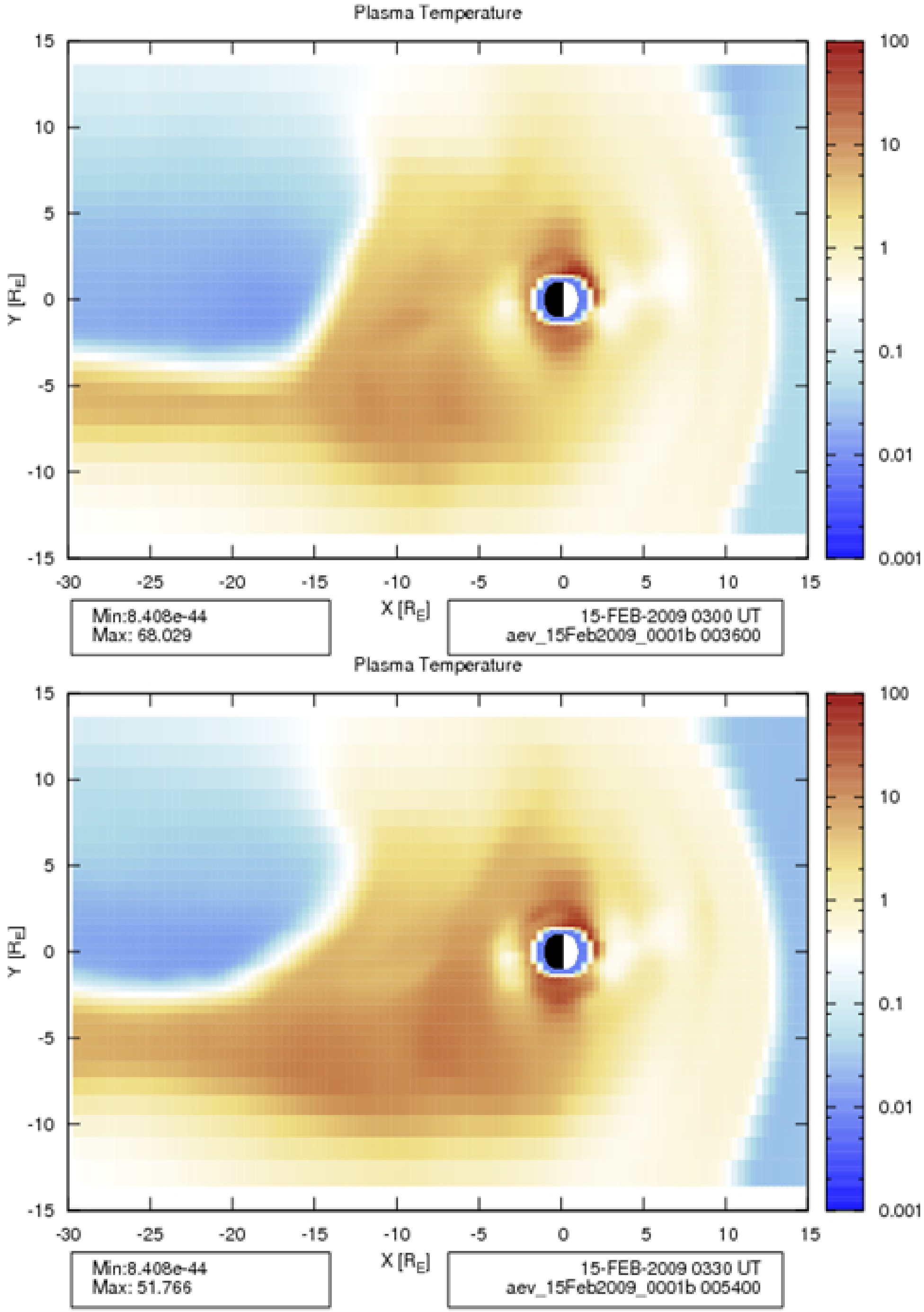


Figure: Plasma temperature [keV] computed by coupled OpenGGCM-CRCM at two different times in the MHD XY-plane. The "cut" at midnight in the ring current is due to the dipole tilt relative to the MHD XY-plane.

Plasma Temperature: OpenGGCM: 15.02.2009

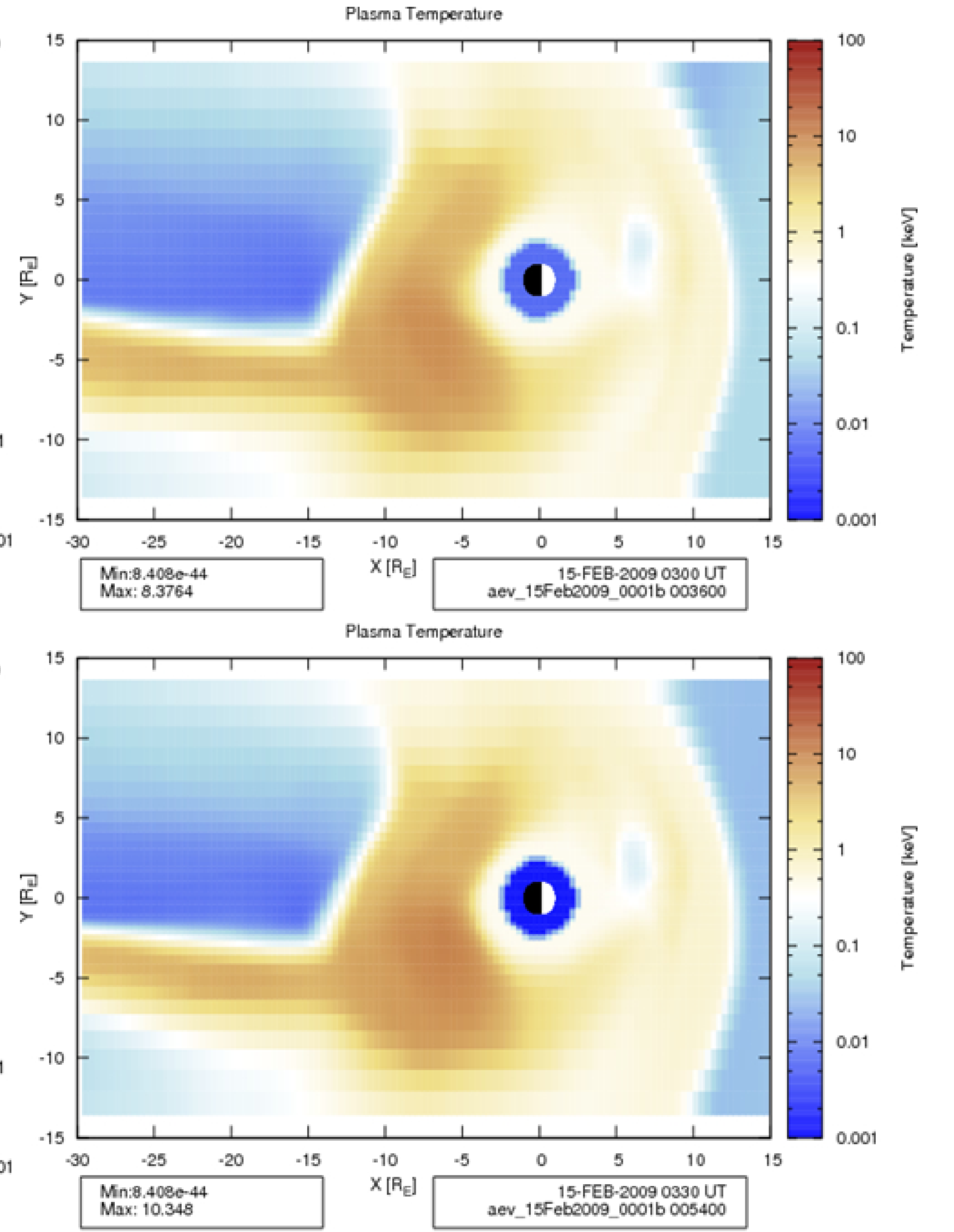


Figure: Plasma temperature [keV] computed by OpenGGCM without CRCM at two different times in the MHD XY-plane. OpenGGCM alone underestimates the plasma density close to Earth.