Energy Flows into the Magnetosphere and Ionosphere in Global MHD Simulations of the Early Phase of the Bastille Day Storm (July 15, 2000)

L. Rastaetter, M. Hesse
CCMC, NASA/GSFC

T. Gombosi
University of Michigan

J. Raeder
University of New Hampshire

Abstract

Due to their different design, global magnetospheric models may at times generate different results for the same solar wind input conditions. In this situation, the average of a quantity obtained from concurrent simulations provides an estimate of the level of geomagnetic activity and the differences between the model results may serve as an estimated error level. We study the shape and location of magnetosphere-solar wind boundaries (bow shock, magnetopause) in simulations with the BATSRUS and UCLA-GGCM models using prescribed and varying solar wind conditions.

Using the flow envelope we determine fluxes of energies into the magnetosphere at different times throughout the simulation and compare results to solar wind parameters.

Introduction

The magnetopause is an important boundary layer between the magnetospheric plasma and the solar-wind particles in the magnetosheath.

In numerical simulations the magnetopause location can be used to verify model results against satellite measurements.

In this paper:

- Magnetopause – **flow envelope** proxy
- July 15, 2000 simulations with **BATSRUS and UCLA-GGCM**

Magnetopheric boundary

Solar Wind Flow envelope

- defined by tracing solar wind flow near subsolar point
- surrounds tail lobes, plasma sheet and inner magnetosphere
- regular shape (no wings or disconnected parts)
- exact position not well defined (depend on velocity threshold) **We can verify relevence of boundary** by comparing it with density and pressure gradients around the magnetosphere.

Gradients alone are not sufficient:

- Density or pressure gradients are also seen ***inside*** of the magnetosphere (between lobes and plasma sheet in addition to the magnetosheath).
- Magnetosheath pressure and density distribution ***is too wide*** to define a precise “magnetopause” boundary.

Magnetosphere slices

Velocity envelope intersecting slice:

- **White dots**: Velocity stream lines
- Stream lines started within 4 R_E of subsolar point at X_S=+20

Magnetic field lines intersecting slices

- **Black asterisks**: closed magnetic field lines

Statistical magnetopause model:

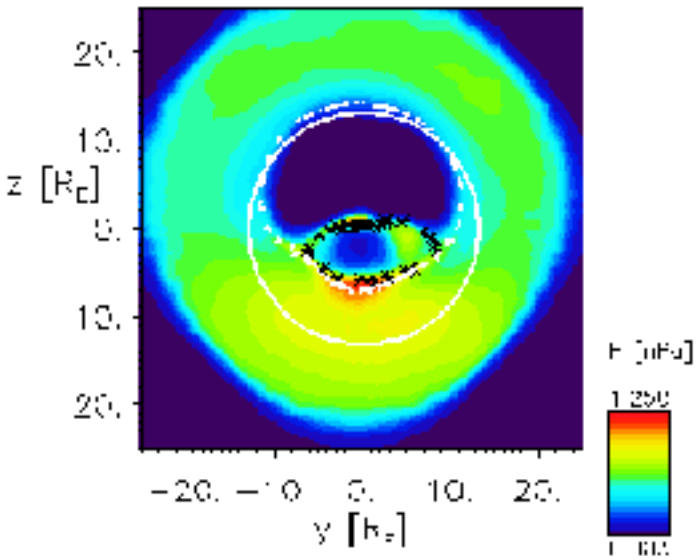
- **Solid white circle**: Shue et al (1997) model using solar wind conditions in slice.

Position of circle center and subsolar point is determined by solar wind velocity in slice at X (or X_S):

$Y_C=X*V_Y/V_X$, $Z_c=X*V_Z/V_X$

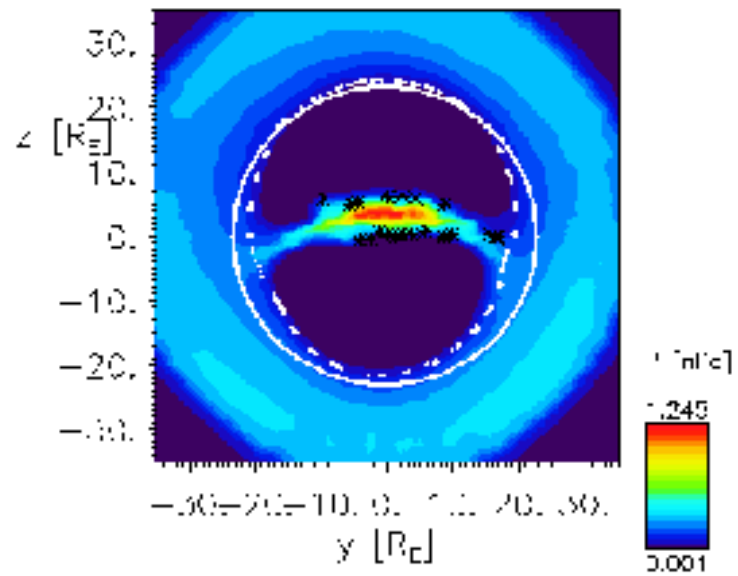
Southward IMF B_z 7/15/2000 13:00 UT

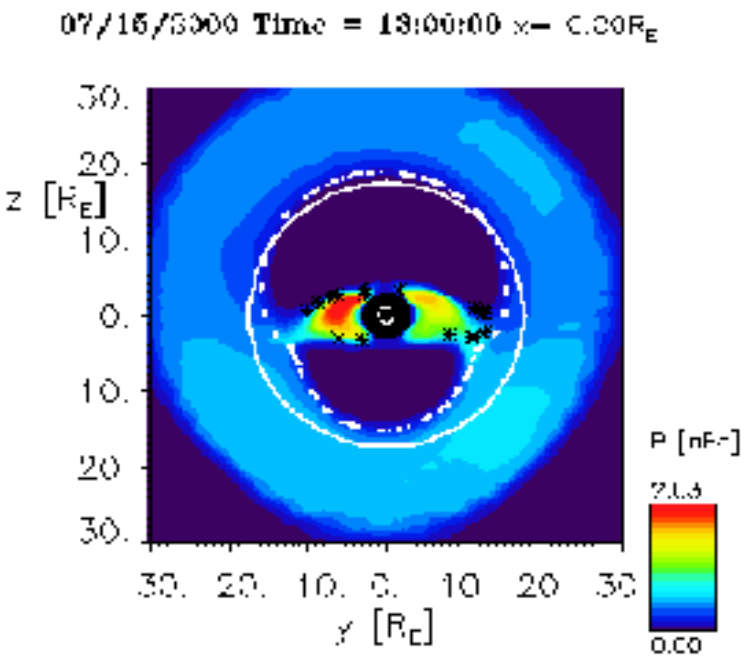
Slices through magnetosphere (UCLA-GGCM)



<u>dayside</u> <u>nightside</u>

X=5 X=-10





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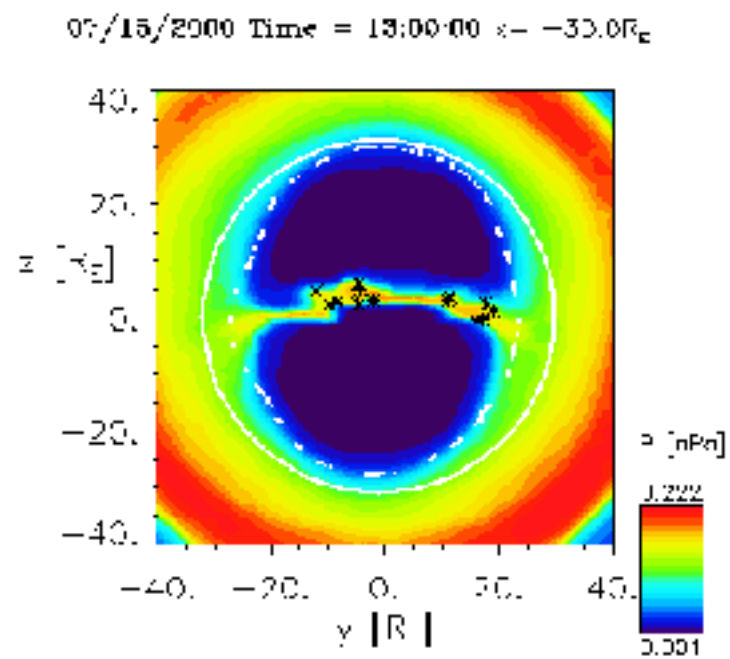
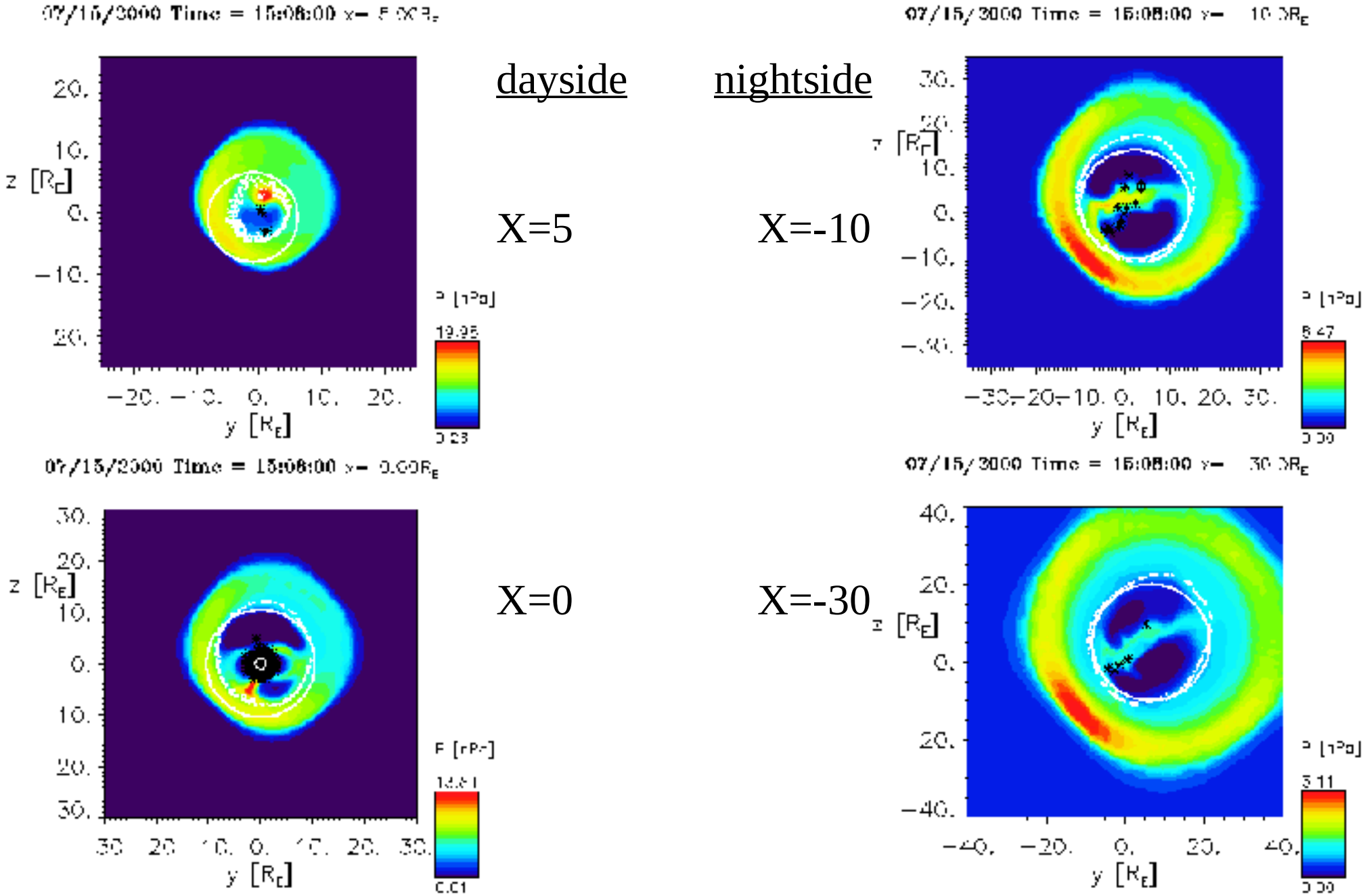


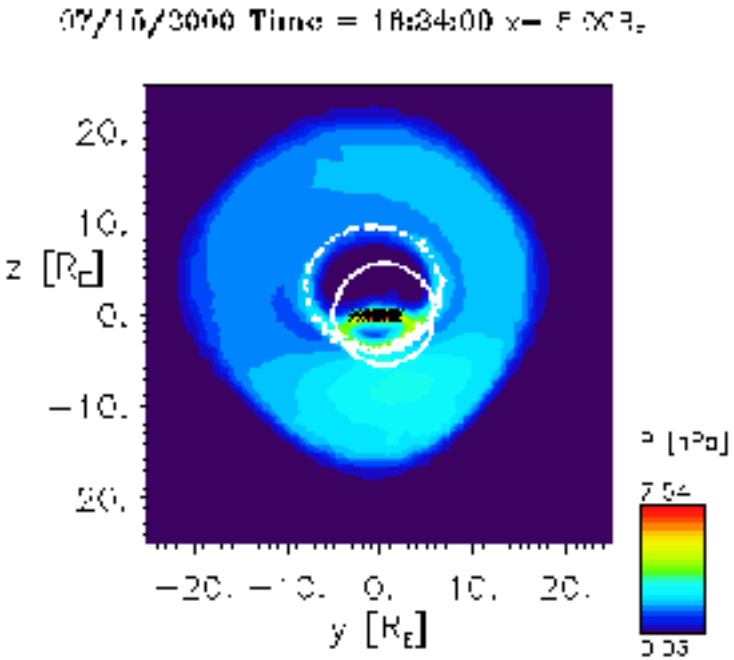
Strong northward IMF B_z

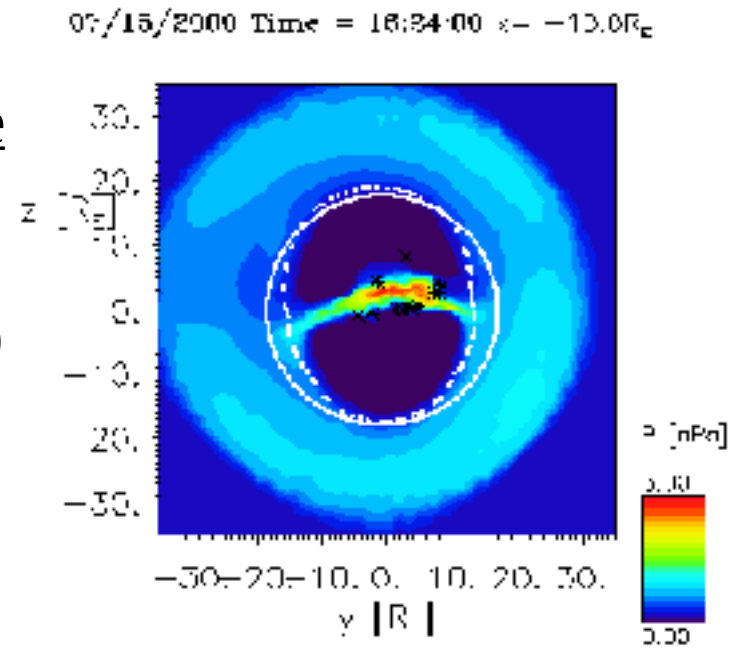
7/15/2000 15:08 UT (UCLA-GGCM)



Strong southward IMF B_z

7/15/2000 16:24 UT (UCLA-GGCM)



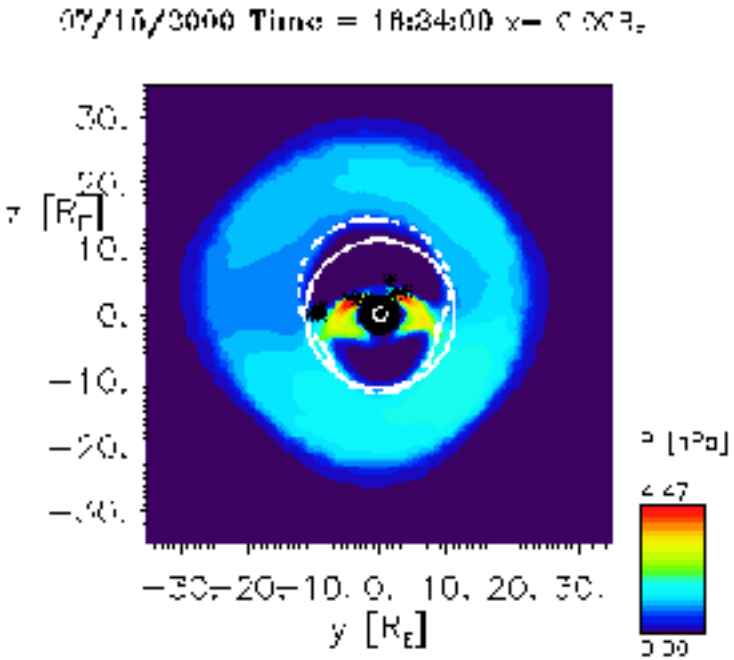


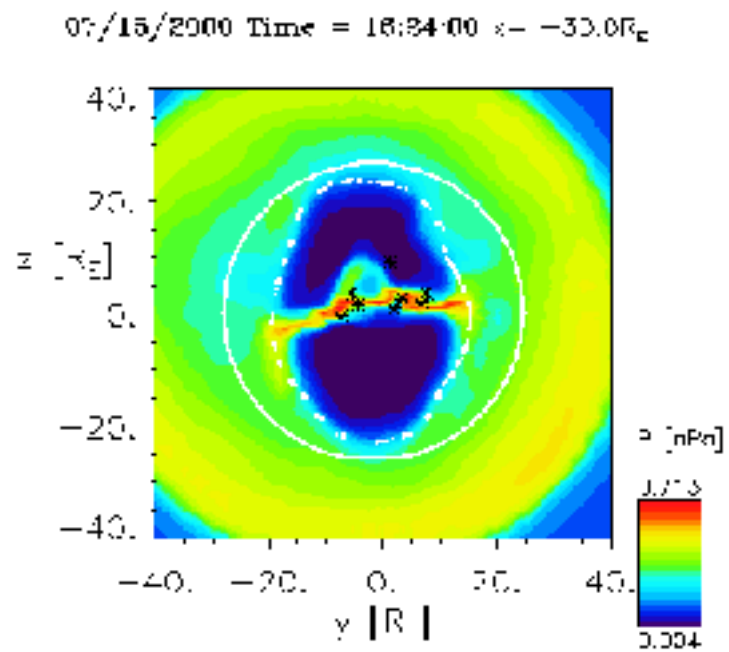
dayside

nightside

X=5

X=-10





X=0

X=-30

Solar Wind Conditions July 15, 2000

<u>13:00 – 14:40 UT:</u>

$N = 5\text{-}7\ cm^{-3}$ $V_x = -600$ km/s

$B_z = -5$ nT $B_y = 0$ nT

<u>14:40 – 15:08 UT:</u>

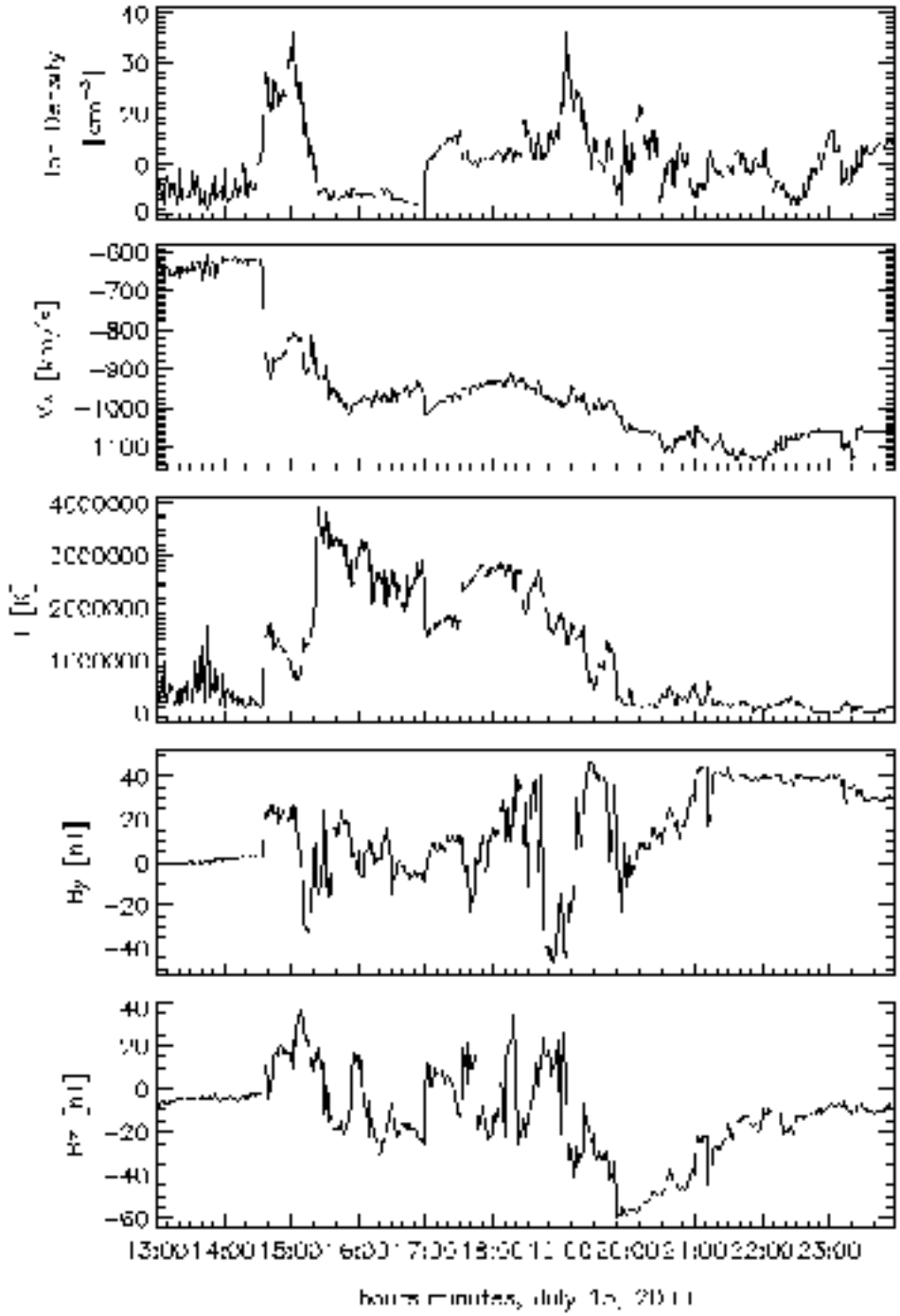
$N = 25\ cm^{-3}$ $V_x = -900$ km/s

$B_z = +20$ to 30 nT $B_y = +20$ nT

<u>16:00 – 16:24 UT:</u>

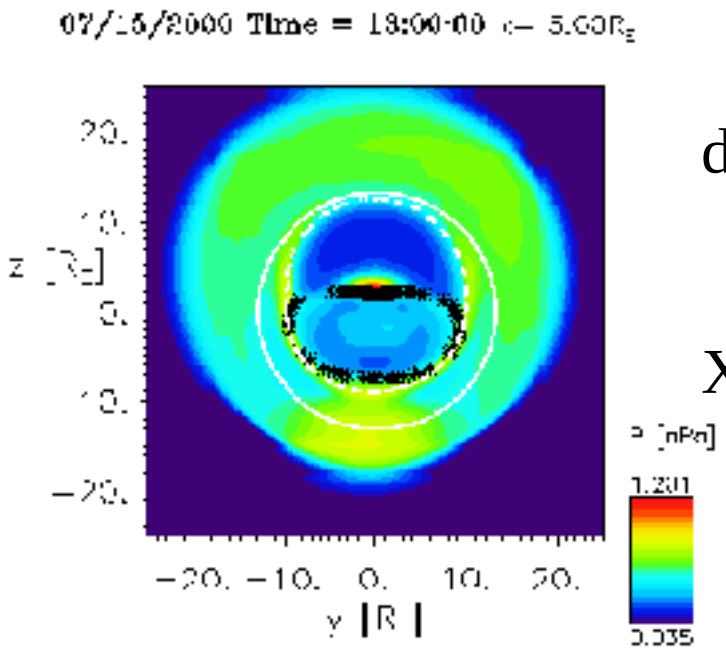
$N = 5\ cm^{-3}$ $V_x = -1000$ km/s

$B_z = -15$ to -20 nT $|B_y| < 10$ nT



Weak southward IMF B_z

13:00 UT - BATSRUS

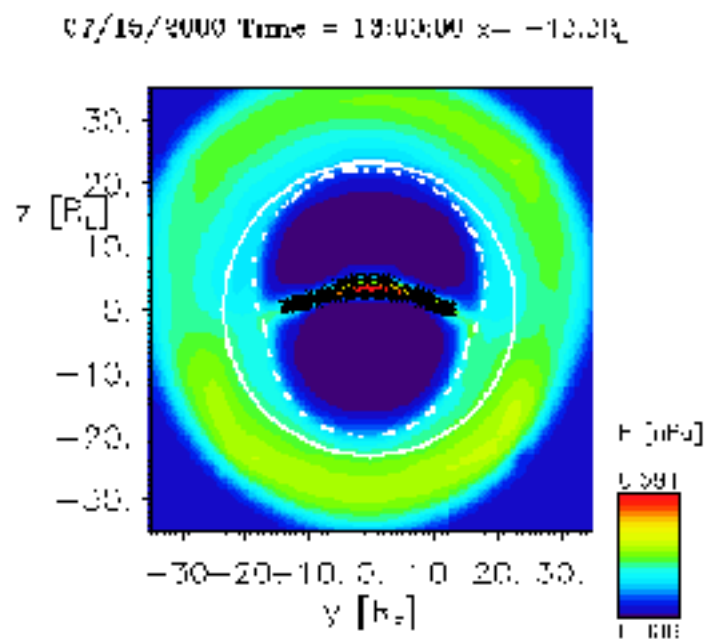


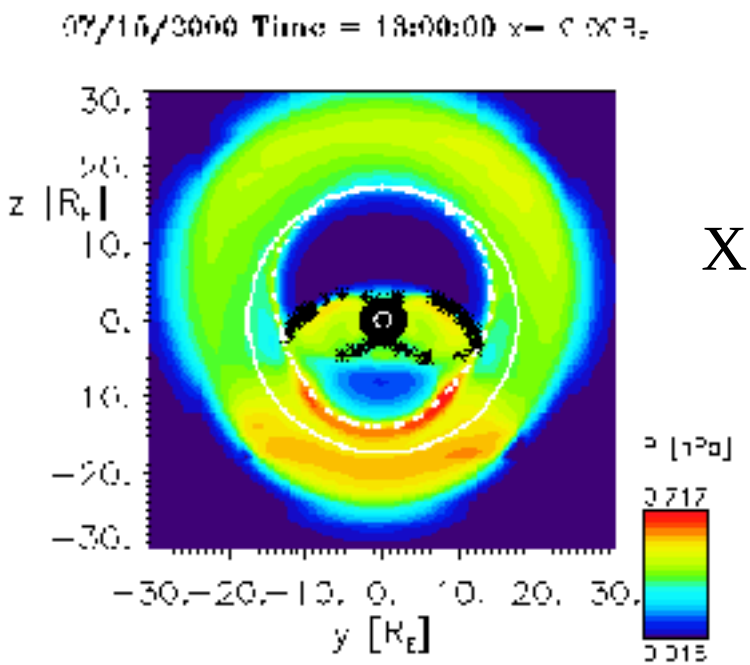
dayside

X=+5

nightside

X=-10

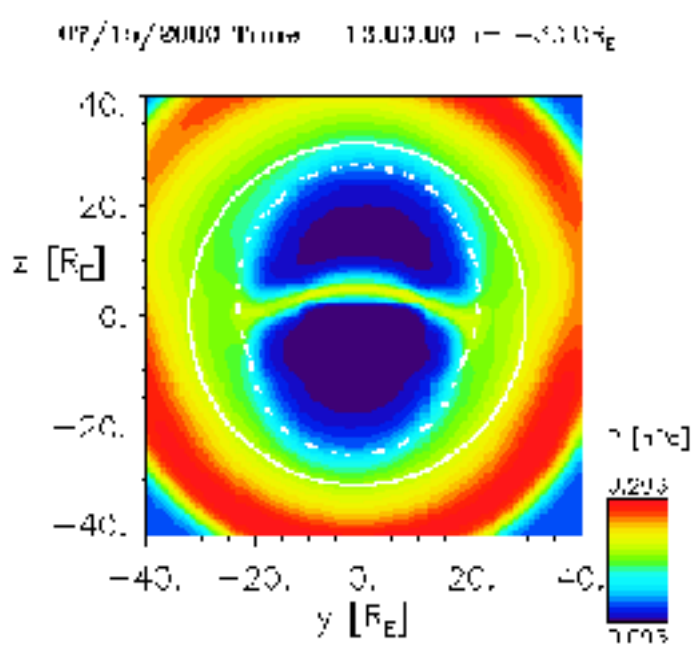




X=0

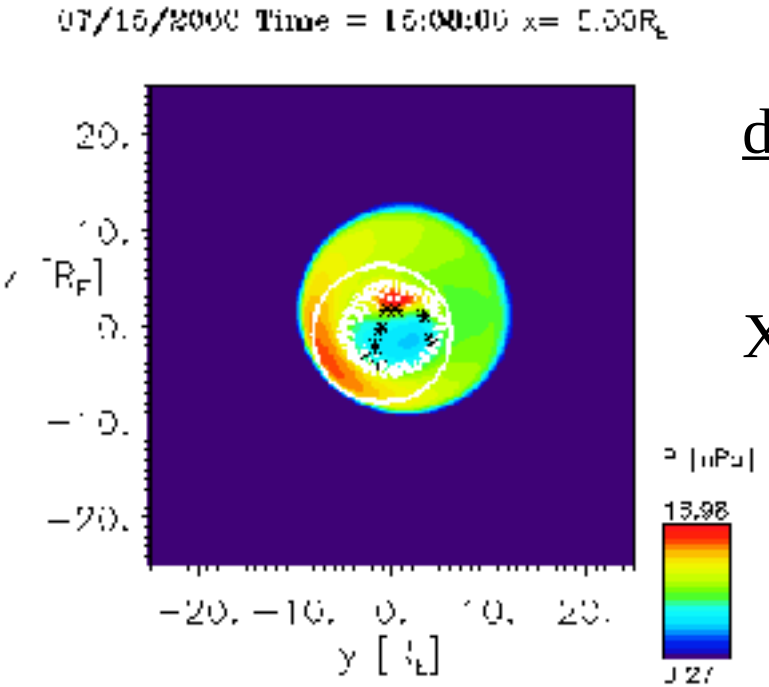
X=-30

Closed field lines end between X=-20 and X=-30



Strong northward IMF Bz

7/15/2000 15:08 UT (BATSRUS)

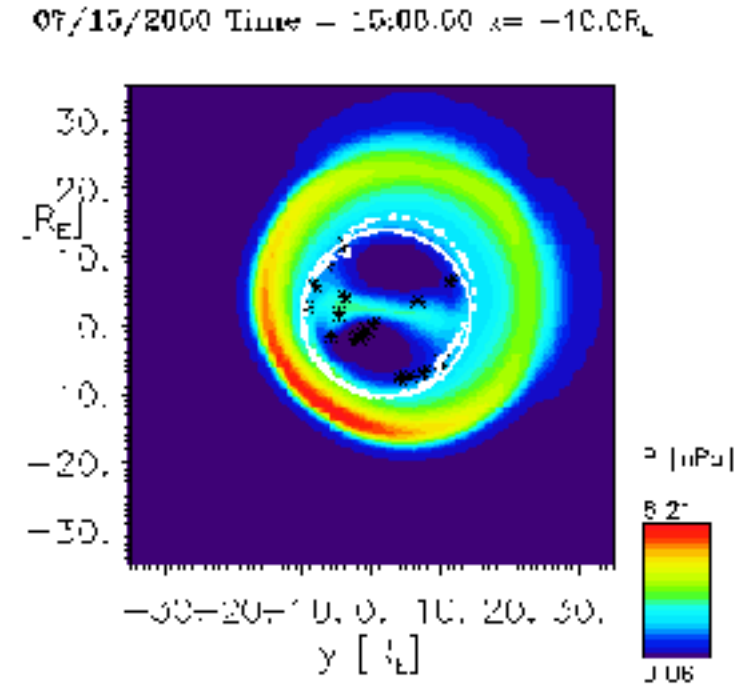


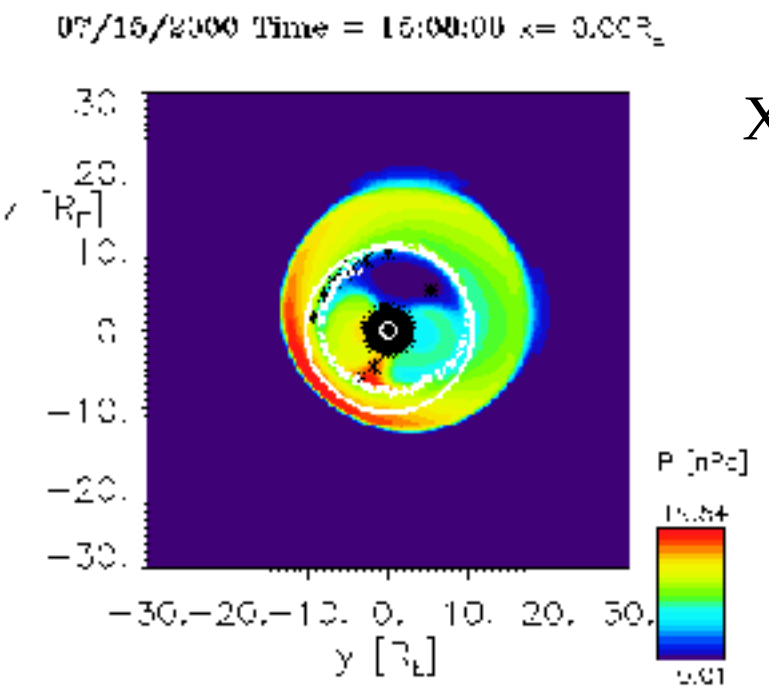
dayside

X=+5

nightside

X=-10

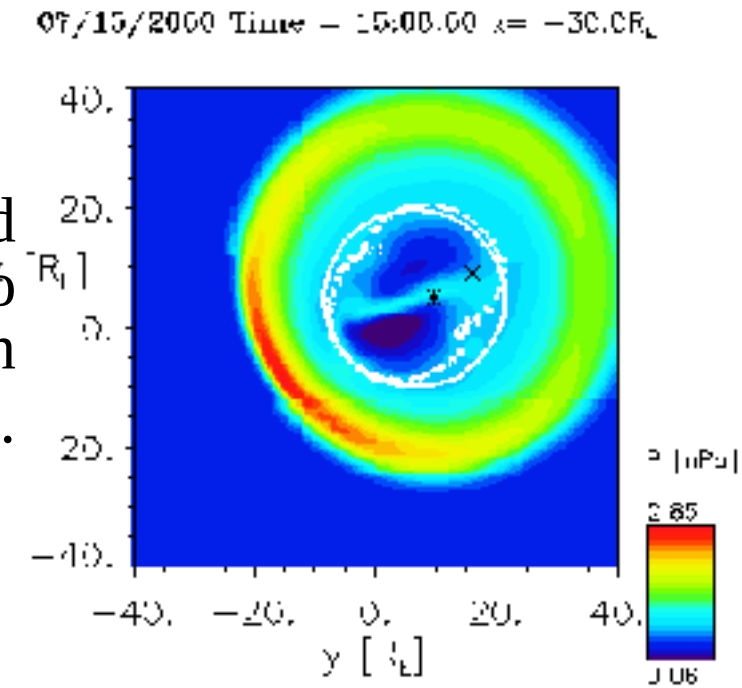




X=0

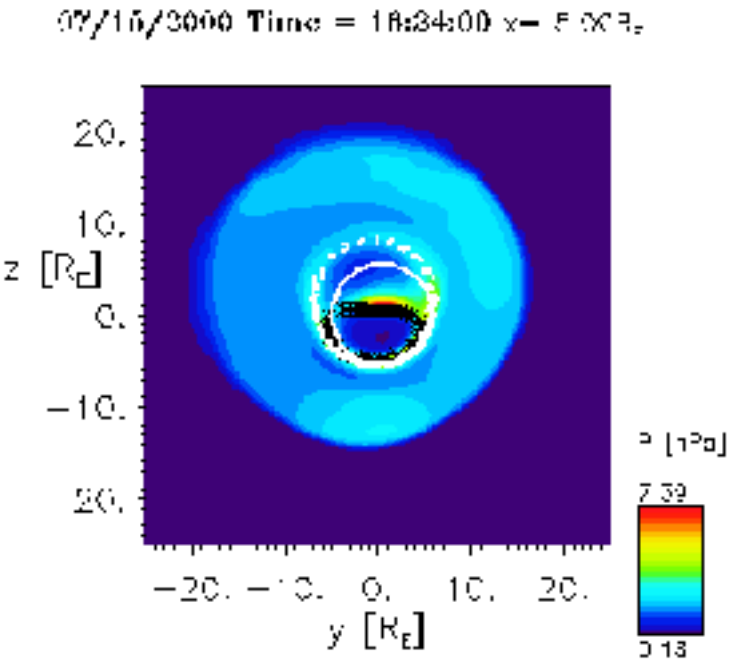
X=-30

Tail axis is displaced from X-axis due to strong V_Y and V_Z in the solar wind.



Southward Bz

16:24 UT (BATSRUS)

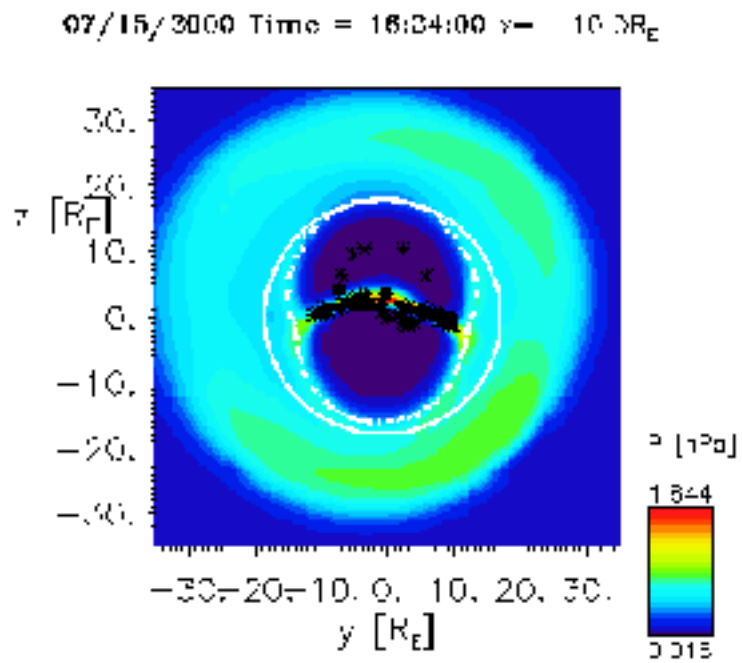


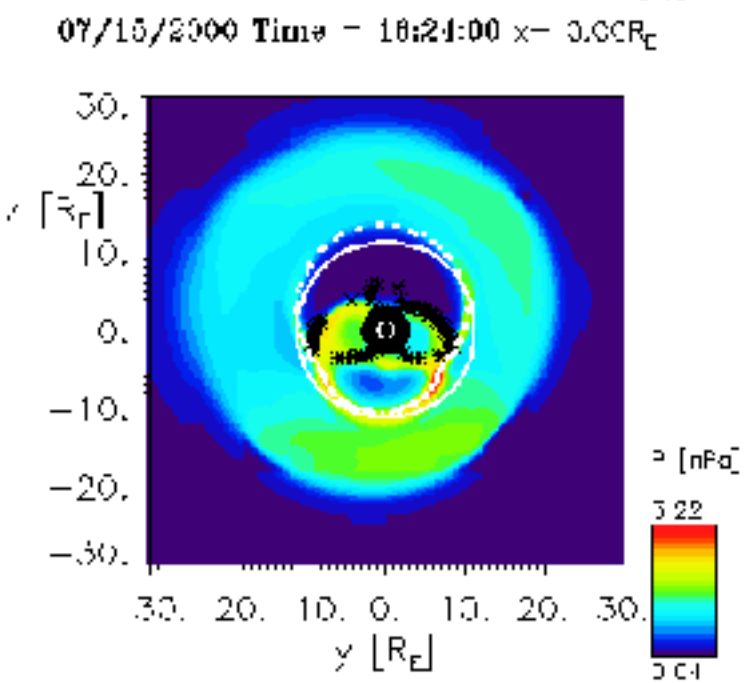
dayside

X=+5

nightside

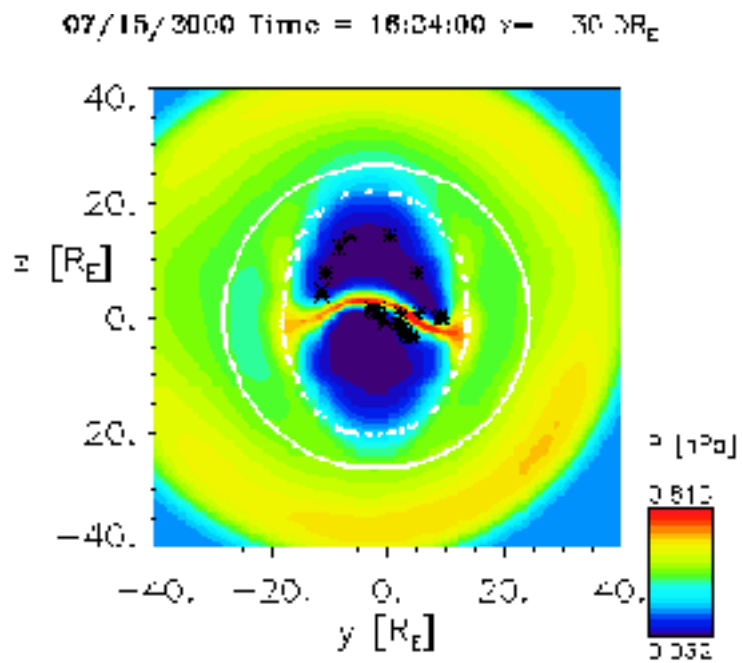
X=-10





X=0

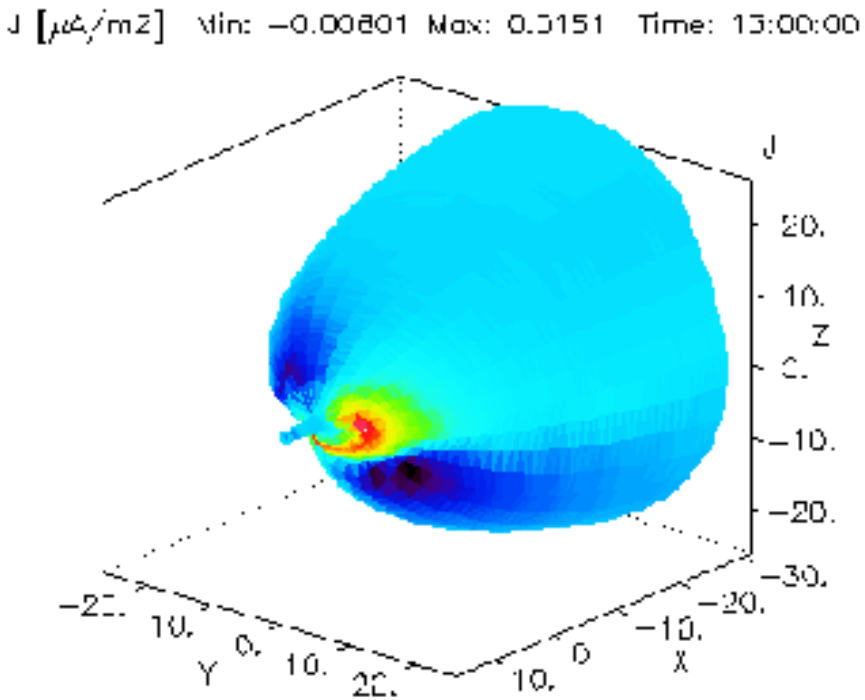
X=-30

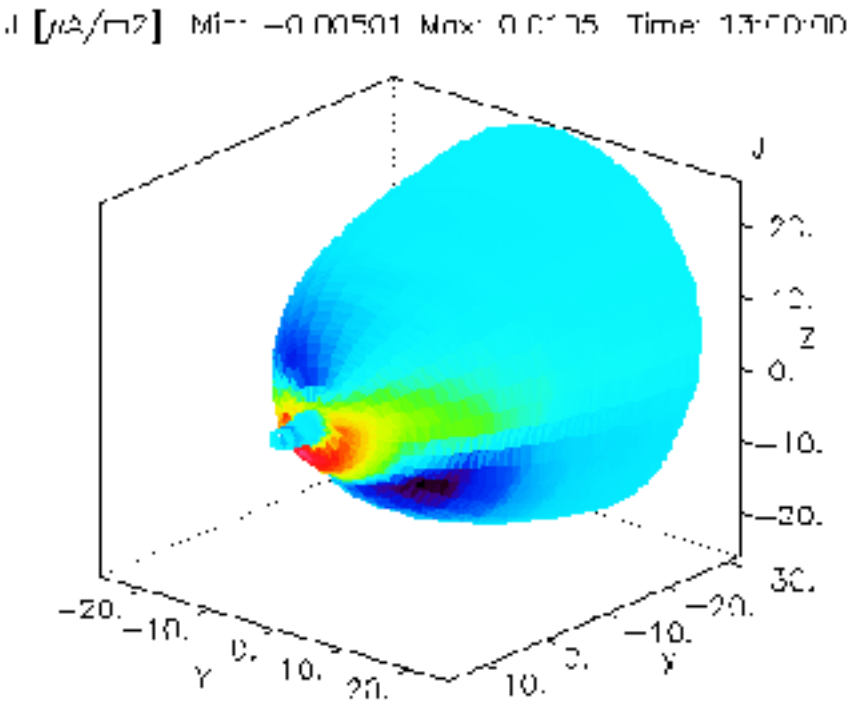


Currents on flow surface at 13:00 UT

UCLA-GGCM 13:00 UT **BATSRUS**

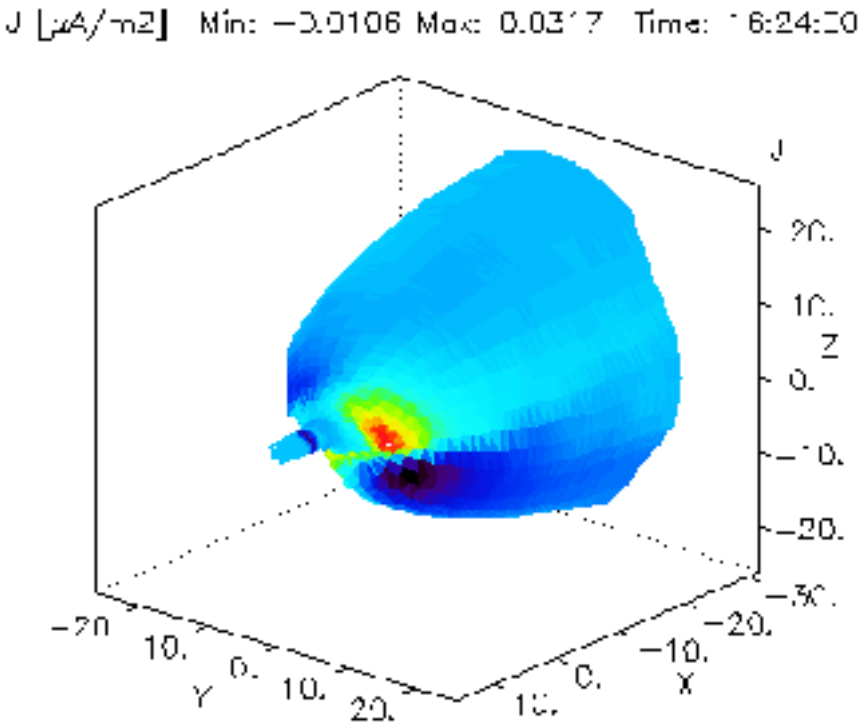
-0.006 < J < 0.015 **range** -0.005 < J < 0.011

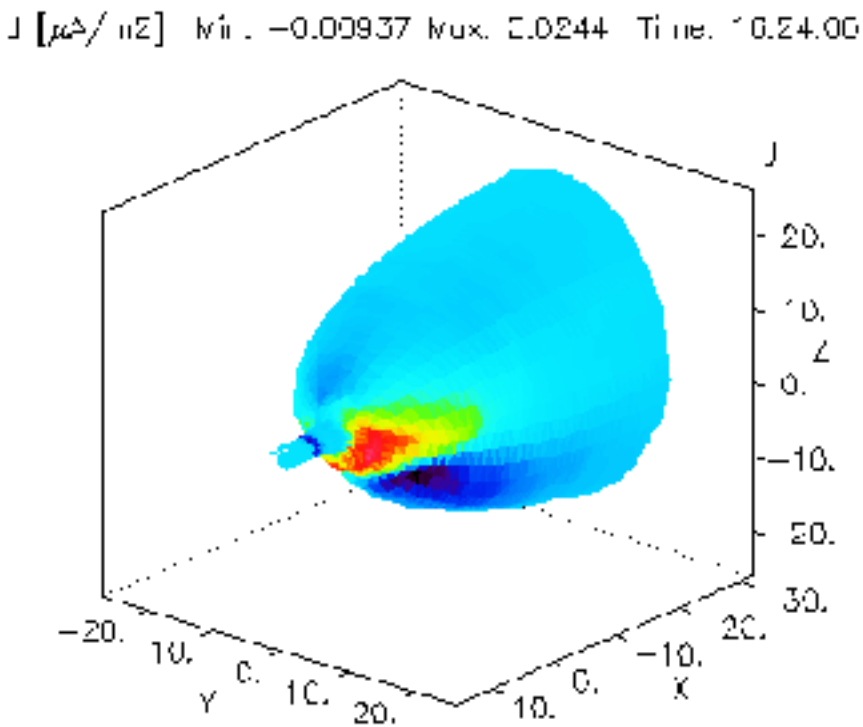




Currents on flow surface at 16:24 UT

UCLA-GGCM	16:24 UT	**BATSRUS**
-0.01 < J < 0.03	**range**	-0.009 < J < 0.024

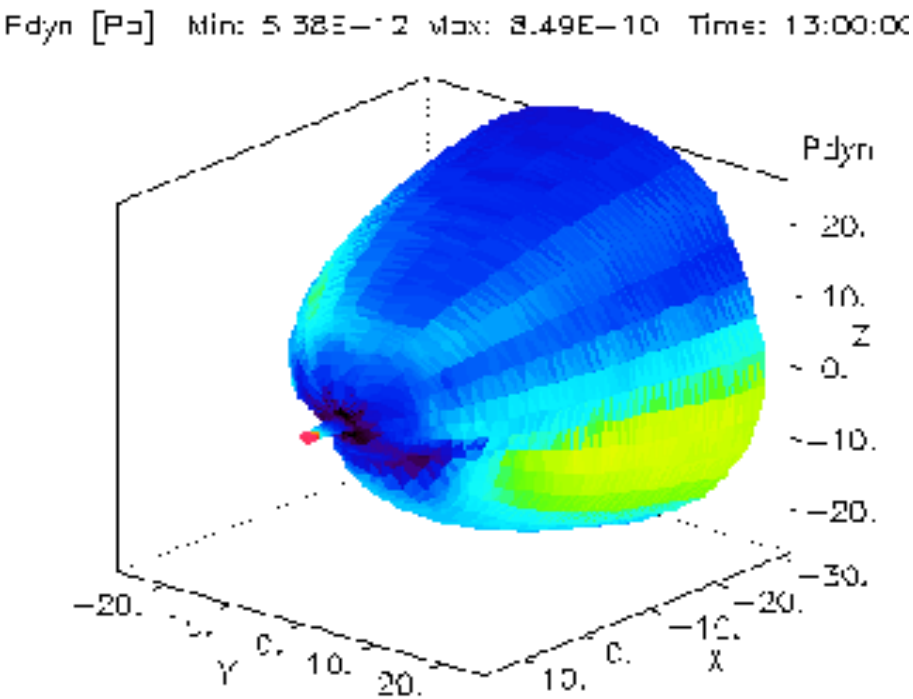


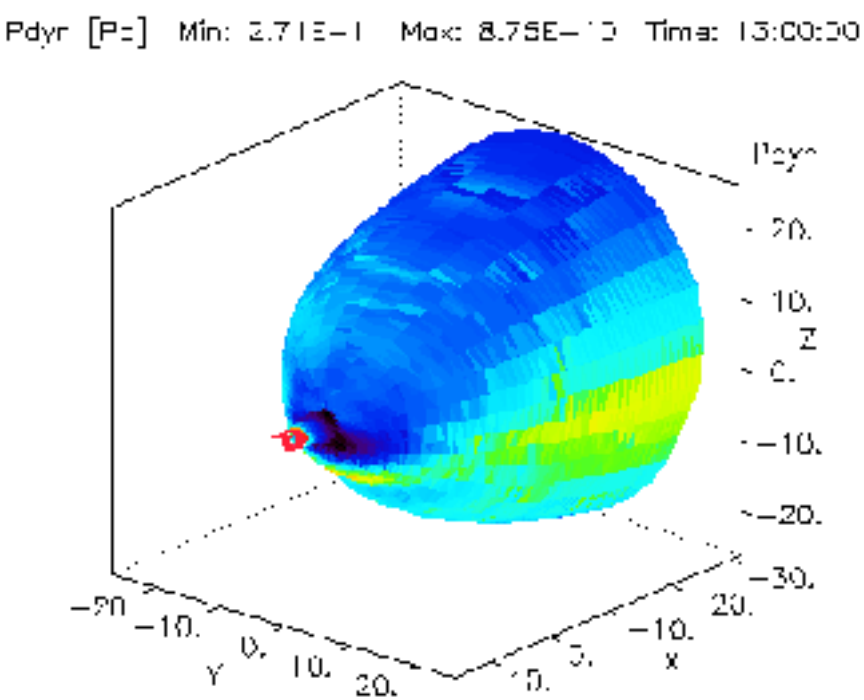


P_{dyn} on flow surface at 13:00 UT

UCLA-GGCM 13:00 UT **BATSRUS**

$0.005 < P_{dyn} < 0.849$ **range [nPa]** $0.003 < P_{dyn} < 0.875$

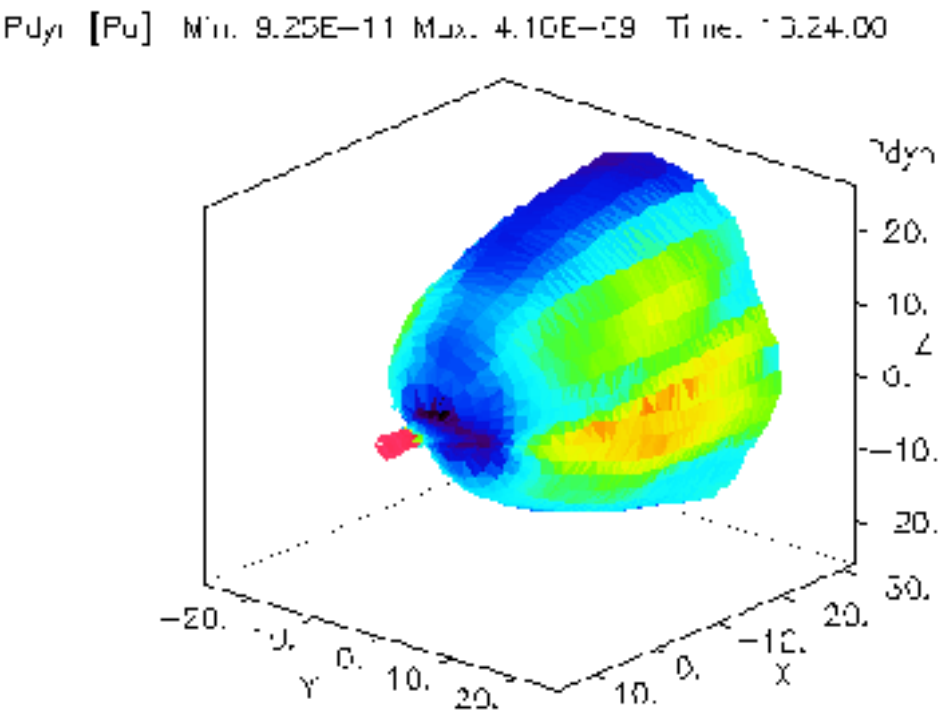


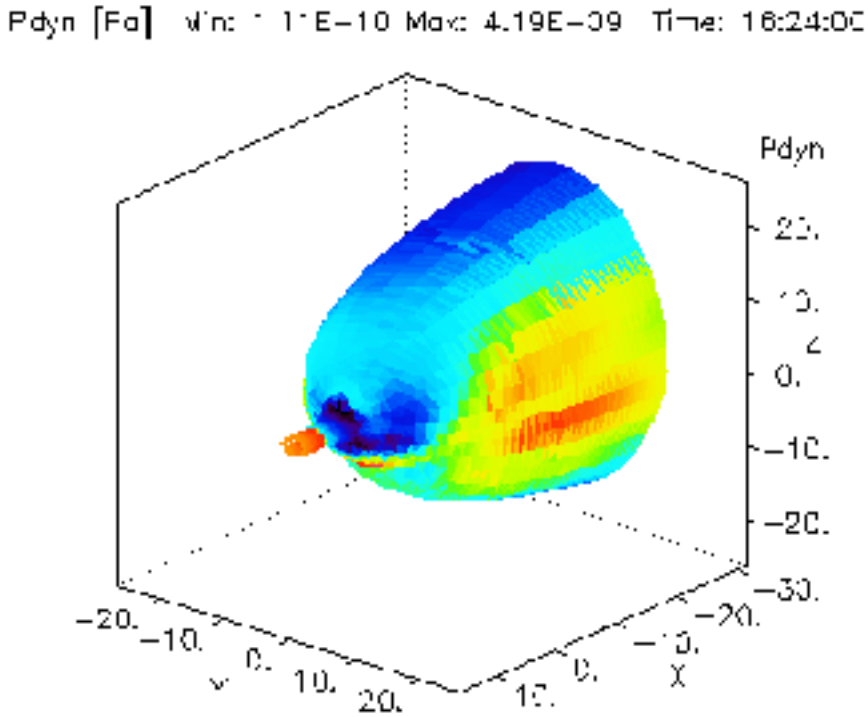


P_{dyn} on flow surface at 16:24 UT

UCLA-GGCM 16:24 UT **BATSRUS**

$0.09 < P_{dyn} < 4.1$ **range [nPa]** $0.11 < P_{dyn} < 4.19$

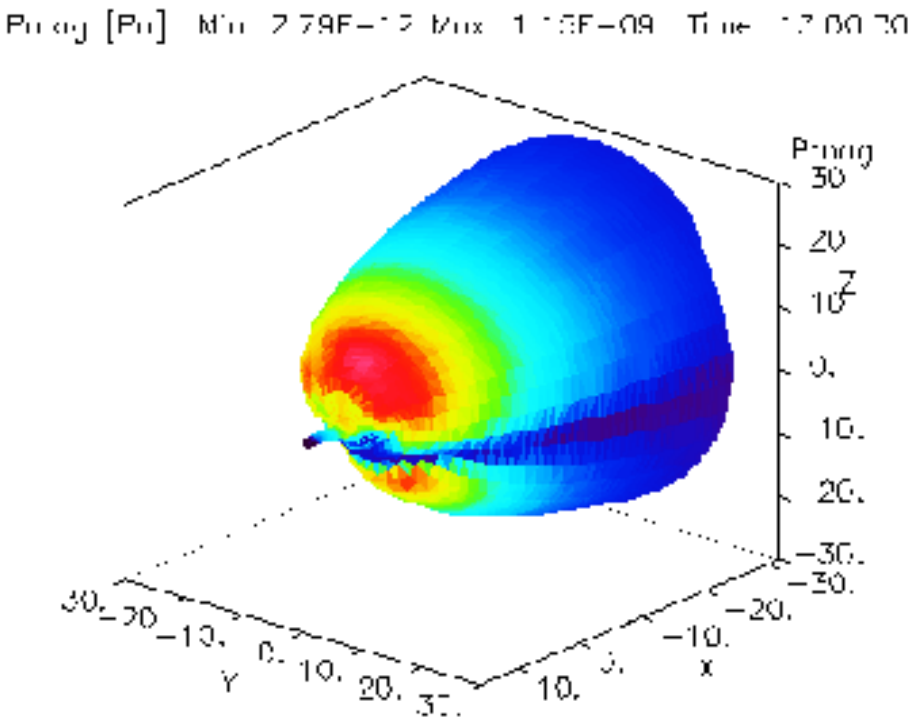


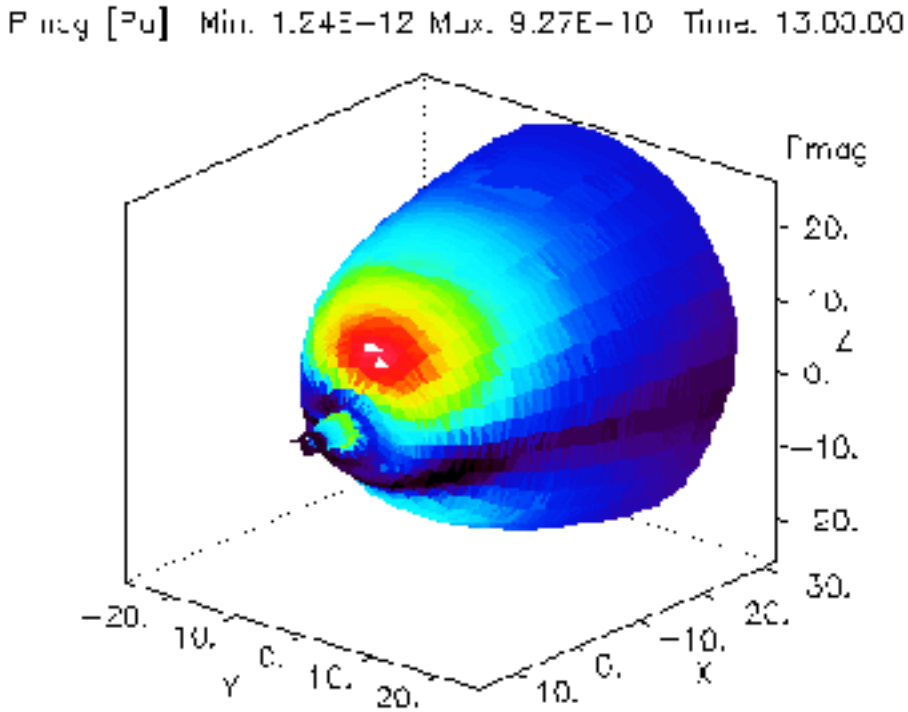


P_{mag} on surface at 13:00 UT

UCLA-GGCM 16:24 UT **BATSRUS**

$0.003 < P_{mag} < 1.15$ **range [nPa]** $0.001 < P_{mag} < 0.93$

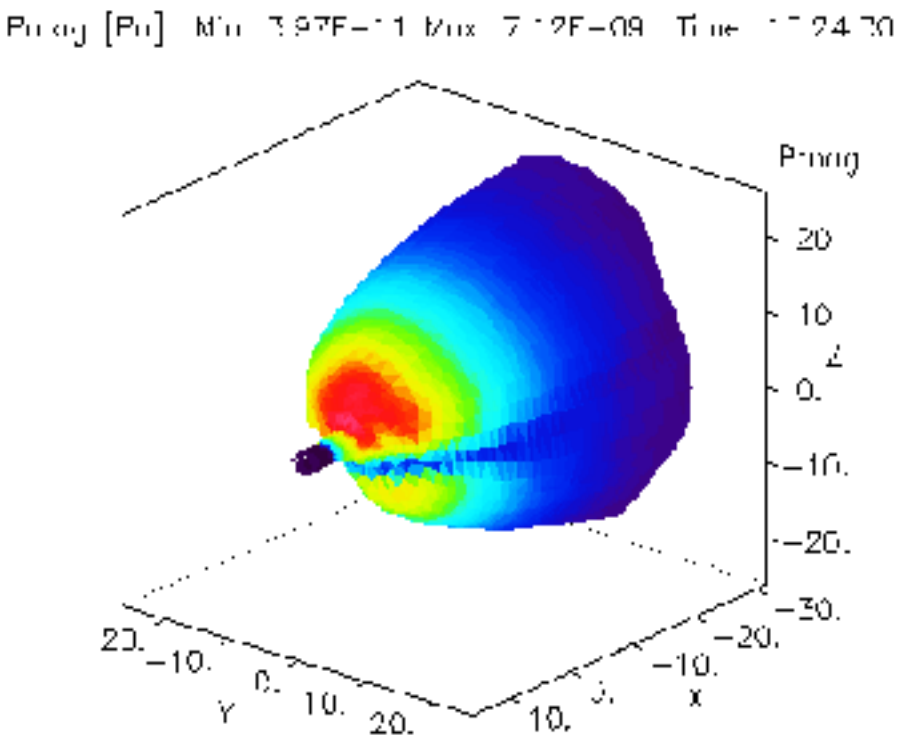


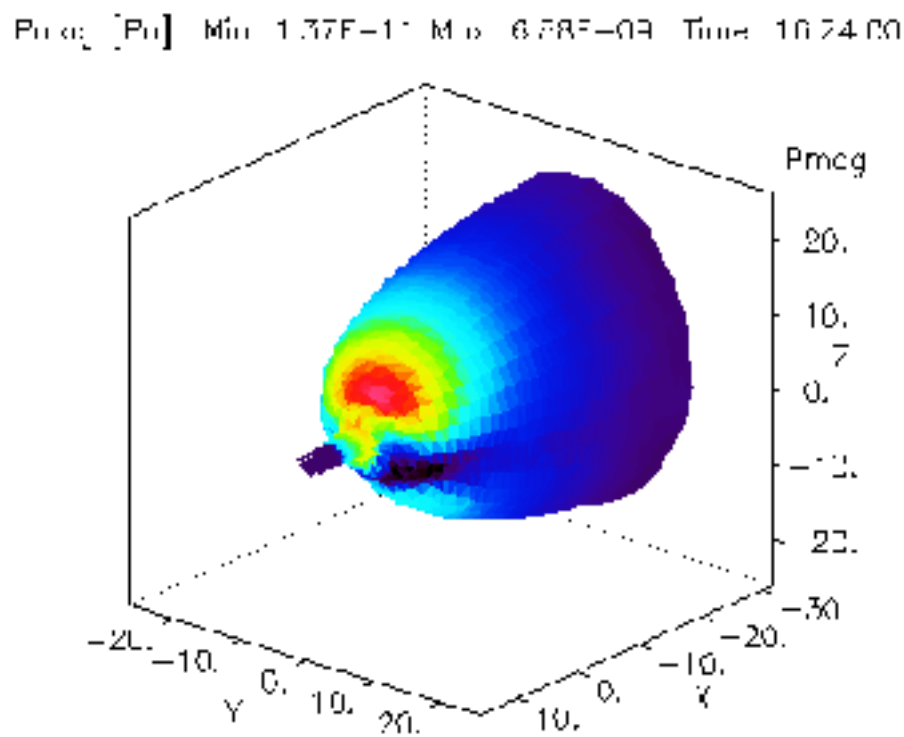


P_{mag} on surface 16:24 UT

UCLA-GGCM 16:24 UT **BATSRUS**

$0.040 < P_{mag} < 7.12$ **range [nPa]** $0.014 < P_{mag} < 6.88$

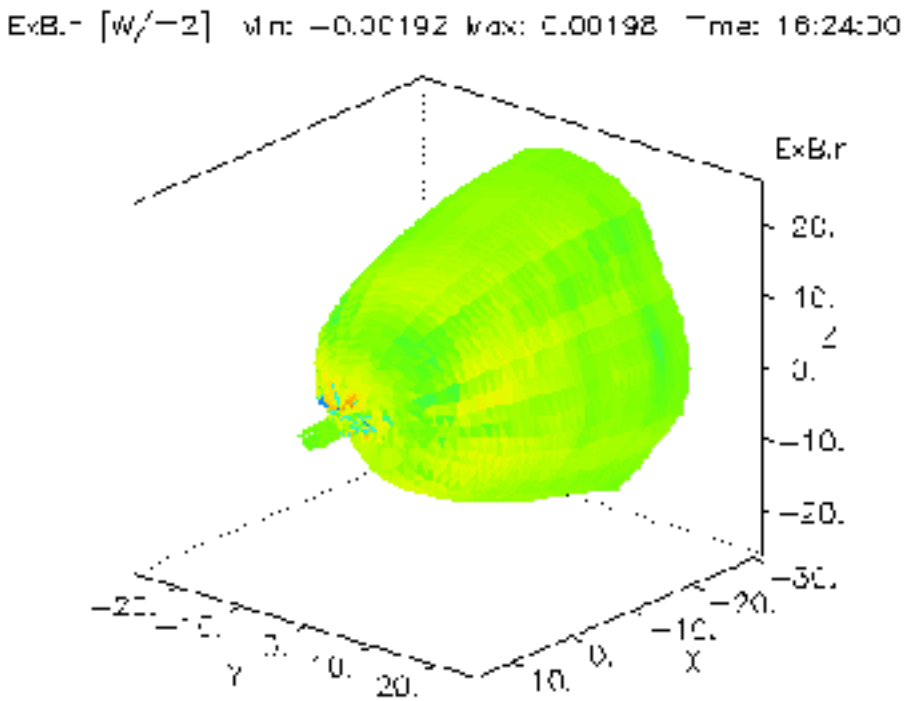


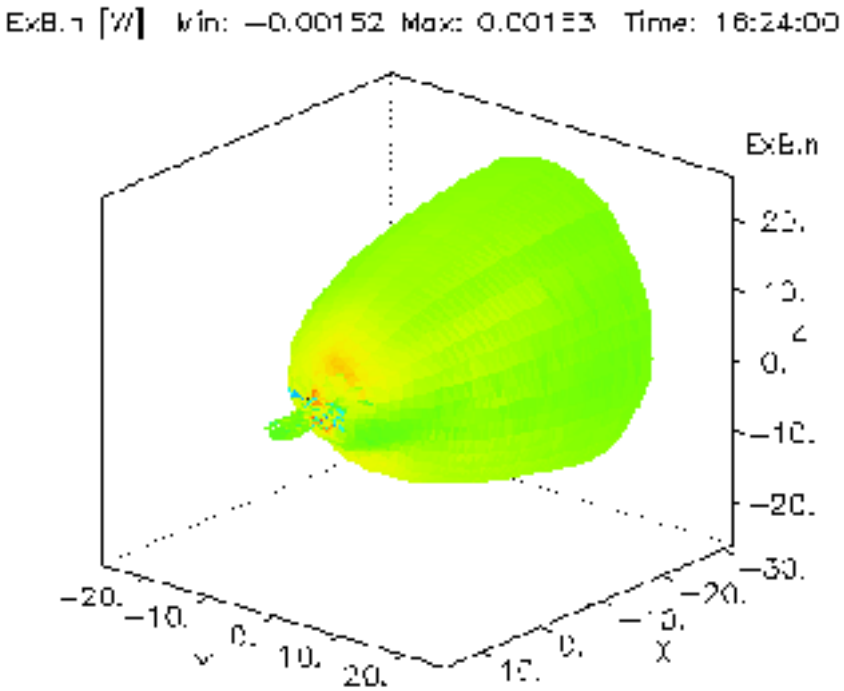


$S = ExB/\mu_0$ on surface 16:24 UT

UCLA-GGCM 16:24 UT **BATSRUS**

-1.92 < S < 1.98 **range [mW/m2]** **-**1.52 < S < 1.63

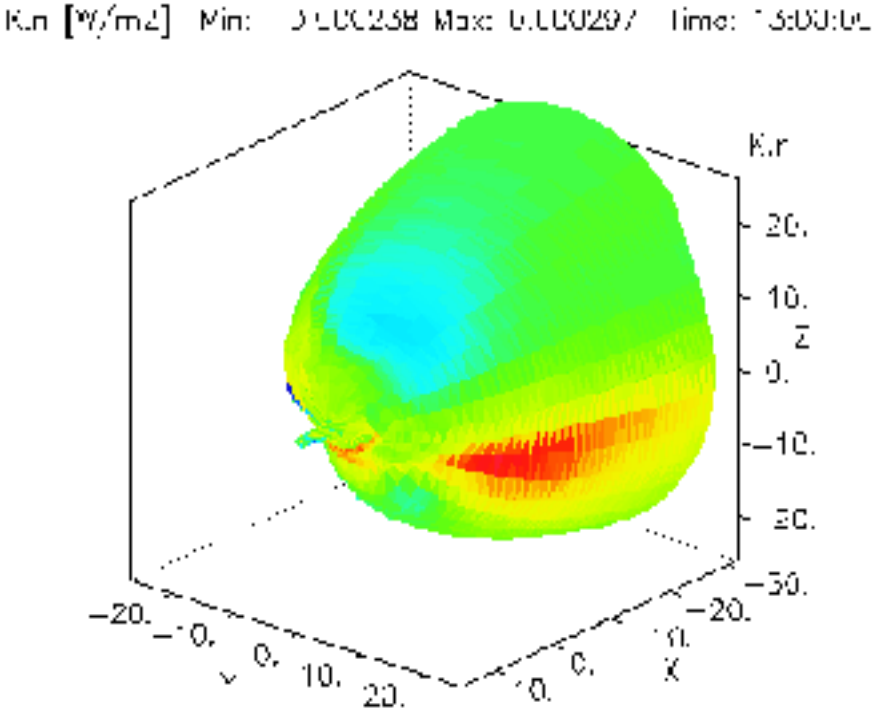


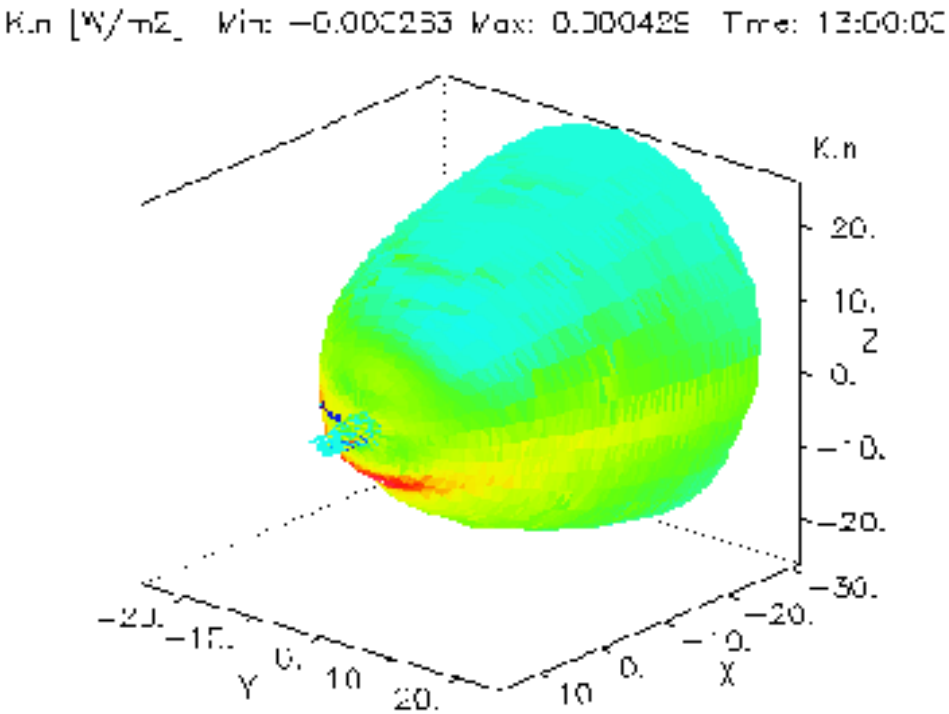


$\mathbf{K}=(U+P-B^2/2)\mathbf{v} + \mathbf{E}\mathrm{x}\mathbf{B}$
(total energy flux) on flow surface

UCLA-GGCM 13:00 UT **BATSRUS**

-0.24<K.n<0.297 **range [mW/m^2]** -0.27 < K.n < 0.429

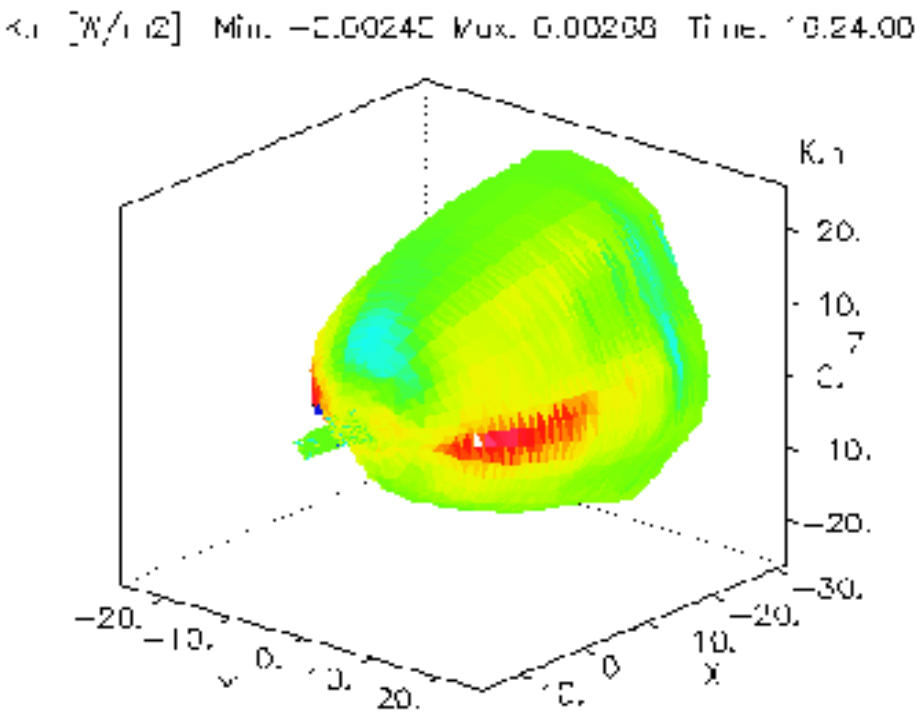


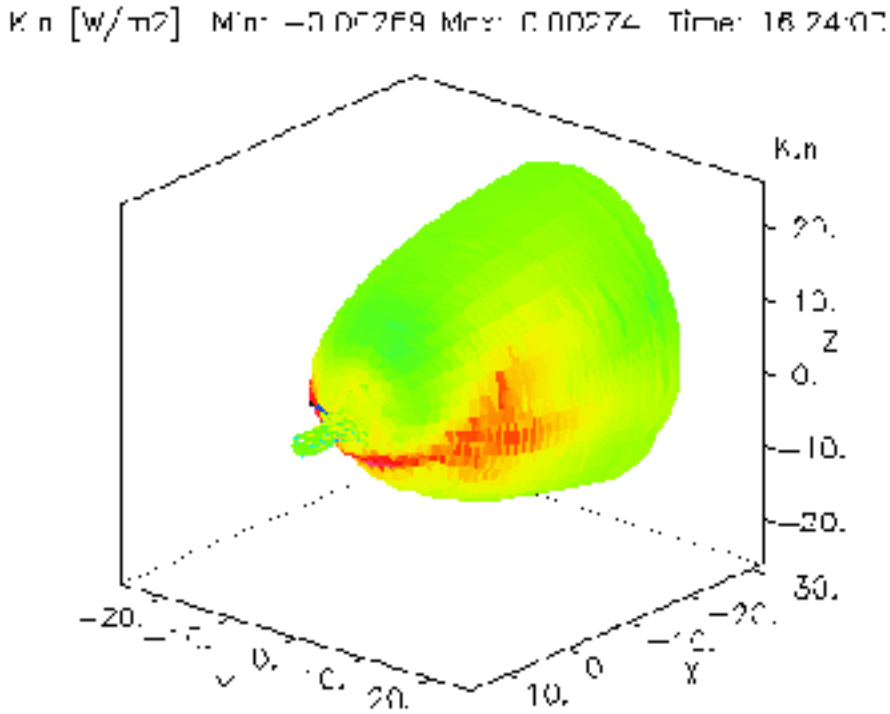


$\mathbf{K}=(U+P-B^2/2)\mathbf{v} + \mathbf{E}\mathrm{x}\mathbf{B}$
(total energy flux) on flow surface

UCLA-GGCM **16:24 UT** **BATSRUS**

-2.45<K.n<2.68 **range [mW/m2]** -2.69 < K.n < 2.74

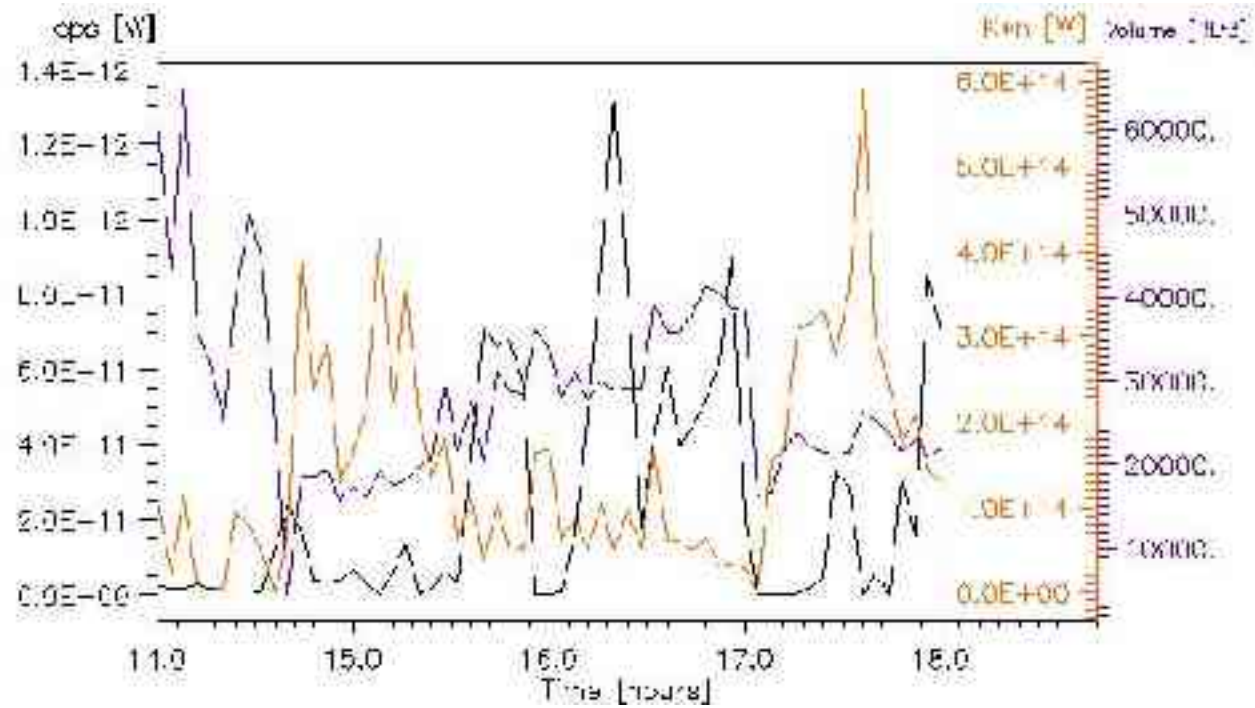




Time histories

UCLA-GGCM:

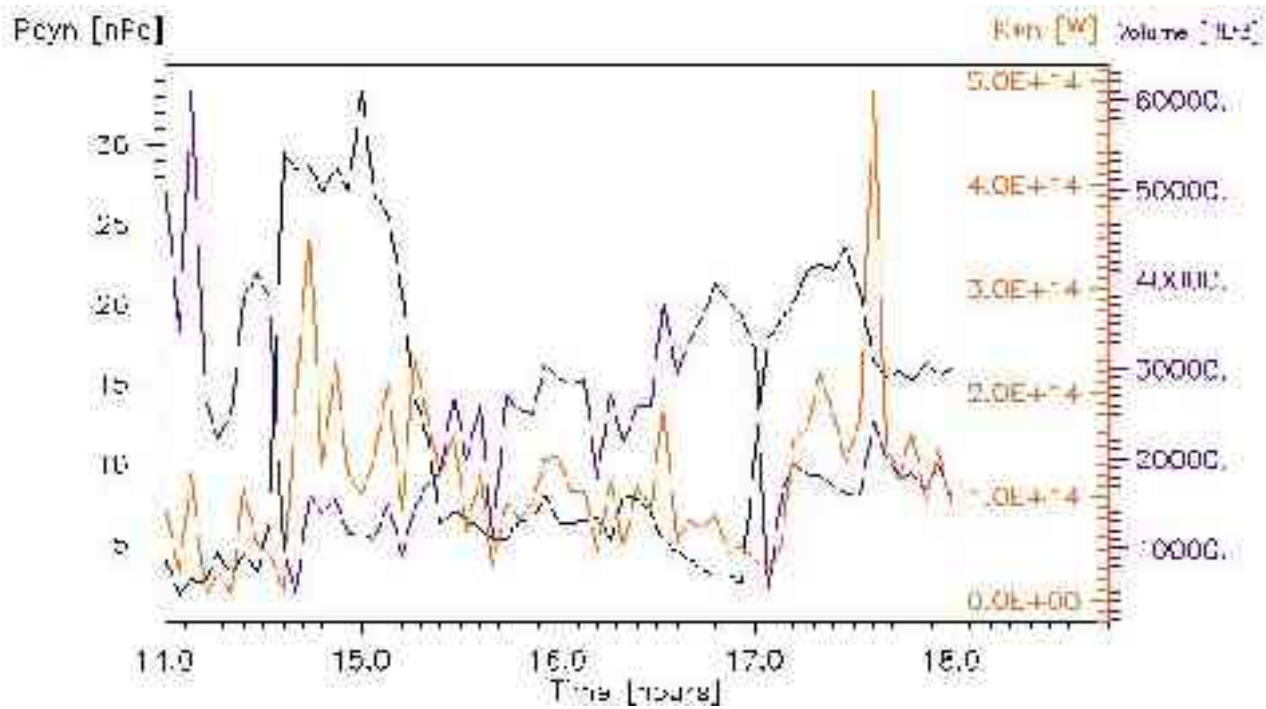
14:00 - 18:00 UT



Surface integral of K.n

Volume inside surface

solar wind: epsilon



solar wind: Pdyn

BATSRUS:

Surface integral of K.n

Volume inside surface

Summary - magnetopause definitions

Velocity envelope:

- **coincides well** with inner edges of **pressure and density gradients** in the magnetosheath,
- velocity is still significant (non-zero) on surface,
- many **parameters describing energy transport** on the surface are **zero by definition** (e.g., **ExB** for **northward IMF**, V_n=0 => no scalar quantity (pressure) is transported with the flow across the boundary
- **ExB**, however, can be **nonzero for southward IMF**
- Envelope appears outside of closed field line regions.

Statistical magnetopause model (Shue et al., 1997):

- **Good agreement with location of flow envelope** in the tail with distance of center from the X-axis determined by the solar wind velocity in cut slice (X=constant).

Total **energy flow** across flow surface seem to be dominated by the solar wind dynamic pressure **Pdyn**.

Flow **surface size and enclosed volume** are **anti-correlated** with **Pdyn**.

Much weaker correlation with solar wind **epsilon** was found.

Energy fluxes do **not** account for the **entire change of the magnetosphere energy**:
Motion and change of the surface itself is important.

Energy fluxes, total **surface area and enclosed volume** are **very similar for both models.**

Outlook

Given suitable and reliable definitions of the magnetosphere boundary in simulations:

- The energy fluxes across the magnetospheric boundaries can be studied in relation to the energy dissipation in the ionosphere and the mapping of open and closed field lines into the ionosphere.
- The results will be complementary to a similar study performed with the GUMICS-4 model (M. Palmroth, JGR **108,** 1048, 2003) where energy transfers were found to follow solar wind parameters in a power-law relation.
- Parameters of this functional relation and correlation coefficients can be calculated for the two models used in this study in a similar manner.
- Results can verify models' performance in comparison with ground and satellite observations.