Flow Channel Analysis using CCMC BATSRUS MHD Model: 15 May 2005 Geomagnetic Storm

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With much support from L. Rastätter

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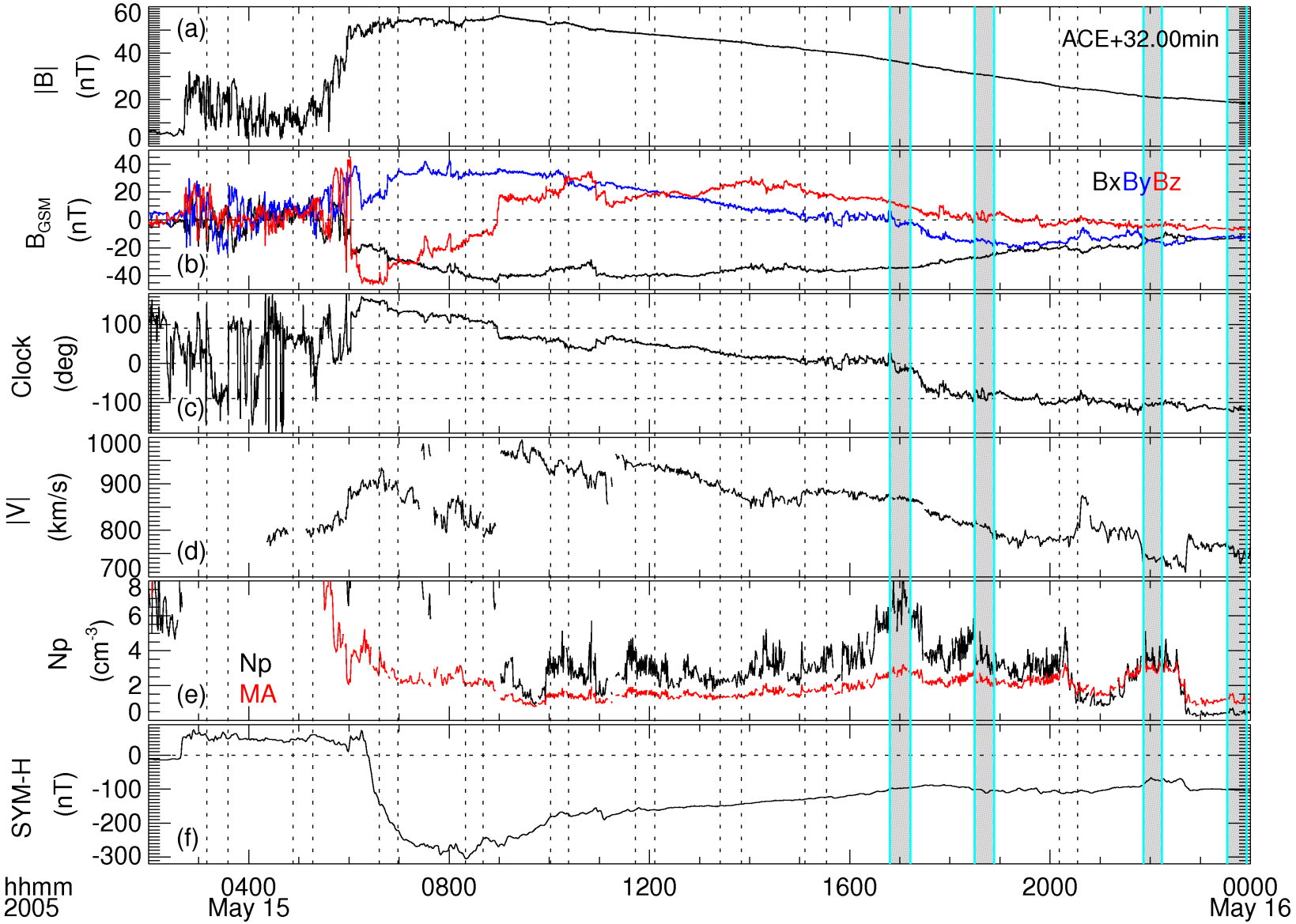
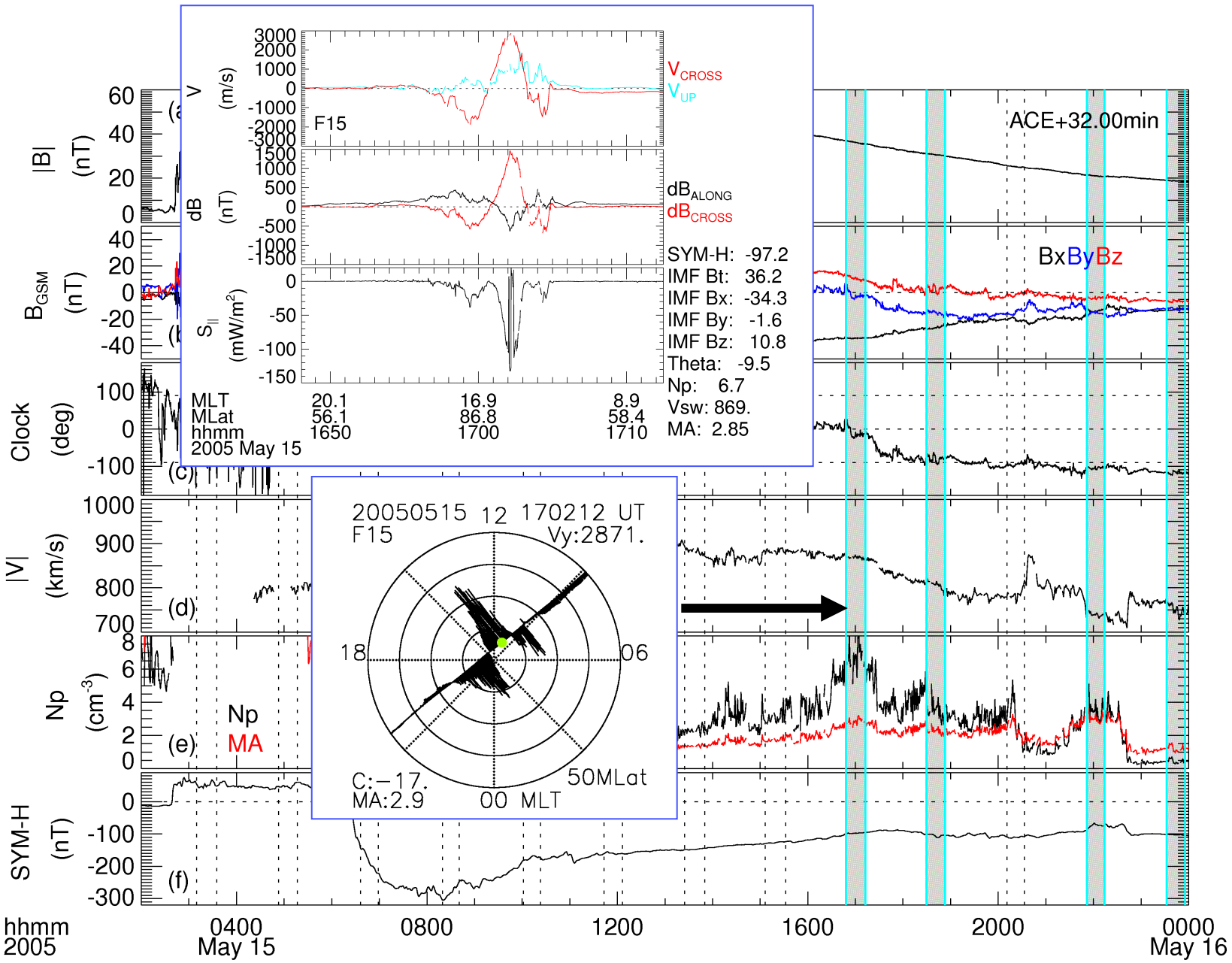
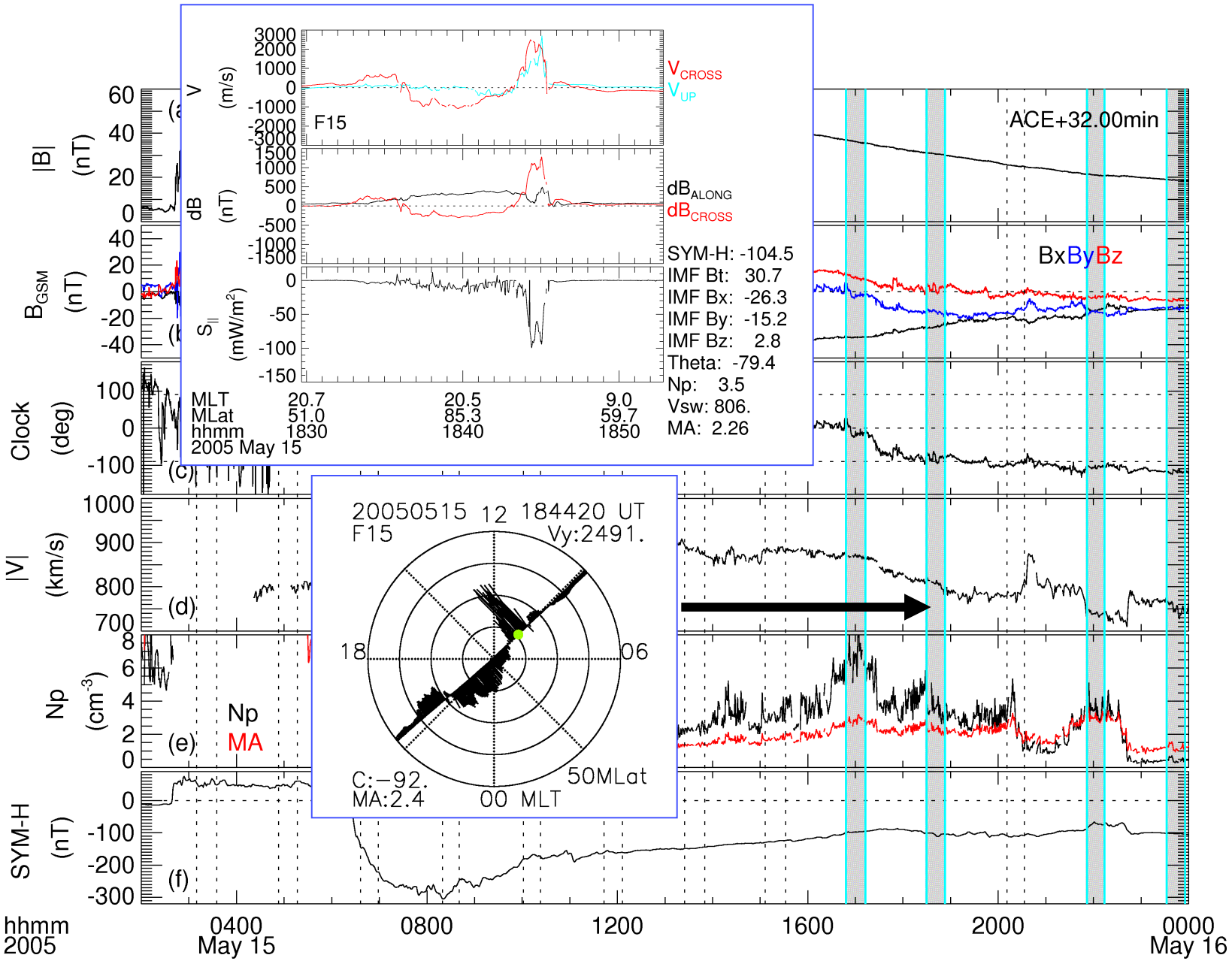
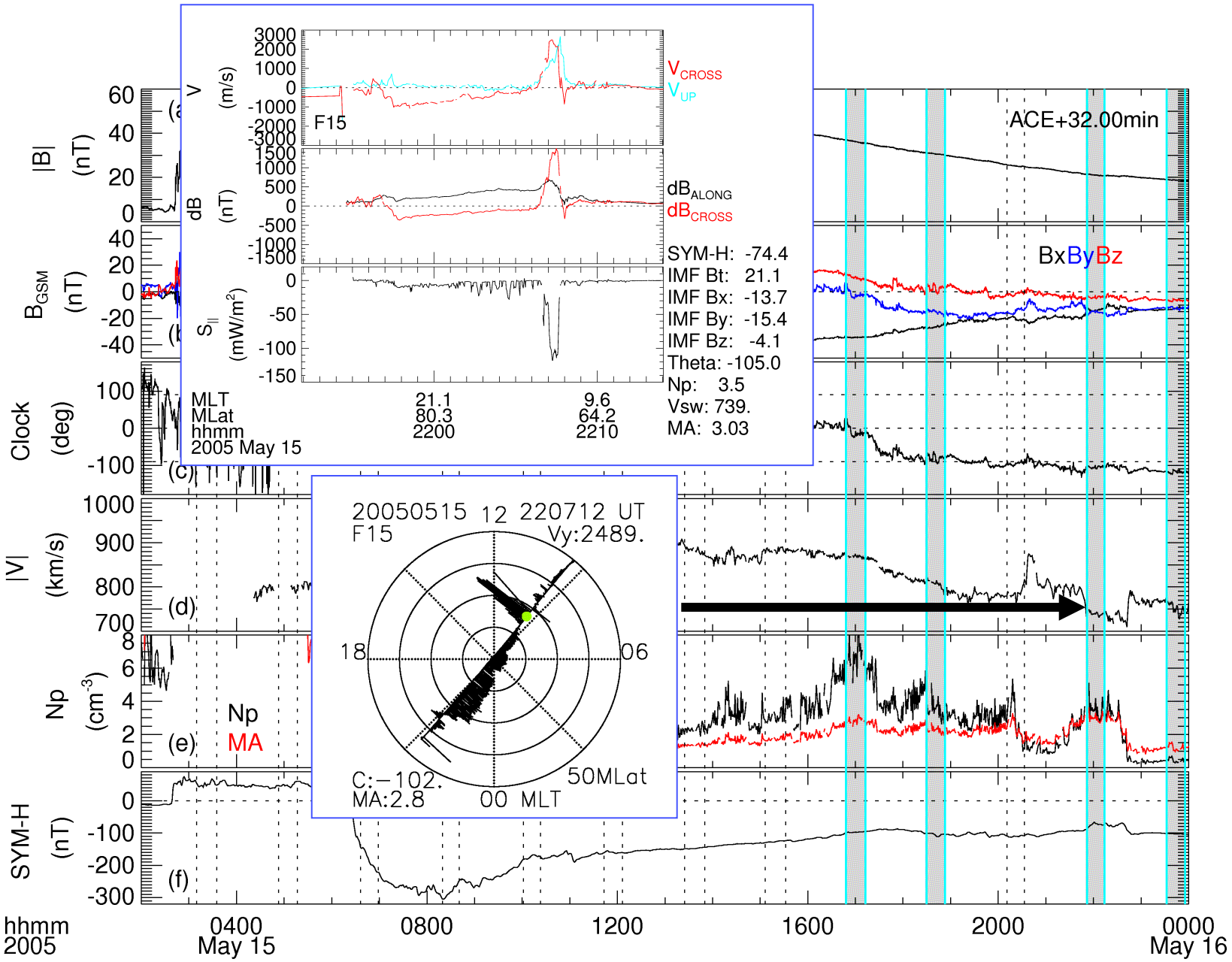
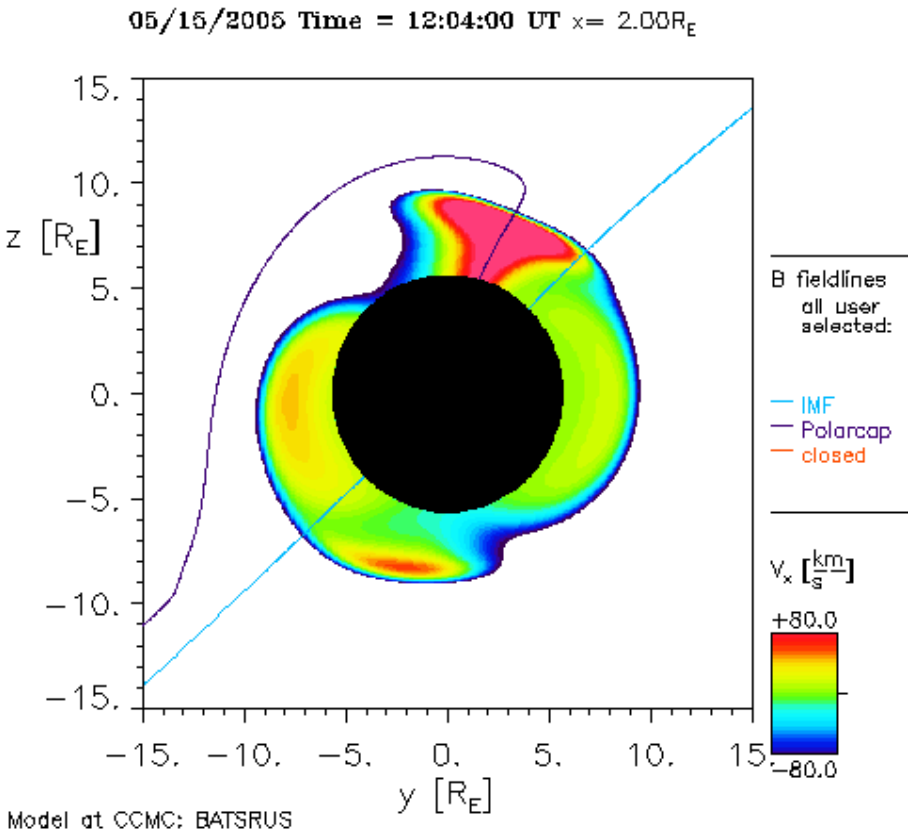
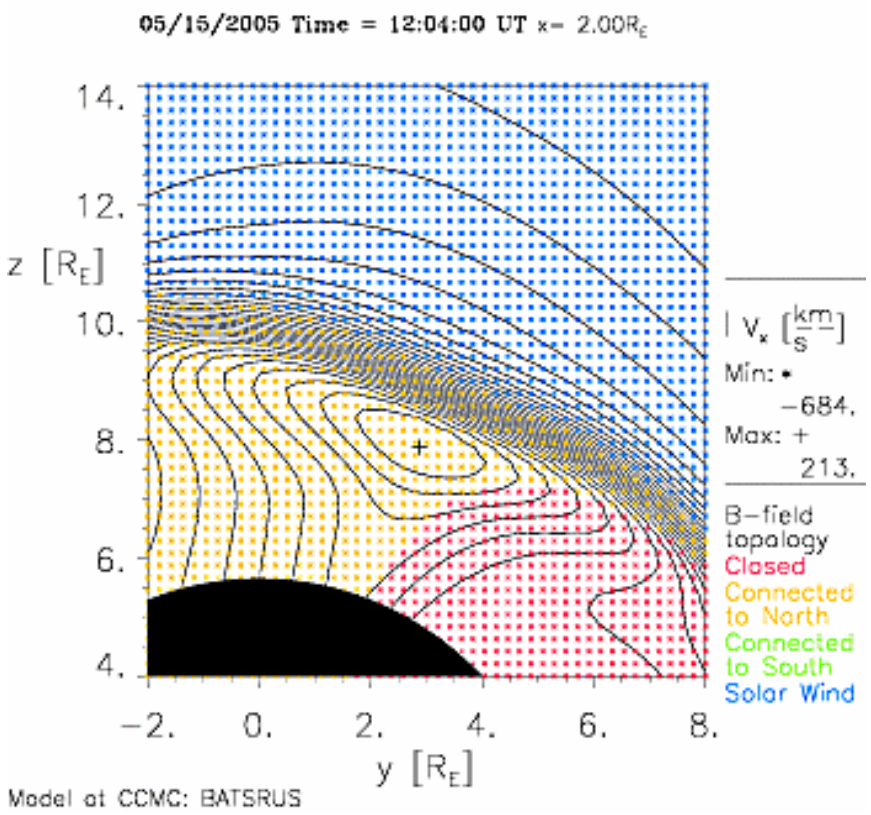

(a)
|B| (nT)
60
40
20
0
ACE+32.00min
(b)
B_GSM (nT)
40
20
0
-20
-40
BxByBz
(c)
Clock (deg)
100
0
-100
(d)
|V| (km/s)
1000
900
800
700
(e)
Np (cm^-3)
8
6
4
2
0
Np
MA
(f)
SYM-H (nT)
0
-100
-200
-300
hhmm
2005
0400
May 15
0800
1200
1600
2000
0000
May 16


ACE+32.00min
BxByBz
|B| (nT)
B_GSM (nT)
Clock (deg)
|V| (km/s)
Np (cm^-3)
SYM-H (nT)
Np
MA
(a)
(b)
(c)
(d)
(e)
(f)
V (m/s)
F15
V_CROSS
V_UP
dB (nT)
dB_ALONG
dB_CROSS
S_|| (mW/m^2)
SYM-H: -97.2
IMF Bt: 36.2
IMF Bx: -34.3
IMF By: -1.6
IMF Bz: 10.8
Theta: -9.5
Np: 6.7
Vsw: 869.
MA: 2.85
MLT 20.1 16.9 8.9
MLat 56.1 86.8 58.4
hhmm 1650 1700 1710
2005 May 15
20050515 12 170212 UT
F15 Vy:2871.
18
06
C:−17.
MA:2.9
00 MLT
50MLat
hhmm
2005
0400
May 15
0800
1200
1600
2000
0000
May 16

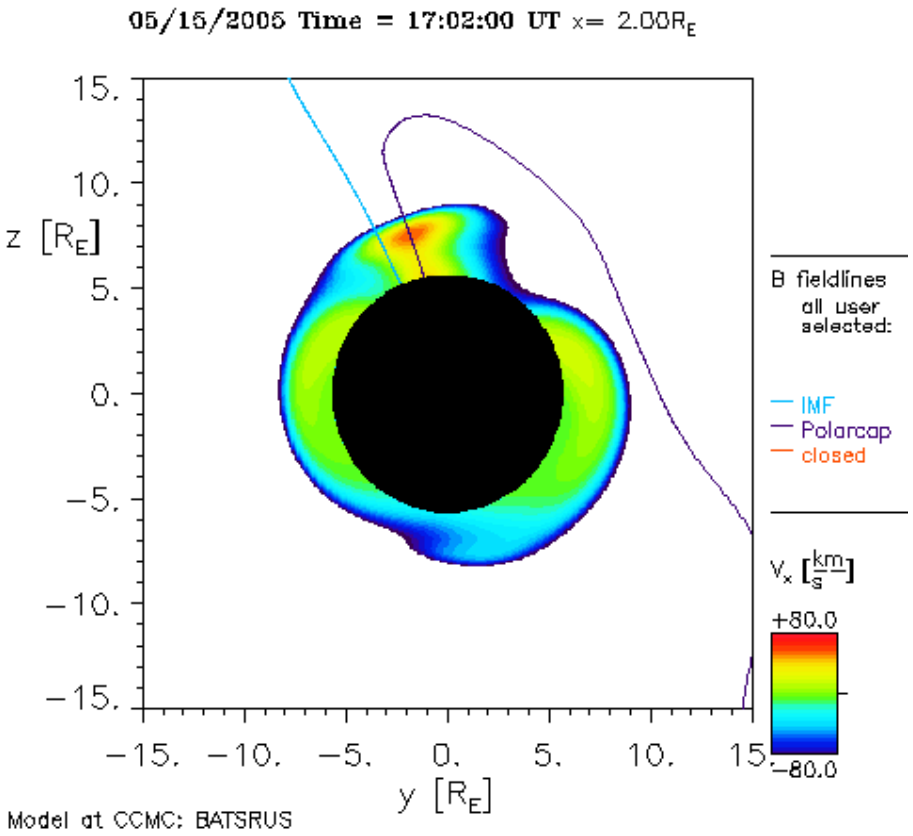

V (m/s)
V_CROSS
V_UP
F15
dB (nT)
dB_ALONG
dB_CROSS
S_|| (mW/m^2)
SYM-H: -104.5
IMF Bt: 30.7
IMF Bx: -26.3
IMF By: -15.2
IMF Bz: 2.8
Theta: -79.4
Np: 3.5
Vsw: 806.
MA: 2.26
MLT 20.7 20.5 9.0
MLat 51.0 85.3 59.7
hhmm 1830 1840 1850
2005 May 15
|B| (nT)
ACE+32.00min
B_GSM (nT)
BxByBz
Clock (deg)
20050515 12 184420 UT
F15
Vy:2491.
18
06
C:-92.
MA:2.4
00 MLT
50MLat
|V| (km/s)
Np (cm^-3)
Np
MA
SYM-H (nT)
(a)
(b)
(c)
(d)
(e)
(f)
hhmm
2005
0400
May 15
0800
1200
1600
2000
0000
May 16

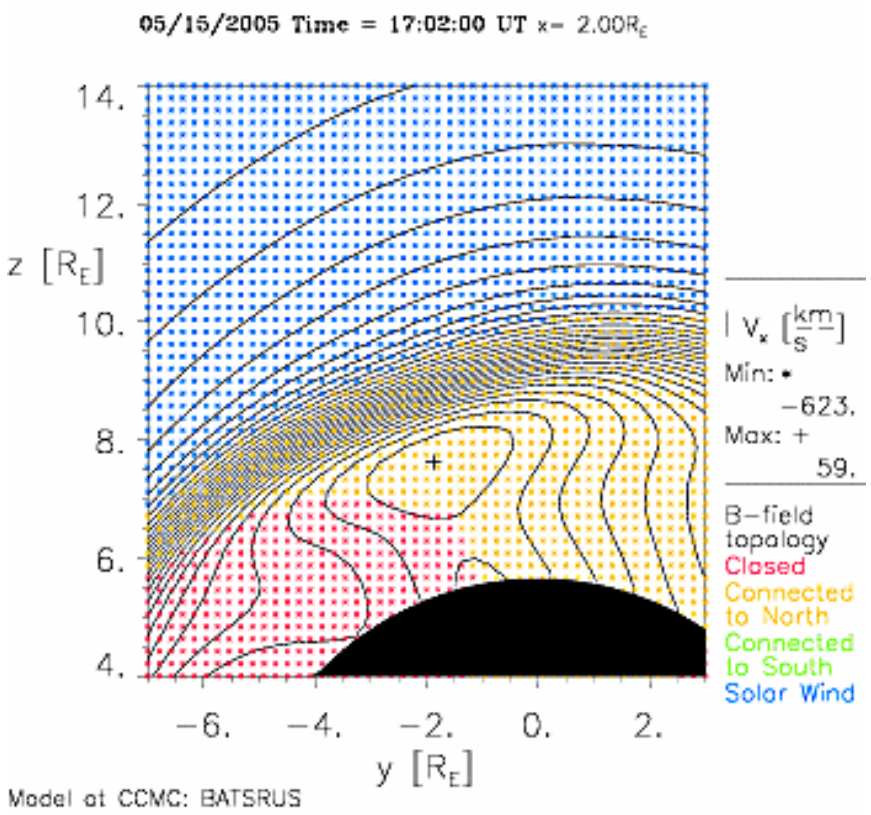

ACE+32.00min
BxByBz
|B| (nT)
B_GSM (nT)
Clock (deg)
|V| (km/s)
Np (cm^-3)
SYM-H (nT)
Np
MA
V (m/s)
V_CROSS
V_UP
F15
dB (nT)
dB_ALONG
dB_CROSS
S_|| (mW/m^2)
SYM-H: -74.4
IMF Bt: 21.1
IMF Bx: -13.7
IMF By: -15.4
IMF Bz: -4.1
Theta: -105.0
Np: 3.5
Vsw: 739.
MA: 3.03
MLT 21.1 9.6
MLat 80.3 64.2
hhmm 2200 2210
2005 May 15
20050515 12 220712 UT
F15 Vy:2489.
18
06
C:-102.
MA:2.8
00 MLT
50MLat
hhmm
2005
0400
May 15
0800
1200
1600
2000
0000
May 16



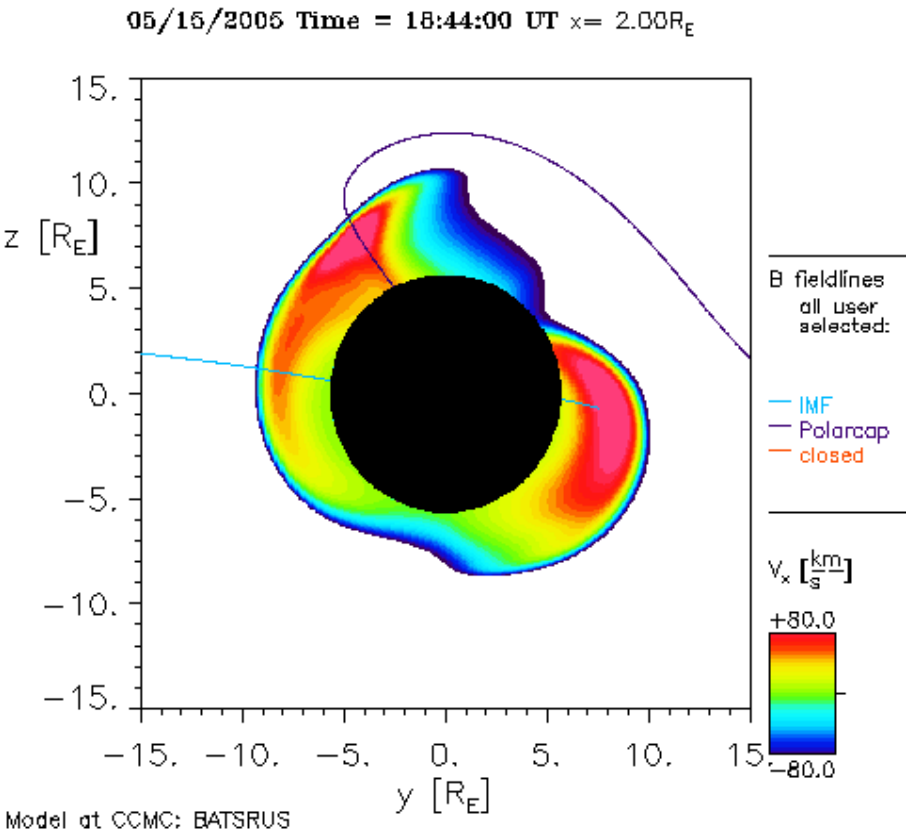


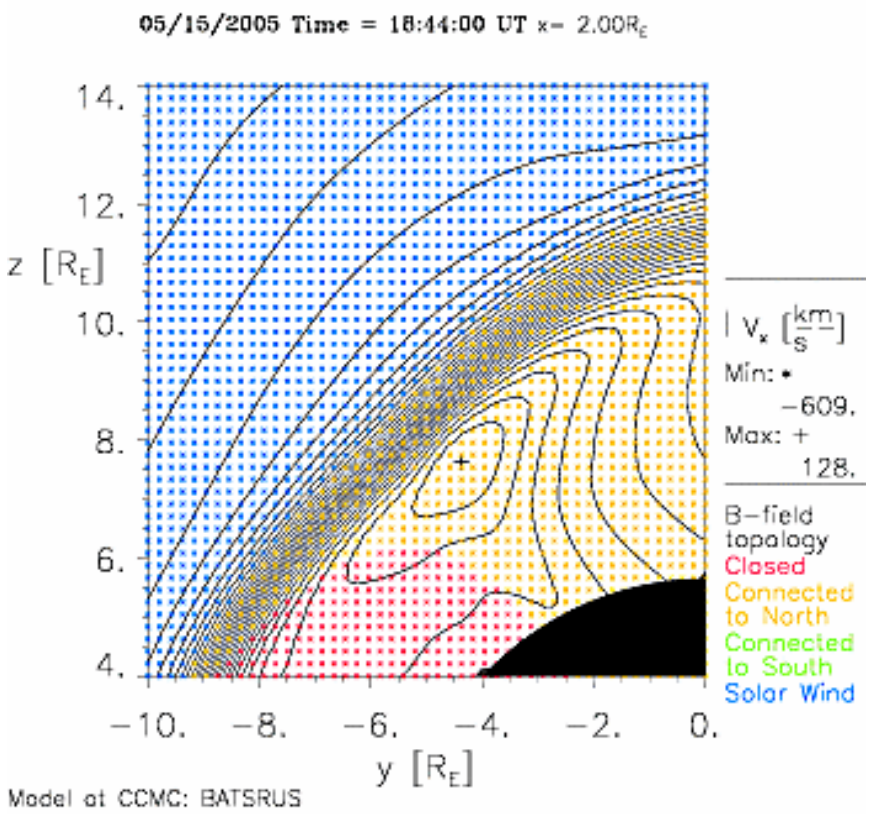
Model: BATSRUS
Run Number: GEM_PFlux_081910_1
Event: 2005/05/15 (GSM)
Time range: 00:00:00 – 20:00:00 UT (1min)
Time: 12:04:00 UT
X=2.00 RE
Vx Max = 213 km/s (+)



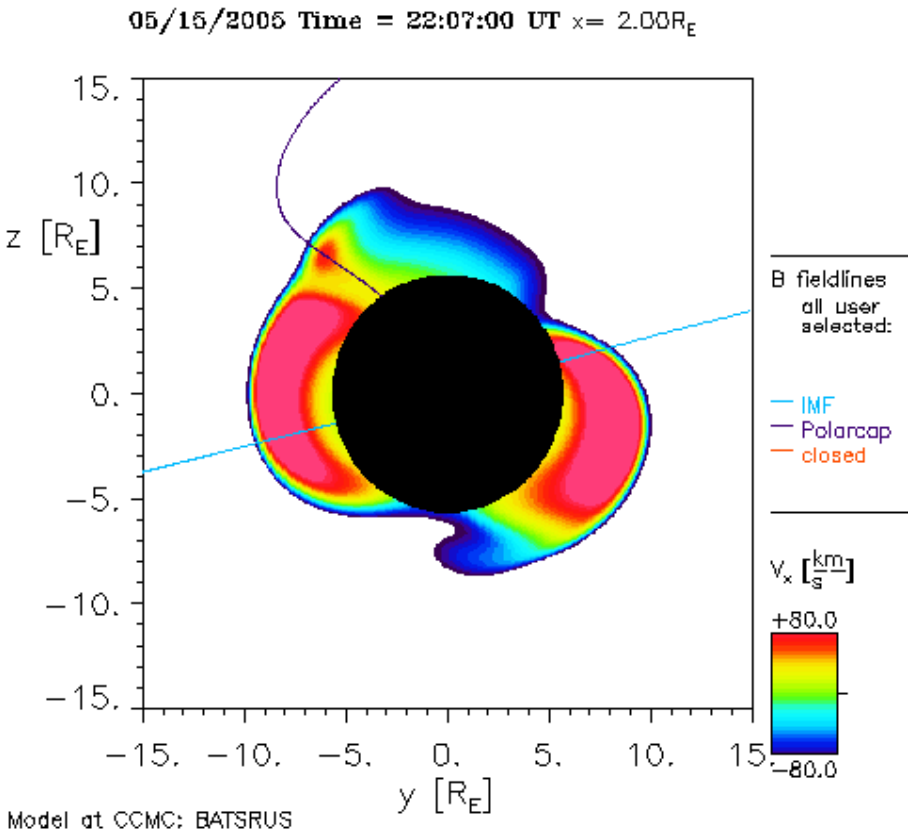


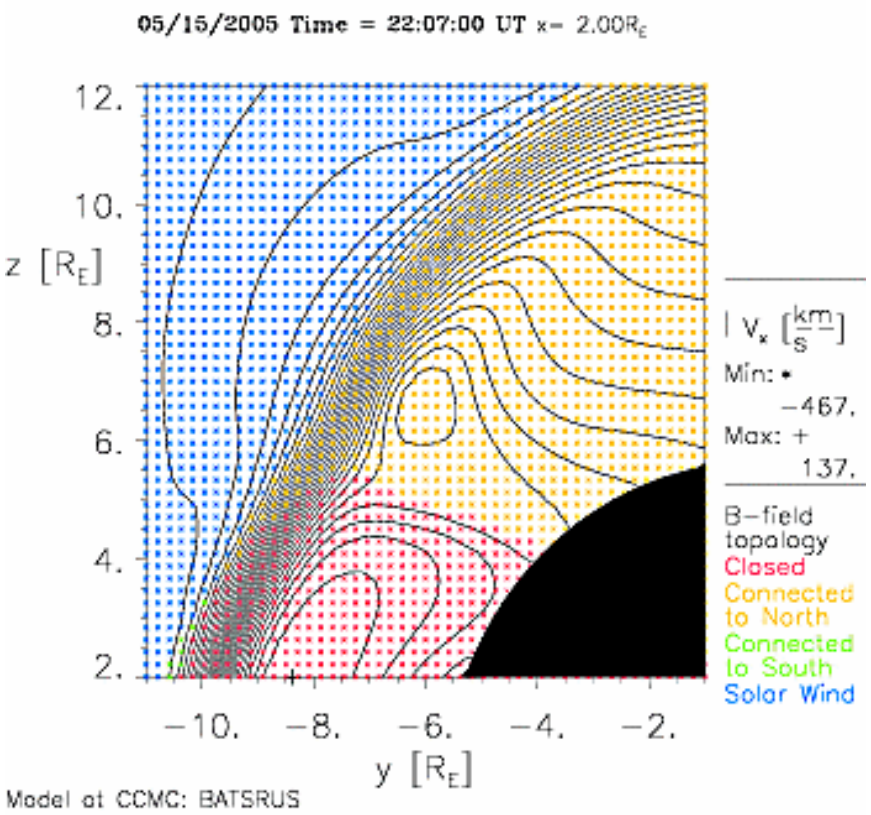
Model: BATSRUS
Run Number: GEM_PFlux_081910_1
Event: 2005/05/15 (GSM)
Time range: 00:00:00 – 20:00:00 UT (1min)
Time: 17:02:00 UT
X=2.00 RE
Vx Max = 59 km/s (+)



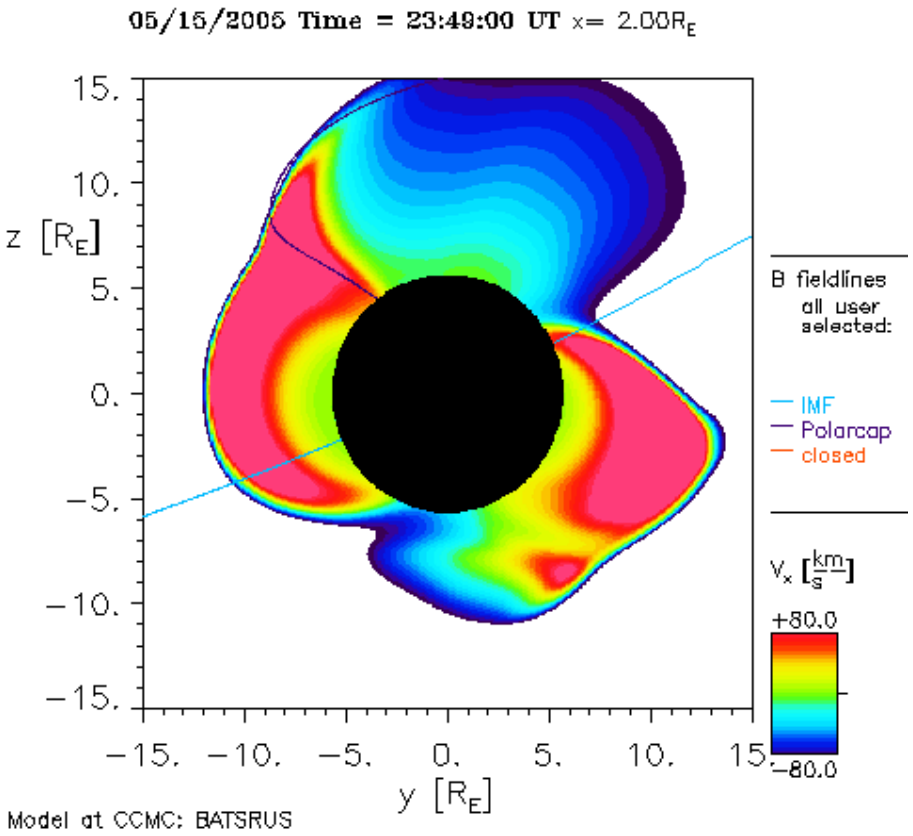


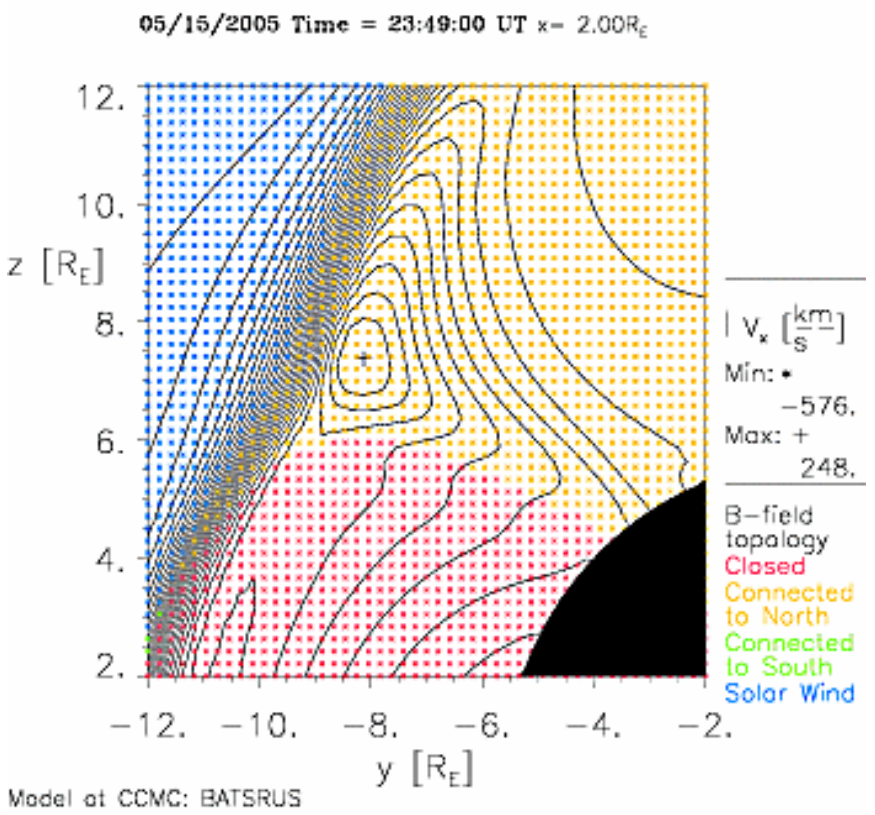
Model: BATSRUS
Run Number: GEM_PFlux_081910_1
Event: 2005/05/15 (GSM)
Time range: 00:00:00 – 20:00:00 UT (1min)
Time: 18:44:00 UT
X=2.00 RE
Vx Max = 128 km/s (+)



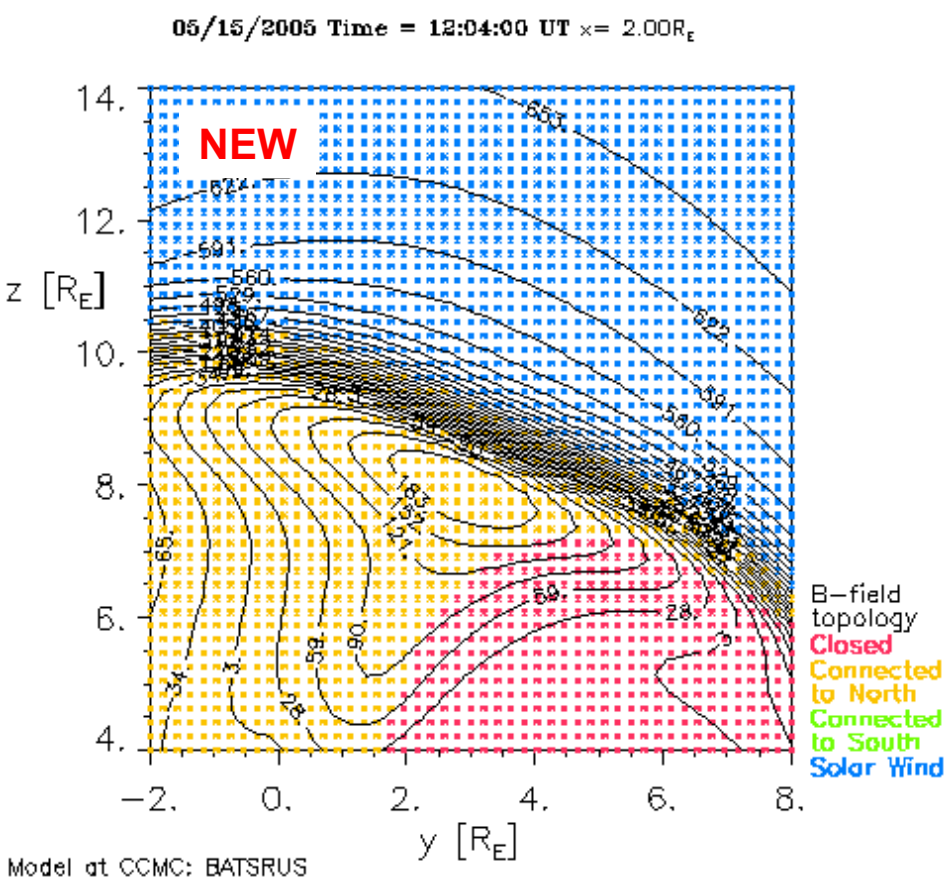


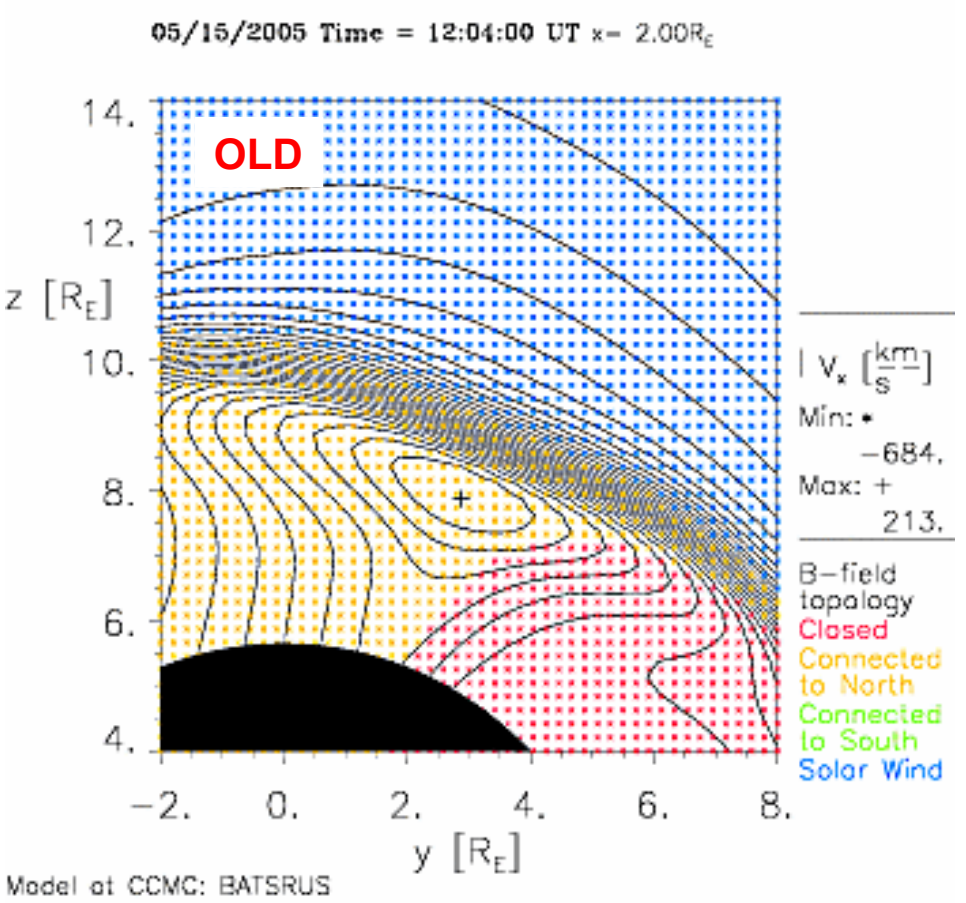
Model: BATSRUS
Run Number: GEM_PFlux_081910_1a
Event: 2005/05/15 (GSM)
Time range: 18:00:00 – 24:00:00 UT (1min)
Time: 22:07:00 UT
X=2.00 RE



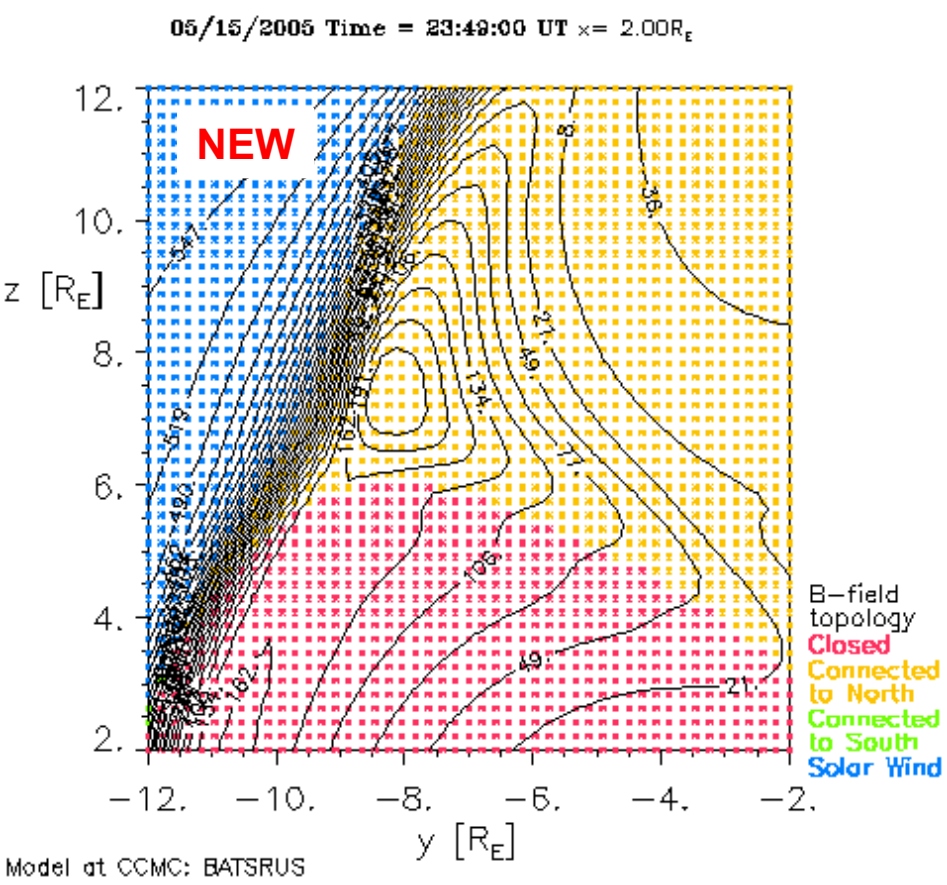


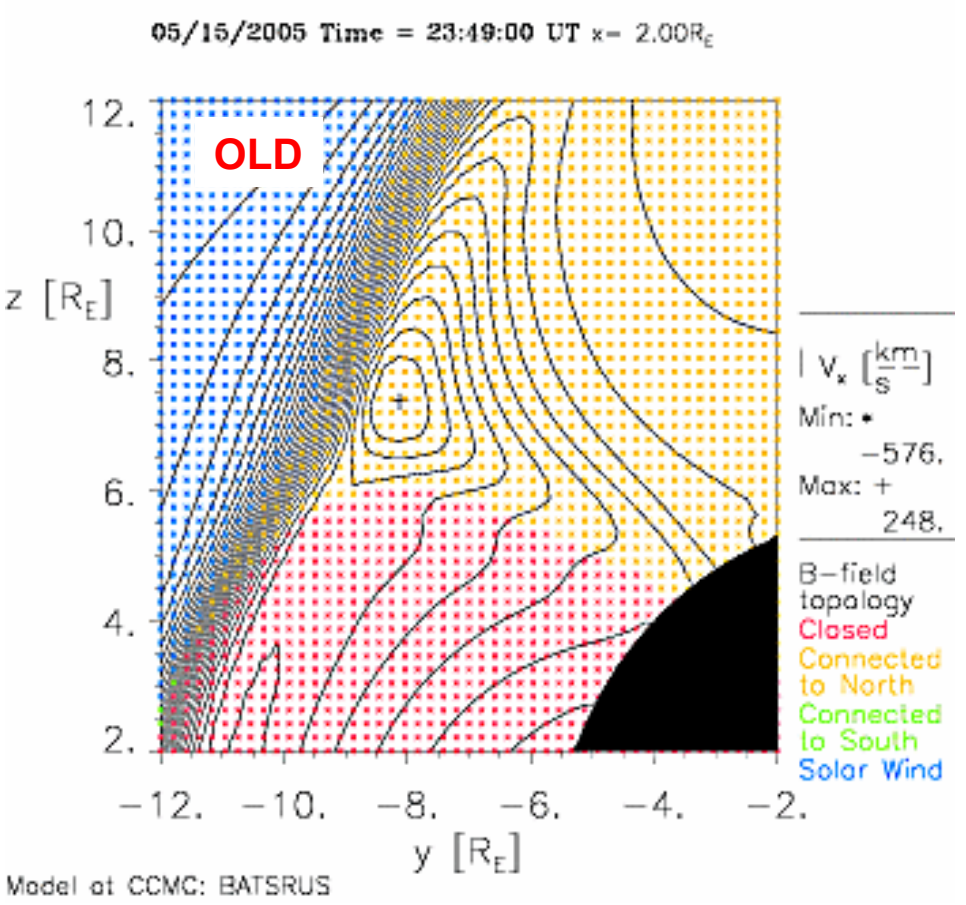
Model: BATSRUS
Run Number: GEM_PFlux_081910_1a
Event: 2005/05/15 (GSM)
Time range: 18:00:00 – 24:00:00 UT (1min)
Time: 23:49:00 UT
X=2.00 RE
Vx Max = 248 km/s (+)



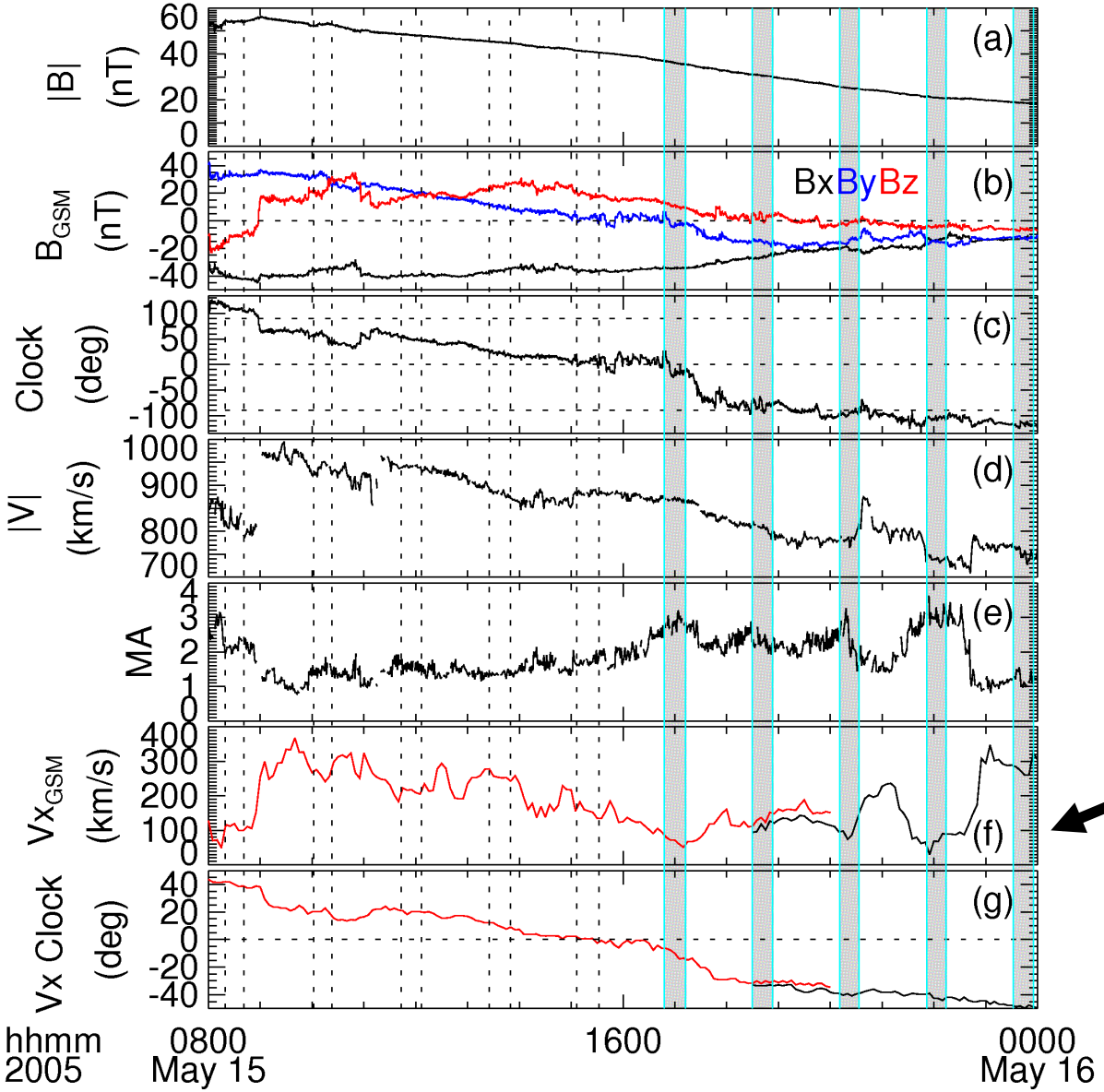


Model: BATSRUS
Run Number: GEM_PFlux_081910_1
Event: 2005/05/15 (GSM)
Time range: 00:00:00 – 20:00:00 UT (1min)
Time: 12:04:00 UT
X=2.00 RE
Vx Max = 213 km/s (+)





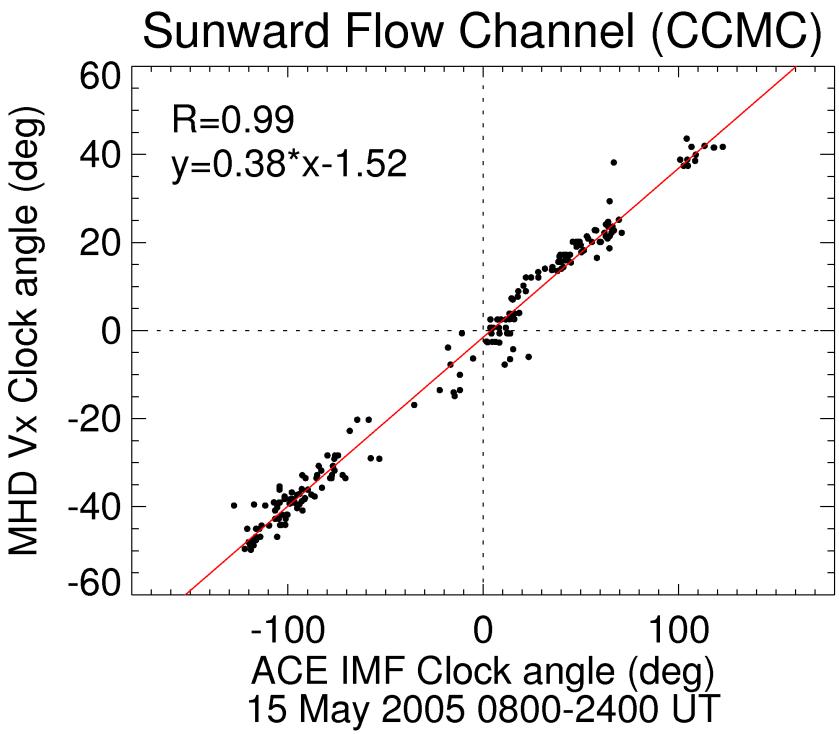
Model: BATSRUS
Run Number: GEM_PFlux_081910_1a
Event: 2005/05/15 (GSM)
Time range: 18:00:00 – 24:00:00 UT (1min)
Time: 23:49:00 UT
X=2.00 RE
Vx Max = 248 km/s (+)

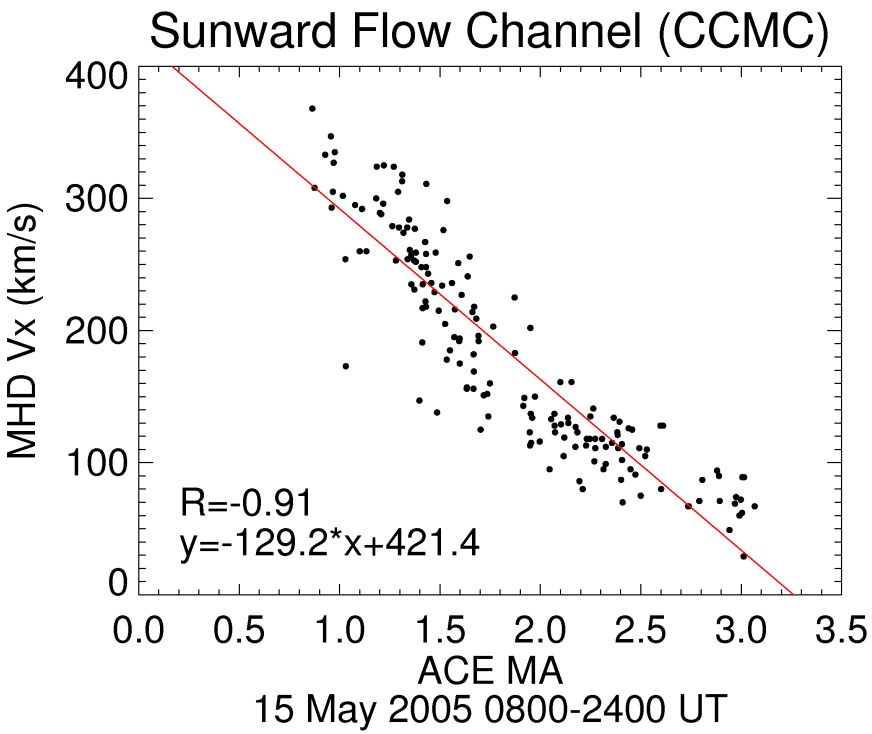


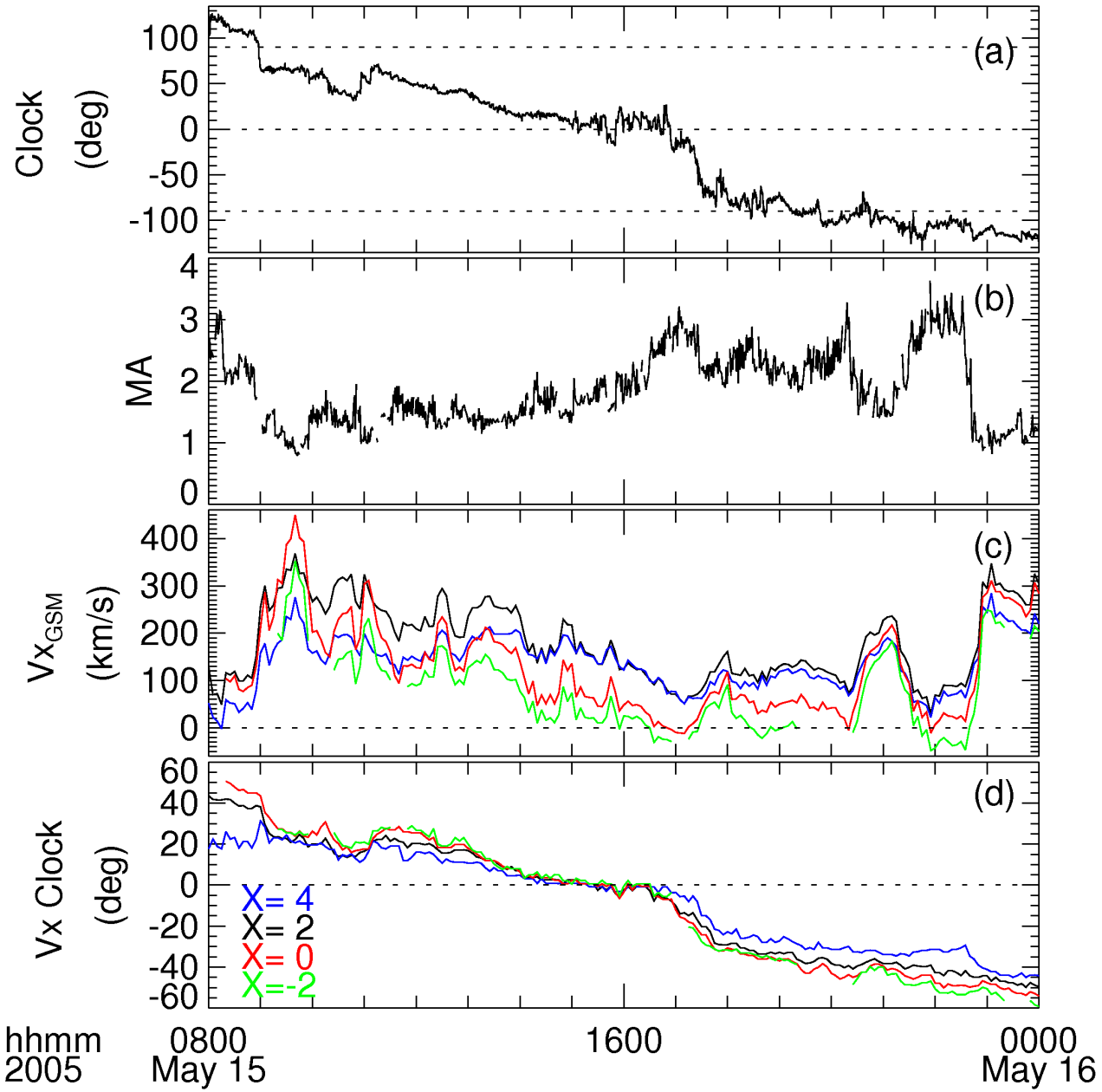
NOTE: Visual recording of maximum "Vx" speed (old version) and its (y,z) location at X=2 RE plane

DESIRED: Output file of max (min) values and their location for given plane and quantity.

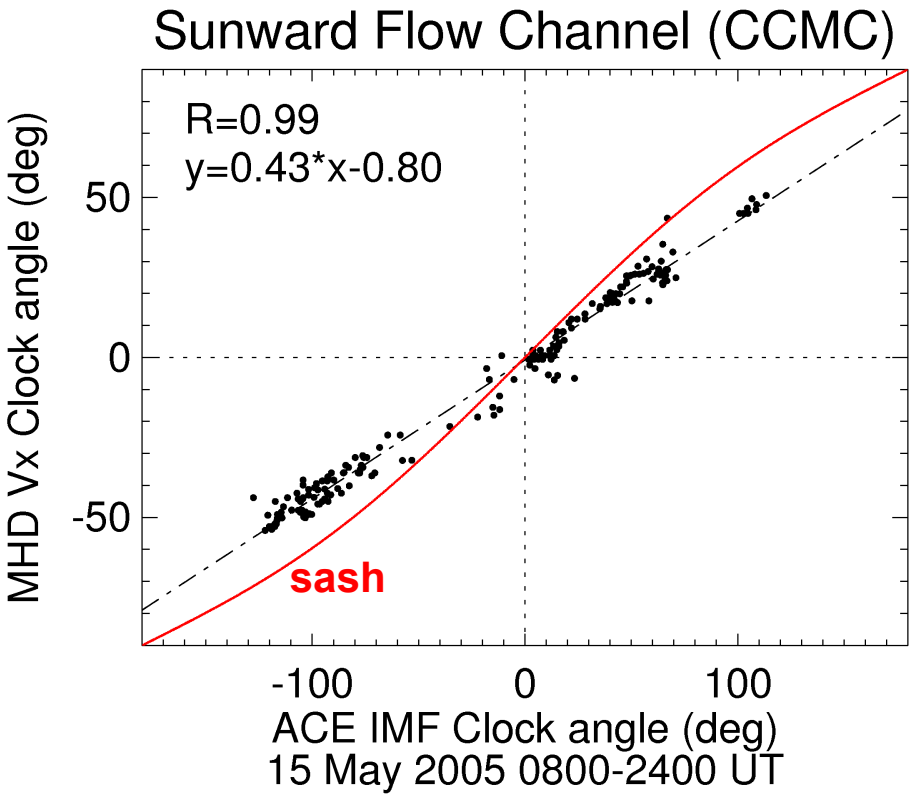
GEM_PFlux_081910_1 **GEM_PFlux_081910_1a**


Sunward Flow Channel (CCMC)
R=0.99
y=0.38*x-1.52
MHD Vx Clock angle (deg)
ACE IMF Clock angle (deg)
15 May 2005 0800-2400 UT
60
40
20
0
-20
-40
-60
-100
0
100


Sunward Flow Channel (CCMC)
R=-0.91
y=-129.2*x+421.4
MHD Vx (km/s)
ACE MA
15 May 2005 0800-2400 UT
400
300
200
100
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5


Clock (deg)
100
50
0
-50
-100
(a)
MA
4
3
2
1
0
(b)
Vx$_{GSM}$ (km/s)
400
300
200
100
0
(c)
Vx Clock (deg)
60
40
20
0
-20
-40
-60
(d)
X= 4
X= 2
X= 0
X=-2
hhmm
2005
0800
May 15
1600
0000
May 16

Flow channel location comparison with the “sash” (low-B) region at X=0 RE



Siscoe et al. [2001] presented a clock angle position of the so-called “sash” [White et al., 1998]

Summary/suggestions

- MHD simulation suggests the existence of a well-defined sunward flow channel driven by flank magnetopause reconnection
- Its location is determined by IMF clock angle
- The maximum sunward flow speed depends on solar wind Alfven Mach number.
- CCMC topology map is an invaluable tool !!
- **User feedback**: Provide output file generation of max/min values of given quantity and its location in a given plane…

Cluster and iPIC3D Kinetic codes at CCMC?

S. Eriksson[1], S. Markidis[2], and G. Lapenta[2]

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2. Katholieke Universiteit, Leuven, Belgium

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iPIC3D
implicit Particle-in-Cell 3D Code

iPIC3D - Features

- Fully electromagnetic Particle-in-Cell code
- 2D ½ and 3D geometries
- Uniform Cartesian grid
- Parallel 3D domain decomposition
- Mostly used to study magnetic reconnection

Ref. Multi-scale simulations of plasma with iPIC3D
Stefano Markidis, Giovanni Lapenta, Rizwan-uddin
Mathematics and Computers in Simulations, 80, 7, 2010.

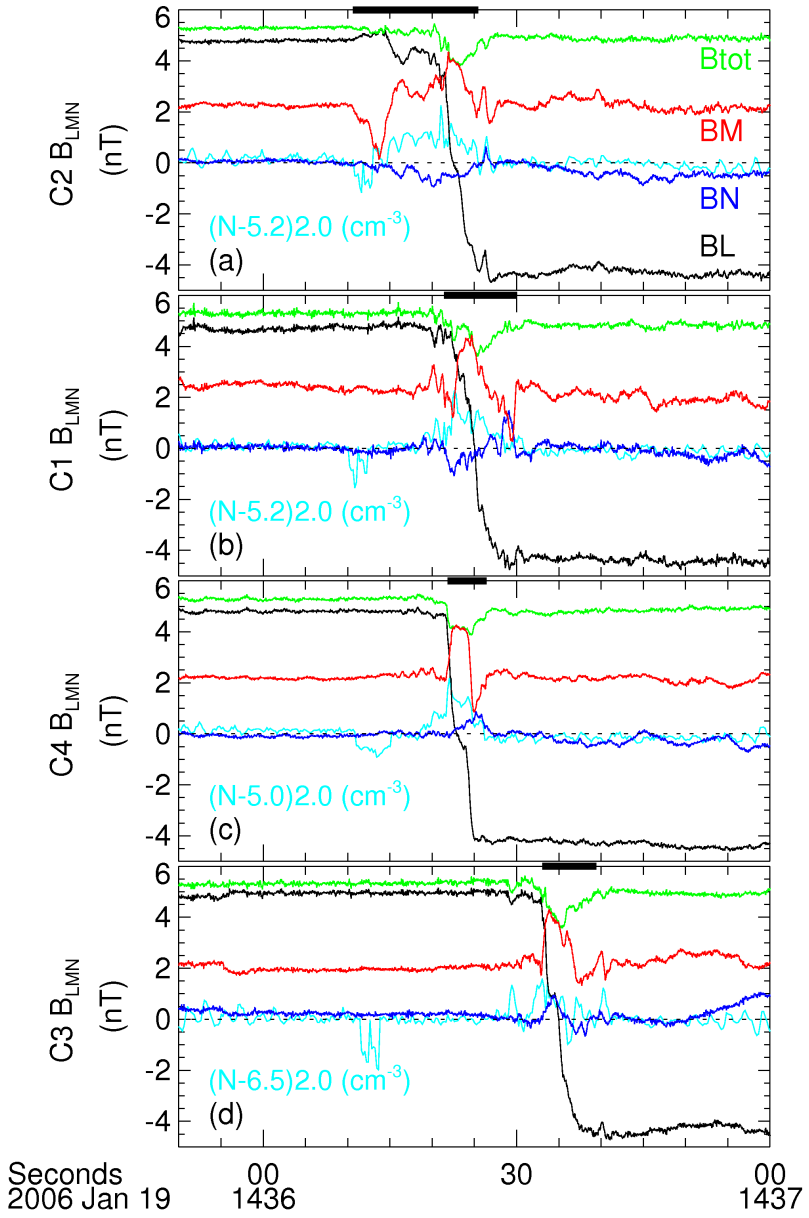
iPIC3D - Code

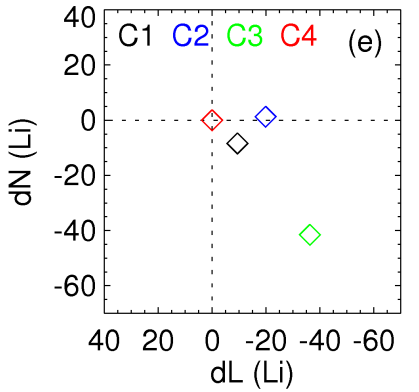
- C++ Particle-in-Cell Code
- 12,500 lines of code
- Parallel code using MPI
- Text input-file
- Output in hdf5 format (each process writes its own hdf5 file), and ASCII for monitoring selected simulation spatial locations (*virtual probes*)
- Post-processing routines available to convert hdf5 files in vtk format

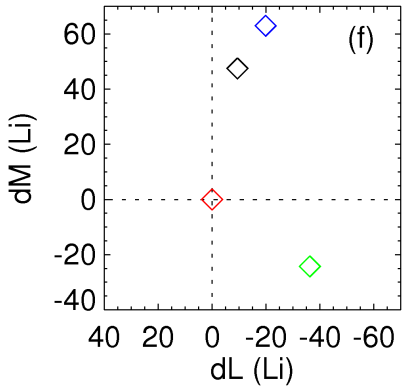
iPIC3D - Implicit PIC Method

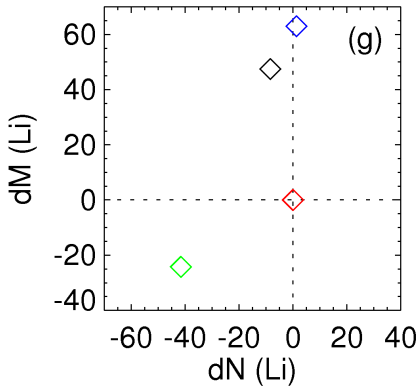
- Maxwell's equations and particle equations of motion are discretized **implicitly in time** and solved by a GMRes linear solver (Maxwell's equations) and 3 predictor-corrector iterations (equations of motion)
- The implicit PIC formulation makes the numerical PIC scheme unconditionally stable, allowing us to use time step and grid spacing, much larger than the one in use in standard PIC codes, and carry out simulations **on large simulation boxes** with **large time steps** and **realistic mass ratios**

Solar wind reconnection event: Cluster B and Nsc on 19 January 2006





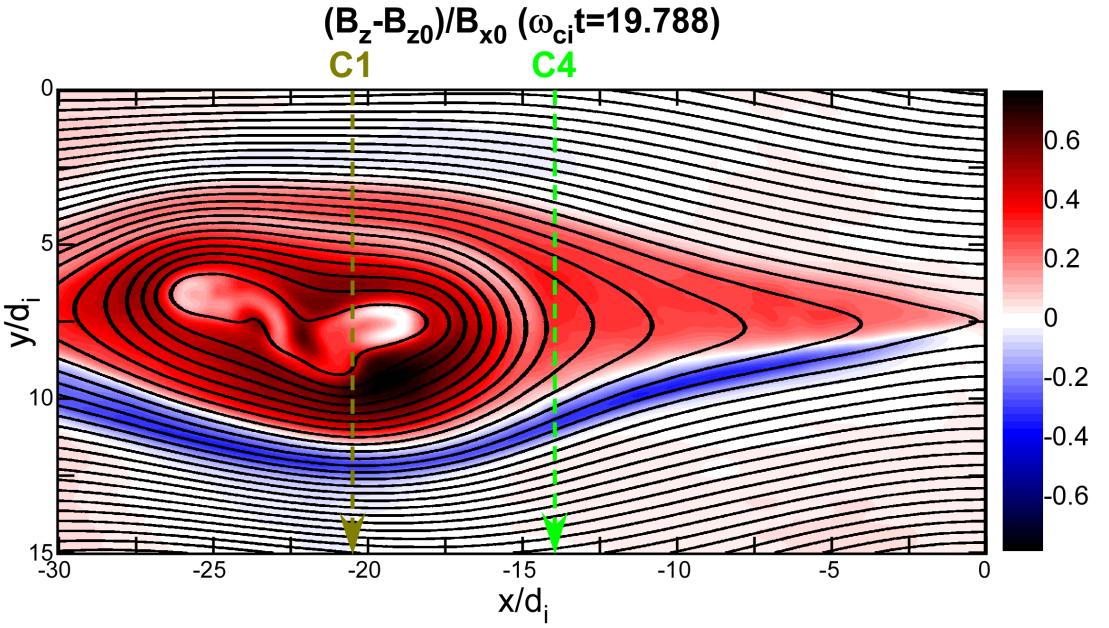


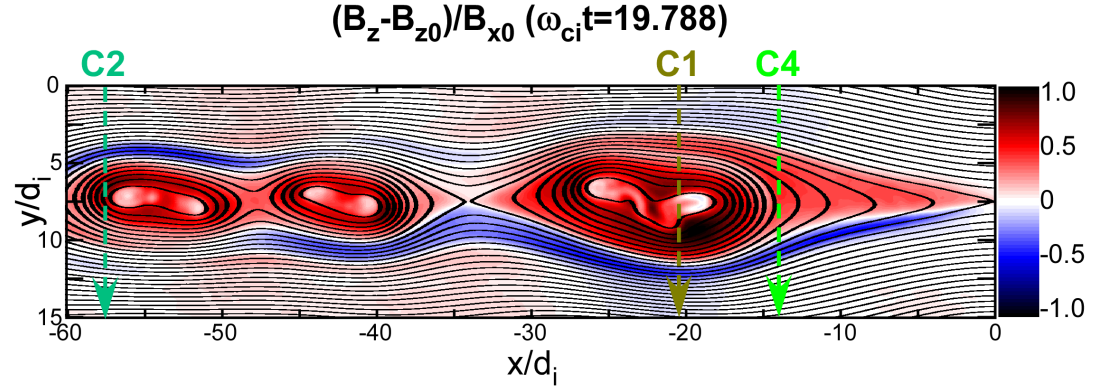


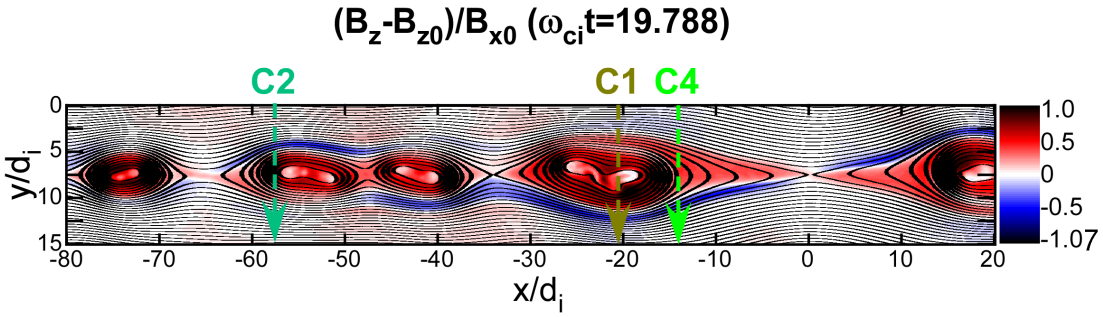
Li=113.9 km

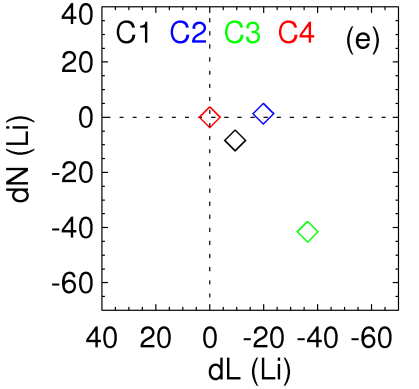
<u>C4 exhaust width</u>:
dt=4.80 s
VN=427.8 km/s
DN=18 Li

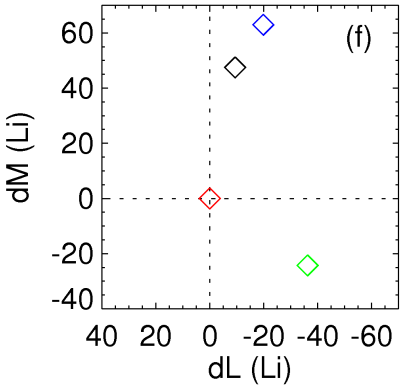
<u>C2 exhaust width</u>:
dt=15.03 s
VN=432.5 km/s
DN=57 Li

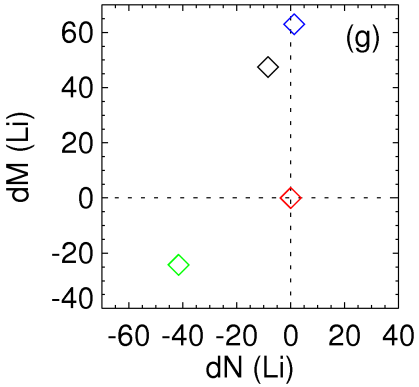

(B_z-B_z0)/B_x0 (ω_ci t=19.788)
C1
C4
y/d_i
x/d_i
0.6
0.4
0.2
0
-0.2
-0.4
-0.6

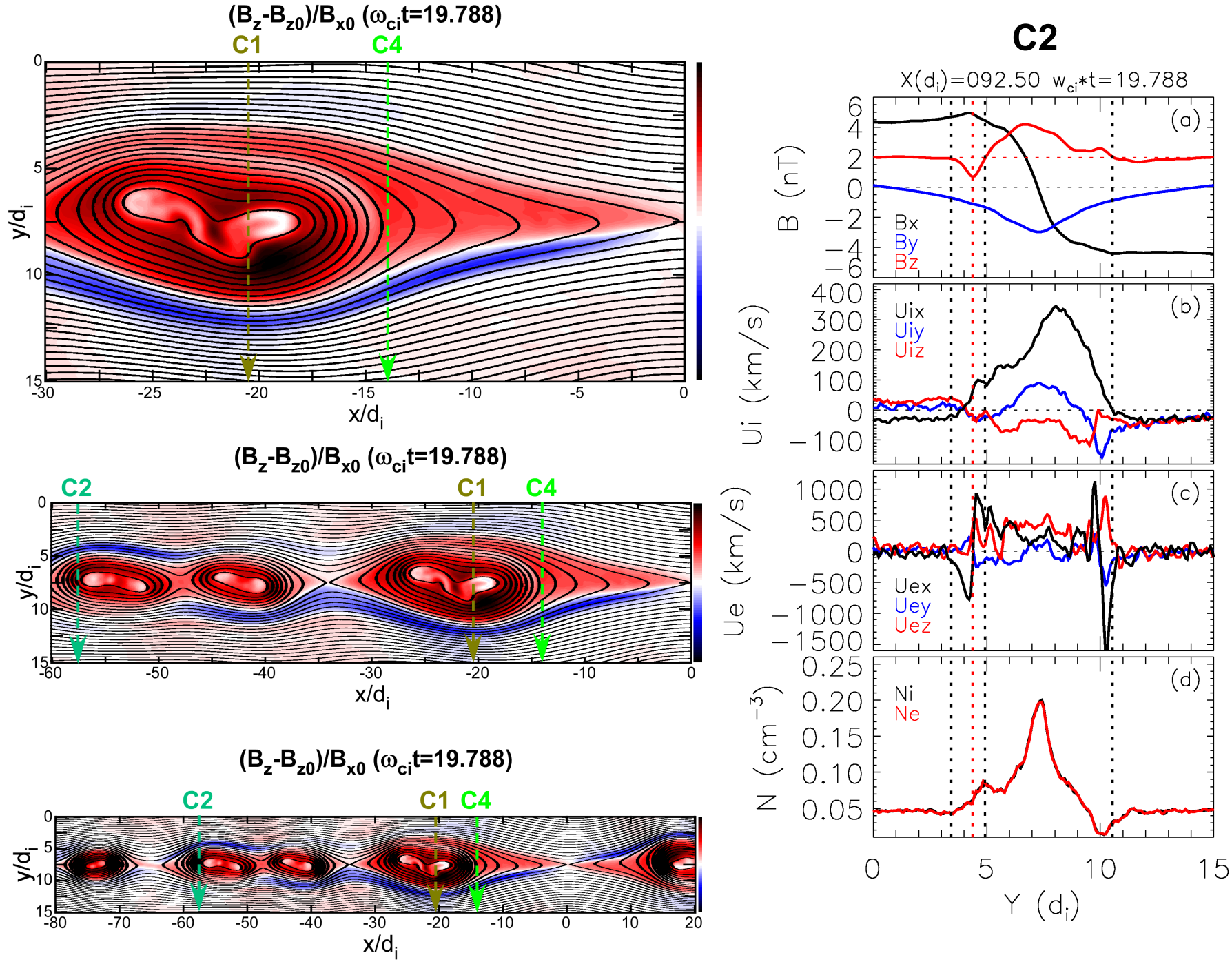

(B_z-B_z0)/B_x0 (ω_ci t=19.788)
C2
C1
C4
y/d_i
x/d_i
1.0
0.5
0
-0.5
-1.0

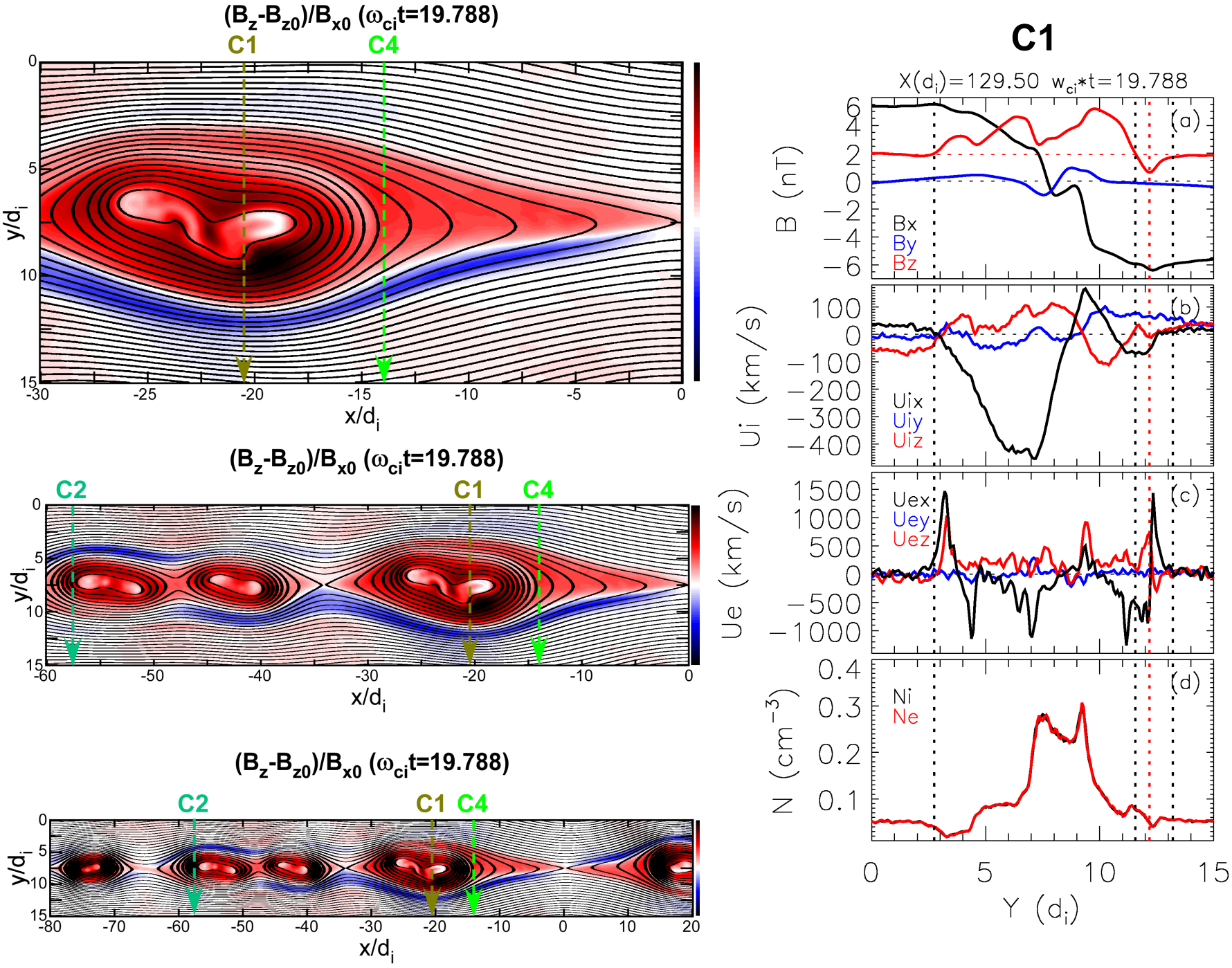

(B_z-B_z0)/B_x0 (ω_ci t=19.788)
C2
C1
C4
y/d_i
x/d_i
1.0
0.5
0
-0.5
-1.07

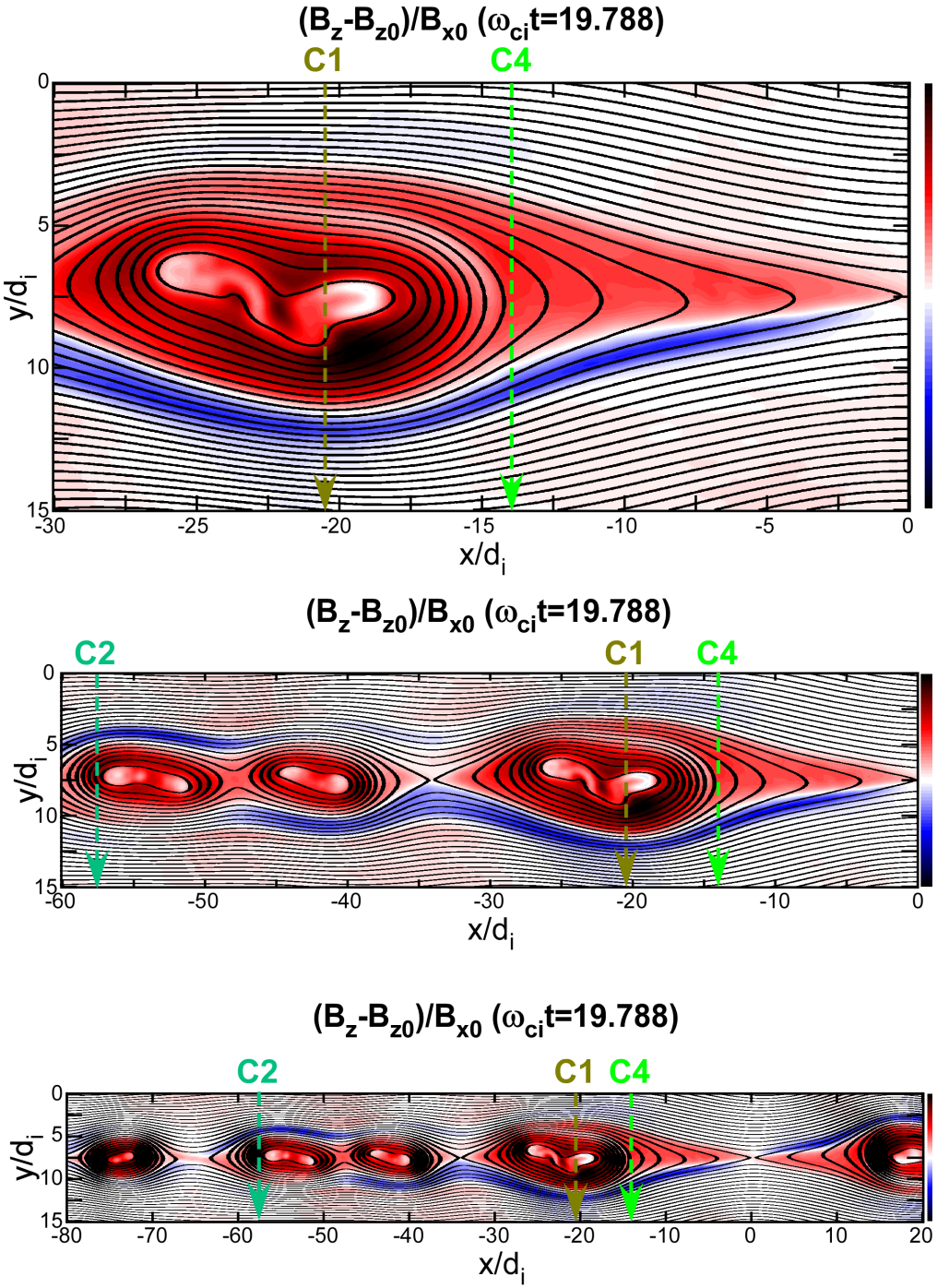

C1
C2
C3
C4
(e)
dN (Li)
dL (Li)

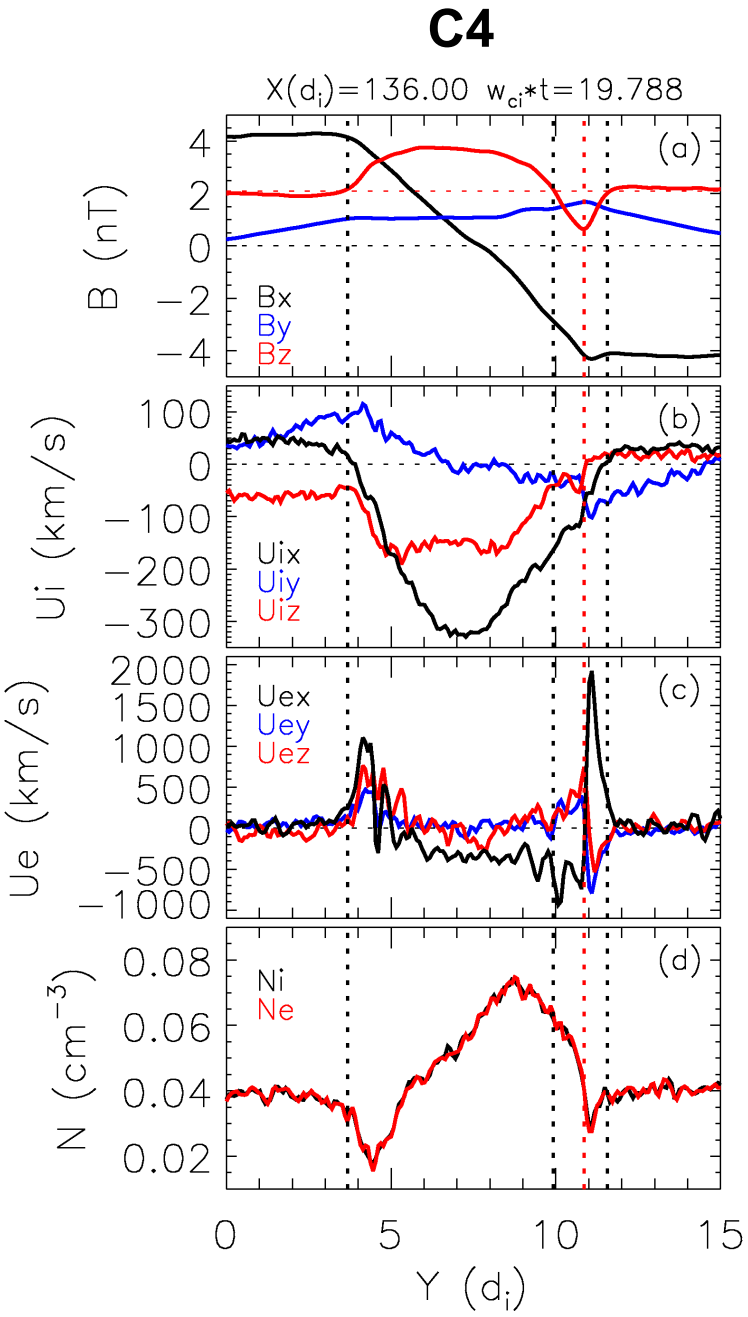

(f)
dM (Li)
dL (Li)

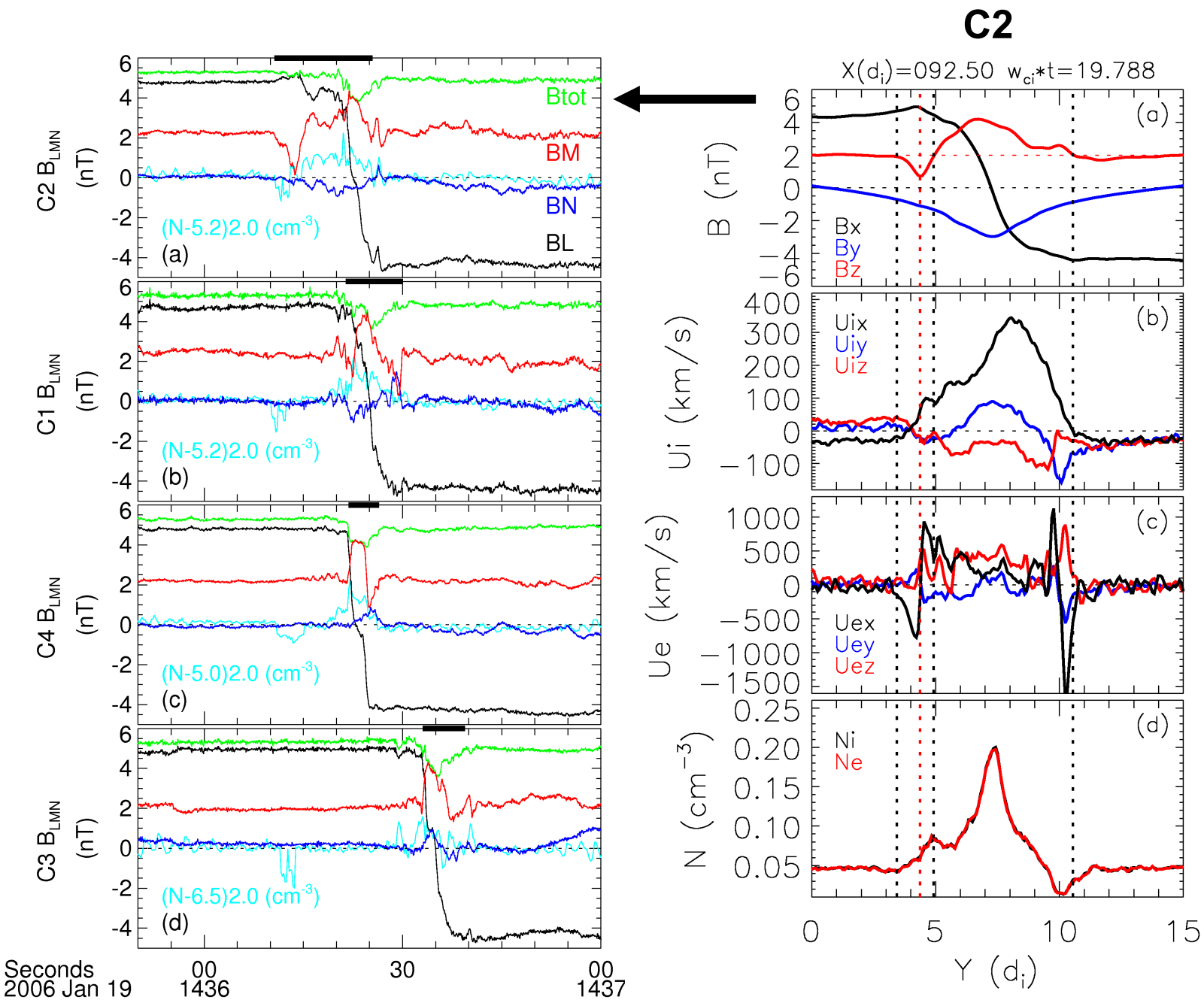

(g)
dM (Li)
dN (Li)

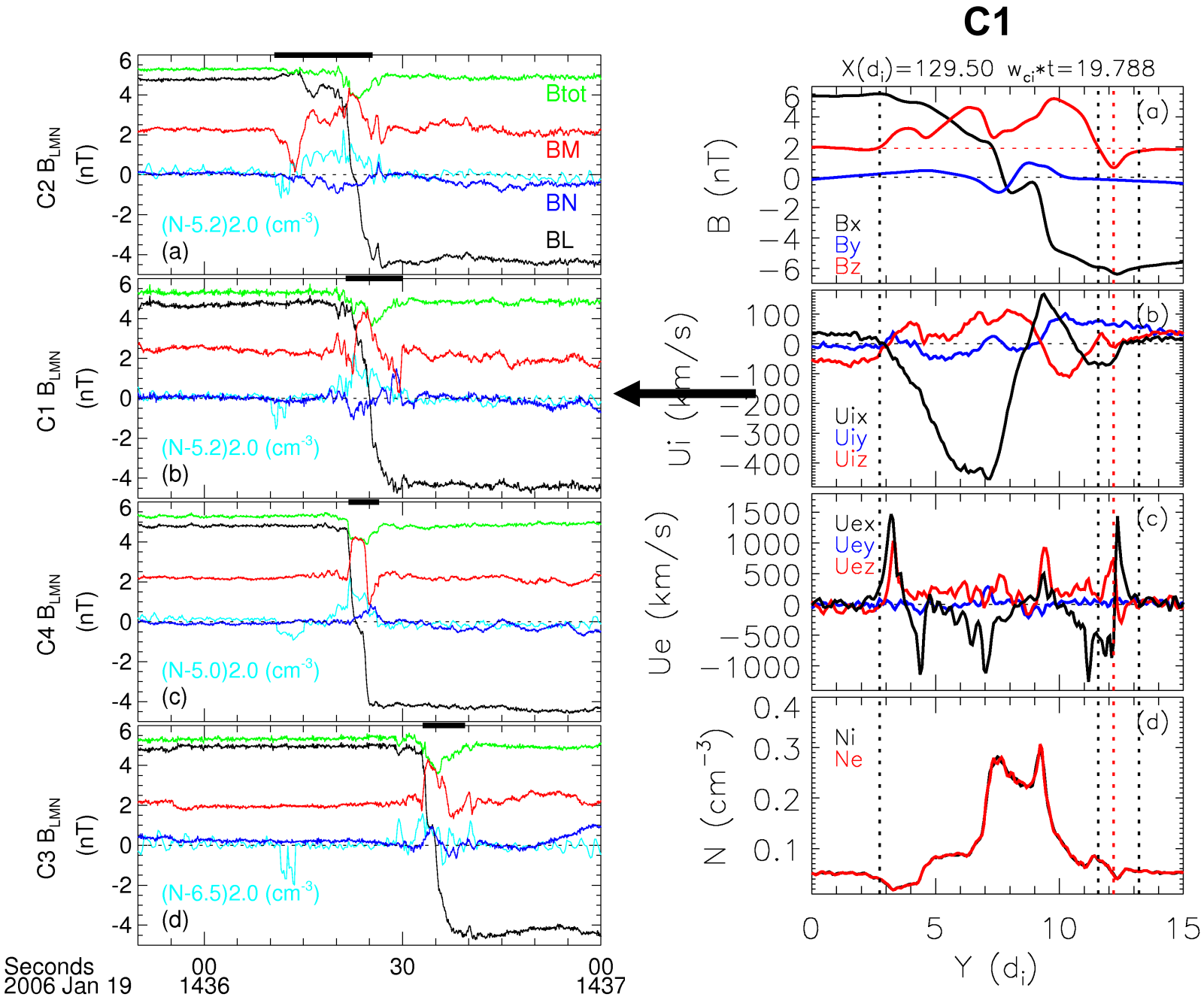

(Bz-Bz0)/Bx0 (ωcit=19.788)
C1
C4
y/di
x/di
(Bz-Bz0)/Bx0 (ωcit=19.788)
C2
C1
C4
y/di
x/di
(Bz-Bz0)/Bx0 (ωcit=19.788)
C2
C1
C4
y/di
x/di
C2
X(di)=092.50 wci*t=19.788
B (nT)
Bx
By
Bz
(a)
Ui (km/s)
Uix
Uiy
Uiz
(b)
Ue (km/s)
Uex
Uey
Uez
(c)
N (cm-3)
Ni
Ne
(d)
Y (di)

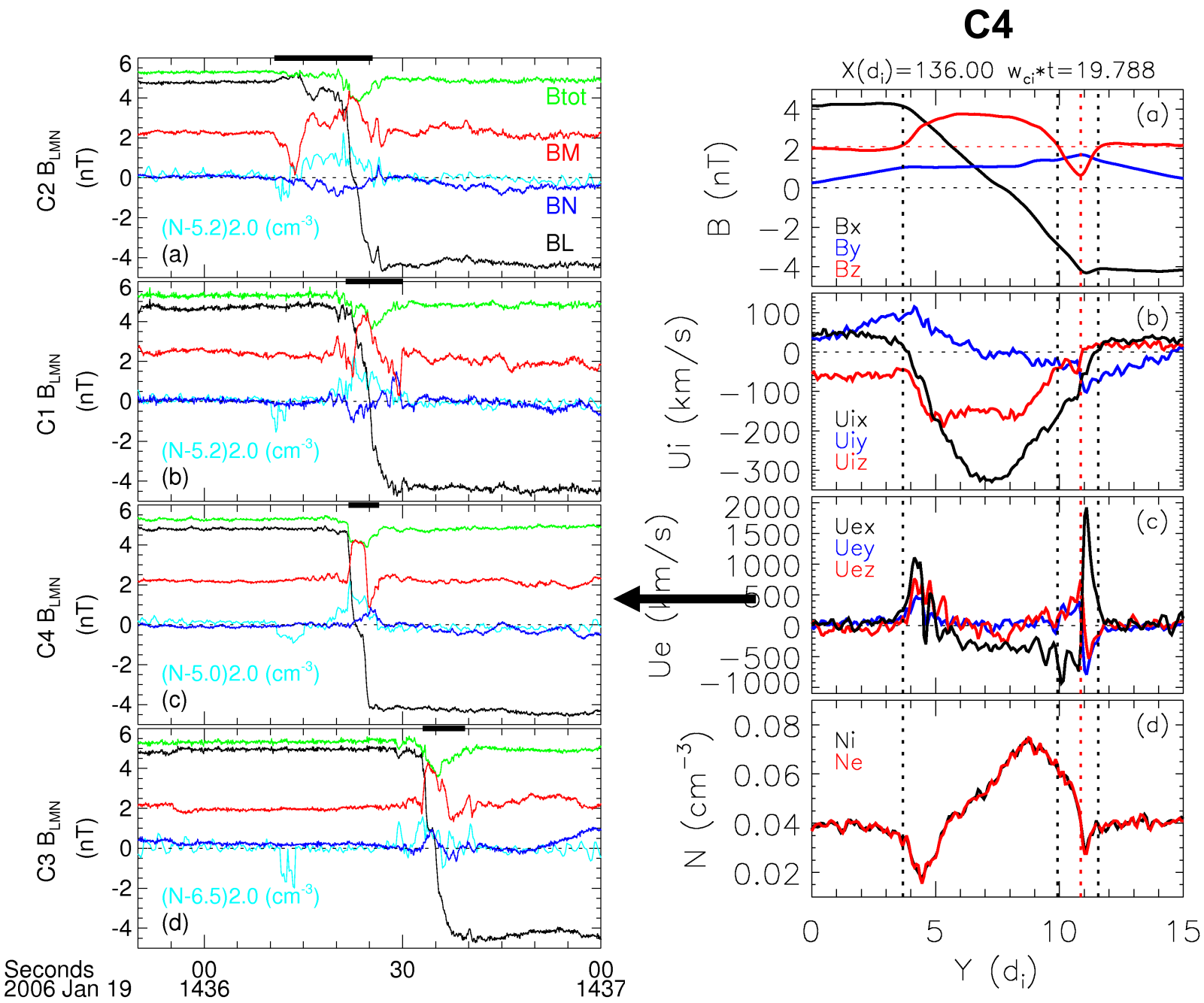

(B_z-B_z0)/B_x0 (ω_ci t=19.788)
C1
C4
y/d_i
x/d_i
(B_z-B_z0)/B_x0 (ω_ci t=19.788)
C2
C1
C4
y/d_i
x/d_i
(B_z-B_z0)/B_x0 (ω_ci t=19.788)
C2
C1
C4
y/d_i
x/d_i
C1
X(d_i)=129.50 w_ci*t=19.788
B (nT)
Bx
By
Bz
(a)
Ui (km/s)
Uix
Uiy
Uiz
(b)
Ue (km/s)
Uex
Uey
Uez
(c)
N (cm^-3)
Ni
Ne
(d)
Y (d_i)


(Bz-Bz0)/Bx0 (ωcit=19.788)
C1
C4
y/di
x/di
(Bz-Bz0)/Bx0 (ωcit=19.788)
C2
C1
C4
y/di
x/di
(Bz-Bz0)/Bx0 (ωcit=19.788)
C2
C1
C4
y/di
x/di


C4
X(di)=136.00 wci*t=19.788
B (nT)
Bx
By
Bz
(a)
Ui (km/s)
Uix
Uiy
Uiz
(b)
Ue (km/s)
Uex
Uey
Uez
(c)
N (cm−3)
Ni
Ne
(d)
Y (di)


C2
X(d_i)=092.50 w_ci*t=19.788
C2 B_LMN (nT)
C1 B_LMN (nT)
C4 B_LMN (nT)
C3 B_LMN (nT)
Btot
BM
BN
BL
(N-5.2)2.0 (cm^-3)
(N-5.0)2.0 (cm^-3)
(N-6.5)2.0 (cm^-3)
(a)
(b)
(c)
(d)
Seconds
2006 Jan 19
00
1436
30
00
1437
B (nT)
Bx
By
Bz
Ui (km/s)
Uix
Uiy
Uiz
Ue (km/s)
Uex
Uey
Uez
N (cm^-3)
Ni
Ne
Y (d_i)


C1
X(d_i)=129.50 w_ci*t=19.788
C2 B_LMN (nT)
C1 B_LMN (nT)
C4 B_LMN (nT)
C3 B_LMN (nT)
Btot
BM
BN
BL
(N-5.2)2.0 (cm^-3)
(N-5.0)2.0 (cm^-3)
(N-6.5)2.0 (cm^-3)
(a)
(b)
(c)
(d)
Seconds
2006 Jan 19
00
1436
30
00
1437
B (nT)
Bx
By
Bz
Ui (km/s)
Uix
Uiy
Uiz
Ue (km/s)
Uex
Uey
Uez
N (cm^-3)
Ni
Ne
Y (d_i)


C4
X(d_i)=136.00 w_ci*t=19.788
C2 B_LMN (nT)
C1 B_LMN (nT)
C4 B_LMN (nT)
C3 B_LMN (nT)
Btot
BM
BN
BL
(N-5.2)2.0 (cm^-3)
(N-5.0)2.0 (cm^-3)
(N-6.5)2.0 (cm^-3)
(a)
(b)
(c)
(d)
Seconds
2006 Jan 19
00
1436
30
00
1437
B (nT)
Bx
By
Bz
Ui (km/s)
Uix
Uiy
Uiz
Ue (km/s)
Uex
Uey
Uez
N (cm^-3)
Ni
Ne
Y (d_i)

Summary iPIC3D

- *Very important tool* for solar wind reconnection analysis (in particular) and elsewhere

- *Kinetic physics* support now needed to guide high-resolution observations from Cluster, THEMIS, and soon MMS…

- Kinetic model results, *as MHD simulations before them*, should be made available to a wider community. There is just too much output for a few selected individuals to fully appreciate.