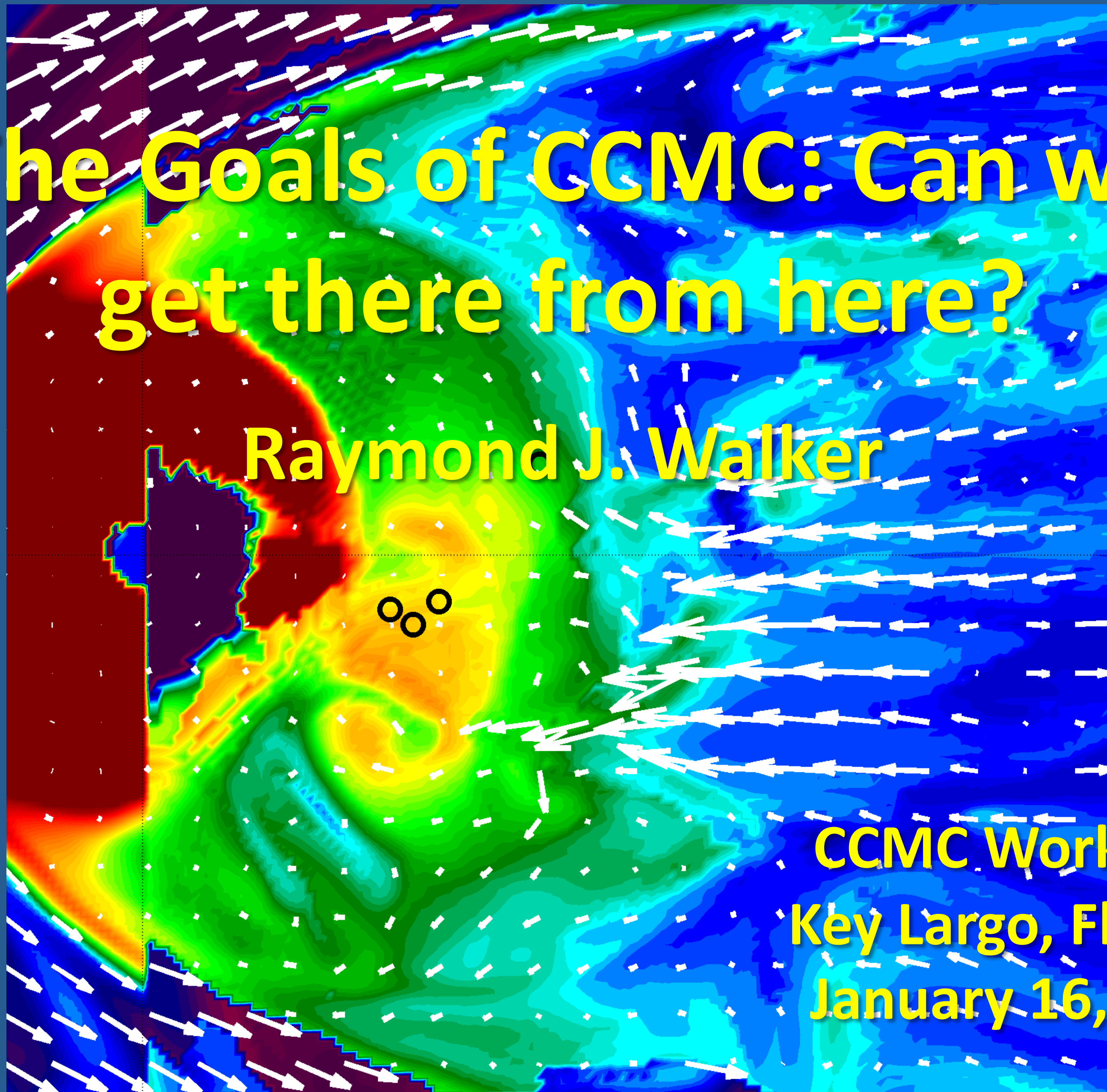
The Goals of CCMC: Can we get there from here?

Raymond J. Walker

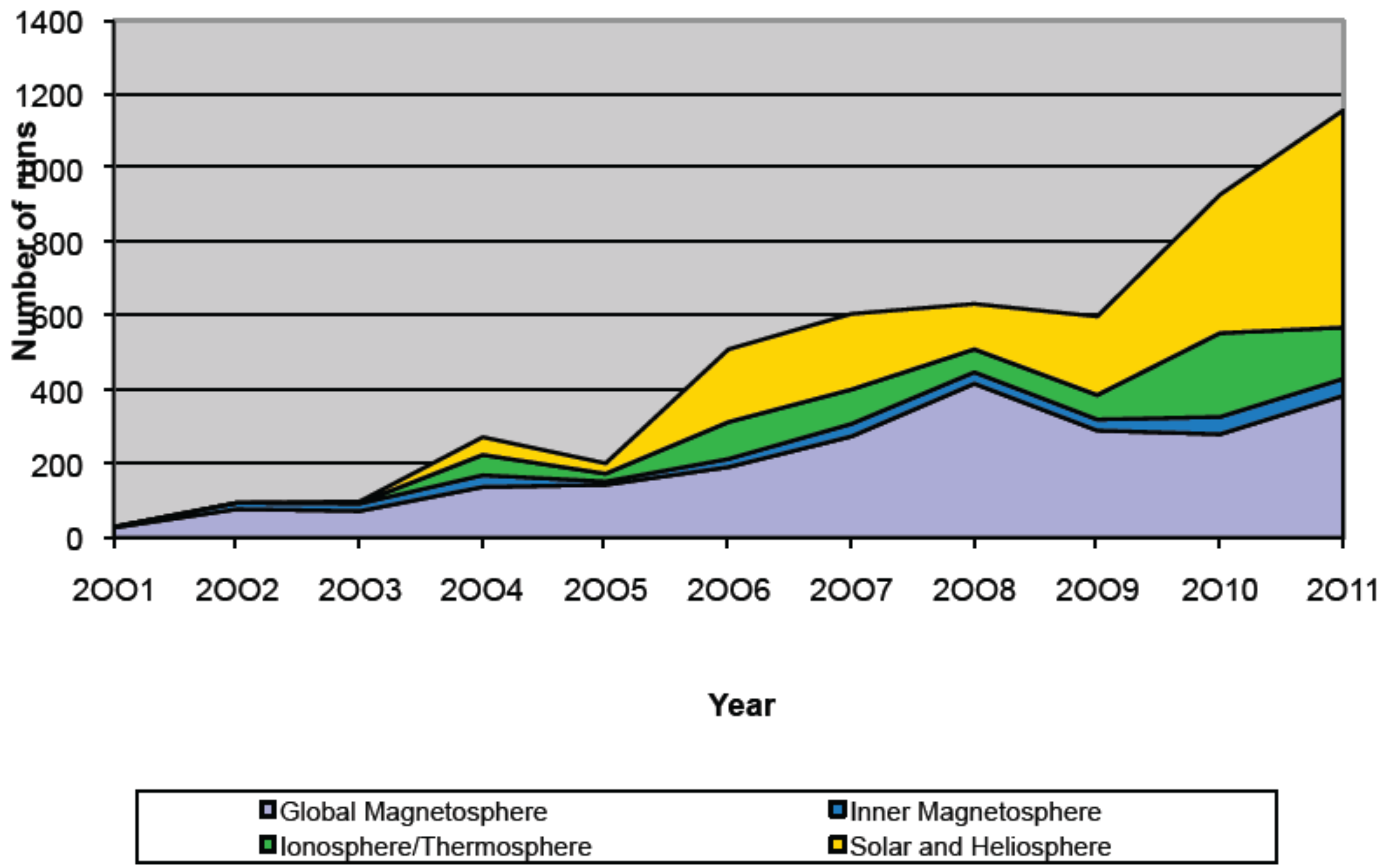


CCMC Workshop
Key Largo, Florida
January 16, 2012

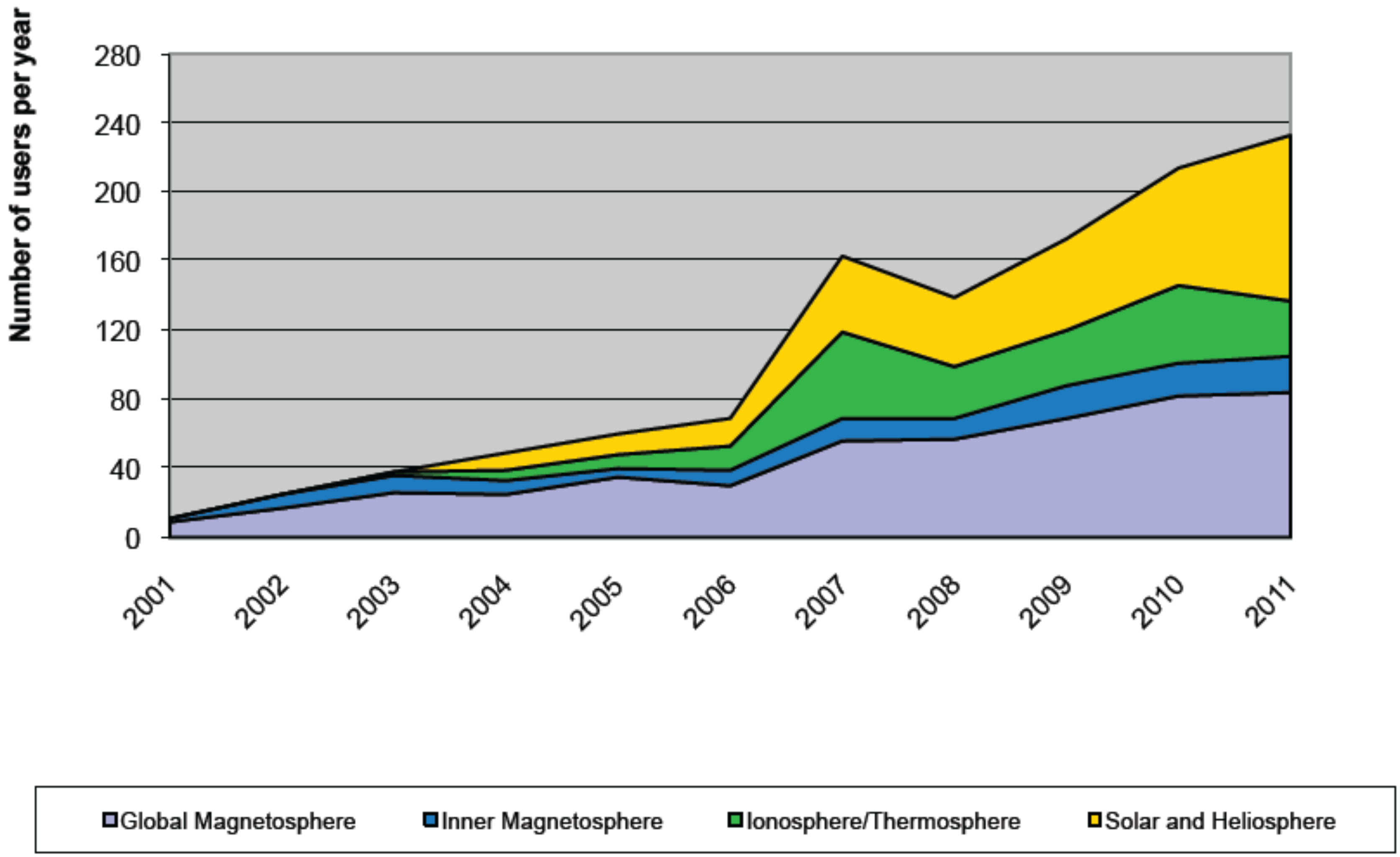
Goals of CCMC- Use Simulations and Models

- To support basic research in solar, heliospheric, magnetospheric and ionospheric physics.
- To support both scientific and operations based space weather research.
- To support improved scientific literacy in space physics.

CCMC is Used: Runs on Request by Discipline



CCMC is Used: Number of Users



The Casual Simulation User

- With the advent of easy to obtain simulations at CCMC a new type of user has been created.
- Data analysts now regularly use simulations to interpret their observations.
- The user frequently knows little about how simulations work.
- Simulations are used as black boxes with little understanding of their strengths or limitations.
- A similar situation occurs with data analysis techniques – with easy to use software (MATLAB, IDL) it is possible to carry out complex analyses without understanding the underlying mathematics.

A Simulation Course for Data Analysts

- **Course goal is to make students into critical simulation users.**
- I am not trying to teach students to become simulators although some simulation students have taken the classes.
- It is not a course in simulation techniques although we discuss them.
- We want students to have a feeling for both the strengths and limitations of simulations.
- Course is based on a current space physics problem that is being addressed by using simulations.
- We study the science problem and the simulations that are being used to address the problem.
- The course covers a lot of material and is fairly intensive.

Course Content

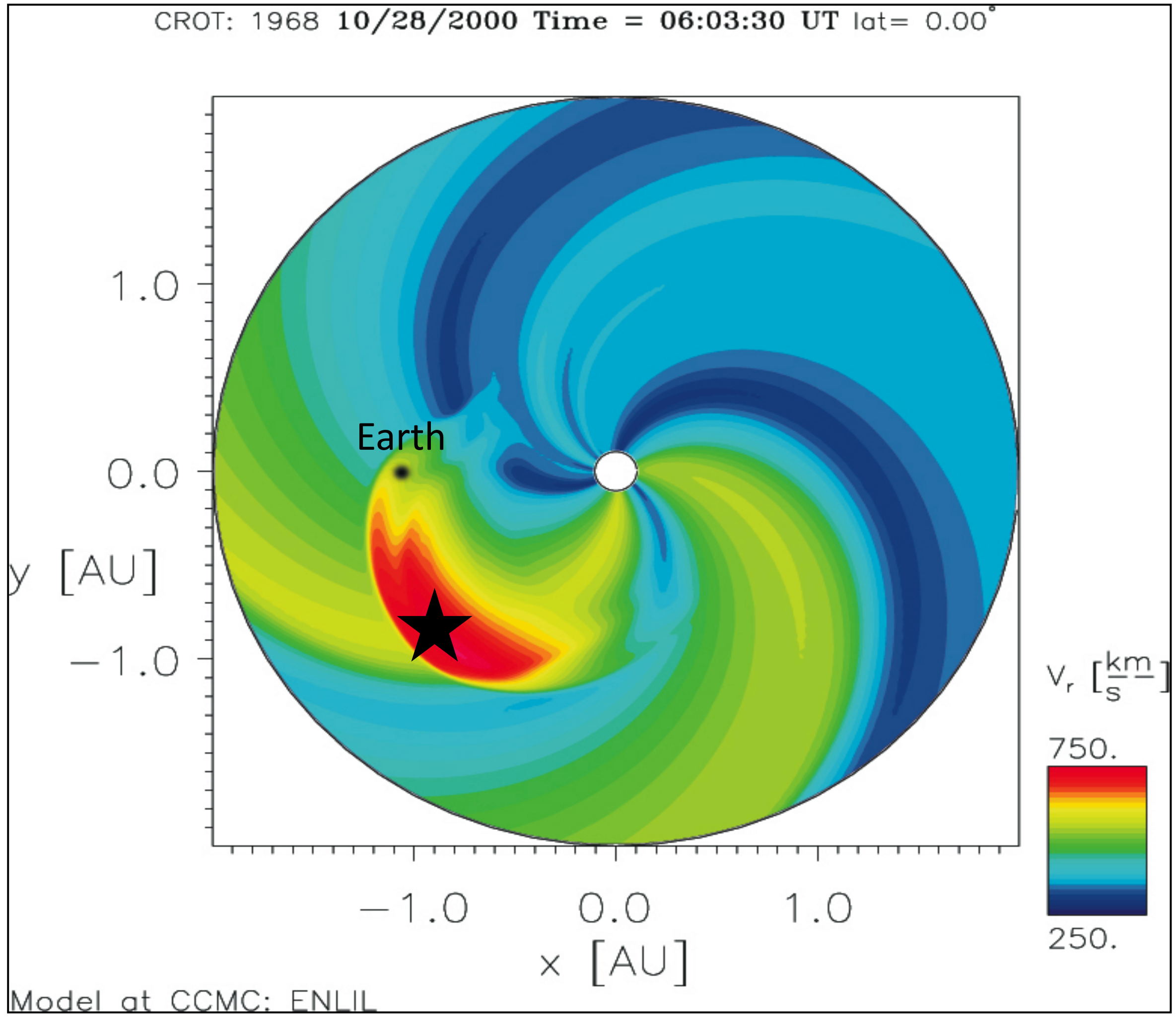
- All of the students have had at least one course in plasma physics and one course in space plasma physics.
- Select a current space physics problem – e.g. simulating the evolution of substorms, simulating the response of the magnetosphere to a ICME.
- Review the state of our understanding of the problem.
- Study the basics of solving sets of partial differential equations.
- Study in detail each of the simulation codes – e.g. Open GGCM, BATSRUS etc.
- Select a problem and then with the help of CCMC run the codes and critically analyze the results.

Simulations and Lower Division Education

- Last quarter I taught a freshman course on the "Perils of Space".
- The students are mostly freshmen with no mathematics background.
- CCMC now has a large archive of runs which in principle can be useful in education.
- Simulations can be useful for
  - Demonstrating basic ideas
  - Visualizing complex systems
  - Showing time dependencies

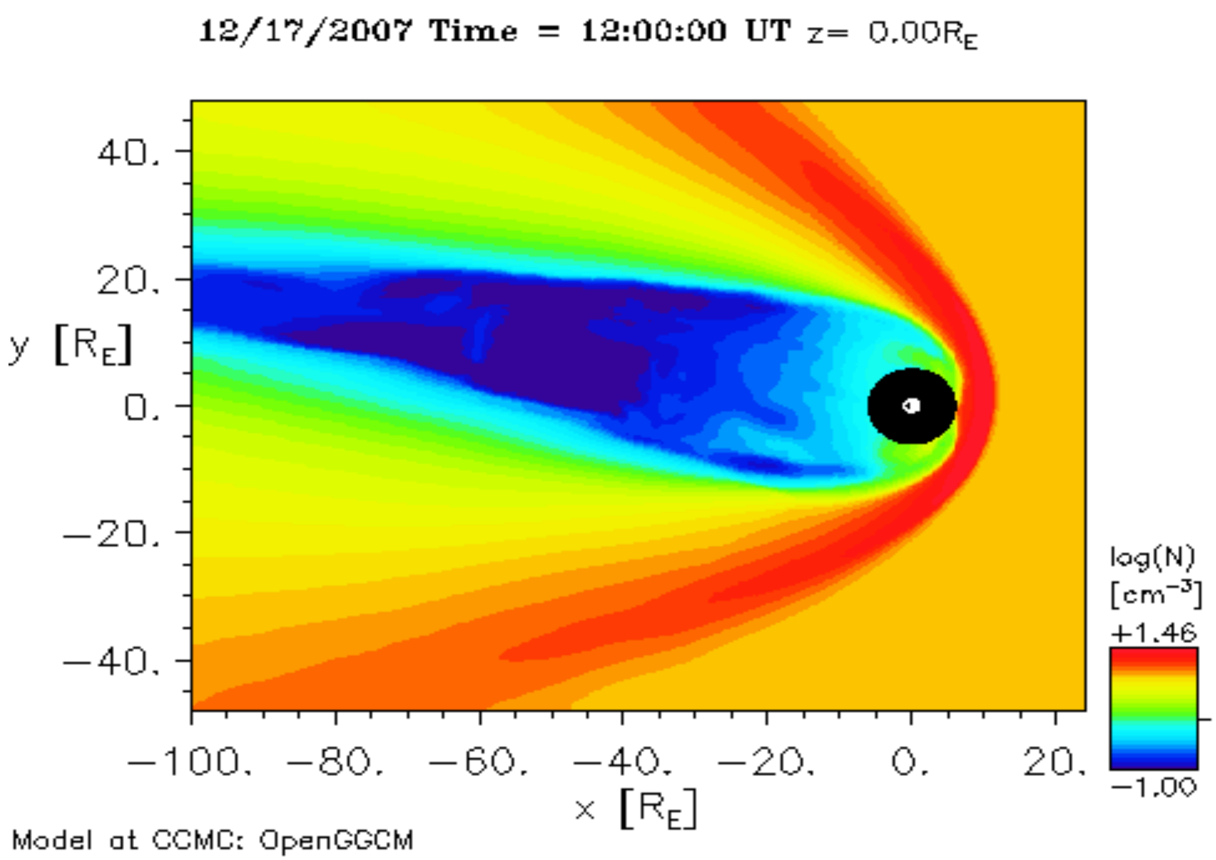
A CME at Earth

- Radial velocity from ENLIL
- Black dot shows location of Earth
- Grazing impact
- Similar results from density and magnetic field
- The star is the "core of the CME"



Demonstrating a Basic Idea

Compression at the Bow Shock



The supersonic solar wind compresses the front side of the magnetosphere and shocked compressed solar wind forms the *magnetosheath*. *Inside* the magnetosphere, the magnetic field dominates and density is low.

Courtesy of Martin Connors

Can we get there from here? Self-consistent Models of the Magnetosphere

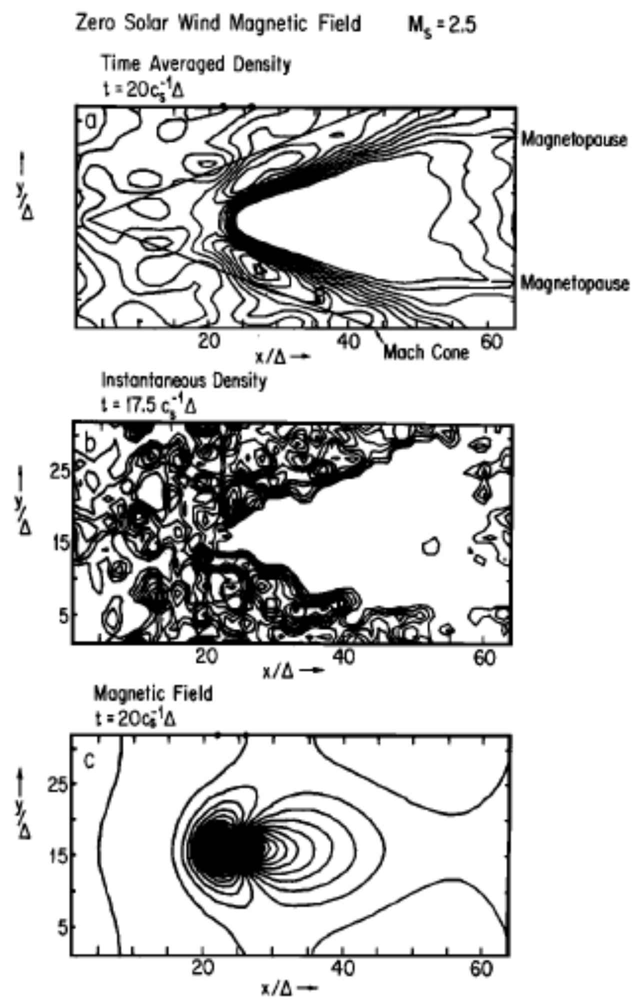


Fig. 1. Magnetosphere with no Solar Wind Magnetic

Le Boeuf et al. 1978

- Global magnetohydrodynamic simulations are the workhorses of early 21st century magnetospheric modeling.
- Reproduce in 3D the major features of the magnetsphere and its boundaries.
- Used to study the overall configuration of the magnetosphere under ideal conditions.
- Used to model the highly dynamic changes in the magnetosphere.

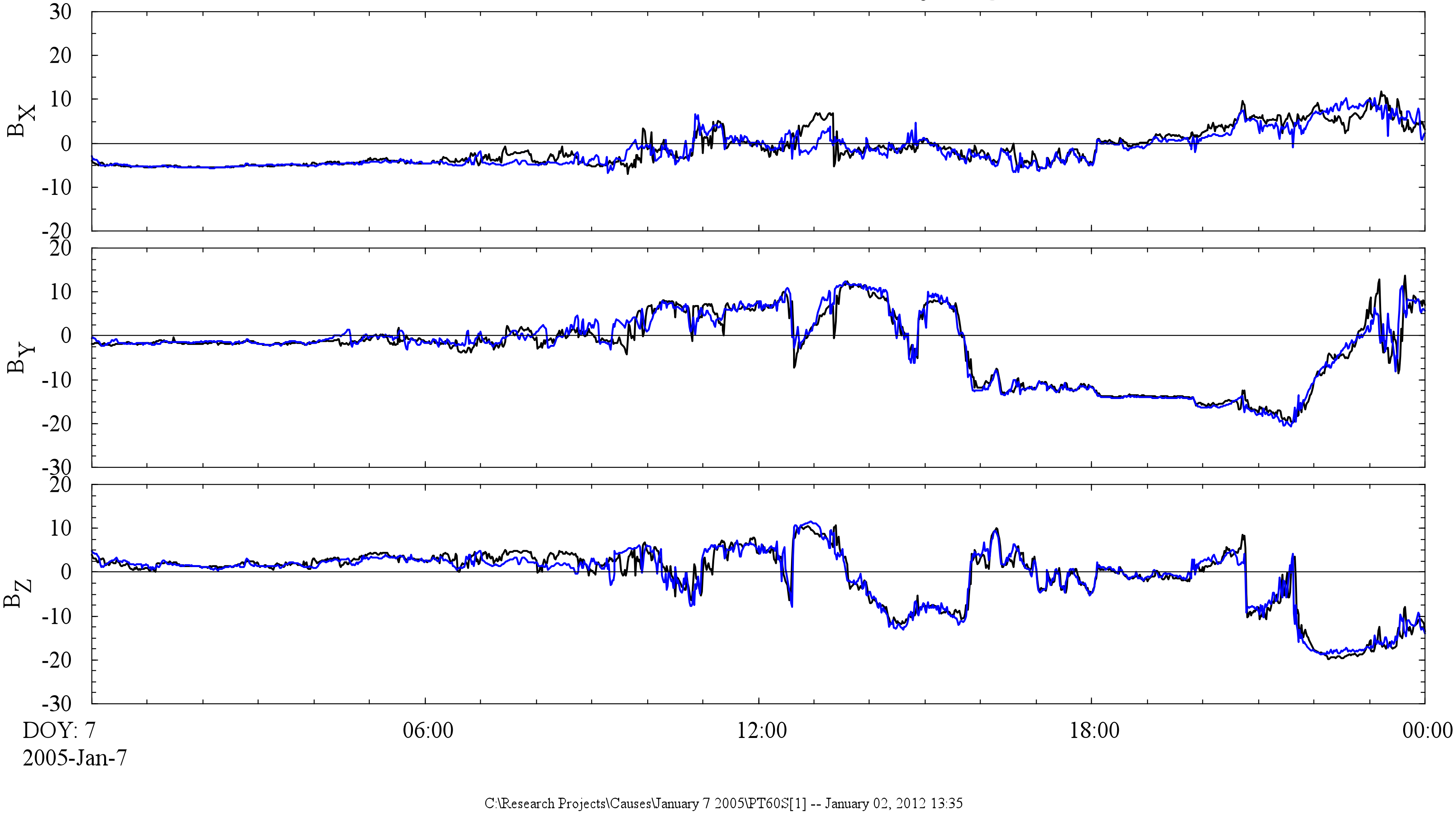
Limitations

- The model
  - Single fluid MHD in principle contains much of the essential physics in the momentum equation but simplifications in transport limit the model.
  - Ionosphere models frequently are simple.
- The implementation
  - MHD equations are solved on a grid. Resolution of gradients is limited.
  - Ionospheric boundary condition is applied at 2 R_E or 3 $R_{E.}$
- The solar wind
  - Assume that the solar wind from monitors is the solar wind the interacts with the magnetosphere.
  - Solar wind monitors used frequently are at L1 on near it so values must be propagated to the Earth.

Approach

- Concentrate on the problem of how well the observations of the solar wind actually give the solar wind interacting with the magnetosphere.
- Consider cases where there are multiple solar wind monitors and compare the propagated observations.
- Use the MHD code to simulate the magnetospheric configuration with input from more than one monitor and compare with observations in the magnetosphere.

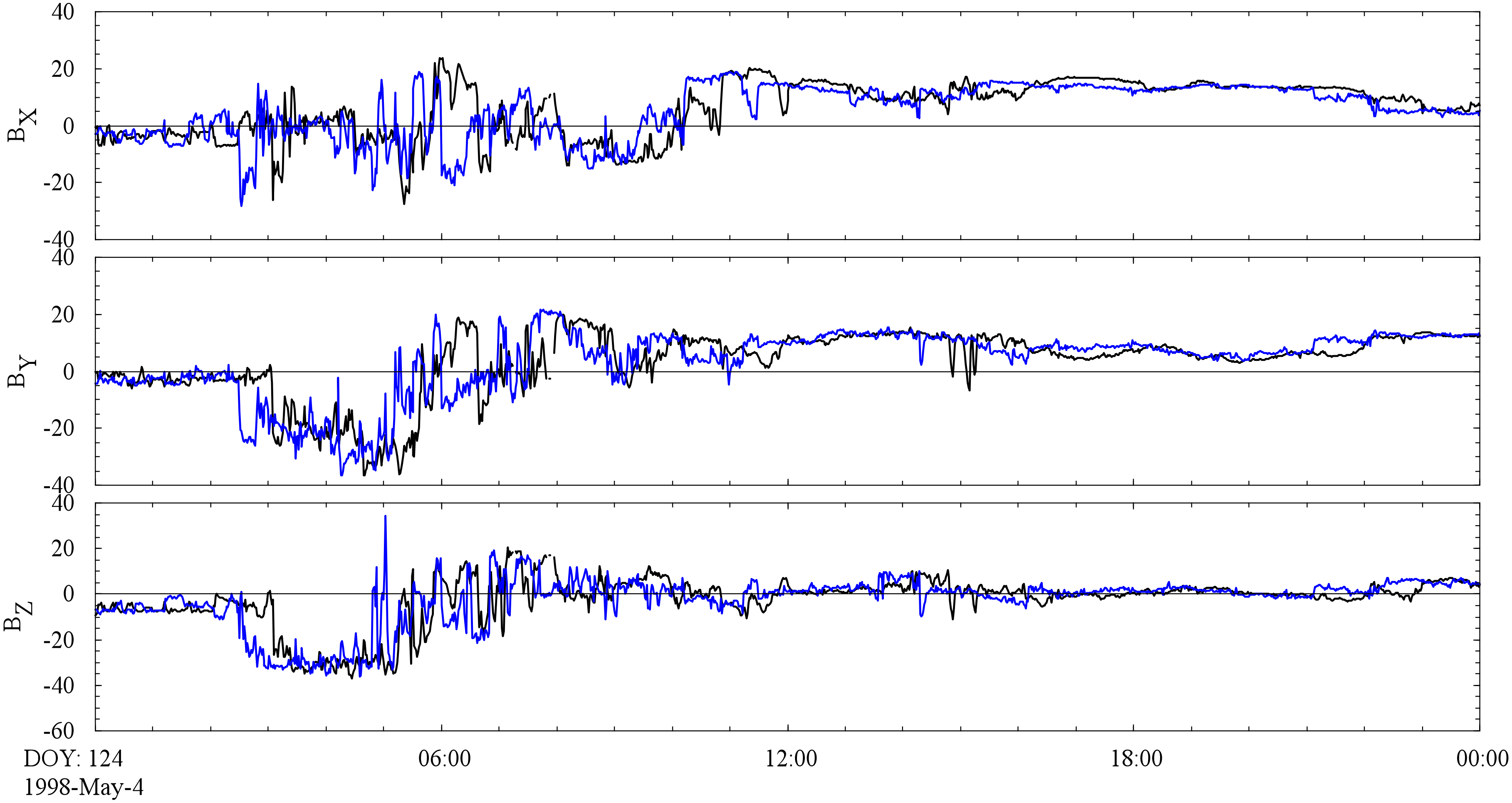
IMF on January 7, 2005
(GSM Coordinates Propagated)



ACE (228.9, -39.2, 24.0)

Wind (254.2, 36.8, 17.1)

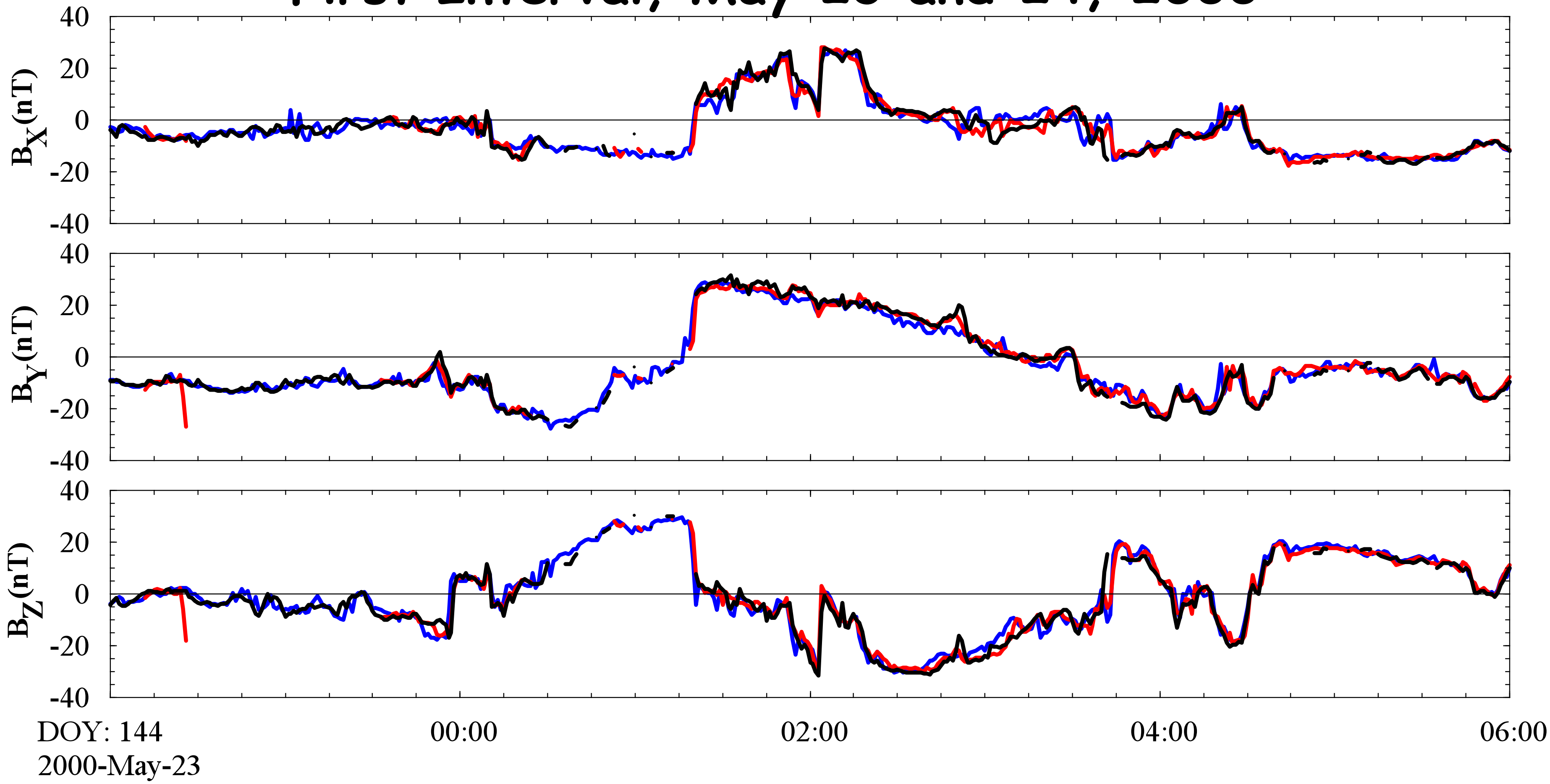
IMF on May 4, 1998
(GSM Coordinates Propagated)



ACE (227.5, -29.1, -20.1)

Wind (214, 0.8, 28)

IMF Observations in GSM coordinates from Wind, ACE and IMP-8
First Interval, May 23 and 24, 2000



IMP-8 (19.40, 34.3, -15.7)

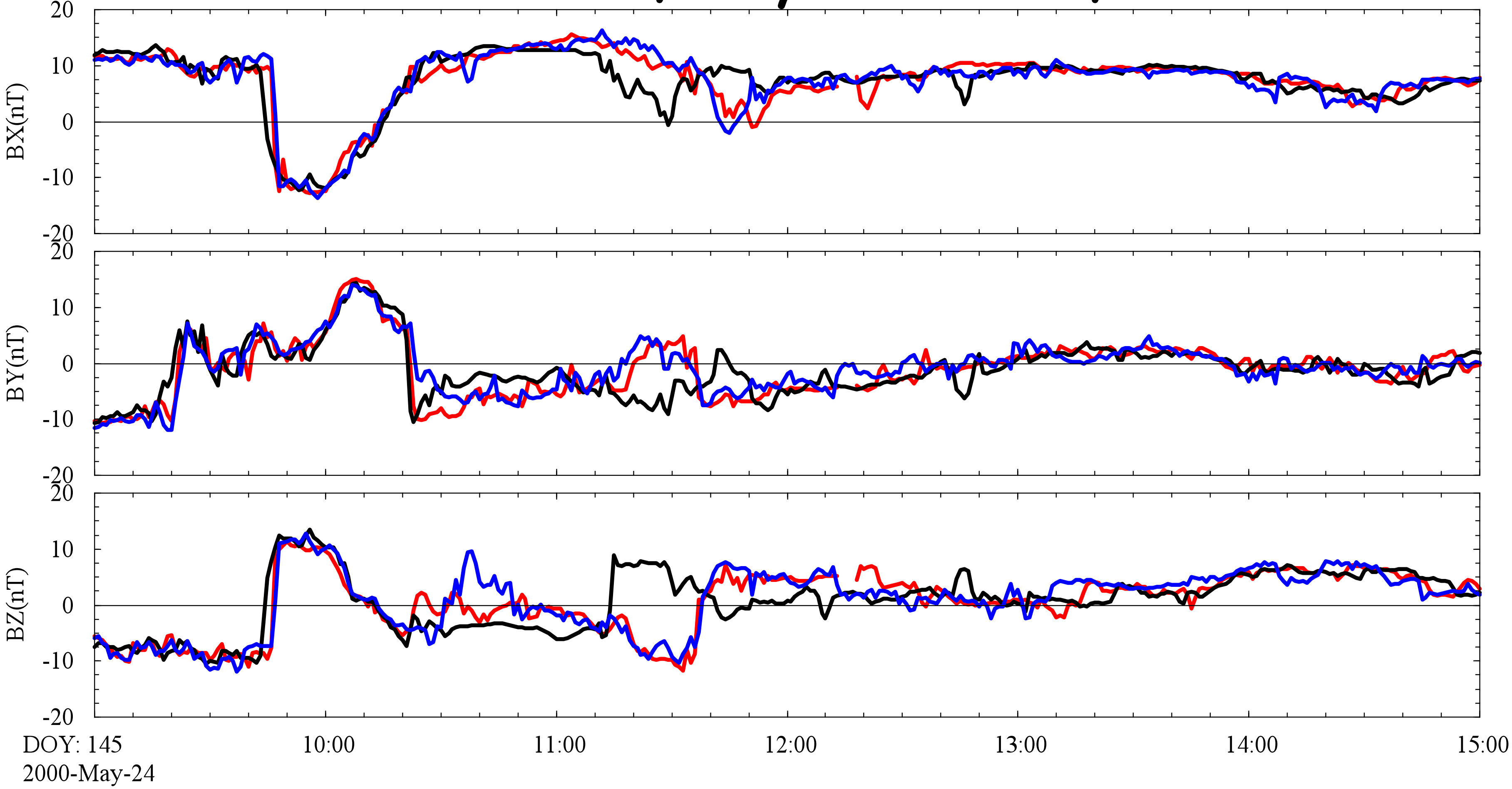
C:\Research Projects\Causes\May 24 2000\Document1 -- November 23, 2011 16:41

Wind (44.62, 5.68, -1.79)

ACE (227.00, 32.87, -9.87)

After Ashour-Abdalla et al., 2008

Propagated IMF Observations in GSM Coordinates from Wind, ACE and IMP-8
Second Interval, May 23 and 24, 2000



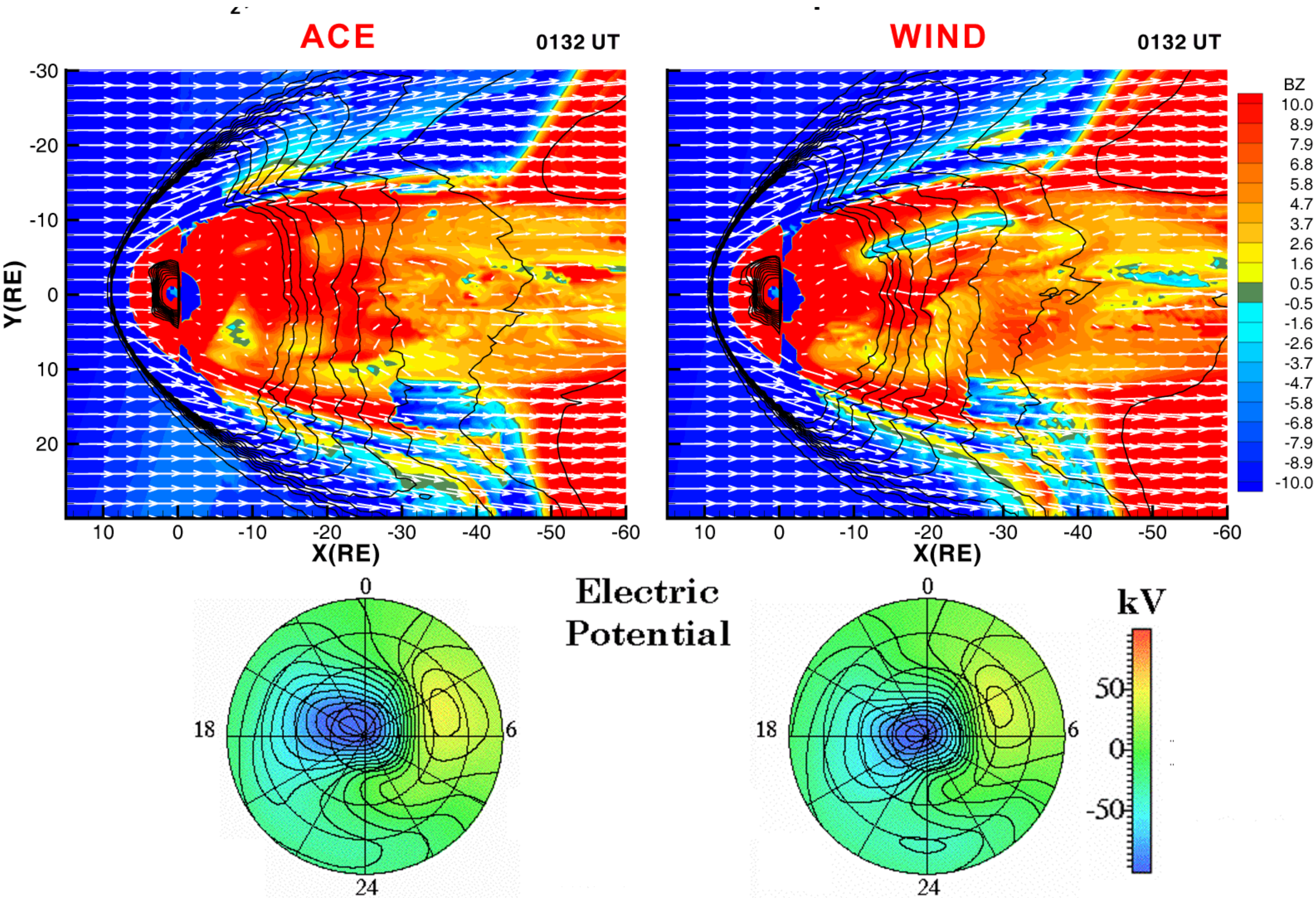
IMP-8 (15.00, 30.3, -24.3) C:\Research Projects\Causes\May 24 2000\BXByBz ACE Wind IMP8 -- November 01, 2011 18:04

Wind (37.58, 6.97, -2.89)

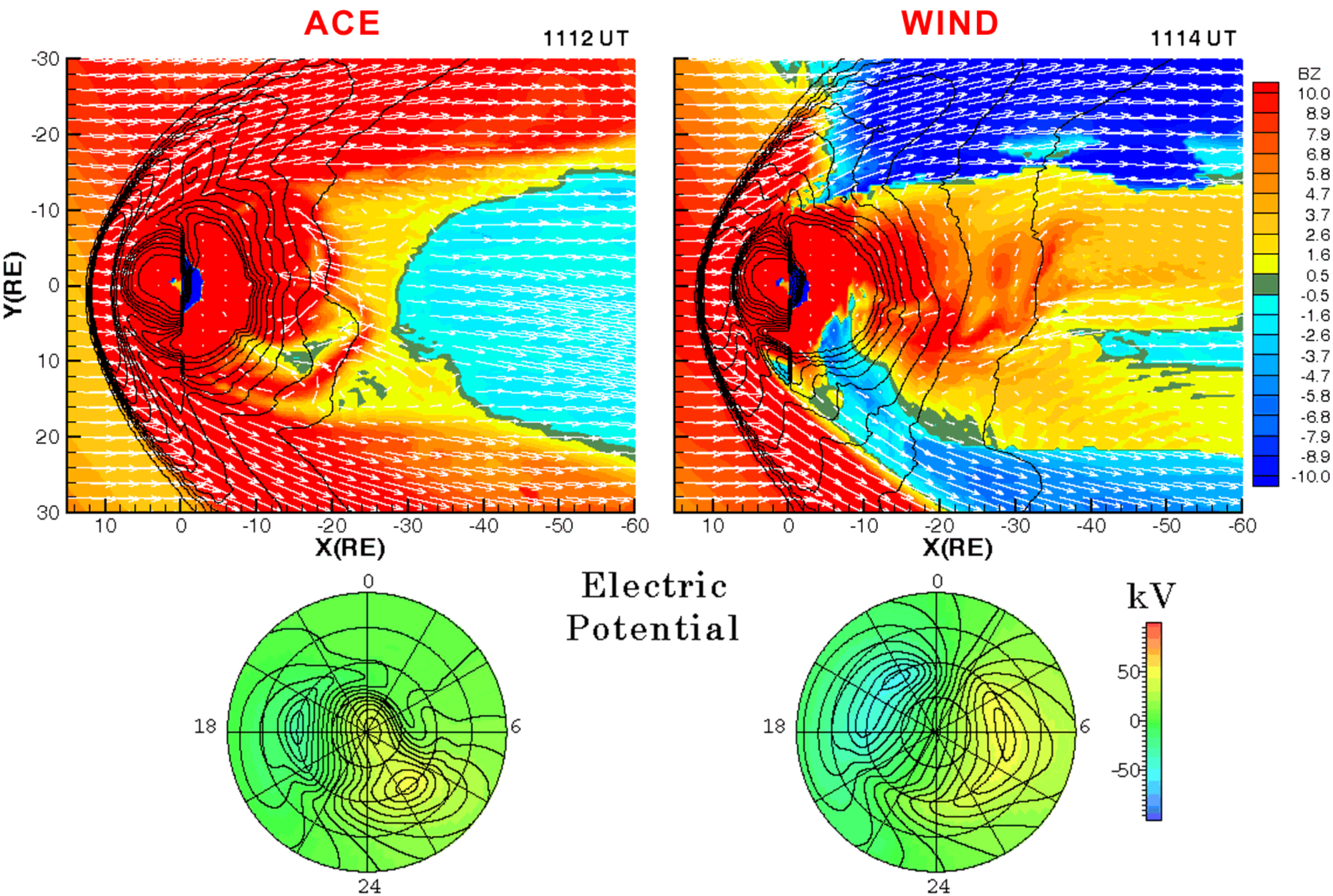
ACE (227.20, 27.59, -20.78)

After Ashour-Abdalla et al., 2008

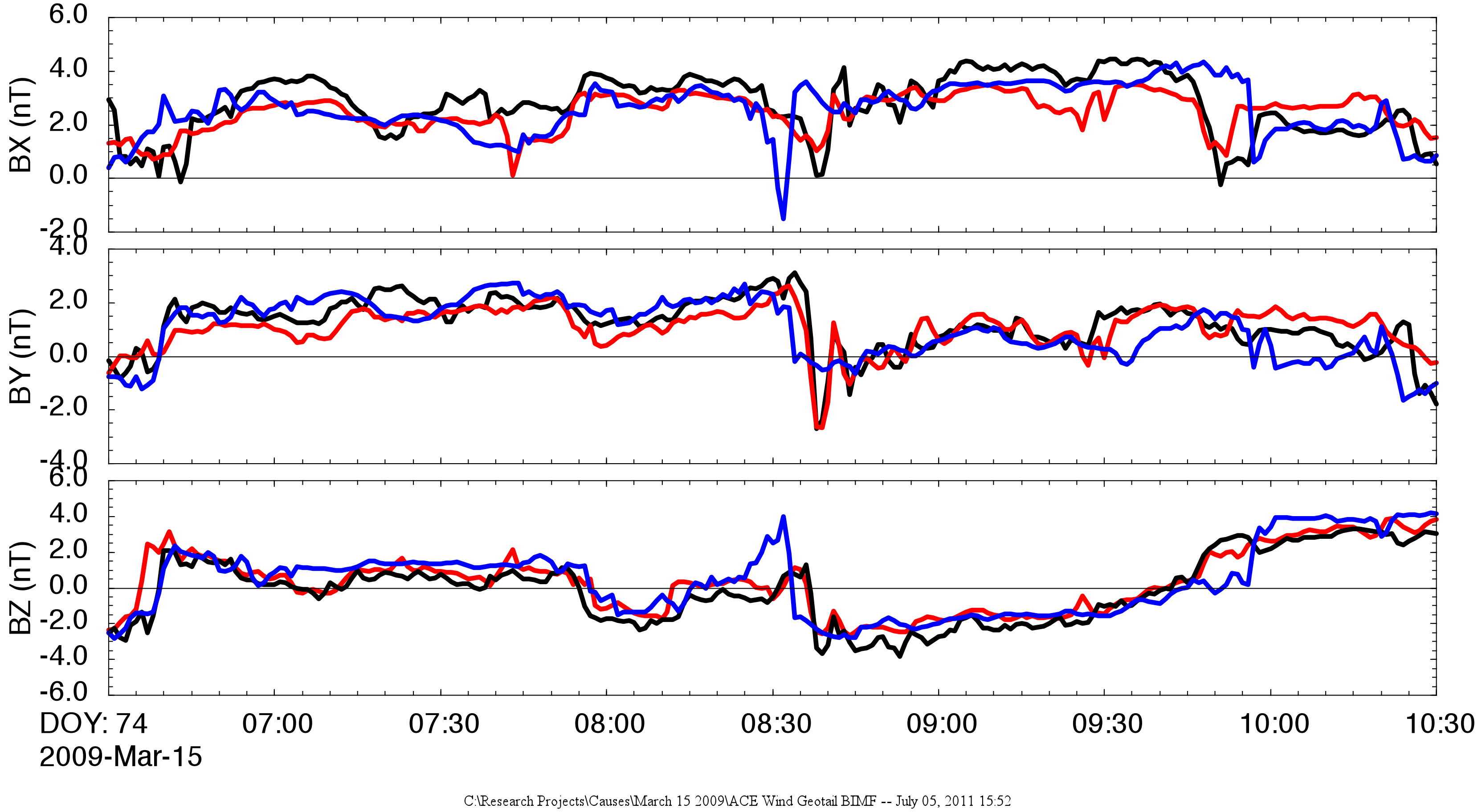
Bz and Flows in the "Equatorial" Plane



Bz and Flows in the "Equatorial" Plane –Second Interval



IMF on March 15, 2009
(GSM Coordinates – Propagated)



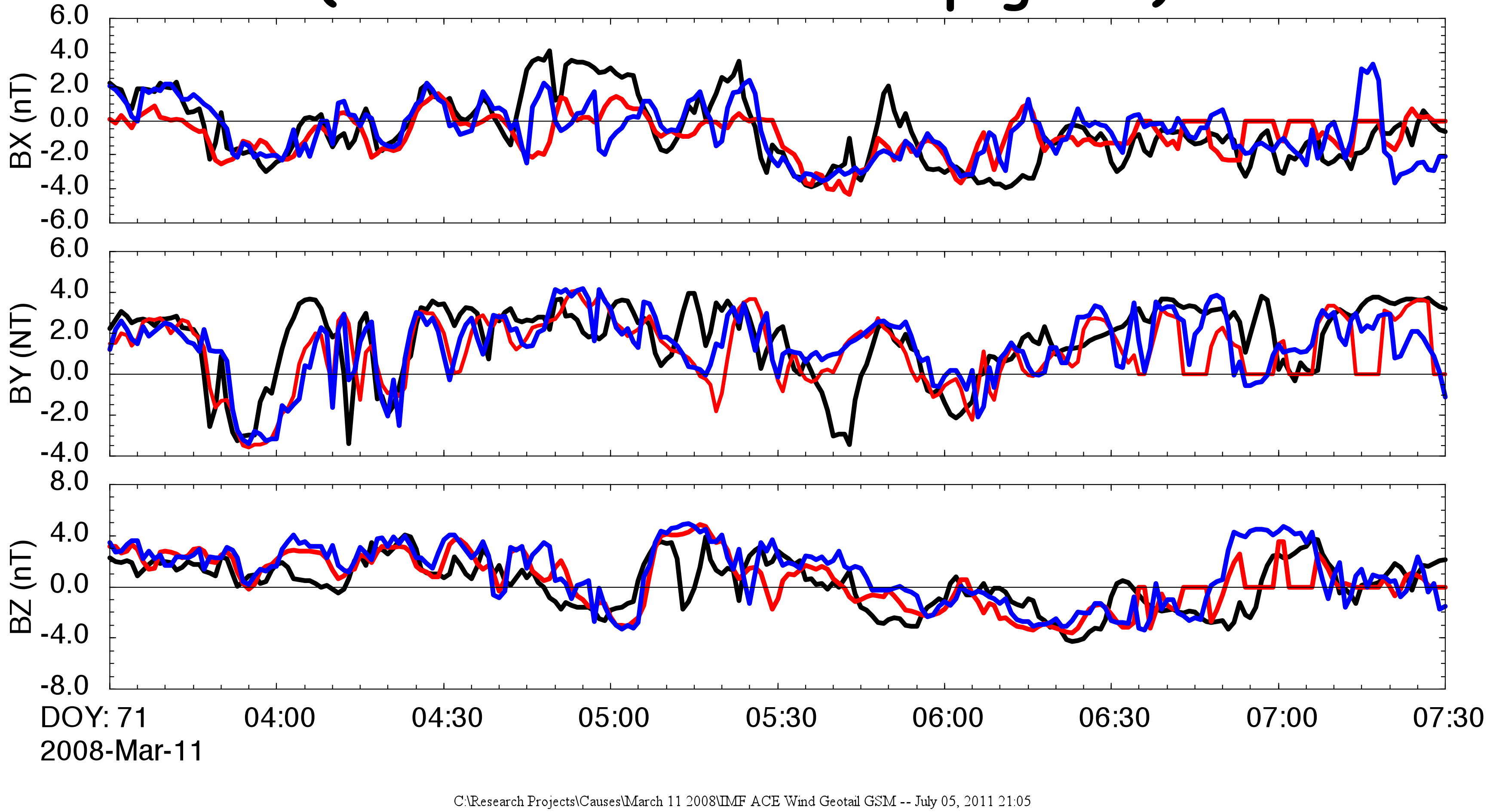
ACE (GSM) 243.6, 18.37, -12.58

Geotail (GSM) 17.74, -14.8, -7.37

Wind (GSM) 197.5, 37.55, 2.88

Courtesy of Meng Zhou

IMF on March 11, 2008
(GSM Coordinates – Propagated)

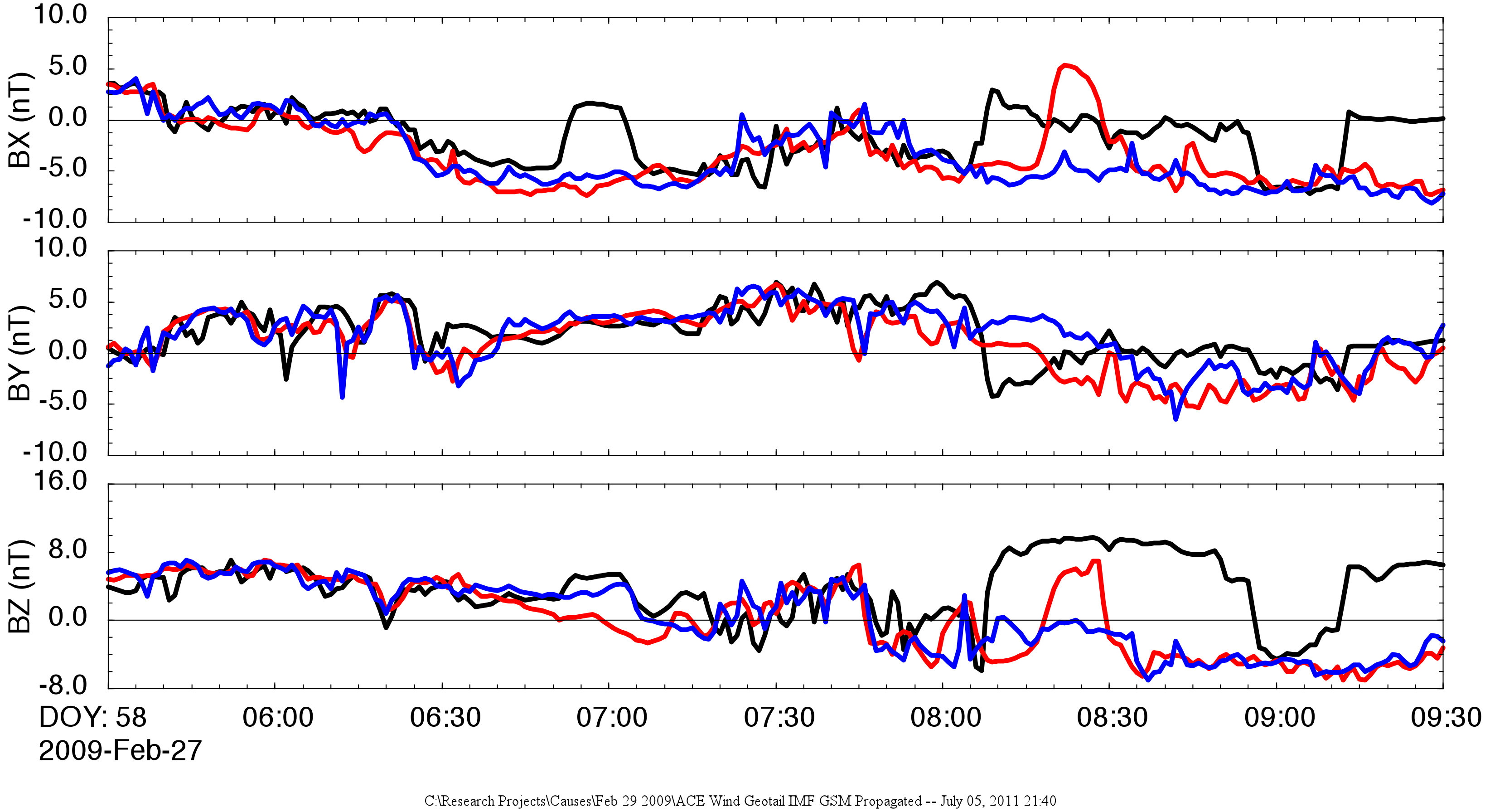


ACE (GSM) 239.6, 35.04, 3.02

Geotail (GSM) 14.56, 0.01, -0.71

Wind (GSM) 197.7, -3.53, -26.3

IMF on February 27, 2009
(GSM Coordinates – Propagated)

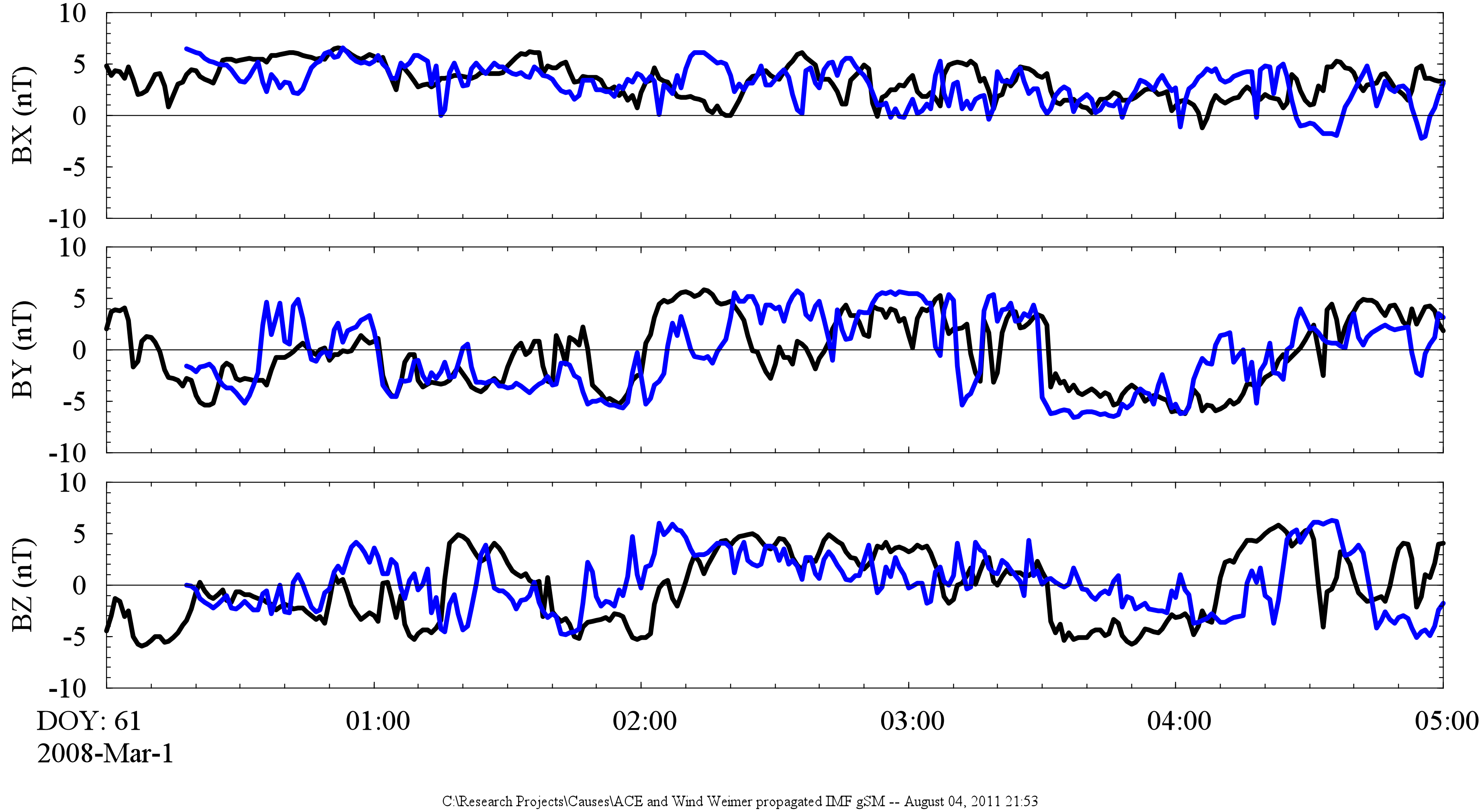


ACE (GSM) 240.0, 29.71, 6.60

Geotail (GSM) 19.43, -14.7, -15.6

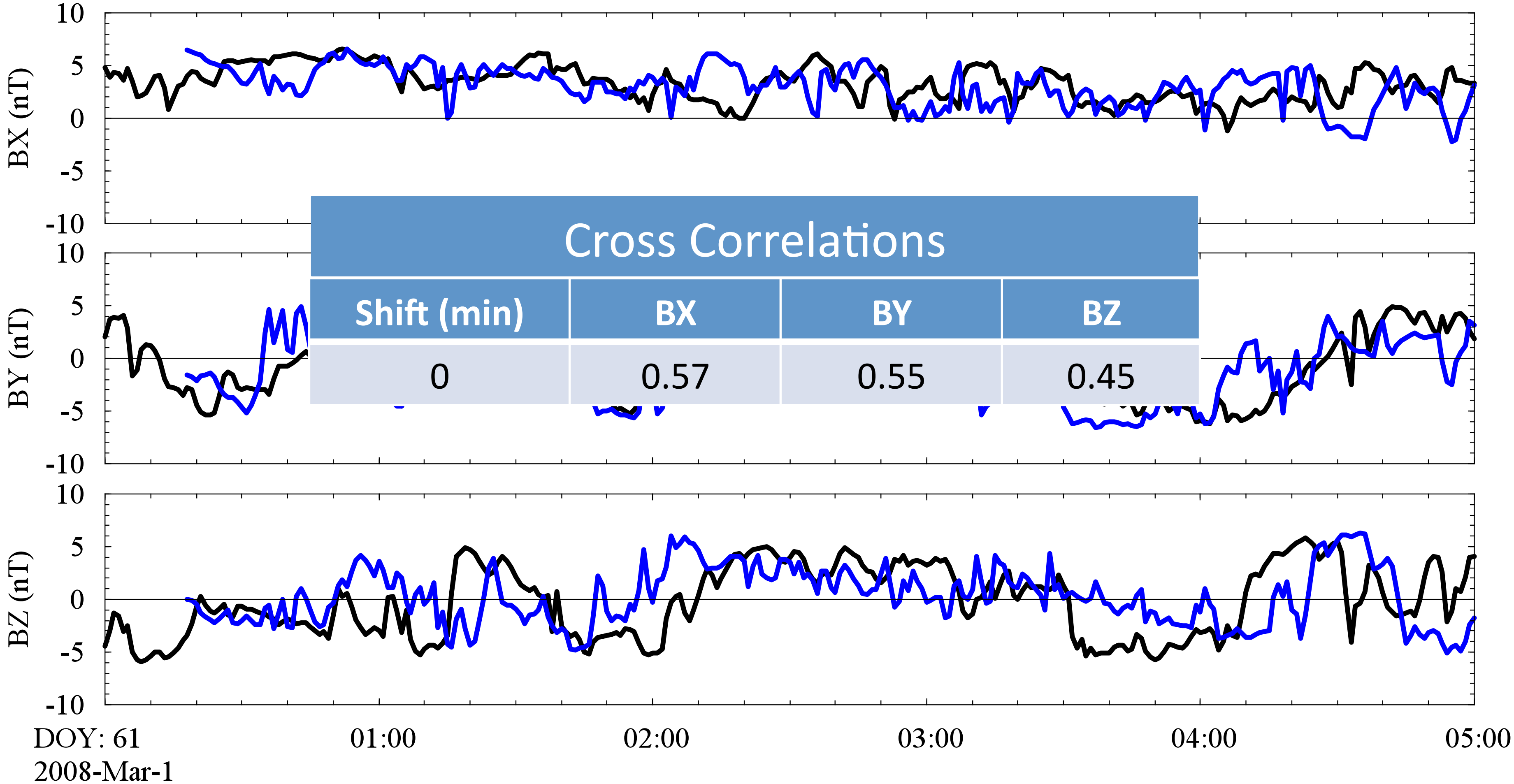
Wind (GSM) 197.5, -10.6, -30.3

ACE (Black) and Wind (Blue) Propagated IMF in GSM



ACE (235, 36, 11) Wind (198, -40, -38)

ACE (Black) and Wind (Blue) Weimer Propagated IMF in GSM



Cross Correlations			
Shift (min)	**BX**	**BY**	**BZ**
0	0.57	0.55	0.45

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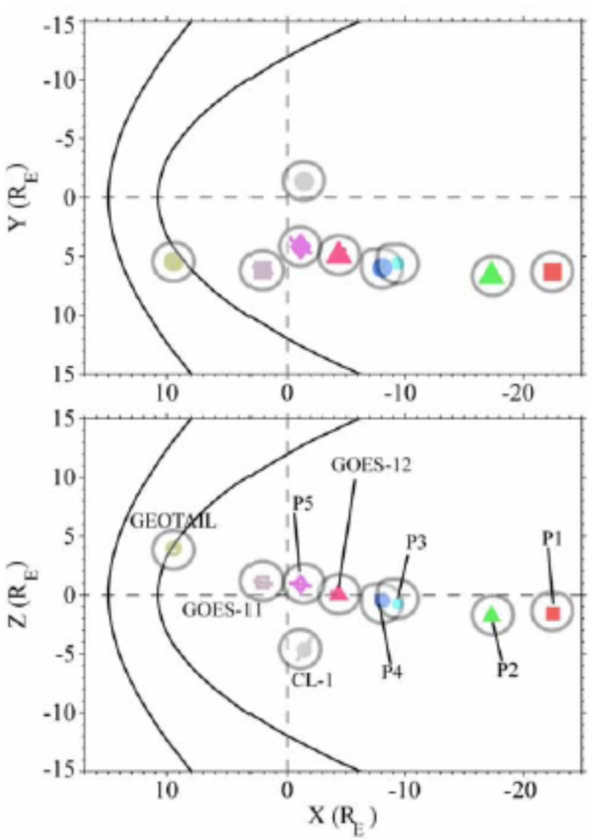
ACE (235, 36, 11) Wind (198, -40, -38)

March 1, 2008 –Solar Wind Monitors and Magnetospheric Spacecraft

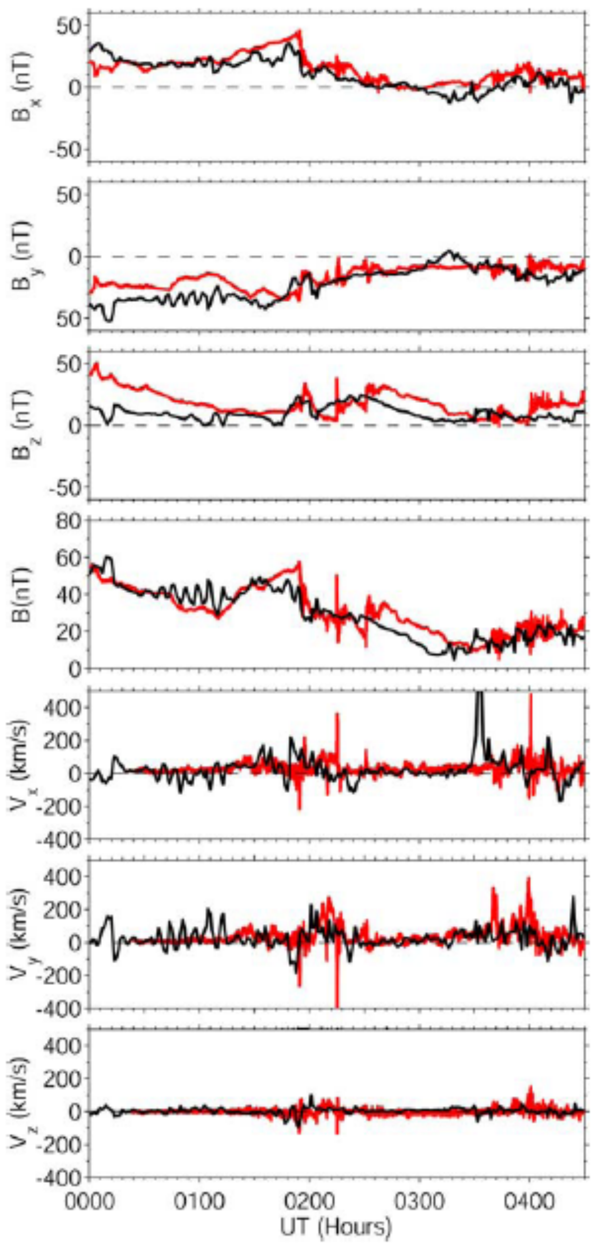
El- Alaoui et al., 2009



- ACE (235, 37, 9), Wind (199,-53, -17) in GSE
- Geotail in the magnetosheath
- THEMIS (P1 – P4) in the near-Earth tail.
- GOES-12 (nightside) and GOES-11 (dayside) synchronous orbit.
- THEMIS P5 in the inner magnetosphere.
- Cluster at high latitudes.

THEMIS P4 Observations (Red) and Wind Driven Simulation (Black)

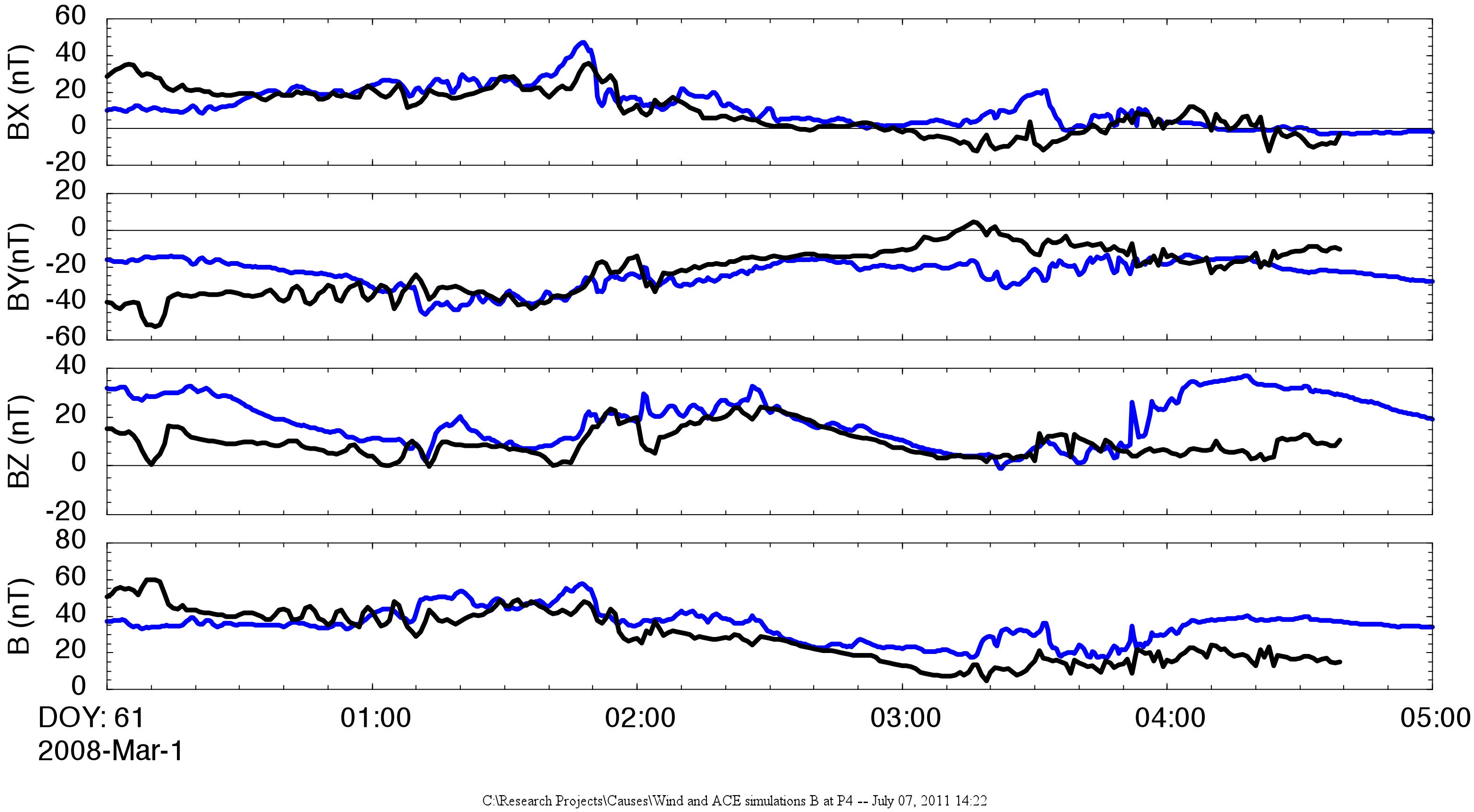
P4 (-8.05, 5.97, -0.43)



El-Alaoui et al., 2009

Cross Correlations			
Shift (min)	**Bx**	**By**	**Bz**
0	0.93	0.81	0.50
5	0.89	0.88	0.70

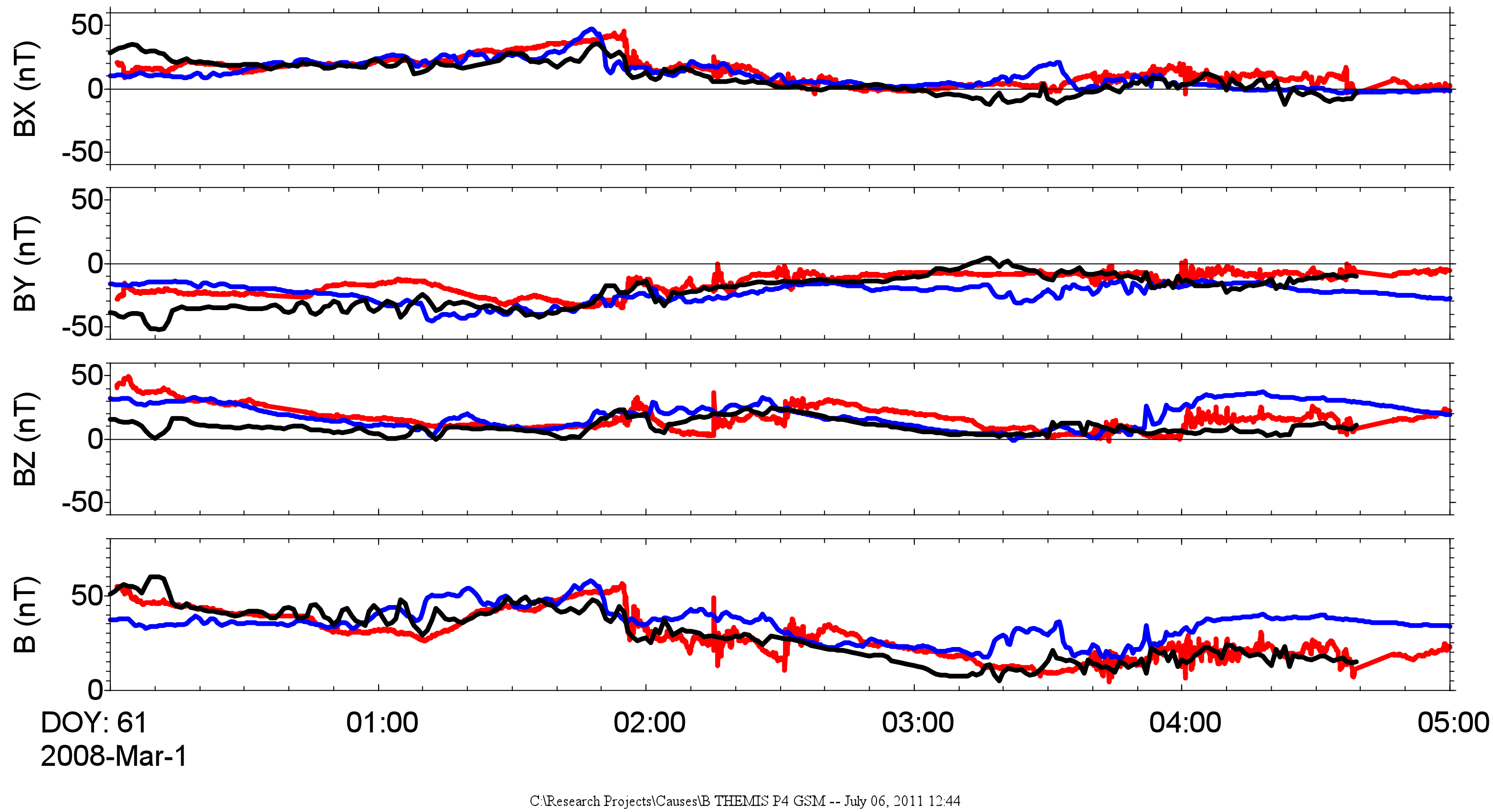
Magnetic Field from ACE and Wind Simulations at THEMIS P4



ACE Simulation

Wind Simulation

ACE and Wind Simulations and THEMIS P4 Magnetic Field in GSM

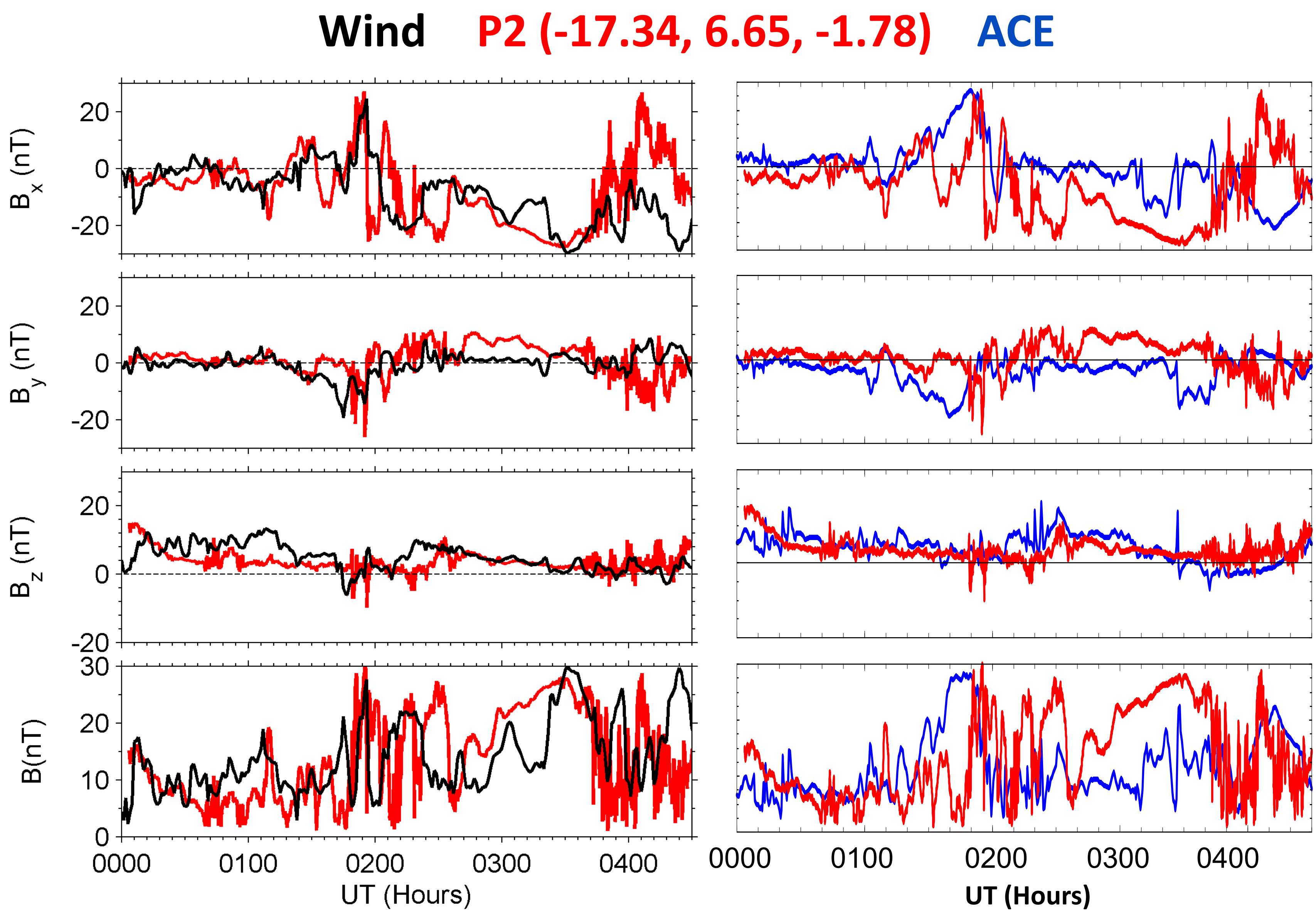


THEMIS P4 B

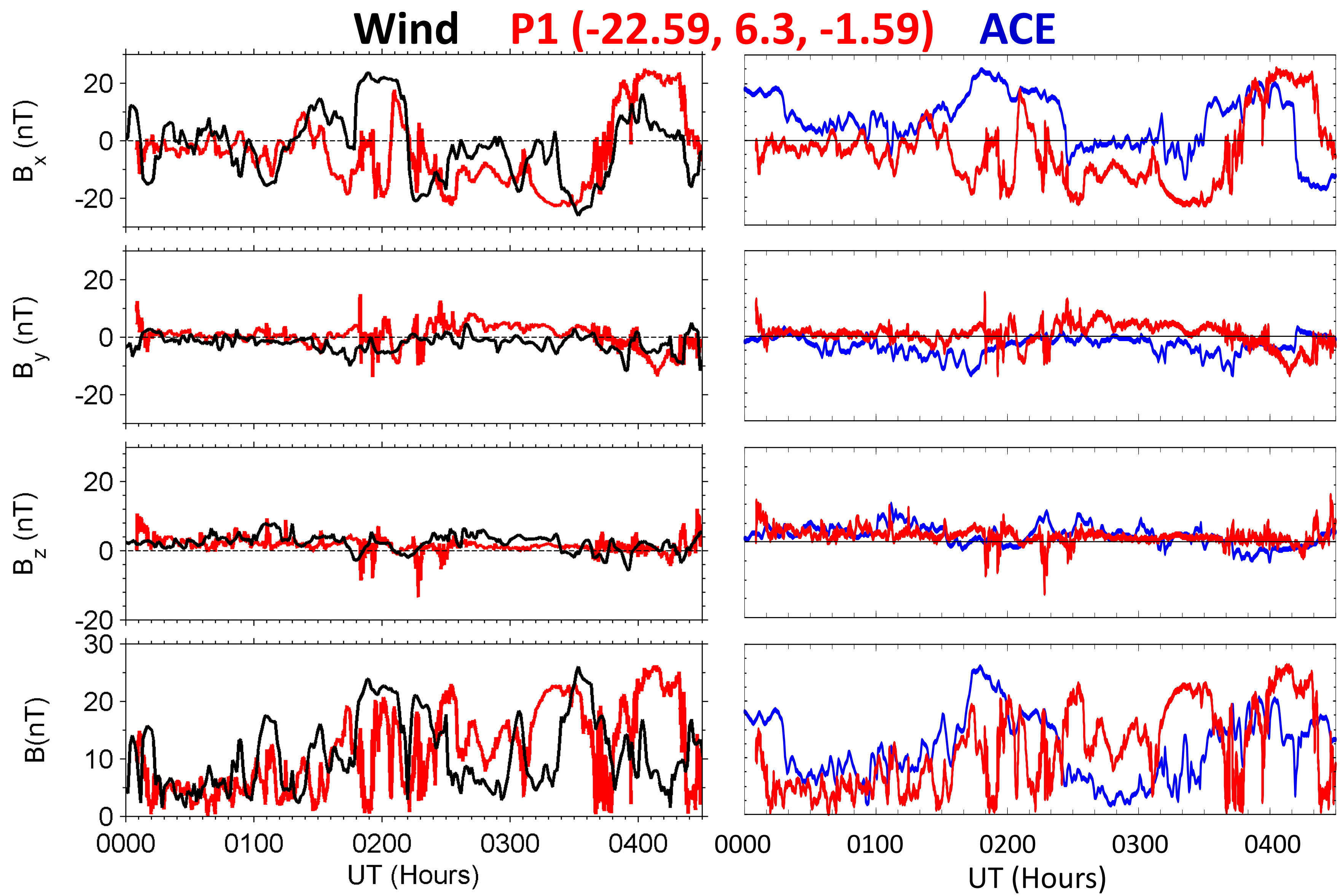
ACE Simulated B

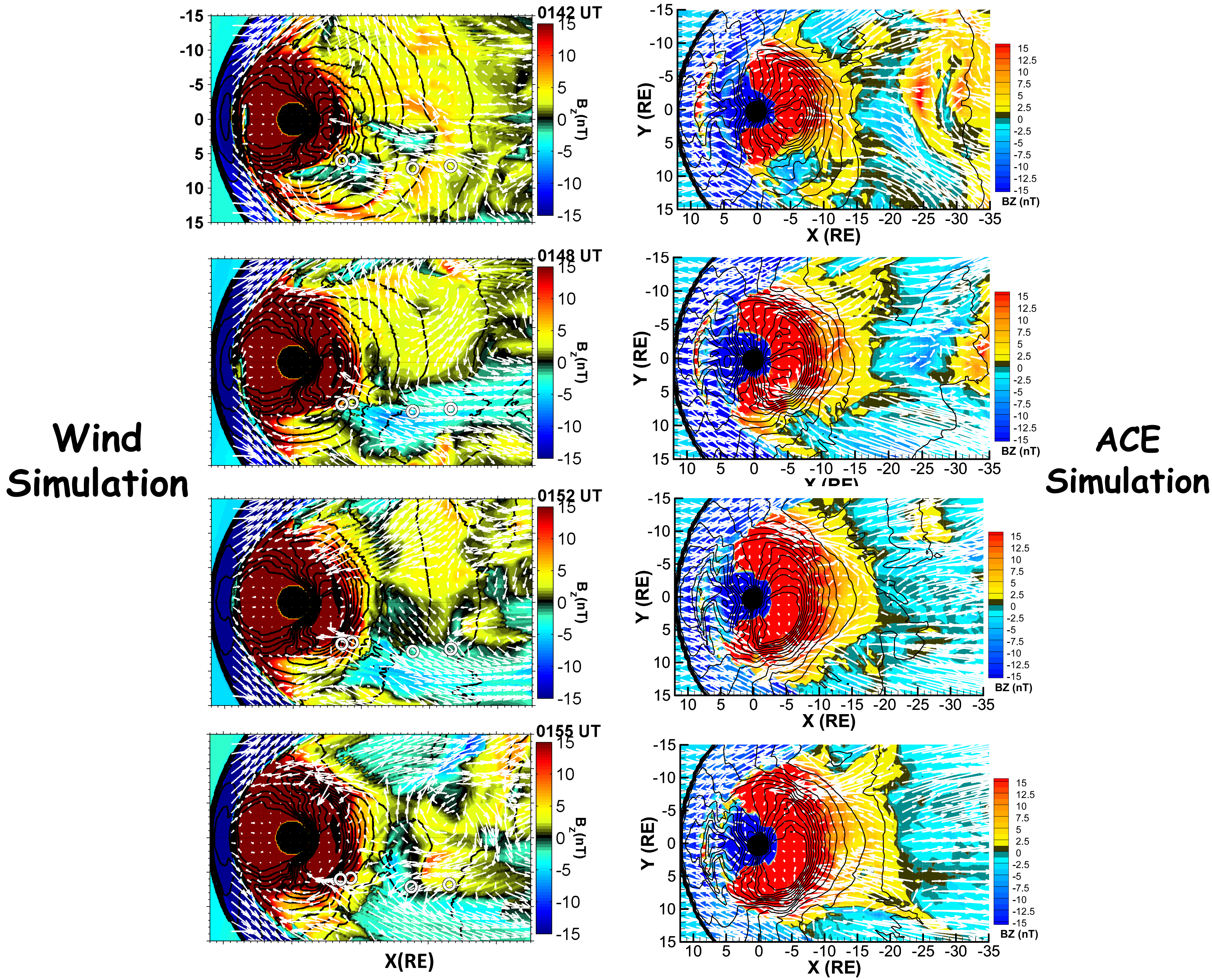
Wind Simulated B

Wind and ACE Simulations at THEMIS P2



Wind and ACE Simulations at THEMIS P1




Wind Simulation
ACE Simulation
0142 UT
0148 UT
0152 UT
0155 UT
B_z (nT)
BZ (nT)
X(RE)
X (RE)
Y (RE)

What Have We Learned?

- During storms the coherent scale length in the solar is comparable or larger than the size of the magnetosphere.
- The simulated magnetosphere acts like at low pass filter and responds mainly to the large scale changes in the IMF.
- The results from the MHD simulations are very sensitive to the solar wind observations used in substorm studies.
- Careful comparison between magnetospheric observations and simulations is critical if we are going to use the simulations to set the global configuration of the magnetosphere.


Thank You