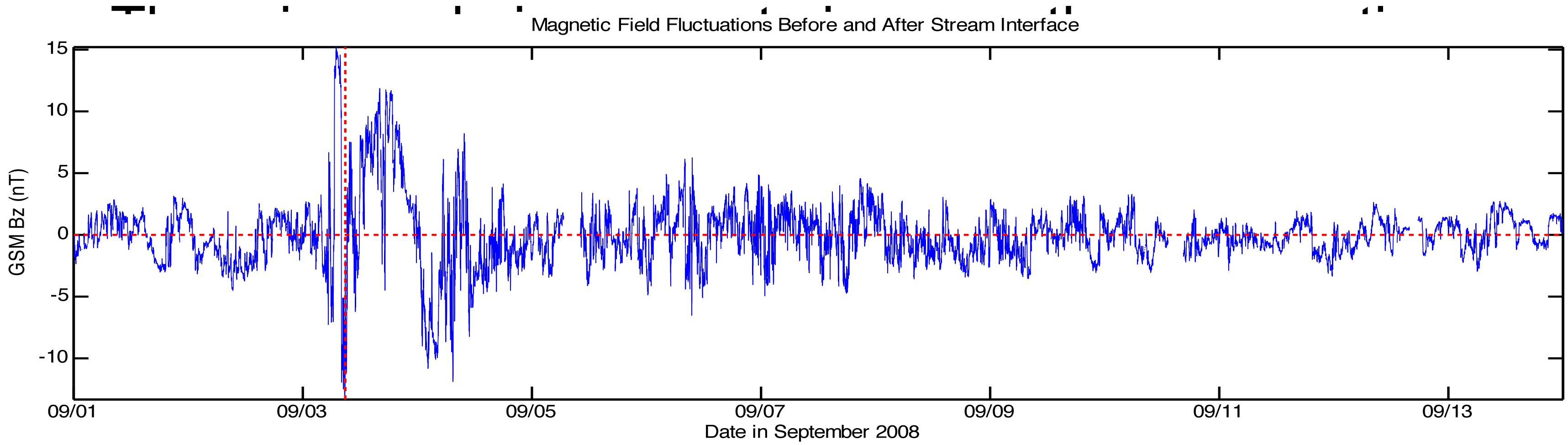
Outline – rmcpherron@igpp.ucla.edu

- The rarity of extreme events means little data to study response
- Empirical and physics-based models require accurate drivers
- Forecast lead time requires measurements be propagated to Earth
- Propagation methods are inadequate and produce large errors



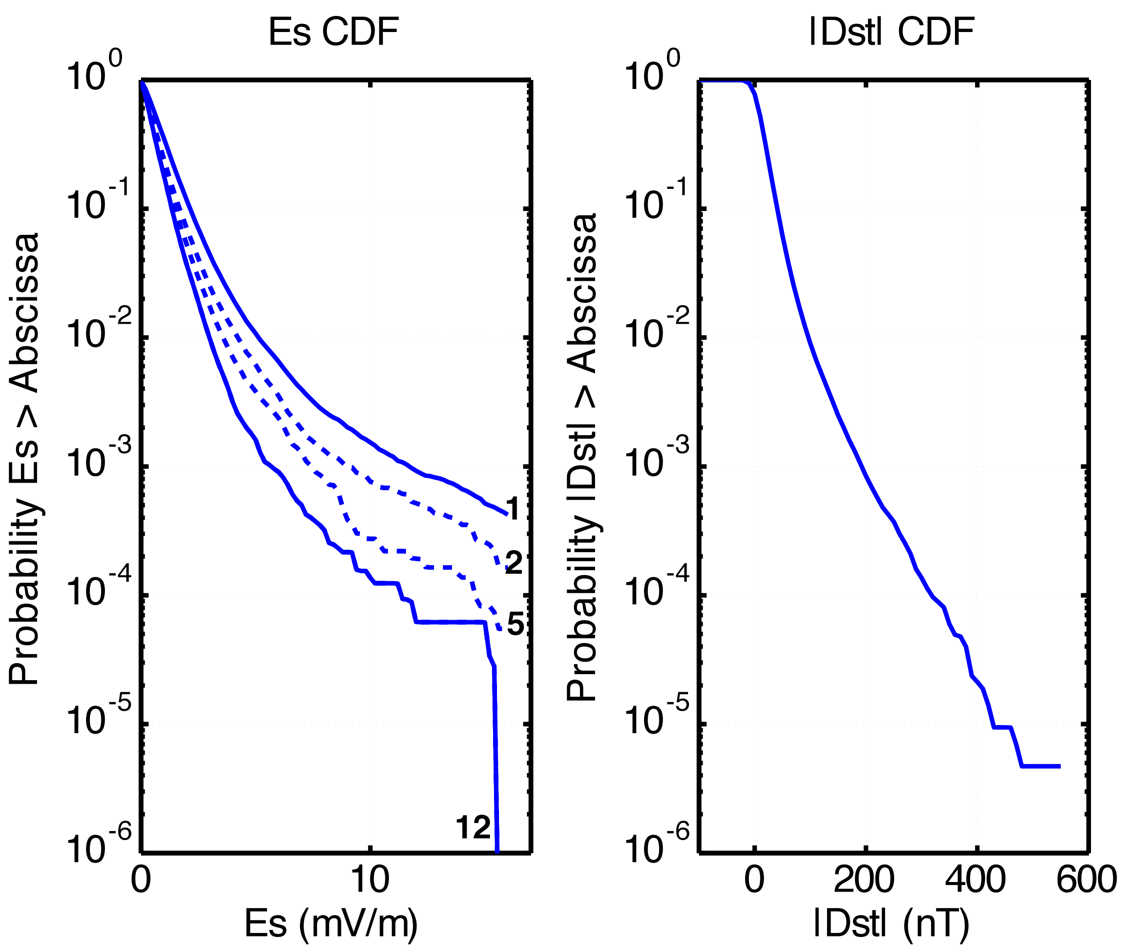
runs

Coupling Questions

- How can we predict the solar wind drivers that impact the magnetopause?
- Is there a better representation of reconnection than coupling functions?
- Why is coupling efficiency modulated by dipole tilt?
- Why does coupling strength change with the solar cycle?
- Why does coupling efficiency change across a solar wind stream interface?
- Does coupling depend on more than the strength of solar wind electric field?
- What determines the response mode of the magnetosphere?
- Does coupling strength change with the response mode?
- What is the role of ionosphere in coupling?
- What are the best measures of magnetospheric response?

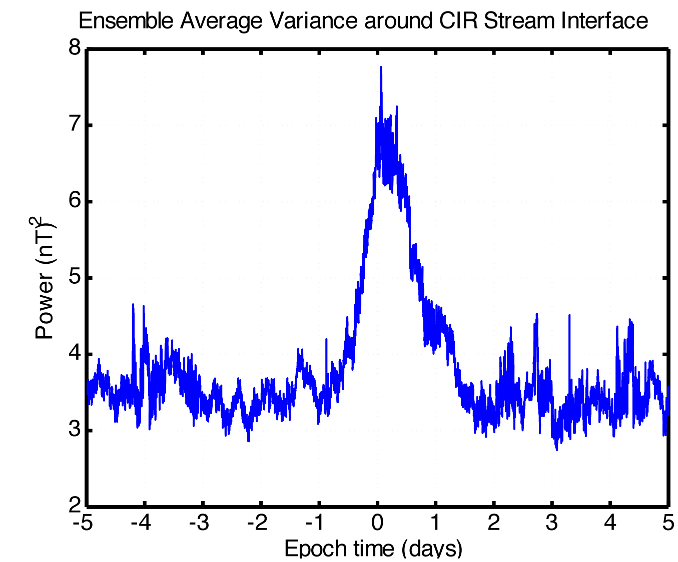
Low Probability of Extreme Events

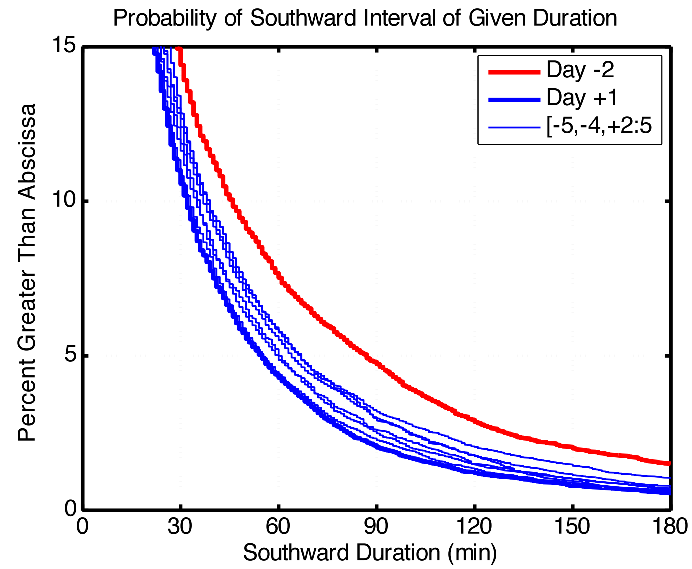
- Large geomagnetic disturbances are produced by the combination of long-duration strong driving
- The probability that a single hourly average of Es = VBs exceeds 12 mV/m is 1/1000 (left)
- The probability is much lower to have more than N hours of strong driving as shown by the dashed lines
- A storm with minimum |Dst| > 400 nT has a probability of about 1e-5 corresponding to once in a solar cycle

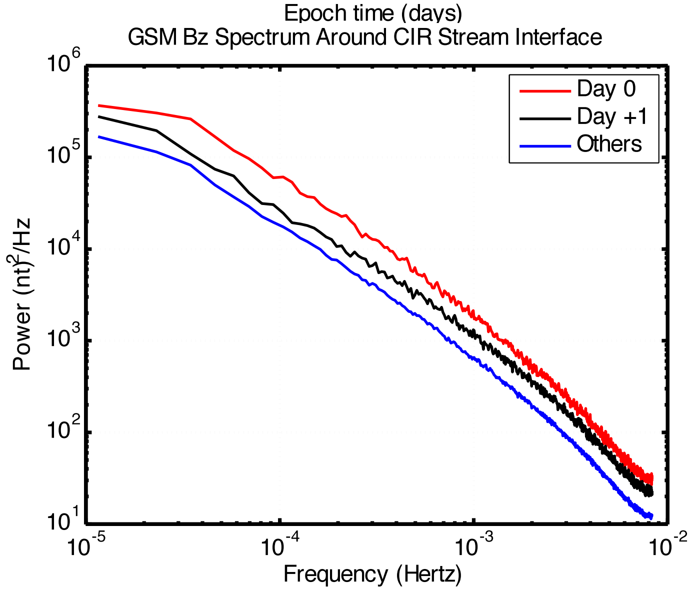


Super storms are so rare that we do not have sufficient data to empirically determine the relation between driver and the ring current!

Fluctuations of the Solar Wind Driver



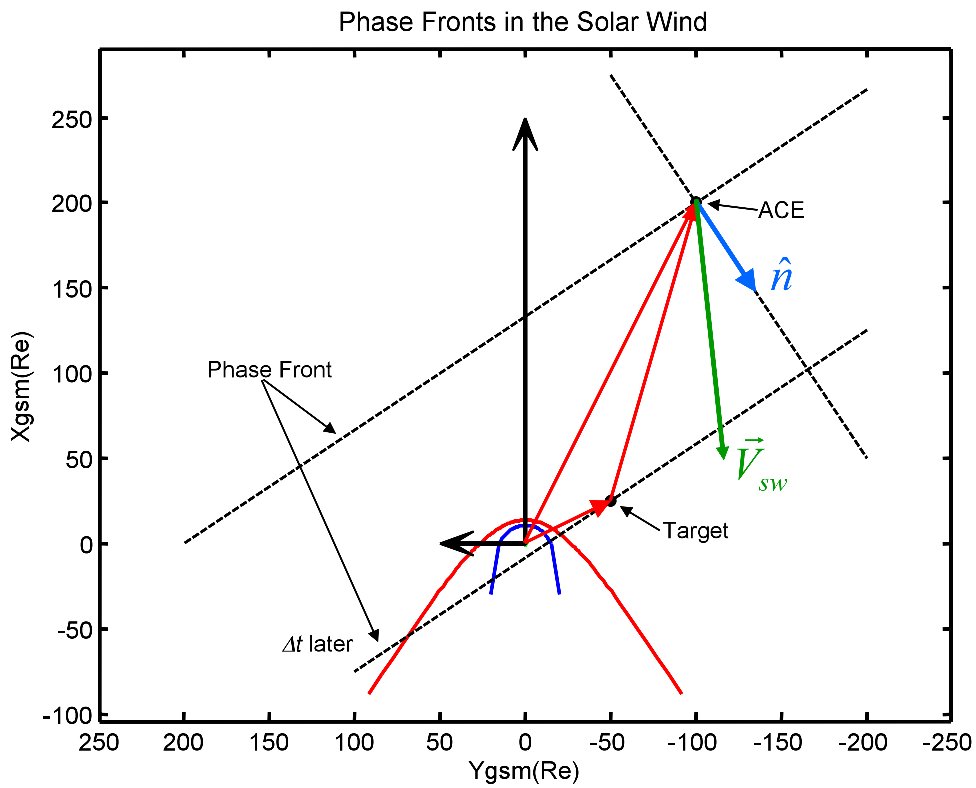




- Create ensemble matrix for GSM Bz for 347 stream interfaces
- Calculate ensemble average variance as function of epoch time ±5 days
- Calculate Fourier transform from one day of 1-min samples and average over ensemble to obtain power spectra
- Determine change in duration of southward Bz intervals with epoch time
- Median duration is 4 minutes!

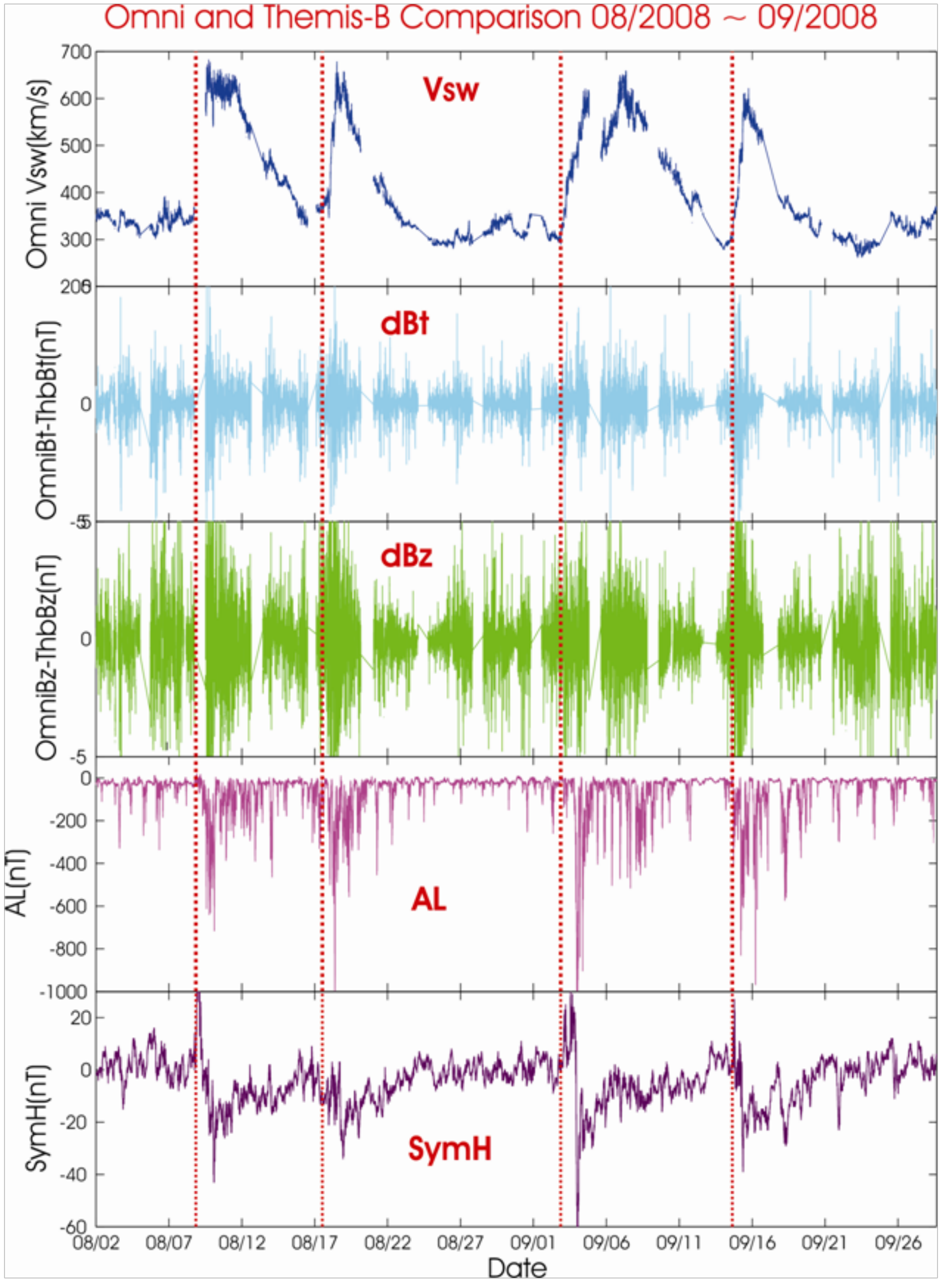
Radial Propagation of Solar Wind

- The interface between two flux tubes is assumed to be a planar interface on the scale of the distance between L1 and Earth
- The interface is characterized by its normal $\hat{n}$
- In a time *Δt* the solar wind convects the interface along the normal displacing it by an amount $\left(\vec{V}_{sw} \cdot \hat{n}\right)\Delta t$
- The separation of the two spacecraft along the normal is $\left(\vec{P}_T - \vec{P}_{ACE}\right)\hat{n}$
- Equate these distances to obtain the time delay $\left(\vec{V}_{sw} \cdot \hat{n}\right)\Delta t = \left(\vec{P}_T - \vec{P}_{ACE}\right)\hat{n}$

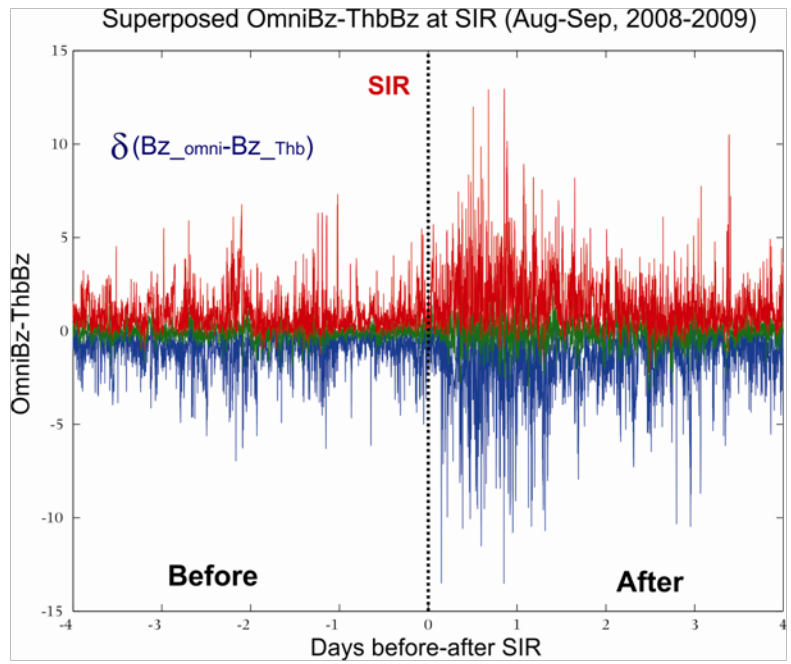


$$\Delta t = \frac{\left(\vec{P}_T - \vec{P}_{ACE}\right)\hat{n}}{\left(\vec{V}_{sw} \cdot \hat{n}\right)}$$

Radial Propagation Residuals in CIRs

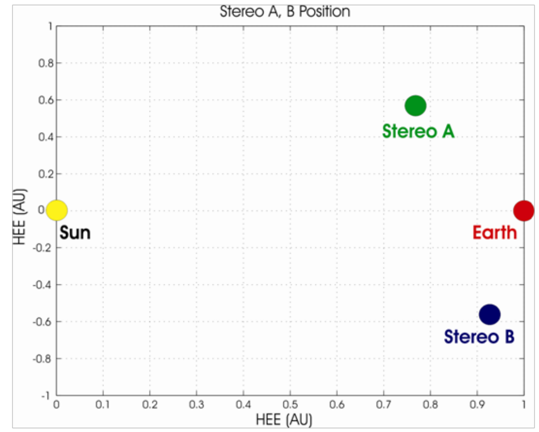


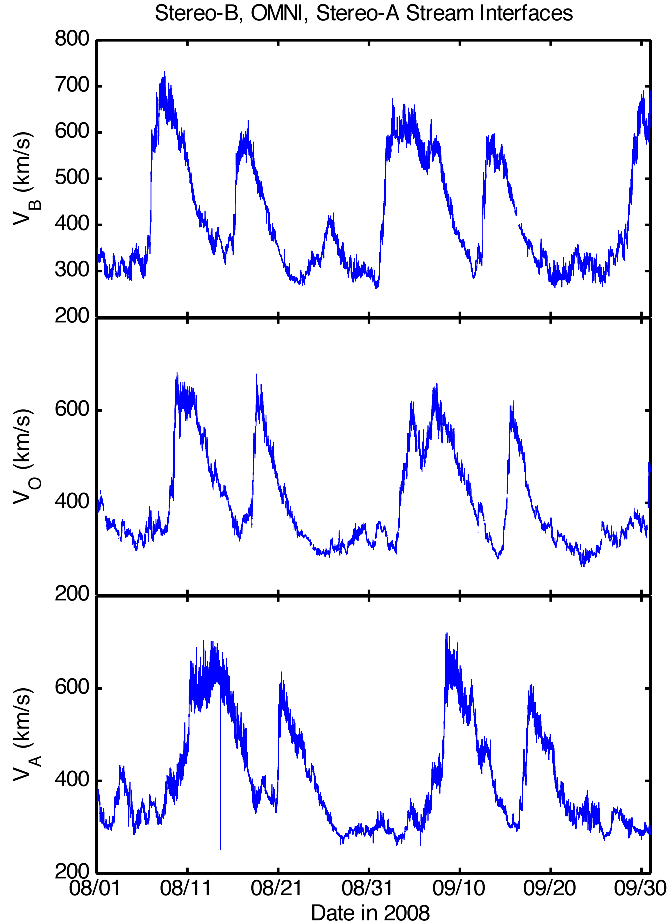
- The vertical lines show times of stream interfaces within CIRs
- Deviations of propagated Bt are smaller than those in Bz
- The deviations of both are larger after the stream interfaces than before
- Unfortunately, the intervals of strongest activity as shown by AL and Dst are the times of largest discrepancy

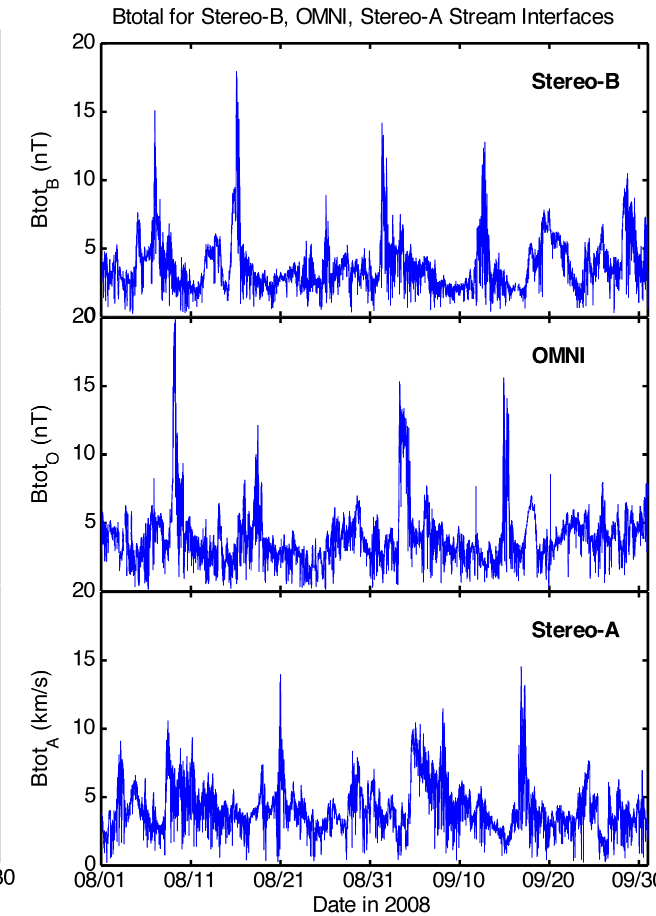


Azimuthal Properties during High-Speed Streams

- Compare Stereo spacecraft observations to OMNI to examine effects of azimuthal propagation
- Location of s/c shown in upper right
- The same CIRs are seen in V at all locations (left) but differ in detail
- Details of magnetic field vary even more between azimuthal locations

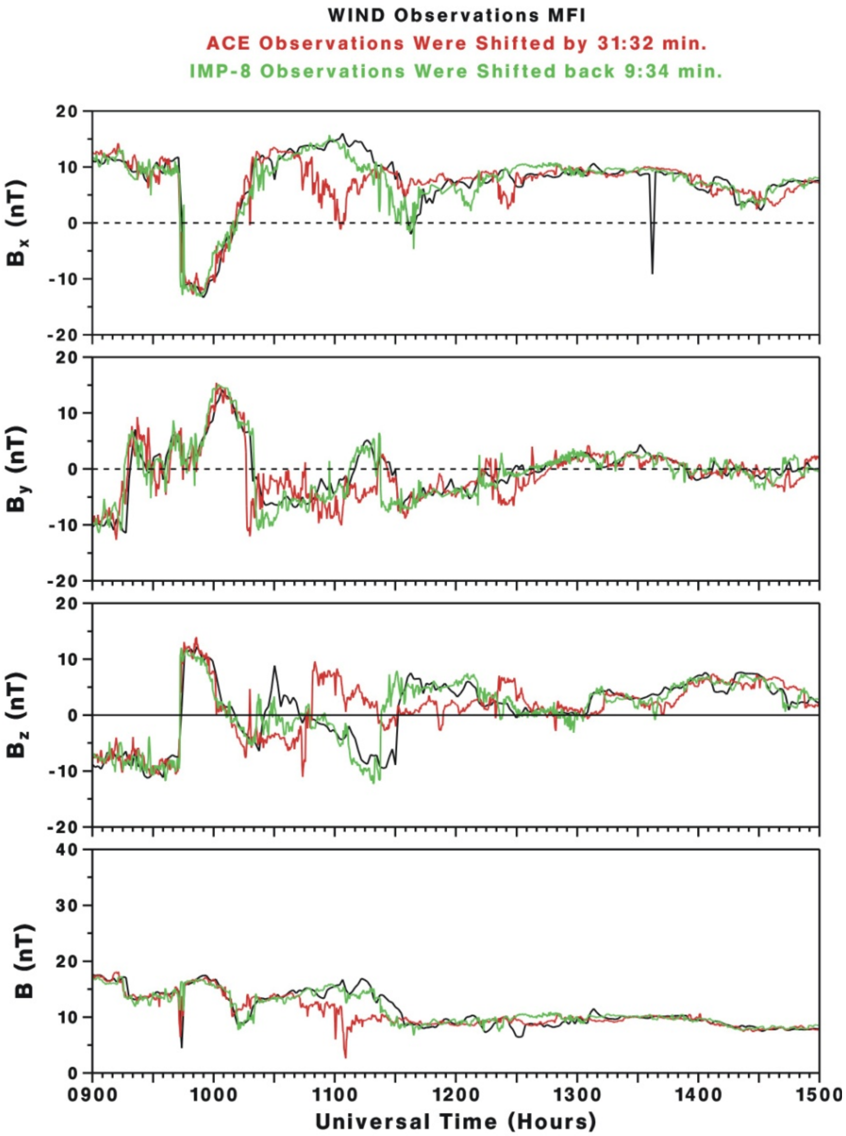


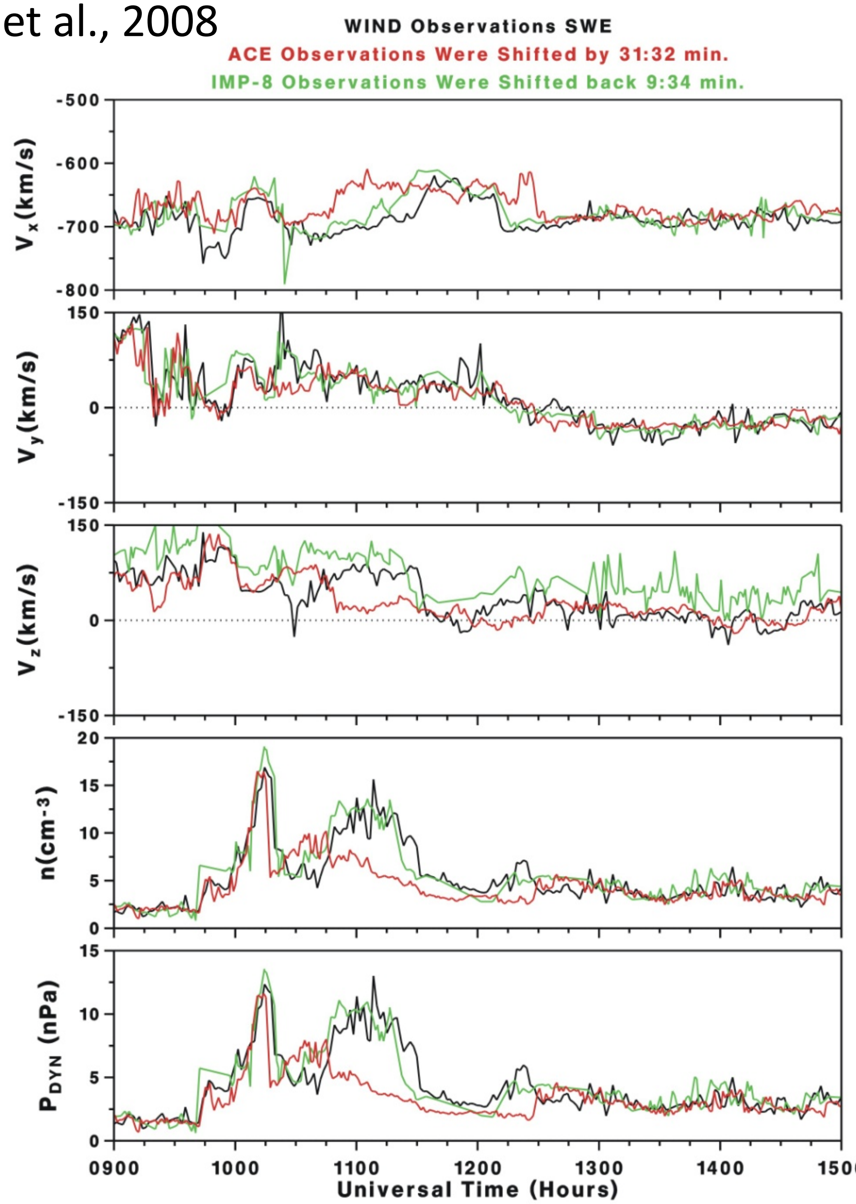




Solar Wind and IMF Observations from Wind, ACE and IMP-8 – Second Interval, May 24, 2000

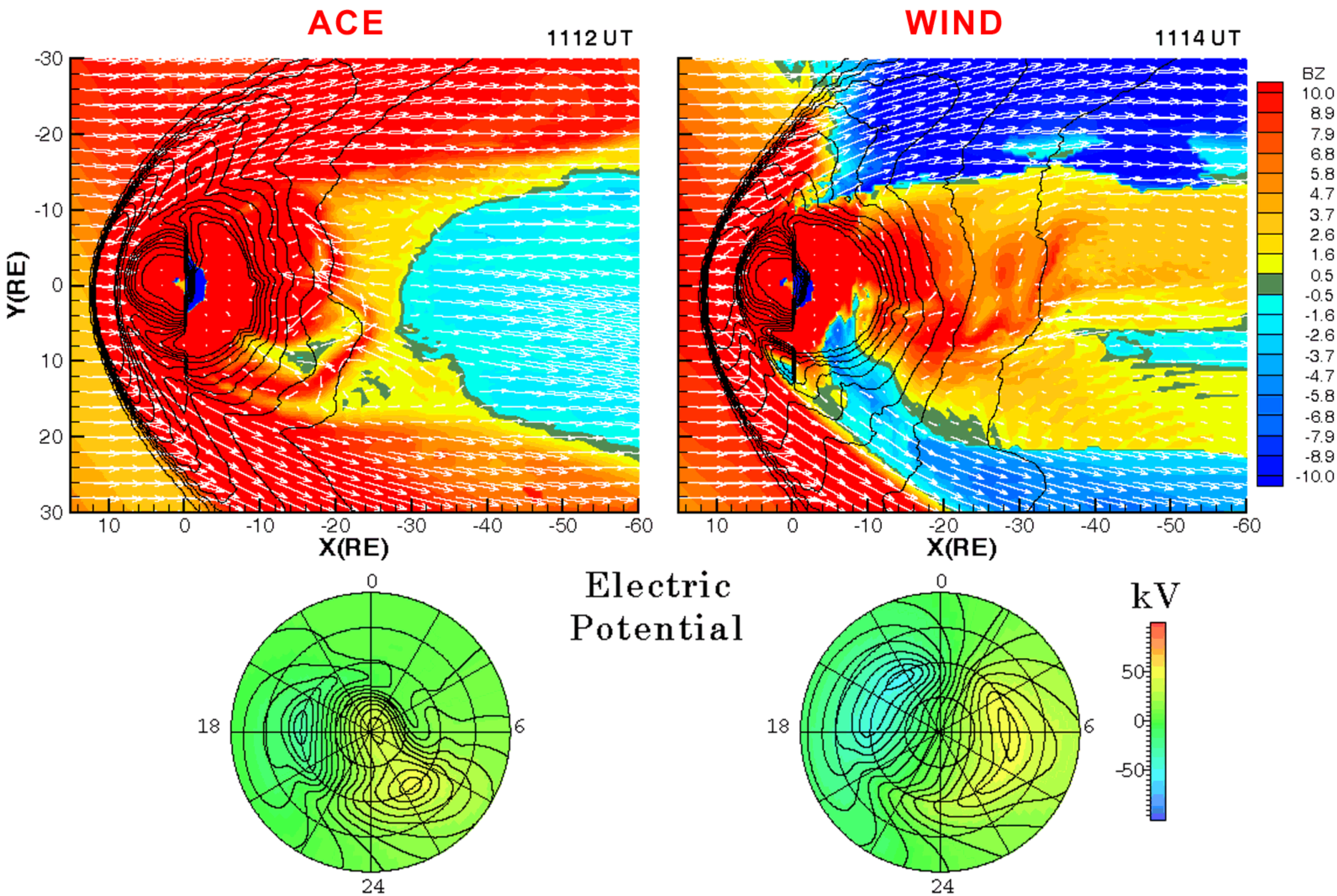
Ashour-Abdalla et al., 2008

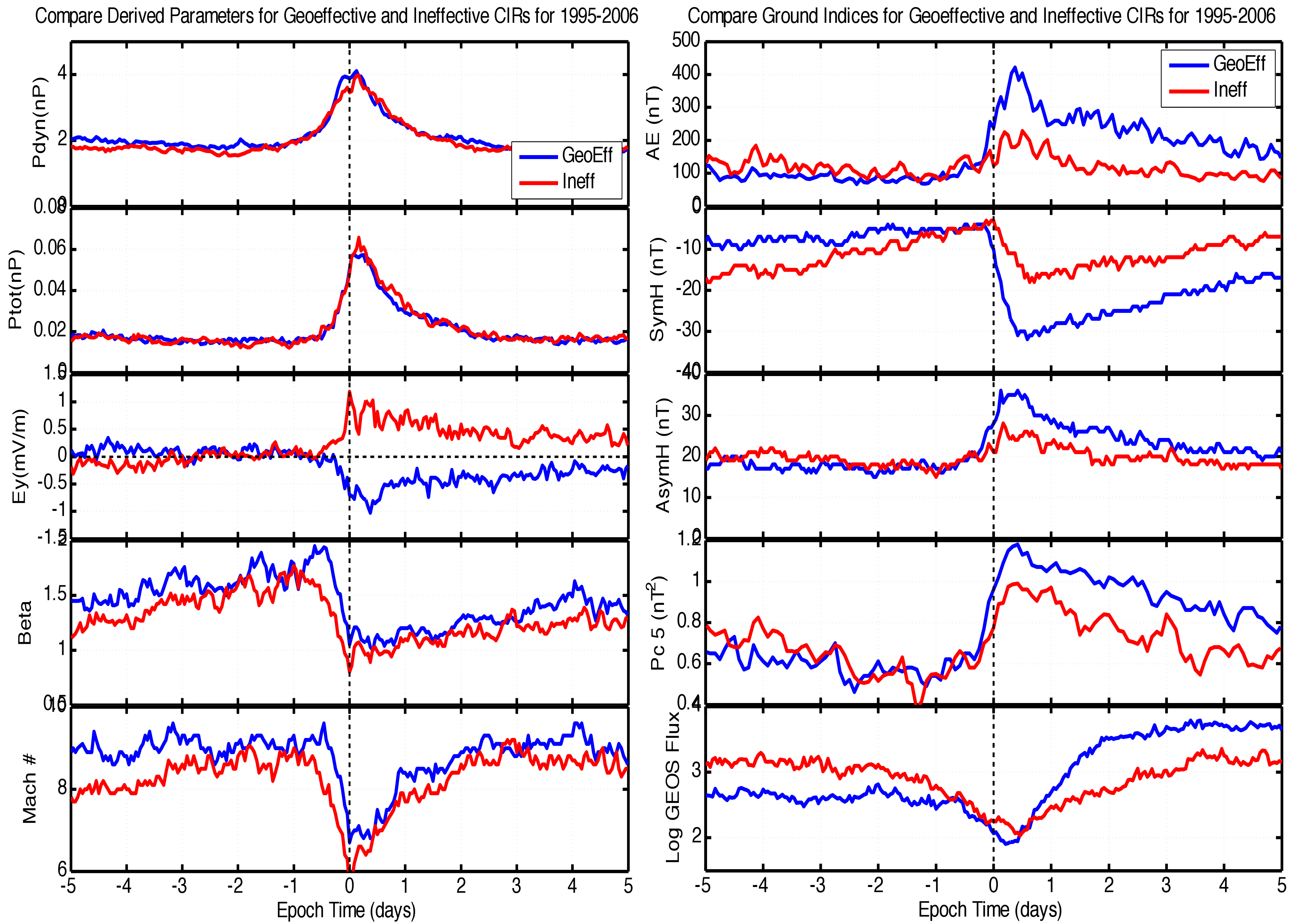




Bz and Flows in the "Equatorial" Plane –Second Interval

(Walker, Abdalla, Alaoui – AOGS, Taiwan, August 9, 2011)




Compare Derived Parameters for Geoeffective and Ineffective CIRs for 1995-2006
Compare Ground Indices for Geoeffective and Ineffective CIRs for 1995-2006
Pdyn(nP)
Ptot(nP)
Ey(mV/m)
Beta
Mach #
AE (nT)
SymH (nT)
AsymH (nT)
Pc 5 (nT^2)
Log GEOS Flux
GeoEff
Ineff
Epoch Time (days)
Epoch Time (days)

Summary

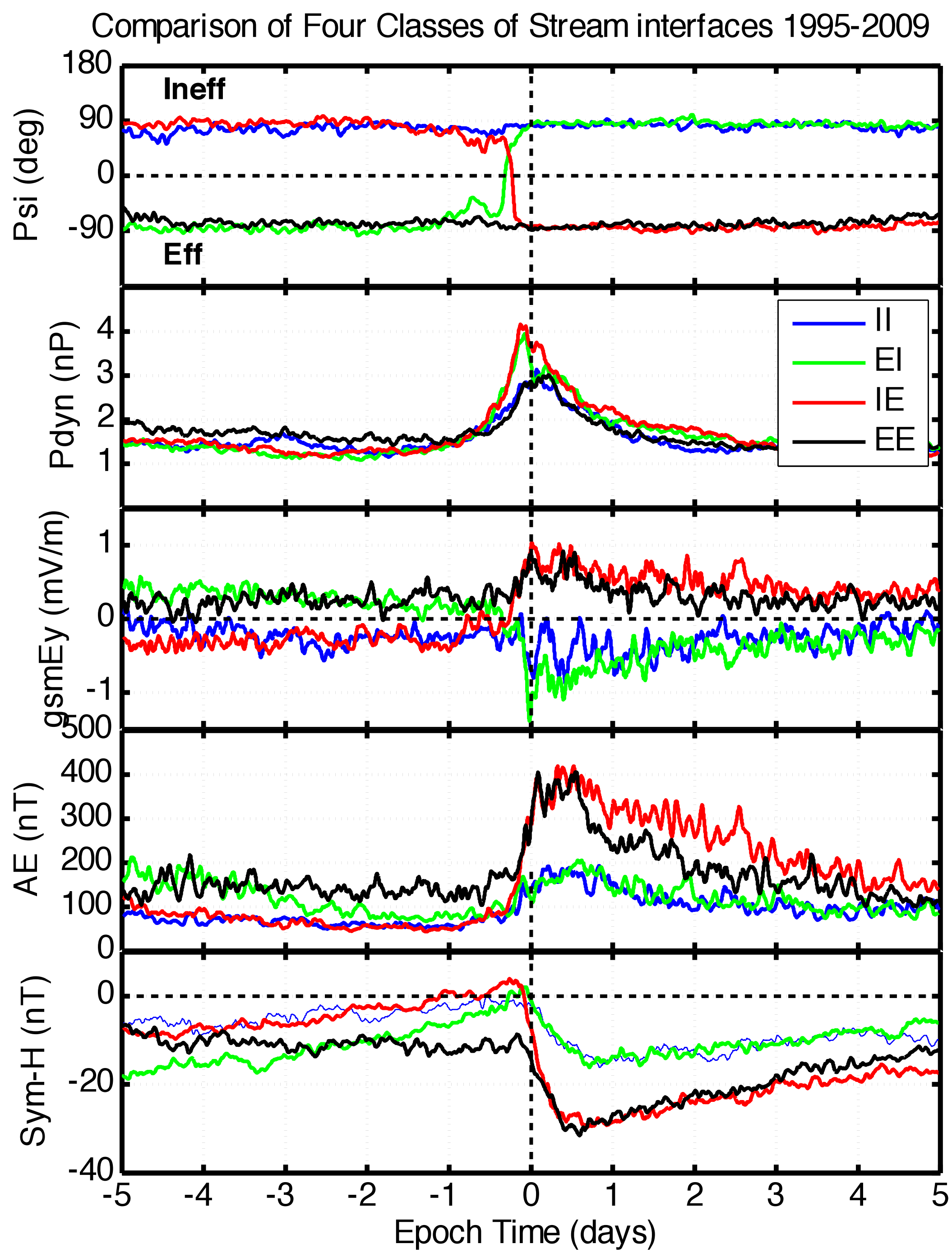
- We do not know how to look at the Sun and predict the waveforms of drivers that will eventually arrive at the Earth
- We do not know how measurements at some distance from Earth either radially or azimuthally can be accurately propagated to the Earth
- It is very unlikely that we will ever be able to provide accurate models of the driving waveforms except with observations immediately upstream of the bow shock
- Details matter in the calculation of geomagnetic response to solar wind

- Probabilistic forecasting by air mass climatology could provide a means for calculation of the expected range of response
- Ensemble averages from multiple simulation runs driven by appropriate climatology is a possible way to obtain reasonable forecasts

The End

Median Behavior of *Four Classes of S/I*

- Use data for each class of CIR and superpose relative to time of S/I
- Display median behavior of various I/O parameters for four classes
- Heliospheric current sheet crossings (sector boundaries) often occur (~60%) before a S/I
- The dynamic pressure is higher at the S/I for the two classes IE & EI
- AE and Sym-H are very weak when high-speed stream is ineffective
- They are twice as strong when the high-speed stream is effective



What do we not know about geomagnetic couplings and responses to solar eruptions

Robert L. McPherron
Department of Earth and Space Sciences
University of California Los Angeles
Presentation at Space Weather Workshop
AMES Research Center
October 15-16, 2011

Empirical and Physical Models of Coupling

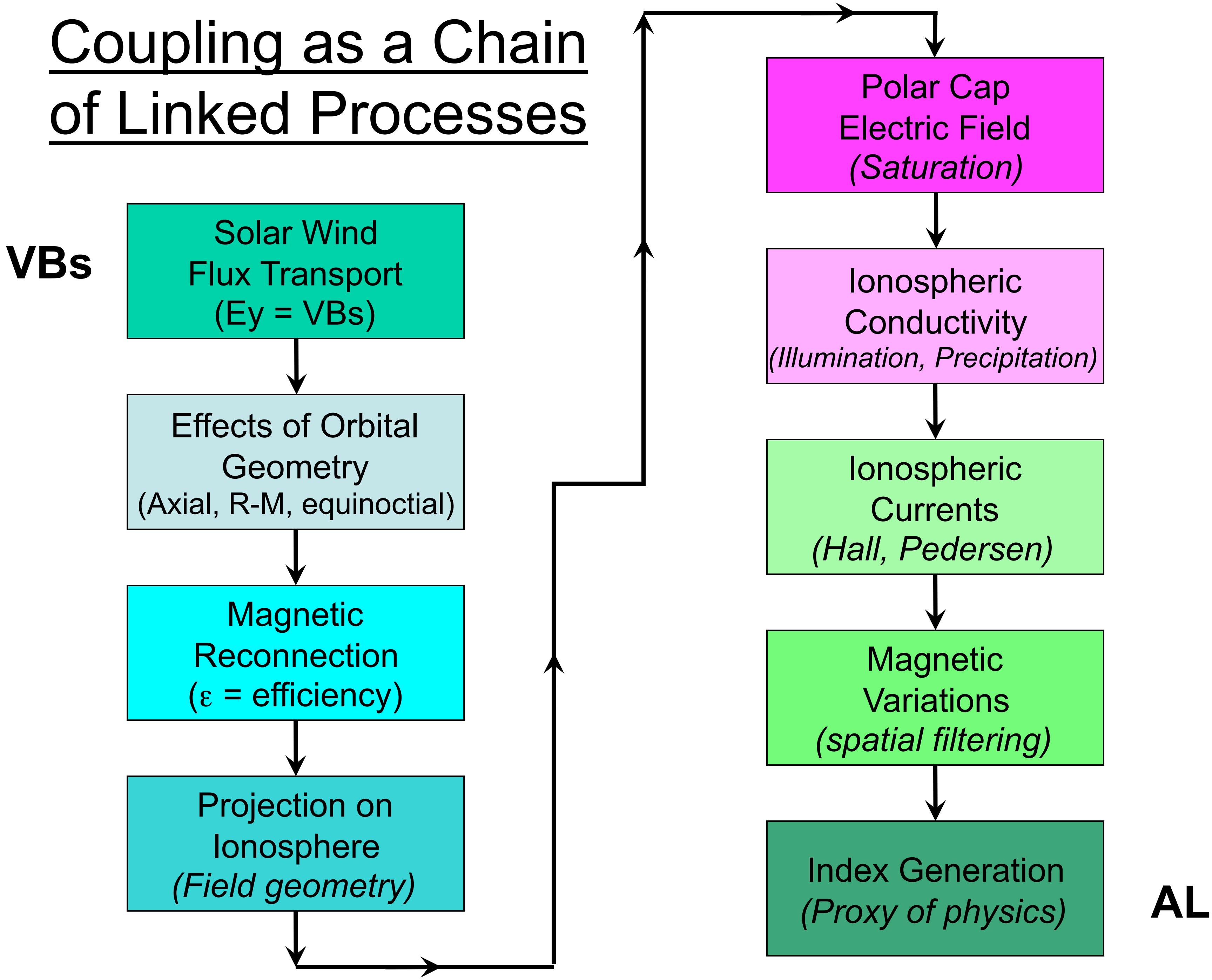
Coupling Functions

- V solar wind speed
- B magnetic field strength
- Bz GSM N-S component of B
- VBz The azimuthal electric field
- VBs Rectified electric field
- UCF Universal coupling function

Indices

- Magnetic character index
- Kp index
- aa index
- AE index
- Dst index
- PC index
- IHV index
- IHD index

Coupling as a Chain of Linked Processes



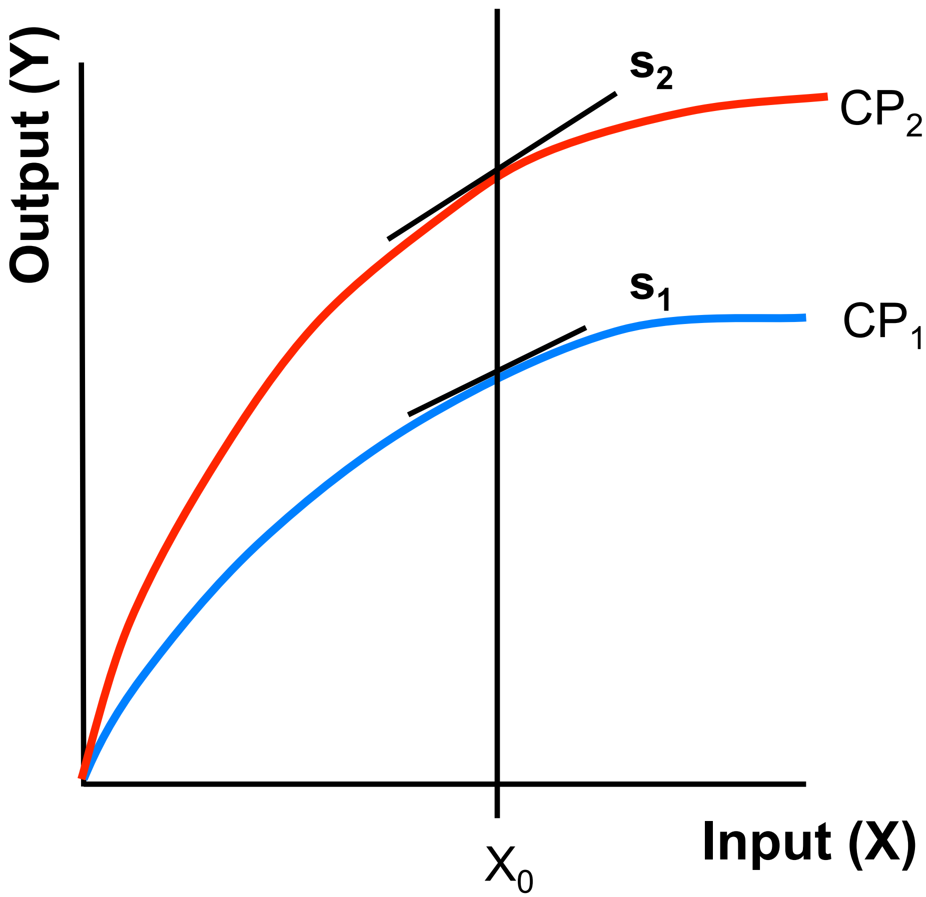
Linear Prediction

- Simple linear regression $O_n = a + bI_n$
- Multiple linear regression $O_n = a + bI_n^1 + cI_n^2 + dI_n^3 + \ldots$
- Time delay regression (Use m delays) $O_n = a + b_0 I_{n-0} + b_1 I_{n-1} + b_2 I_{n-2} + \ldots$
- Many instances of a linear relation (data)

$$O_{n+0} = a + b_0 I_{n-0} + b_1 I_{n-1} + b_2 I_{n-2} + \ldots$$
$$O_{n+1} = a + b_0 I_{n+1} + b_1 I_{n-0} + b_2 I_{n-1} + \ldots$$
$$O_{n+2} = a + b_0 I_{n+2} + b_1 I_{n+1} + b_2 I_{n-0} + \ldots$$

- Matrix representation $\vec{O} = X * \vec{b}$
- Least square solution (empirical model) $\vec{b} = inv(X' * X) * X' * \vec{O}$

Local Linear Approximation



- A nonlinear function *Y(X)* depends on a control parameter *CP*
- At a specific point X_0 we make a local linear approximation to the function
  $Y = a(x_0,cp)X+b(x_0,cp)$
- The coefficients depend on X_0 and the value of the control parameter
- We use many examples of the relation between *X* and *Y* to do a least square approximate fit to the function for different X_0 and different values of the control parameter

The Newest Solar Wind Coupling Function

Newell, P. T., T. Sotirelis, K. Liou, C.-I. Meng, and F. J. Rich (2007), A nearly universal solar wind-magnetosphere coupling function inferred from 10 magnetospheric state variables, *J. Geophys. Res.*, *112*(*A1*), 1-16.

$$UCF = d\Phi_{MP}/dt = V^{4/3}\, B_T^{2/3} \sin^{8/3}\left(\theta_c/2\right)$$

$$V \equiv \text{Solar wind speed}$$

$$\mathrm{B_T} \equiv \text{Transverse magnetic field}$$

$$\theta_\mathrm{c} \equiv \text{Clock angle}$$

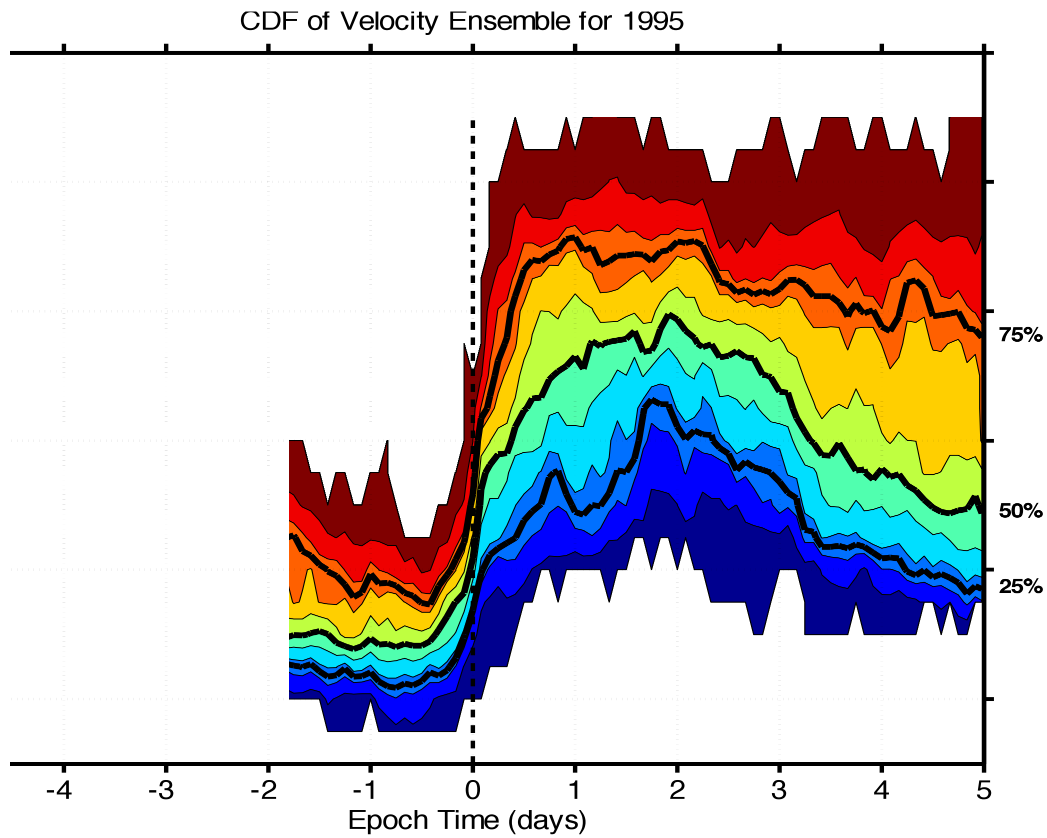
An Algorithm for Probabilistic Forecasting of ap (Declining Phase of Solar Cycle)

- Use Wang-Sheeley to predict V, B, and polarity at 1 AU 4-days ahead
- Determine expected arrival time of a stream interface
- Use table of cdfs depending on interface time, V, B, and polarity to predict probability of observing ap greater than specific value for next four days
- Use precursor detector to refine estimate of interface arrival
- Modify 4-day predictions based on refined interface time
- Use observed interface and profile of speed to refine predictions of velocity and B and hence ap

Dynamic Cumulative Probability Distribution for Solar Wind Speed at Steam Interfaces

One year and 26 events used to construct an ensemble array

A time window of width 11 samples was advanced in 10 min increments



Contours at 0.1 levels from 0 to 1.0

Quartiles of CDF

Epoch zero is zero crossing of azimuthal flow angle

What I Don’t Know about CME and CIR

CMEs

- Where and when a large CME will erupt
- How large, how fast, and in what direction it will move
- How the CME evolves as it moves toward the Earth interacting with ambient solar wind
- What is the configuration of the IMF and plasma in different regions of the CME
- Importance of pre-conditioning of magnetosphere by sequence of CME related changes
- How important is the feedback between ionosphere and magnetosphere in controlling activity

CIRs

- What controls the evolution of coronal holes
- Can we determine the speed of solar wind as it emerges from hole
- How to propagate the observed stream to the Earth
- How do solar wind properties change along the stream interface
- How does the CIR evolve as it rotates azimuthally at a fixed distance
- What determines which side of the heliospheric current sheet the Earth will encounter