Solar-Wind/Magnetosphere Coupling

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1. **Get a feeling for how the coupling works**
2. **Get an understanding of how reconnection works**
3. **Look at some coupling in the data: solar wind correlations with geomagnetic indices.**

Useful Stuff

The magnetic field points into the northern polar cap of the Earth.

The Alfven speed is $v_A = 21.8$ km/s $B/n^{1/2}$ where B is in units of nT and n is in units of cm^{-3}.

Access the OMNI2 solar-wind and geomagnetic-index data set (1963-present) at:

http://omniweb.gsfc.nasa.gov/form/dx1.html

The Magnetosphere-Ionosphere System Is Driven by the Solar Wind

What does it mean that the magnetosphere is driven?

Convection occurs (magnetosphere and ionosphere).

Plasma enters the magnetosphere from the solar wind.

Magnetic flux accumulates in the magnetotail.

Consequences of the driving:

Convection drives the aurora.

Convection drives internal current systems.

Convection heats plasmas.

Flux buildup leads to substorms.

Convection and substorms energize the radiation belts.

How Does the Solar Wind Couple to the Magnetosphere?

1. Via magnetic-field-line reconnection

Magnetically connects the moving solar-wind plasma to the Earth.

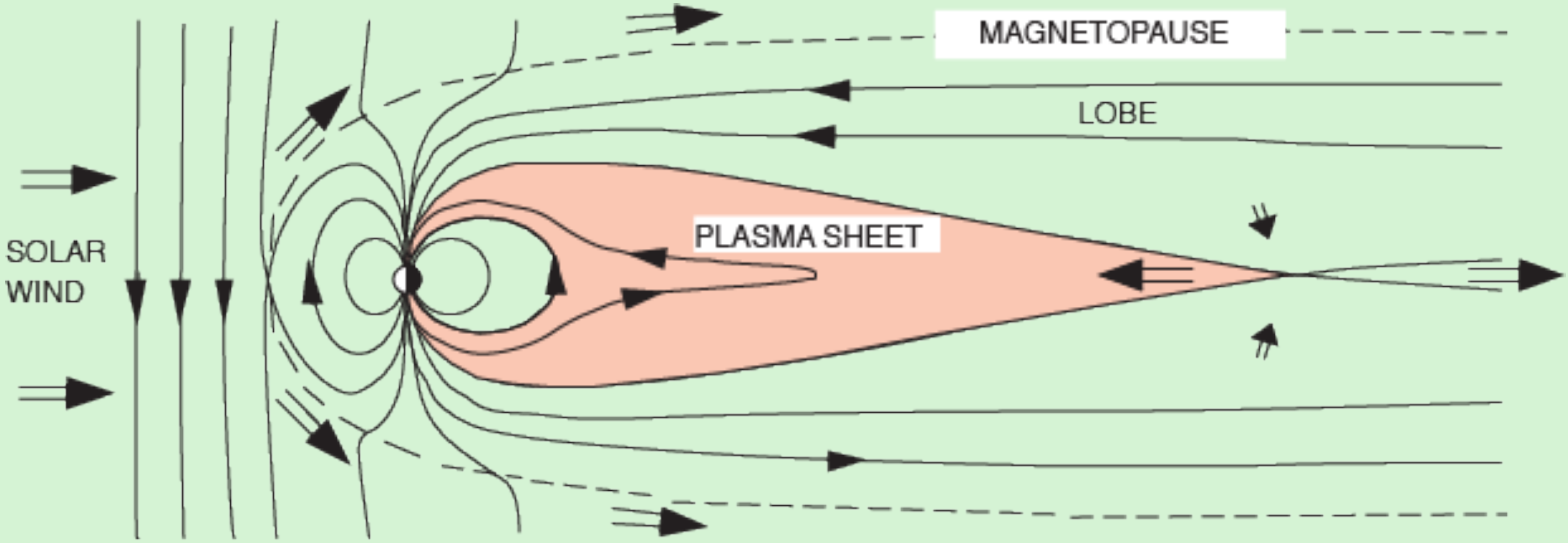
1. **Allows currents to flow from the solar wind into the magnetosphere.**
2. **Allows solar-wind plasma to enter into the magnetosphere.**

2. Via a viscous interaction

A. particles diffuse across the magnetopause carrying momentum.

B. Kelvin-Helmholtz ripples mix the plasma and magnetic field and tranport momentum.

A Sketch of the Solar-Wind Magnetic Field Reconnecting with the Magnetosphere



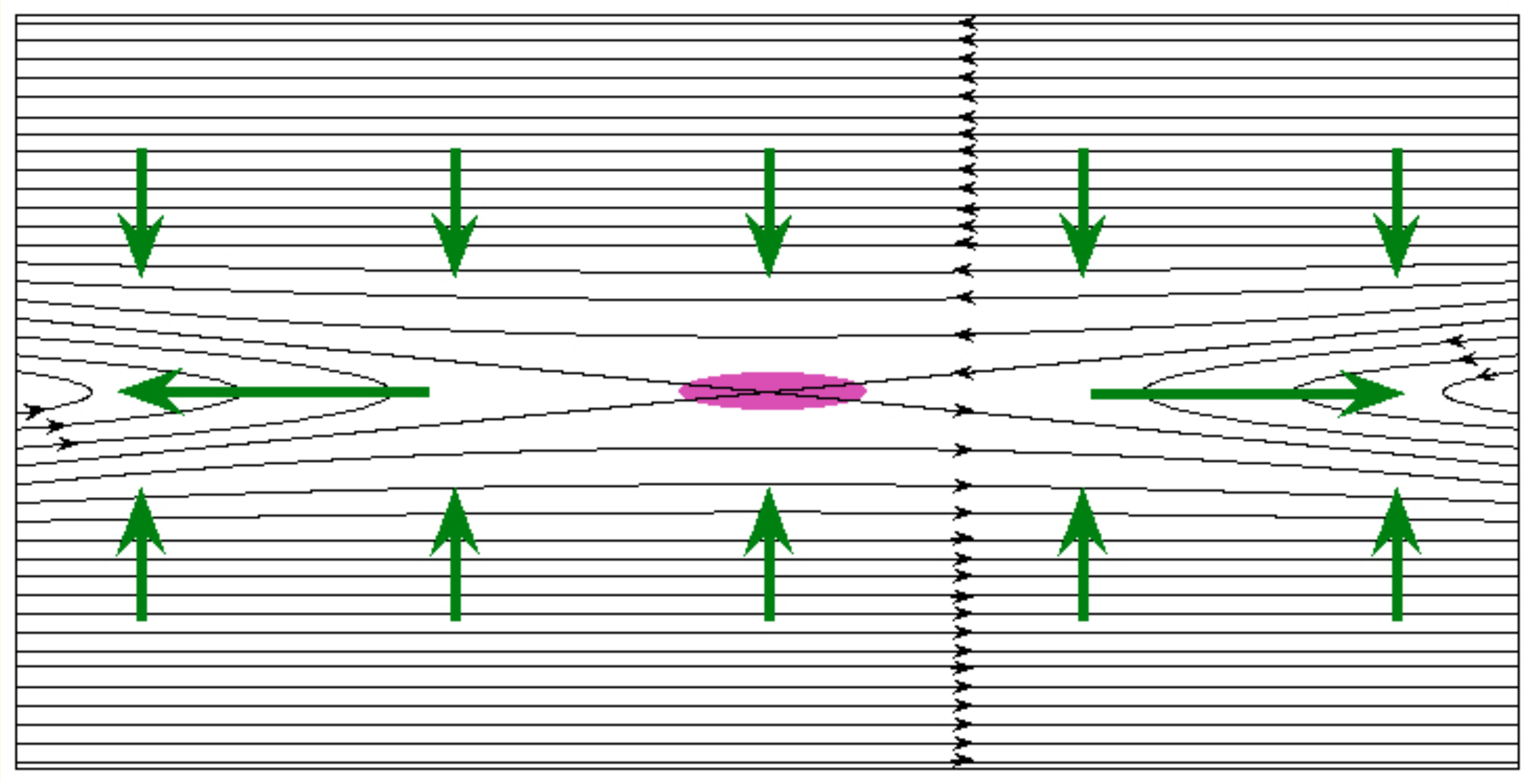
In steady state (or on average) there is a convection of flux through the magnetosphere.

Plasma convects with the magnetic flux.

There is an accompanying convection of the magnetic-field footpoints in the ionosphere.

Reconnection

(for collisionless plasmas it is Petschek “fast” reconnection)



1. Diffusion zone: Breaking the frozen-in condition.
2. Inflow and outflow: Field-line tension.
3. Energy conversion: $B^2/2\mu_o \rightarrow 0.5\rho v^2$
4. Most of the action is not at the diffusion zone.
5. Reconnection is difficult to start and it is difficult to stop.

Reconnection Rate R
(for Symmetric Collisionless Plasmas

"R" is the amount of flux changed per unit time per unit length of the reconnection line.

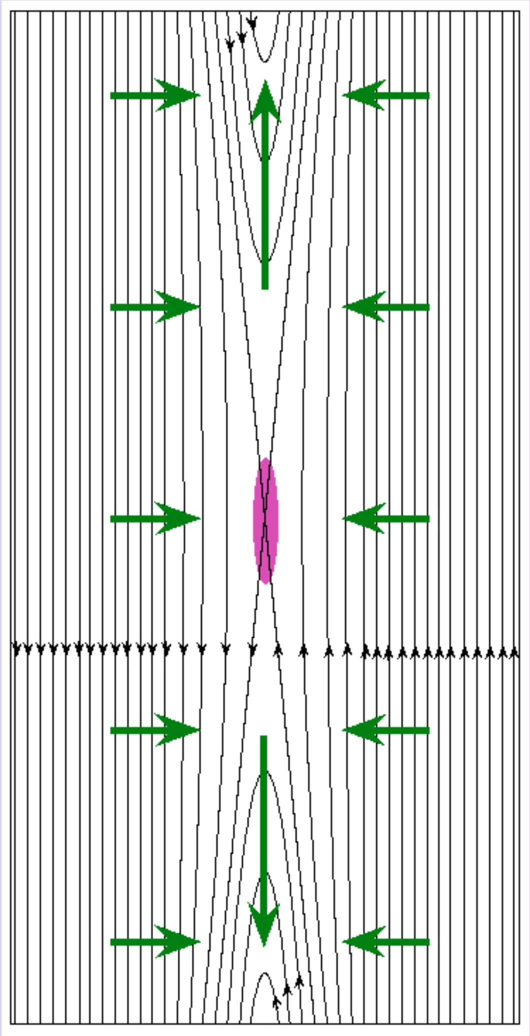
For antiparallel reconnection:

$$\mathbf{R = 0.1\, v_A\, B}$$

$$v_A = B/(\mu_o \rho)^{1/2}$$

= Alfven speed of plasma

Note that R has the units of an electric field.



Clock-Angle Dependence of Reconnection

When the magnetic fields in the two plasmas are not antiparallel, the reconnection rate depends on the "clock angle" θ_{clock} between the two fields.

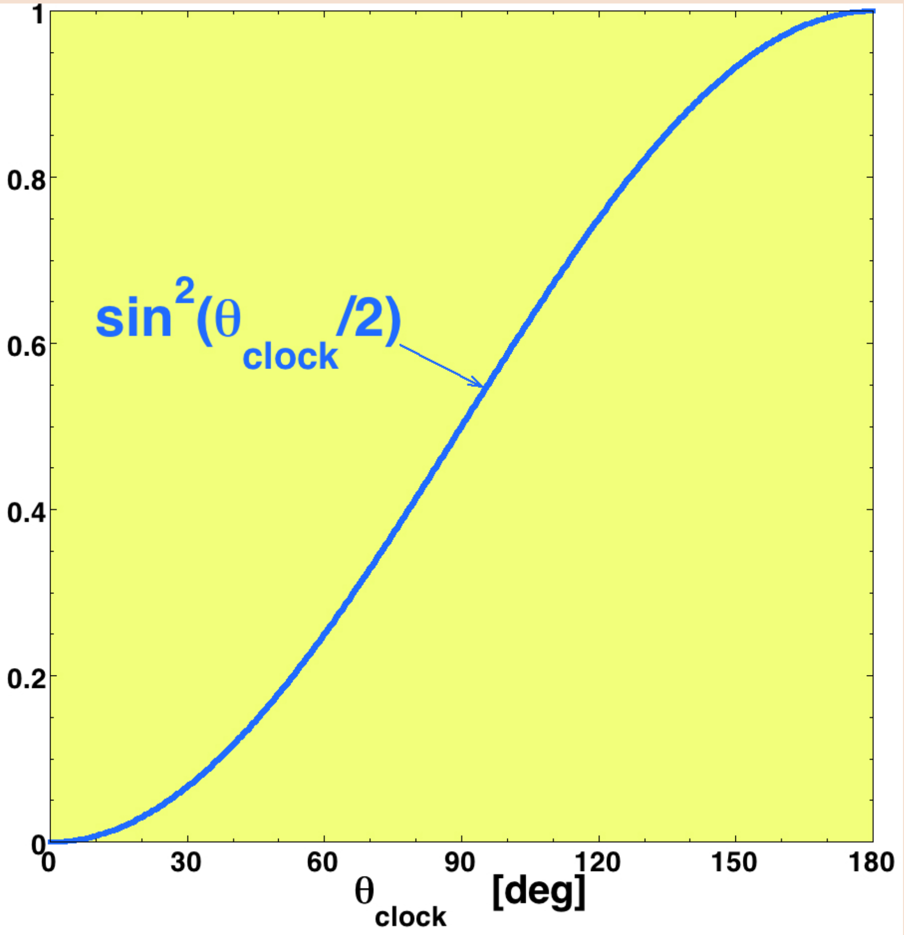
For parallel fields, $\theta_{clock} = 0^o$.

For antiparallel fields, $\theta_{clock} = 180^o$.

$$R = 0.1\, v_A\, B \sin^2(\theta_{clock}/2)$$

For the solar wind and the Earth the mean clock angle is about 90^o.

The clock angle varies considerably on the timescale of minutes.



The Cassak-Shay Equation for Asymmetric Reconnection (for collisionless plasmas)

When $B_1 \neq B_2$ and/or $\rho_1 \neq \rho_2$, the rule of thumb $R = 0.1 v_A B$ does not work.

Cassak-Shay reconnection-rate equation:

$$R = (0.2/\mu_o^{1/2}) B_1^{3/2} B_2^{3/2} / \{(B_1\rho_2 + B_2\rho_1)^{1/2} (B_1 + B_2)^{1/2}\}$$

R depends on 4 local parameters: B_1, B_2, ρ_1, ρ_2.
Whatever controls those parameters controls the rate.

For symmetric plasmas ($B_1 = B_2$ and $\rho_1 = \rho_2$) Cassak-Shay reduces to:

$$R = 0.1\, v_A\, B$$

Some Solar-Wind Variables that Drive the Earth

v_{sw} : geomagnetic activity is higher when the solar-wind speed is higher

B_{mag} : geomagnetic activity is higher when the magnetic-field strength is higher

θ_{clock} : geomagnetic activity is higher when the field direction is more southward.

n_{sw} : geomagnetic activity is higher when the solar-wind density is larger.

M_A : geomagnetic activity is lower when the Mach number is higher.

α/p : geomagnetic activity is higher when the alpha-to-proton ratio is higher.

δB : geomagnetic activity is higher when the amplitude of fluctuations in the solar wind is greater.

Some of these are physical, and some are coincidental. Determining causality from correlations is very difficult.

The Strength of the Driving is Measured by Geomagnetic Indices

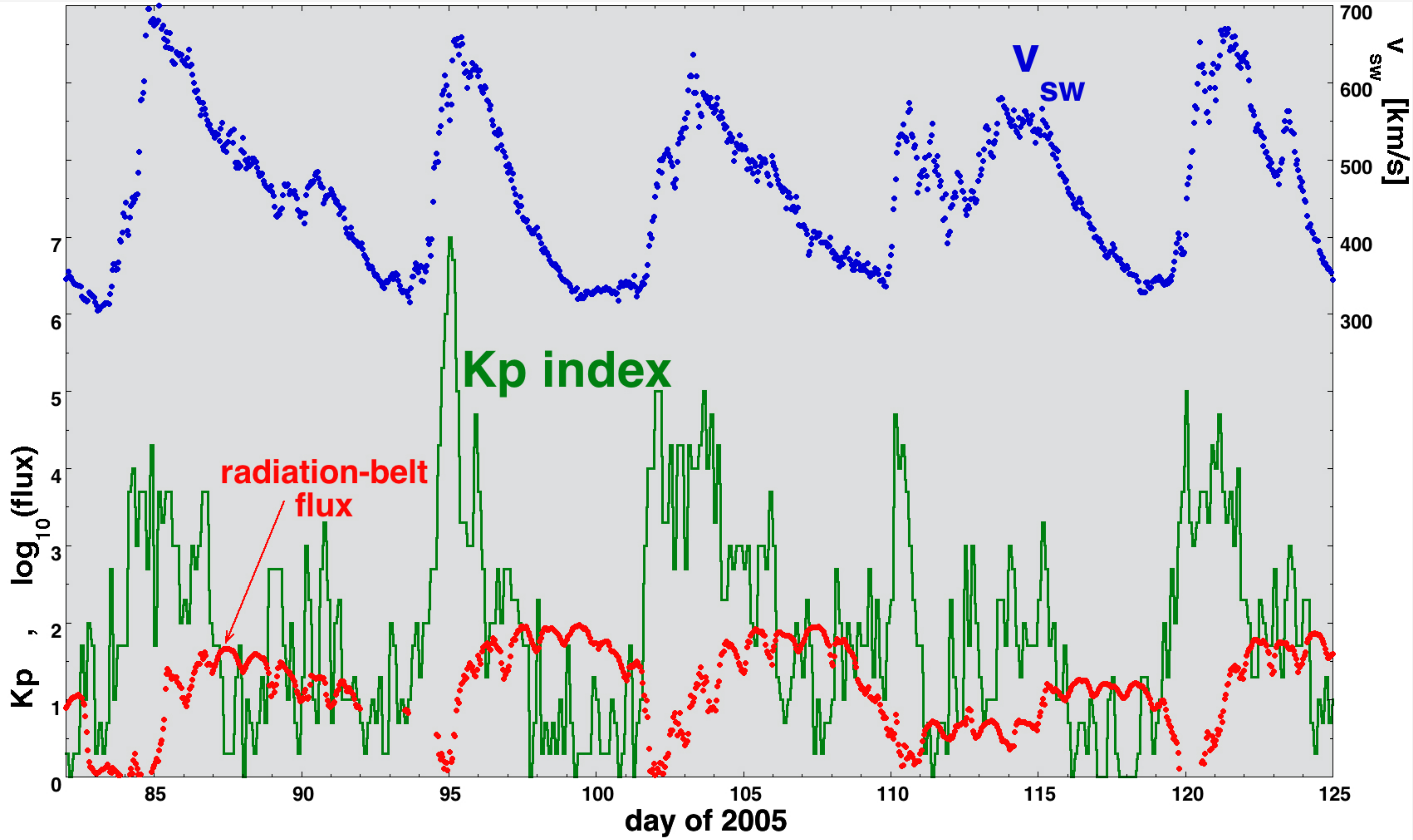
Geomagnetic indices are made from measurements by ground-based magnetometers measuring the size and locations of currents in the magnetosphere-ionosphere system.

These currents are indicators of what is going on:

Kp index -- measure of strength of magnetospheric convection
AL index -- measure of nightside auroral activity
AE index -- measure of high-latitude nightside and dayside current
Dst index -- measure of plasma pressure in the inner magnetosphere

Kp = 0-1 very quiet
Kp = 1-2 quiet
Kp = 2-3 normal activity
Kp = 3-4 active
Kp = 4-5 mild storm
Kp = 5-6 strong storm
Kp = 6-9 very strong storm

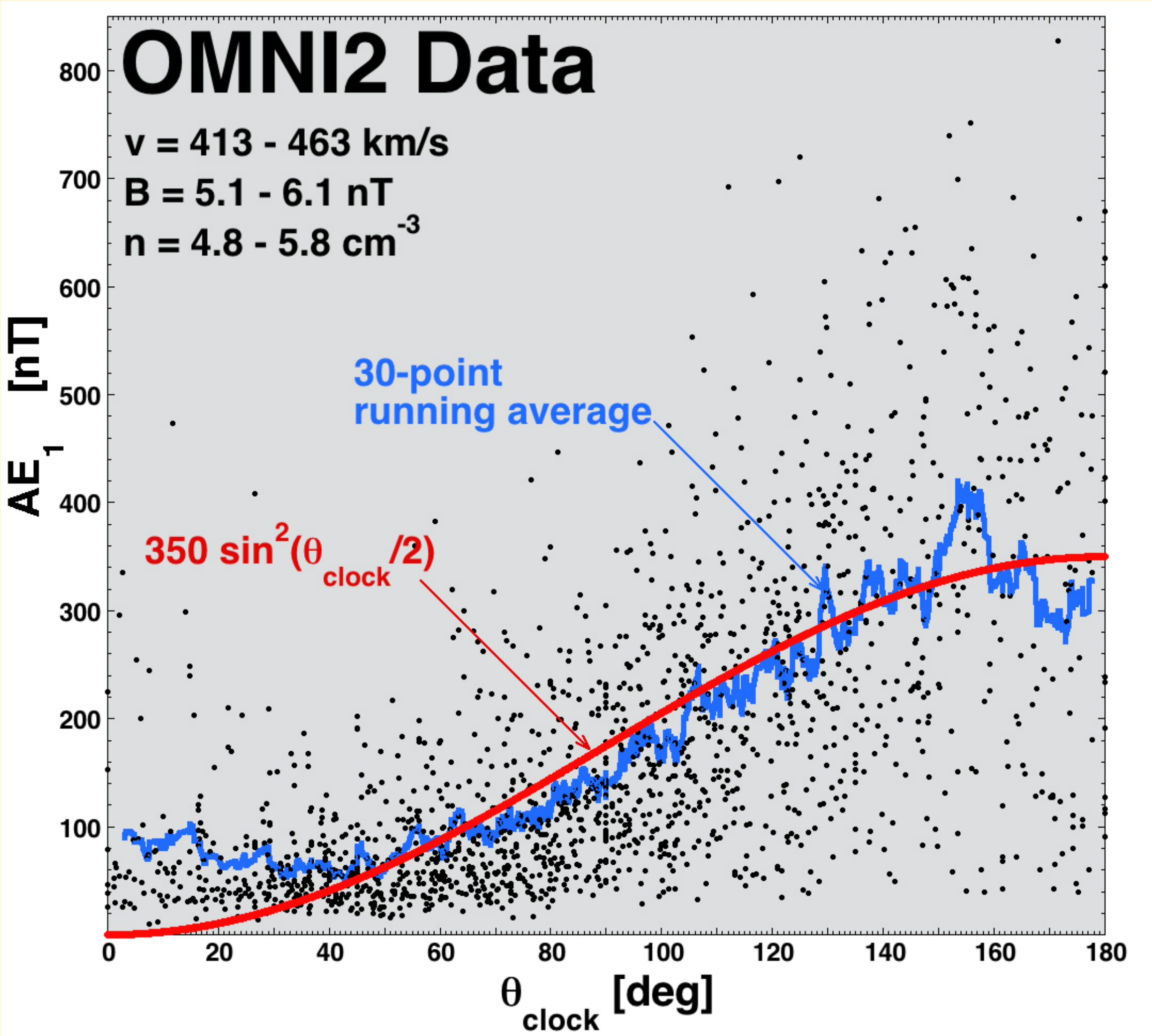
Example: High Speed Streams



Solar-Wind Magnetosphere Coupling

From reconnection theory:
$R \propto \sin^2(\theta_{clock}/2)$.

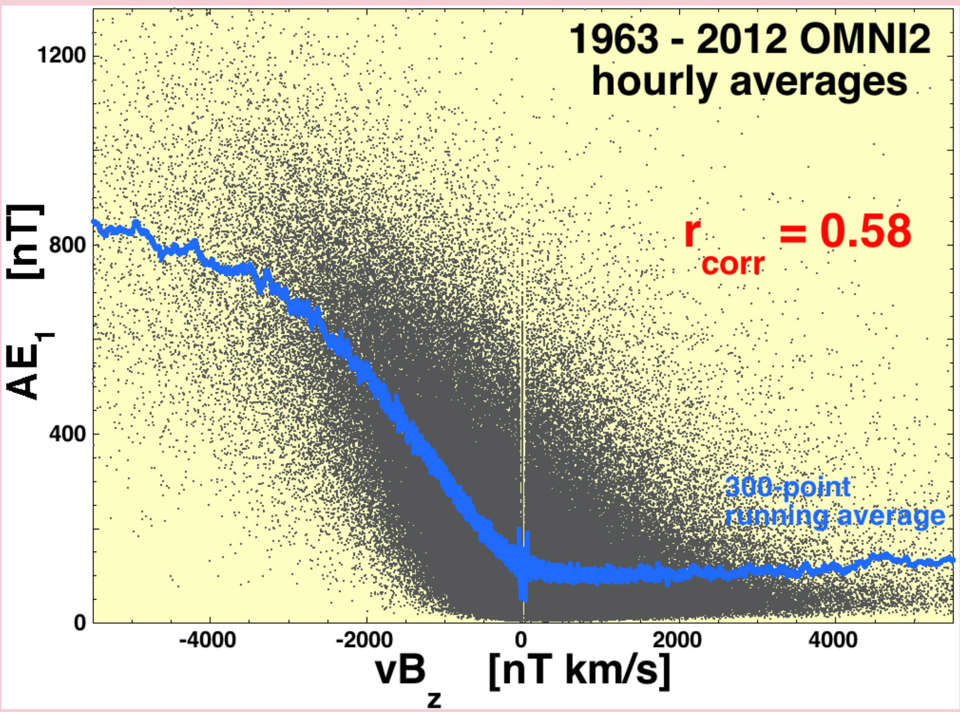
Do we see a $\sin^2(\theta_{clock}/2)$ dependence in the driving of the magnetosphere?



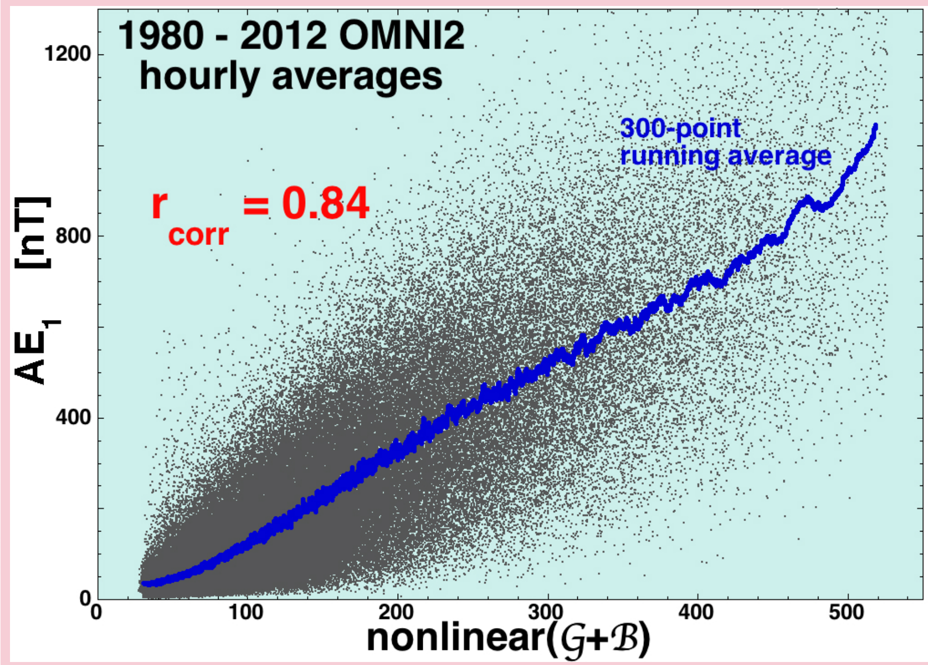
Solar-Wind Coupling Functions

There is a search for the solar-wind formula that best describes the driving of the magnetosphere. These formulas are useful for predicting "space weather".

a poor driver function



a very good driver function



r_{corr} is the "linear correlation coefficient": r_{corr}^2 is the amount of variance of one variable that is described by the variance of the other variable.

Solar-Wind Driver Functions

Some of the common driver function in the literature.

Coupling Function	**AE_1**	**KP_1**	**8-index average**
$v_{sw}B_z$	0.575	0.346	0.472
$\varepsilon = v_{sw}B^2\sin^4(\theta/2)$	0.475	0.435	0.480
$v_{sw}B_{south}$	0.688	0.534	0.613
$v_{sw}B_{\perp}\sin^2(\theta/2)$	0.708	0.618	0.657
$v_{sw}B_{\perp}\sin^4(\theta/2)$	0.718	0.585	0.650
$v_{sw}^{4/3}B_{\perp}^{2/3}\sin^{8/3}(\theta/2)$	0.775	0.649	0.695
R_{quick}	0.761	0.692	0.702

Solar-wind electric-field functions

The "Newell" function

A reconnection function

Excercize: Pachamama

Use OMNI2 1-hr-resolution data to look at the solar wind and the Earth's geomagnetic indices on the day you were born: http://omniweb.gsfc.nasa.gov/form/dx1.html

Was geomagnetic activity high or low that day? (Kp, AE) Was there a storm? Was it calm? Why? (Was the wind very fast or very slow? Was the IMF northward or southward?)

If you look at the week before the day you were born, what was the solar wind doing?

If you look at the interval 27 days earlier than the day you were born, was the solar-wind similar? Was the reaction of the Earth similar?

When you were born, was it during a toward sector or an away sector?

The solar wind at Earth on the day you were born: when did it leave the Sun?

What was phase of the solar cycle?