The Driving of the Magnetosphere-Ionosphere-Thermosphere System by the Solar Wind

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What is solar-wind/magnetosphere coupling?

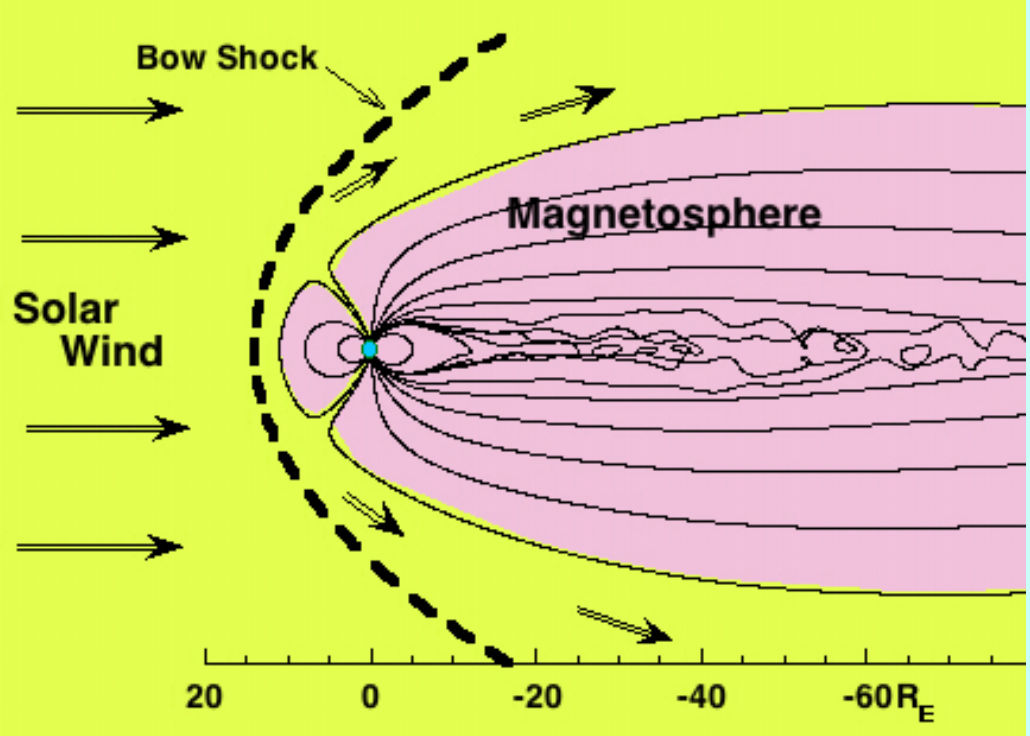
How does the coupling work?

What controls the coupling?

Difficulties and outstanding questions.

The Solar Wind

The solar wind compresses the dayside magnetosphere and draws the nightside magnetosphere out into a long tail.



The distortions of the dipole are associated with currents.

Typical solar wind parameters:

- **speed = 300 - 700 km/s**
- **number density = 3 - 40 cm^{-3}**
- **magnetic field = 3 - 30 nT**
- **Mach number = 2 – 20**
- **composition: protons with a few % He^{++}**

Note: It is the magnetosheath plasma that makes contact with the magnetosphere.

What Is Coupling?

The transfer of energy, momentum and mass from the solar wind into the magnetosphere-ionosphere system.

Drives convection and currents in the magnetosphere and ionosphere.

Transport of plasma, creation of ionospheric outflows, driving aurora, energization of the radiation belt.

Two Pathways to Coupling

1. Dayside reconnection (dominant)

Dungey [1961]

2. The viscous interaction (secondary*)

Axford and Hines [1961]

***But may be important for mass transport**

Dayside Reconnection

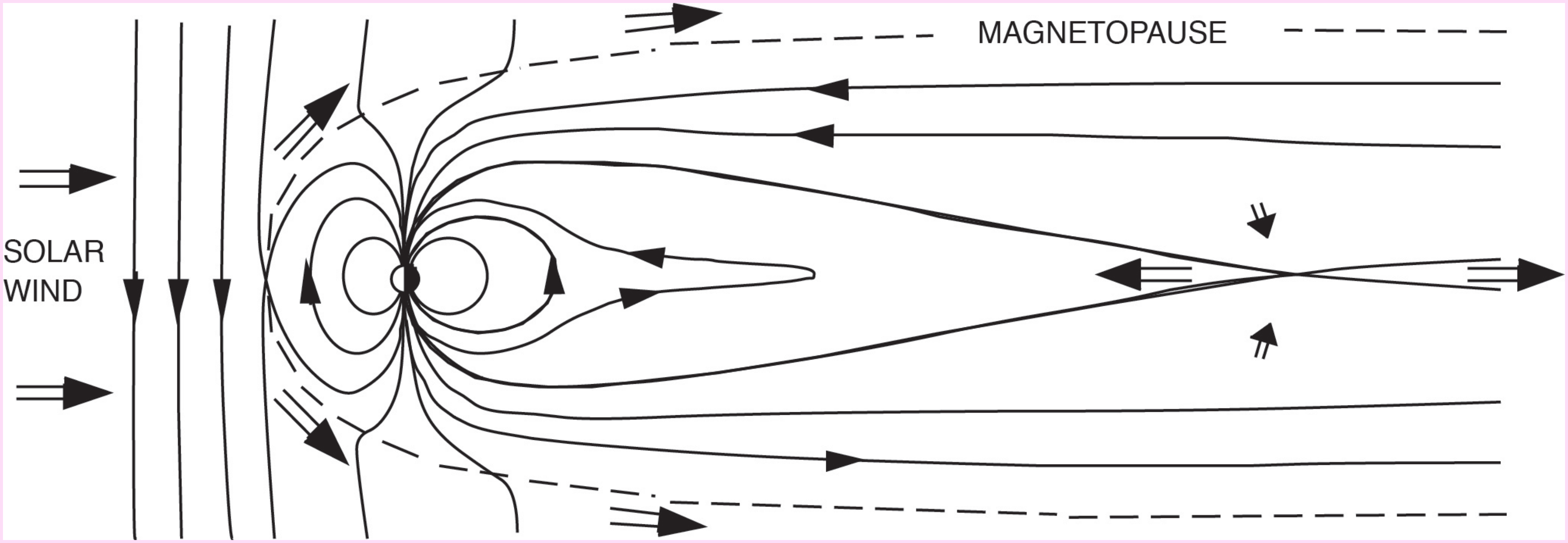
The dayside reconnection rate largely controls the amount of coupling.

1. Reconnection on the dayside connects the solar wind to the magnetosphere.

2. The moving solar wind drags magnetic flux into the magnetotail.

3. Reconnection in the tail disconnects the solar wind and allows magnetic flux to convect from the nightside to the dayside.

Reconnection allows plasma to enter and it drives magnetospheric and ionospheric convection. Convection energizes the plasmas in the Earth's magnetosphere and creates aurora..



Magnetic Reconnection
(Petschek “fast” reconnection)

The outflow speed controls the rate of reconnection.

Transfer of magnetic energy into flow kinetic energy.

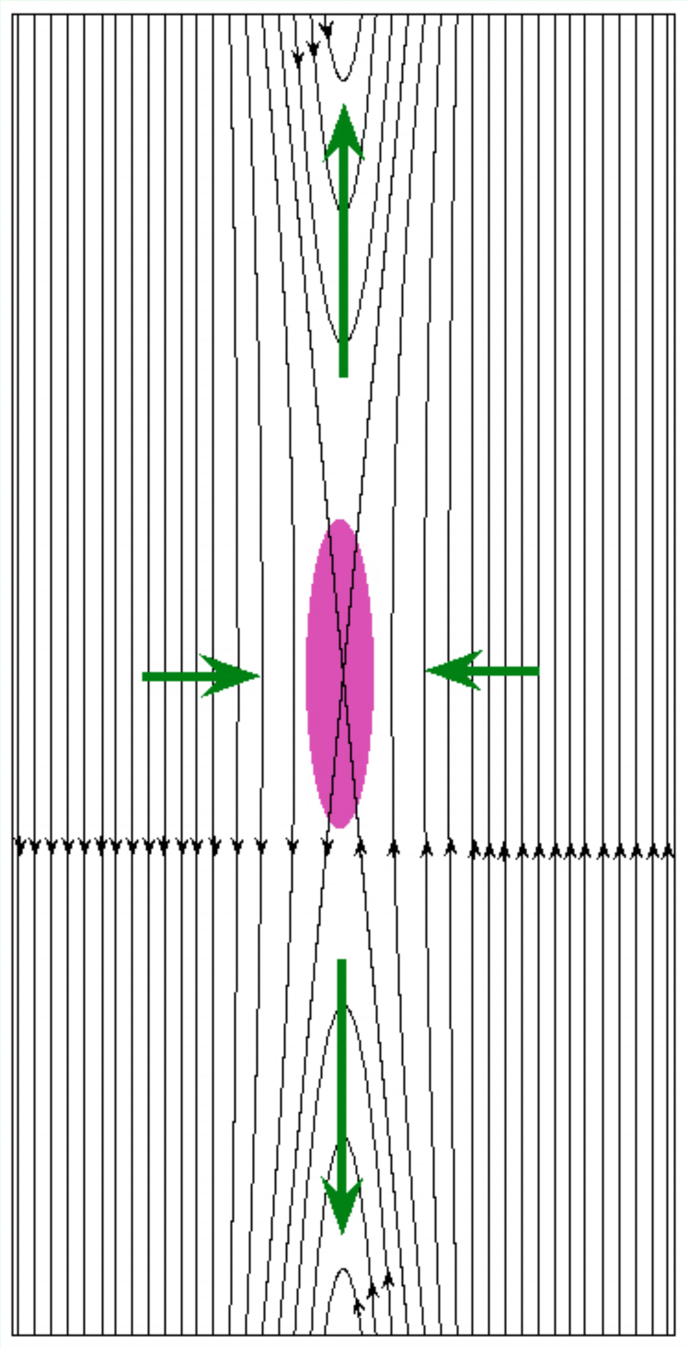
$$B^2/8\pi = 0.5\,\rho\, v^2$$

$$v = B/(4\pi\rho)^{1/2} = v_A$$

Inflow speed is ~0.1 v_A (geometry).

Reconnection rate is $0.1 v_A B$, where v_A and B are measured in the inflowing plasma.

Clock angle: $0.1 v_A B \sin^2(\theta_{clock}/2)$



The Cassak-Shay Equation for the Reconnection Rate

For "symmetric" reconnection, the reconnection rate $R = 0.1 v_A B$.

If v_A and B differ in the two plasmas: "asymmetric reconnection".

Cassak-Shay Equation (2007):

$$R = (0.1/\pi^{1/2}) B_1^{3/2} B_2^{3/2} / \{(B_1\rho_2 + B_2\rho_1)^{1/2} (B_1 + B_2)^{1/2}\} \sin^2(\theta_{clock}/2)$$

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

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

For strongly asymmetric plasmas with $v_{Aslow} << v_{Afast}$, the Cassak-Shay equation simplifies to

$$R \approx 0.2\, v_{Aslow} (B_{slow} B_{fast})^{1/2} \sin^2(\theta_{clock}/2)\,.$$

At the dayside, slow = magnetosheath and fast = magnetosphere.

¿What in the Solar Wind Controls the Dayside Reconnection Rate?

$R \approx 0.2\, v_{Asheath}\, (B_{sheath} B_{mag})^{1/2} \sin^2(\theta_{clock}/2)$.

This formula contains 4 variables: B_{mag}, B_{sheath}, n_{sheath}, θ_{clock}.
What in the solar wind controls these 4 variables?

1. B_{mag} is controlled by the solar-wind ram pressure:

Pressure balance:

$$B_{mag}{}^2/8\pi \;=\; 0.5\, \rho_{sw}\, v_{sw}{}^2 \;=\; 0.5\, m_p\, n_{sw}\, v_{sw}{}^2$$

2. B_{sheath} is controlled by the solar-wind Mach number M_A:

Pressure balance:

$$B_{sheath}{}^2/8\pi + 1.5\, n_{sheath}\, k_B\, T_{sheath} \;=\; B_{mag}{}^2/8\pi$$

$$B_{sheath} \;=\; B_{mag} / (1 + \beta_{sheath})^{1/2}$$

$$\beta_{sheath} = (M_A/6)^{1.92}$$

¿What in the Solar Wind Controls the Dayside Reconnection Rate?

3. n_{sheath} is controlled by n_{sw} and the Mach number M_A:

$$n_{sheath} = C\, n_{sw}$$

$C = C(M_A)$ **is the bow-shock compression ratio**

4. θ_{clock} is controlled by the solar-wind clock angle θ_{clock}:

$$\theta_{clock} = \theta_{clock}$$

Control of the 4 variables that control the dayside reconnection rate:

$$B_{mag} \Leftarrow n_{sw}\, v_{sw}^2$$

$$B_{sheath} \Leftarrow n_{sw}\, v_{sw}^2\ ,\ M_A$$

$$n_{sheath} \Leftarrow n_{sw}\ ,\ M_A$$

$$\theta_{clock} \Leftarrow \theta_{clock}$$

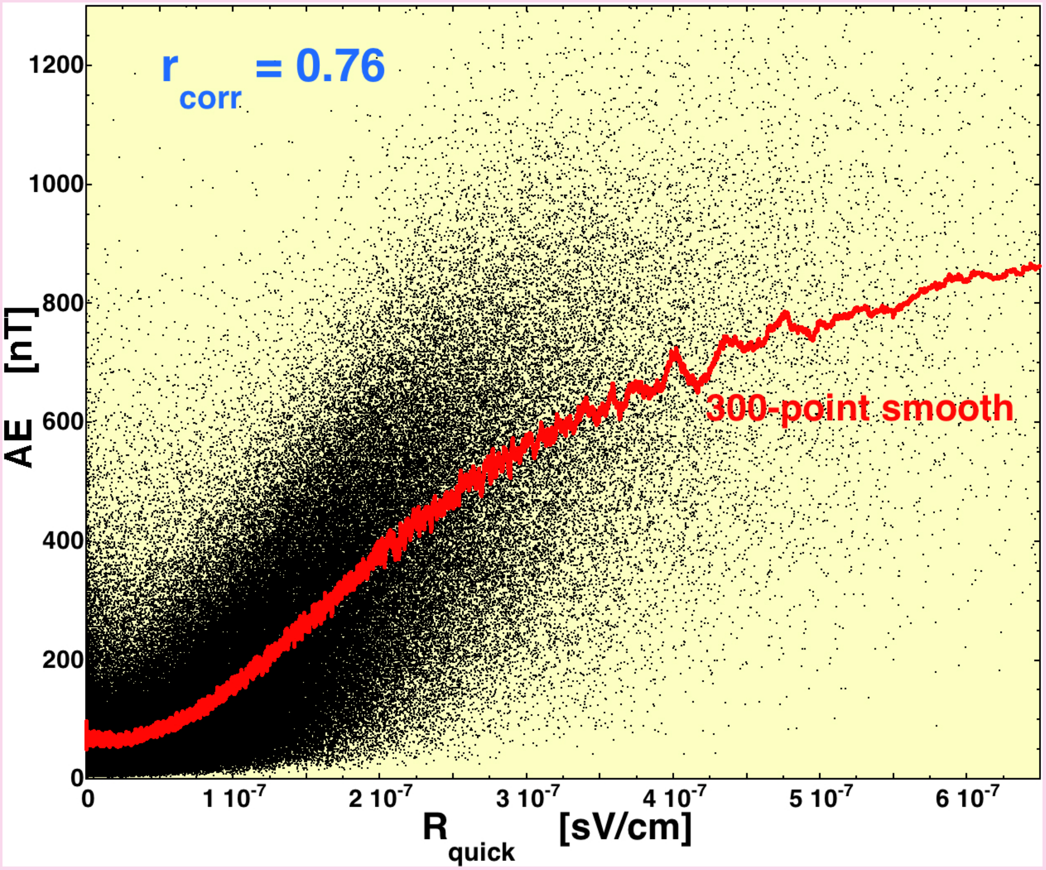
The Quick Reconnection Function

Cassak-Shay Reconnection equation:

$$R \approx 0.2\, v_{Asheath}\, (B_{sheath} B_{mag})^{1/2}\, \sin^2(\theta_{clock}/2)$$

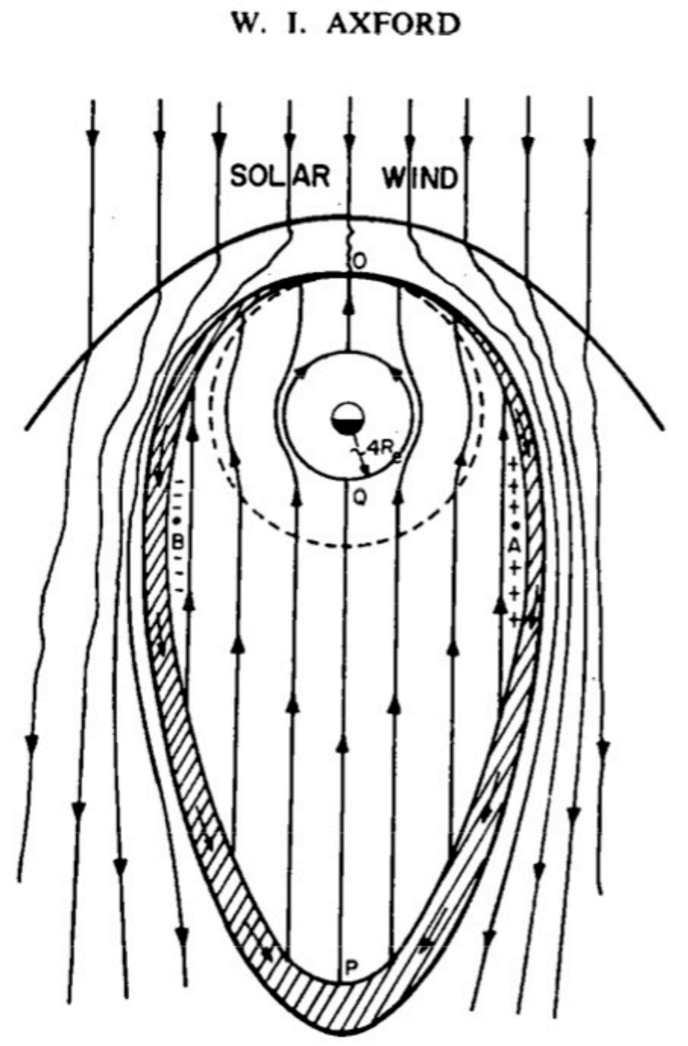
is written in terms of upstream solar-wind variables as:

$$R_{quick} = 3.89\, \pi^{1/2}\, m_p^{\ 1/2}\, n_{sw}^{\ -0.175}\, v_{sw}^{\ 0.65}\, B_{sw}^{\ 1.35} [1 + (7.2/M_A)^{3.30}]^{-1/4} \sin^2(\theta/2)$$



Note that this is the local reconnection rate at the nose of the magnetosphere.

The Viscous Interaction Is Poorly Understood



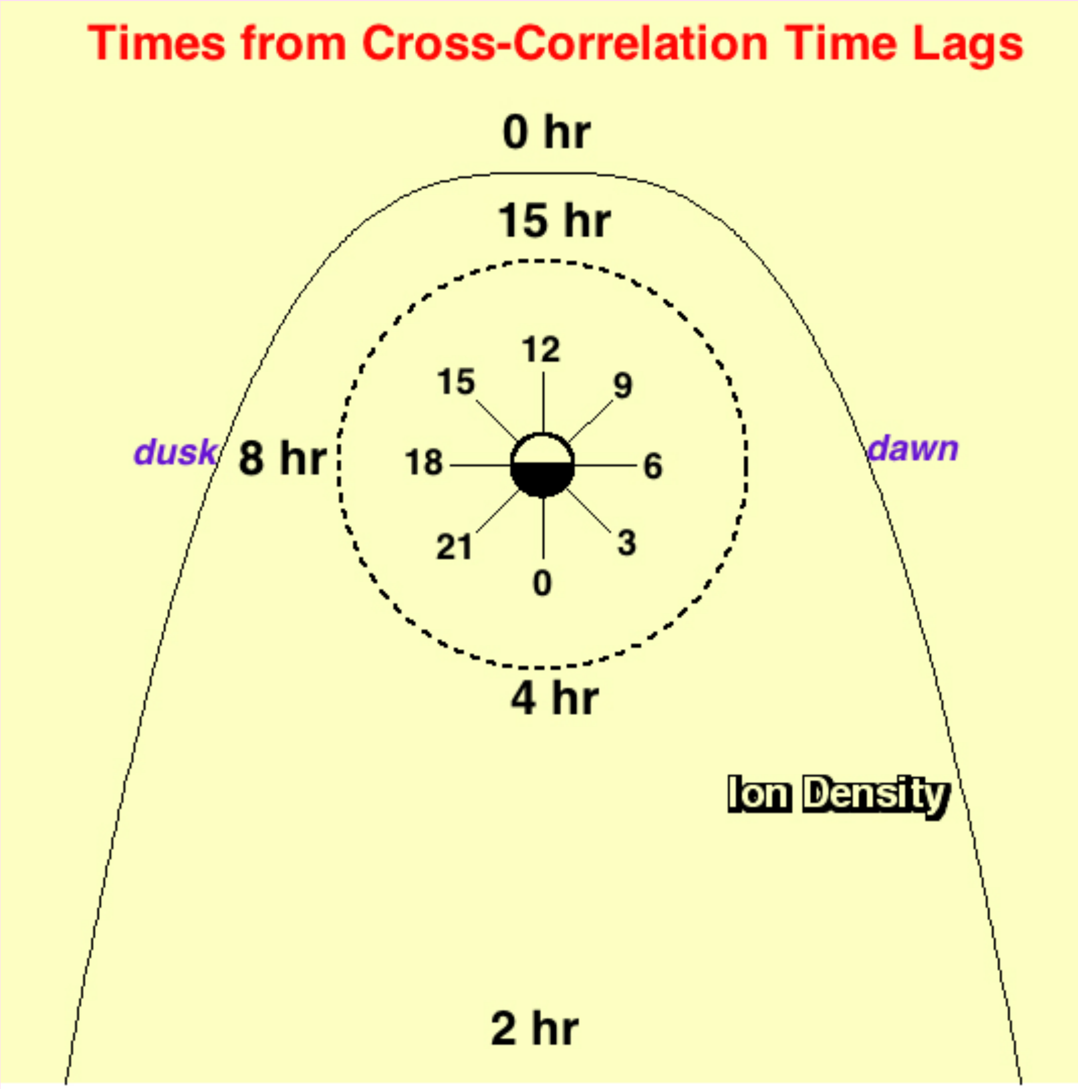
(1) What is the magnitude of the viscous interaction?
(viscous interaction versus reconnection behind the cusps)

(2) What physical mechanisms are acting?
Kelvin-Helmholtz rollups?
Plasma-wave diffusion?
Turbulence ?

(3) What variables in the solar-wind control the viscous interaction?

(4) How is the viscous interaction related to plasma entry?

Plasma Entry and Transport

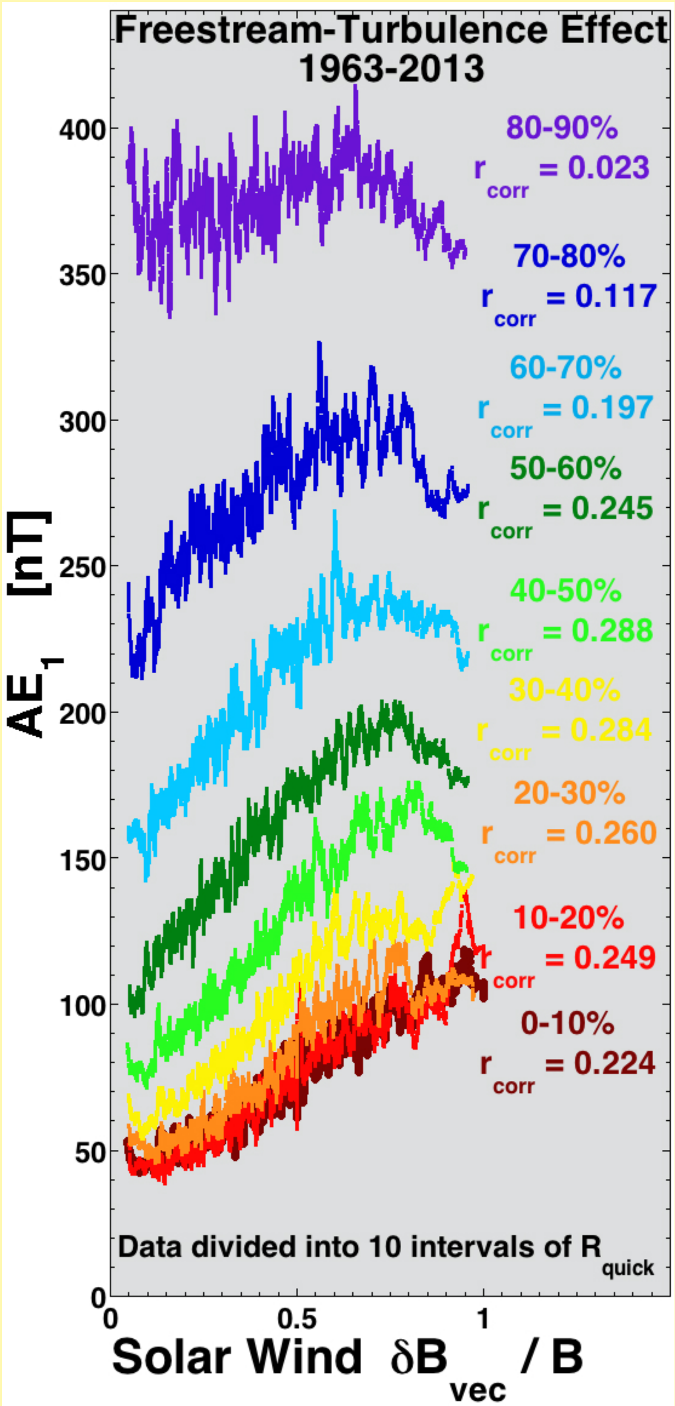


Solar-wind (magnetosheath) plasma enters the magnetosphere via reconnection and via the viscous interaction.

¿Which pathway is more important?

¿What controls the rate of entry?

The plasma is caught up in the global magnetospheric convection pattern.



The Turbulence Effect

AE, AU, -AL, Kp, -Dst, and PCI are positively correlated with δB/B of the upstream solar wind.

These correlations hold when the reconnection driver functions are binned.

These correlations hold when the fluctuations are purely northward.

Is there a physical mechanism that couples solar-wind turbulence to the magnetosphere?

What type of solar-wind fluctuations are important?

Some Outstanding Questions

(1) What in the solar wind controls the total amount of dayside reconnection?

(2) How strong is the viscous interaction, how does it work, and what controls it?

(3) What are the entry mechanisms of solar-wind plasma into the magnetosphere, and what in the solar wind governs the amount?

(4) Why does geomagnetic activity increase with increasing levels of solar-wind turbulence?

Review

1. Dayside reconnection is the dominant pathway for coupling.
2. The reconnection rate is controlled by the plasma properties at the reconnection site.
3. The viscous interaction is poorly understood.

Issues for the Future

A. There are major issues of not understanding the coupling.

B. Our test of the coupling are problematic.

C. There are major issues of not understanding the M-I-T system's reaction to the coupling.

$\Rightarrow$ Work needs to be done!