User Feedback (Heliosphere/Magnetosphere)

The Effect of Sudden Wind Shear on the Earth's Magnetosphere

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Motivation: Looking at the Reaction of the Earth to the Solar Wind's Mesoscale Structure

1. 10-20 wind-shear events per day hit the Earth.

2. Statistical properties of sudden wind shears.

3. Reaction of the Earth's magnetosphere.

CCMC Projects

Exploratory (E) and Quantitative (Q) simulations.

1. **What causes field stretching in the dayside magnetosphere (E)?**
2. **Magnetosphere and magnetosheath under low-Mach-number solar wind (E).**
3. **Effect of magnetospheric plasma on solar-wind/magnetosphere coupling (Q).***
4. **Deriving a formula for the dayside reconnection rate (Q).***
5. **Polar-cap saturation (Q).***
6. **Looking at the Earth's reaction to sudden wind shear (E).**

*** = project that required code modification by CCMC personnel.**

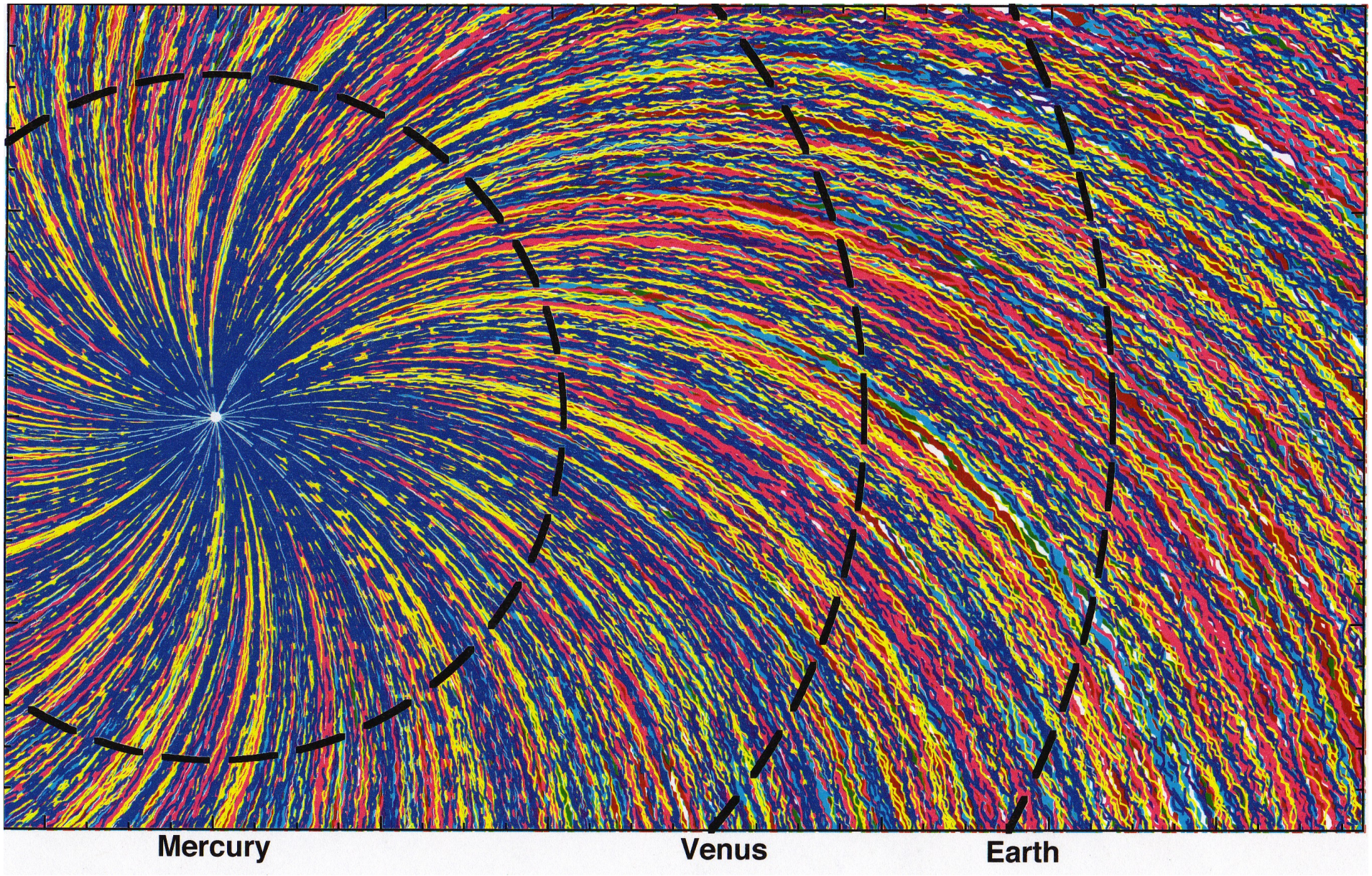
CCMC Has Given Me My Freedom

Having your hands on the controls of the simulations and having direct access to the outputs is much more efficient than asking colleagues for runs.

Similar to the “open-data” policy.

CCMC is fast and flexible.

The Solar-Wind Structure Drawn to Scale at Earth



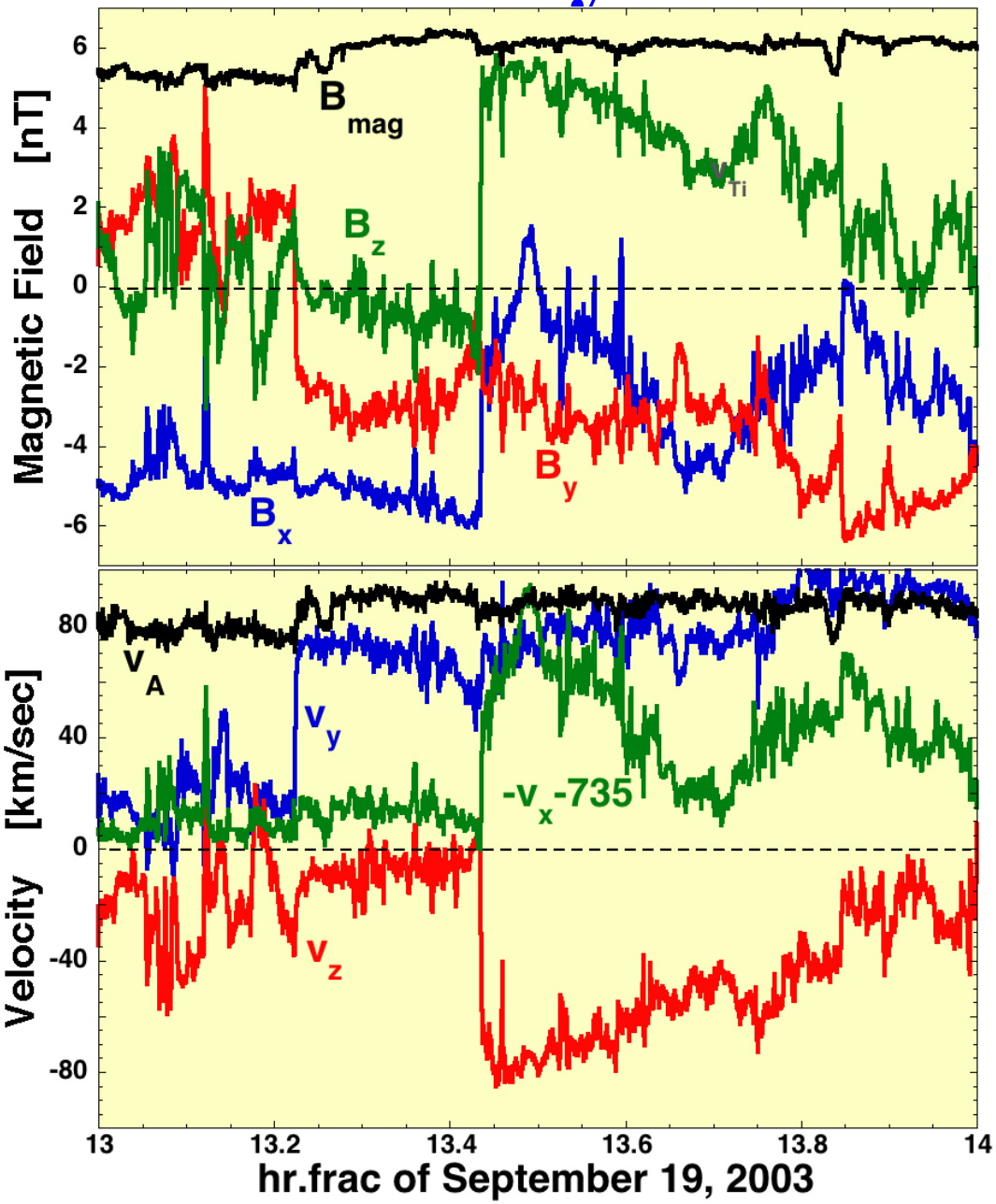
Current Sheets and Velocity Shears

Big $\Delta\underline{v}$ and big $\Delta\underline{B}$ are co-located.

$\Delta\underline{v}$ can be ~v_A.

Shear layers and current sheets have thicknesses ~ few seconds (~ 0.5 R_E).

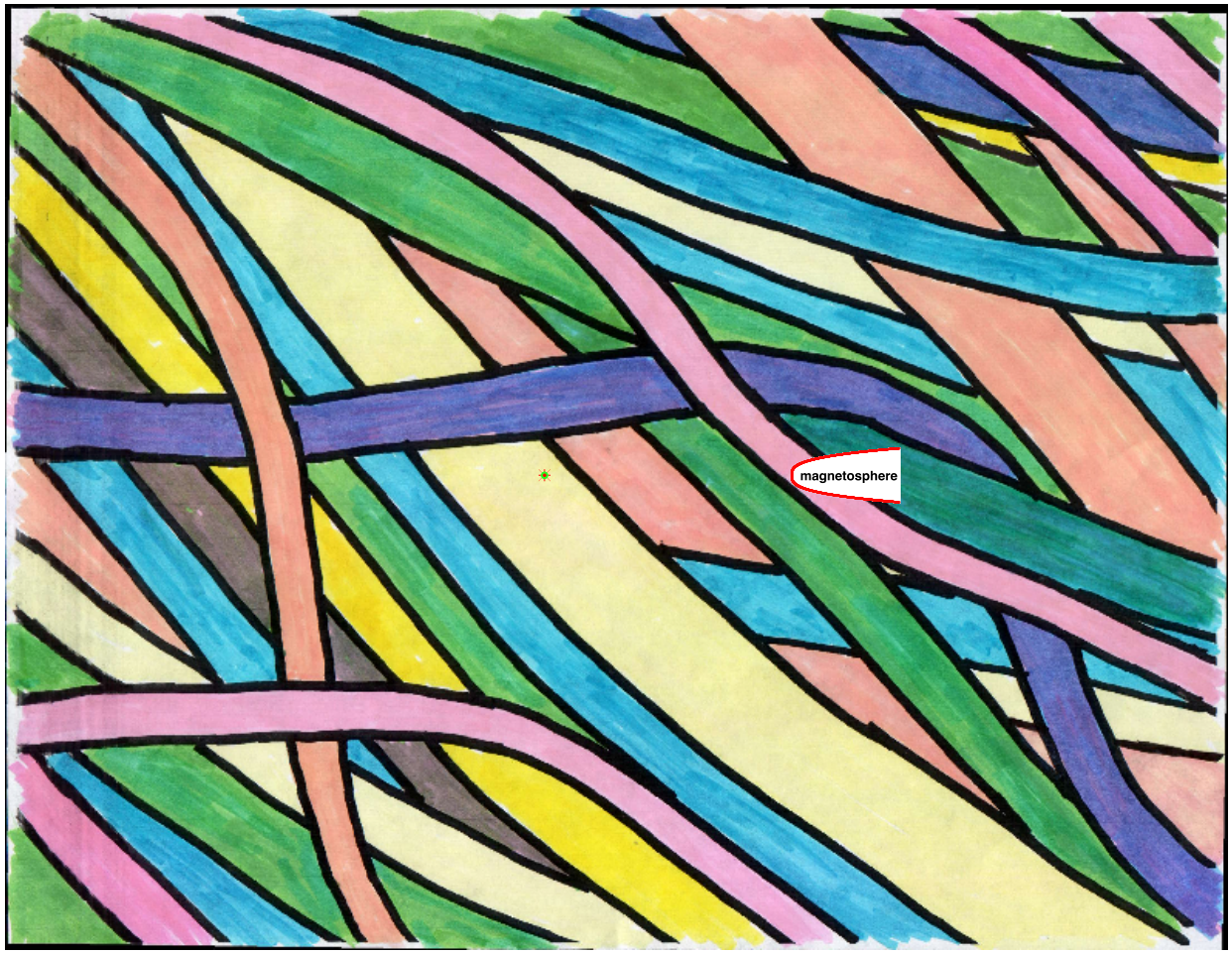
In the slow solar wind, shear layers are located on plasma boundaries.



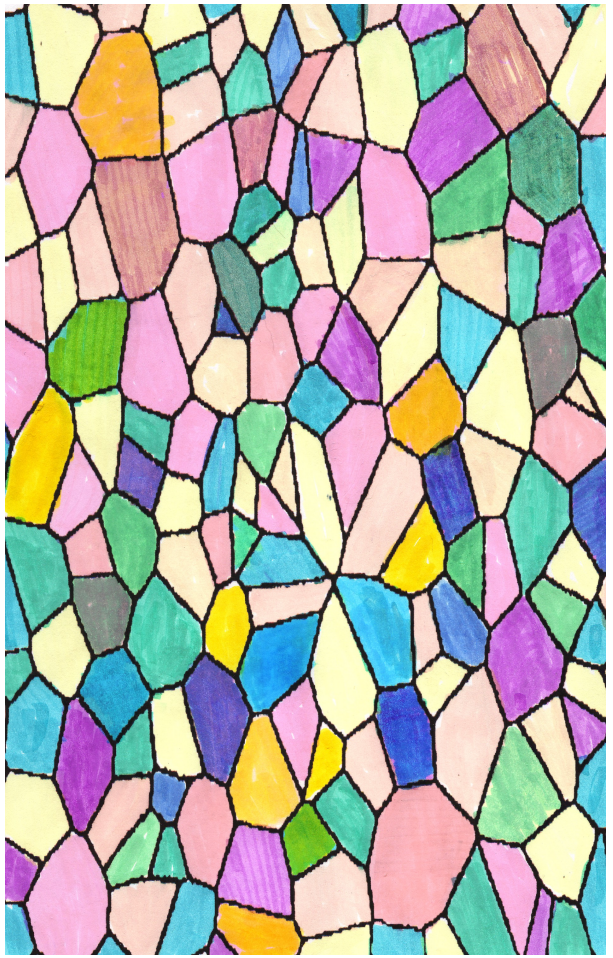
Spaghetti Model of Solar-Wind Structure

- Solar-wind plasma is partitioned into individual robust flux tubes
- The flux tubes are braided around the Parker-Spiral direction
- The wiggling flux tubes are separated by current sheets (tangential discontinuities).

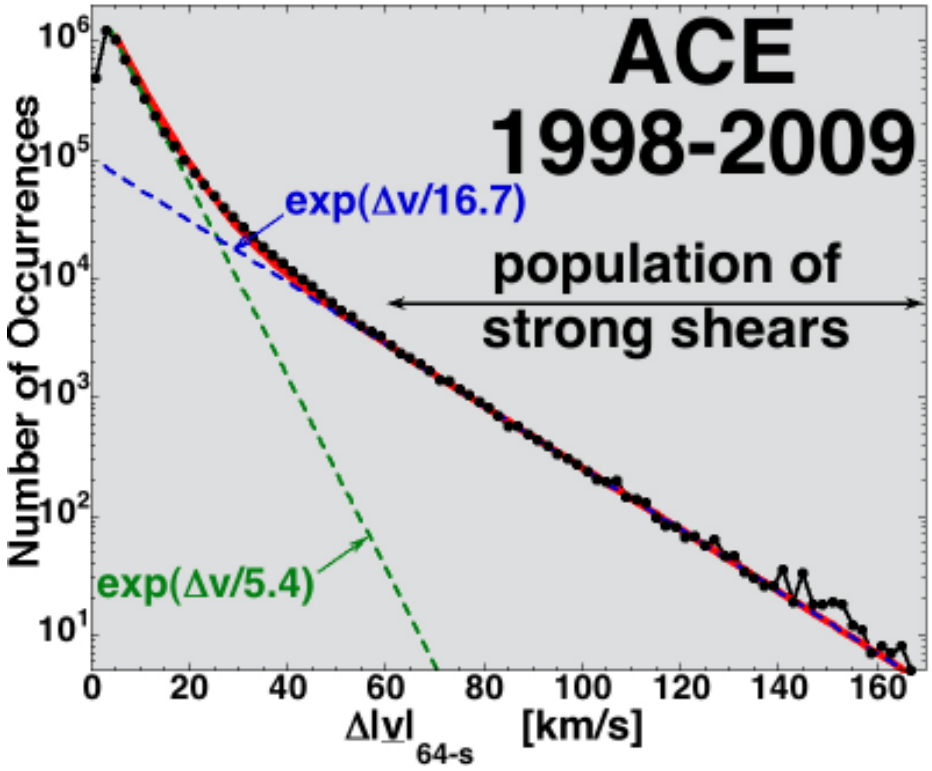
looking down on the tubes



looking into the tubes



Sudden Wind Shears



A collection of 23,875 shears with Δv > 60 km/s.

Symbol	Quantity	Value
Δv	Vector jump of the solar-wind velocity across the shear	78 ± 19 km/s
$\Delta\theta_v$	Angular change of solar-wind velocity vector across the shear	$6.7^o \pm 2.3^o$
$\Delta\theta_B$	Angular change of magnetic-field vector across the shear	$60^o \pm 31^o$
ΔB	Vector jump in the magnetic field across the shear	6.9 ± 3.8 nT
$\Delta v/v_A$	Velocity jump across the shear relative to Alfven speed	1.03 ± 0.53
$\Delta v/C_{ms}$	Velocity jump across the shear relative to magnetosonic speed	0.77 ± 0.24

Sudden Wind Shears

Occurrence Rate:

$\Delta\underline{v} > 60$ km/s ⇨ 6 per day

$\Delta\underline{v} > 50$ km/s ⇨ 11 per day

$\Delta\underline{v} > 40$ km/s ⇨ 23 per day

Orientations:

Normals $\underline{n}$ to the shear layers tend to be ⊥ to the Parker spiral.

Vector changes $\Delta\underline{v}$ tend to be ⊥ to the radial direction.

Rules: $\Delta\underline{v}$, $\Delta\underline{B}$, $\underline{n}$, B_x: coronal-hole vs non-coronal-hole wind

Global MHD Simulations with Wind Shear

Identical runs with:

- **GUMICS**
- **Open GGCM**
- **BATSRUS**
- **LFM**

Solar-wind input:

$n = 6\ cm^{-3}$

$v_x = -450\ km/s$

$v_y = 0\ km/s$

$v_z = \pm 40\ km/s$

$B_x = 0$

$B_y = 5\ nT$

$B_z = 0$

$T = 7\ eV$

$M_{ms} = 9$

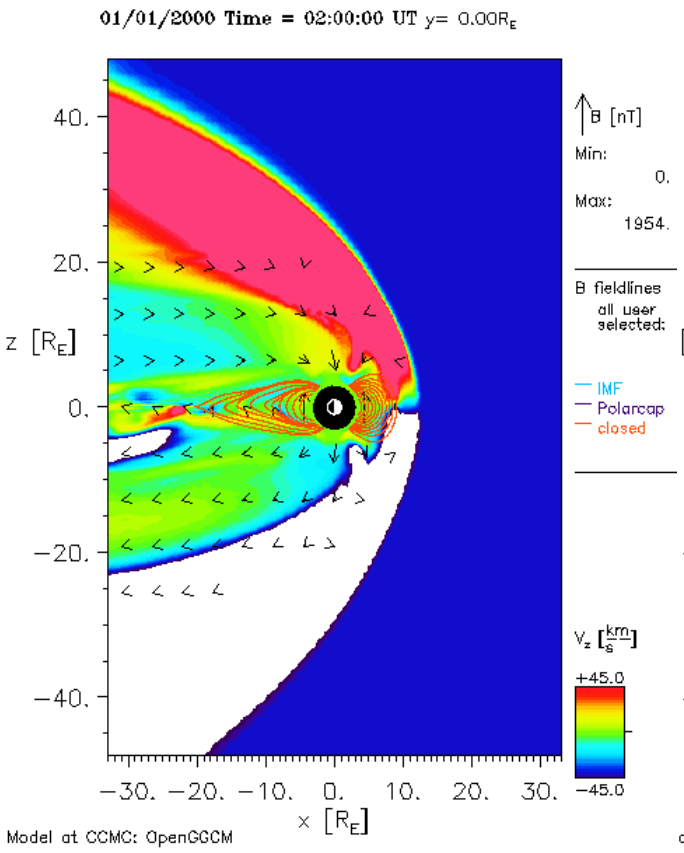
First 2 hours: $v_z = -40$ km/s
Following 2 hours: $v_z = +40$ km/s
No <u>B</u> change.

The Wind Shear

Orientation of shear plane: normal to the plane is radial.

Open-GGCM

t = 2:00



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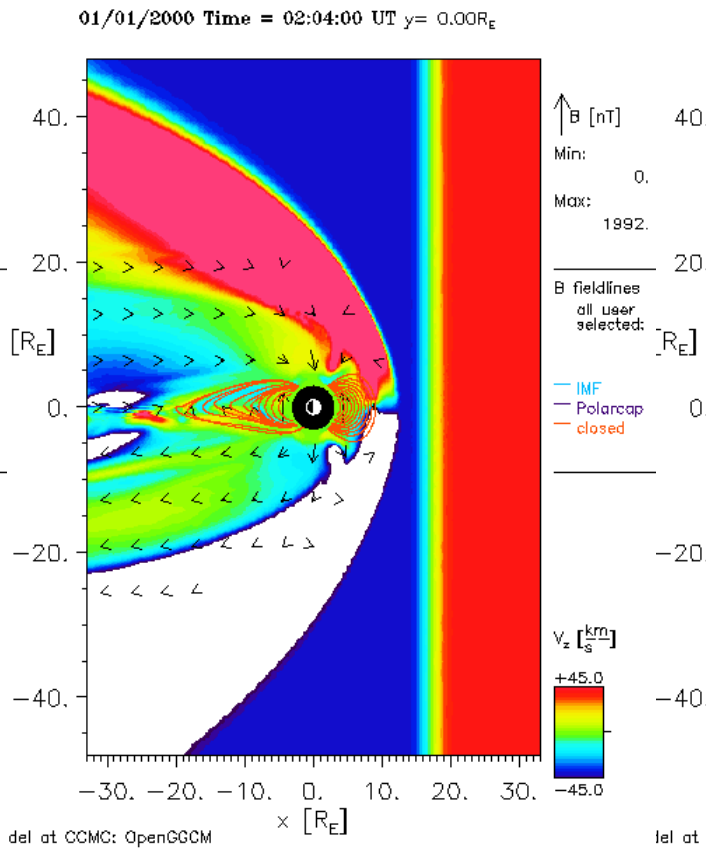

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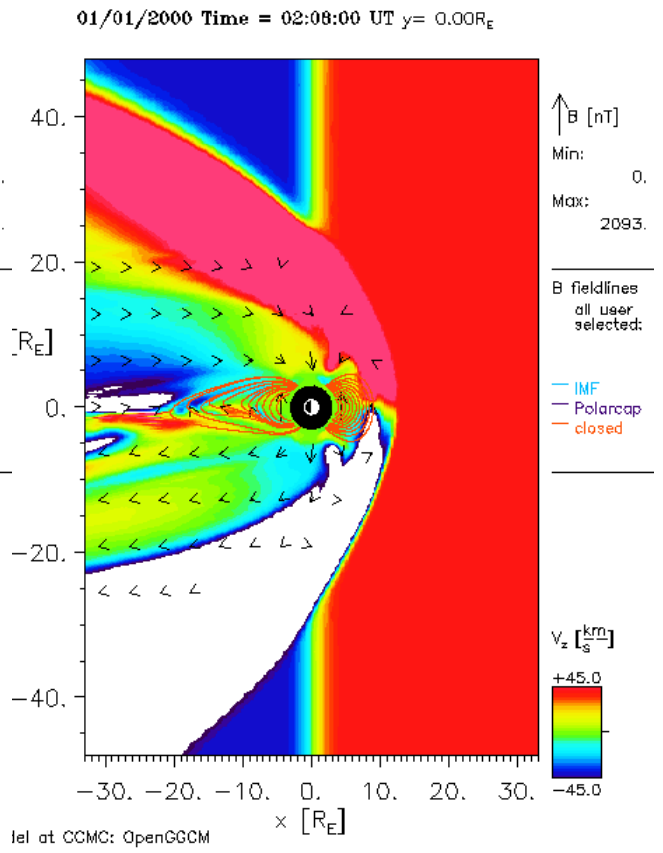
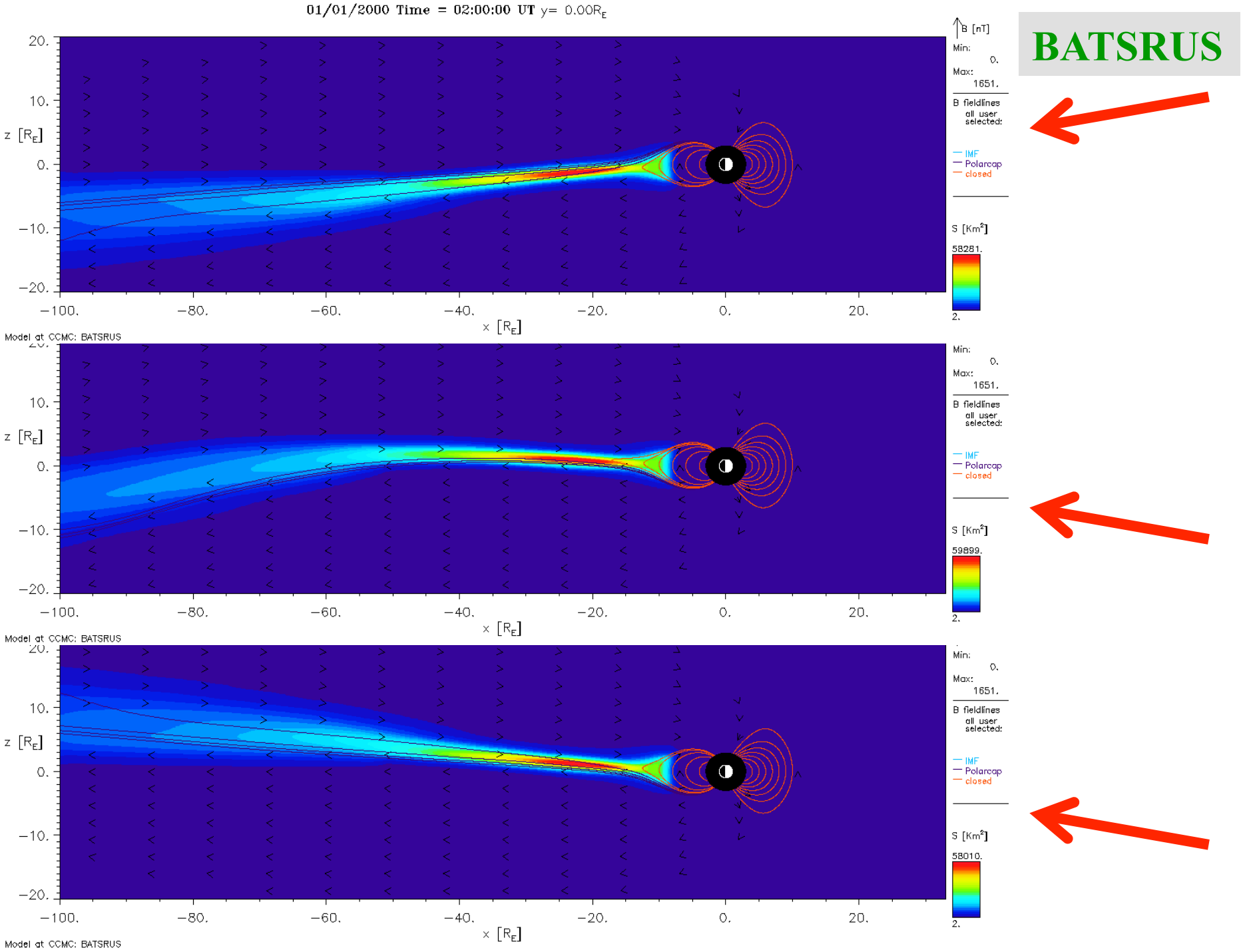
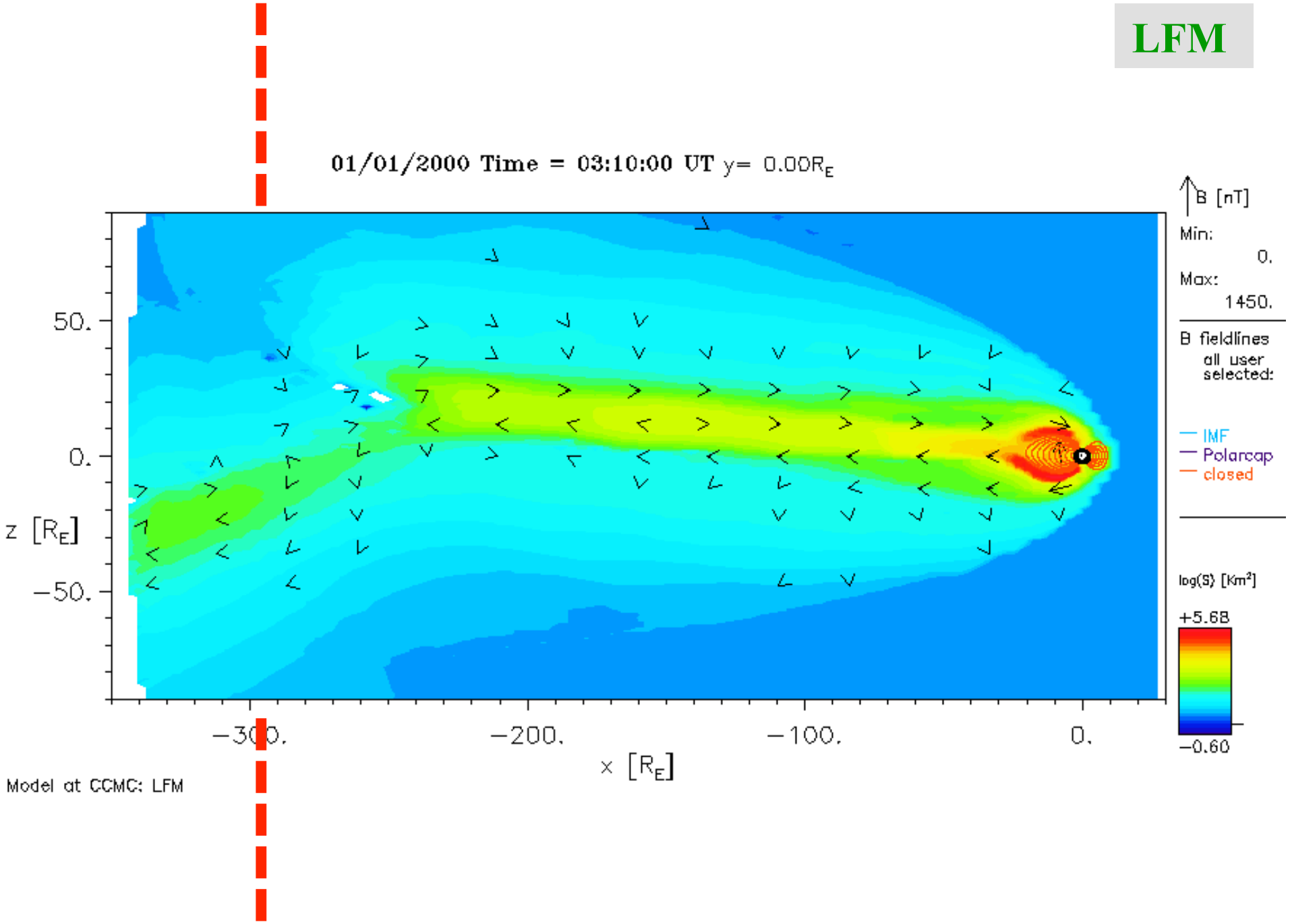



01/01/2000 Time = 02:00:00 UT y= 0.00R_E
B [nT]
Min:
0.
Max:
1651.
B fieldlines all user selected:
IMF
Polarcap
closed
S [Km²]
58281.
2.
z [R_E]
x [R_E]
Model at CCMC: BATSRUS
59899.
58010.
BATSRUS

LFM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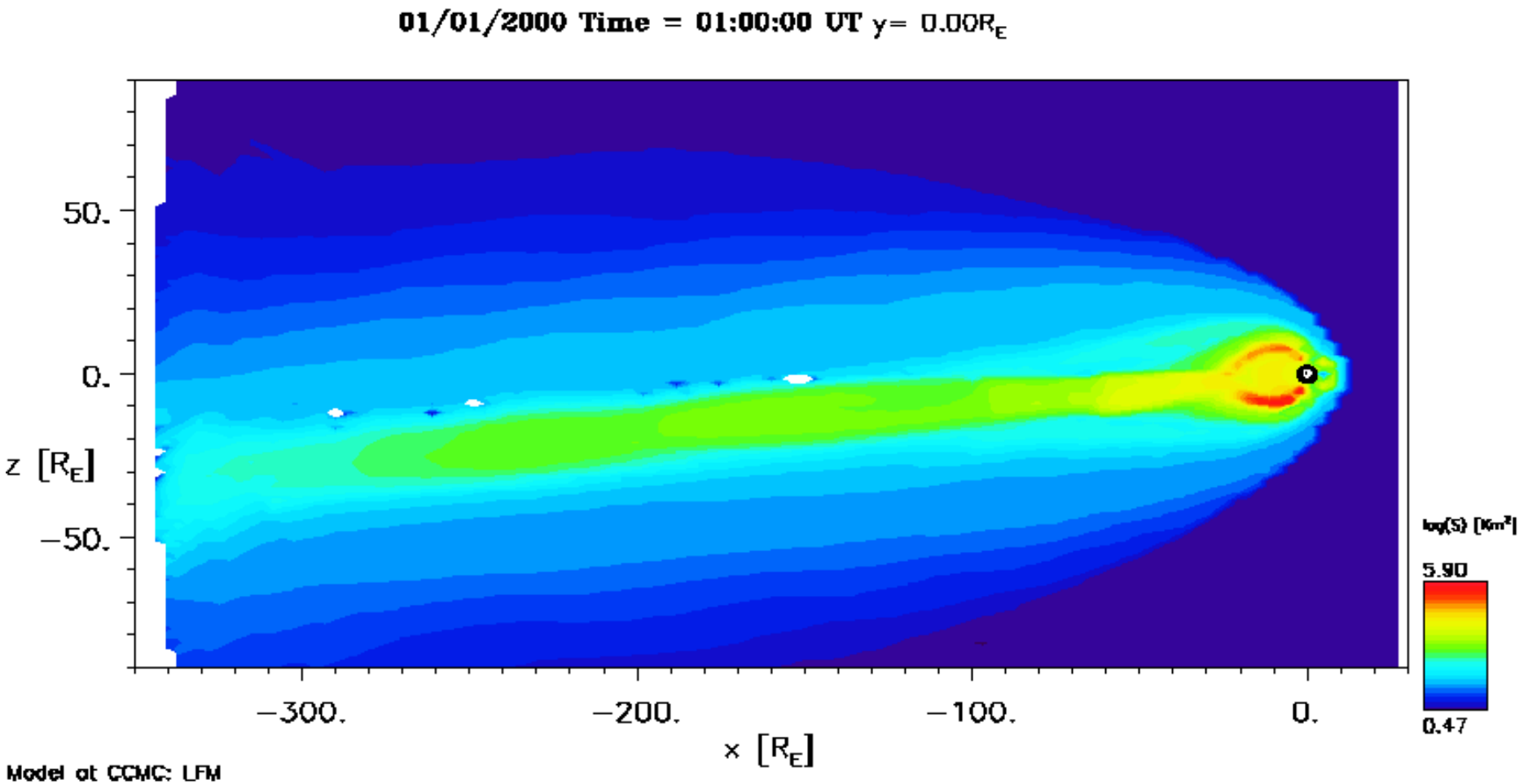
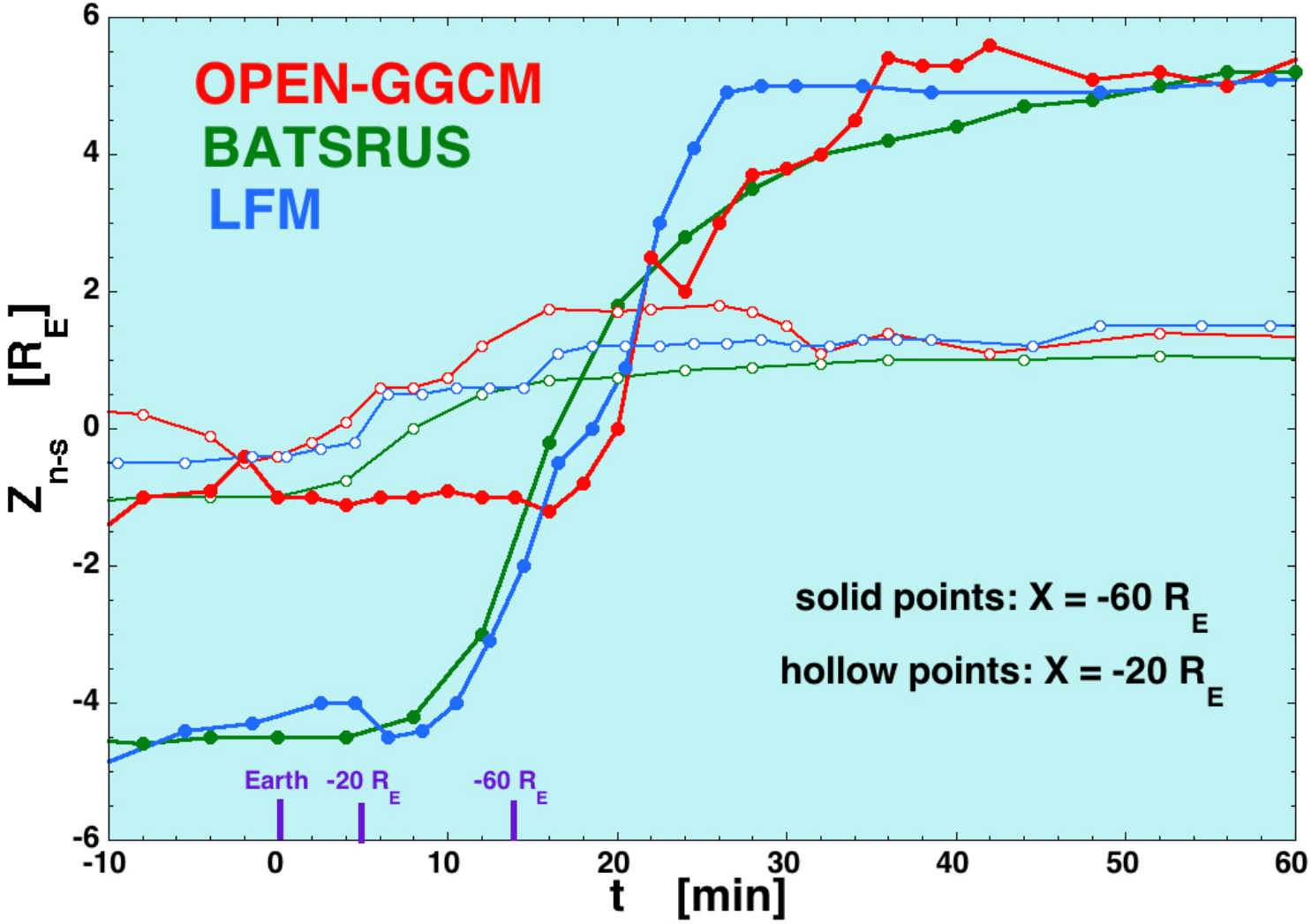
B [nT]
Min:
0.
Max:
1450.
B fieldlines
all user
selected:
IMF
Polarcap
closed
log(S) [Km²]
+5.68
−0.60
50.
0.
−50.
z [R_E]
−300.
−200.
−100.
0.
x [R_E]
Model at CCMC: LFM


01/01/2000 Time = 01:00:00 UT y= 0.00R_E
50.
0.
−50.
z [R_E]
−300.
−200.
−100.
0.
x [R_E]
log(S) [Km²]
5.90
0.47
Model at CCMC: LFM

Measuring Motions in the Tail

Plotting the z-position of the neutral sheet versus time.

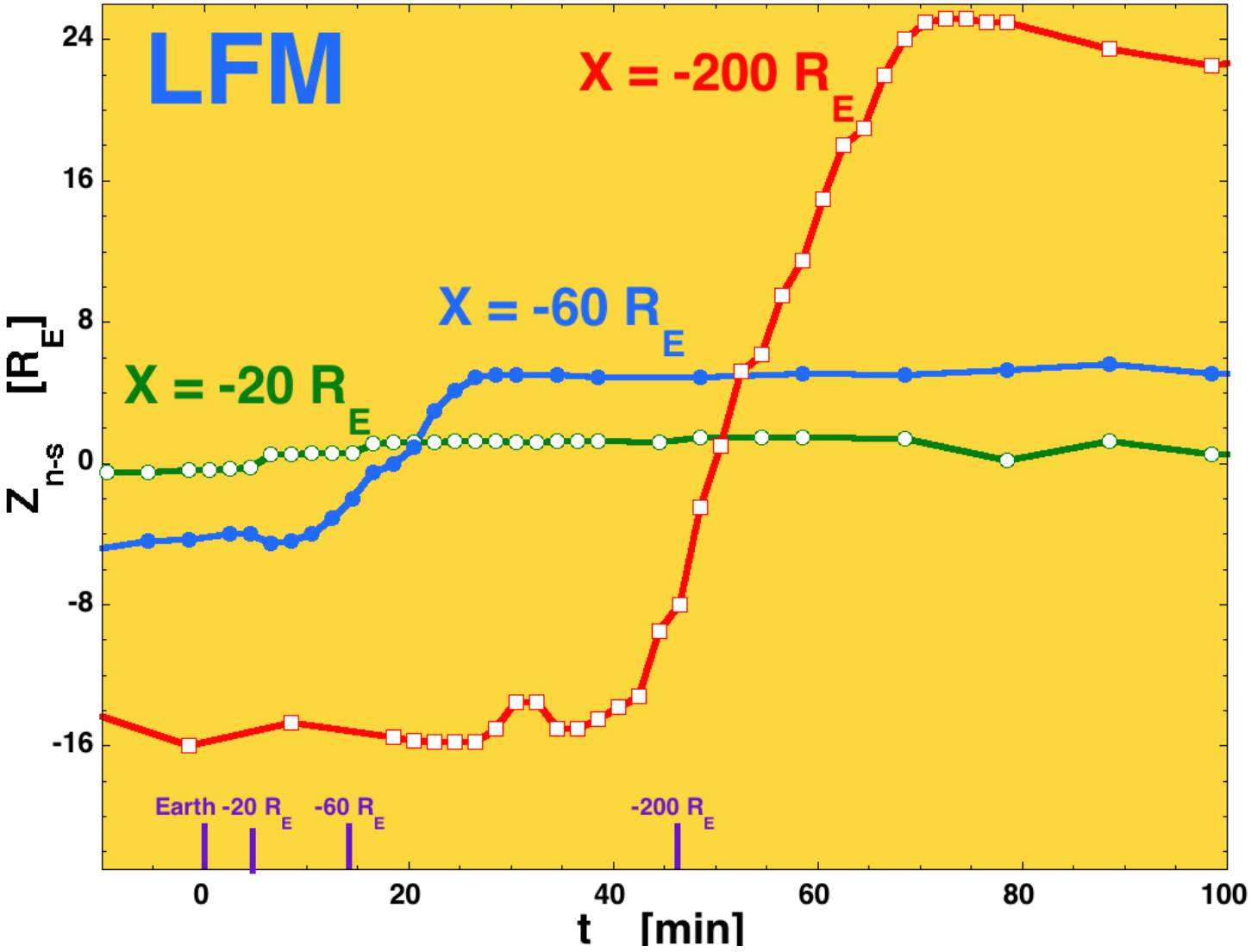


At -20 R_E
v_z = 12-15 km/s

At -60 R_E
v_z = 37-58 km/s

Solar wind
Δv_z = 80 km/s

Measuring Motions in the Tail



Solar wind
Δv_z = 80 km/s

At -20 R_E
v_z = 12-15 km/s

At -60 R_E
v_z = 37-58 km/s

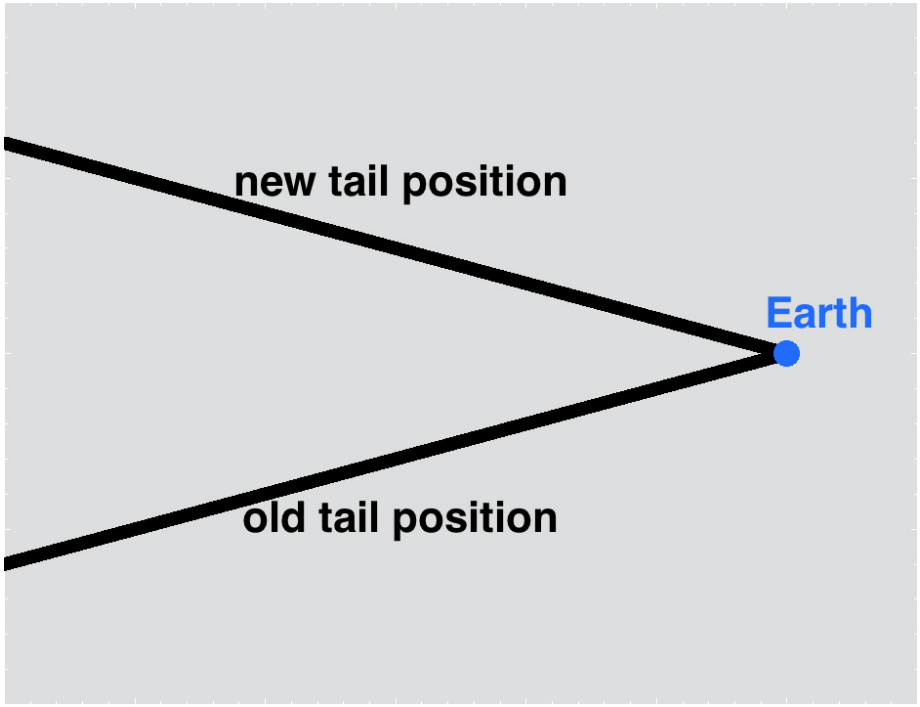
At -200 R_E
v_z = 149 km/s

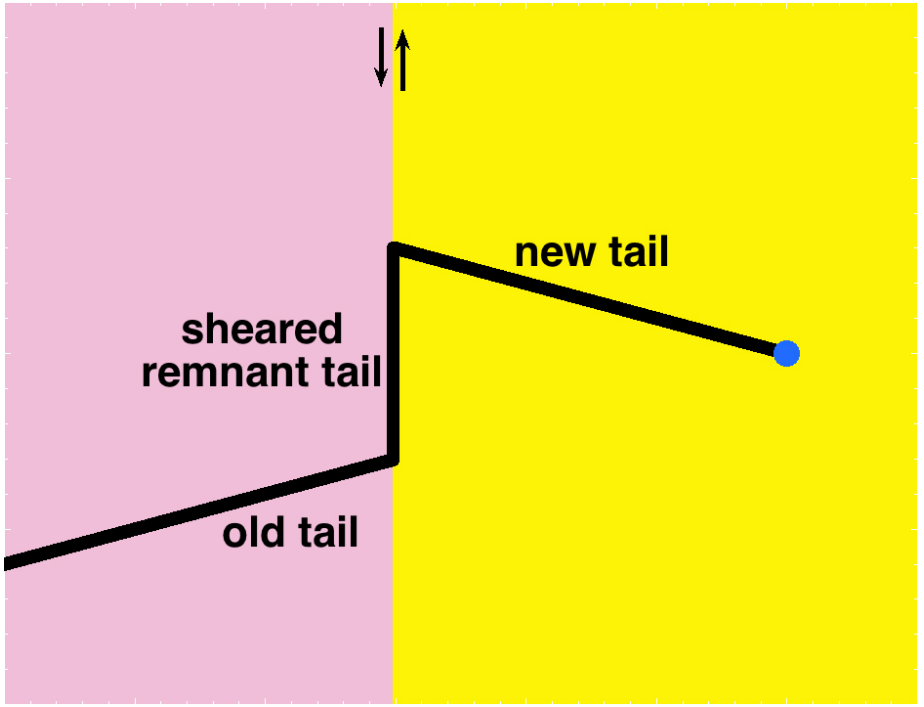
At -200 R_E
v_A ~ 50 km/s

Note: At X = -200 R_E, plasma v_z flows are < 60 km/s !

Tail Breaking

Eventually, tail motions will exceed the Alfven speed.





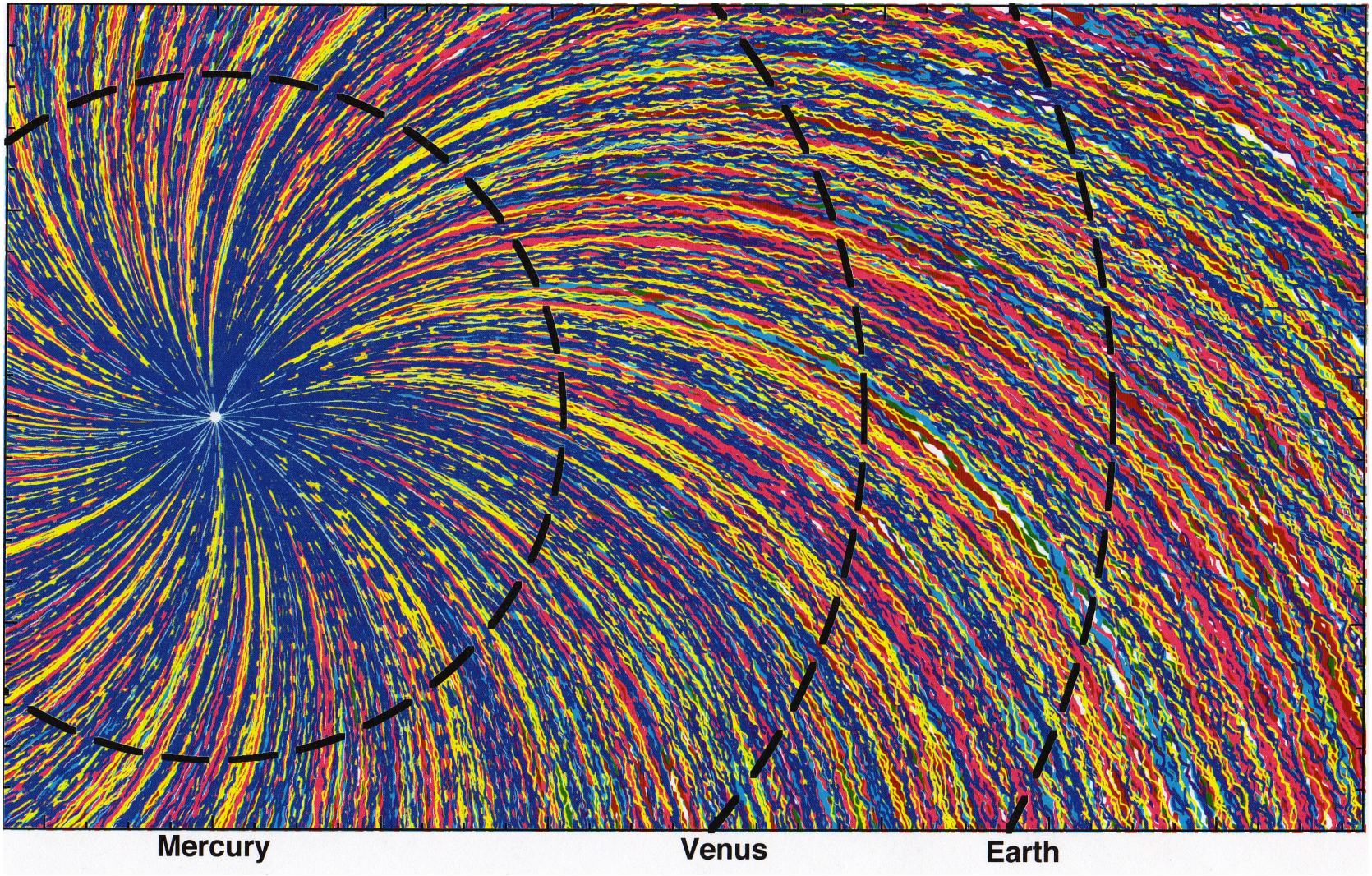
Don't forget, one shear event is followed by another!

Future CCMC Runs

- **Tail-severing demo.**
- **Large-spatial-domain run:**
  (plenty of solar wind around the magnetotail).
- **$\Delta\underline{B}$ changes with $\Delta\underline{v}$ changes.**
- **Non-perpendicular (to radial) shear planes.**
- **Look for triggering of magnetospheric activations.**
- **High-time-resolution probes to look for ringing.**

Desired Improvements for CCMC

Heliosphere Models: **CCMC models are not at the resolution level of the solar wind's mesoscale structure.**



Desired Improvements for CCMC

Solar-Wind-Driven Global Magnetosphere Models

(*Besides reconnection, drift physics, and the plasmasphere)*

- **Internal boundaries:**
  Momentum equation and incorrect transport
  – need shear-dependent coefficient of viscosity?
- **Numerical Reynolds numbers are low:**
  Would like R set by ionosphere, not magnetospheric gridding
- $\Delta\phi_{magnetosphere} \neq \Delta\phi_{ionosphere}$

Summary of Wind-Shear Project

- **Earth sees 10 or 20 strong wind shear events per day.**
- **CCMC simulations show a magnetosphere strongly distorted by wind shear.**
- **CCMC will be crucial for a more-complete exploration.**

Acknowledgements:

CCMC Staff
John Lyon
Dan Welling

Support:

NASA CCMSC-24 Program
NSF SHINE

Test for Substorm Triggering

Use Morley-Freeman technique to look for statistical associations between vorticity spikes and substorm onsets.

Weygand-UCLA propagated ACE data (60-s).

Vorticity spike is $\Delta\theta > 4^{o}$ in 120 seconds.

Substorm onsets are from the Frey IMAGE-FUV list.

26759 vorticity spikes and 3494 substorm onsets in 2001-2005.

No separating east-west shears from north-south shears.

No statistical association found ***(same Morley-Freeman answer as for northward turnings).***