1999 CEDAR Workshop
Boulder, Colorado
June 13-18, 1999

Solar-Terrestrial Coupling Processes
Tutorial Lecture II

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Magnetospheric Interactions with the Solar Wind and Ionosphere
Interplanetary Sources for Geomagnetic Activity

General

- **Convection**: IMF $B_z$, $B_y$ effects on strength; response to IMF changes
- **Tail plasma source**: dependence on convection strength?
- **Strong convection**: Earthward penetration of plasma sheet and resulting large distortion of $B$

Geomagnetic disturbances: Characteristics of, distinctions between types, relations to interplanetary conditions.

- **Poleward boundary intensifications**
- **Substorms**
- **Convection bays**
- **Storms**, including newly discovered response to pressure pulses
Fig. 1. Total transpolar voltage measured by four low-altitude spacecraft plotted versus simultaneous $vB_z$ in the solar wind (from Cowley, 1984).
Convection Strength

Increases as IMF $B_z$ becomes increasingly negative (well known)

Also increases significantly as IMF $|B_y|$ increases (not as well studied)

<table>
<thead>
<tr>
<th>$B_x$ (nT)</th>
<th>$B_y$ (nT)</th>
<th>$B_z$ (nT)</th>
<th>N. hem. $\Delta\Phi$</th>
<th>S. hem. $\Delta\Phi$</th>
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<tbody>
<tr>
<td>7.6</td>
<td>-1.9</td>
<td>6.8</td>
<td>30 kV</td>
<td>20 kV</td>
</tr>
<tr>
<td>5.1</td>
<td>-19.7</td>
<td>6.5</td>
<td>50 kV</td>
<td>80 kV</td>
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<tr>
<td>1.9</td>
<td>13.1</td>
<td>1.1</td>
<td>81 kV</td>
<td>74 kV</td>
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<tr>
<td>7</td>
<td>0</td>
<td>0</td>
<td>15 kV</td>
<td>25 kV</td>
</tr>
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Width of open region \( W = \Delta \phi / (V_{sw} \times B_{IMF}) \)
\( \sim 100 \text{kV}/(400 \text{ km/s} \times 5 \text{ nT}) \)
\( \sim 8 \text{ RE} \)

Length of open region \( L \sim \Phi / (B_{IMF} \cdot W) \sim 400 \text{ RE} \)

Open magnetic flux \( \Phi \sim 7 \times 10^8 \text{T-m}^2 \)
1992 Jan 28
19:05 UT
+- 45 min
$B_x = 7.6$
$B_y = -1.9$
$B_z = 6.8$

Separatrix
Separatrix?
Flow direction

Northern hemisphere
$\Delta \phi \sim 30 \text{ kV}$

Southern hemisphere
$\Delta \phi \sim 20 \text{ kV}$

Figure 8
1992 Jan 27
15:20 UT
+/- 115 min

$B_x = 5.1$
$B_y = -19.7$
$B_z = 6.5$

Separatrix

Northern hemisphere

Separatrix?

Southern hemisphere

$\Delta \phi \sim 50 \text{kV}$

$\Delta \phi \sim 80 \text{kV}$
1992 JUL 20 20:15 UT ± 75 min

Bx,y = 1.9, 13.1
Bz = 1.1
MH I 6
HPI = 6

ELECTRIC POTENTIAL
$\Delta \phi = 81$ kV

1992 JUL 20 20:15 UT ± 75 min

Bx,y = 1.9, 13.1
Bz = 1.1
MH I 6
HPI = 6

ELECTRIC POTENTIAL
$\Delta \phi = 74$ kV
1989 Jan 12-13
1830-0700 UT
Bx ~ 7
By ~ 0
Bz ~ 0

Northern hemisphere
Δφ ~ 15 kV

Southern hemisphere
Δφ ~ 25 kV

- Plasma sheet-polar rain boundary
- Inner edge soft electron zone
- Plasma sheet-cusp boundary
- Cusp/mantle boundary
- Soft electron zone
- Intermittent weak polar-cap arcs
- Polar-cap arc
Ridley et al. [1998]
Fig. 4. Field line configuration in the noon-midnight meridian plane. With $r_e = 10$ earth radii, the critical latitude is about 83°. The dipole lines are compressed on both the daytime and nighttime side.
For average $\Delta \phi_{\text{tail}} \sim 50$ kV

$\sim 2.7$ hrs to move $\sim 15$ RE from mantle to current sheet ($\text{tail width} = 50$ RE, $B_{\text{lobe}} = 15$ nT)

Only particles with $V_\parallel < 67$ km/s reach current sheet earthward of X-line ($x = -100$ RE)

Small fraction of mantle particles, since $V_{\text{mantle}} \sim 150$ km/s

For $\Delta \phi_{\text{tail}} \sim 120$ kV

$\sim 1.1$ hrs to reach current sheet; particles with $V_\parallel < 160$ km/s enter earthward of X-line

Much larger fraction of mantle particles have access

Potential for greatly enhanced cross-tail current when have strong convection for $\sim 1$ hrs (storm conditions)
Figure 3. Magnitude of magnetic field in the XY plane as a function of $X'$. The empirical curve by Slavin et al. [1983] is drawn as a reference.
IMF effects strength of convection and probably solar wind plasma access

How does this lead to geomagnetic activity?

- Get enhanced J·E within tail and ionosphere
- High $\beta$ of plasma sheet greatly modifies $B$
- Get enhanced plasma and magnetic energies

Largest plasma pressure and $B$ changes at $r \sim 6-10 \, R_E$

- Due to earthward motion of plasma sheet driven by enhanced $E$
20 MeV/G (-20 keV @ r = 7 Re) Equatorial Proton Trajectories

Magnetopause

$\Delta \phi \sim 100$ kV

$\Delta \phi \sim 30$ kV
Pre-onset conditions

- Kistler et al. [1992]

- Spence et al. [1989], $K_p = 1$–

Equatorial pressure, nPa

Radial Distance, $R_E$

10
1
0.1
4 6 8 10 12 14 16 18 20
McPherron and Manka [1985]

March 22, 1979

GROUND

GOES 3

Universal Time

Universal Time

Universal Time
Geomagnetic Disturbances: Identification; relation to plasma sheet

Plasma sheet ions, electrons pitch-angle scattered and precipitate

- Resulting auroral emissions excellent for identifying geomagnetic disturbances & determining relation to time evolution of plasma sheet

Will use data from CANOPUS meridian scanning photometers.

- **Hβ emissions** (proton precip.)
  - Identifies & locates ionospheric mapping of inner plasma sheet

- **6300 Å emissions** (< ~1 keV elec. precip.)
  - Identifies & locates latitude range of plasma sheet electrons
  - Poleward edge locates ionospheric mapping of separatrix
    (+/-1°, Blanchard et al. [1996])

- **5577 Å emissions** (> ~1 keV elec. precip.)
  - Identifies & locates auroral disturbances associated with geomagnetic activity
18 December 1990

Universal Time [hr]

ΔX

<table>
<thead>
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<th>Rank</th>
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<th>FCHU</th>
<th>BACK</th>
<th>GILL</th>
<th>ISLL</th>
<th>PINA</th>
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<td>65</td>
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January 18, 1997

Cloudy

--- 6300 A poleward boundary 24 MLT

\[ \text{Intensity (R)} \]

\[ \begin{array}{c|c|c|c|c}
\text{UT (hr)} & 04:00 & 05:00 & 06:00 & 07:00 & 08:00 \\
\hline
\text{RANK} & \Delta X & \Delta X & \Delta X & \Delta X & \Delta X \\
\text{ESKI} & \pi 2 & \pi 2 & \pi 2 & \pi 2 & \pi 2 \\
\text{FCHU} & \pi 2 & \pi 2 & \pi 2 & \pi 2 & \pi 2 \\
\text{GILL} & \pi 2 & \pi 2 & \pi 2 & \pi 2 & \pi 2 \\
\end{array} \]

\begin{array}{c|c}
\text{Intensity (R)} & \Lambda \\
\hline
10k & 74 \\
5k & 72 \\
2k & 70 \\
1k & 67 \\
500 & 67 \\
200 & 67 \\
100 & 67 \\
\end{array}
de la Beaujar dière et al. [1997] Period of PPI

PACE GEOMAG. LAT. (Deg)

74.0
73.5
73.0
72.5

0130 0150 0210 0230 UT

1 km/s
Poleward Boundary Intensifications (PBIs)

Active aurora initiates near separatrix, can then move equatorward.

Very common, individual events often ≤10 min apart.

Occur during all levels of geomagnetic activity.

Generally brightest feature in auroral zone

Associated few min flow bursts
   — Equatorward in ionosphere [Sergeev et al., 1990; de la Beaujardière et al. 1994]
   — Earthward in tail (i.e., BBF’s) [Lyons et al., 1999]

PBIs not associated with substorms have clear preference for radial IMF [Zesta et al., 1998]
   — Related to enhanced magnetosheath turbulence from quasi-parallel bow shock?
13 December 1990

RANK

ESKI

FCHU

BACK

GILL

ISLL

PINA

Universal Time [hr]

200 nT

Λ

74

72

70

69

67

65

61
MAGNETIC FIELD TOPOLOGY
27 OCTOBER 1992

0526 UT

0545 UT

[Graph showing magnetic field topology with labels and colors for unconnected, open, and closed regions.]

[Legend: UNCONNECTED, OPEN, CLOSED]
SUMMARY

General

• Convection
  — IMF $B_z$ and $B_y$ control strength
  — Response to IMF changes rapid throughout polar cap

• Tail plasma source
  — Significant dependence on convection strength strongly affects tail?

• Strong convection
  — Gives earthward penetration of plasma sheet and associated large distortion of $B$
  — Of major importance to substorms, convection bays, storms

• Important consideration for studying interplanetary sources for activity
  — IMF structure in plane perpendicular to $V_{SW}$
Geomagnetic disturbances:

- **Poleward boundary intensifications (PBIs):** All levels of activity
  - Associated few min flow bursts (equatorward ionosphere, earthward tail)
  - PBIs not associated with substorms have preference for radial IMF

- **Substorms:** Follow > 0.5 hr of enhanced convection (negative IMF Bz)
  - Growth: earthward plasma sheet penetration, tail energy enhancement
  - Onsets often (at least?) assoc. with IMF changes that reduce convection
  - Initial predictions using such IMF changes successful [Blanchard et al., 1999]

- **Convection bays:** Prolonged periods of steady enhanced convection
  - Plasma sheet, tail B like end of substorm growth phase, but ~steady state
  - Activity dominated by large PBIs, substorms (if any) much less significant

- **Storms:** Prolonged periods of strongly enhanced convection
  - Plasma sheet and geomagnetic activity like during convection bays
  - Also global auroral, current enhancements from interplanetary dynamic pressure enhancements?