Unusual Solar Wind Associated with Global Sawtooth Oscillations: CCMC Simulations of the Magnetosphere

Joe Borovsky\textsuperscript{1}, Joachim Birn\textsuperscript{1}, and Aaron Ridley\textsuperscript{2}

\textsuperscript{1} Los Alamos National Laboratory
\textsuperscript{2} The University of Michigan

1) What Global Sawtooth Oscillations Are.


3) Perform Simulations of the Magnetosphere for “Sawtooth Solar Wind”.

4) What Is Learned. What is Outstanding.
CPA Fluxes at Geosynchronous  February 8, 1986

Proton Flux

Universal Time
Evolution of the Dipolar Magnetosphere During a Global Sawtooth Cycle
Size of Sawtooth Crash Versus Local Time

GOES 5,6,7,8,9,10

Rapid Rotation in Tilt Angle [deg] vs. Local Time

- East-Coast Satellites
- Central Satellites
- West-Coast Satellites

from Borovsky et al., 2003
Properties of Global Sawtooth Oscillations

- Global: Signatures appear at all local times
- Geosynchronous E-P fluxes ~dispersionless
- Geosynchronous field stretches and dipolarizes
- Lobe can be encountered at geosynchronous equator

- Sawtooth period is 2-4 hours
  - Slow Stretching
  - Fast Crash (~5 minutes)

- Sawtooths occur during storms
  - Kp  6.2 ± 1.4
  - Dst  -127 ± 72 nT

- Sawtooth has a signature in Dst
  - Crash corresponds to 20 - 50 nT drop in |Dst|
  - Symmetric perturbation
  - No ionospheric current wedge with crash

- Might require geosynchronous plasma B > 1
Statistical Analysis of the Solar Wind Finds:

- $B$ is large
- $n$ is low
- $v$ is medium to fast
- $P_{\text{ram}}$ is average
- IMF is southward
- $\frac{B}{B}$ is anomalously low

These parameters combine to yield:

- A low-Mach-number solar wind.
- A magnetosheath flow that has very low beta.
Distributions of Solar-Wind Magnetosonic Mach Numbers

Number of Occurrences

Mach Number of Solar Wind

sawtooth times
(median = 3.3)

periodic-substorm intervals
(median = 5.5)

all data
1975-2002
(median = 5.4)

SMC intervals
(median = 4.5)
Distributions of Magnetosheath

Number of Occurrences

- sawtooth times (median = 0.8)
- periodic-substorm intervals (median = 6.3)
- SMC intervals (median = 4.0)
- all data 1975-2002 (median = 7.8)
CCMC Simulations of the Magnetosphere for "Sawtooth Solar Wind"

Utilize the BATSRUS code, with verification by the UCLA code.

The MHD simulations do not exhibit sawtooth oscillations.

Analysis of simulations focuses on the stretching of B in the dipole regions of the magnetosphere.

The fiducial "sawtooth solar wind" run has:
- $B = 19.6 \text{ nT}$
- $(B_x, B_y, B_z) = (6.6, -8.6, -16.3) \text{nT}$
- $n = 3.4 \text{ cm}^{-3}$
- $v = 408 \text{ km/sec}$
- $T = 8.6 \text{ eV}$
- $M_{ms} = 1.74$
- $\theta_{sheath} \sim 0.15$

Look at the effects of varying the solar wind (one parameter at a time) on the field stretching in the dipole.
Stretching Regions in the Dipole Are Associated with:
- Sunward flow of hot plasma from the magnetotail
- High plasma pressure
- Weakened field strength $|B|$ near the equator
- High plasma $B$
- A horseshoe of toroidal current in the equator
01/01/2000 Time = 02:00:00 \( z = 0.00 \text{Re} \)

\[ J \left[ \frac{\mu A}{m^2} \right] \]

Min: 0.000
Max: 0.012

\( J \)-flowlines
connection to Earth:

- user
selected

\[ J \left[ \frac{\mu A}{m^2} \right] \]

+0.01348
-0.00001

Plot: CCMC
Model: BATSRUS  Region: magnetosphere
Effects of Varying Solar-Wind Parameters on the Field Stretching in the Dipole

<table>
<thead>
<tr>
<th>Type of Variation</th>
<th>Effect on Stretching at Terminator</th>
</tr>
</thead>
<tbody>
<tr>
<td>B weak</td>
<td>stretching gone</td>
</tr>
<tr>
<td>n high</td>
<td>stretching gone</td>
</tr>
<tr>
<td>v high</td>
<td>stretching maintains</td>
</tr>
<tr>
<td>v low</td>
<td>stretching reduced</td>
</tr>
<tr>
<td>northward IMF</td>
<td>stretching gone</td>
</tr>
<tr>
<td>sideways IMF</td>
<td>stretching weakens</td>
</tr>
<tr>
<td>southward-northward switching (15 min)</td>
<td>stretching gone</td>
</tr>
<tr>
<td>rapidly varying southward IMF</td>
<td>stretching maintains</td>
</tr>
<tr>
<td>ionospheric conductivity forced low</td>
<td>stretching gone</td>
</tr>
<tr>
<td>ionospheric conductivity forced high</td>
<td>stretching maintains</td>
</tr>
</tbody>
</table>

CCMC simulations support two causes for stretching at the terminator:

1. Internal pressure from presence of hot plasma
2. Squeezing by lobe magnetic flux
Summary, Outstanding Question, and Future Work

Summary: What Causes the Stretching in the Dipole?
• Build up of pressure in equator and lowering of B there.
• Squeezing from the lobe field lines.

Question: What Causes this Stretching to Collapse?
• Interchange or ballooning instability in dipole?
• Reconnection around the dipole?
  • Radial motion of the ring current??
  • Thinning/thickening of the ring current??
  • Reduction of the ring current??

Future Plans
• Look for sawtooth oscillations and causes with coupled CSEM (BATSRSUS + Rice-Convection-Model) simulations.

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