THE IMPACT OF SUDDEN STORM COMMENCEMENT ON MAGNETOSPHERIC ION DISTRIBUTIONS

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Outline

• Introduction
  – Motivation
  – Approach
• The 28 October 2001 Storm
  – Observations
  – Large-Scale Kinetic Results
    • Physics of ion population
    • Physics of ion injection
    • Physics of ion acceleration
• Comparison with the 17 April 2002 and 24-25 September 1998 Storms
Motivating Question

- Impact of CME with Earth’s magnetosphere is the most violent component of a geomagnetic storm.

*How does Sudden Storm Commencement affect the ion distributions in the inner magnetosphere: how are ions energized and injected?*
The magnetosphere is defined by its current systems and by its plasma regimes.
Population of the Magnetosphere

- Two sources: Solar wind (Mostly H⁺, some He^{++}) and ionosphere (H⁺, He⁺, O⁺, …)
Approach

• Run global magnetohydrodynamic (MHD) simulation of each storm event using upstream data from solar wind monitor spacecraft.

• Follow orbits of millions of ions in time-dependent electric and magnetic fields from MHD simulation using full Lorentz force equation.

• Launch H⁺ ions in the solar wind; launch O⁺ ions from the ionosphere throughout each storm.
The Large-Scale Kinetic (LSK) Modeling Technique

- Follow the orbits of a large number of particles in specified global electric and magnetic fields.
- Use Lorentz Force Equation to integrate particle orbits:

\[ m \frac{d\vec{v}}{dt} = q \left( \vec{E} + \frac{\vec{v} \times \vec{B}}{c} \right) \]

*Include kinetic physics on global scales*
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Solar wind H\(^+\) Ion Launch Scheme

- Ions launched at \(X = 17\ \text{R}_E\), upstream of bow shock at 1-minute intervals beginning \(\sim 140\ \text{min}\) prior to the SSC.
- Grid spacing \(0.5\ \text{R}_E \times 0.5\ \text{R}_E\) (Y-Z).
- 100 ions per grid point.
  (>2 \(\times\) \(10^7\) ions per launch)
- Ions launched as a drifting Maxwellian with \(V_{\text{SW}}\) and \(T_{\text{SW}}\).
- Flux of launched ions normalized to solar wind flux through upstream boundary.
Ionospheric O⁺ Ion Launch Scheme

- Ions launched every minute using Strangeway et al. [2005] formula relating upflow to precipitating density obtained from MHD simulation.
- Spatial Distribution (SM coordinates): \( \lambda = \pm (60^\circ - 85^\circ) \) All MLTs
- Altitude: \( 2.2 \, R_E \)
- Temperature: 30 eV
- Streaming Energy: 50 eV
- Total of \( > 2 \times 10^7 \) ions launched.
Densities of Ions in the Ring Current and Plasma Sheet

- 3 $R_E < r < 8 R_E$ (Night Side)
- $-30 R_E < x < -10 R_E, |y| < 7 R_E$

- Solar Wind H$^+$
- Ionospheric O$^+$
- Total LSK
- MHD Density

Time (UT Hours)

Ring Current Density (cm$^{-3}$)

Plasma Sheet Density (cm$^{-3}$)
Solar Wind Ions in the Inner Magnetosphere
28 October 2001 0300 UT
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ACE Observations on 17 April 2002 Propagated to X = 17 RE

- $B_x$ (nT)
- $B_y$ (nT)
- $B_z$ (nT)
- $V_x$ (nT)
- $V_y$ (nT)
- $V_z$ (nT)
- $n$ (cm$^{-3}$)
- $P_{dyn}$ (nPa)

Time (UT Hours): 0900 to 1900
17 April 2002 Magnetic Storm

Solar Wind H⁺ Ion Distributions in the Magnetotail

- $X = -20 - -25R_E$
- $X = -10 - -15R_E$
- $X = 3 - 8R_E$

![Graph showing solar wind H⁺ ion distributions with X-values ranging from 3 to 20 R_E at different UT times from 11:00 to 11:40.]
Wind Observations on September 24 - 25, 1998

GSE Coordinates - Shifted for SW Propagation

B_x (nT)  B_y (nT)  B_z (nT)  V_x (km/s)  V_y (km/s)  V_z (km/s)  n (cm^-3)

Time (UT Hours)

22:00  0:00  02:00  04:00  06:00  08:00
Solar Wind H⁺ Ion Distributions in the Magnetotail

23:50 UT

0:00 UT

0:10 UT

0:20 UT

$V_y$ (km/s)

$V_x$ (km/s)

Number of Particles

-20 > x > -15 RE

-10 > x > -10 RE

-5 > x > -5 RE
Solar Wind H\(^+\) Energy Densities in the Ring Current

**28 October 2001**

**17 April 2002**

**24 September 1998**
Summary

Plasma Population:

- Plasma sheet fills in with solar wind $H^+$ ions gradually from dawn and dusk, with dominant entry occurring on dawn flank throughout the interval.
- $O^+$ ions fill plasma sheet gradually, are 10% - 20% of density throughout storm.
Summary

Plasma Injection

- SSC results in ion injection into inner magnetosphere at all local times for both $H^+$ and $O^+$.  
- 0430 Substorm onset shows strong injection at dawn, gradual increase in density at midnight and dusk for $H^+$ ions, very little change for $O^+$ ions.
Summary

Plasma Acceleration:

- 28 October 2001 Ion velocity distribution functions show energization spreading from midnight to dusk and entry of solar wind ions from the dawn flank.
- Energization for both 24 September 1998 and 17 April 2002 storms more dramatic:
  - Stronger dynamic pressure
  - Highly variable IMF during the SSC.
A Word About Forecasting

• “Geoeffectiveness” of magnetic storms in accelerating ions cannot be characterized by Dst alone:
  – Solar wind dynamic pressure and IMF $B_y$ and $B_z$ fluctuations more important.
• Any remote sensing of a magnetic cloud must be able to tell us about the characteristics of the IMF within the cloud, especially along its leading edge.