The Effects of the Solar Wind on the Density of Earth’s Upper Atmosphere

REU Student: Mariah Law
Mentor: Ingrid Cnossen
Overview

• Background information
• Previous observations
  – Neutral/electron densities
  – Comparison of 2008 solar minimum to 1996
  – Solar wind
• Goals of this project
• Numerical methods
• Results
• Future plans
"Geomagnetism: The Magnetic Field of the Earth."
Upper Atmosphere

- Solar Extreme Ultraviolet (EUV) irradiance levels
- Geomagnetic Activity
  - Joule heating
  - Particle precipitation
- Thermal Expansion!
- Density: Atmospheric drag on ~5000 objects orbiting the Earth
Why do we care?

• Satellites!
  – U.S. Space Surveillance Network (SSN) tracks over 20,000 man made objects larger than 10cm in size

• Trajectories affected by atmospheric drag
  – Difficult force to model

• To better understand the solar wind-magnetosphere-ionosphere-thermosphere relationship

Stansbery, E.
Anomalously Low Thermospheric Density

- Global-average thermospheric density at 400km
- Black Line: annual average; Blue Line: 81-day centered running mean; Green Line: envelope of expected decrease due to CO$_2$ levels
- 2007-2009 lowest density years on record
- 2008/2009 were 29% lower than predicted

Solomon et al. (2010)
Comparison of Ne over Jicamarca

- Seasonal average of electron density
- White lines: $H_m F_2$ height

Liu et al. (2012)
Why So Different?

- Low EUV irradiance ~22%
  - EUV and FUV photons are the primary heat source of the thermosphere
  - Expands and contracts in response to temperature change
  - Reduction of ~15% in solar flux

- CO₂ Levels ~%3

- Geomagnetic Activity ~2.2%

- Solar Wind Conditions ~?
**Solar Minimum 1996**

Low solar activity

Comparable sunspot numbers

Narrow equatorward extensions from polar coronal holes

Disorganized short-duration energy flows into the Earth's atmosphere.

Weak radiation environment

**Solar Minimum 2008**

Multiple broad low-latitude coronal holes

Periodic long-duration energy flows into the Earth's atmosphere. Atmosphere ringing with solar wind periodicities.

Enhanced radiation environment

Gibson et al. 2009
Comparison of Solar Wind Conditions

- Low solar wind magnetic field strength
- Lower solar wind density ~45%
- High solar wind velocity ~13%

Gibson et al. 2009
Goals

• To understand why the neutral and electron density of 2008 was so unusually low

• To understand the effects that different solar wind conditions have on the density of the upper atmosphere through numerical model simulations
  – Solar wind density
  – Solar wind speed
Coupled Magnetosphere Ionosphere Thermosphere model (CMIT)

• Lyon Fedder Mobarry (LFM)
  – Responsible for magnetosphere
  – 3D Ideal MHD equations
  – Requires: Solar wind and IMF conditions
  – Requires: Ionospheric inner boundary conditions

• Thermosphere Ionosphere Electrodynamics-General Circulation Model (TIE-GCM)
  – Responsible for thermosphere and ionosphere
  – 5°x5° Global Grid that ranges from 97-500 km
  – Requires: Solar radiation flux
  – Requires: High latitude electric potential
  – Required: energetic particle precipitation
CMIT

Coupler Module

Solar Wind Data → LFM → Currents → Electric Field Potential → Calculated New Potential → TIE - GCM

Field-aligned

Ionospheric Conductance

Particle Flux

Energy of Particles Precipitating into Upper Atmosphere
Solar Wind Data

- OMNIweb solar wind data
- ACE, Wind, IMP 8 and Geotail data
- 81 day centered average around June 30th

Solomon et al. (2011)
## The Three Simulations

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>LowDens</th>
<th>HighVel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (cm(^{-3}))</td>
<td>9.0</td>
<td>4.5</td>
<td>9.0</td>
</tr>
<tr>
<td>Speed(_x) (km/s)</td>
<td>-380.0</td>
<td>-380.0</td>
<td>-450.0</td>
</tr>
<tr>
<td>(B_z) (nT)</td>
<td>-5</td>
<td>-5</td>
<td>-5</td>
</tr>
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Model Parameters

- 36 hour simulations
- IMF was always southward during the last 24 hours used for analysis

“Magnetic Reconnection: A Prominent Mystery, Part 2...”
Global Mean Profile Plots of Neutral and Electron Density Levels
Results

<table>
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<tr>
<th>LowDens vs. Control</th>
<th>HighVel vs. Control</th>
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<tbody>
<tr>
<td>• Less than 1% higher ND levels @ ~400km</td>
<td>• Larger differences in both ND and NE @ ~ 400km</td>
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<tr>
<td>• From 1% lower to 3% higher NE levels @ ~400km</td>
<td>• Day (12LT) – higher NE levels</td>
</tr>
<tr>
<td>• Little difference in vertical profiles from control data</td>
<td>• Night (0LT) – lower NE levels</td>
</tr>
</tbody>
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Conclusions / Future Plans

• Solar wind density difference between 2008 and 1996 did not have a significant effect on neutral or electron density in the numerical simulations

• Solar wind velocity difference did produce an interesting effect and should be explored further
  – Night: consistent with observed electron density differences
  – Day: produced the opposite effect

• Run the simulations for a longer period of time in order to better analyze the results

• Test IMF strength and direction
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