The Effects of Differences in Solar Wind Conditions between 1996 and 2008 on the Earth's Upper Atmosphere

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Abstract

The recent solar minimum of 2008 was anomalously low and prolonged. During this time, record lows in both neutral and electron densities were observed in the Earth's upper atmosphere. The low extreme ultraviolet (EUV) irradiance levels observed throughout the 2008 minimum can partially explain this, however it may not be the only process operating. The solar wind conditions of 2008 were also different from those of the 1996 solar minimum. Via coupling through the magnetosphere, this difference in solar wind conditions could also have an effect on the upper atmosphere. This study investigates the effects of systematically varied solar wind conditions on the upper atmosphere through numerical simulations with the Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) model. The simulation results suggest that the higher solar wind velocity in 2008 compared to 1996 may have had a substantial effect on the electron density levels in the upper atmosphere, but at most a minor effect on the neutral density. While the lower solar wind density in 2008 did not have a significant effect on either the electron or neutral density. Interestingly, a higher solar wind speed resulted in higher electron densities by day, but lower electron densities by night. Further analysis will be needed in order to explore these preliminary results in more detail and to investigate differences in other solar wind parameters, such as the strength of the Interplanetary Magnetic Field (IMF).

Goal

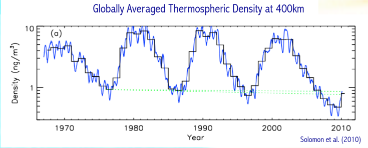
To understand the effects that different solar wind conditions have on the density of the upper atmosphere through numerical model simulations

- Solar wind density
- Solar wind speed

1. Background Information

- Satellite drag observations showed that in 2008 the thermosphere was significantly less dense and cooler than at any other time since the beginning of the space age.

Globally Averaged Thermospheric Density at 400km

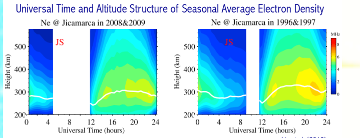


Solomon et al. (2010)

Black Line: annual average; Blue Line: 81-day centered running mean; Green Dotted: envelope of expected decrease due to CO_2 levels

- 2008/2009 thermospheric density was 29% lower than the expected 6% decrease from 1996
- Lower electron densities were seen in 2008 as well as lower peak electron density height in the F2 region (HmF2) observations

Universal Time and Altitude Structure of Seasonal Average Electron Density



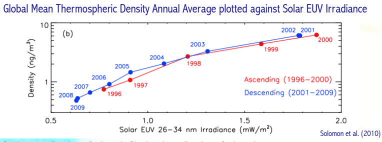
Liu et al. (2012)

White line: HmF2 height

What contributes to thermospheric density levels? (levels distinguished by Solomon et al. (2011), using TIE-GCM model simulations)

- A reduction of extreme ultraviolet (EUV) irradiance levels in 2008 contributes ~22%, corresponding with low electron

Global Mean Thermospheric Density Annual Average plotted against Solar EUV Irradiance



Solomon et al. (2010)

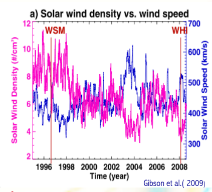
Red line: ascending phase of solar cycle; Blue line: descending phase of solar cycle

EUV Irradiance measured by Solar EUV Monitor (SEM) on board the Solar Heliospheric Observatory (SOHO)

- Increase in CO_2 level contributes ~ 3%
- Geomagnetic activity contributes ~ 2.2%
    - Influenced by solar wind conditions and the state of the ionosphere
- Solar wind conditions alone contributes ?

2. Methods

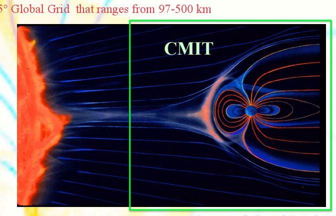
- Compared 2008 solar wind conditions to those of 1996
    - Lower solar wind magnetic field strength
    - Lower solar wind density by ~45%
    - Higher solar wind speed by ~13%
- Created solar wind data using an 81-day average centered on June 30th 2008 & 1996
    - Solar wind data provided by OMNIweb



Gibson et al.(2009)

3. Numerical Models

- Coupled-Magnetosphere-Ionosphere-Thermosphere (CMIT) model
    - Lyon Fedder Mobarry (LFM)
        - Responsible for the solar wind & magnetosphere interactions
        - 3D Ideal MHD equations
    - Thermosphere Ionosphere Electrodynamics-General Circulation Model (TIE-GCM)
        - Responsible for the Thermosphere & Ionosphere interactions
        - 5°x5° Global Grid that ranges from 97-500 km



"Geomagnetism: The Magnetic Field of the Earth."

4. Simulations

- Three simulations

	Control	LowDens	HighVel
Density (cm^{-3})	9.0	4.5	9.0
$Speed_x$ (km/s)	-380.0	-380.0	-450.0
B_z (nT)	-5	-5	-5

Table 1: Solar Wind Data Used for Simulations

- 36 simulated hours (discard the initial 12hours to allow for proper spin-up cycle in CMIT)
- Solar wind data stays constant for entire simulation after spin-up cycle is complete

5. Results

Figure 1: Altitude Profile Plots of Global Mean Neutral and Electron Density Levels

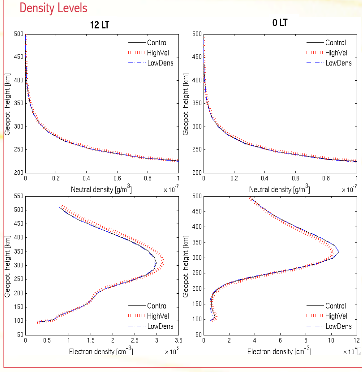


Figure 2: Neutral and Electron Density averaged over last 24hrs of simulation @ ~400km

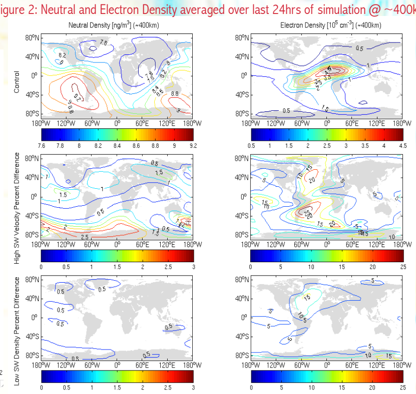
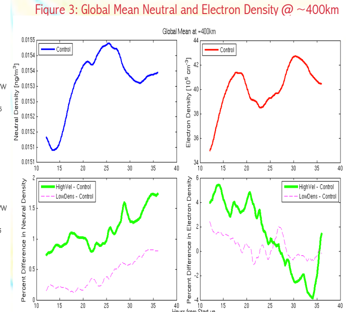


Figure 3: Global Mean Neutral and Electron Density @ ~400km



6. Conclusions

Solar wind density difference between 2008 and 1996 did not have a significant effect on thermospheric density, but did produce a small effect on electron density in the numerical simulations.

Solar wind velocity difference did produce an interesting effect and should be explored further.

Night: consistent with observed lower electron density levels in 2008

Day: produced the opposite effect

The change over time of percent differences in electron density shown in figure 3 indicate that CMIT may not have completely stabilized.

If I had more time I would…

- 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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