



Modeling the Density of the Thermosphere

Suzanne Smith
Mentor: Tomoko Matsuo

Site: National Oceanic & Atmospheric Administration, NOAA



Abstract: The top level of the Earth's atmosphere is the thermosphere. Its density is so susceptible to change that it lends itself to control by weak external drivers such as solar extreme ultraviolet (EUV) and electromagnetic energy deposited in the polar atmosphere as a result of solar wind/magnetosphere interactions. It is nonetheless enough to exert significant drag on orbiting spacecraft, motivating numerous observational and modeling efforts since the dawn of space exploration. The need to predict the orbits of many objects in space (currently about 14,000 objects that can be tracked), and to predict conjunction between any two objects, emphasizes the need for improved methods of characterizing and predicting density variability as accurately and efficiently as possible. An important component of space weather characterization and prediction is the development of succinct and computationally efficient relationships between geospace variability and the solar and geomagnetic drivers that best capture that variability. In this project I have developed a computationally efficient emulator of the thermospheric density variability by analyzing the neutral density modeled by a general circulation model (GCM) of the thermosphere and ionosphere. In addition, I have utilized daily F10.7 and geomagnetic indices, solar wind data, and joule heating rate computed by the GCM, to gain a deeper understanding of thermospheric density changes. I tested the predictive capability of the emulator against the GCM as well as observations obtained from the accelerometer experiment on board the CHAMP satellite.

Introduction

Previous work

CTIPE model: The Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics Model, Tim Fuller-Rowell et al. 1996

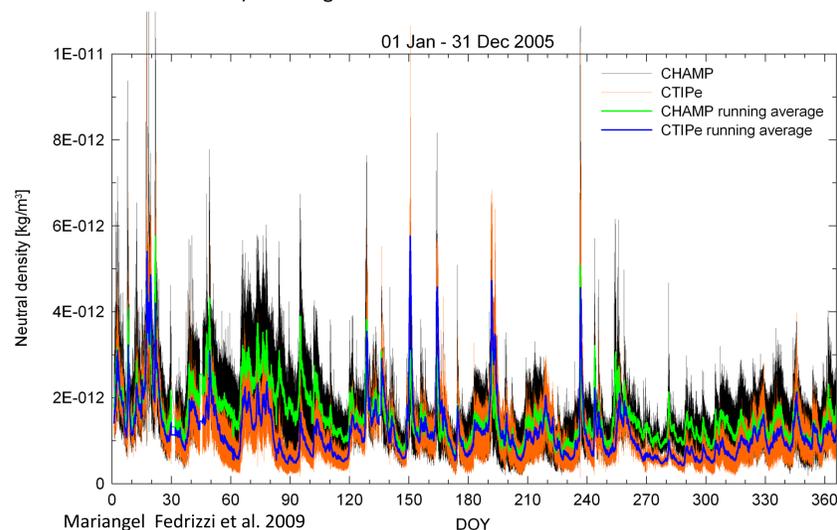
Global Thermosphere 80-500km: solves momentum, energy, composition
Ionosphere 80-10,000km: solves continuity, momentum, energy, etc.

Forcing: solar UV and EUV, empirical high latitude electric field and auroral precipitation models, tidal forcing.

CHAMP Satellite: Challenging Minisatellite Payload Satellite

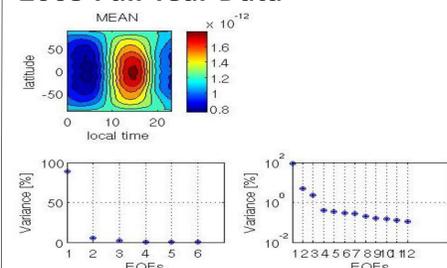
height ~ 400km; 90min orbital period; Launched date: July 2000.

2005 CTIPE 5-min Run, Mariangel Fedrizzi et al. 2009

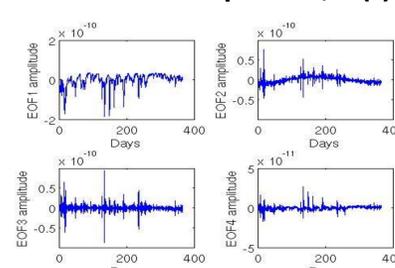


Singular Value Decomposition Analysis

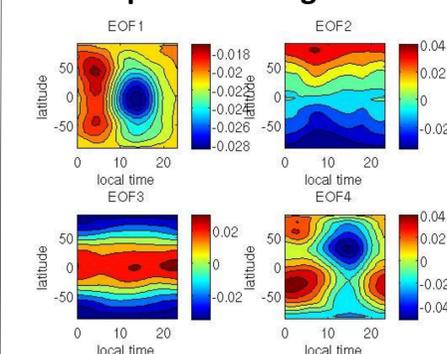
2005 Full Year Data



2005 EOF Amplitude; $\alpha(t)$

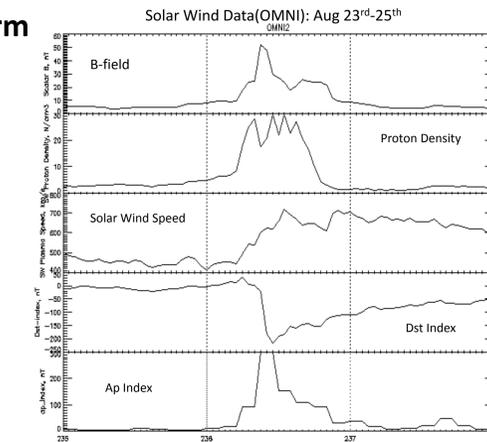
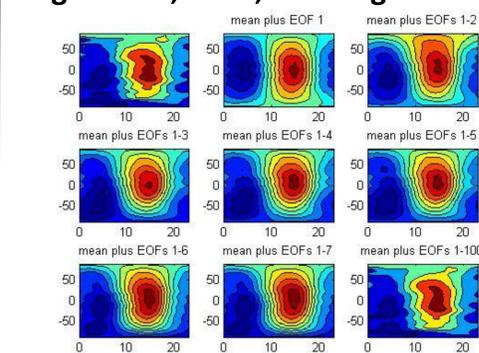


2005 Empirical Orthogonal Functions, EOF 1-4; $\Phi(r)$



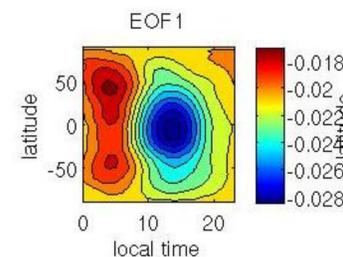
In the mean plot you can see the density plot over all twelve months of the year 2005. The two variance plots show how much each EOF contributes to the total density change. Notice how EOF contributes 80-90% of the density change. The combination of the EOF plots and the EOF amplitude plots give you the full picture of the density of the thermosphere.

August 24th, 2005; Geomagnetic storm



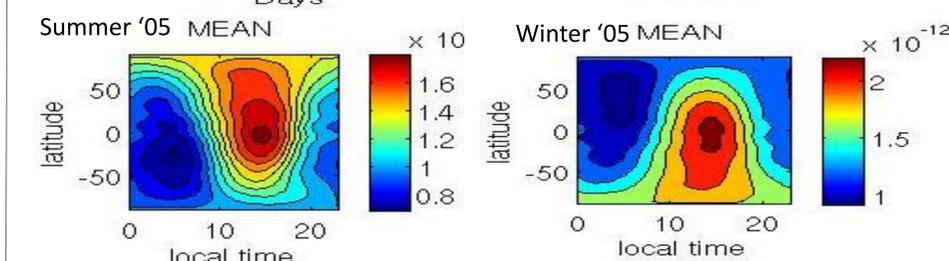
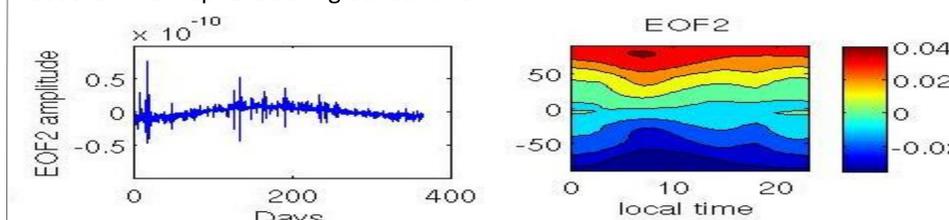
EOF 1: Diurnal EUV

EOF 1 represents diurnal density changes. It is caused by the 24 hr rotation of the Earth on its axis. The neutral density of the thermosphere on the day side due to the increased EUV. In the same way the night side has a lower density because of the lack of EUV. (Figure to right August 2005)



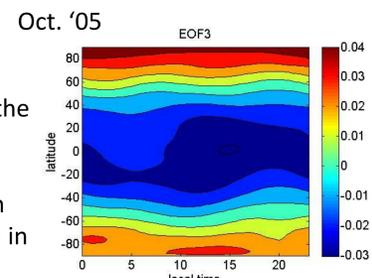
EOF 2: Seasonal EUV

I combined the EOF 2 and the EOF 2 amplitude to show the seasonal difference in the thermospheric density. Notice the sinusoidal behavior of the EOF 2 amplitude. These amplitudes are multiplied to the EOF 2 pattern and you can get the expected result of higher density in the Northern hemisphere and lower density in the Southern hemisphere during our summer.



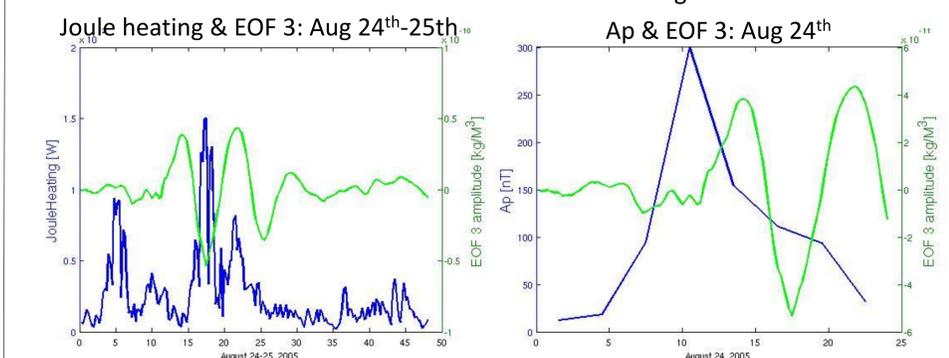
EOF 3: Auroral Activity

I believe that the 3rd EOF is caused by high latitude electromagnetic forcing resulted from the interaction between Solar Wind and the earth's magnetosphere (i.e., auroral activity). You can see the symmetric pattern that is expected with auroral activity, because the aurora occurs both in the Northern and Southern hemisphere.

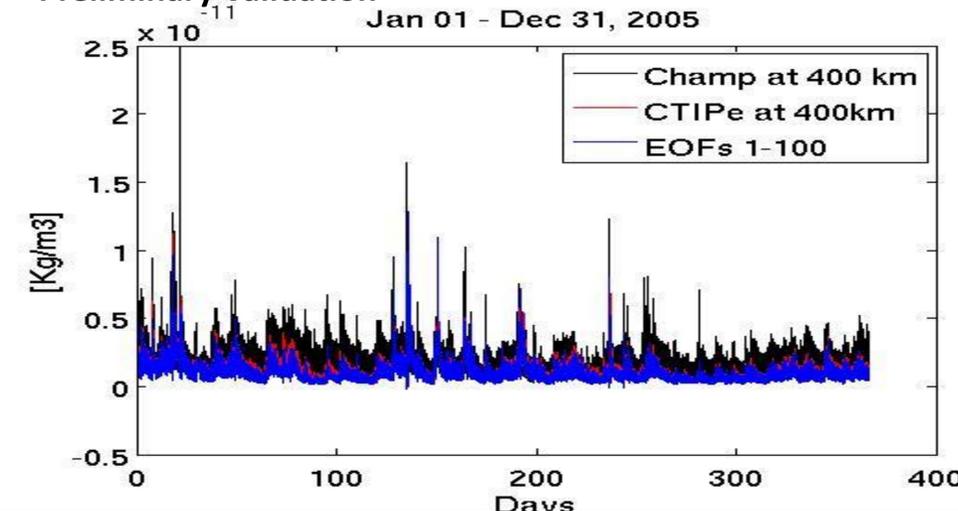


| Correlation | Ap | Ap > 150 |
|-------------|--------|----------|
| EOF 3 | 0.0097 | 0.2548 |

Surprisingly, the Ap, geomagnetic index, did not correlate with the EOF 3 amplitude as well as I was expecting so I looking into other data including Joule Heating values.



Preliminary Validation



My Work

I have taken the multidimensional general circulation model output and reduced its dimension. Specifically, I conducted a Singular Value Decomposition (SVD) analysis of CTIPE 5-min Run data from 2005 and constructed a low-dimensional model of thermospheric density. The density of thermosphere is given in terms of position and time:

$$\rho(r, t) = \Phi_1(r) \alpha_1(t) + \Phi_2(r) \alpha_2(t) + \dots + \Phi_n(r) \alpha_n(t)$$

Where ρ is density in terms of position, r , and time, t . $\Phi_n(r)$ is an EOF mode and $\alpha_n(t)$ is the amplitude of the EOF.

Drivers of Density Change

Extreme Ultra Violet (EUV) rays from the sun is one of the major drivers of density change within the thermosphere. EUVs cause changes both diurnally (daily) and seasonally. Another driver is Solar wind/Magnetosphere Interactions (auroral activity). There are hundreds of drivers that effect the density of the thermosphere but once you get past the first four types get very complicated very fast.

References

- CTIPE, Tim Fuller-Rowell et al. 1996
- CHAMP & CTIPE data plot, Mariangel Fedrizzi, et al. 2009
- Ap Index, <http://wdc.kugi.kyoto-u.ac.jp/kp/index.html>.
- Solar Wind Data, NASA OMNIWeb, <http://omniweb.gsfc.nasa.gov/>
- Joule Heating, CTIPE Model

Contact: Suzanne E. Smith, smisuz@lycoming.edu