Variability of the Ionosphere with Solar Activity

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1. Abstract

This study focuses on the Sun's interactions with the Earth and the Solar System and the fundamental physical processes of the space environment from the Sun to Earth. The primary goal of this project is to better understand the sources and sinks of the variability in Earth's Ionosphere (*e.g.*, seasonal variations, the solar cycle, magnetic latitude/longitude, etc.). In order to accomplish this goal, we analyzed multiple seasons of radio occultation data from the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) satellite. The resulting ionospheric maps are compared to models during the deepest part of the recent solar minimum to quantify the variability of the ionosphere during extremely low solar activity. Our results show that the primary model currently used to represent the ionosphere should be improved upon to more accurately reflect its structure.

2. Introduction and Background

What is the Ionosphere?

The ionosphere is a region of the Earth's upper atmosphere that is characterized by containing particles that have been ionized by solar radiation.

Where is the ionosphere and how does it "look"?

It is located from ~60-1000km above Earth's surface within the thermosphere and portions of the mesosphere and exosphere (**Fig. 1**). It has three major regions: the F, E, and D regions, which vary in intensity with time of day, lat/lon, and the solar cycle. (**Figs. 2 & 3**).

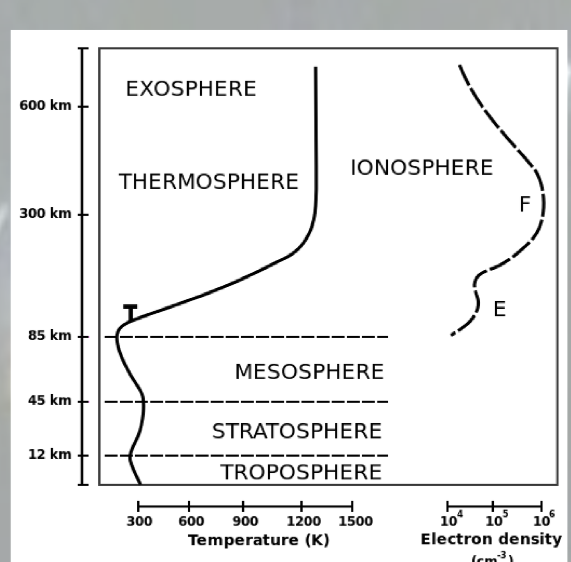

Figure 1: Temperature and electron density variations throughout the atmosphere and ionosphere (Image credit: [1]).

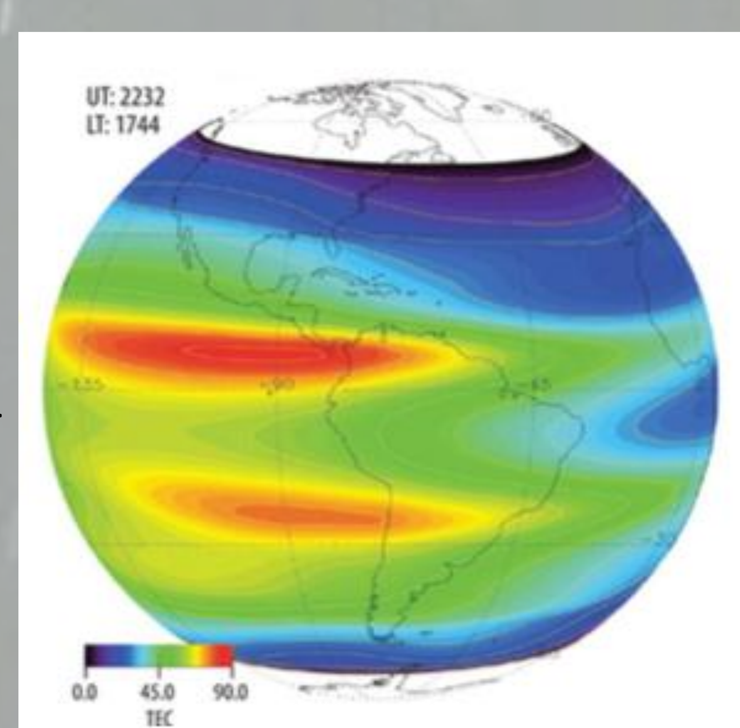

Figure 2 (right): Model of the global total electron content, showing late afternoon equatorial anomaly enhancement (Image credit: Fig. 20 from [2]).

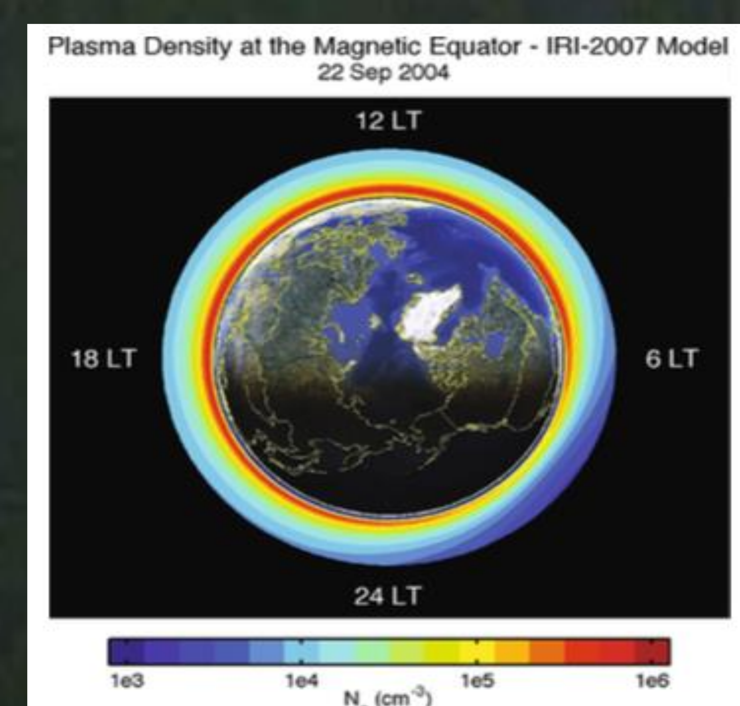

Figure 3: Model of global plasma density at the magnetic equator (Image credit: Fig. 8 from [2]).

How do we study the ionosphere?

There are a number of ways to measure the ionosphere and its constituents (*e.g.*, ionosonde and *in-situ* composition detection). Our study focuses on electron density data acquired by radio occultation (**Fig. 4**).

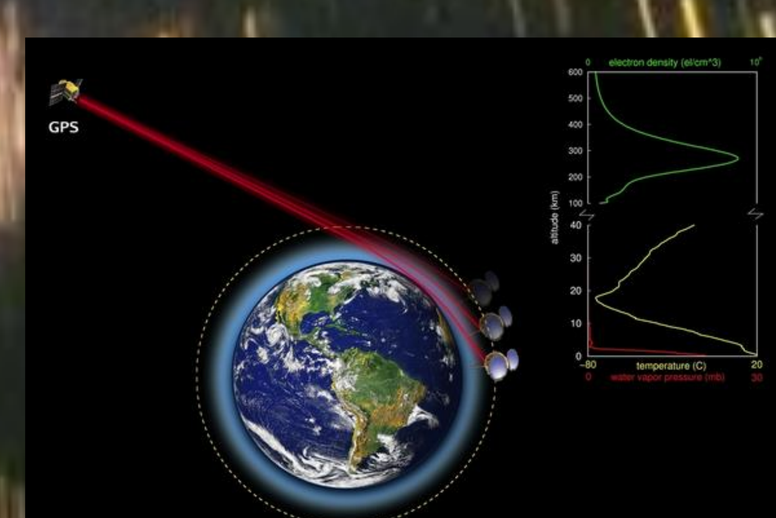

Figure 4: Example of atmospheric profiling using GPS radio occultation; inset: atmospheric profiles of electron density, temperature, and water vapor content (Image credit: [3]).

Why should we care about the ionosphere?

The ionosphere is home to the Aurora Borealis and Australis on Earth. It is important in our daily lives because it affects the transmission of radio signals through the atmosphere, thereby affecting our technology.

3. Our work

Outstanding Questions:

1) What is the behavior of the ionosphere during extremely low solar activity observed in 2008, and how does this compare to periods of higher solar activity?
2) How well do the empirical models, such as the International Reference Ionosphere (IRI), capture this variability?

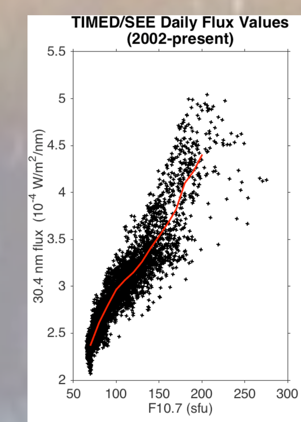

Figure 5: EUV measurements from TIMED/SEE data plotted against solar radio flux at 10.7 cm (Image credit: [5]).

Solutions:

Using the COSMIC dataset, we created global maps of the shape of the Ionosphere. We also generated seasonal maps of the mid- and low-latitude F-region Ionosphere, specifically focusing on the median values of maximum ionospheric densities (NmF2) and the corresponding ionospheric altitudes (hmF2) (**Figs. 6 & 7**). We considered median electron density values for 81 days around the 2008 and 2011 December solstices. We then generated IRI models (**Figs. 8 & 9**) and compared our maps to the models.

Methods/Software:

All analyses were completed using the computer software program Python, and an extension toolkit called the Python Science Analysis Toolkit (pysat) [6].

4. Results

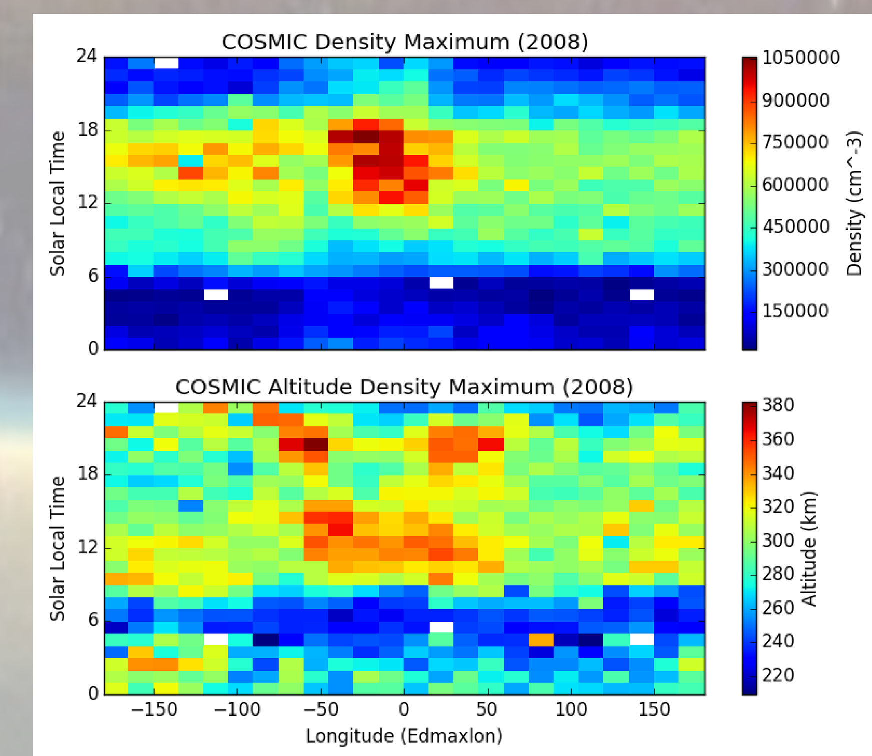

Figure 6: Maximum electron density (top) and corresponding altitude (bottom) as functions of longitude and solar local time. Data used are median values for 81 days around the December solstice, 2008.

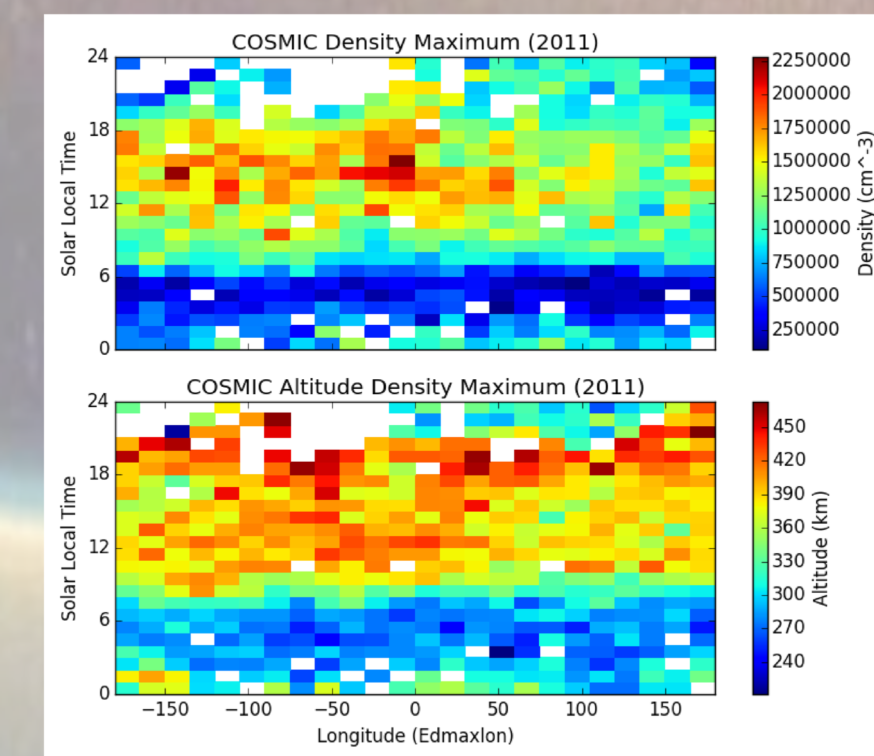

Figure 7: Maximum electron density (top) and corresponding altitude (bottom) as functions of longitude and solar local time. Data used are median values for 81 days around the December solstice, 2011.

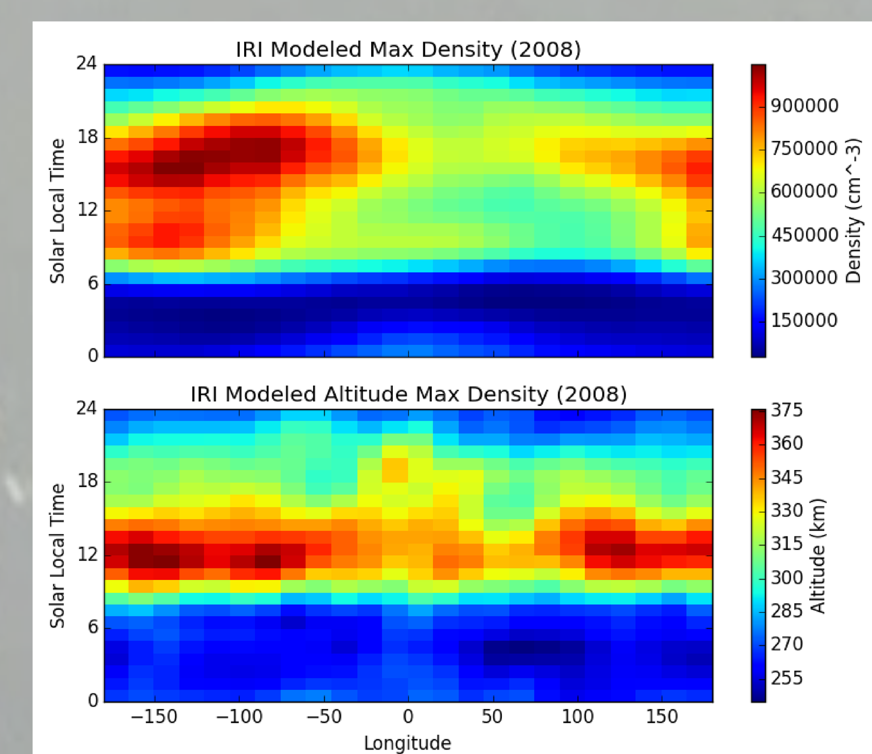

Figure 8: IRI model of the maximum electron density (top) and corresponding altitude (bottom) for data in Figure 6.

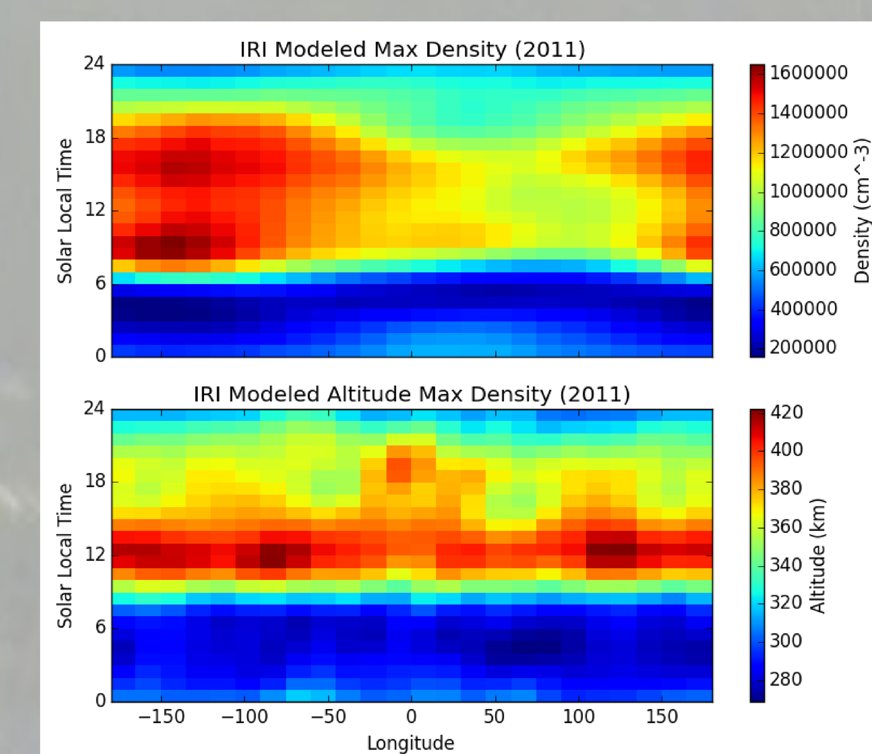

Figure 9: IRI model of the maximum electron density (top) and corresponding altitude (bottom) for data in Figure 7.

5. Discussion and Conclusions

•Using COSMIC data in conjunction with IRI models, we found that the models represent the general trend of the data, but do not perfectly represent the data. We note a number of locations where the model does not accurately represent the data. Irregularities in the lower longitudes suggest a potential latitude bias introduced by either the data processing method or the IRI model.

•The results of this project provide useful information regarding how well the IRI model represents the ionosphere. These results can be used to improve the model, thereby allowing scientists to more accurately represent the ionosphere, predict its behavior during solar extremes, and ultimately protect society and technology.

6. Future Work

•Complete longitude specific studies to test the accuracy of the IRI on a regional scale.

•Combine COSMIC study results with the Coupled Ion-Neutral Dynamics Investigation (CINDI) climatologies [4] to compare the behavior of the F-peak with the topside ion density.

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•Data for this project were made available by the COSMIC/UCAR team. Background image is courtesy of Thomas Immel.

•Pysat can be downloaded from http://rstoneback.github.io/pysat/index.html

References

[1] "Atmosphere with Ionosphere" by Bhamer (Wikipedia). [2] Pfaff et al. (2012), The Near-Earth Plasma Environment, Space Sci. Rev. [3] COSMIC/UCAR website (http://www.cosmic.ucar.edu). [4] Klenzing et al. (2011), Topside equatorial ionospheric density and composition during and after extreme solar minimum, J. Geophys. Res., 116, A12330. [5] Klenzing et al. (2016, In Prep).