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Using SDO-EVE Satellite Data to Model for the First Time How Large Solar Flares Influence the Earths Ionosphere

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Why We Care About the Ionosphere

The ionosphere is important in our everyday communications. Many satellites, like GPS satellites, have to send signals through the ionosphere, and many emergency radio communicators depend on the ionosphere to extend the range of their communications. We also have many satellites and even the International space station located in this region of the atmosphere. It becomes important for the astronauts in the ISS and for the health of the satellites to know what is going on in the ionosphere and how it can affect their systems. See figure 1.

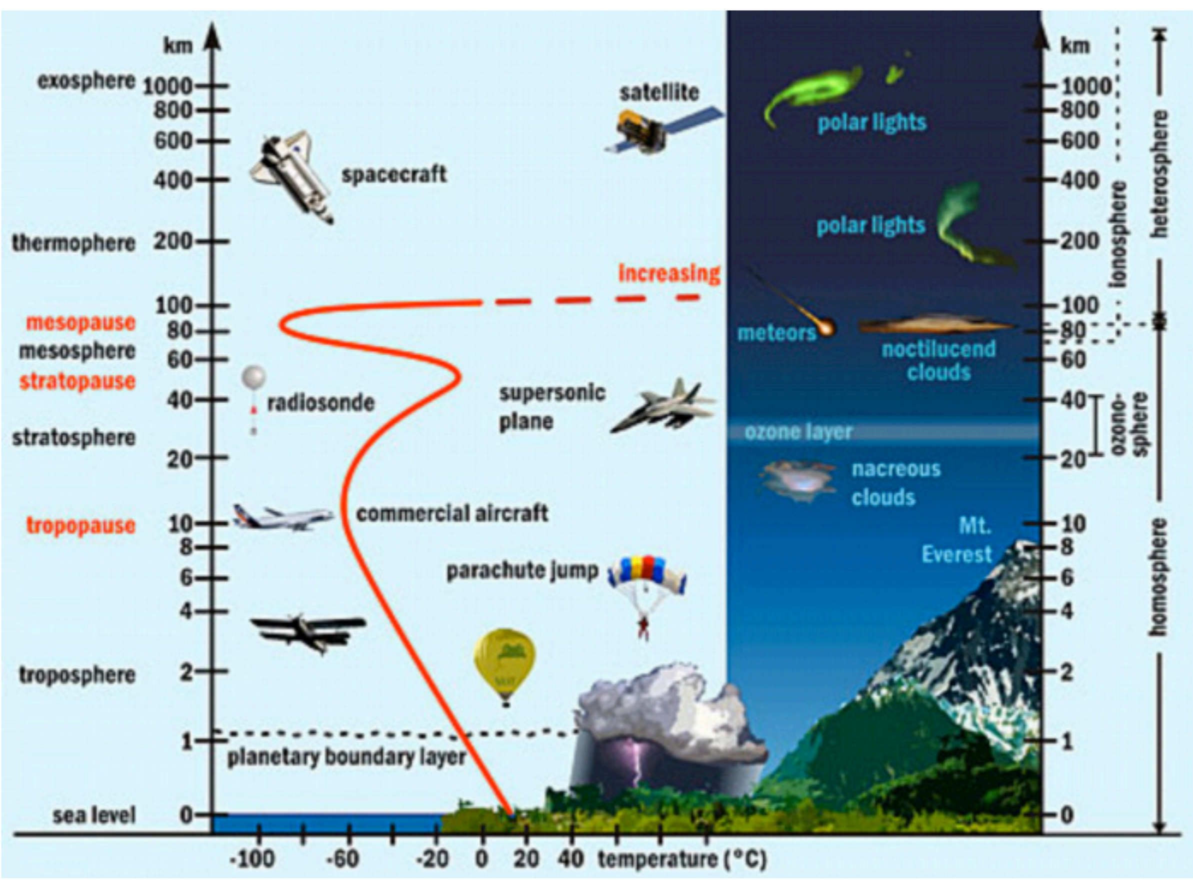
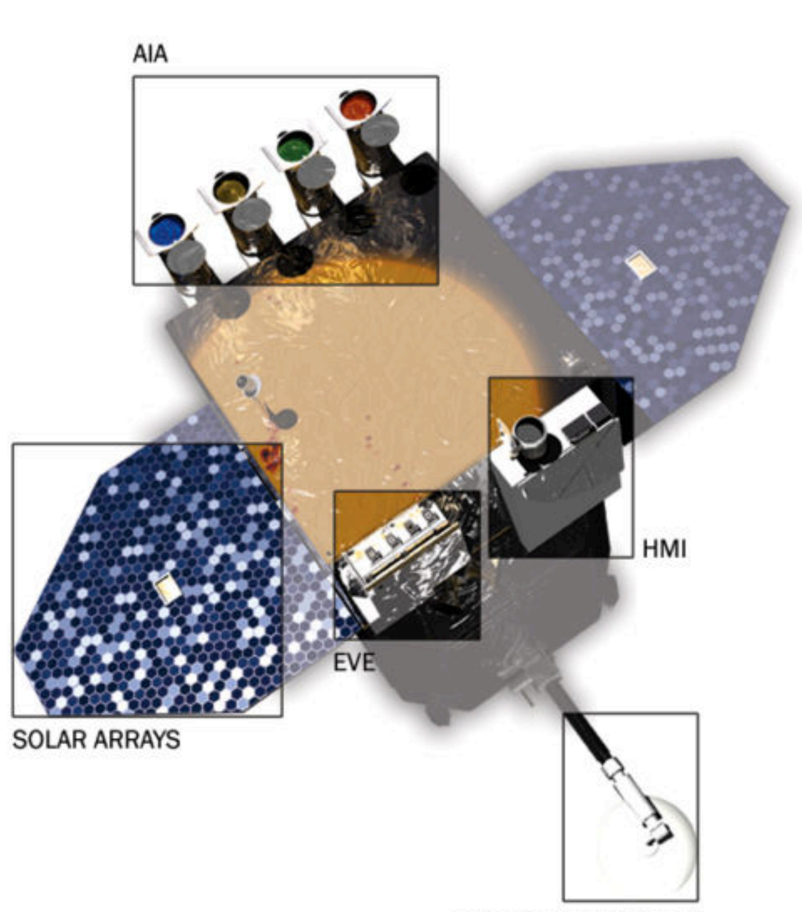


Figure 1, shows the atmosphere, the Ionosphere and phenomenon that occur at different heights. Some of the travelers in each of the layers of our atmosphere are also included to get a sense of the height of the Ionosphere

The lower regions are important because the E-region will extend the distance that a High Frequency (HF) radio operator can communicate, and when the E-region is expanded it will absorb the communications and cause a radio blackout, so any emergency personnel that depend on those HF radio communications won't be able to communicate. And both the F and E regions will affect GPS satellites communication and can cause errors in position on the earth of up to 20 meters.

NASA SDO-EVE Instrument

The NASA Solar Dynamics Observatory or SDO satellite was sent into orbit February of 2010. It's mission was to study the sun. It had three primary instruments, the Atmospheric Imaging Assembly (AIA), the Helioseismic and Magnetic Imager (HMI), and the Extreme Ultraviolet Variability Experiment (EVE). The EVE instrument measures the photons that are coming off the sun, and measures their energy, in the wavelength range of .1-105 nm with an amazing spectral resolution of . 02nm. In the past data with a time resolution of only 90 minutes has been available, but with the EVE instrument they take a measurement every 10 seconds. This has been particularly important while studying flares, as the duration of a large flare is on the order of minutes to tens of minutes. With the SDO-EVE instrument this is a thing of the past. We can now see flares better than ever before.



Figures 2 and 3 are pictures of the SDO satellite on the left the three different instruments are shown and the picture on the right puts in perspective the size of the satellite.

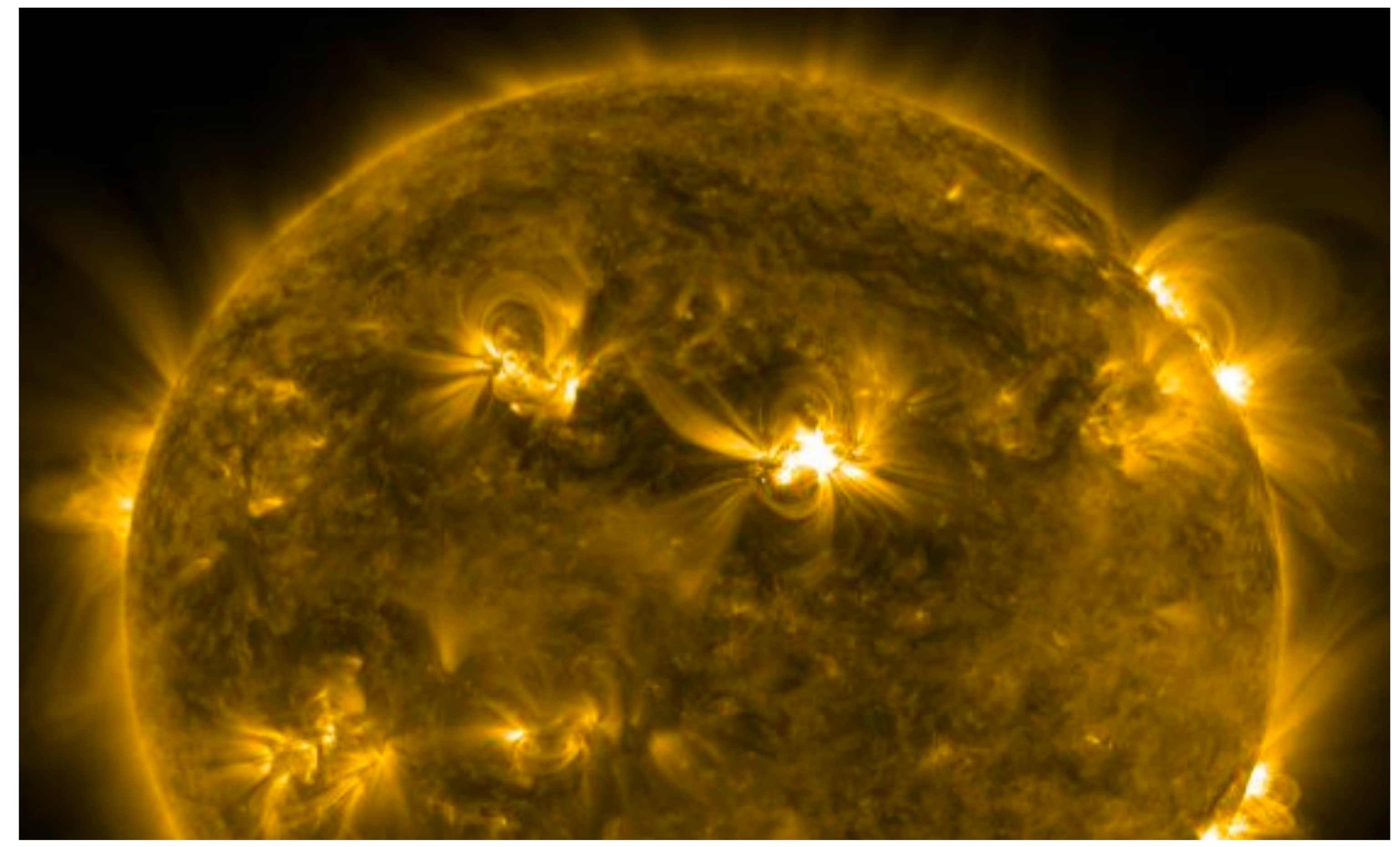


Figure 4 this is a picture of the sun during the March 9, 2011 flare, the active region from which the flare erupted is AR 1166 (the bright spot seen in center of the solar disk)

What Solar Flares do to the Ionosphere

When the sun has a large solar flare a lot of energy is released, and this comes to the earth as energetic particles and photons. During the solar flare the extreme ultraviolet light spectrum is greatly enhanced, and this has huge impacts on the lower ionosphere at about 88-130km known as the E region of the ionosphere. The ionosphere is mostly composed of the ion species NO+, O2+, and O+. The O+ ions are typically found higher in the ionosphere, so the two major species that compose the E-region are NO+ and O2+. These are greatly influenced by the 2-15nm and the 90-105 nm wavelength photons that are coming from the sun.

We took as a test case the X1.6 flare on March 9, 2011, and analyzed it's affect on the ionosphere using the Utah State University Time Dependent Ionosphere Model (TDIM) code. We input this data from the EVE satellite into our ionospheric modeling code.

Figure 5 shows the Ion densities in a log plot for the different species at the peak of the flare. As can be seen the enhancement is greatest in the NO+ species with a 30% change in the ion densities. The O2+ has a noticeable enhancement as well with a maximum percentage change of 20%, The O+ has a slight enhancement of 10%. The overall change for the three plots is shown In the bottom right panel. There is a noticeable increase in the E-region peak and even up into the F1-region.

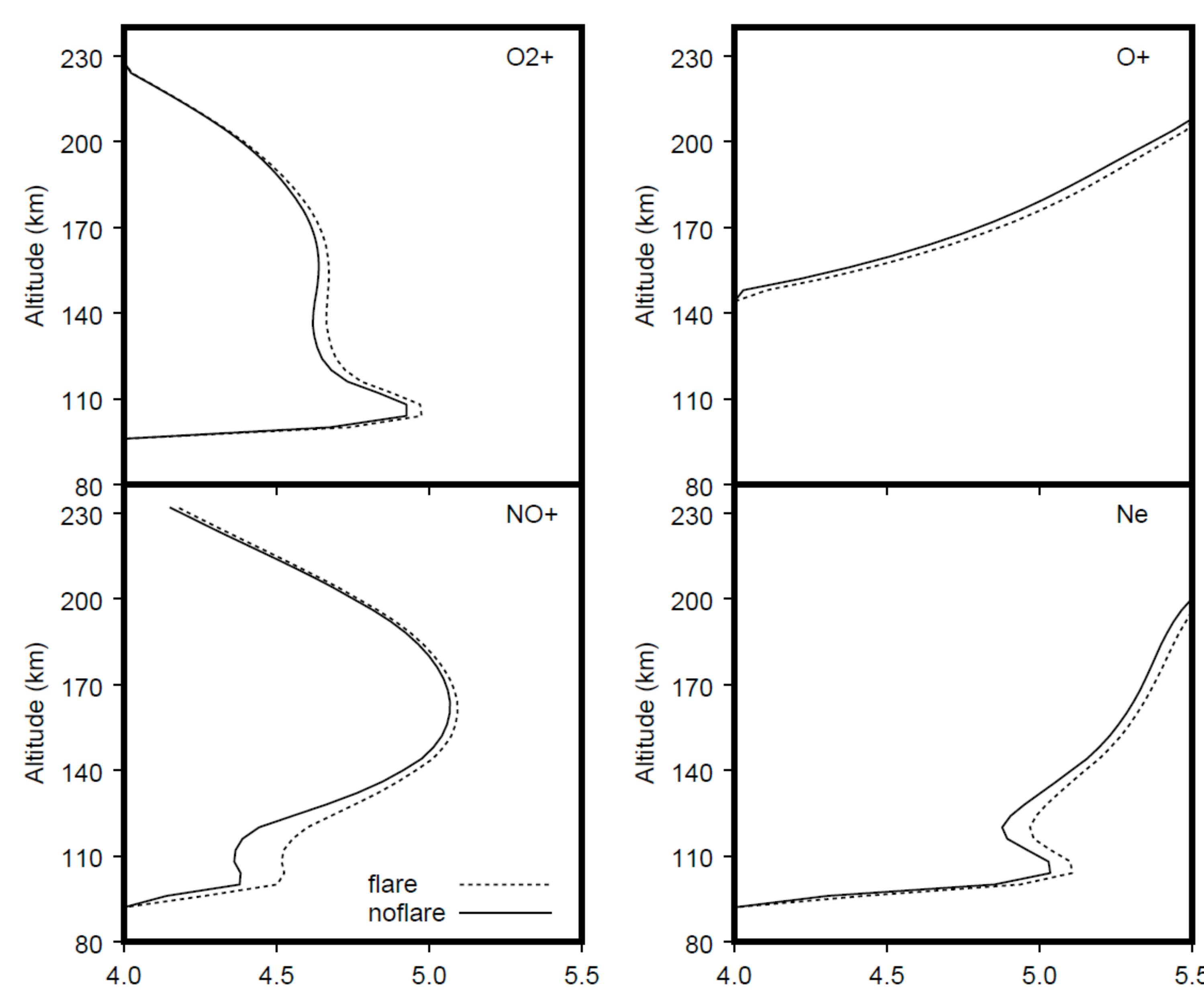
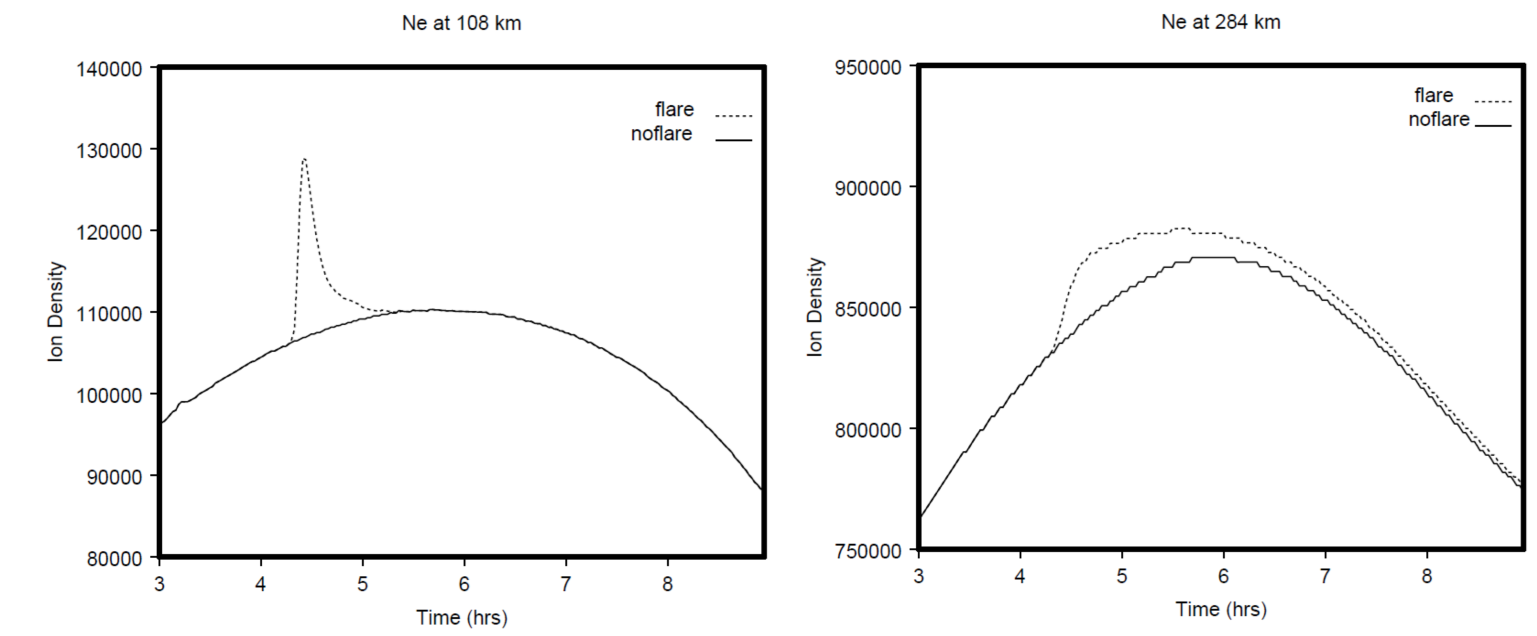
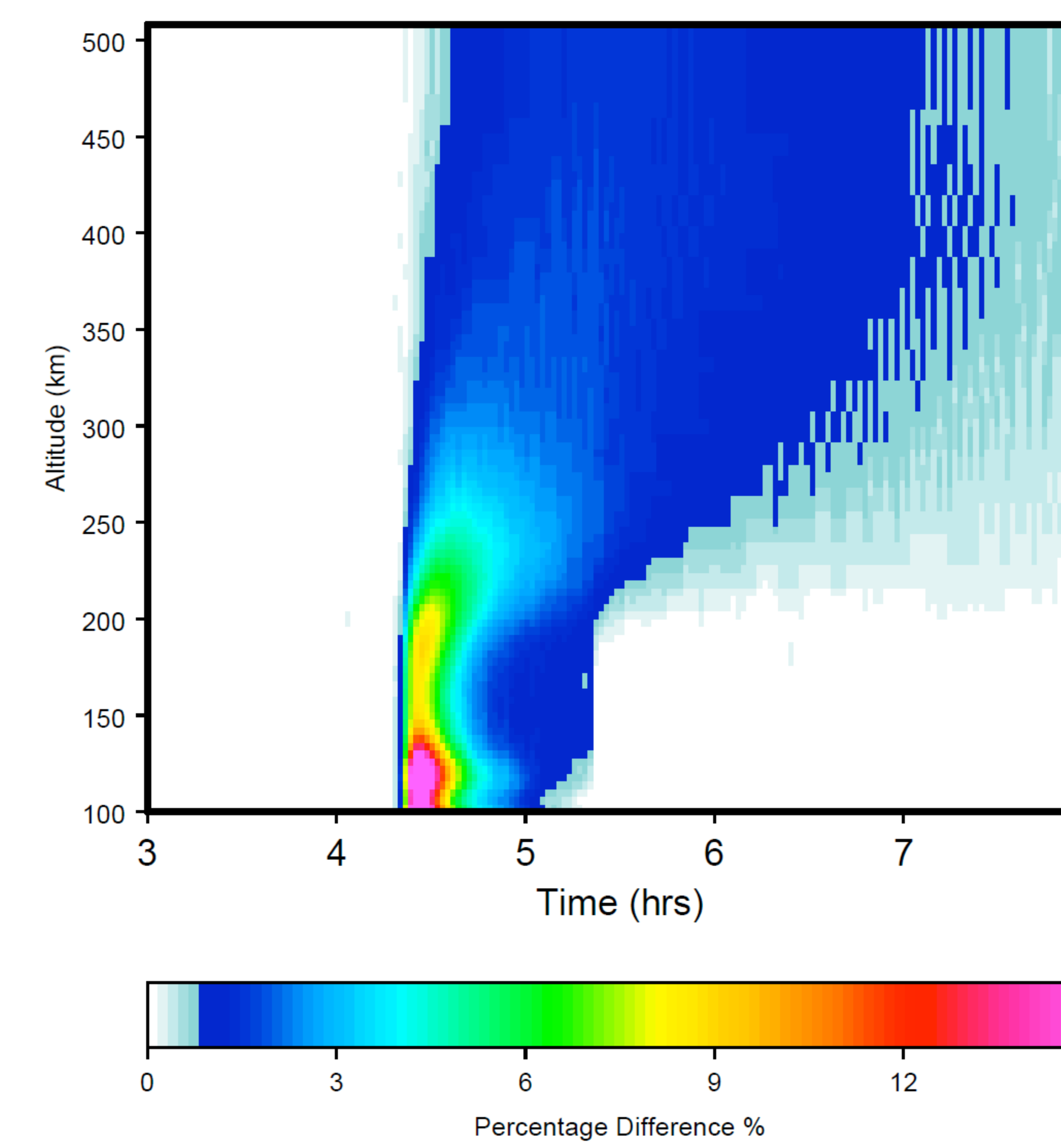


Figure 5; this is a graph of the ion densities at the peak of the flare on March 9,2011 flare.



Figures 6 and 7 (above) show a time evolution of the flare at two different altitudes, 108 km and 254 km, particular to note is that the ionosphere returns back to it's original state much faster lower down in the ionosphere, while the effect is felt for multiple hours at the 284 km mark. Figure 8 (below) shows the percentage difference of the flare and non flare ionosphere for March 9, 2011



We took, as shown in figure 6 and 7, a time series of the ionospheric response to the flare to see how it evolves. We looked at two heights 108 km (E-region peak) and 284 km (F-region peak). This shows a plot of the ionosphere 1 hour before the flare occurs and 5 hours after, the effects rapidly go away in the E-region, but they can last for hours up in the F-region.

Figure 8 shows the response of both the E and F region of the ionosphere. We took the quiet (no flare) ionosphere and compared them with the flare ionosphere and found the percentage change. We found that down in the E and F1 regions the change was very large with a large percentage increase in the number of ionizations taking place of about 20%. As we move upward in altitude the percentage was not as big, but the length of time that it is affected is much longer. The flare conditions will last up in the F region for hours. Flares of this magnitude can affect the signal of any device that depends on communications from a GPS satellite.

Conclusion

Solar flares impact the Ionosphere in big ways. With just a minor X-class flare the Ionosphere can increase in density by up to 20%. This is enough to cause HF radio blackouts, and disrupt GPS satellite communications. Also the effect of the flare is felt for 30-60 minutes in the lower E-region of the ionosphere, while the effects last much longer in the F-region, on the order of several hours. With the new EVE instrument on the SDO satellite it has become more reliable than ever to analyze these flares that have great impacts on our technology dependent society.

References

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-Chamberlin, P. C., Woods, T. N., & Eparvier, F. G. "Flare Irradiance Spectral Model (FISM): Flare component algorithms and results" 2008, Space Weather, 6, 5001
-SDO and Ionosphere pictures obtained at <http://en.wikipedia.org/wiki/Solar_Dynamics_ Observatory>
-Figure 4 obtained using Jhelioviewer 1/14/2013
-We would like to acknowledge NASA grant # NAS 5-02140