The Role of the Solar Soft X-ray Irradiance on Thermospheric Structure

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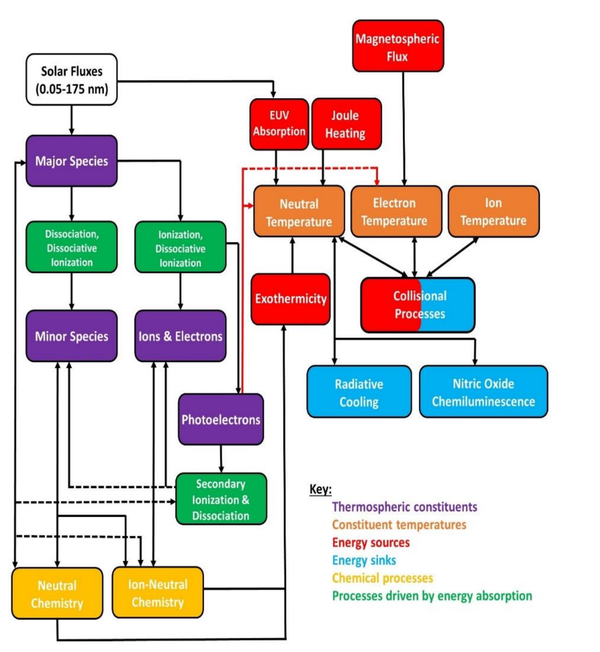
A. Introduction and Motivation

Solar soft X-ray irradiance (λ less than 30.4 nm) deposit energy in the lower thermosphere / ionosphere, however the impact of this wavelength region spans entire thermosphere. We use a recently developed 1D model of the thermosphere and ionosphere to explore the impact of the solar soft X-ray irradiance on temperature.

B. Description of ACE1D model

The Atmospheric Chemistry and Energetics (ACE) 1D model is a global average model that self consistently solves the continuity and energy equations to give the densities and temperatures of the ions, electrons as well as major and minor neutral species. The model includes all important radiative, chemical, and conductive processes. Calculations of neutral densities and exospheric temperatures are found to be in good agreement with empirical data for a wide range of solar activity. The primary input to the model is the solar irradiance (0.05-175 nm) obtained from the EUVAC model.



Major Species	N_2, O_2, O
Minor Species	$N(^2D)$, $N(^4S)$, $N(^2P)$, NO, $N_2(A)$, $O(^1D)$
Ions	O^+, $O^+(^2D)$, $O^+(^2P)$, N^+, NO^+, N_2^+, O_2^+
Vertical grid ($\ln(p/p_0)$)	Z=-7 to 7, ΔZ=0.25, z_0=97 km
Neutral Temperature (T_n)	LBC: 177 K, UBC: $\frac{\partial T}{\partial Z}=0$
Electron/Ion Temperatures (T_e, T_i)	LBC: $T_e = T_i = T_n$, UBC: $\frac{\partial^2 T_i}{\partial Z^2}=0$, $\lambda\frac{\partial T_e}{\partial Z}=f$
Solar input	EUVAC/F10.7
Joule Heating Input	95 GW

The flow chart summarizes the processes included in the model. The table lists the key inputs and outputs from the model. The figure shows model calculations of the key heating processes. Heat transfer from charged particles is the dominant process controlling temperature at high altitudes.

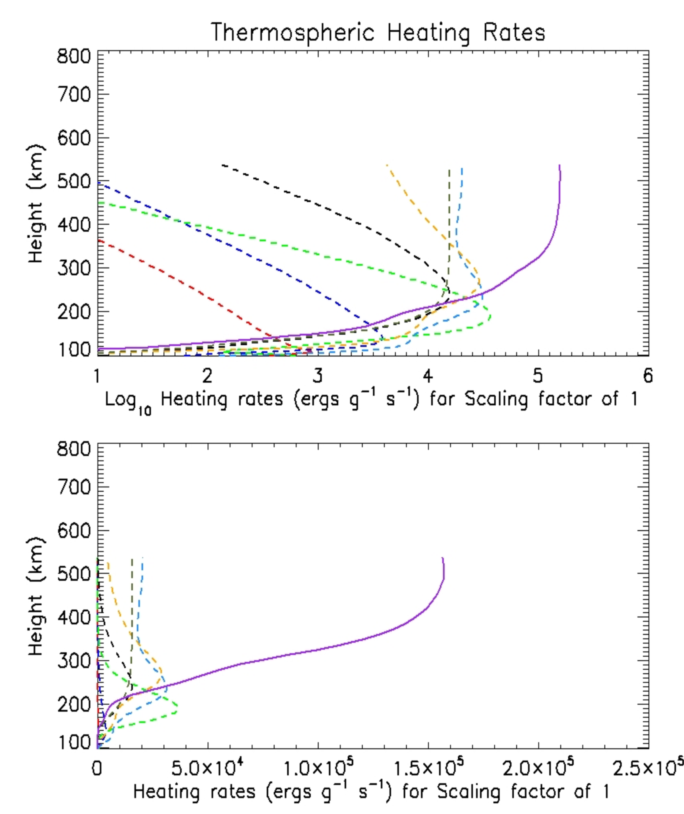
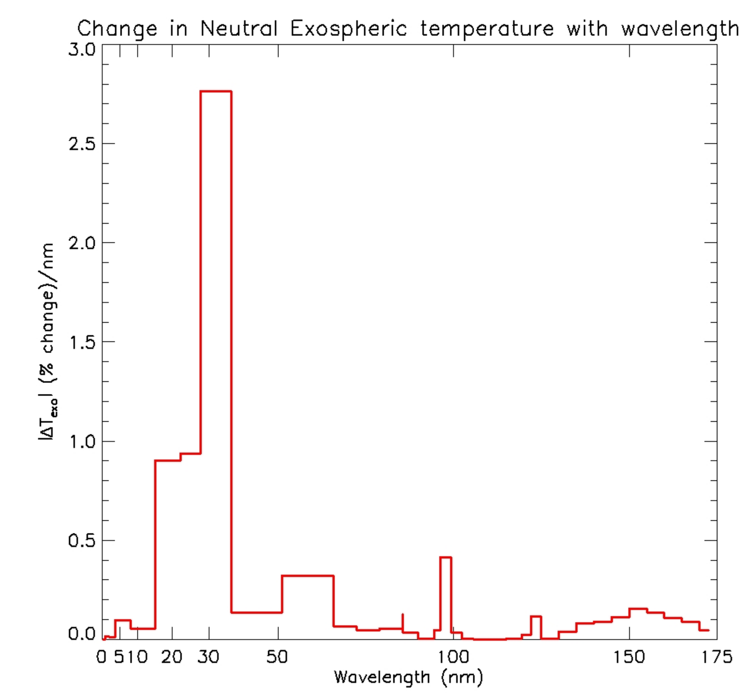
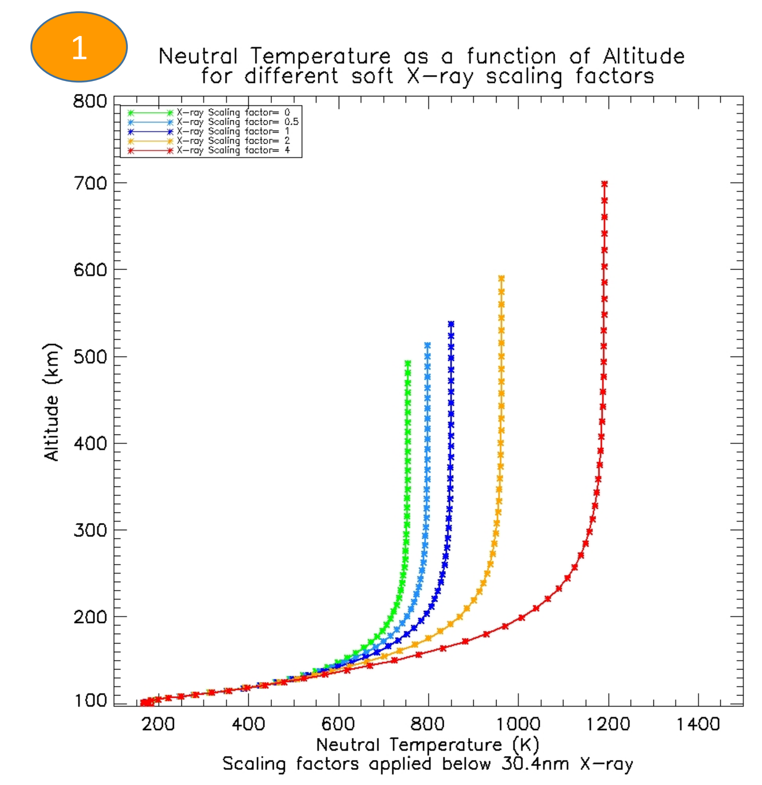


Figure (right): Heating due to absorption in the Schumann Runge bands (red) and Schumann Runge continuum (blue); exothermic reactions of neutral species (green), quenching of excited species (dodger blue), direct heating due to thermal collisions with photoelectrons (olive), exothermic ion recombination and ion-neutral reactions (black), joule heating (orange) and thermal collisions of neutrals with ions and electrons (purple)

Our approach is to run the model with select wavelength ranges that are scaled and then to examine the impact on modeled temperature. In the first case, we scale the spectrum in individual ~1nm wavelength bins. We perform 37 models runs with one wavelength bin scaled by zero and all others by 1.0. By looking at the change in model temperature (compared to the case where all scaling factors are 1.0), we see that thermospheric temperature is especially sensitive to solar soft X-ray wavelengths. We continue by looking at cases where the entire solar soft X-ray spectrum is scaled, and look at terms in the heat equation to explain how solar soft X-rays warm the entire thermosphere. We end by comparing the effect of solar soft X-ray irradiance to the impact of the important He 30.4 nm emission.

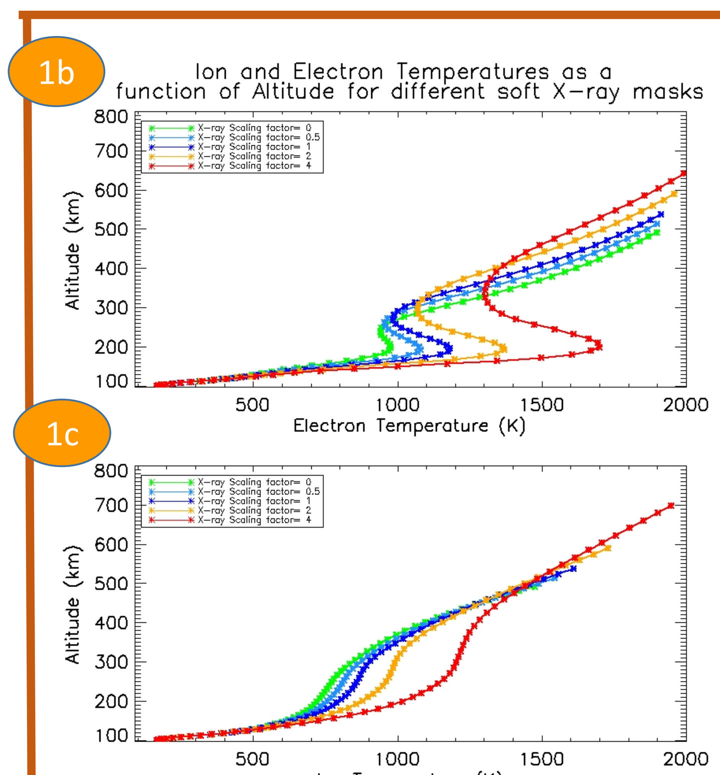


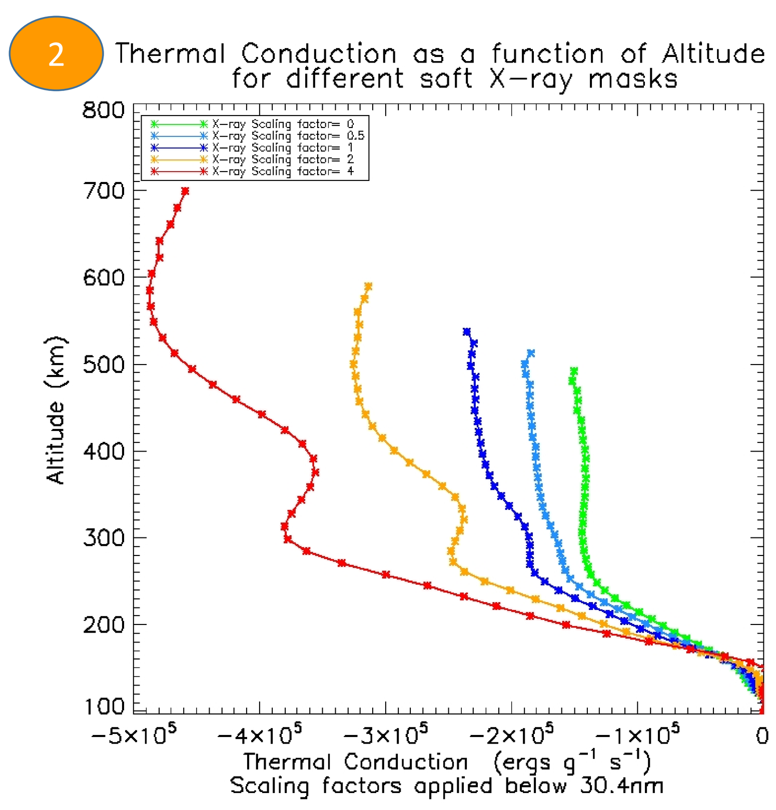


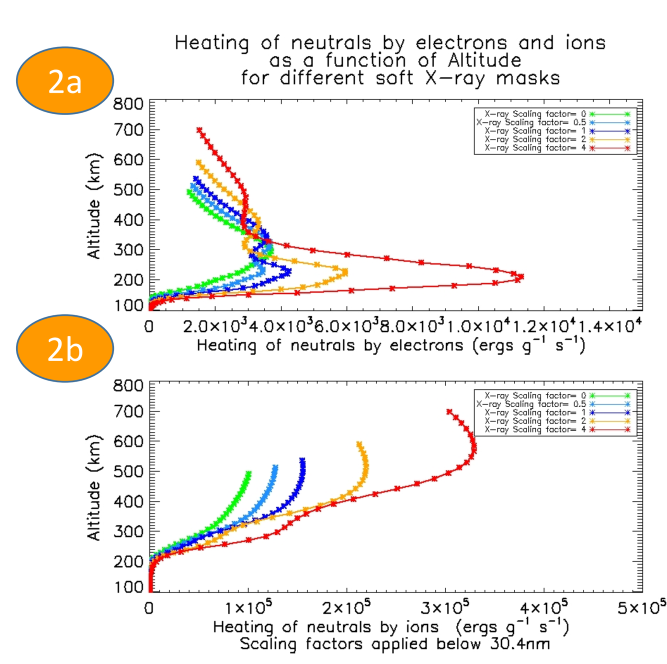
C. Understanding the Impact of the solar soft X-ray Irradiance

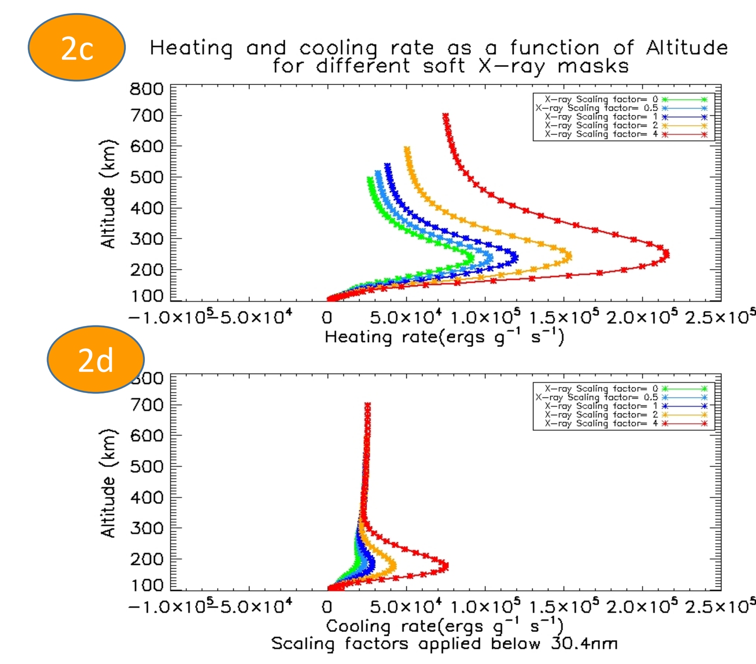
In this sequence of figures, we show model results that illuminate the role of the solar soft X-ray irradiance on temperature. In each panel, the various color lines are showing calculations with the solar spectrum below 30.4 nm scaled according to the factors listed.

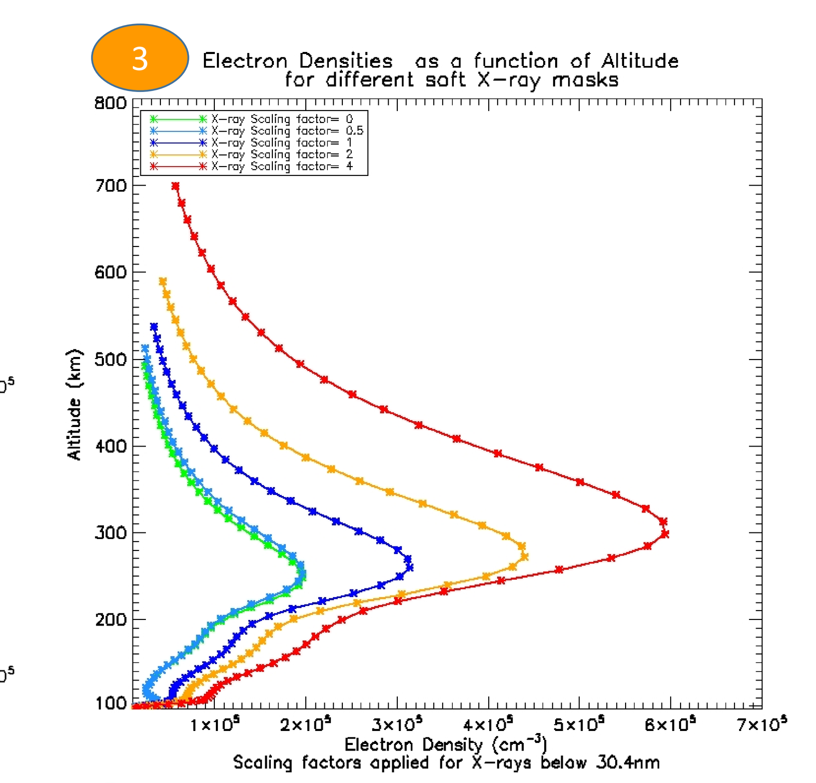
1. Thermospheric temperature is shown to increase significantly with increase in solar soft X-ray irradiance.
2. The major components in the temperature calculation are shown in three figures. Heat conduction increases dramatically with solar soft X-ray irradiance. This is caused by increase in heat transfer by ions and electrons. The effect by electrons is especially significant.
3. Electron densities increase at all altitudes due to increase in solar soft X-ray irradiance. Ambipolar diffusion leads to rapid upward transfer of electron densities. This leads to the increased heating of the neutrals by electrons.



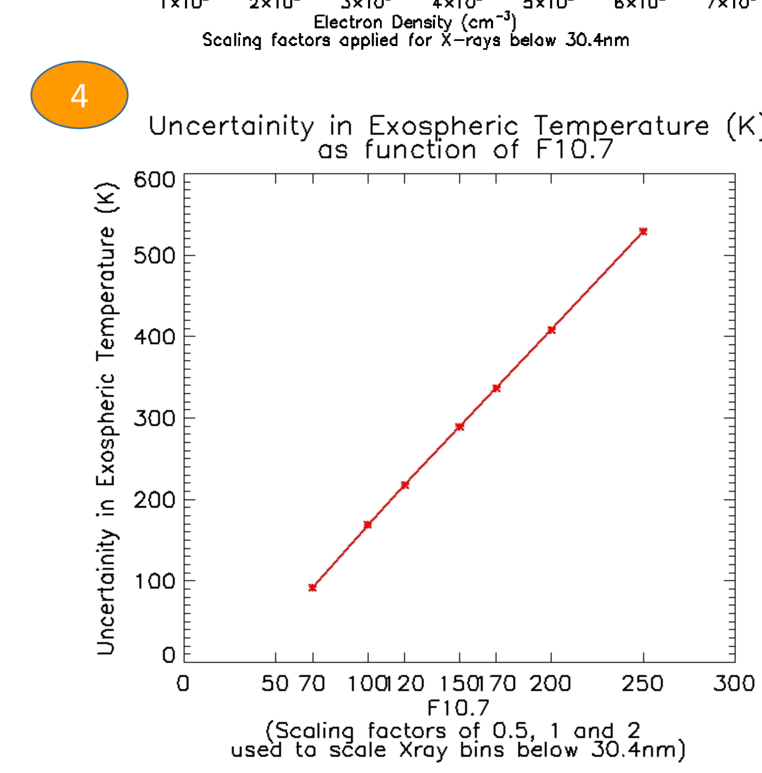




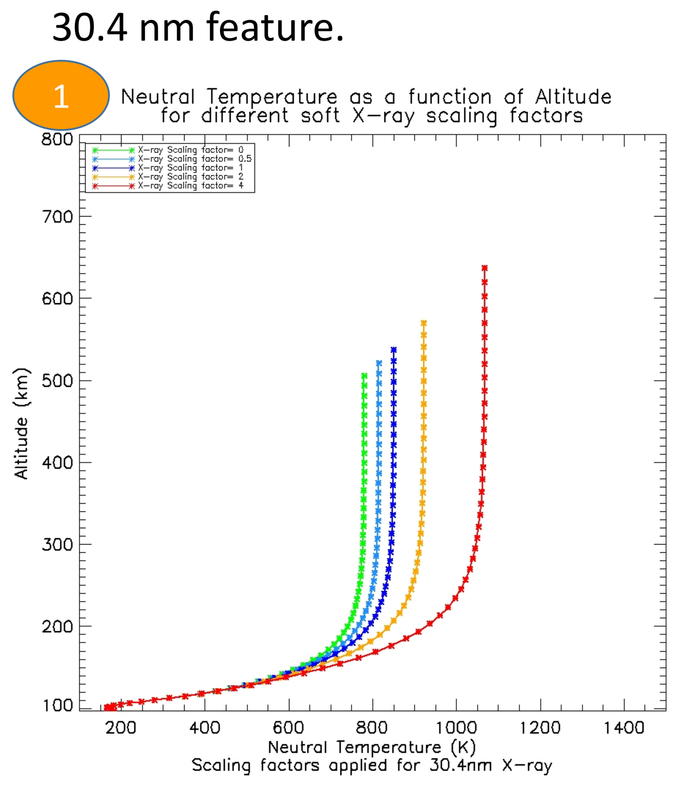


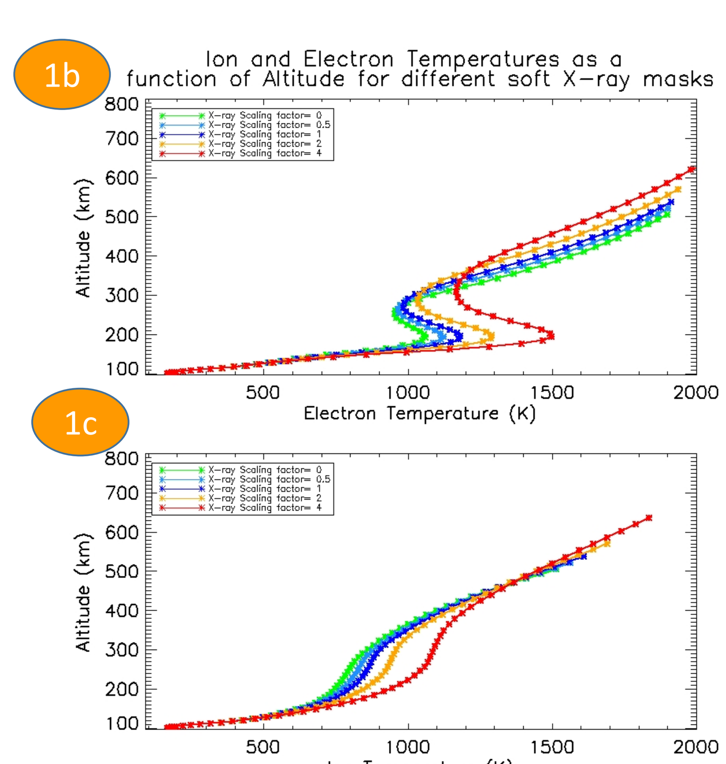


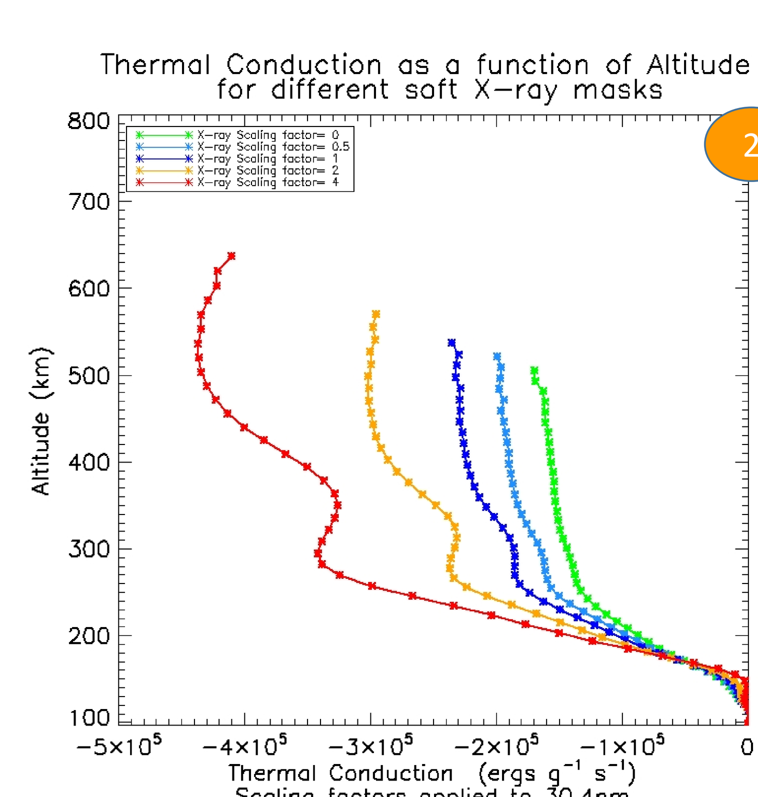
4. Based on the above results, we estimate the impact of a factor-of-two uncertainty in the solar soft X-ray irradiance on thermospheric temperatures. The uncertainties in temperature are estimated by running the model at various F10.7 (driving EUVAC irradiances), scaling $\lambda < 30.4$ by factors of 0.5 and 2 and taking the averages of the differences between runs with unity scaling.

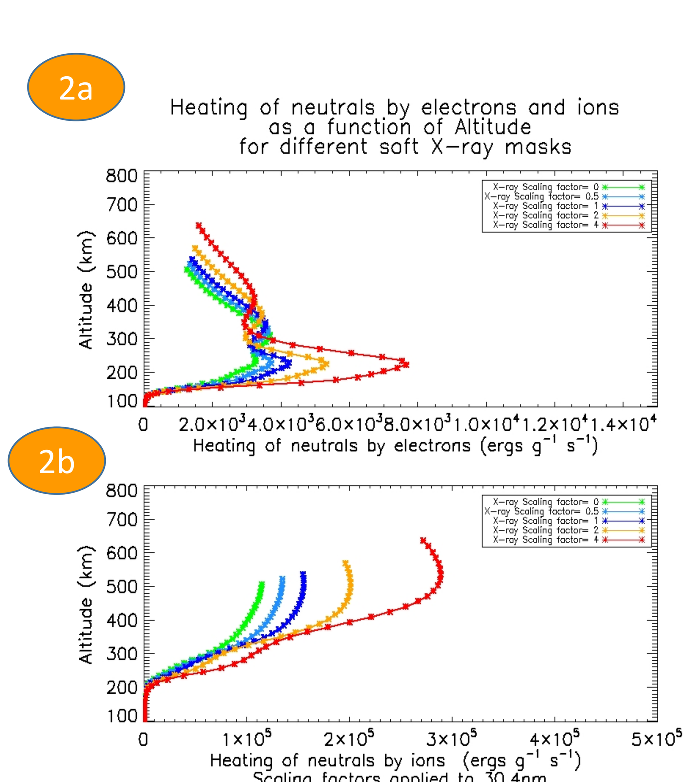


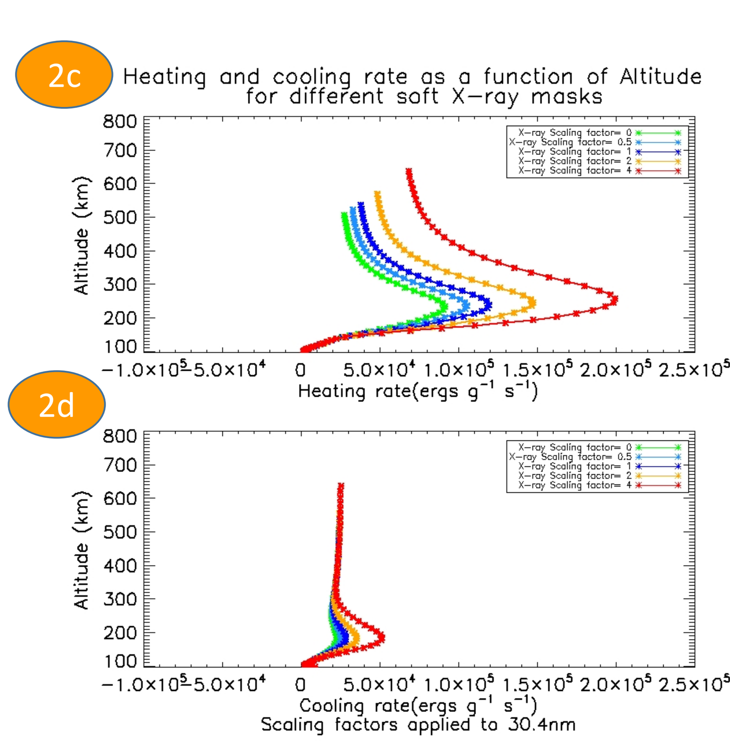
D. The same analysis performed in box C is performed with the scaling applied only to the important 30.4 nm solar emission. It is well documented that this emission plays a key role in the thermosphere and ionosphere. Comparison of the above figures and those of Panel C shows that the shorter wavelengths play a combined role that is significantly larger than the 30.4 nm feature.

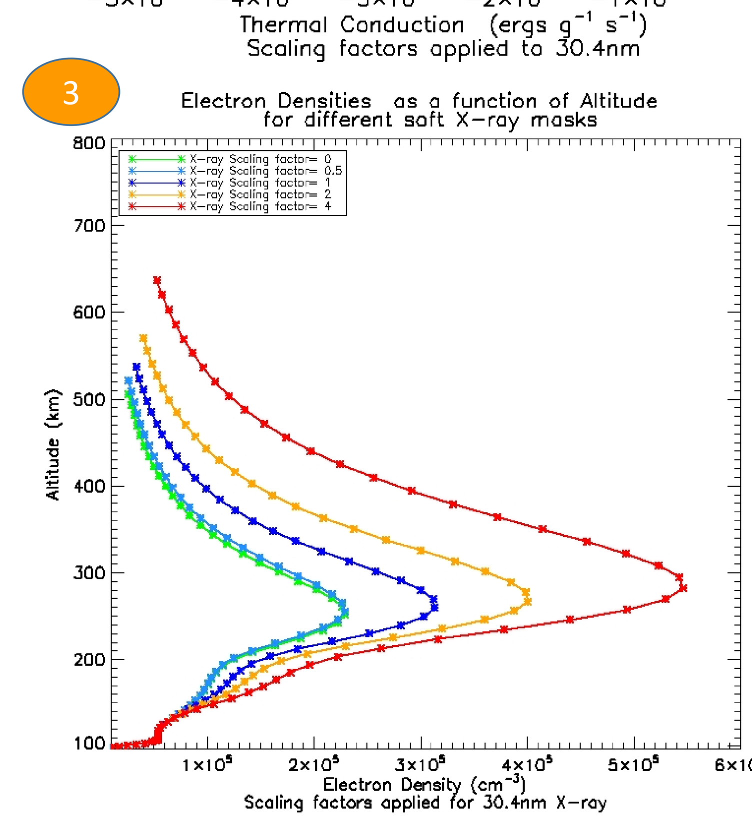


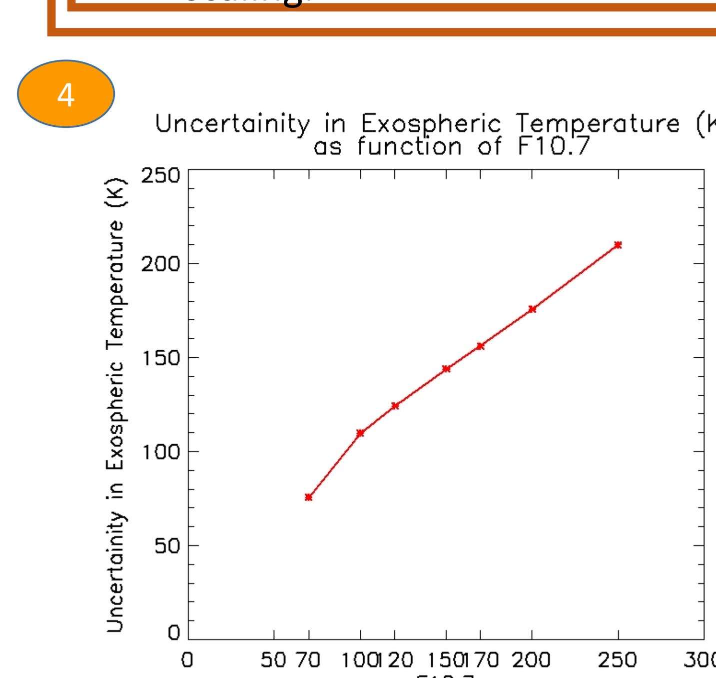












E. Conclusion

Using the ACE1D model, we have shown that the solar soft X-rays below 30.4nm are important drivers of the temperature of the entire thermosphere and ionosphere, although their energy is deposited in lower thermosphere. The main source of this temperature variability shown to be heat conduction by the collisions of the ions and electrons collisions with the neutrals. It is also shown that uncertainty in the solar soft X-ray irradiance can lead to very large errors in model-predicted thermospheric temperature.

References

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