Modeling the Earth's Thermal Conduction Coefficients

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Introduction

All but two planets in our solar system along with some moons and comets are enveloped in an ionosphere. This region is where many free ions and electrons are free to undergo chemical reactions, diffusion, and, while charged, be propelled by electric and magnetic forces. When these particles collide with neutrally charged molecules, energy is transferred in the form of heating.

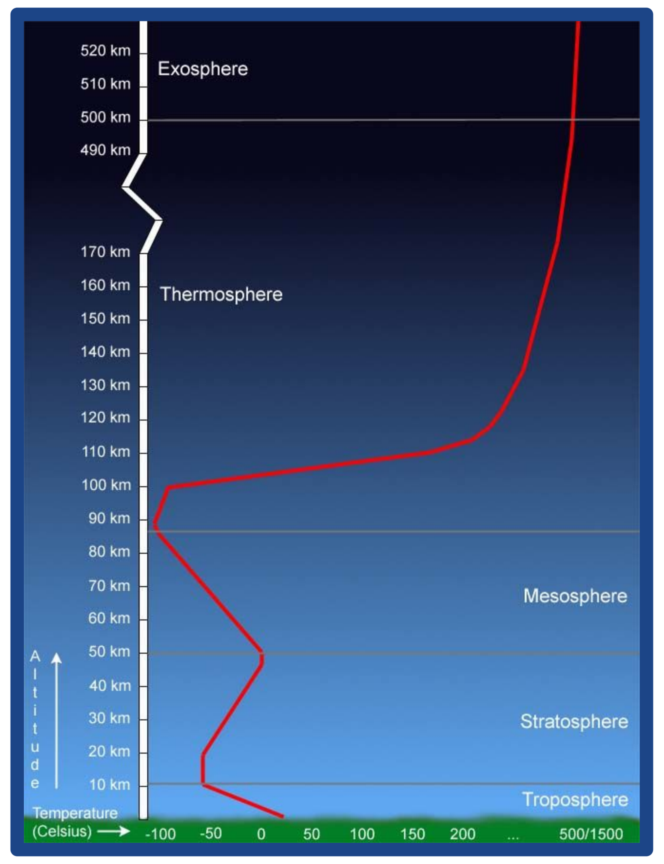

Figure 1: Typical temperature profile of atmosphere. The thermospheric region's (100 - 600 km) thermal conduction coefficients are our area of interest. Uncertainty in these terms lead to errors in modeling state variables in this region.

- Heating can be related in terms of a thermal conduction coefficient which describes the transport of heat from hot to cold regions.
- Physics based atmospheric models includes intrinsic terms, such as the thermal conduction, to the environment that are not well understood.

My goal is to model this complex process more simply in order to improve upper atmosphere models. To do so, I compare the Global Ionosphere Thermosphere Model (GITM) mass density output to the Challenging Minisatellite Payload (CHAMP) data.

Heat Diffusion Equation

- In the magnetohydrodynamic energy equation, the non-adiabatic effects of particle collisions are related by:

$$\frac{dT}{dt} \propto \frac{1}{\rho}\nabla(\lambda\nabla T)$$

- GITM approximates the thermal conduction, λ, in the form:

$$\lambda = \sum A_i T^s = (A(O_2) + A(N_2) + A(O))T^s$$

$$\lambda = (2A(O_2, N_2) + A(O))T^s$$

- There are approximations for the thermal conduction coefficients given in Pavlov, 2017 and Schunk and Nagy, 2004. Pawlowski and Ridley, 2009 uncertainty due to changes in thermal conductivity and seven other parameters.

Working with GITM

GITM is a well-established, physics based, 3D spherical code that couples the ionosphere and thermosphere of Earth. GITM allows constants for 'A' and 's' to be prescribed easily in an input file and calculates the thermal conduction. Then, comparing the simulated mass density to the measured mass density of CHAMP, the response of the atmosphere can be recorded.

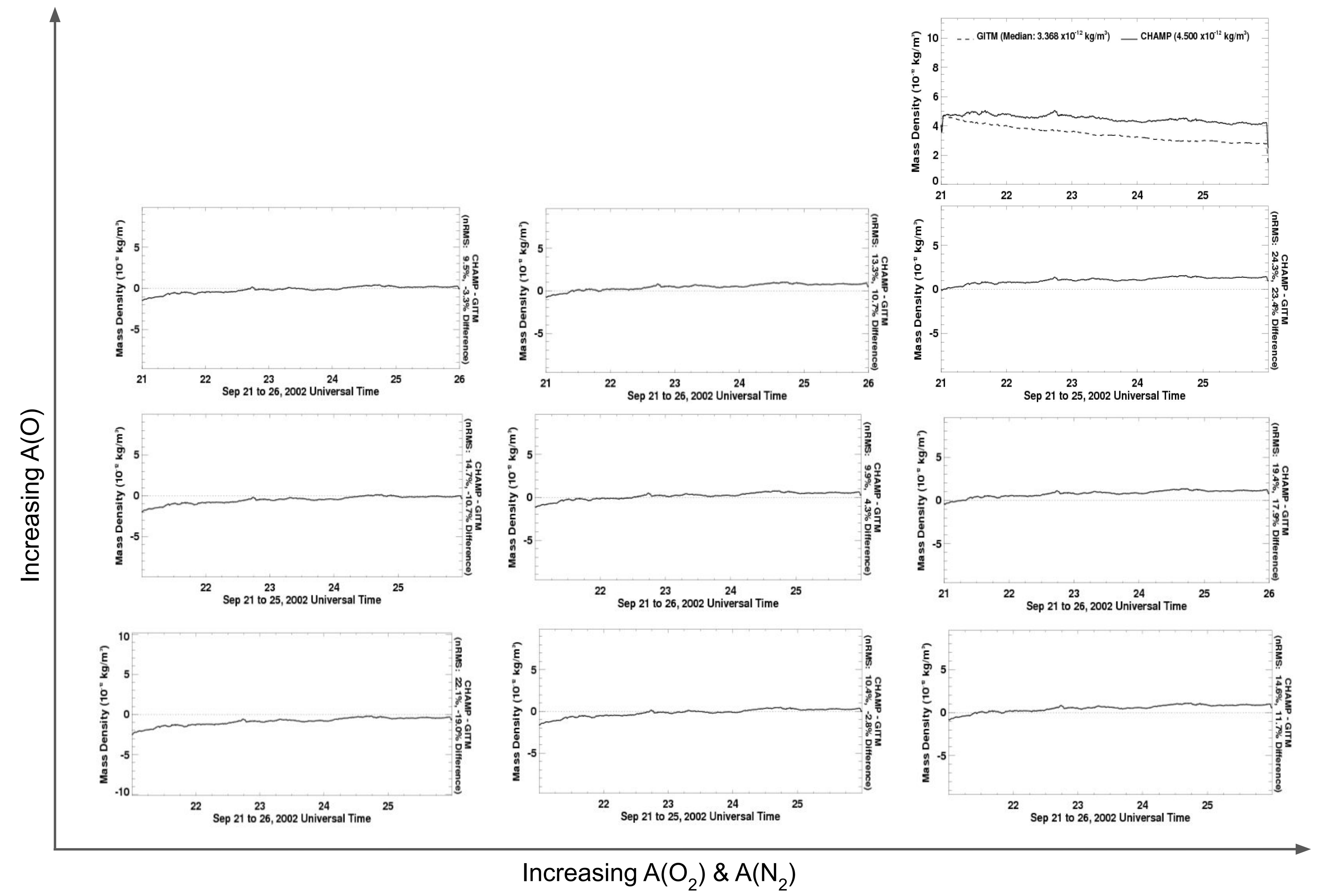

Figure 2: Plots of GITM mass density differences from CHAMP satellite data along the satellite path with varying thermal conduction coefficients. For the nine panels in a square, it should be viewed in terms of a 3x3 with varying inputs. The tenth panel (top right) shows the raw density changes over time and used to plot the differences shown in the other panels.

- Beginning from the bottom left, the thermal conduction coefficients for A(O$_2$) & A(N$_2$) = 3.6 x 10^{-4} $Jm^{-1}s^{-1}K^{-1}$ and A(O) = 4.6 x 10^{-4} $Jm^{-1}s^{-1}K^{-1}$. Moving one panel to the right, increases A(O$_2$) & A(N$_2$) by 10^{-4} $Jm^{-1}s^{-1}K^{-1}$. Moving vertically increases A(O) by 10^{-4} $Jm^{-1}s^{-1}K^{-1}$.
- **The overall impact of increasing thermal conduction (regardless of species), is a decrease in the mean neutral mass density. Modifying the diatomic molecules has a more significant effect than the monatomic oxygen.**

Recording the mean percent differences we created contours to predict model outputs that yield the lowest percent differences. Figure 3 shows these contours for results from Figure 2 (2002) and for another set of runs during September 21-26, for 2004.

- The contours between 2002 and 2004 are not identical. This implies that constants used universally during different times will not necessarily give the best results. We need to resolve one set of inputs that work best for both times.
- We can perform a discrete convolution to find overlapping regions between 2002 and 2004 that gives us a space where with the same input parameters can be used and will output results to within 5% mean neutral densities of CHAMP.
- For example:
  - A(O$_2$) & A(N$_2$) = ~ 4.6 x 10^{-4} $Jm^{-1}s^{-1}K^{-1}$ with A(O) = ~ 4.6 x 10^{-4} $Jm^{-1}s^{-1}K^{-1}$ would be good inputs. Additionally, A(O$_2$) & A(N$_2$) = ~ 3.6 x 10^{-4} $Jm^{-1}s^{-1}K^{-1}$ with A(O) = ~ 6.6 x 10^{-4} $Jm^{-1}s^{-1}K^{-1}$ are possible solutions.
  - Runs for both of these sets of inputs applied in 2002 can be seen in Figure 2.

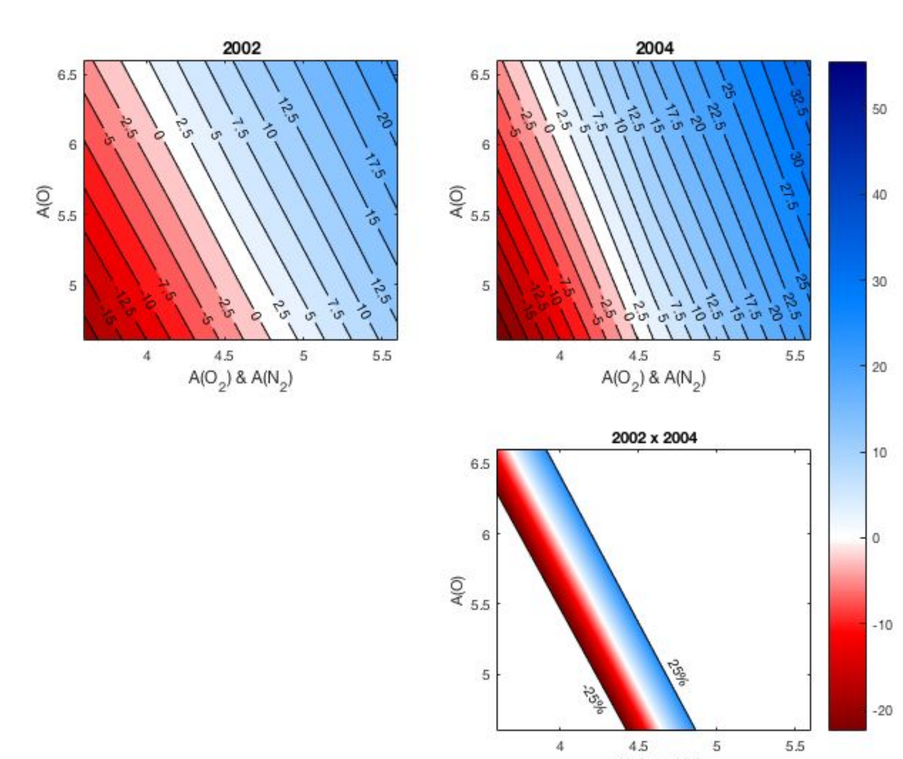

Figure 3: The blue regions indicate run inputs that would result in GITM having mass densities lower than CHAMP observed. Red values would correspond to GITM being too high. The bottom panel shows a plane potential candidates for thermal conduction values that yield good results for both 2002 and 2004 runs.

Next Steps

- In order to find the best solution, we compared the solution sets and apply them during times of low geomagnetic activity with varying solar intensity, $F_{10.7}$. **In the future, we will be applying these inputs during a geomagnetic storm to better understand if they have a noticeable impact.**
- Eddy diffusion is a complex mixing process that ultimately affects the density and composition of the atmosphere. Using the eddy diffusion coefficient (EDC), we are able to modify the total electron content (TEC) and use this as another comparison method for GITM validation. The Madrigal CEDAR database has this information in 1° × 1° resolution in 5 minute intervals to compare.

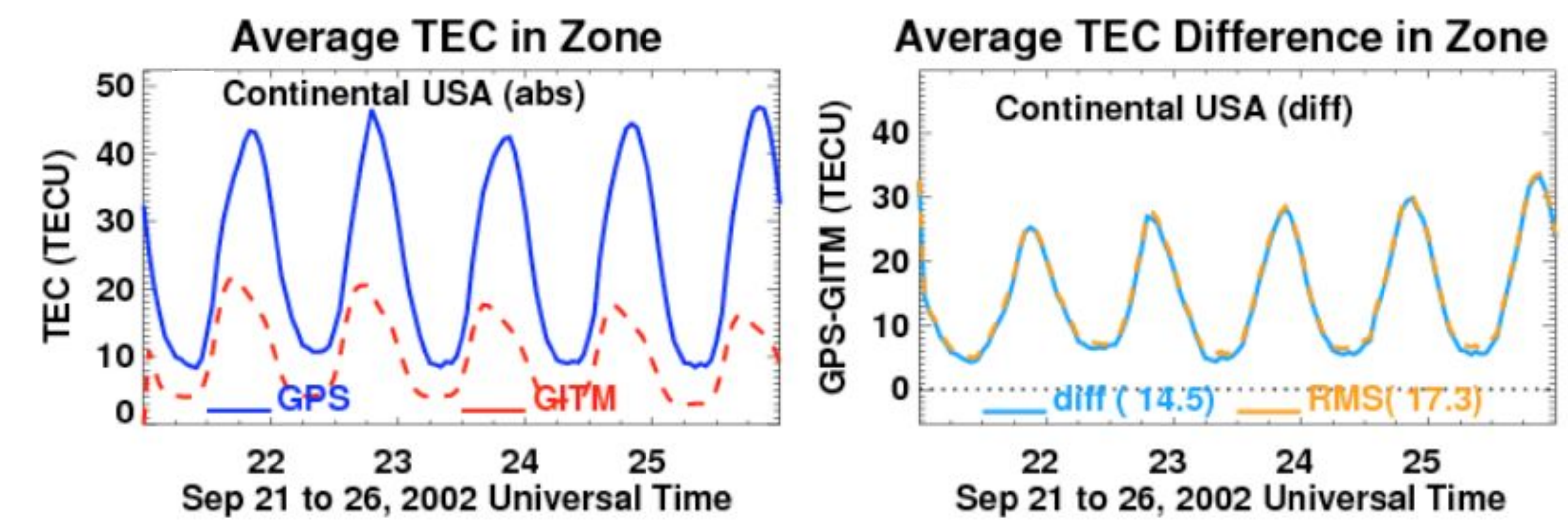

Figure 4: For a typical GITM EDC input (1000 $Jm^{-1}s^{-1}K^{-1}$), the panel on the left is GITM's projected TEC (dotted, red) alongside ground-based sensor measurements (blue). On the right is the difference and root mean square (RMS) where we see GITM is largely under approximating TEC.

- When removing all the eddy diffusion GITM will see the upper limit of TEC which is useful to reduce the percent difference. Although not shown, GITM still under approximates TEC by nearly 9 % in this situation. **To reduce this uncertainty, we are investigating the other factors that control TEC, like ion advection, and what is needed to match GITM's electron count to GPS observed values.**

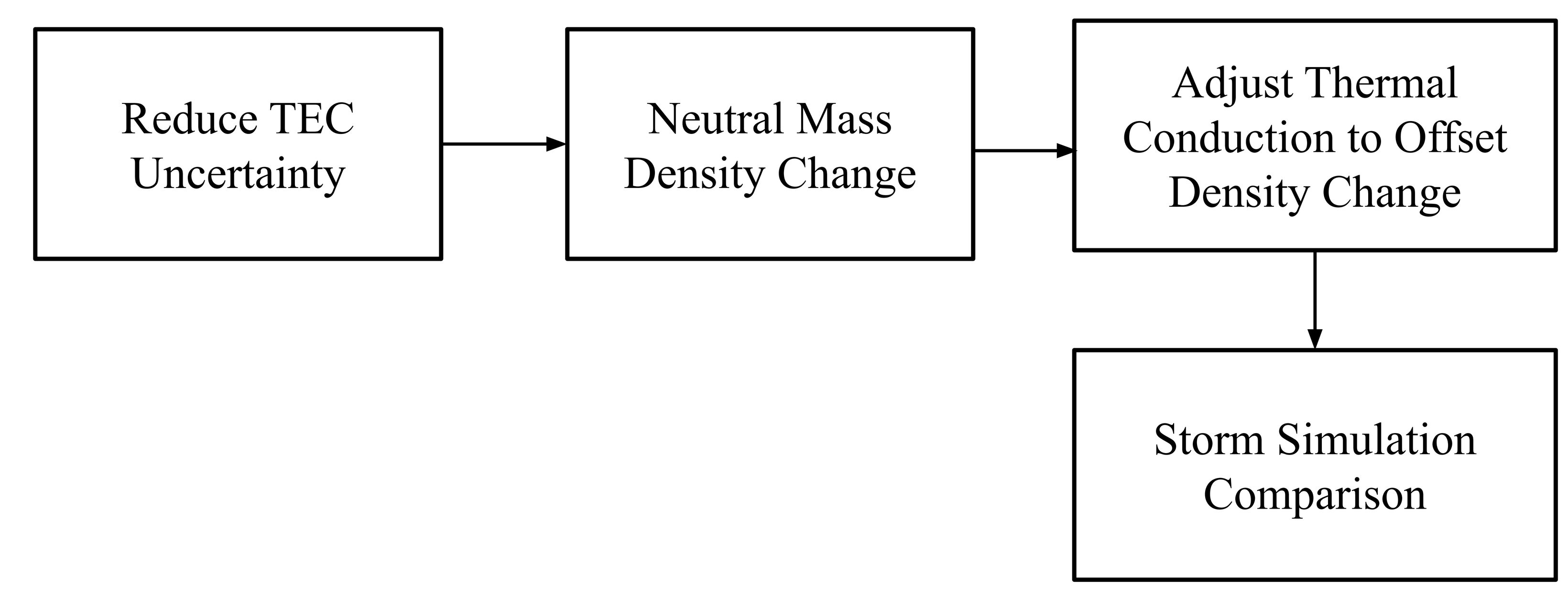

Figure 5: Block diagram of method for determining thermal conduction coefficients for use in GITM model.

References

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