Understanding the Effects of Lower Boundary variations on the Ionosphere-Thermosphere System using GITM

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ABSTRACT

The exchange of energy between lower atmosphere with the ionosphere thermosphere (IT) system is not well understood. A number of studies have observed day-to-day and seasonal variabilities in the difference between data and model output of various IT parameters. It is widely speculated that the forcing from the lower atmosphere, variability in weather systems and gravity waves that propagate upward from troposphere into the upper mesosphere and lower thermosphere (MLT) may be responsible for these spatial and temporal variations in the IT region, but their exact nature is unknown. These variabilities can be interpreted in two ways: variations in state (density, temperature, wind) of the upper mesosphere or spatial and temporal changes in the small-scale mixing (Eddy diffusion that is parameterized within the model). In a previous study, while analyzing the sensitivity of the thermospheric densities, O/N_2, TEC to the turbulence from the lower atmosphere we estimated a seasonal and latitudinal variation in the eddy diffusion coefficient (K_{zz}) that would be required to match the measurements with the Global Ionosphere Thermosphere Model (GITM) results and found that often the K_{zz} shoots over the preferred range indicating that there are other processes contributing to these thermospheric properties as well. In this new study, we now investigate the sensitivity of the thermospheric parameters O/N_2, total electron content (TEC) - to various lower boundary conditions in the GITM. We use WACCM-X to drive the lower atmospheric boundary in GITM at ~97 km, and compare the results with the current MSIS-driven version of GITM. The tidal structures seem dissipated in WACCM-X resulting in different spatial and temporal structures in the O/N_2 and TEC of the WACCM-X driven GITM. Also, because of larger difference between MSIS and WACCM-X O densities at 100 km during solstices, larger differences are seen in the ionospheric TEC during solstices as compared to equinoxes. We also perform a GITM simulation with MSIS lower boundary and introduce a latitudinal variation in K_{zz} to understand its effects in the thermosphere. We find that the variation of zonal mean densities, temperature and vertical velocity are in accordance to the governing equations of continuity and energy.

INTRODUCTION

- The source of Annual Oscillation (AO) and Semi-Annual Oscillation (SAO) observed in different thermospheric parameters is unknown and it is believed that the disturbances from the lower atmosphere such as tides, gravity waves might be responsible for it.
- The first principles thermospheric models and observations do not match well with regards to SAO. Two possible reasons for this disagreement might be - inaccurate lower boundary conditions and incomplete description of eddy diffusion coefficient (K_{zz}).
- Different thermospheric models use different conditions for the lower boundary, which result in different results. Hence, it becomes important to determine the correct lower boundary conditions.
- Traditionally Mass Spectrometer Incoherent Scatter (MSIS), which is an empirical model of mesosphere and thermosphere has been used as the lower boundary for GITM. In this study, we change the lower boundary of GITM to Whole Atmosphere Community Climate Model, WACCM-X.
- Eddy diffusion (K_{zz}) is used to parametrize the turbulent mixing at the turbopause. It is a parametrization for unresolved processes and subgrid-scale motion such as gravity wave breaking [*Lindzen,* 1981]. It is often said that the seasonal variations in gravity wave breaking in Mesosphere and Lower Thermosphere (MLT) region causes seasonal variation in K_{zz} which might be responsible for driving the global-mean AO and SAO in the IT region. Qian [2009] introduced a seasonal variation in K_{zz} in TIEGCM to generate SAO in the model.
- In our previous study, we found that GITM already has an SAO in its thermospheric parameters because of MSIS lower boundary conditions, however, there are still some discrepancies from the observations, which are seasonal in nature. Introducing K_{zz} did not help this situation and was in fact found to be insufficient condition to correct these differences.
- In order to further understand the effect of K_{zz} in the thermosphere, we introduce a latitudinal variation in K_{zz}. Any change in eddy diffusion at the turbopause causes change in the mixing and temperature in the MLT region, which then propagates up to higher altitudes via molecular diffusion.

Open Questions:

- How does the thermosphere respond to different lower boundary conditions ? Is there any 'one' correct lower boundary dataset that we can use ?
- How are the thermospheric properties affected by the changes in eddy diffusion? How does K_{zz} vary spatially (latitudinally and vertically) and temporally?

METHODOLOGY

- GITM is a three-dimensional spherical code that models the Earth's thermosphere and ionosphere system using a stretched grid in latitude and altitude.
- The daily averaged concentrations from WACCM-X are converted into hourly values. The hourly concentrations for O, O_2, N, N_2, NO, rho, and U, V, T from WACCM-X then replace the current MSIS model in GITM at the lower boundary.
- Runs : Runs (of 3-4 days) during solstices and equinoxes for each lower boundary, with constant K_{zz}, and during geomagnetically quiet times.
- GITM Model Resolution : $2^o \times 4^o$, WACCM-X model resolution : $1.9^o \times 2.5^o$
- We also introduce two different latitudinal profiles in the eddy diffusion of GITM and observe the changes in the thermospheric properties. The first latitudinal profile is :
  - Lat_1 Profile : K_{zz} = 300 for $-30^o<Lat<30^o$, 1000 everywhere else. Units : m^2/s
  - Lat_2 Profile : K_{zz} =1000 for $-30^o<Lat<30^o$, 300 everywhere else. Units : m^2/s

Lower Boundary Conditions

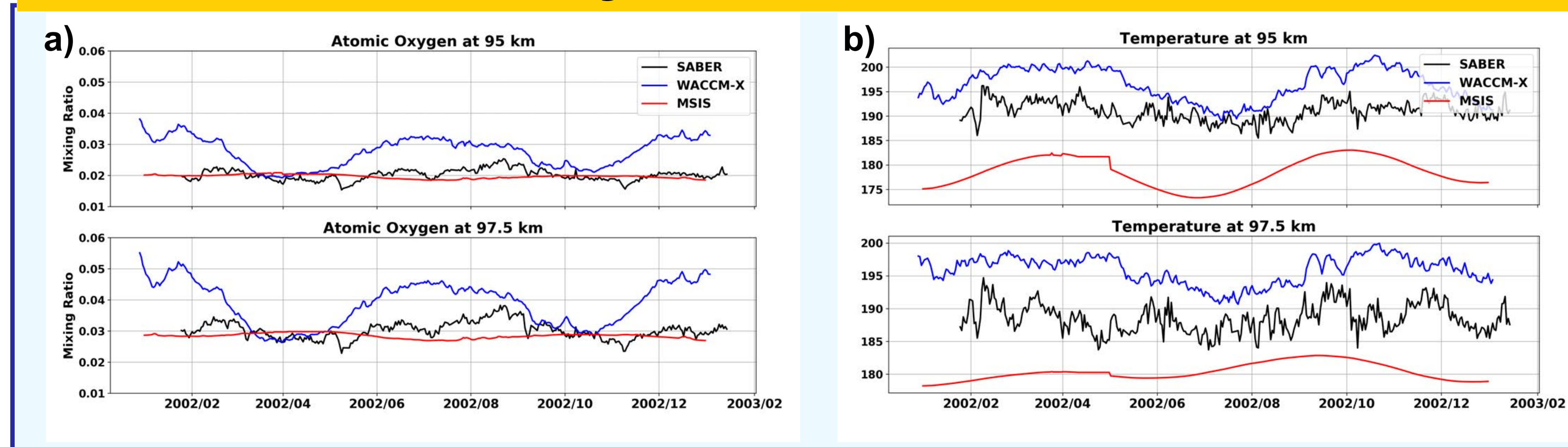

Figure 1 : The daily mean atomic oxygen mixing ratios (a) and temperatures (b) for SABER, WACCM-X. The upper panels are the mixing ratios and temperatures linearly interpolated at 95 km, while the lower panels are at 97.5 km. For MSIS, the mixing ratios are derived at the midnight of that day, and are not daily means.

MSIS vs WACCM-X driven GITM

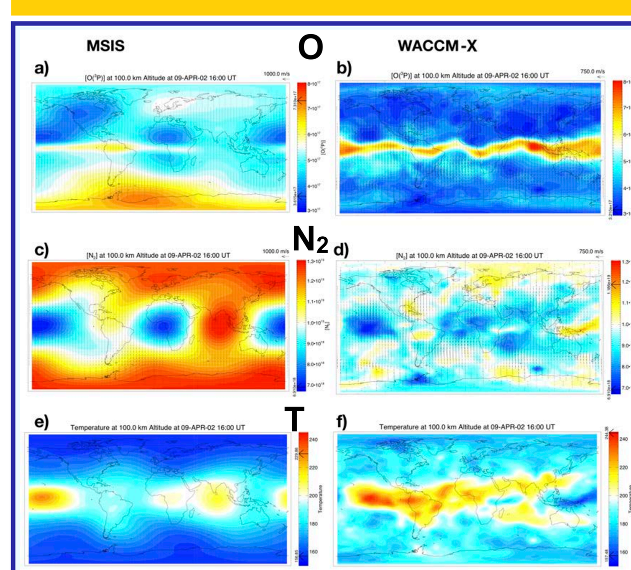

Figure 2 : GITM Lower boundary conditions at 100 km, MSIS vs WACCM-X, for April 9, 2002, 16:00 UT.

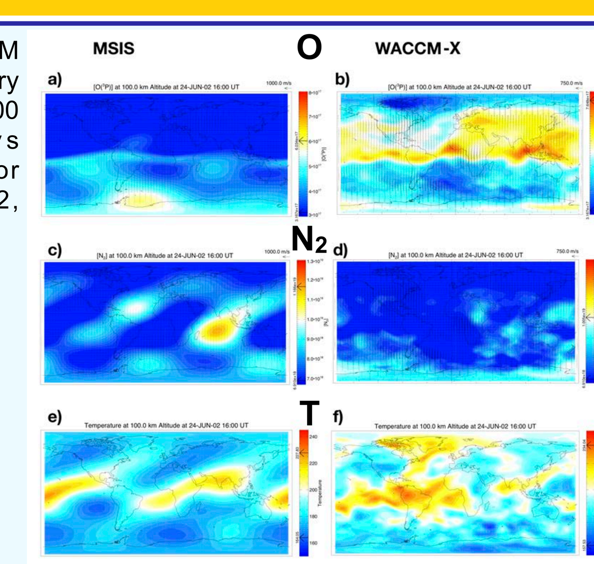

Figure 3 : GITM Lower boundary conditions at 100 km, MSIS vs WACCM-X, for June 24, 2002, 16:00 UT.

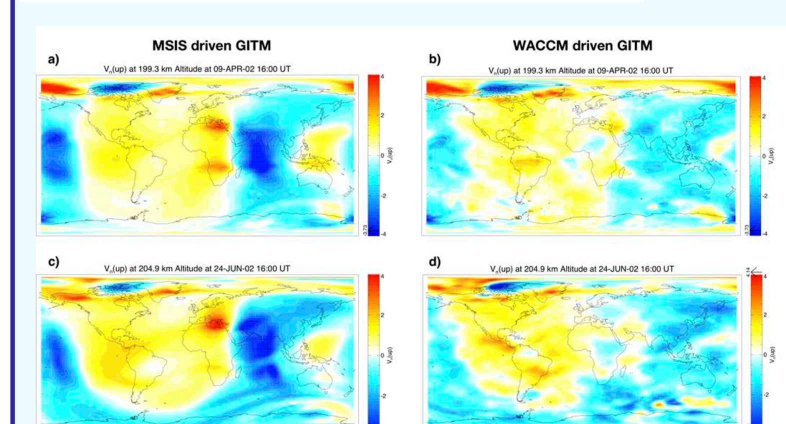

Figure 4: Vertical velocities for GITM simulations with different lower boundary conditions. Panels (a) and (b) are the vertical velocities for April, 9, 2002, for MSIS driven GITM and WACCM-X driven GITM, respectively. Panels (c) and (d) are the vertical velocities for June, 24, 2002, for MSIS driven GITM and WACCM-X driven GITM, respectively.

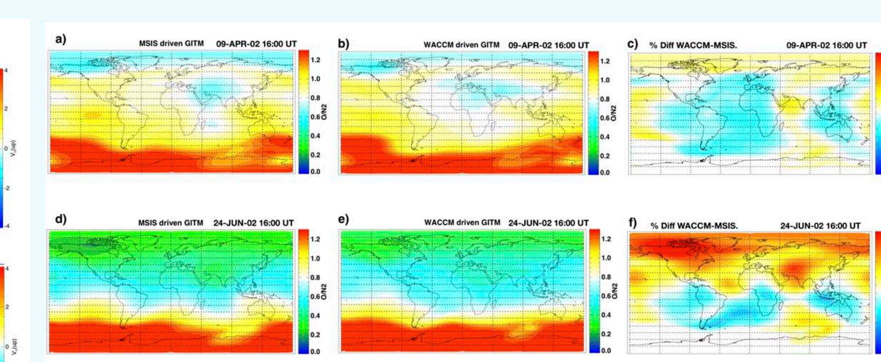

Figure 5 : Comparison of O/N2 for MSIS vs WACCM-X driven GITM simulations. Panels (a) and (b) show the O/N_2 for April, 9, 2002 for MSIS and WACCM-X driven GITM runs, respectively. Panel (c) is the percentage difference of WACCM-X driven GITM O/N_2 and MSIS driven GITM O/N_2. Panels (d), (e) and (f) are similar but for June, 24, 2002.

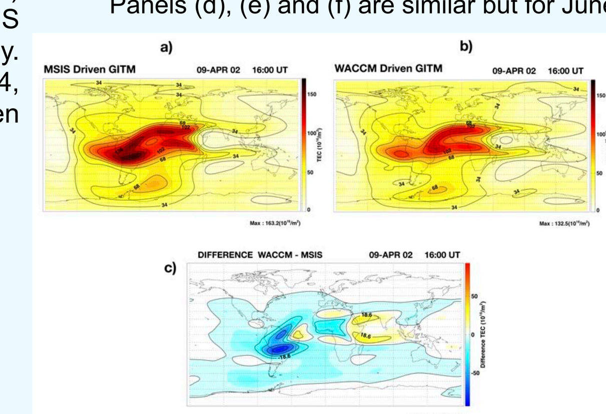

Figure 6 : Total Electron Content in TECU for GITM Simulations for April 9, 2002, 16:00 UT. Panel (a) and (b) are for the MSIS and WACCM-X driven GITM runs respectively. Panel (c) shows the difference between panels (a) and (b), WACCM-X - MSIS driven GITM.

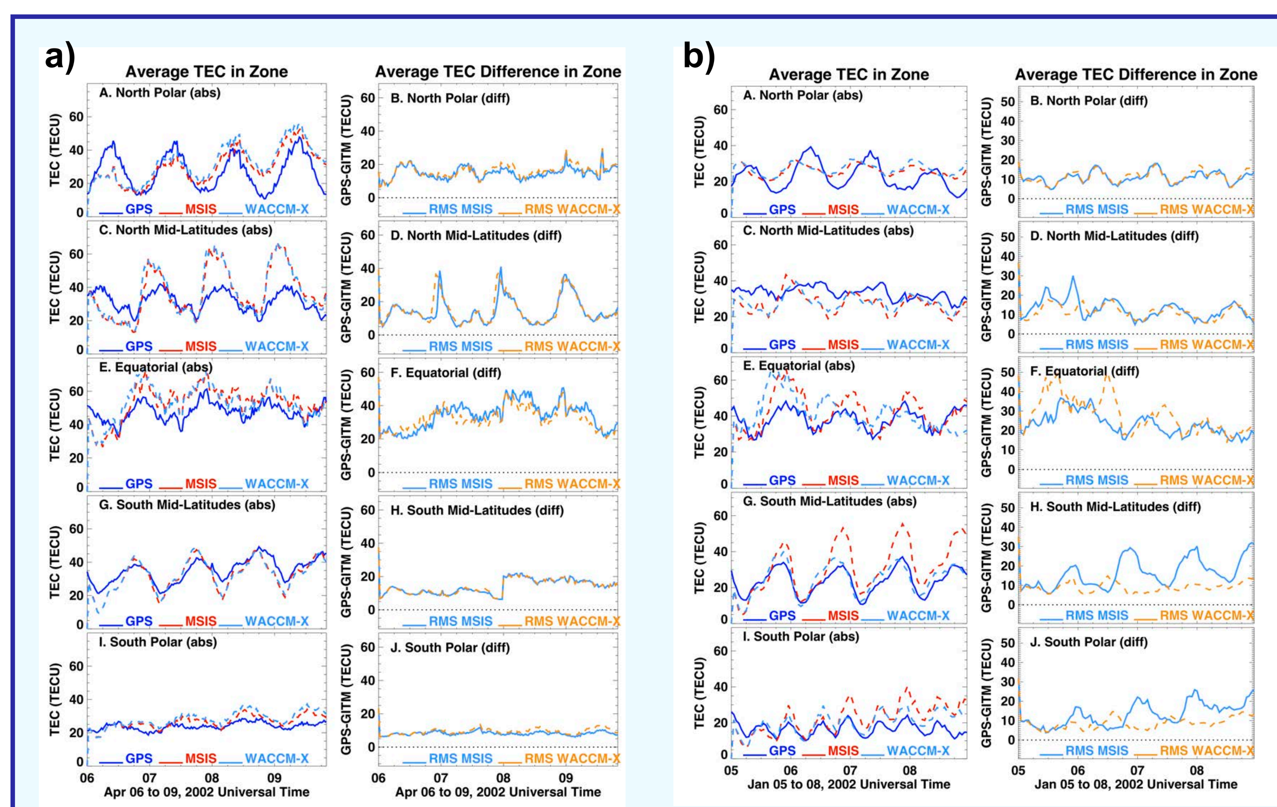

Figure 7: Comparison of TEC b/w MSIS driven GITM, WACCM-X driven GITM and GPS. The horizontal panels represent different latitudinal bands of width 30°. For the vertical panels, the left panels represent the data and the right panels represent the RMS b/w model TEC and GPS TEC a) For Apr 06-09 2002. b) For Jan 05-08, 2002

Effect of Latitudinal profile in K_{zz}

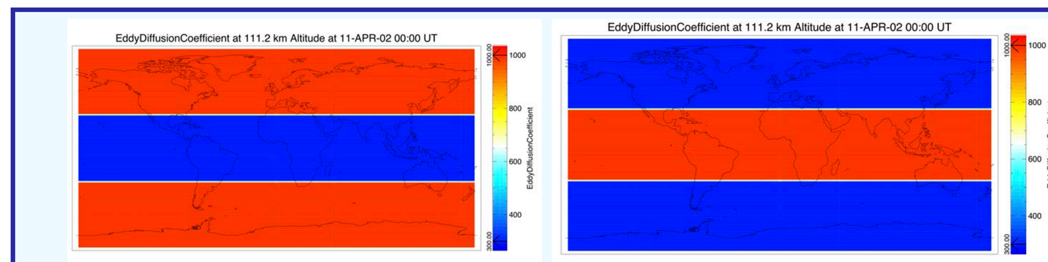

Figure 8 : K_{zz} Latitudinal profiles
a) Lat_1: K_{zz} = 300 for $-30^o<Lat<30^o$, 1000 elsewhere
b) Lat_2: K_{zz} = 1000 for $-30^o<Lat<30^o$, 1000 elsewhere. Units = m^2/s

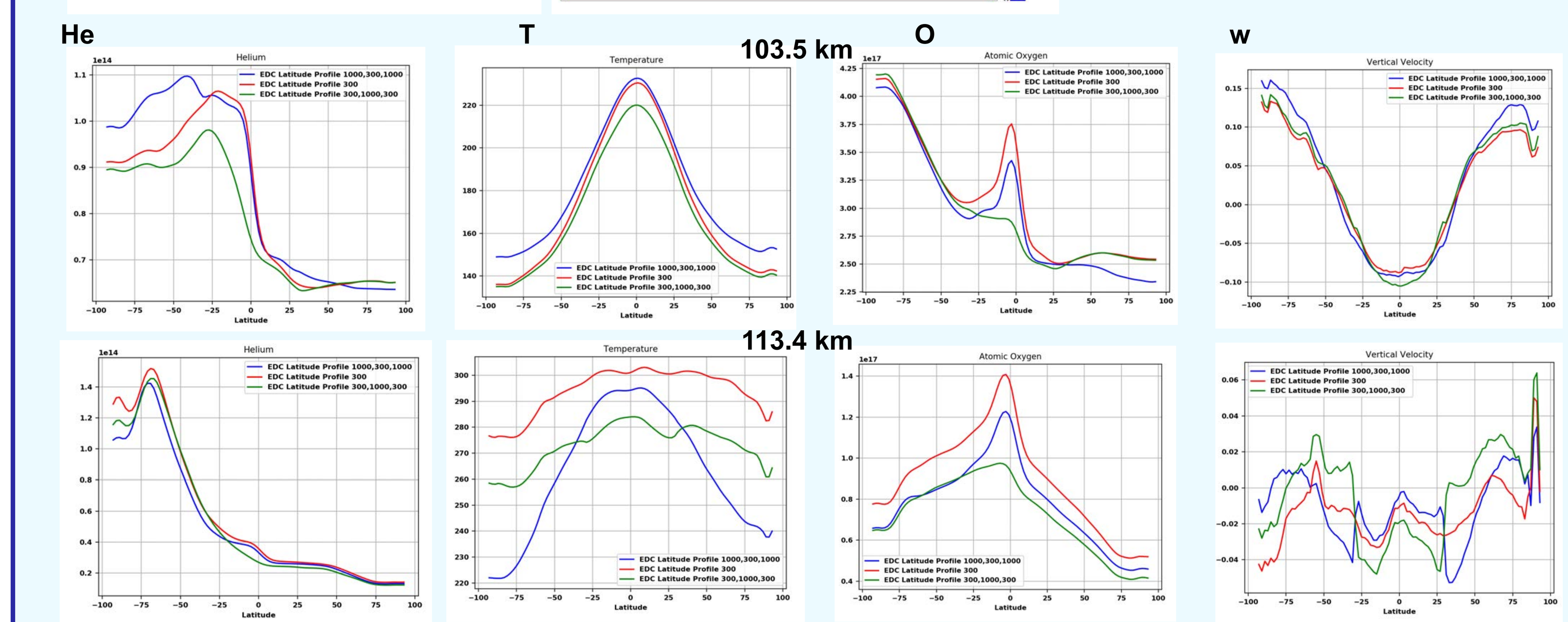

Figure 9: GITM run with MSIS lower boundary condition but different latitudinal profiles of K_{zz}. The upper panel represents the zonal mean parameters at 103.5 km and the lower panel at 113.4 km. These runs are for Apr 11, 2002, 00:00 UT.

DISCUSSION AND FUTURE WORK

- MSIS and WACCM-X atomic oxygen at 95 and 97.5 km are different in magnitude and seasonal variation. MSIS atomic oxygen peaks during equinoxes while WACCM-X densities peak during solstices. For both O and T, SABER and WACCM-X match better with each other. Maybe this has to do with our data processing technique- the MSIS densities are not daily means but midnight values for each day. This needs to be further investigated.
- WACCM-X has smaller magnitude of tides as compared to MSIS at 100 km. This causes differences in integrated thermospheric and ionospheric parameters, such as O/N_2 and TEC, and vertical velocity of MSIS and WACCM-X driven runs.
- During equinoxes, the TEC of the two runs match well. But, the difference between the two runs peaks during solstices and at lower latitudes, which might be related to Figure 1a) where in the difference between MSIS and WACCM-X O densities at 100 km was the highest during solstices. It is hard to say which lower boundary condition is better for all times, and this needs to be further investigated by longer runs.
- One surprising result, is that higher WACCM-X atomic oxygen at 100 km during solstices, does not translate into higher TEC in the GITM run. In fact, during Jan, 2002, TEC is higher for MSIS driven run than the WACCM-X driven run.
- By introducing a latitudinal profile in the K_{zz}, we wish to understand its effect on different thermospheric properties. We compare two different altitudes and observe opposite effects of mixing.
- At 103.5 km, a higher K_{zz} leads to increase in Helium, higher temperature, and greater magnitude of vertical velocities, which means higher mixing. At 113.5 km, the effect in Helium and Temperature are opposite. Mostly, any discrepancies can be resolved by looking at meridional fluxes. This is an evidence that while estimating K_{zz}, horizontal winds should also be taken into account, and a 1D model is not sufficient.

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