Understanding the Effects of Lower Thermospheric Atomic Oxygen on Upper Ionosphere-Thermosphere system

- Using GITM driven at the lower boundary with MSIS and WACCM-X

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UNIVERSITY OF MICHIGAN

Garima Malhotra[1], Aaron Ridley[1], Daniel R. Marsh[2], Chen Wu[3], Larry Paxton[4]

[1]Climate and Space Sciences and Engineering Department, University of Michigan, USA
[2]National Center for Atmospheric Research, USA
[3]Wuhan University, China
[4]Applied Physics Laboratory, USA

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 may be responsible for these spatial and temporal variations in the IT region, but their exact nature is unknown. One of the parameters that is important at the lower boundary of thermosphere is Atomic Oxygen. In recent years, it has been observed that the distribution of atomic oxygen reverses between the two hemispheres at the upper mesospheric heights from higher in the winter hemisphere at around 80 km to higher in summer hemisphere at around 95 km. In this study, we investigate the sensitivity of the thermospheric parameters such as O/N_2 to these different atomic oxygen distributions using Global Ionosphere Thermosphere Model (GITM). We use Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension (WACCM-X) to drive the lower atmospheric boundary in GITM at ~97 km, and compare the results with the current Mass Spectrometer Incoherent Scatter (MSIS) driven version of GITM. These two boundary conditions are different because MSIS has higher atomic oxygen in the winter hemisphere while WACCM-X has higher atomic oxygen in the summer hemisphere consistent with SABER data. The reversal of atomic oxygen affects the pressure distribution between 100-120 km which changes the wind magnitudes, temperatures, scale heights and O/N_2 composition in the upper thermosphere. It also modifies the interhemispheric summer to winter circulation. All these differences between the two simulations in the lower thermosphere map to higher altitudes due to diffusive equilibrium. Thus, the lower boundary plays a significant role in the IT system and should be defined using a model which is closer to observations.

INTRODUCTION

- GITM is a three-dimensional spherical code that models the Earth's thermosphere and ionosphere system using a stretched grid in latitude and altitude and does not assume hydrostatic solution.
- Traditionally, Mass Spectrometer Incoherent Scatter (MSIS), which is an empirical model of thermosphere has been used as the lower boundary for GITM (~97 km). It has higher atomic oxygen in winter hemisphere b/w 95-100 km because it extrapolates from the upper thermospheric interhemispheric circulation (based on diffusive equilibrium).
- In this study, we change the lower boundary of GITM to Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension (WACCM-X) which has higher atomic oxygen in the summer hemisphere b/w 95-100 km. WACCM-X is a comprehensive numerical model, spanning the range of altitude from the Earth's surface to the thermosphere.
- *Smith et al. (2010)* observed the same using SABER data at 94 km. According to them, the high summer atomic oxygen values could be an indication that the normal upwelling circulation seen in the summer mesosphere has reversed and there is a downwelling circulation cell. Another possible cause is molecular diffusion, which would be enhanced with the high temperatures. Molecular diffusion mixes air with higher *O* down from the thermosphere and may contribute to the seasonal pattern.
- *Qian et al. (2018)* observed the same increase in summer mesopause atomic hydrogen density using WACCM-X and SABER. *Qian et al. (2017)* discussed about lower thermospheric residual winter to summer circulation (b/w 97 km to 107 km) to be responsible for high vertical gradient in summer CO_2.

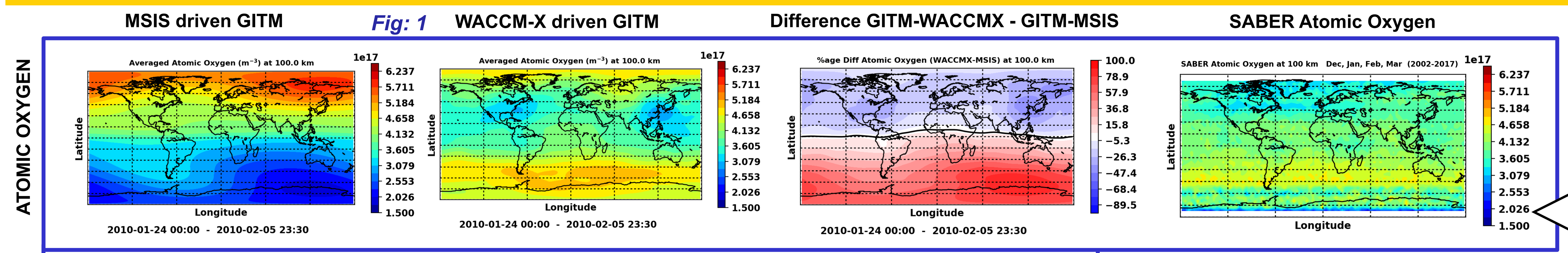
Open Questions:

- How does the lower and upper thermosphere respond to different different atomic oxygen distribution between 95-100 km ?
- Why does atomic oxygen distribution reverse between upper mesospheric and lower thermospheric heights ?

METHODOLOGY

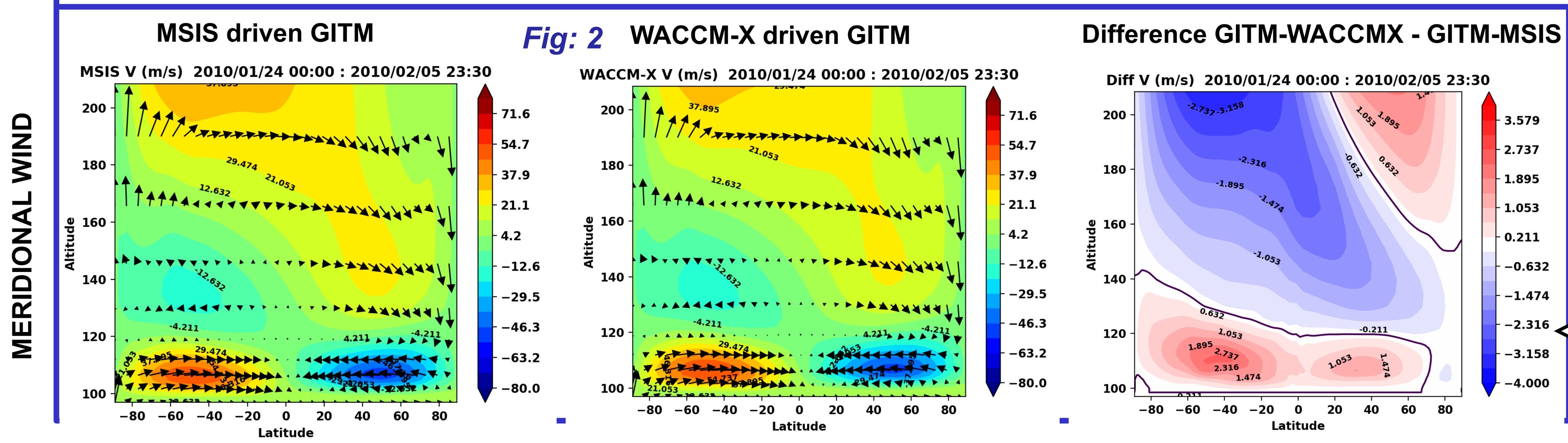
- The hourly concentrations for O from WACCM-X at 95 km, 97.5 km, 100 km are used to replace the lower boundary of GITM.
- O_2, N_2, NO, T, U, V are given a constant value at the lower boundary.
- Runs : Simulations of 20 days during Jan with MSIS and WACCM-X (hereon referred to as GITM-MSIS and GITM-WACCM).
- GITM Model Resolution : 2° x 4°, WACCM-X model resolution : 1.9° x 2.5°,
- It takes around 10 days for the model to get stable. We plot the results only for the last 10 days of each simulation.

RESULTS AND DISCUSSION



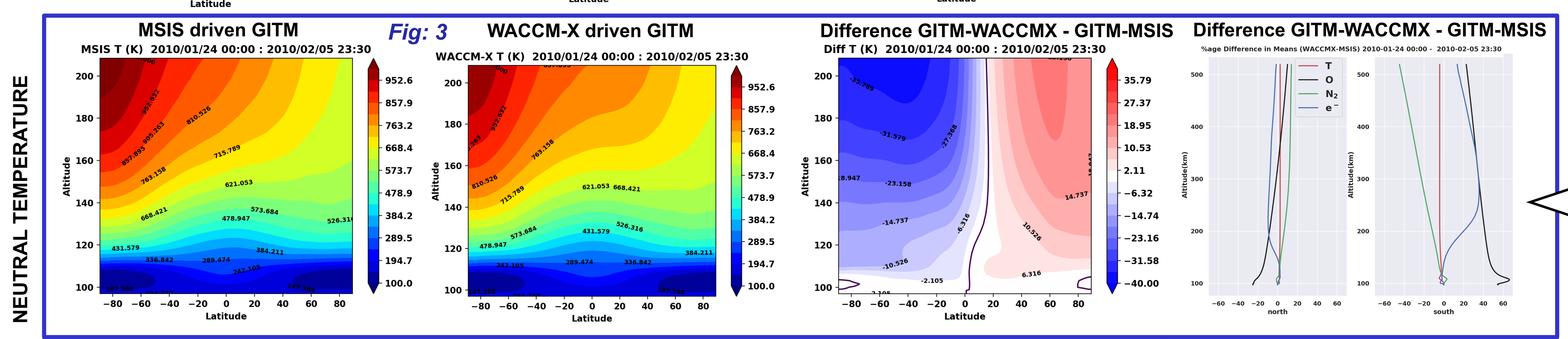
LOWER BOUNDARY ATOMIC OXYGEN

- GITM-WACCMX has larger O in summer hemisphere than in winter hemisphere which matches better with SABER observations.



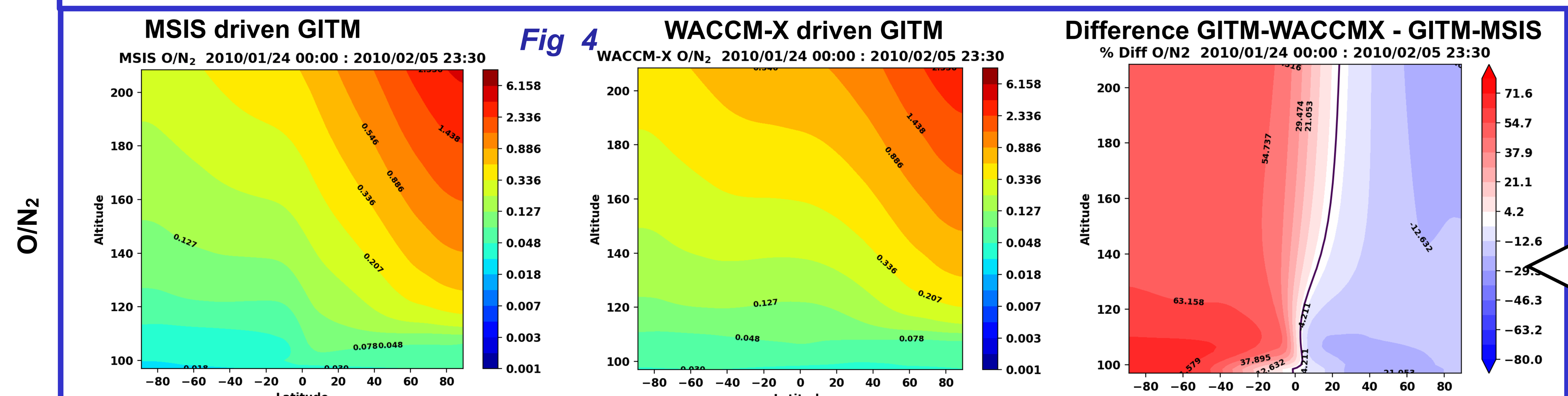
EFFECT ON WINDS IN 100-130 KM

- Zonal Mean winds in both the simulations are equatorward.
- Higher O densities in a hemisphere lead to larger equatorward winds due to pressure gradients.
- In the summer hemisphere, GITM-WACCM has larger equatorward winds.
- In the winter hemisphere, GITM-MSIS has larger equatorward winds.



EFFECT ON TEMPERATURE in 100-130 km

- Equatorward winds leads to divergence and cooling in the polar regions.
- In the summer hemisphere, larger equatorward winds In GITM-WACCM and hence more divergence lead to lower temperatures.
- Similarly, In the winter hemisphere, GITM-MSIS has lower temperatures.
- The temperature differences between two simulations lead to corresponding effect on scale heights in the two hemispheres, and hence affects species' densities such as N_2.

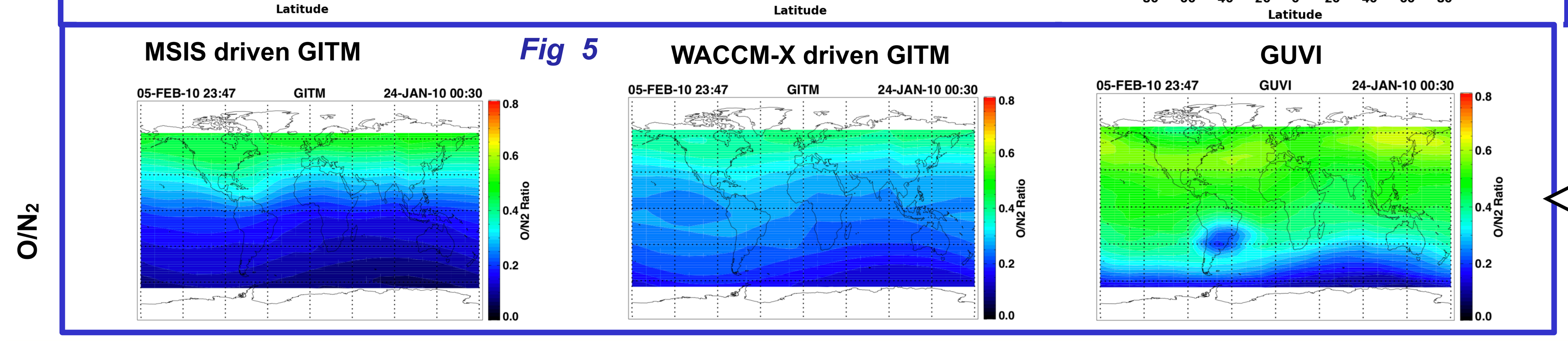


EFFECT ON O/N_2

- Apart from the diffusive equilibrium, the effect of temperature on scale height of N_2 leads to larger difference in O/N_2 between the two simulations.

EFFECT ON INTERHEMISPHERIC SUMMER-WINTER WINDS (ABOVE 150 KM) - using Fig 2

- The equatorward winds in the 100-130 km lead to larger O/N_2 in the equatorial region in GITM-WACCM which also leads to larger electron density.
- Larger equatorial O/N_2 in GITM-WACCM runs changes the summer to winter winds in the upper thermosphere by modifying the summer to winter pressure gradients.
- For GITM-WACCM runs, the winds slow down in the summer hemisphere while they speed up in the winter hemisphere as compared to GITM-MSIS runs.



COMPARISON WITH GUVI

- In the summer hemisphere, GITM-WACCM-X O/N_2 matches better with the GUVI data.
- In the winter hemisphere, GITM-MSIS O/N_2 matches better with GUVI data.

CONCLUSIONS AND FUTURE WORK

- In the lower thermosphere between 95 - 100 km, MSIS has higher atomic oxygen in the winter hemisphere, while WACCM-X has higher atomic oxygen in summer hemisphere which is consistent with SABER observations. We use GITM to investigate the effect of these two lower boundary conditions. (Fig 1)
- We find that the hemisphere with larger atomic oxygen density has larger equatorward winds between 100-130 km which leads to divergence and cooling in that hemisphere, which changes the scale height of the thermosphere. (Fig 2 and 3)
- We also observe that using GITM-WACCMX increases O/N_2 in the equatorial region and slows the upper thermospheric interhemispheric winds in the summer hemisphere and speeds them up in the winter hemisphere which further affects the density distribution. All the results here hold true for June solstice as well. (Fig 4)
- We also find that in the summer hemisphere, the GITM-WACCMX matches better with the GUVI observations, while in the winter hemisphere, GITM-MSIS is better. (Fig 5)
- Future work - We plan to compare the results during equinox conditions and during different solar activity periods.

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garimam@umich.edu