



COSMIC Observations and TIEGCM Simulations of Eddy Diffusion and Tidal Effects on the Semi-annual Oscillation in the Ionosphere



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Introduction

A study by Qian *et al.* [2009] (Q09) showed that the eddy diffusion may have a strong impact on the thermospheric density seasonal variations. In order to make the NCAR TIEGCM model produce similar amplitudes of the annual/semiannual (AO/SAO) variations in the thermosphere, Q09 imposed a seasonal varying K_{zz} coefficient at the TIEGCM lower boundary and were able to reproduce similar amplitudes of AO/SAO. Qian *et al.* [2013] examined the eddy diffusion effect on the AO/SAO variation of the ionosphere. Eddy diffusion changes the thermospheric density and composition, which in turn affects the ionosphere.

The imposition of the AO/SAO in the K_{zz} brings the simulation results from TIEGCM closer to the thermospheric density observations as shown by Q09. However, as Qian *et al.* [2013] pointed out, this is an ad-hoc measure to simulate the gravity wave effect on the thermosphere and ionosphere. Qian *et al.* [2013] also showed some discrepancies in the F2 peak electron densities between the model and observations. Siskind *et al.* [2014] (S14) used NOGAPS output as the lower boundary to drive the TIEGCM and experimented with the different K_{zz} and tidal configurations for the TIEGCM. When S14 used a standard constant K_{zz} for TIEGCM, they obtained small SAO in the ionosphere. They then reduced the constant K_{zz} by a factor of 5, and obtained larger SAO in the ionosphere, which is comparable to the standard GSWM run of TIEGCM with a standard constant K_{zz} . Salinas *et al.* [2016] used K_{zz} based on SABER CO₂ observation ($K_{zz,C}$) to drive the TIEGCM, the $K_{zz,C}$ is smaller than that from Q09 with a smaller SAO. Their TIEGCM simulation with $K_{zz,C}$ produced smaller SAO in the ionosphere compared to the observation and Q09. The electron density, on the other hand, is larger than that based on Q09 parameters. Recently, Jones *et al.* [2017] (J17) using the NCAR TIEGCM were able to obtain similar amplitudes of the SAO in the thermosphere with K_{zz} similar to the $K_{zz,C}$ and without adding SAO to the K_{zz} . It is apparent that there are still many unresolved issues associated with the K_{zz} effect on the SAO of the thermosphere and ionosphere.

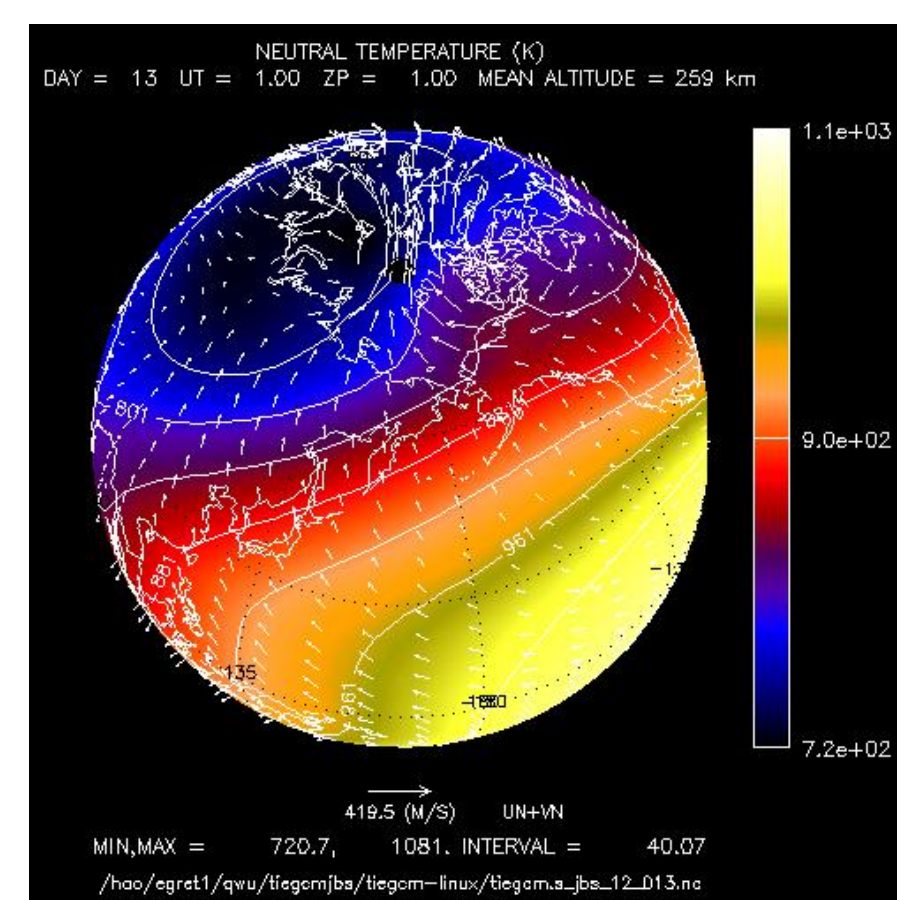
To further examine the K_{zz} effect on the ionosphere, we use the NCAR TIEGCM model simulations with SAO varying eddy diffusion and that with a constant eddy diffusion for a comparison with COSMIC observations. We will focus on SAOs of mean electron density, diurnal and semidiurnal variations.

COSMIC (Constellation Observing System for Meteorology, Ionosphere, and Climate) Observations

COSMIC is a six-satellite constellation for GPS radio occultation (RO) of both lower atmosphere and ionosphere [Anthes, 2011; Anthes *et al.*, 2008]. The GPS RO data were inverted to obtain ionospheric electron density profiles using Abel inversion [Schreiner *et al.*, 1999; 2007]. The COSMIC data have been used widely in ionosphere research and compared with ground-based ionosonde data by Lei *et al.* [2007], who mostly showed consistent results. The six COSMIC satellites were launched into the same orbit and gradually separated in local time. We selected the year of 2008 for analysis because the COSMIC satellites had been separated in local time by then. That allows a short time for COSMIC to cover all local times. Another reason for selecting 2008 is the low solar activity when the lower atmospheric effect to the ionosphere is more prominent.

NCAR Thermosphere Ionosphere Electrodynamics General Circulation Model (TIEGCM)

- TIEGCM is a comprehensive, first-principles, three-dimensional, non-linear representation of the coupled thermosphere and ionosphere system that includes a self-consistent solution of the middle and low-latitude dynamo field.
- The model solves the three-dimensional momentum, energy and continuity equations for neutral and ion species at each time step, using a semi-implicit, fourth-order, centered finite difference scheme on each pressure surface in a staggered vertical grid. The time step is typically 120 s.
- The standard low-resolution grid parameters are: Spherical geographic coordinates Latitude: -87.5° to 87.5° in 5° increments Longitude: -180° to 180° in 5° increments
- Altitude: Pressure levels from -7 to +7 in increments of 1/2. Lower boundary: ~97 km Upper boundary: ~500 to ~700 km depending on solar activity



Data Processing

COSMIC electron density profile data were binned into magnetic latitude (5°) and altitude (1 km) bins. A 20-day sliding window was used to select data from each bin. Then the electron density data were analyzed with 2D Lomb Scargle in longitude and universal time to extract tidal signals of different frequencies and zonal wavenumbers. In this study, DW1, SW2, and zonally averaged values are used. The same method was used by Wu *et al.* [2008; 2009].

Both the TIEGCM results are processed with this method. The results are binned in magnetic latitude (2.5°) and altitude (a quarter of the scale height). A 5-day sliding window is used for the model because the models have the coverage for all local times at all longitudes (hourly data).

Mean Electron Density Profiles at March Equinox

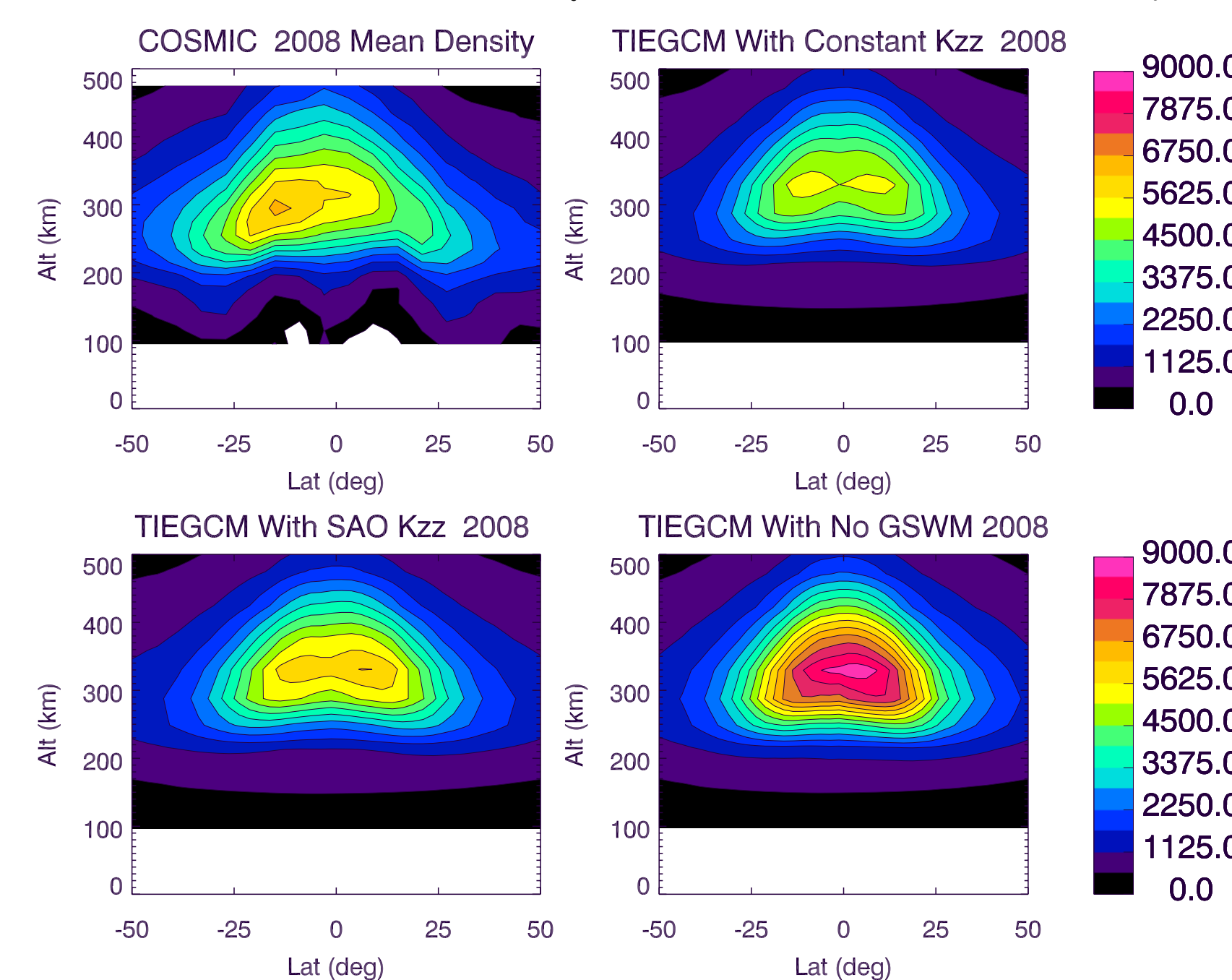


Figure 1. Vertical profiles of the ionospheric density from COSMIC (a), TIEGCM with (b) and without (c) semi-annual oscillation (SAO) K_{zz} , and TIEGCM without GSWM tides with SAO in K_{zz} (d) at the March equinox. The density unit is electrons 10^2 cm^{-3} .

Mean Electron Density at ~ 290 km

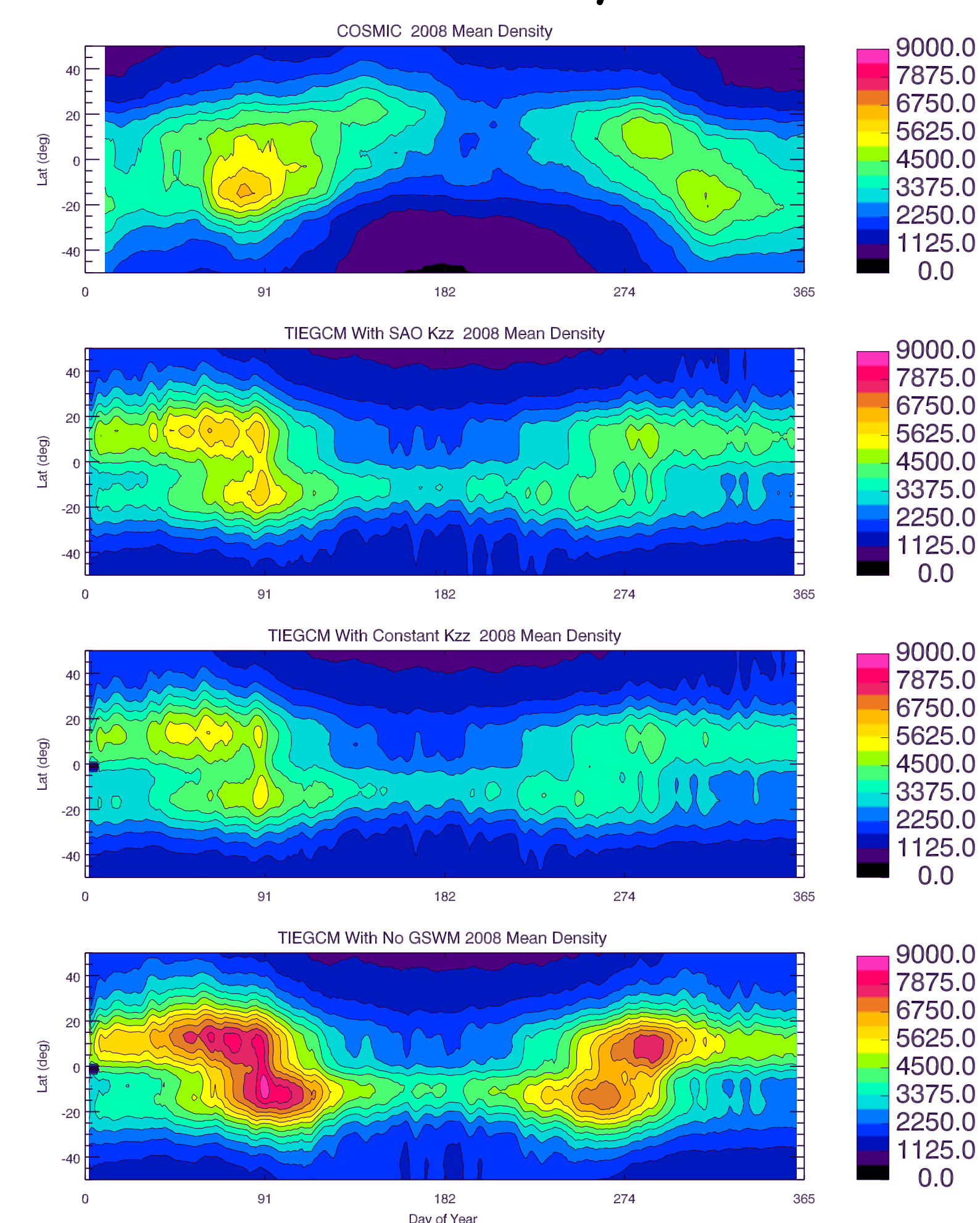


Figure 2. COSMIC observation (a), TIEGCM simulations of mean electron density with (b) and without semi-annual variation (SAO) in the K_{zz} (c), and without GSWM tides (with SAO in K_{zz}) (d) at 1.875 pressure level (~290 km). The density unit is 10^2 cm^{-3} . The values were obtained in different magnetic latitude (5°) and altitude bins (a quarter of scale height) within a 5-day sliding window for the models and a 20-day sliding window for the COSMIC data.

The two TIEGCM simulations with GSWM are very similar to the COSMIC observations. The TIEGCM with the K_{zz} SAO are slightly closer to the COSMIC observation in the southern hemisphere and overestimates the ionospheric density in the northern hemisphere. COSMIC shows slightly stronger amplitudes in the south compared to the north, whereas TIEGCM simulations give slightly larger values in the north compared to the south. The TIEGCM simulation without the GSWM overestimate the electron density compared to the COSMIC observations.

Electron Density DW1 at ~ 290 km

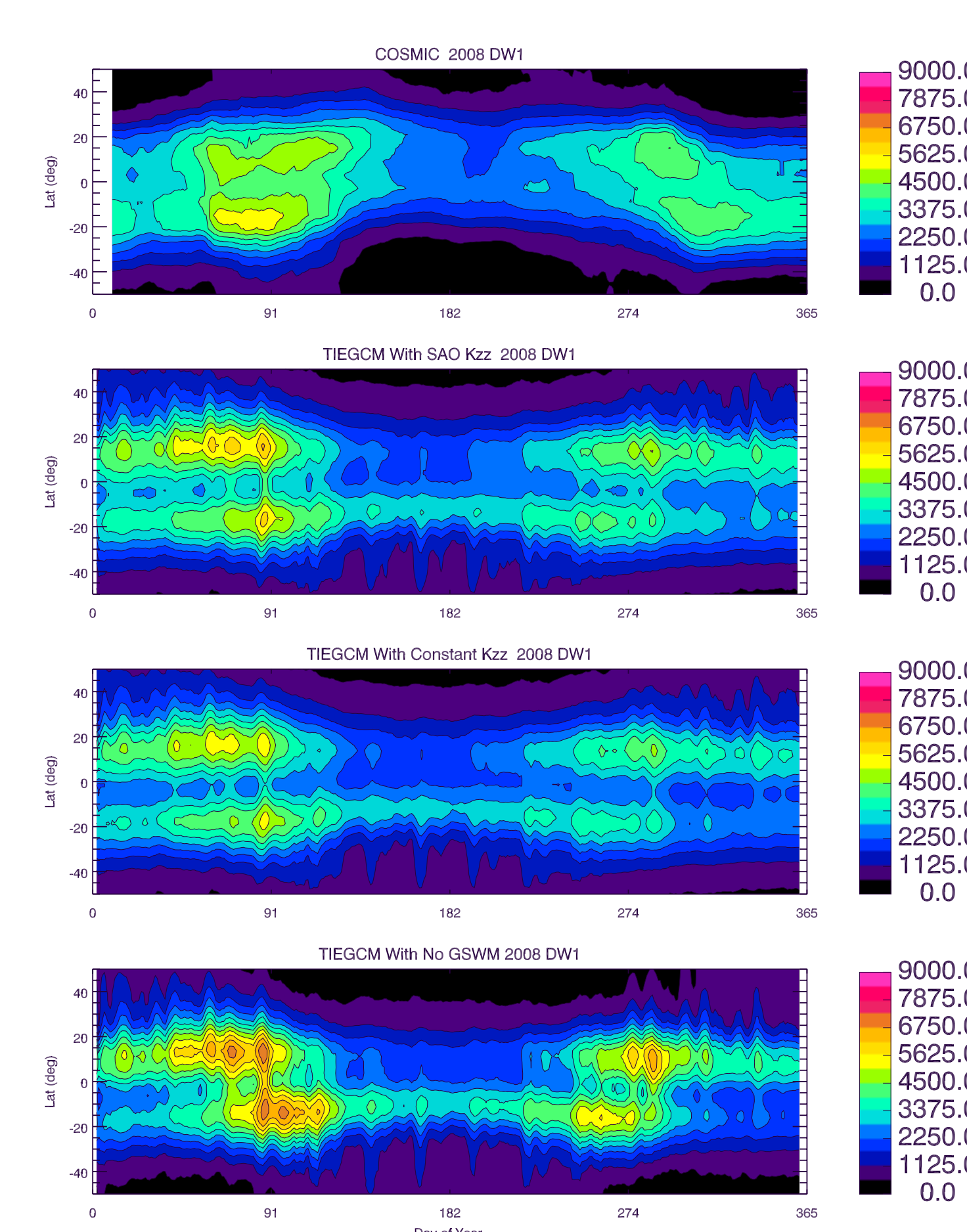


Figure 3. Same as Figure 1, but for the DW1. The COSMIC data shows that the DW1 amplitudes are slightly smaller than the mean electron density. The two TIEGCM simulations with the GSWM tidal input have the DW1 amplitudes about the same size as their respective mean electron densities. The TIEGCM simulation without GSWM input has DW1 amplitude smaller than the mean electron density from the same simulation. The DW1 from the no GSWM simulation is larger than other two TIEGCM simulations with GSWM, but the increase is not comparable to the electron density. That suggests that the electron density enhancement after removing the GSWM tidal input occurs during both day and night.

Electron Density SW2 at ~ 290 km

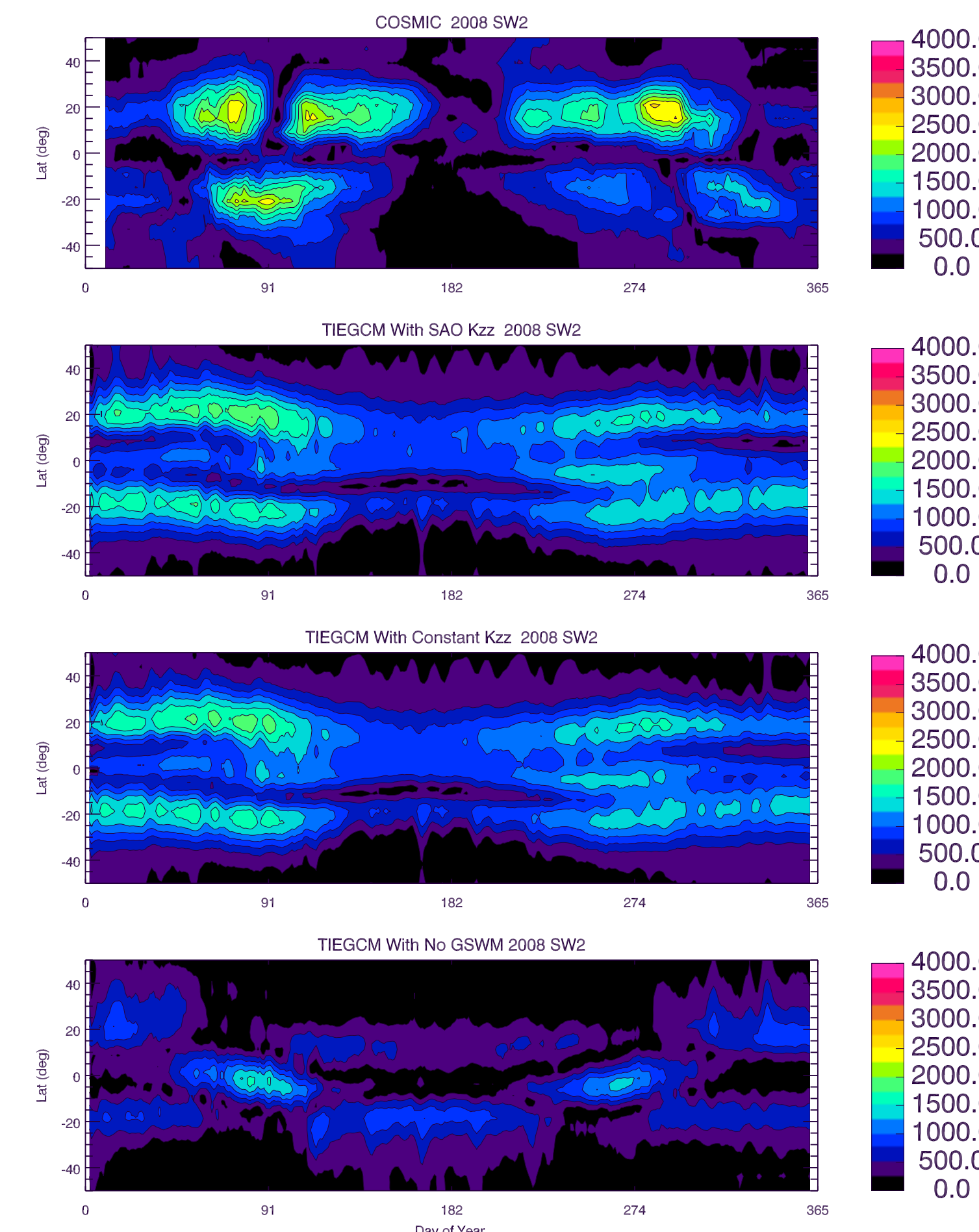


Figure 4. Same as Figure 1, but for the SW2. The SW2 is mostly from lower atmosphere. After turning off the GSWM tides, the SW2 signal mostly went away. The SAO in the K_{zz} did not seem to affect SW2 much.

O/N2 ratio and O density at ~ 290 km

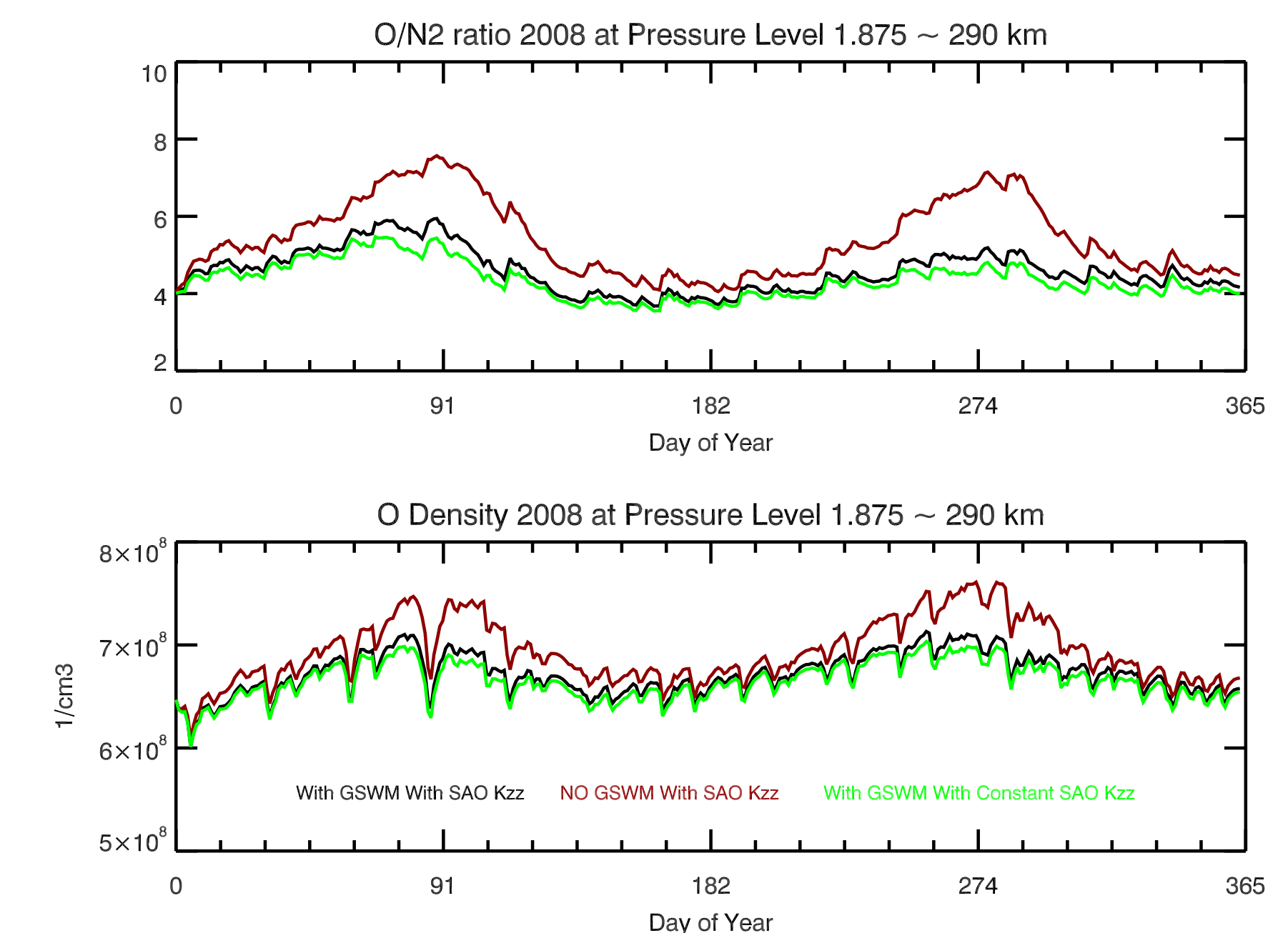


Figure 5. O/N₂ ratio and O density at pressure level 1.875 (~290 km) from TIEGCM simulations with GSWM tide and SAO K_{zz} (black), without GSWM and with SAO K_{zz} (red), without SAO K_{zz} and with GSWM (green).

The data were averaged in the lower latitude region from -30° to 30° latitudes over all longitudes and times. Under similar conditions, the ionospheric density at pressure level 1.875, which is near the F2 peak, should be roughly proportional to the O/N₂ ratio due to the approximate balance between production of O⁺ by photoionization and loss of O⁺ from fast recombination of O⁺ with the N₂ molecules. That is the case for all the TIEGCM simulations. The simulation without GSWM tides has the largest O/N₂ ratio, thus larger ionospheric density. After turning on the GSWM tides, the O/N₂ ratio drops. Switching off the K_{zz} SAO also reduces the O/N₂ ratio.

We also examine the O densities from these simulations (Figure 5b). The O densities were low latitude region averages obtained in the same way as the O/N₂ ratios. The O densities from TIEGCM simulations are similar except in the case of without GSWM, where the O density is higher in accordance with the O/N₂ ratio. So switching off the GSWM tide causes an increase in the O density and O/N₂ ratio. Turning on the K_{zz} SAO also causes an increase in the O density and O/N₂ ratio though to a lesser extent.

Summary

COSMIC satellite GPS radio occultation (RO) observed the semiannual oscillation (SAO) in the ionosphere. NCAR TIEGCM simulations were used to investigate the eddy diffusion and tidal effects on the ionosphere SAO. Imposing SAO to the eddy diffusion coefficient in the TIEGCM increases the ionosphere SAO and has better agreement with COSMIC observations. Mesospheric and lower thermospheric tides can reduce the ionospheric density. Both tidal and the eddy diffusion can affect the ionosphere SAO and need to be considered in the TIEGCM simulation. The diurnal variation DW1 in the electron density increase in the TIEGCM simulation is nearly proportional to the electron density when the GSWM tides are applied. When the GSWM tides were turned off, the DW1 also increased but not as much as the electron density. The simulation from TIEGCM showed the SW2 signal in the ionosphere seems to be unaffected by the K_{zz} SAO. It is mostly from lower atmosphere.

Acknowledgement

This research is supported by NSF grants AGS1522830 and AGS1339918. NASA grants NNX13AF93G, NNX14AD84G, NNX15AK75G. NCAR is supported by the National Science Foundation. We would like to acknowledge high-performance computing support from Yellowstone (ark:/85065/d7wd3xhc) provided by NCAR's computational and information systems laboratory, sponsored by the National Science Foundation. The TIEGCM model can be downloaded at (<http://www.hao.ucar.edu/modeling/tgcm/download.php>). COSMIC data are available from (<http://cdiac-icvww.cosmic.ucar.edu/cdiac/products.html>).

