# Physics-based Simulations to Study the Influences of Day-to-Night Flow in the Thermosphere

Zachary Waldron, University of Colorado, Boulder
Eric Sutton, Jeff Thayer, CCAR, SWx-TREC

## Research Questions

The day-to-night ratio of the thermosphere neutral mass density is an indicator of general circulation

1. What is the sensitivity of the NCAR TIEGCM model to changes in external drivers of the lower boundary conditions?
2. What is the model's fidelity relative to the CHAMP satellite?

## Model description

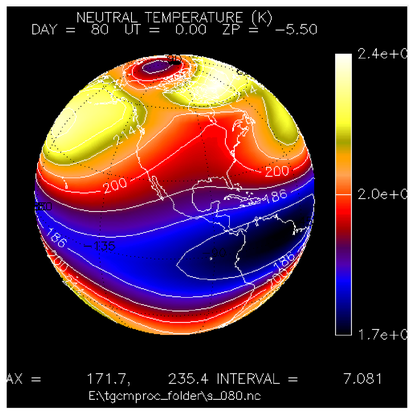



Figure 1: Example output of mass density plotted on a sphere from TIEGCM

# TIEGCM 2.0

Thermosphere
Ionosphere
Electrodynamics
Global
Circulation
Model

**Model properties and parameters** (single resolution)**:**

- Boundaries: ~97 km to ~700 km (depends on solar activity)
- Longitude: -180° to 180°
- Latitude: -87.5° to 87.5°
- Single resolution: 5° separation between longitude and latitude
- Vertical pressure level measured on log scale from -7 to 7.

**Model Output:**

Output fields are specified in 3 spatial dimensions plus time:

- Geopotential: Height of pressure surfaces (cm)
- Temperature Neutral, ion, electron (K)
- Neutral Wind zonal, meridional, vertical (m/s)
- Composition: $\rho$, O, O2, NO, N(4S), N(2D), O+, O2+, N2+, NO+, N+, Ne, He
- Potential: In geomagnetic and geographic coordinates

## Objectives

**Investigate factors controlling the diurnal structure of the thermosphere:**

- What is causing possible discrepancies between CHAMP and TIEGCM?
- We start here with looking at the lower boundary forcing.

**Effect of Tides on forcing the lower boundary:**

- **Migrating tides-** sun synchronous tides that follow the apparent motion of the sun
- **Non-migrating tides-** also have periods of 24 hours, but do not follow the apparent motion of the sun

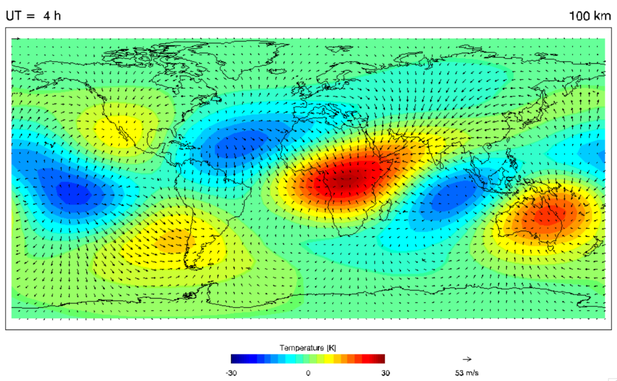



Figure 2: Example visualization of the impact of the migrating and non-migrating tides on the atmosphere (Creative Commons)

## Sampling TIEGCM with CHAMP

**Two different TIEGCM model runs:**

- 2002-2005 with migrating and non-migrating tides turned off
- 2002-2005 with **migrating tides on** and non-migrating tides turned off

**CHAMP**: CHAllenging Mini-satellite Payload

- orbit is nearly polar
- low-eccentricity
- 90 minute orbital period

We use the ephemeris from CHAMP to sample TIEGCM output for all times and positions of its orbit from 2002 through 2005.

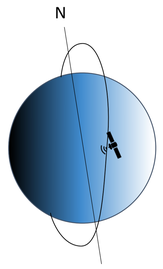



Figure 3: Example of near-polar circular orbit

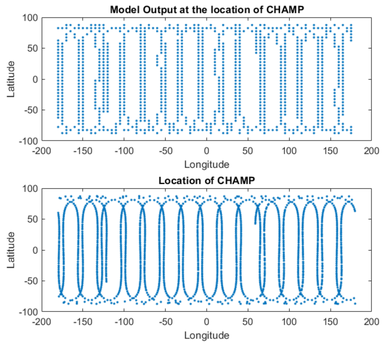



Figure 4: Model being sampled in longitude and latitude by the CHAMP satellite

**Calculate the day-to-night mass density ratio**

**Analysis procedure:**

- Day is from 10:30am to 4:30pm
- Night is from 10:30pm to 4:30am
- Only consider latitudes between -30° and 30°
- Only consider Kp values < 3
- Density values are interpolated to satellite altitude and normalized to 400 km.

## Results

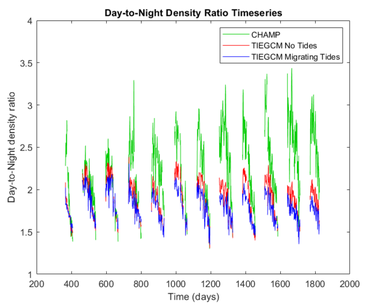



Figure 5: Timeseries of the day-to-night Density Ratio of the three datasets

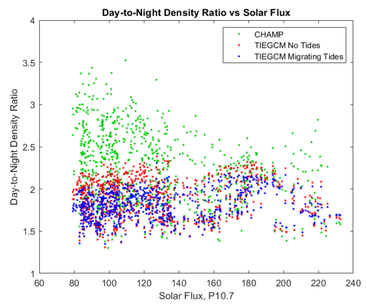



Figure 6: Day-to-night Density Ratio vs. Solar Flux

The above plots show that in either case of having the migrating tide on or off, the model consistently shows lower day-to-night density ratio than the CHAMP satellite. The model timeseries above (blue and red) show relatively consistent characteristics in the peaks. The local time of the satellite decreases slowly but continuously, with peaks generally occurring in the afternoon local time.

| Day-Night Ratio Statistics | CHAMP | Migrating Tides Only | No Tides |
|---|---|---|---|
| Mean day-night ratio | 2.2650 | 1.8069 | 1.8909 |
| Standard Deviation | 0.4212 | 0.1707 | 0.2279 |

| Data being compared | Percent differences |
|---|---|
| CHAMP and Migrating Tides | 14.45 % |
| CHAMP and No Tides | 11.65 % |
| Migrating tides and No Tides | 3.05 % |

## Changes in Structure through Altitude and Time

We investigated the equinoxes and solstices to better visualize the structure of the mass density as outputted by the model throughout the 2002 through 2005 time period. The QR code provides a link to animations showing the structure of the density as a ratio of the two model runs, moving upwards in the vertical pressure coordinate, at each equinox and solstice throughout the time period. We can see the tides in the lower sections of the atmosphere as blue and orange bulges in the contour plots.

Use QR code to see animations!

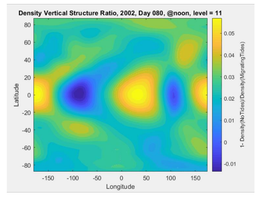
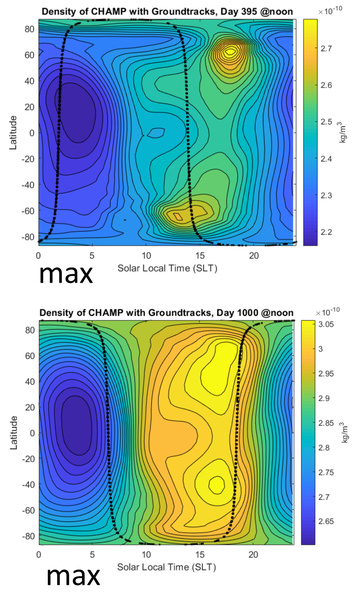



Figure 7: Example plot of density ratio between model runs

## Density Ratio Peaks and Satellite Location

The periodic oscillations seen in the timeseries in Figure 5 can be explained by the location of the satellite relative to the daily peaks in density between daytime and nighttime. Here we have plotted the ground tracks overlaying the density of the CHAMP satellite at the times of MIN and MAX day-to-night density ratio. Day 400 is near the start of the timeseries. Day 1000 is halfway through.




## Conclusions and Continued Work

In this study, we present progress using the TIEGCM (a physics based model) to study influences of Day-to-Night Flow in the Thermosphere. We investigate the impact of turning migrating tides on and off and find that the model shows higher day-to-night ratio with migrating tides off, which is closer to the true values given by the CHAMP sampled data. While this shows that the model is indeed sensitive to toggling the migrating tides, it is not a strong sensitivity. We can see from Figure 6 (Day-to-night Density Ratio vs. Solar Flux) that the sensitivity in the model appears to be connected to solar flux and that toggling the tides does not impact this sensitivity. We looked at the satellite ground tracks in the late afternoon to see the peaks in density for local day and local night with respect to the satellite local time. We present these results as an update to this ongoing project.

**Future steps:**

- Continue investigating sources of sensitivity in the TIEGCM's ability to reproduce the day-night ratio observed in CHAMP data.
- Determine the model's sensitivity to other factors, such as external drivers and viscous and ion drag forcing.
- Identify and isolate diurnal variations from the errors caused by external forcing in the context of a recently developed data assimilation technique.

## Acknowledgements

I would like to thank University of Colorado Boulder and the Colorado Center for Astrodynamics Research their support. I would also like to thank the Space Weather Technology Research Education Center (SWx-TREC).

I would like to thank my advisors Dr. Jeffrey Thayer and Dr. Eric Sutton for their dedication, leadership, and guidance in support of this work.