Variability of thermospheric neutral densities from satellite observations

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I. Introduction

The thermosphere is an atmospheric layer spanning from approximately 90 to 500 kilometers. Thermospheric neutral densities play a crucial role in the planning and execution of Low Earth Orbit satellite missions. The neutrals cause perturbations on satellite orbits due to drag, so the study of the density and its variations is very important. Furthermore, understanding the behavior of the ionosphere, a layer of free ions and electrons embedded within the thermosphere, becomes very important, as it affects technologies such as Global Navigation Satellite Systems and radio communications.

In this study, data from the Gravity field and steady-state Ocean Explorer (GOCE) mission have been employed. GOCE has yielded valuable information on dawn and dusk neutral densities within an altitude range of about 220 km to 280 km. Thermospheric neutral densities exhibit variability influenced by a multitude of factors, including altitude, latitude, longitude, solar flux, geomagnetic conditions, seasonal changes, and local time.

In particular, we investigate the longitudinal variability of the densities from zonal mean values and we obtain the contributions of zonal components up to wave-5 using a Fourier analysis.

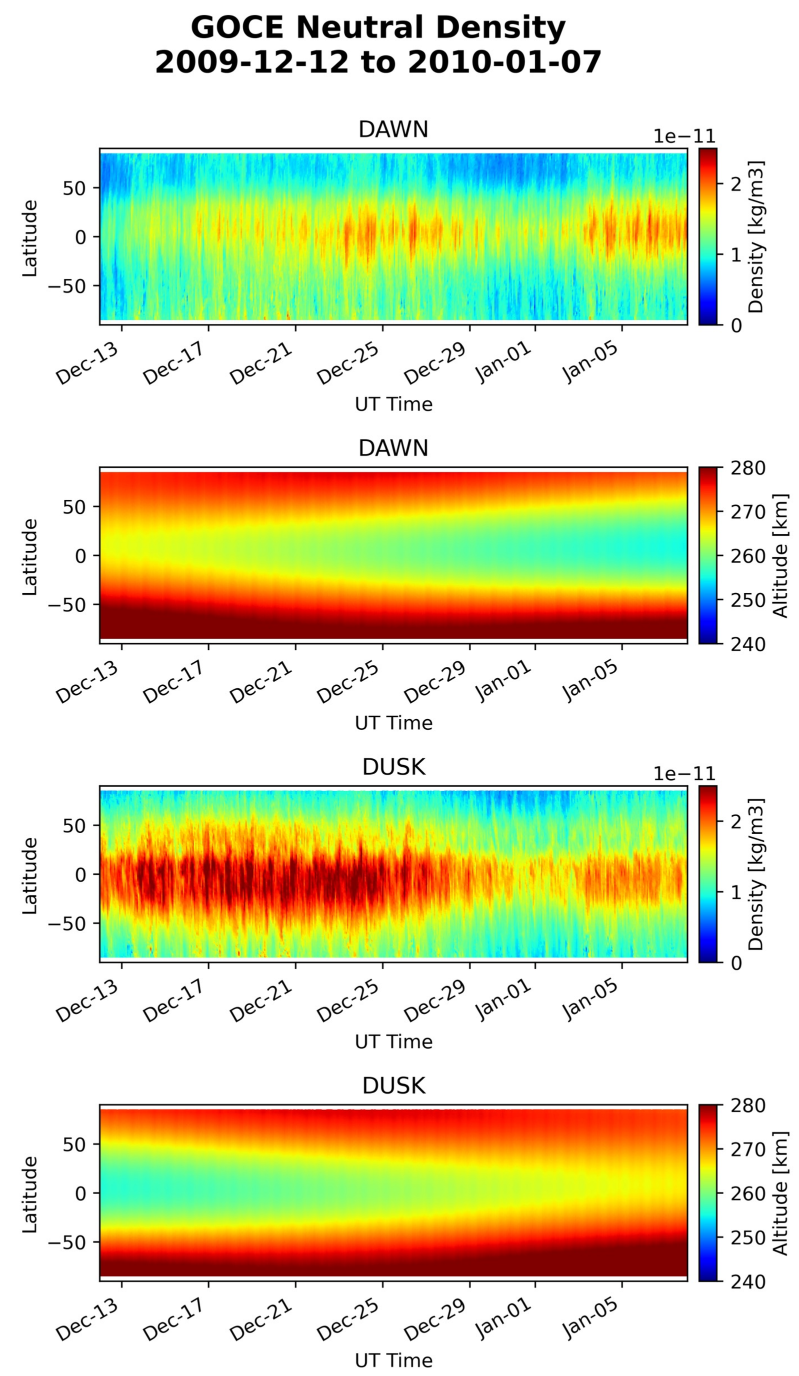

Figure 1: GOCE neutral densities for dawn and dusk (1st and 3rd panels) for December solstice 2009, and altitude for each corresponding observation (2nd and 4th panels).

II. Methodology

For our goal of studying the longitudinal variability of the neutral density, we started by choosing a 27-day window centered as close as possible to the December solstice for the years 2009, 2010, 2011 and 2012, taking into account gaps in the data and geomagnetically active periods. The selected periods are:

- December solstice 2009: 12 December 2009 to 07 January 2010
- December solstice 2010: 05 December 2010 to 31 December 2010
- December solstice 2011: 08 December 2011 to 03 January 2012
- December solstice 2012: 08 December 2012 to 03 January 2013

27 days are selected to help minimize the effect of the Sun's rotation in the final longitudinal analysis.
The average values of the geomagnetic index Kp did not exceed 1^0.

Figure 1 shows the GOCE neutral densities for dawn and dusk (1st and 3rd panels) for the 2009 period, and the altitude for each corresponding observation (2nd and 4th panels).
The GOCE densities were normalized to a constant altitude (270 km) to minimize altitude-related variations. This was accomplished by using the MSIS 2.0 model (Emmert et al., 2021) and taking the logarithm of the densities, due to the variation with altitude being an exponential function. The result for December 2009 is shown in **Figure 2**.

Then, the normalized densities were binned into 1° geographic latitude bands for both dawn and dusk conditions. The median value for each latitude band was calculated, serving as a reference to compute density perturbations (dDens) by subtracting the corresponding median from each observation.

Next, the perturbation values (dDens) were binned into a 5° latitude by 2° longitude grid. Outliers, defined as data points beyond two standard deviations from the mean within each bin, were removed. The remaining data points were then averaged. This process reduced noise and helped in averaging out small-scale fluctuations and is necessary to apply the Fourier analysis.

A 1-D Fast Fourier Transform was then applied to the binned and averaged perturbations in each latitude band. This was followed by applying a filter and an inverse Fast Fourier Transform, retaining only the contributions from the combined effect of zonal wave-1 to wave-5.

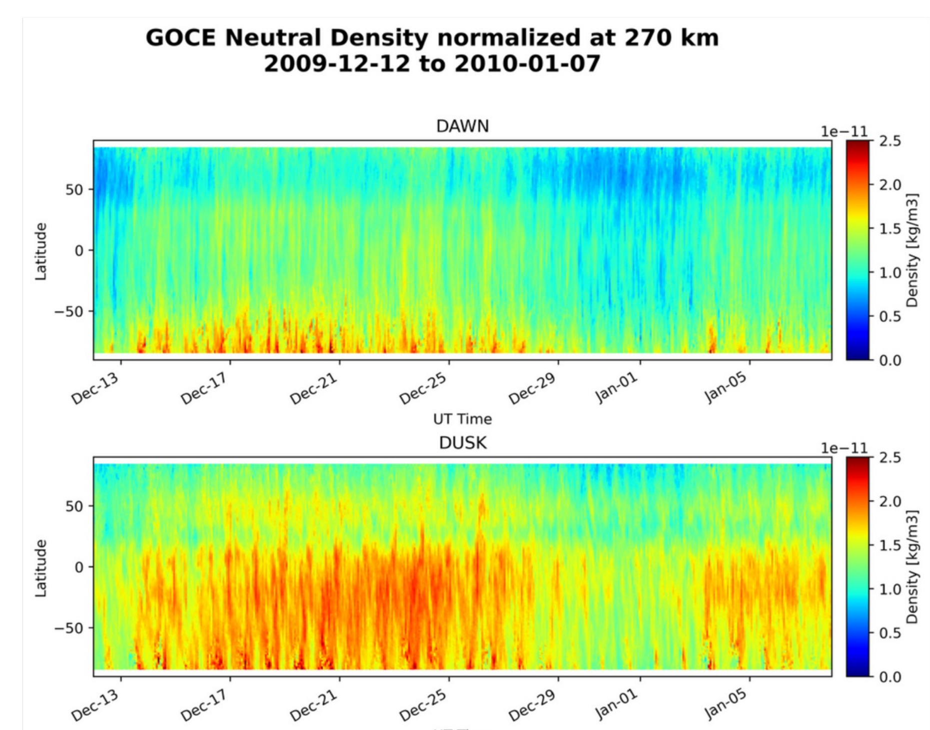

Figure 2: GOCE neutral densities for December solstice 2009 normalized at 270 km.

III. Results

Figure 3 shows the contributions of zonal wave-1 to wave-5 to the GOCE neutral density perturbations (dDens) for dawn and dusk conditions during the December solstice periods from 2009 to 2012.

Each year, the plots show alternating bands of positive and negative perturbations across various longitudes and latitudes.

Dawn vs. Dusk:

- Dawn: Displays a clearer year-to-year progression with well-defined perturbation patterns that shift slightly in longitude from one year to the next. The largest overall magnitudes are present during 2011.
- Dusk: 2009 and 2010 present similar characteristics. 2011 and 2012 also share a similar structure.

These characteristics have been observed in the GOCE neutral winds by Molina & Scherliess (2023). They attribute the behavior to the variations in F10.7. The average F10.7 value for the selected window in December 2009 was 76 sfu. For 2010 that value was 81 sfu. The averages for 2011 and 2012 were higher, at 132 sfu and 109 sfu respectively.

IV. Future work

We will separate the individual zonal wave-1 to wave-5 components to analyze their behavior and year-to-year variations. This will help in understanding the contributions of each component to the overall density variations.
The results will also be compared with the Climatological Tidal Model of the Thermosphere (CTMT).

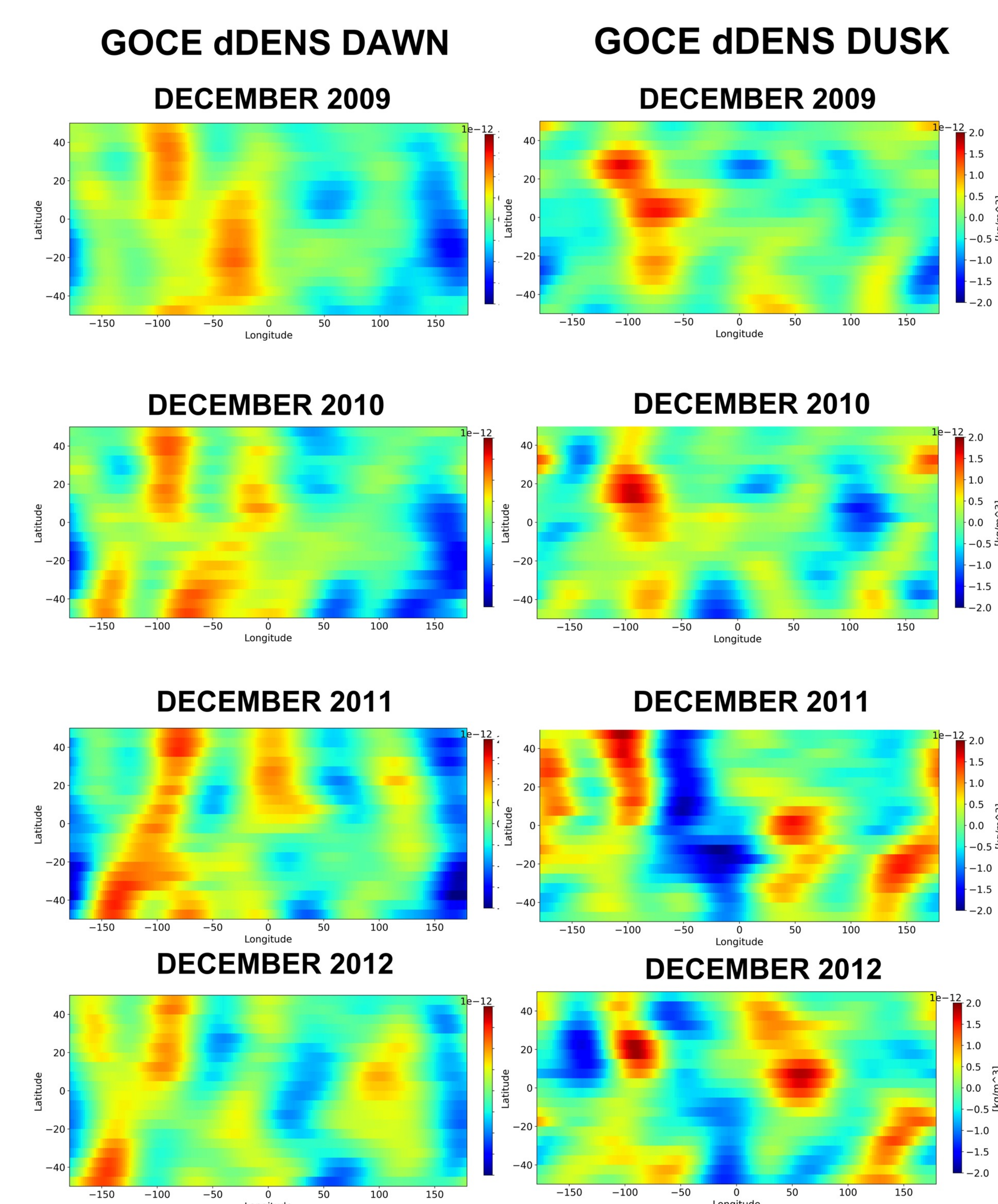

Figure 3: Contributions of zonal wave-1 to wave-5 to the GOCE neutral density perturbations (dDens) for dawn (left) and dusk (right) conditions during the December solstice periods from 2009 to 2012 (top to bottom)

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