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Understanding the Non-linear Effects of Eddy Diffusion on the Ionosphere-Thermosphere System

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ABSTRACT

The exchange of energy between lower atmospheric regions with the ionosphere thermosphere (IT) system is not well understood. Specifically, we lack the data and methods to understand the spatial and temporal effects of eddy turbulence in the thermosphere. This arises mainly because turbulence due to eddy diffusion cannot be directly measured and that it is a challenge to completely characterize its linear and non-linear effects from other influences. In this study, we analyze the sensitivity of the thermospheric densities, O/N_2, TEC to the turbulence from the lower atmosphere by understanding the nature of eddy diffusion in Global Ionosphere Thermosphere Model (GITM). We also estimate a seasonal and latitudinal variation in the eddy diffusion coefficient (EDC) that would be required to match the measurements from GOCE densities, and GPS TEC and GUVI O/N_2. We find that these variations (higher during equinoxes) in the EDC are different when calculated using densities, TEC and O/N_2. Often the EDC shoots over the preferred range indicating that there are other processes contributing to these thermospheric properties as well. Also, the degree of contribution of eddy diffusion vs. other turbulence sources might change with the latitude and season.

INTRODUCTION

- The solar forcing and geomagnetic forcing are not enough to drive the global-mean Annual Oscillation (AO) and Semi-Annual Oscillation (SAO) in the IT region.
- *Qian et al.* [2009] suggested that lower atmospheric forcing is important in the AO and SAO. This is estimated using eddy diffusion coefficient (EDC).
- EDC is a parametrization for unresolved processes and subgrid-scale motion such as gravity wave breaking [*Lindzen,* 1981]. It is expected that the seasonal variations in gravity wave breaking in Mesosphere and Lower Thermosphere (MLT) region causes seasonal variation in EDC.
- Atomic oxygen and molecular nitrogen are two main thermospheric constituents and their ratio (O/N_2) is used as a parameter for thermospheric composition.
  - Reducing their ratio increases mean molecular mass and a reduction in density. This in turn affects the electron density.
  - Electron production rate depends on atomic oxygen concentration and the electron loss rate depends on the concentrations of N_2.

Open Questions:

- How does EDC vary spatially (latitudinally and vertically) and temporally?
- Which thermospheric properties are more strongly affected by the changes in eddy diffusion?
- Will the addition of eddy diffusion variation at the lower boundary of the thermosphere be enough to explain some of the significant discrepancies between the observations and model outputs?

METHODOLOGY

- Model used : GITM
- Data sets : GPS TEC (2010), GUVI O/N_2 (2010), GOCE for neutral densities (2013).
- We do a sample run using GITM for December 2010, using different values of EDC and understand the dependence of each of the thermospheric properties (TEC, O/N_2, Densities) on EDC (A sample run is shown in Fig. 1).
- We retrieve the midnight values for each day of the year (2010 or 2013) for the model (EDC=1000) and data sets, and fit it with an annual and a semi-annual components to remove any local time dependencies or higher frequency variations. (Fig 2a, 3a, 4a)
- The differences between the model output and the data are then used to estimate EDC (Fig 2b, 3b, 4b) using the relationship determined by the GITM runs of Fig 1.

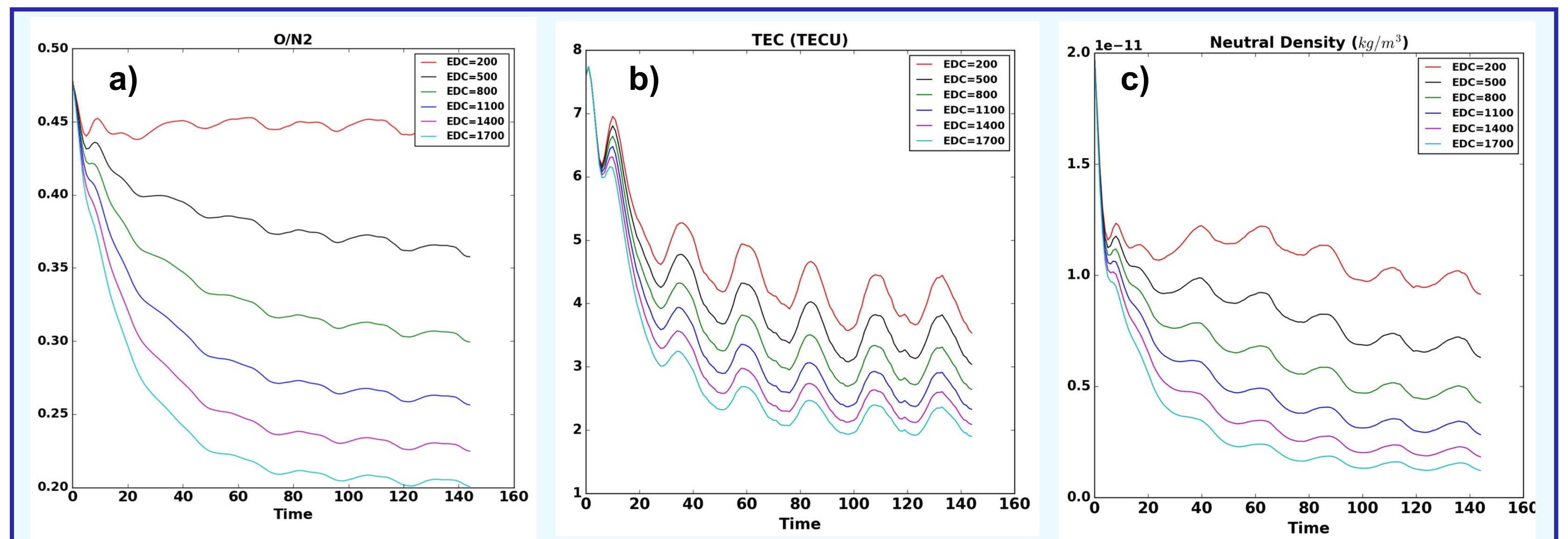

Figure 1 - (From left) - a) GITM O/N2, b) TEC, and c) Neutral density for different eddy diffusion coefficients for a brief period in December 2010. Horizontal axis represents the time in hours.

RESULTS

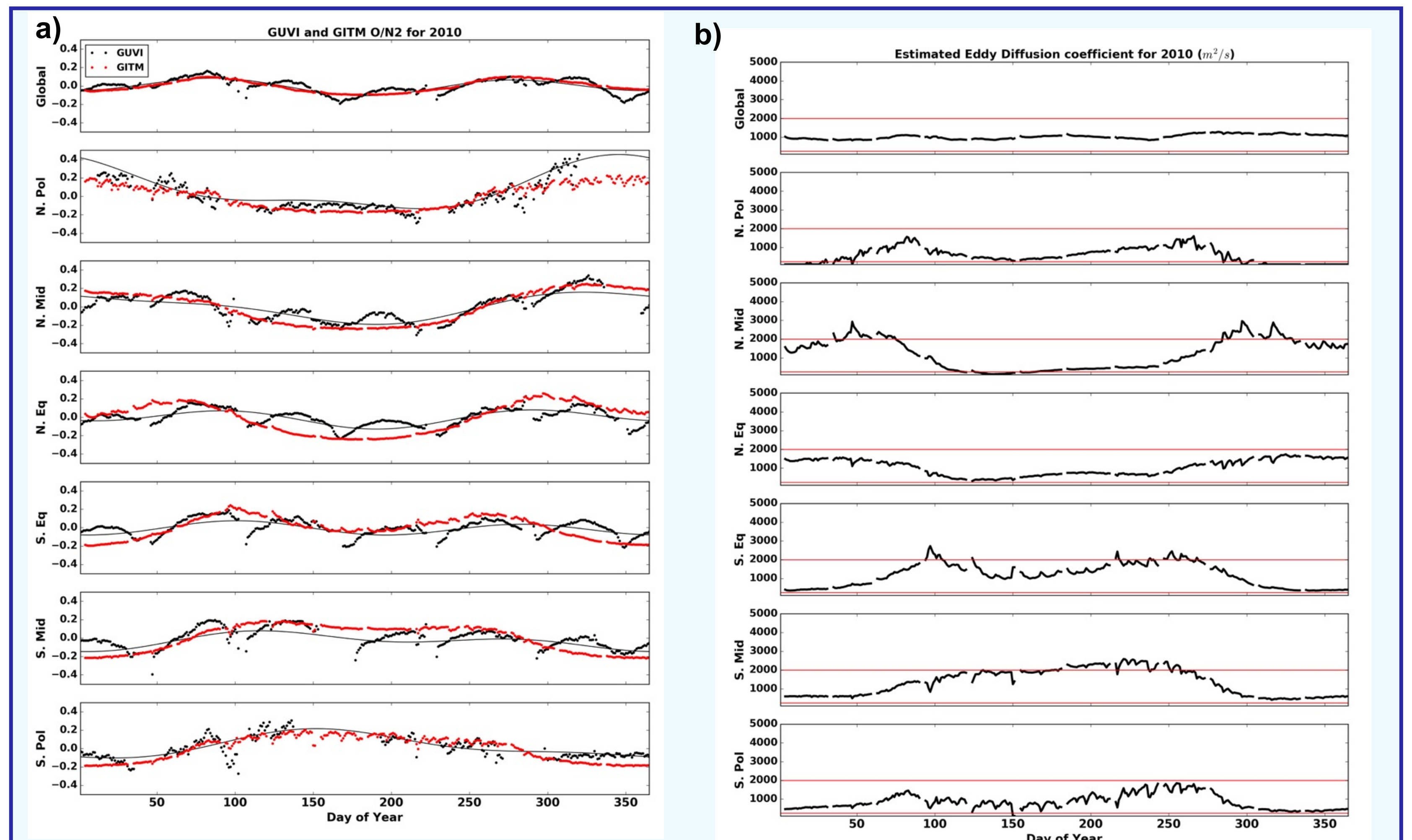

Figure 2: (a) O/N_2 for GITM (red dots) and GUVI (black dots) for 2010. For GUVI, black curves represent the fitted annual and semi-annual components. (b) Estimated EDC using the differences of the curves of Fig. 2a and relationship derived b/w EDC and O/N_2 from GITM runs of Fig. 1a. Horizontal red lines represent the permitted EDC GITM range of [250,1000].

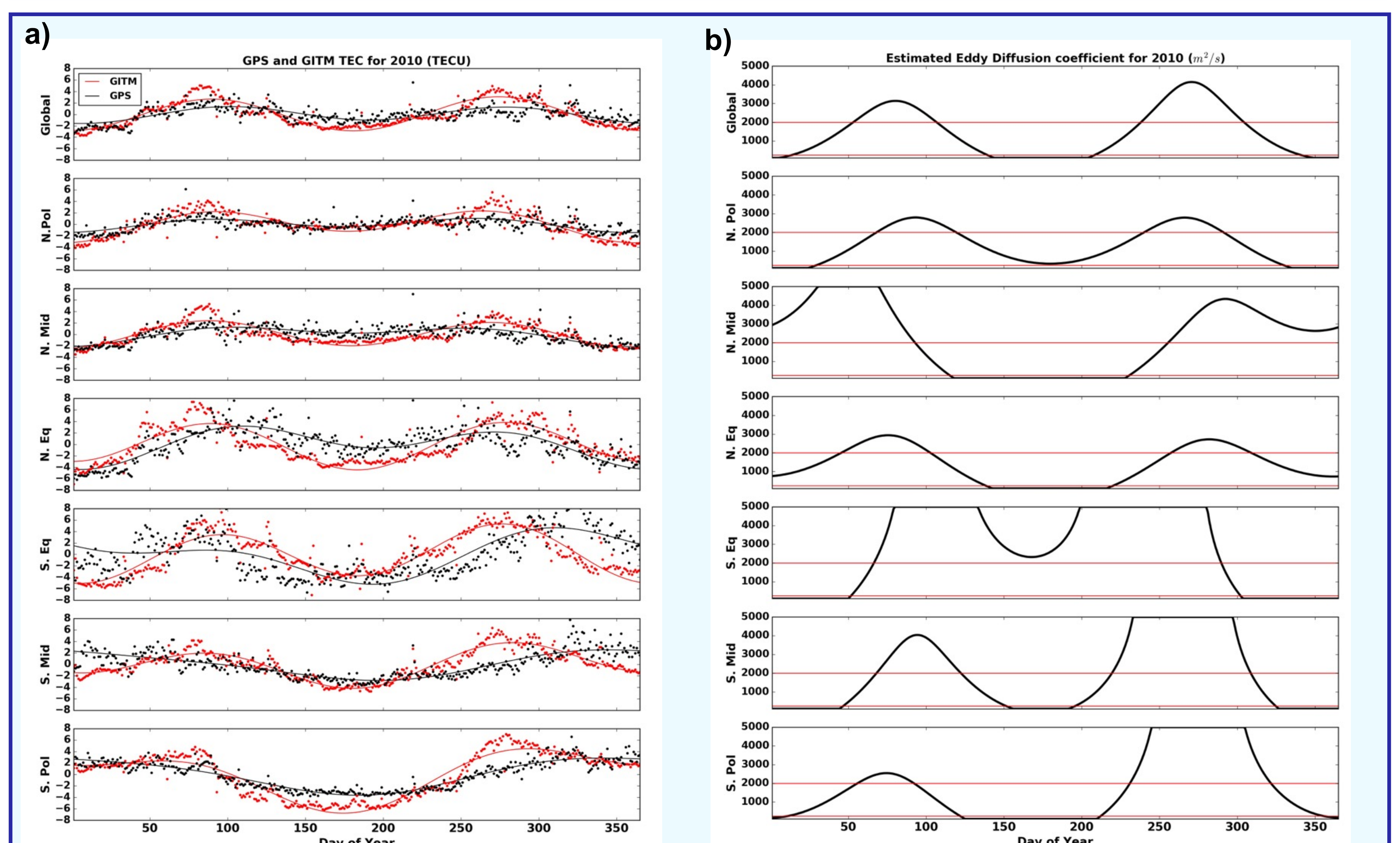

Figure 3: (a) TEC for GITM (red dots) and GPS (black dots) for 2010. The red and black curves represent the fitted annual and semi-annual components for GITM and GPS, respectively. (b) Estimated EDC using the differences of the curves of Fig. 3a and relationship derived b/w EDC and TEC from GITM runs of Fig. 1b. Horizontal red lines represent the permitted EDC GITM range of [250,1000].

RESULTS

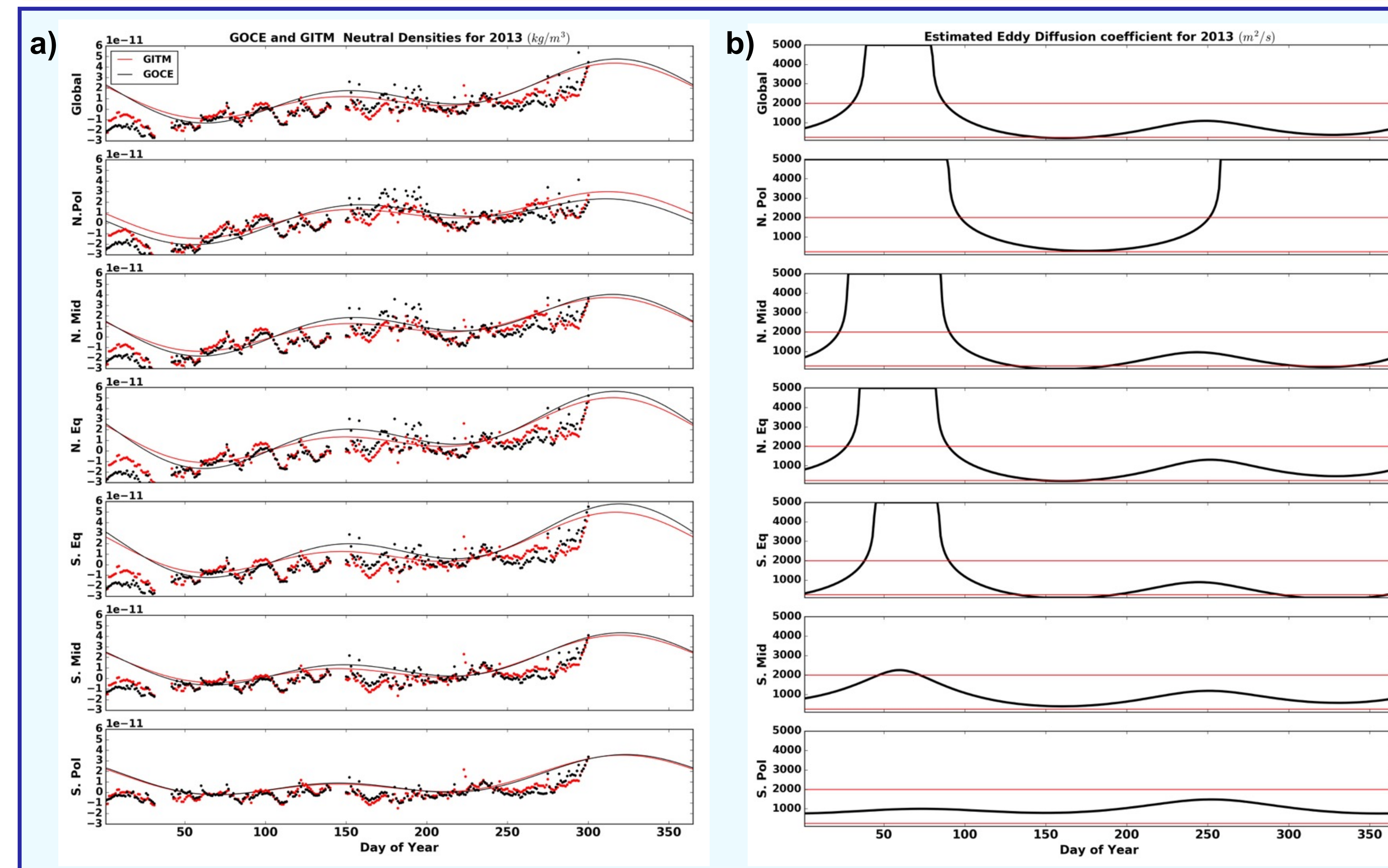

Figure 4: (a) Neutral Densities for GITM (red dots) and GOCE (black dots) for 2013. The red and black curves represent the fitted annual and semi-annual components for GITM and GOCE, respectively. (b) Estimated EDC using the differences of the curves of Fig. 4a and relationship derived b/w EDC and neutral densities from GITM runs of Fig. 1c. Horizontal red lines represent the permitted EDC GITM range of [250,1000].

DISCUSSION

- Estimating empirically the spatial and temporal variability of turbulent diffusion (as parameterized by diffusion coefficients) is clearly important for improving theoretical understanding, numerical models, and predictions.
- There is a clear AO and SAO in O/N_2, TEC, and neutral density (Fig. 2a, 3a, 4a).
- The estimated EDC (Fig. 2b, 3b, 4b) has latitudinal and seasonal variations showing usually higher values during equinoxes. However, these variations and the amplitude of EDC are different when calculated using O/N_2, density, and TEC.
- The estimated EDC overshoots the permitted range of [250,1000] in Fig 3b and 4b indicating that the differences between the model and data are high and cannot be appropriately adjusted by just modifying EDC in the model and other factors are at play. This would also imply that gravity wave breaking might not be the dominant lower atmospheric forcing in the thermosphere.

FUTURE WORK

- The estimated EDC need to be constrained by the processes in the lower atmosphere and hence a comparison with the Whole Atmosphere models is required. These latitudinal and seasonal variations of EDC will eventually be included in GITM
- Relationship of density, O/N2, TEC with EDC as shown in Figure 1 needs to be determined for different periods.

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