Seasonal and solar cycle variability of DE2 and DE3 in the CO_2 15 µm cooling of the lower thermosphere

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Abstract

This work is based on recently accepted JGR-Space Physics paper (Nischal et al., 2017, 10.1002/2017JA024273). We demonstrate that upward propagating nonmigrating tides forced by latent heat release in the troposphere impact the thermospheric energy budget by modulating the longitudinal/local time behavior of the CO_2 infrared cooling of the lower thermosphere. Tidal diagnostics of SABER data shows that the CO_2 cooling rate amplitudes for the DE2 and DE3 are on the order of ~ 20-50% relative to the zonal monthly means and their seasonal behavior closely follows the dynamical tides. DE2 and DE3 cooling rate amplitudes have decreased by about 27% over the solar cycle (2002-2008) due to variability of mean temperature and mean atomic oxygen. The photochemical modeling reproduces the observed results, although with systematic amplitude differences which are related to the uncertainty in the model input backgrounds, especially atomic oxygen. The main tidal coupling mechanism below 110 km is temperature; however, neutral density becomes equally important above 110 km, thereby explaining observed evanescent phases which are not present in the temperature tides. The contribution of vertical advection is comparatively small. Modeled results are found to be independent of the choice of backgrounds and do not impact our conclusion about the DE2 and DE3 cooling rate tides and the relative contributions.

Science Questions

1. How large is the DE2 and DE3 nonmigrating tidal signal in the observed CO_2 15 µm cooling rates and how does it vary for different altitude, latitude, month and over a solar cycle?
2. What are the underlying coupling mechanisms, that is, how is the tidal signal transmitted into the CO_2 emissions?

Methodology

1. A two-dimensional Fourier analysis of SABER CO_2 15 µm cooling rates data.
2. Photochemical modeling using dynamical tides from the empirical CTMT model. Separating the tidal drivers requires the computation of CO_2 15 µm cooling rates that are governed by CO_2-O collisions.

$$VER = h\nu A[CO_2](01101) \qquad (1)$$

Wise et al., 1995

$$[CO_2](01101) = \frac{J_R + 2k_o e^{-960/T}[O]}{A + k_o[O]}[CO_2](00001) \qquad (2)$$

Backgrounds: $[CO_2]$, [O], T and density: **SABER, TIME-GCM & NRLMSISE-00**

Tides: T, density and vertical winds: **CTMT (empirical tidal model)** [Oberheide et al., 2011]

Conclusions

- Tidal diagnostics of SABER CO_2 cooling rates shows that the DE2 and DE3 amplitudes are on the order of ~ 20-50% relative to the monthly means and depending on season which indicates that the upward propagating tides from the troposphere are important in modulating the energy budget of the lower thermosphere in longitude and time.
- Modeled amplitude structures match the observations well, though with some systematic differences. The phases are well reproduced including the phase slope transition around 110 km from propagating to evanescent.
- Temperature is the main tidal driver, however, neutral density becomes equally important above 110 km thus explaining the observed phase transition. Vertical advection contribution is comparatively small.
- Photochemical modeling using different set of backgrounds (e.g., TIME-GCM) results in similar findings, thereby implying that our results are not dependent on the choice of backgrounds and the uncertainties present in the model input fields do not impact the conclusion about the modeled DE2 and DE3 CO_2 cooling rate tides.

DE2 & DE3 in CO_2 cooling rates

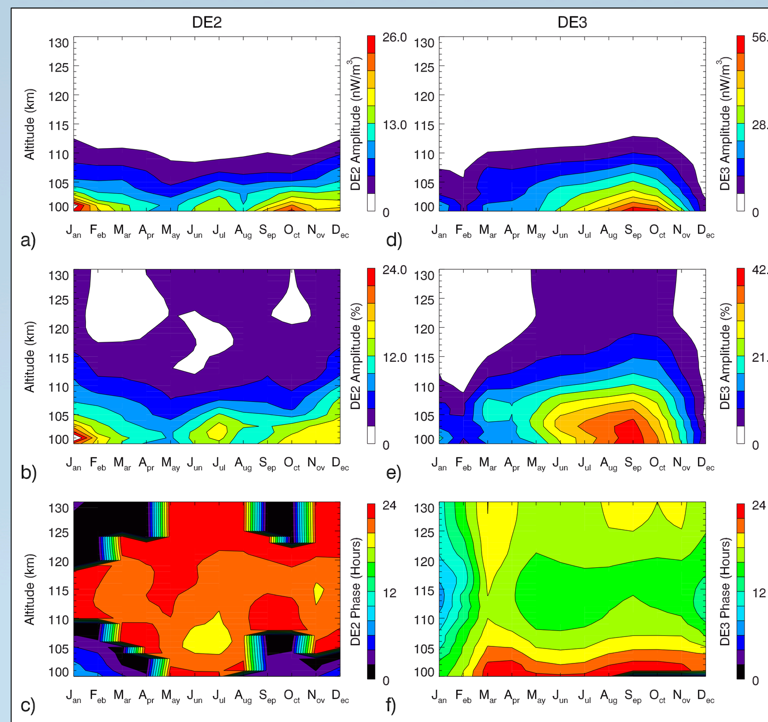


Figure 1. Observed DE2 & DE3 amplitudes and phases in CO_2 cooling rates for the year 2008 at 20°N and the equator, respectively.

The seasonal variations of the DE2 & DE3 tidal signal closely follow those of dynamical tides, especially temperature tides.

DE2 & DE3 phases show upward propagation up to ~110 km, then they transition into constant phases: SUCH PHASE SLOPE TRANSITIONS ARE NOT OBSERVED IN TEMPERATURE TIDES (not shown here).

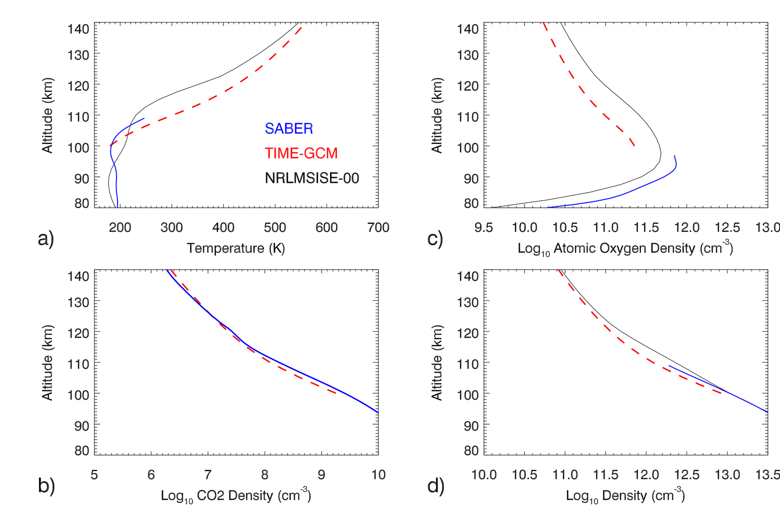


Figure 2. Monthly mean zonal mean profiles from SABER & NRLMSISE-00 for September 2008 at the equator, and TIME-GCM climatological simulation for solar min conditions.

Choosing different data sources for the photochemical modeling allows to test the sensitivity of the modeling results to the uncertainties in the input parameters.

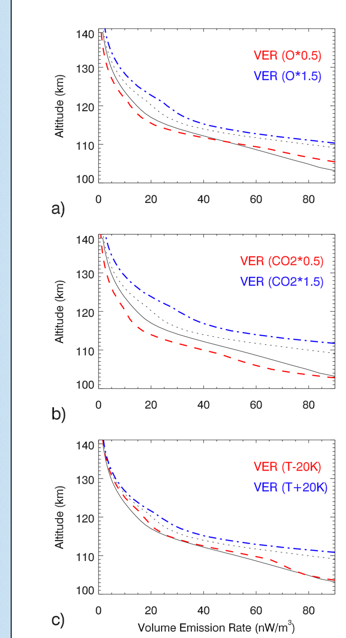


Figure 3. Observed (solid black line) and computed CO_2 cooling rates (using equations 1 & 2).

The uncertainties in the model input parameters only contribute towards the uncertainties in the absolute tidal amplitudes in the cooling rates from photochemical modeling.

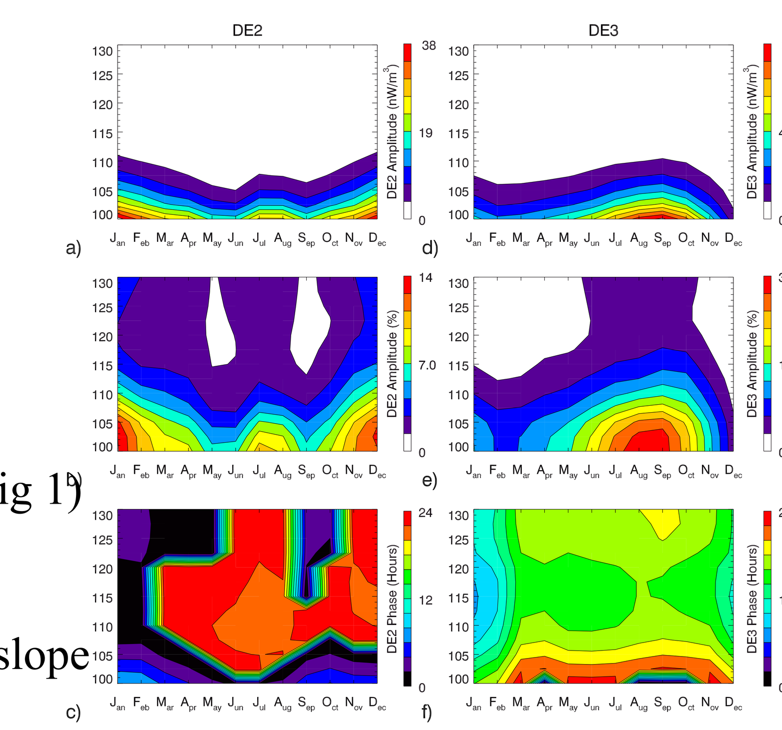
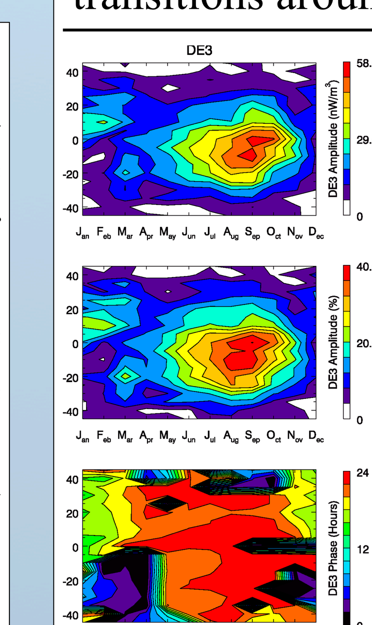


Figure 4. Same as Figure 1 but from photochemical modeling.

The seasonal variations of the modeled tidal components follow the observed signatures (Fig 1). Overall, general amplitude structures are well reproduced for all months. The photochemical modeling also reproduces the observed phase slope transitions around 110 km.



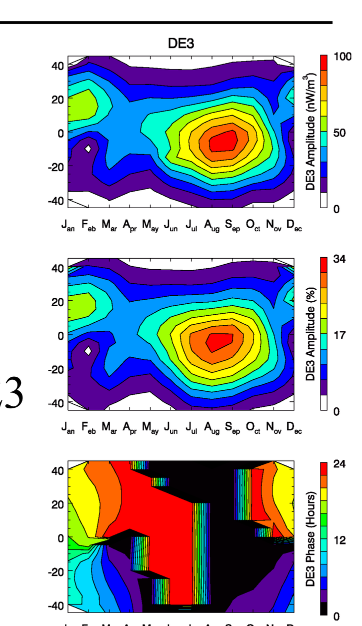


Figure 5. Observed (left) & Modeled (right) DE3 in CO_2 cooling rates for the year 2008 at 100 km as a function of months and latitudes.

Latitudinal structures of DE2 (not shown here) & DE3 in CO_2 cooling rates follow those of dynamical tides. Modeled and observed DE3 match well.

Acknowledgement

This work was supported by the NSF Aeronomy Program, Award AGS-1112704.

Tidal Coupling Mechanisms

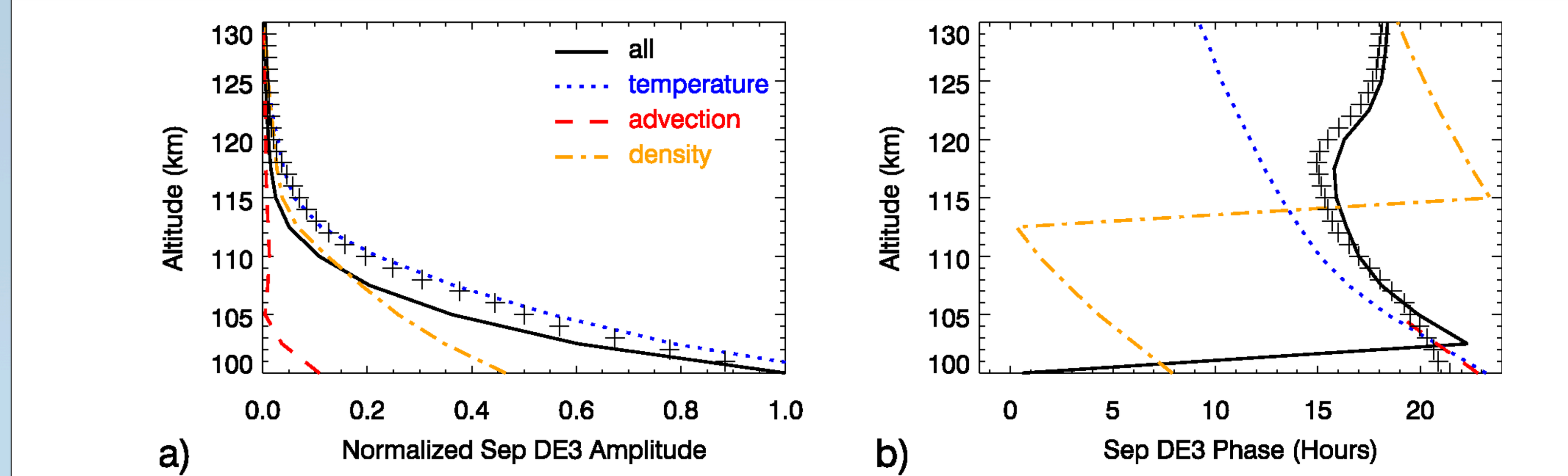


Figure 6. (a) Normalized September 2008 DE3 amplitudes at the equator from photochemical modeling. Shown are the total (all) response and the individual responses due to temperature, density and advection. Overplotted as "+" is the SABER observation (b) Corresponding DE3 phases.

Temperature is the main driver of the CO_2 cooling rate tides that comes from the high temperature dependence of equation (2) and this is true throughout the whole altitude range. However, the neutral density starts becoming equally important upward of ~100 km. This explains the observed phase slope transition in DE2 and DE3 phases (Fig 1) around 100 km. The response to temperature is out of phase with the response to the neutral density. Vertical advection, on the other hand, has a very small contribution.

Relative Contributions

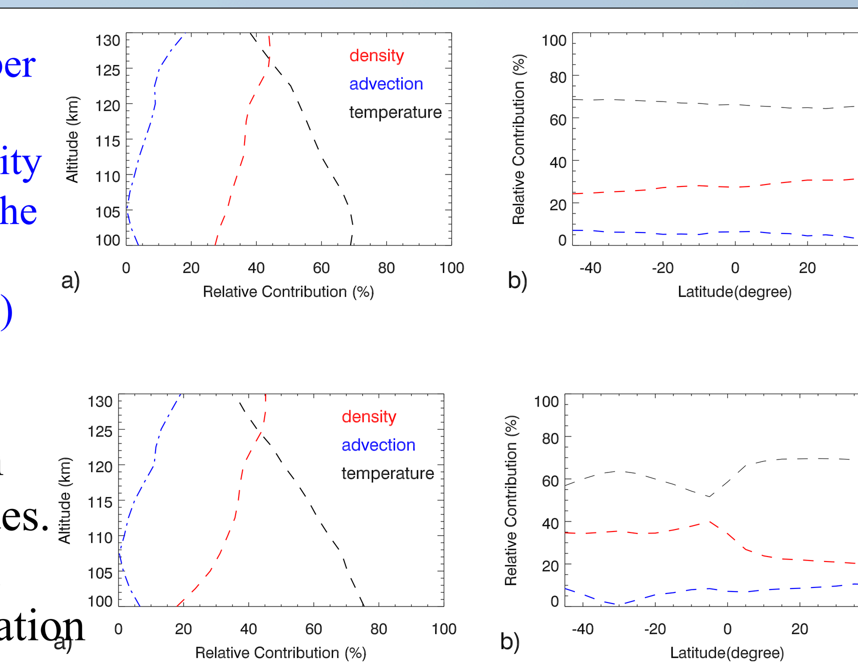


Figure 7. (Top) DE3 amplitudes for September from photochemical modeling. Shown are individual response due to temperature, density and advection as a function of (a) altitude at the equator, and (b) latitude at 100 km.
(Bottom) DE2 for January as a function of (a) altitude at 20°N, and (b) latitude at 100 km

Noticeable is the increasing contribution from the neutral density at higher altitudes. Latitudinal structures in these individual contributions come from latitudinal variation of dynamical tides.

Solar Cycle Variation

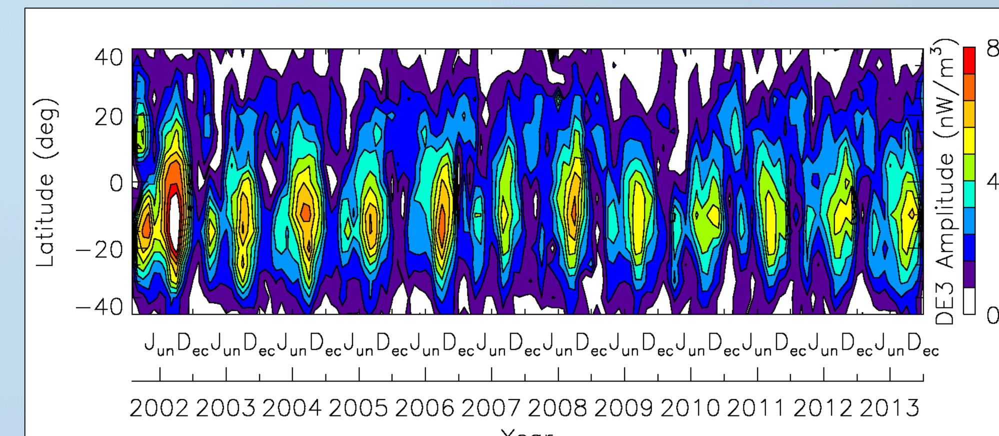


Figure 8. Observed (SABER) DE3 amplitudes as a function of latitude and year at 100 km.

DE3 in CO_2 cooling rates does not show any significant solar cycle dependence. This is consistent with the solar cycle variability of CO_2 cooling rates which are less sensitive to the change in temperature [Mlynczak et al., 2010]. Similar results hold true for DE2 (not shown here).

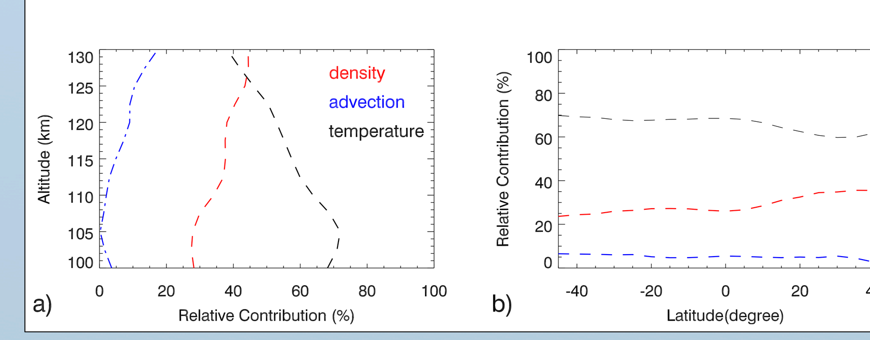


Figure 9. Same as Fig 7 (top) but for year 2013.

There is no significant changes in the relative contributions although, slightly larger latitude dependence is visible.

References

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