Photochemical modeling of nonmigrating tides in the 15 μm cooling of the lower thermosphere

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Abstract

We explore the impact of nonmigrating tides originating from tropospheric weather system on the 15 μm CO_2 infrared cooling of the lower thermosphere for the solar minimum year 2008. Tidal diagnostics of SABER CO_2 15 μm volume emission rate (VER) data shows that the CO_2 cooling rate amplitudes for the DE2 and DE3 components are on the order of 15-60% relative to the monthly means, depending on season. Supporting photochemical tidal modeling reproduces the general amplitude structures and phases. The main tidal coupling mechanism in the MLT region during solar minimum is the temperature dependence of the collisional excitation of the CO_2 (01101) fundamental band transition (ν_2). However, the response to neutral density variations becomes as important as temperature above 115 km and as such explains an unexpected tidal phase behavior in the observation. The contribution of vertical advection is comparatively small. Although using observed data from SABER in the photochemical modeling reproduces better structures, the general results are independent of the choice of background. While change in the background impacts the absolute DE2 and DE3 amplitudes, it does not have any significant impact on our conclusion about the relative importance of the tidal coupling mechanisms.

Photochemical Modeling

Separating the tidal drivers requires the computation of CO_2 15 μm volume emission rates (VER) that are governed by CO_2-O collisions.

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

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

Wise et al., 1995

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]

Background Comparisons

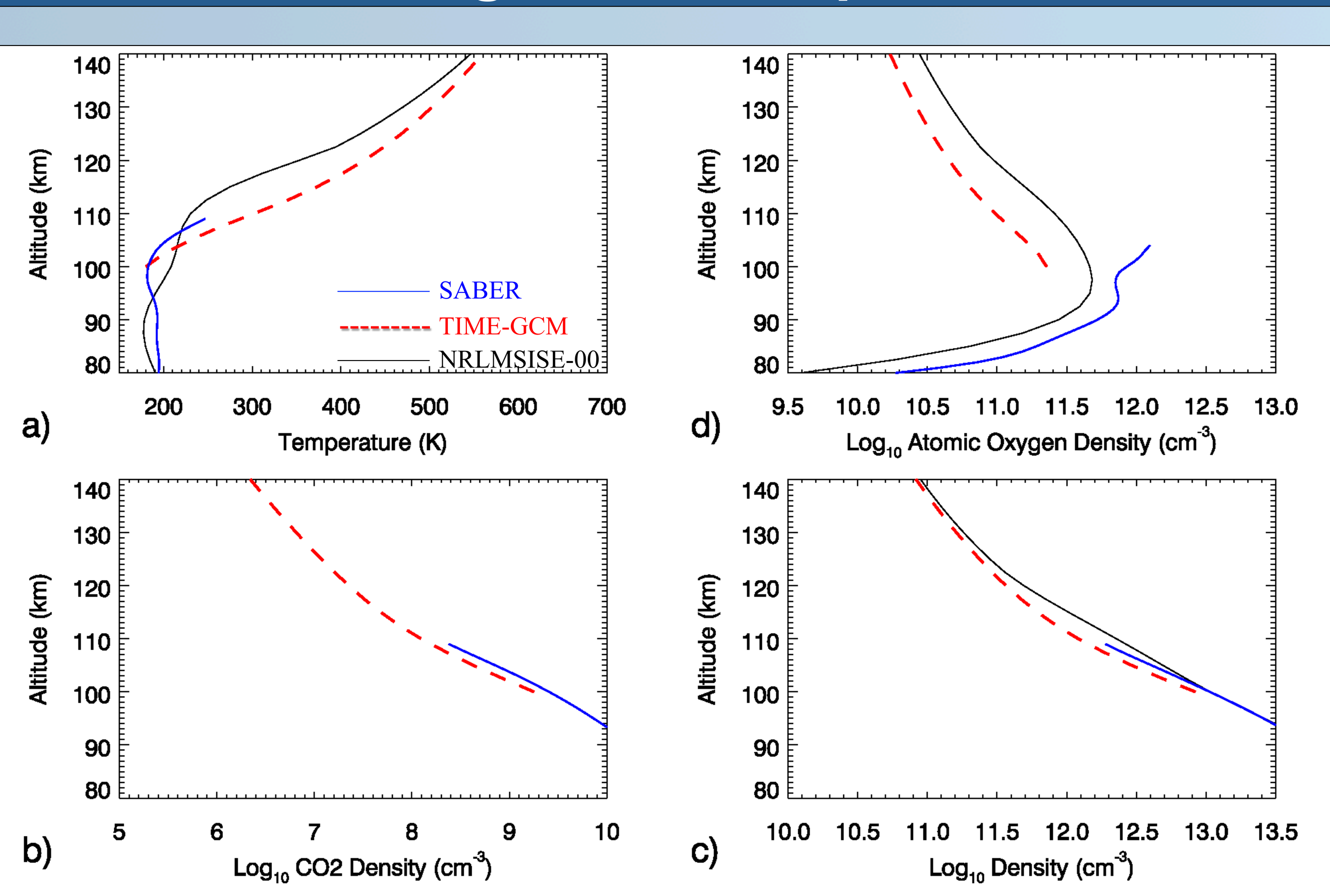

Figure 1. Monthly mean zonal mean profiles at the equator for September, 2008. (a) Temperature from NRLMSISE-00, TIME-GCM & SABER. (b) Atomic oxygen density from NRLMSISE-00 & TIME-GCM. (c) CO_2 density from TIME-GCM and SABER. (d) Neutral density from NRLMSISE-00, TIME-GCM & SABER. TIME-GCM backgrounds are generally smaller than those of NRLMSISE-00. Atomic oxygen density from SABER shows a surprisingly increasing behavior above 100 km which needs to be further investigated. These multiple data sources allow us to perform sensitivity tests of the modeled CO_2 cooling rate tides and tidal driving mechanisms to the specific choice of background as shown in Figure 2.

Observed vs Modeled DE2 & DE3 Tides in Cooling Rates

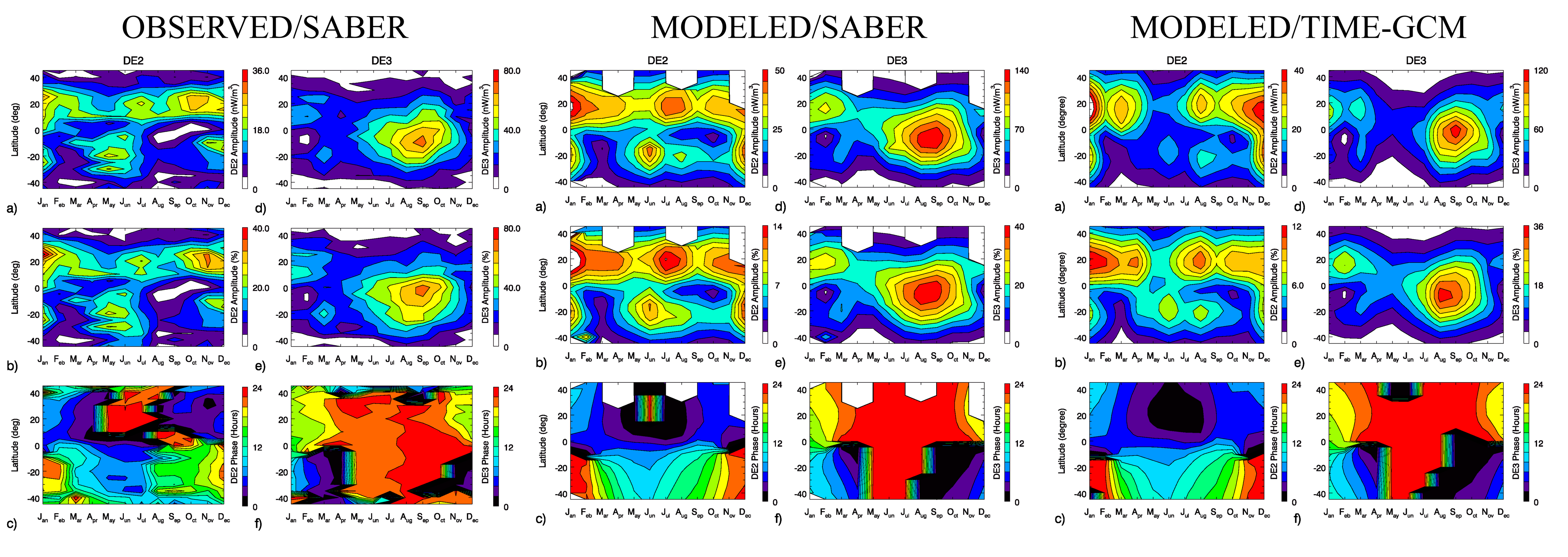

Figure 2. (**left**) CO_2 cooling rate amplitudes and phases for the year 2008 at 100 km from SABER, (**middle**) photochemical modeling using SABER backgrounds, (**right**) photochemical modeling using TIME-GCM backgrounds. (**a**) Diurnal eastward wave number 2 (DE2) amplitude in 10^{-9} W/m^3. (**b**) DE2 amplitude in percent deviation from the mean. (**c**) DE2 phases in local time of maximum. (**d-f**) Same as (a-c) but for the diurnal eastward wave number 3 (DE3) tide. **Note the different color scales**.

Seasonal variations resemble those of the temperature tides (not shown). The models reproduce the same general structure though with systematic amplitude differences. Phases agree well with the observations. Photochemical modeling using observed SABER background reproduces better seasonal variability structures in comparison to the TIME-GCM. DE2 shows a clear antisymmetric structure about the equator while DE3 has a symmetric structure about the equator. These results show that upward propagating tides from the troposphere modulates the CO_2 cooling rates in the lower thermosphere.

DE3 Lat/Lev Comparison

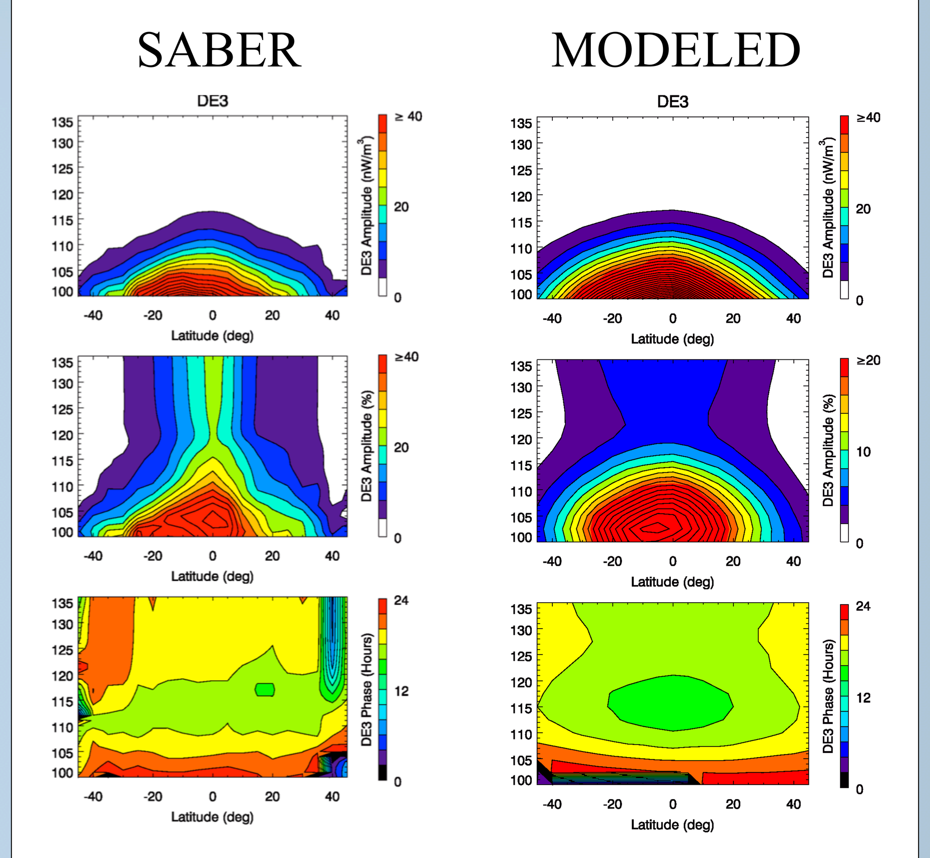

Figure 3. (left) DE3 CO_2 cooling rate amplitudes and phases for September 2008 from SABER, **(right)** photochemical modeling using TIME-GCM background. The transition in the phase slope ~ 115 km can be seen which is not present in the corresponding temperature phases (not shown here).

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Tidal Coupling Mechanisms

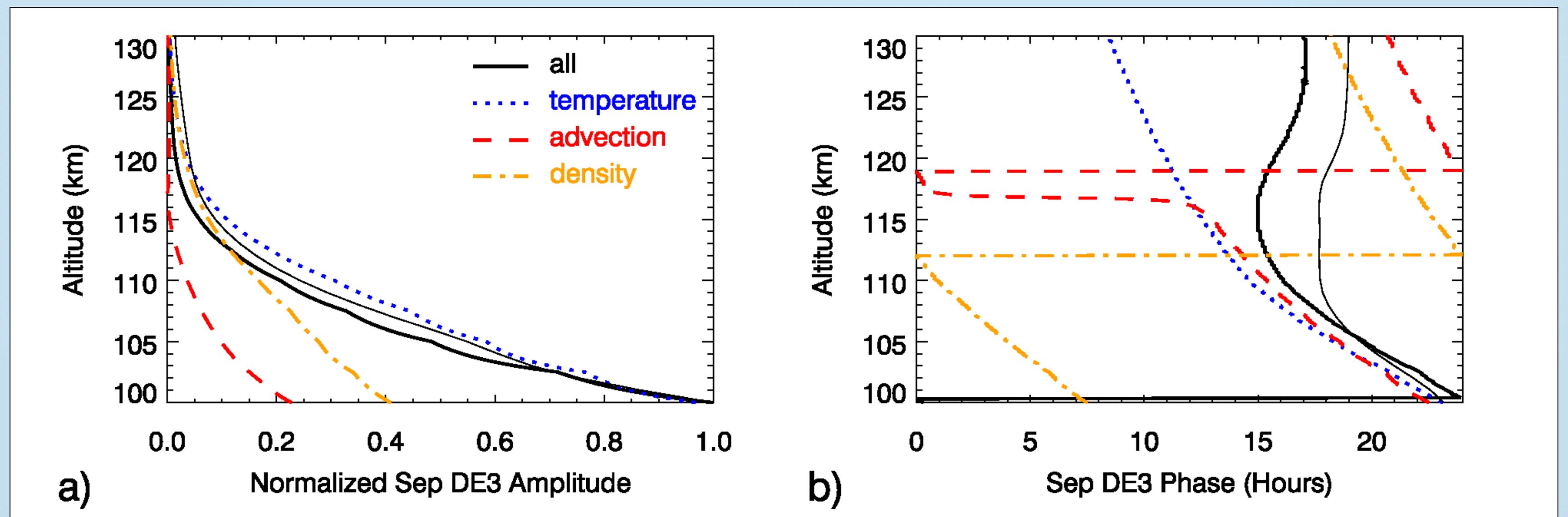

Figure 4. (a) Normalized September DE3 amplitudes from the photochemical modeling of the CO_2 15 μm VER at the equator. Shown are the total (all) response (black) and the individual responses due to temperature (blue), density (orange), and vertical advection (red). Over plotted as a thin line is the SABER observation. (b) Corresponding DE3 phases. Note that the observed phase transition around 115 km from propagating to evanescent is well reproduced. It is caused by the increasing contribution from tidal density variations at higher altitudes.

References

- Wise et al., (1995), J. Geophys. Res., 100, A11, 21357-21373, doi: 10.1029/95JA02053
- Oberheide, J., et al (2011), J. Geophy. Res., 116, A113006, doi: 10. 1029/2011JA016784

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Future Work

- Constrain MSIS atomic oxygen with observed data from SABER & SCIAMACHY for photochemical modeling above 105 km.
- Analyze tidal coupling effects over a full solar cycle in order to understand the relative importance of temperature and density tides as a function of solar activity (which impacts tidal dissipation).

Conclusions

- Cooling rates amplitudes are on the order of 15-60% relative to the monthly means which indicates that upward propagating tides from the troposphere are important for modulating the energy budget of the lower thermosphere.
- Photochemical modeling reproduces the same general structure though with some systematic differences in amplitude. This is likely related to the background fields. Phases agree well with the observation.
- The main tidal coupling mechanism below ~115 km is temperature but neutral density becomes equally important above ~115 km. This explains the observed phase slope transition in DE3.
- Photochemical modeling using observed SABER background reproduces better seasonal variability structures in comparison to TIME-GCM background. However, it does not impact our conclusion about the relative importance of the tidal coupling mechanisms.
- Work on investigating the impact of uncertainties in the vertical gradient of atomic oxygen and CO_2 is under way.