A Quantitative Assessment of Vertical Wave Energy Flux Due to Upward Propagating Tides

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Abstract

Atmospheric tides couple the lower and upper atmosphere by transferring energy and momentum from their source regions in the troposphere and stratosphere to the thermosphere. However, how much energy the upward propagating tides transport per unit time and area (vertical wave energy flux) is poorly known. Though a few studies have been conducted in the past to assess wave energy flux, most approaches were solely based on theory and models rather than on observations. To address this gap in observation-based assessment, we derive the vertical wave energy flux and heating rates for solar minimum conditions from TIMED observations. Our approach utilizes fluid dynamical equations and Hough Mode Extension (HME) fits to tidal wind and temperatures from SABER and TIDI. Our results point to a smaller vertical wave energy flux than predicted by SD-WACCM-X.

Objective

What is the vertical wave energy flux due to upward propagating tides based on observations?

Motivation

The few previous studies were all theory or model-based. HME-fits allow one to do an observation-based assessment.

Methodology

Data sources

TIMED: **SABER** temperatures and **TIDI** wind measurements.

SD-WACCM-X: First principles numerical model.

Extracting upward propagating tides

HMEs: Self-consistent latitude vs. height sets of amplitudes & phases of **upward propagating tides** that come from classical tidal theory

- Pole-to-pole, 0 - 400 km
- *T, u, v, w,* ϕ_h and $\Delta\rho/\rho$
- do not depend on day of year

HME fitting to T, u, v tides in the upper mesosphere in TIMED observation allows us to obtain tidal fields at latitudes and altitudes not observed and in additional parameters (like geopotential height, etc.)

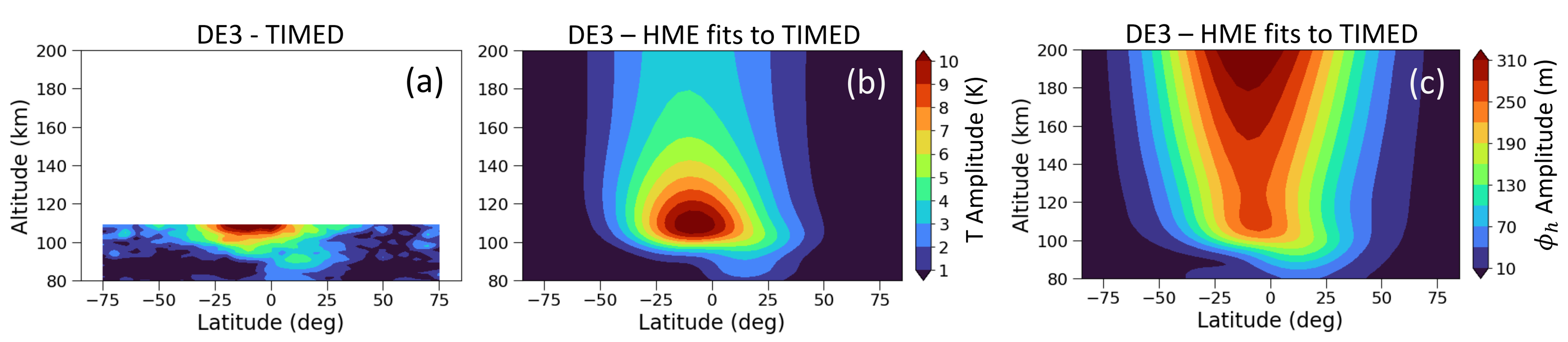


Figure 1: DE3 (Diurnal nonmigrating) tides for March 2009 from TIMED observation, (a) temperature, (b) HME fitted temperature, (c) HME fitted geopotential height

- HMEs for ω have been computed from their relationship with $w \rightarrow \omega = -w\rho g$
- Self-consistency of HMEs allows us to reconstruct the tidal fields for ϕ_h and ω using the fit coefficients obtained from fitting T, u, v HMEs to observed T, u, v .

HME fitting to T, u, v tides in SD-WACCM-X allows us to extract the upward propagating contribution due to tides

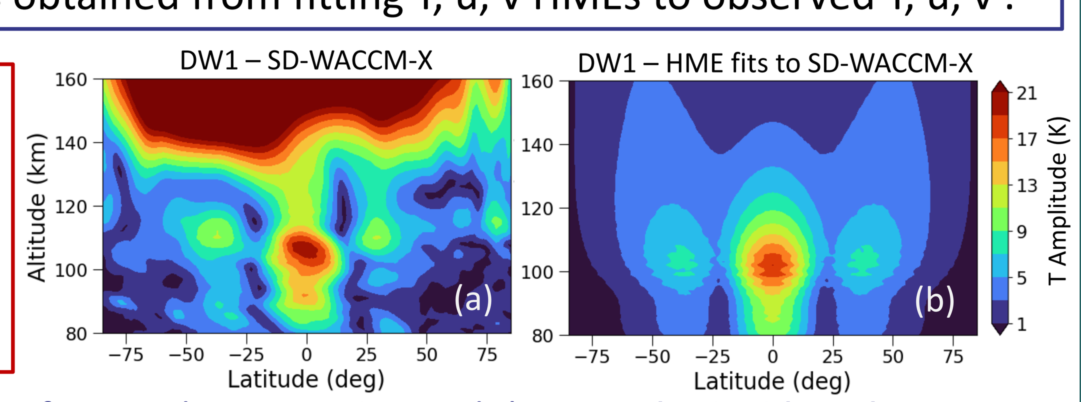


Figure 2: DW1 is a combination of upward propagating and thermospheric tides. Shown are March 2009 SD-WACCM-X temperatures (a) Full, (b) Upward propagating contribution to DW1.

Vertical wave energy flux

Energy flux, $E_w = \overline{\phi_h'\omega'} = \frac{1}{2}\ \hat{\phi}_h\ \hat{\omega}\cos(\varphi_\omega - \varphi_\phi)$

Global average, $\bar{E}_w = \frac{1}{2}\int_0^\pi E_w\ (\theta)\ sin\theta\ d\theta$

Tidal heating rate, $Q_{tidal} = -\frac{d\bar{E}_w}{dz}$

$\phi_h{}'$ - geopotential height perturbation

ω' - omega perturbation

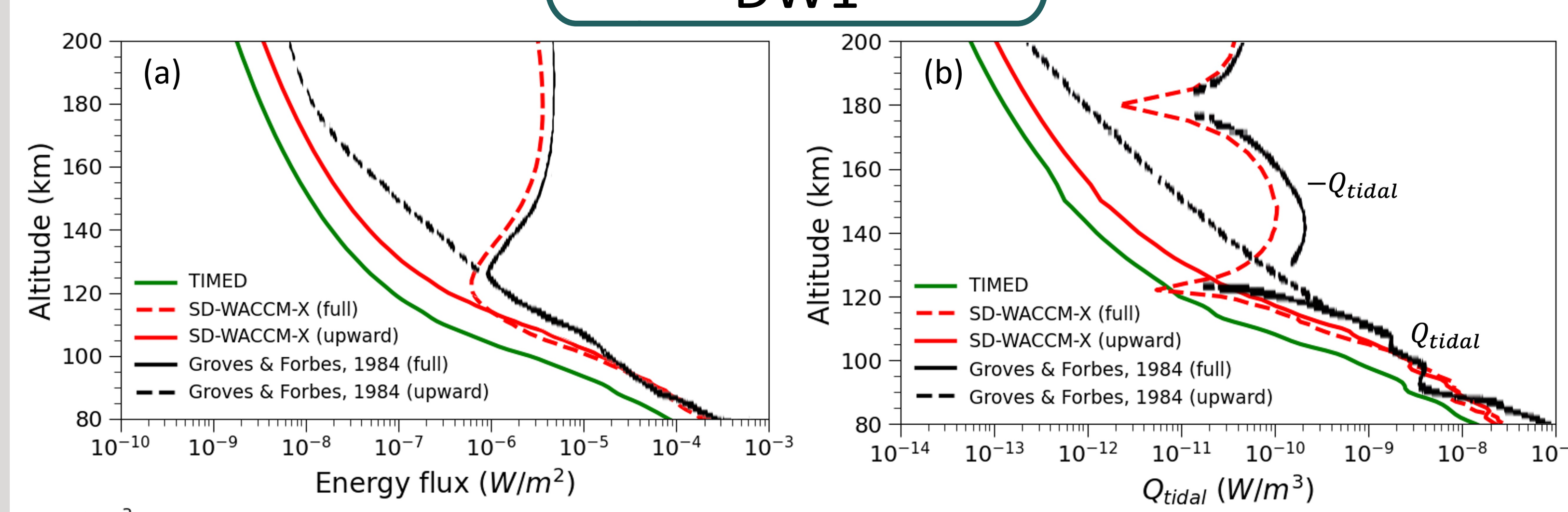
θ - colatitude

z - altitude

Energy fluxes are computed using HME fitted ϕ_h and ω amplitudes and phases. The presented results are global averages of the vertical energy fluxes.

Wave energy flux – TIMED vs. SD-WACCM-X

DW1



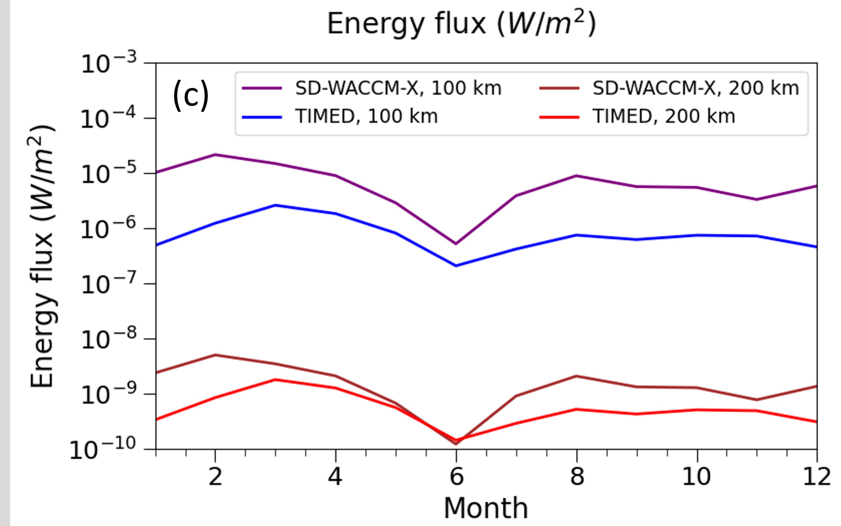


Figure 3: Comparison of (a) Global average wave energy flux, (b) Heating rate between TIMED, SD-WACCM-X, and Groves & Forbes, 1984 for Spring equinox 2009 for DW1, (c) Temporal comparison of wave energy flux for 2009 for DW1

DE3

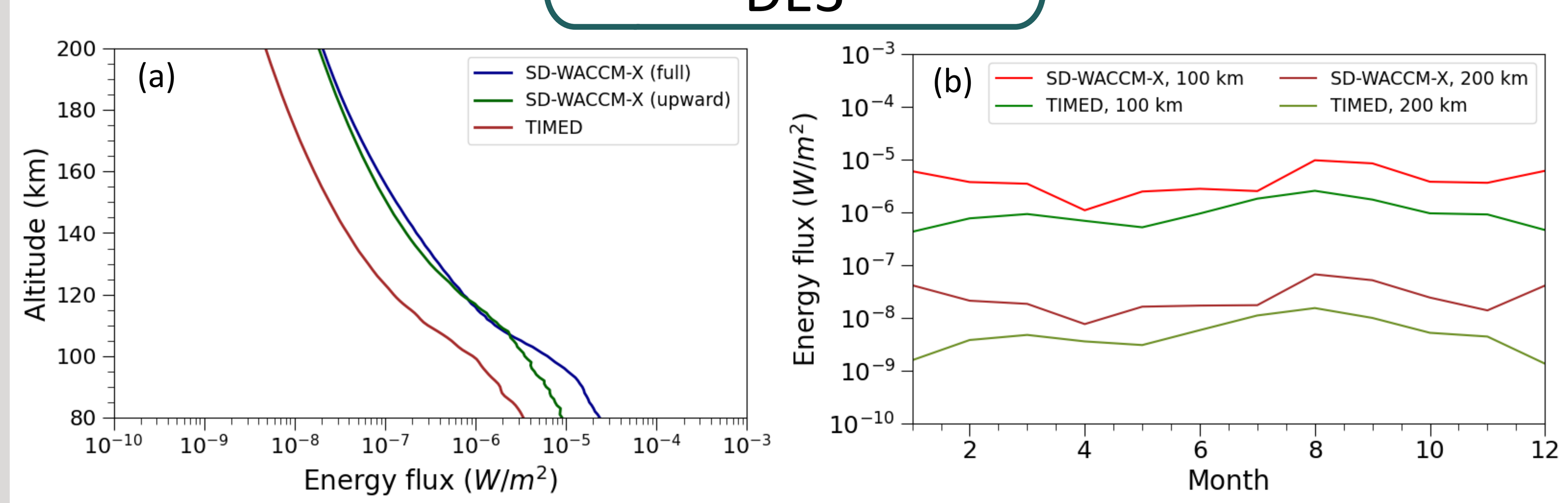


Figure 4: Comparison of Global average wave energy flux between TIMED and SD-WACCM-X for (a) March 2009, (b) Temporal comparison for 2009 for DE3

SW2

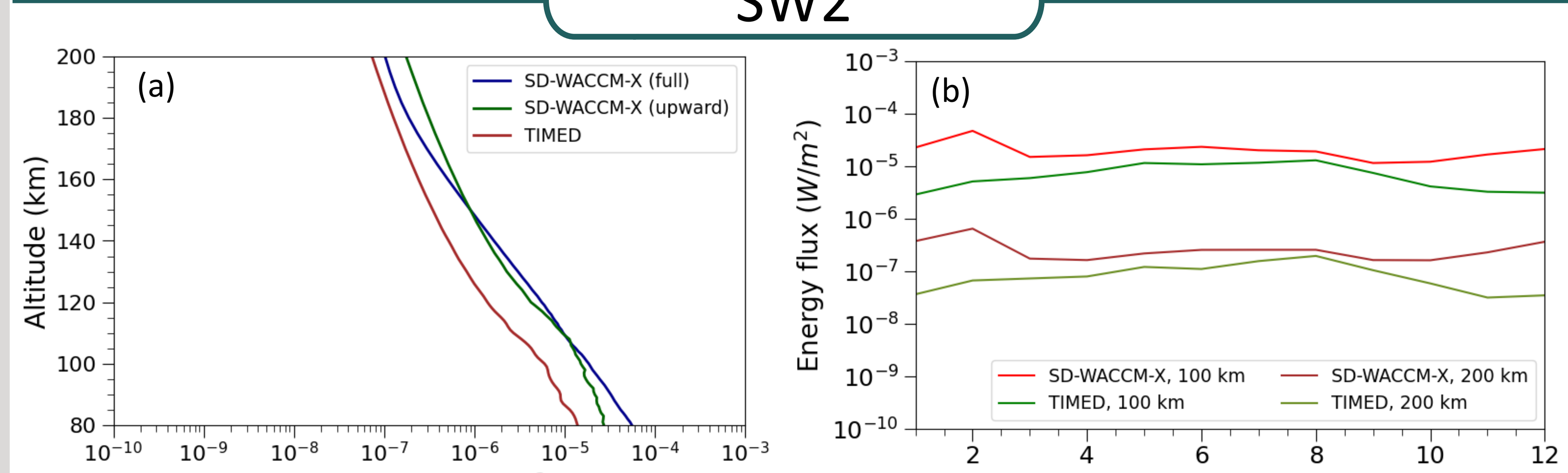


Figure 5: Same as Figure 4, but for SW2

Observations from TIMED provide smaller vertical wave energy flux values compared to the model.

Diurnal and semidiurnal wave energy fluxes – TIMED

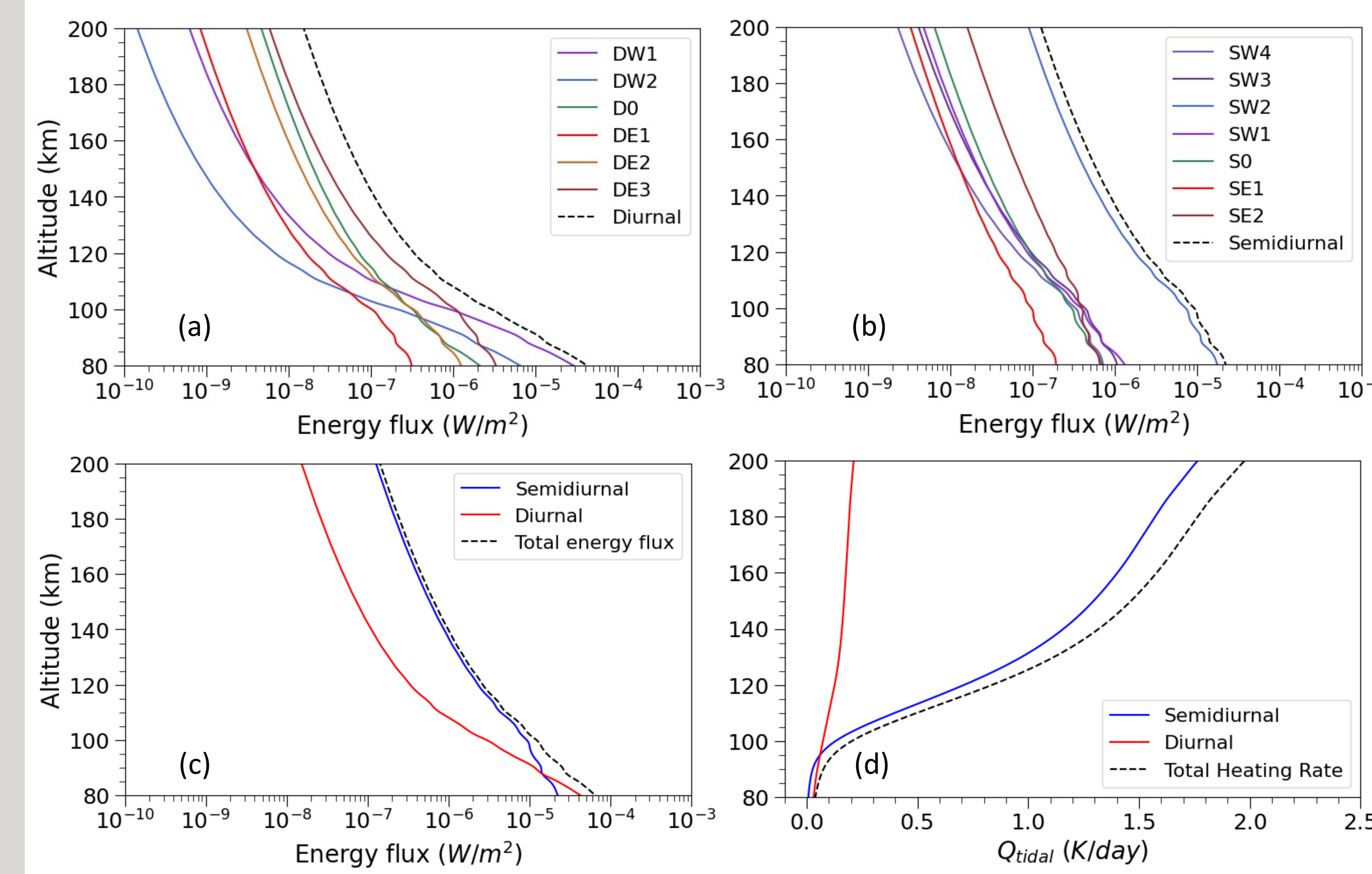
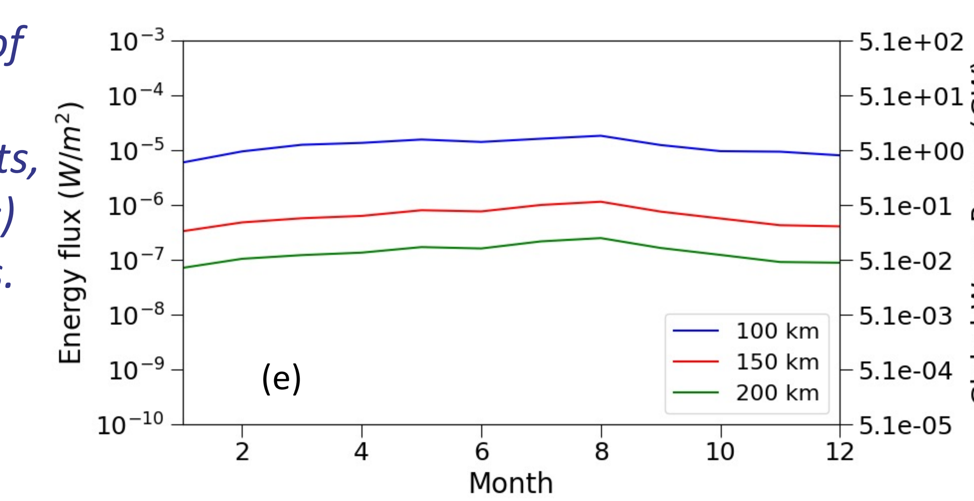


Figure 6: Global annual mean of upward wave energy flux for 2009 for (a) Diurnal components, (b) Semidiurnal components, (c) Total from all tidal components. (d) Total heating rate, (e) Temporal variability of energy flux values for 2009.



These plots show energy flux contribution only from upward propagating tides

Conclusions

- For **diurnal** tides, the wave energy flux below 100 km is dominated by the migrating diurnal tide DW1 while the nonmigrating DE3 tide becomes dominant above 100 km.
- For **semidiurnal** tides, the wave energy flux throughout the whole thermosphere is dominated by the migrating semidiurnal tide SW2.
- Most of the tidal wave energy flux is due to semidiurnal tides.
- The global tidal wave power is around 5 GW at 100 km.
- The total heating rate due to all upward propagating tidal components is approximately 2 K/day at 200 km.
- TIMED observation-based results indicate smaller vertical wave energy flux values than SD-WACCM-X and theory in Groves & Forbes, 1984.

References

Groves, G.V., and Forbes, J.M. (1984). Equinox tidal heating of the upper atmosphere. *Planet. Space. Sci.* 32, No. 4, pp. 447-456

Oberheide, J., Forbes, J. M., Zhang, X., and Bruinsma, S. L. (2011). Climatology of upward propagating diurnal and semidiurnal tides in the thermosphere. *Journal of Geophysical Research: Space Physics*, 116(11).

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