The quasi 2 day wave response in TIME-GCM nudged with NOGAPS-ALPHA

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ABSTRACT

The quasi 2 day wave (QTDW) is a traveling planetary wave that can be enhanced rapidly to large amplitudes in the mesosphere and lower thermosphere (MLT) region during the northern winter postsolstice period. In this study, we present five case studies of QTDW events during January and February 2005, 2006 and 2008–2010 by using the Thermosphere-Ionosphere-Mesosphere Electrodynamics-General Circulation Model (TIME-GCM) nudged with the Navy Operational Global Atmospheric Prediction System-Advanced Level Physics High Altitude (NOGAPS-ALPHA) Weather Forecast Model. With NOGAPS-ALPHA introducing more realistic lower atmospheric forcing in TIME-GCM, the QTDW events have successfully been reproduced in the TIME-GCM. The nudged TIME-GCM simulations show good agreement in zonal mean state with the NOGAPS-ALPHA 6 h reanalysis data and the horizontal wind model below the mesopause; however, it has large discrepancies in the tropics above the mesopause. The zonal mean zonal wind in the mesosphere has sharp vertical gradients in the nudged TIME-GCM. The results suggest that the parameterized gravity wave forcing may need to be retuned in the assimilative TIME-GCM.

INTRODUCTION

QUASI 2 DAY WAVE (QTDW)

- The quasi 2 day wave (QTDW) is one of the prominent planetary wave modes in Earth's mesosphere and lower thermosphere (MLT) region.
- Many observations from ground and space over last four decades have shown that this robust and recurrent planetary wave amplifies rapidly in the summer hemisphere around postsolstice times with a period of 40–60 h.
- The QTDW has a prominent westward propagating zonal wave number 3 in the austral summer, as well as westward propagating zonal wave number 3 and 4 (W3 and W4) in the boreal summer.

MOTIVATION

- At present, TIME-GCM must rely upon unrealistically large lower boundary perturbations, commonly the 3,0 Rossby-gravity normal mode in geopotential height at the lower boundary [Yue et al., 2012], to excite QTDW inside TIME-GCM simulations.
- This approach has been verified to resolve many salient features of QTDW events and has been helpful in identifying the mechanisms of QTDW-tidal interactions, the excitation mechanisms of the QTDW in the summer hemisphere, and the coupling of the QTDW in the neutral atmosphere with the ionosphere.
- On the other hand, this method also has some drawbacks, the most important one being that it results in an unrealistically large stratospheric QTDW response in TIME-GCM, although it does not affect the plausible excitation and duration of the QTDW in the MLT in TIME-GCM.
- Another concern is the consequences of this continuous forcing on the general circulation, which has not been investigated in previous studies.

QUESTION

- Can the TIME-GCM resolve the origin and propagation of the traveling planetary waves by the nudging method?
- Does the nudged TIME-GCM give a more realistic background atmosphere while avoiding the effects of a continuous unrealistic perturbation at the model lower boundary used in previous QTDW experiments?

METHOD

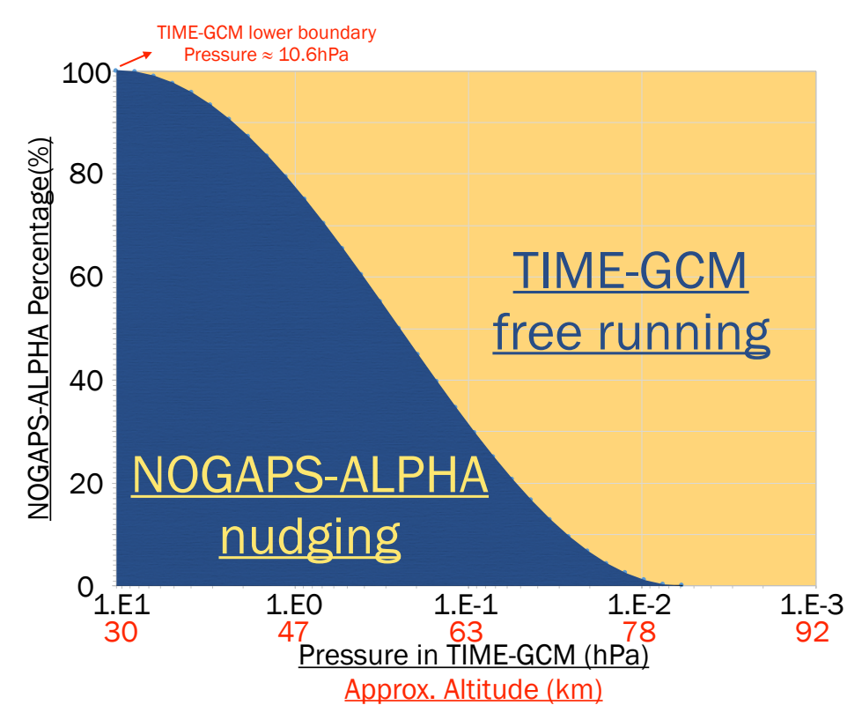


Figure 1. Schematic, illustrating the nudging ratio of NOGAPS-ALPHA in TIME-GCM.

- In this study, we utilize TIME-GCM version 1.5 with double resolution, a spatial grid of 2.5° in latitude and longitude, and 97 log pressure levels with vertical resolution of one quarter of a scale height. The model runs also assume a low geomagnetic activity condition with cross-tail potential = 30 kV and hemispheric power = 8 GW. The daily and 81 day average $F_{10.7}$ solar radiation values are 70, which represents the solar minimum condition. The model time step is 30 s.
- Following the method introduced by Liu et al. [2013], we conduct a one-way coupling between NOGAPS-ALPHA and TIME-GCM from the stratosphere to the mesosphere by equations (1)–(4):

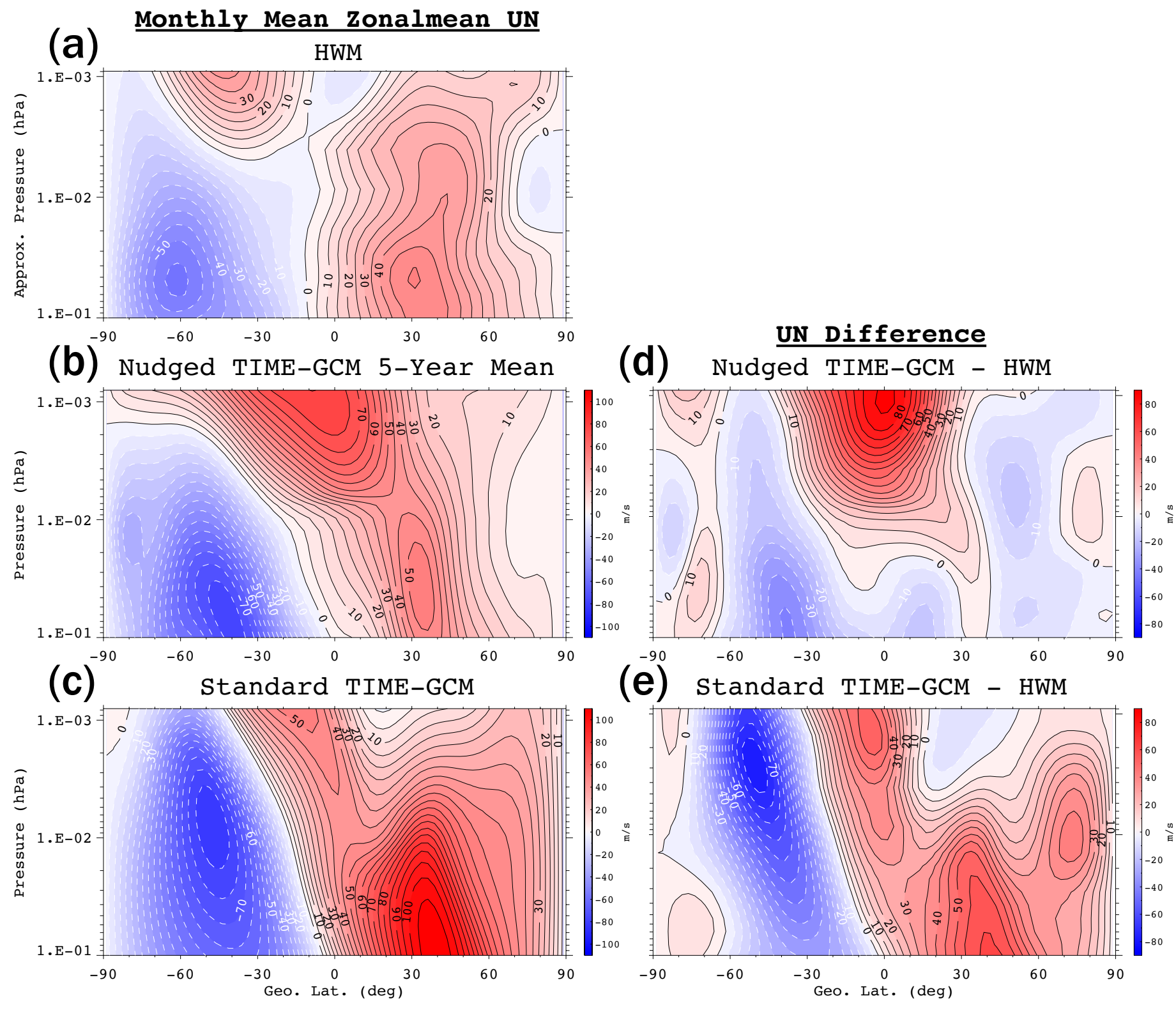
$$T_{\text{nudged}}(\lambda,\theta,z,t) = \zeta(z)T_{\text{NOGAPS-ALPHA}}(\lambda,\theta,z,t) + [1-(\zeta(z))]T_{\text{original}}(\lambda,\theta,z,t) \qquad (1)$$

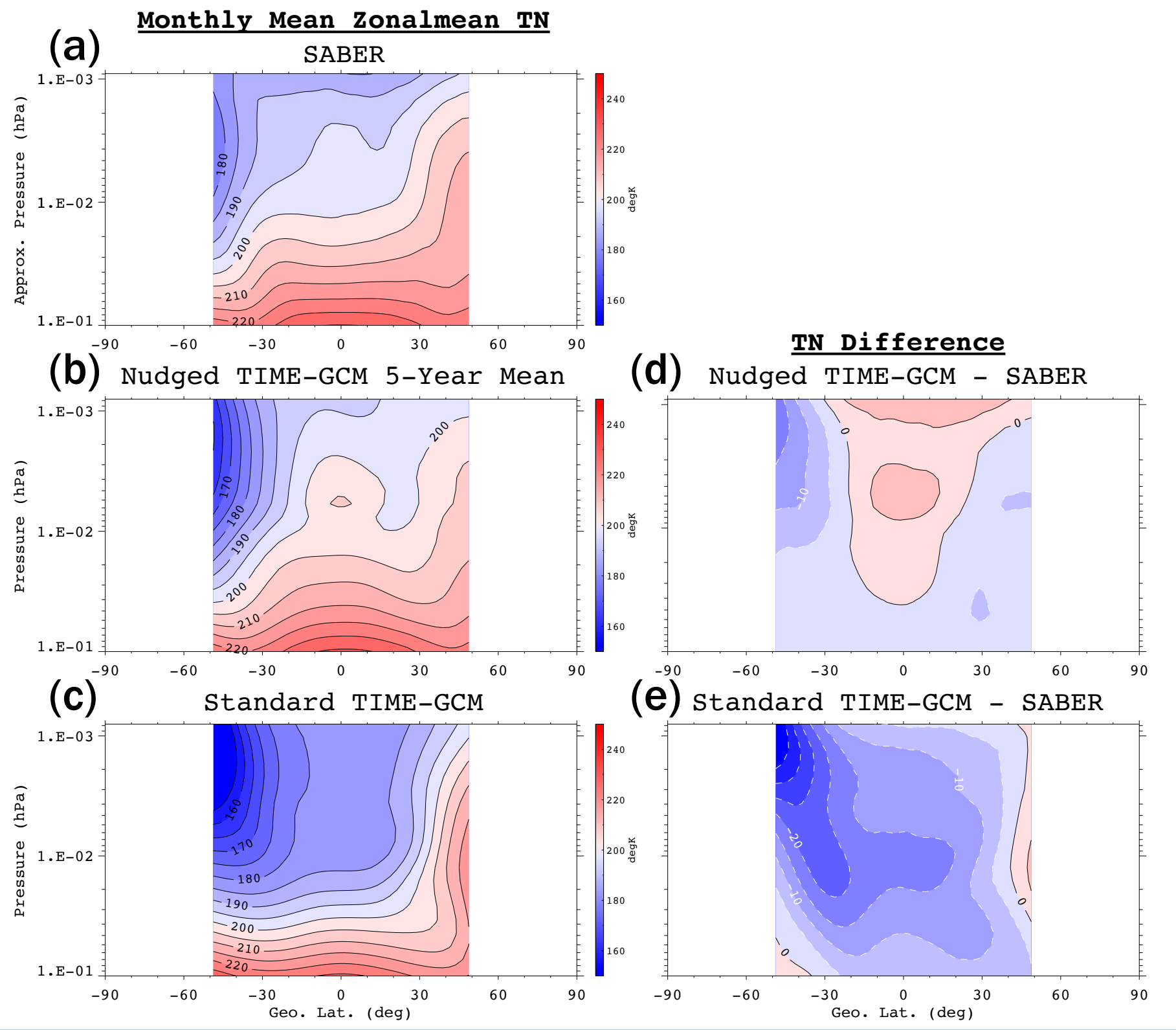
$$U_{\text{nudged}}(\lambda,\theta,z,t) = \zeta(z)U_{\text{NOGAPS-ALPHA}}(\lambda,\theta,z,t) + [1-(\zeta(z))]U_{\text{original}}(\lambda,\theta,z,t) \qquad (2)$$

$$V_{\text{nudged}}(\lambda,\theta,z,t) = \zeta(z)V_{\text{NOGAPS-ALPHA}}(\lambda,\theta,z,t) + [1-(\zeta(z))]V_{\text{original}}(\lambda,\theta,z,t) \qquad (3)$$

$$\zeta(z) = \cos^2\left(\frac{\pi}{2}\times\frac{z-z_{\text{LBC}}}{z_{6\times10^{-3}\text{hPa}}-z_{\text{LBC}}}\right) \qquad (4)$$

ZONAL MEAN STATE OF NUDGED TIME-GCM

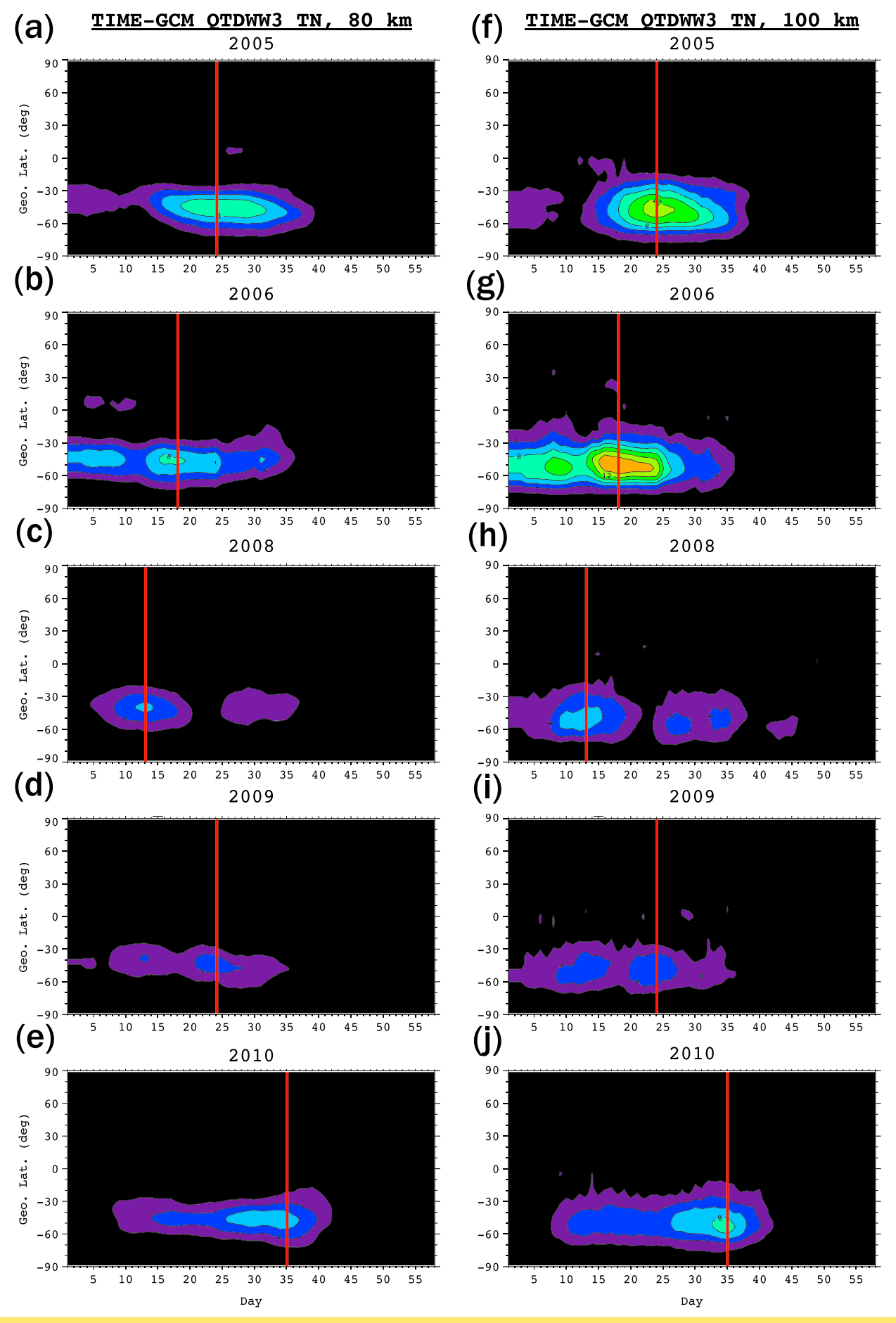


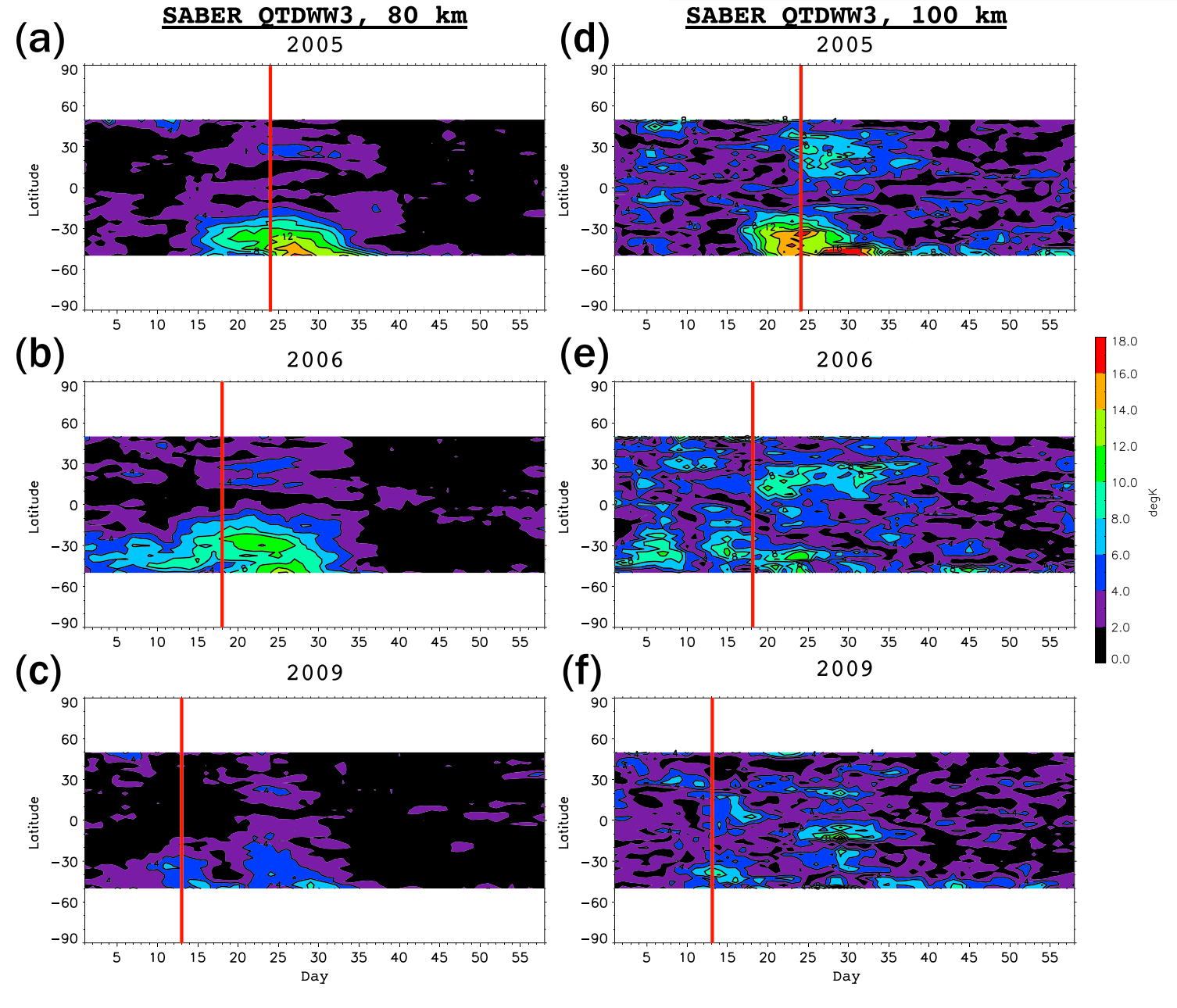


- These results can serve as benchmarks for the nudged TIME-GCM.
- The mesospheric low latitudes have a relatively strong eastward jet and warmer in nudged TIME-GCM.
- It is apparent that the nudged TIME-GCM run has a better agreement in mesospheric midlatitudes than standard TIME-GCM run.
- However, the nudged TIME-GCM has a notable discrepancy with the HWM climatology in the tropics. (Fig. 2d)
- One potential reason for these discrepancies is that the gravity wave parameterization needs to be retuned to account for the presence of nudging [Pedatella et al., 2014; Maute et al., 2015].
- It has already been known that gravity wave drag can play a crucial role in the dynamical structure of the MLT region [McLandress, 1998], and our nudging approach constrains the stratospheric zonal mean state, which will strongly affect the gravity wave propagation and filtering by the critical layers in the model.

Figure 2. (left) (a) The monthly mean zonal mean zonal wind from HWM in January. (b) The 5 year average monthly mean zonal mean zonal wind from TIME-GCM nudged with NOGAPS-ALPHA in January. (c) The monthly mean zonal mean zonal wind from TIME-GCM standard run in January. (d) The difference between the nudged TIME-GCM and HWM. (e) The difference between the standard TIME-GCM and HWM. The contour interval is 5 m/s.
Figure 3. (right) The 5 year average monthly mean zonal mean temperature in January (a) from SABER. (b) from TIME-GCM nudged with NOGAPS-ALPHA. (c) The monthly mean zonal mean zonal wind from TIME-GCM standard run in January. (d) The difference between the nudged TIME-GCM and SABER. (e) The difference between the standard TIME-GCM and SABER. The contour interval is 5 K.

QTDW RESPONSE IN TIME-GCM





- It can be clearly seen that the amplitudes in all 5 years reach their maximum during the postsolstice period, and these maxima show peaks occurring around 40–50°S in 80 km; at 100 km, the maximum amplitudes appear around 45–55°S.
- In general, the QTDW W3 events in our simulation have a duration of 20–35 days, though often the amplitudes show a double peak separated by about 10–15 days.
- The corresponding QTDW W3 events obtained from the SABER observations show similar interannual variation to the model at 80 km.
- Interestingly, there were weak QTDW peaks at 100 km in the Northern Hemisphere, which were not seen in the TIME-GCM simulations, though the peaks in the Northern Hemisphere were only 4–5 K.
- One hypothesis for the underestimation of the QTDW W3 amplitudes in the Northern Hemisphere in TIME-GCM is the overestimation of the zonal mean zonal wind in the Northern Hemisphere [Chang et al., 2011a].
- When a continuous artificial geopotential perturbation applied at the model lower boundary, an unrealistic stronger eastward wind in the model stratosphere is unfavorable to the vertical propagation of the planetary wave.

Figure 4. (left) QTDW W3 amplitudes in TIME-GCM nudged with NOGAPS-ALPHA simulations as a function of geographic latitude and time for southern summers (a–e) at 80 km, (f–j) at 100 km during 2005, 2006, 2008-2010. Day 1 corresponds to 1 January; the day of peak QTDW amplitudes is marked by the thick red line. The contour interval is 2 K.
Figure 5. (right) Same as Fig. 4 but from SABER observations during 2005, 2006, and 2009.

SUMMARY

In this research, we report a novel method of nudging the TIME-GCM with the output from a data driven weather forecast model, NOGAPS-ALPHA. Although this approach achieves our main goal in this research of reproducing a realistic QTDW response in a TIME-GCM simulation without resorting to artificially large forcing at the model lower boundary, the zonal mean zonal wind has significant discrepancy above the low-latitude mesopause. The zonal behavior agrees quite well below the mesopause between the TIME-GCM simulations and the observations. However, discrepancies in the zonal mean zonal winds and temperatures arise above the mesopause. The zonal mean zonal wind is substantially more eastward in the tropical region, and the zonal mean temperature is considerably warmer between the southern midlatitudes through the Arctic. The zonal mean wind climatology from HWM indicates that the zonal mean wind above the mesopause in the nudged TIME-GCM is problematic. The zonal mean wind from the nudged TIME-GCM has an unrealistic eastward jet sitting in the thermosphere tropics.

The main difference in zonal mean state between TIME-GCM and NOGAPS-ALPHA might be due to the different gravity wave parameterizations used in the two models (Table). This suggestion follows that of Maute et al. [2015] who nudged the TIME-GCM with WACCM-X-L116/GEOS-5 (WACCM-X with 116 height levels and Specified Meteorology from the Goddard Earth Observing System Data Assimilation System version 5 (GEOS-5)) up to ~95 km and also produced sharp vertical gradients in the zonal mean zonal wind at the low-latitude region. This is similar with our results. Certainly, the resolution of this question is an important topic for future work but beyond the scope of the present study.

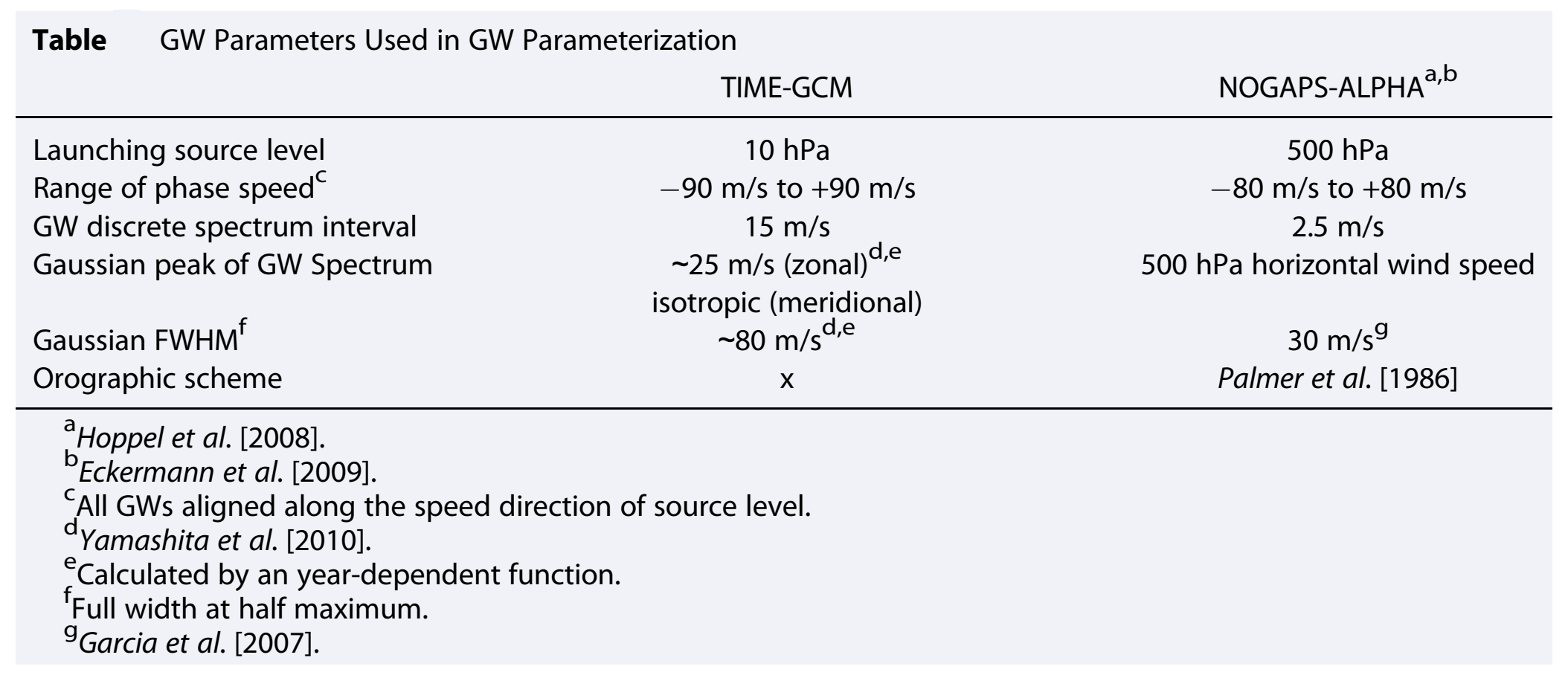


Table GW Parameters Used in GW Parameterization

	TIME-GCM	NOGAPS-ALPHA[a,b]
Launching source level	10 hPa	500 hPa
Range of phase speed[c]	−90 m/s to +90 m/s	−80 m/s to +80 m/s
GW discrete spectrum interval	15 m/s	2.5 m/s
Gaussian peak of GW Spectrum	~25 m/s (zonal)[d,e] isotropic (meridional)	500 hPa horizontal wind speed
Gaussian FWHM[f]	~80 m/s[d,e]	30 m/s[g]
Orographic scheme	x	*Palmer et al.* [1986]

[a] *Hoppel et al.* [2008].
[b] *Eckermann et al.* [2009].
[c] All GWs aligned along the speed direction of source level.
[d] *Yamashita et al.* [2010].
[e] Calculated by an year-dependent function.
[f] Full width at half maximum.
[g] *Garcia et al.* [2007].