Momentum Budget Analysis of the Migrating Diurnal Tide in WACCM4: Effects of Gravity Wave Forcing and Advection

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Mean Winds



Mean Temperature



Meteor Radar Observation Amplitude of the diurnal tide (Maui, HI, 21°N)



Semiannual Oscillation (SAO) of amplitude (Maui, 21°N)



SAO of Amplitude Cerro Pachon, Chile (30°S)



Tidal Amplitudes

Momentum Budget Analysis

Advection Term:
$$-\vec{V} \cdot \nabla u = -(\frac{u}{a\cos\phi}\frac{\partial u}{\partial\lambda} + \frac{v}{a}\frac{\partial u}{\partial\phi} + w\frac{\partial u}{\partial z})$$

Linear advection Term:

$$\begin{cases} u = \overline{u} + u' \\ v = \overline{v} + v' \\ w = \overline{w} + w' \end{cases} \Rightarrow F_{LinAd,x} = -\left(\frac{v'}{a}\frac{\partial u}{\partial \phi} + w'\frac{\partial u}{\partial z}\right) - \left(\frac{\overline{u}}{a\cos\phi}\frac{\partial u'}{\partial \lambda} + \frac{\overline{v}}{a}\frac{\partial u'}{\partial \phi} + \frac{\overline{v}}{\partial z}\right)$$

WACCM

Amplitude of Time Tendency (Zonal Wind)

Zonal Time Tendency Amplitude (m/s/day) W1 Mar Alftude (km) -40 -20 Latitude (degree) Total Zonal Advection Forcing Amplitude (m/s/day)

Total Zonal GW Forcing Amplitude (m/s/day)

GW+Advection Zonal Forcing Amplitude (m/s/day)

Amplitude of Time Tendency (Meridional Wind)

Meridional Difference Amplitude (m/s/day) W1 Mar

Total Meridional Advection Forcing Amplitude (m/s/day)

GW+Advection Meridional Forcing Amplitude (m/s/day)

Which advection is more dominant?

(b) Nonlinear Zonal Advection Amplitude (m/s/day) W1

GW sources Frontogenesis > Convection> Orography

Equivalent Rayleigh Friction

[Miyahara and Forbes, 1991]

$$\begin{aligned} \frac{\partial u'}{\partial t} &= F' \\ u' &= \hat{u}(t)e^{i(\omega t - s\lambda)} = a(t)e^{i(-\varphi(t))}e^{i(\omega t - s\lambda)} = a(t)e^{i(\omega t - s\lambda - \varphi(t))} \\ F' &= \hat{F}_u(t)e^{i(\omega t - s\lambda)} \end{aligned}$$

Define the Equivalent Rayleigh Friction as:

$$ERF = -\frac{\hat{F}_u}{\hat{u}} = -\frac{\frac{\partial a(t)}{\partial t}}{a(t)} - i(\omega - \frac{\partial \varphi(t)}{\partial t})$$

Real Part of ERF determines the amplitude change and imaginary part determines the phase change.

ERF Real Part (Zonal Wind)

20

10

-10

-20

-30

30

20

10

-10

-20

-30

-40

Latitude (degree)

Gravity Wave Linear Advection LinAd Real ERF-U mar(10⁻⁶s⁻¹) GW Real ERF-U mar(10⁻⁶s⁻¹) _10 ාන 115 115 30 110 110 d_{2} 105 105 20 100 100 10 95 95 Altitude (km) Altitude (km) 90 90 85 85 F. -10 80 80 -20 75 75 70 70 -30 65 65 -40 -30 -20 -10 20 30 40 0 10 -40 -30 -20 -10 0 Latitude (degree) 10 20 30 40 Latitude (degree) **Nonlinear Advection** Total Total Real ERF-U mar(10⁻⁶s⁻¹) NlinAd Real ERF-U mar(10⁻⁶s⁻¹) 115 115 110 110 30 105 105 20 100 100 10 95 95 Altitude (km) Altitude (km) S \diamond 90 90 85 85 -10 40 80 80 -20 75 75 70 70 S -30 65 65 -40 -30 -20 -10 0 10 20 30 40 -40 -30 -20 -10 0 10 20 30 40

Latitude (degree)

ERF Imaginary Part (Zonal Wind)

ERF Imaginary Part (Meridional Wind)

Gravity Wave

Frontogenesis-GW drag to mean flow Units: m/s/day

Convection-GW drag to mean flow Units: m/s/day

Oct

-50-40-30-20-10 0 10 20 30 40 50 Latitude (Degree)

0 -50-40-30-20-10 0 10 20 30 40 50 Nov

Apr

120

30

20

10

0

-10

Frontogenesis-GW drag to the migrating diurnal tide

Convection-GW drag to the migrating diurnal tide

Conclusions

- Advection and GW drag are two most important terms to account for the momentum budget of the migrating diurnal tide.
- For zonal wind, the magnitudes of linear advection and GW forcing are comparable while for the meridional wind, advection is more dominant.
- GW drag always damps the tide and advances its phase.
- For the zonal wind, GW is most responsible to change the amplitude and linear advection to the change of tidal phase. In meridional wind, nonlinear advection is the most significant factor to change both amplitude and phase of tide.
- GW drag is strongly modulated by the migrating diurnal tide, the seasonal variation of GW forcing is more like a feedback to that of the tidal modulation, rather than a cause for the seasonal variation of tide.

Thank you!