Parameterized Gravity Wave Effects on Major Tidal Modes in eCMAM and WACCM

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MLTT-03

Introduction

Global Circulation Models (GCMs) are global scale models used to study and predict the state of the atmosphere. These models typically use limited resolution due to current computational limits. While certain dynamical features of the atmosphere can be directly resolved such as thermal tides and planetary waves, smaller scale features such as gravity waves must be parameterized for their effects to be included. It has been shown that the interaction between the parameterized gravity waves and the thermal tides have a strong dependency on the type of gravity wave parameterization scheme used in a GCM. A comparative analysis of the DW1 thermal tide between the eCMAM and the WACCM and GW parameterization schemes is presented here. Contributions from each term in the momentum equations to the tidal forcing are considered to determine how much of the differences in tidal forcing between the models is due to GW parameterization schemes. Several properties of the schemes are also considered such as forcing direction relative to the wind and dissipation altitude.

eCMAM Model Description

- Grid resolution is T32
- GW Sources separated into Orographic and Non-Orographic
- Horizontal winds and temperature are nudged from the bottom using the ERA Interim reanalysis data
- GW's are parameterized using the Hines Doppler Spread Scheme

WACCM Model Description

- Horizontal resolution is 2.5° in longitude and 1.89° latitude
- GW sources separated into Orographic, Convective and Frontogenesis
- Horizontal winds and temperature are nudged from the bottom using the GEOS-5 data
- GW's are parameterized using the Lindzen scheme

DW1 Tidal Components in eCMAM and WACCM

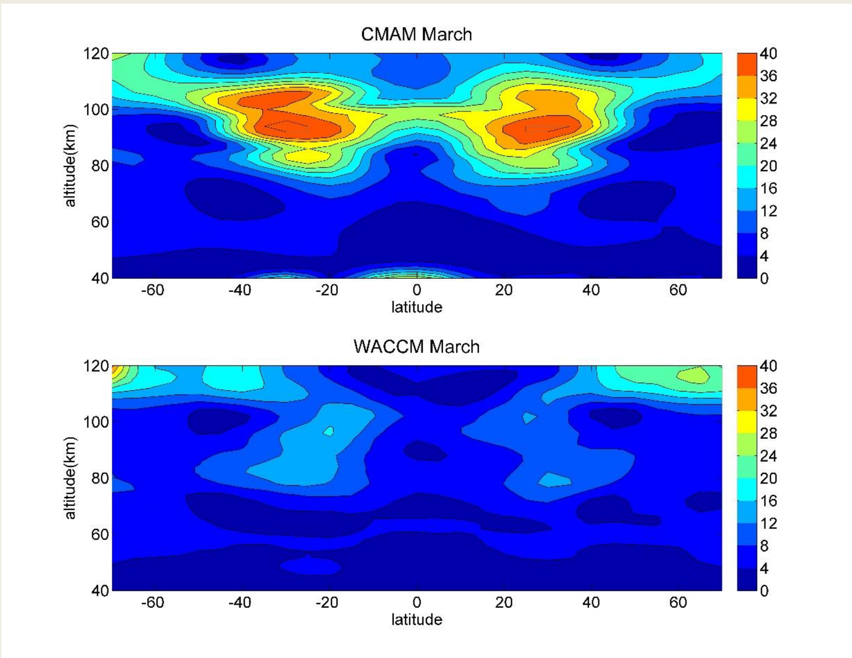


Figure 1: Amplitude of the Zonal DW1 Tide (m/s) in March

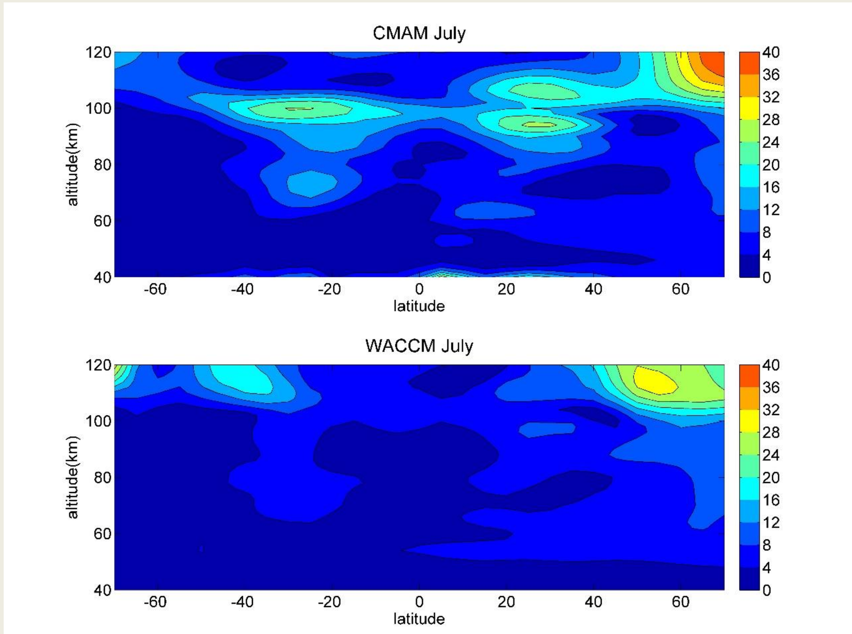


Figure 2: Amplitude of the Zonal DW1 Tide (m/s) in July

- The above figures show the amplitude of the DW1 tide in both models in March and July calculated from a 2D FFT in longitude and time at every latitude and altitude. As predicted by previous studies, the DW1 amplitude in eCMAM is larger than WACCM with a similar structure.
- The amplitudes are much larger in CMAM throughout the year at mid latitudes but are more similar at high latitudes.

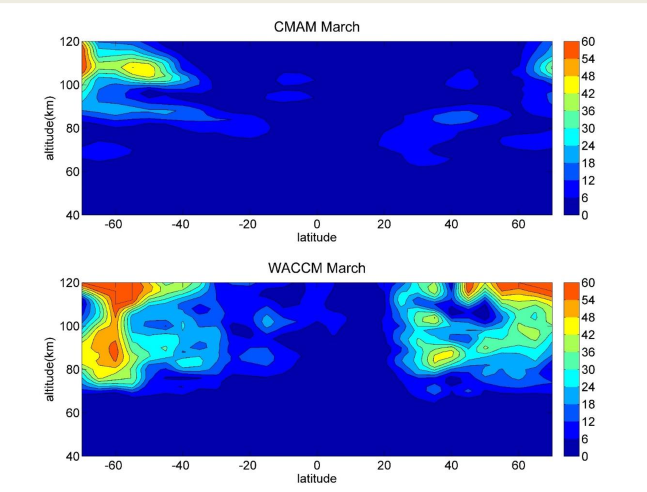


Figure 3: Amplitude of the Zonal DW1 components of the GW Forcing (m/s/day) in March

- Figures 3 and 4 show the DW1 component of the GW forcing in both models in March and July
- At high latitudes above 100km, the GW forcing is similar in both models which corresponds to areas where the tide is similar.
- The largest differences occur at mid-latitudes where the DW1 component of GW forcing is much stronger.
- Large magnitudes of the GW forcing in WACCM are near the DW1 tidal maximums but locations of strong GW forcing do not generally occur where DW1 is strongest.
- Stronger DW1 components of the GW drag are present at locations where the DW1 tide is largest in July in both models.

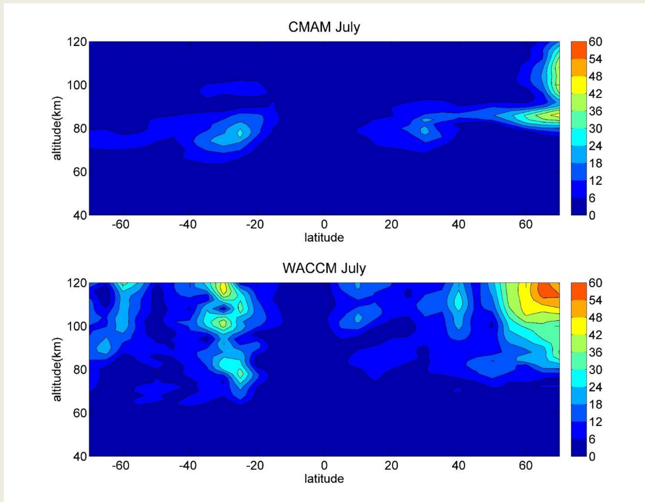


Figure 4: Amplitude of the Zonal DW1 components of the GW Forcing (m/s/day) in March

Momentum Balance of the Tide

- Each term in the momentum equations was calculated at every grid point as follows:

$$\frac{\partial u}{\partial t} = fv - \frac{1}{a * \cos(\phi)}\frac{\partial \Phi}{\partial \lambda} + \frac{uv}{a}\tan(\phi) - \vec{V}\cdot\nabla u + F_{GW_x} + X$$

Where X and Y are considered as residuals containing various smaller forcings such as molecular and eddy diffusion and ion drag in the zonal direction, a is the earths radius and:

$$-\vec{V}\cdot\nabla u = -F_{advection_x} = -\left(\frac{u}{a * \cos(\phi)}\frac{\partial u}{\partial \lambda} + \frac{v}{a}\frac{\partial u}{\partial \phi} + w\frac{\partial u}{\partial z}\right)$$

- A 2D FFT in longitude and time was calculated at every latitude and altitude for each momentum equation term in each month.
- At most latitudes the classical terms (Coriolis and Pressure Gradient) have the largest effect on the tide with the gravity wave effect being smaller.
- There is a region in March (35° latitude and 86km) in WACCM however where GW's have a larger amplitude rate on the tide compared to the classical terms.
- GW's have a smaller effect in CMAM at this particular latitude and altitude.

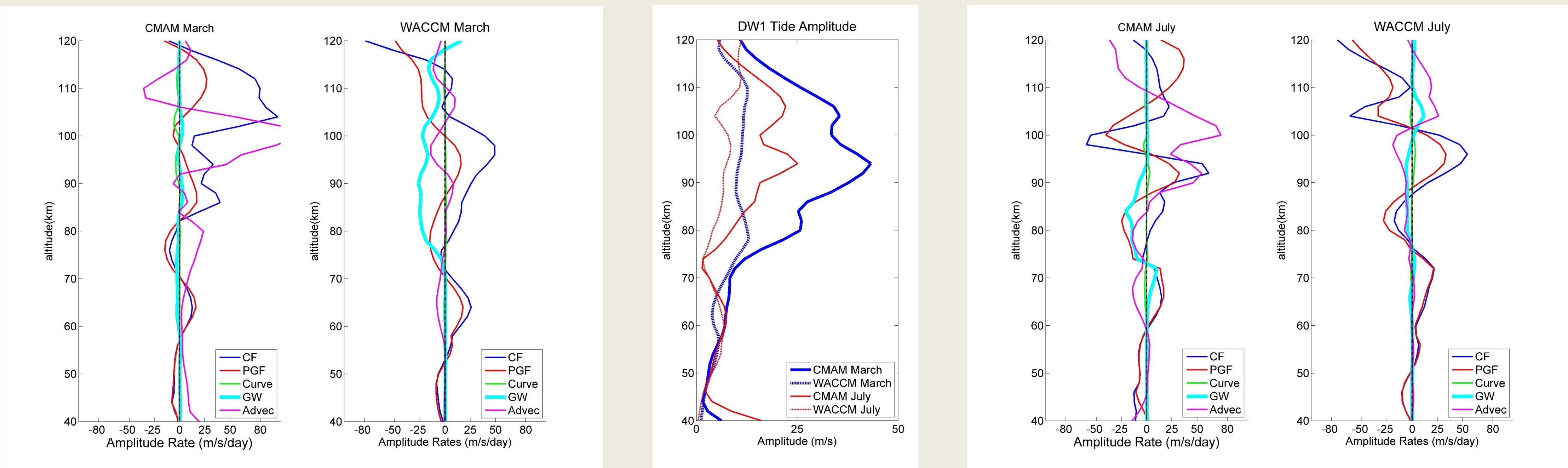


Figure 5: Amplitude rates of DW1 tide due to momentum terms at 35° latitude in March (Left) and July (Right) and the DW1 Zonal Amplitude at 35° latitude (Center)

- Figure 5 show the amplitude rate from each momentum term and the DW1 wind amplitude across entire altitude range at this latitude for March when DW1 is strong and for July when the tide is weaker.
- Generally, the Coriolis Force and the Pressure Gradient Force act together to either increase or dampen the tide.
- The forcing from Curvature is negligible.
- The GW and/or the Advective forcing generally act to counteract the classical terms.
- In March, when the tidal amplitudes are very different between models, the GW forcing on the tide is much larger in WACCM while the Coriolis forcing is much smaller.
- In July, when the tidal amplitudes are similar, the GW forcing and the Coriolis forcing on the tide is similar in both models.
- This latitude is an example. Other latitudes also show the pattern of increasing GW forcing amplitude rates on the tide corresponding to decreasing Coriolis forcing amplitudes rates on the tide.
- This indicates different balancing in the momentum equation to account for increased GW drag.

Non-Tidal Compnents of GW Parameterization Schemes effects on the Wind

- Figures 6 and 7 show the monthly mean wind and GW forcing in WACCM and CMAM.
- Both the wind and the GW forcing are very similar in both models below 60km. This is true at all latitudes, not just the examples shown here.
- The largest difference in the mean winds occur at locations where the GW forcing between models are more different.
- WACCM sometimes shows similar GW forcing magnitudes to CMAM at certain altitudes but it is much larger above.

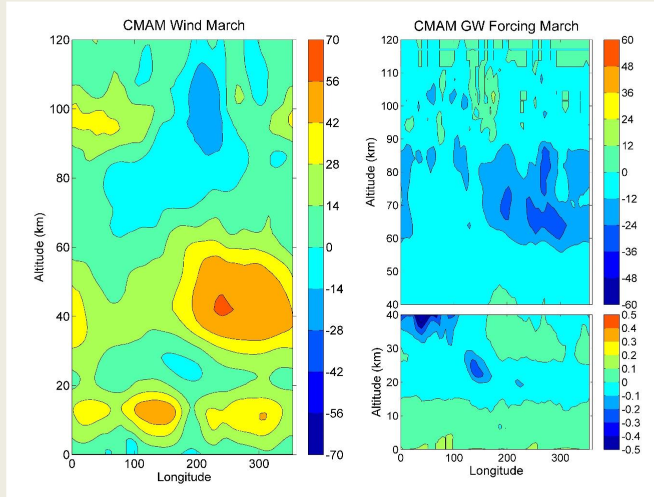


Figure 6: Monthly Mean Winds (m/s) and GW Forcing (m/s/day) in CMAM at 35° latitude

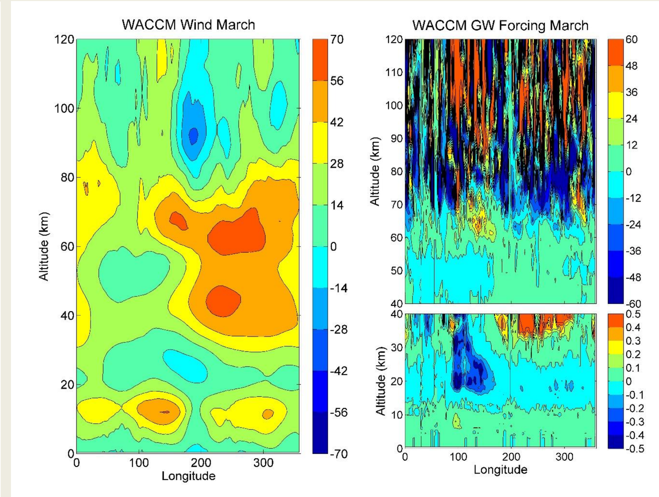
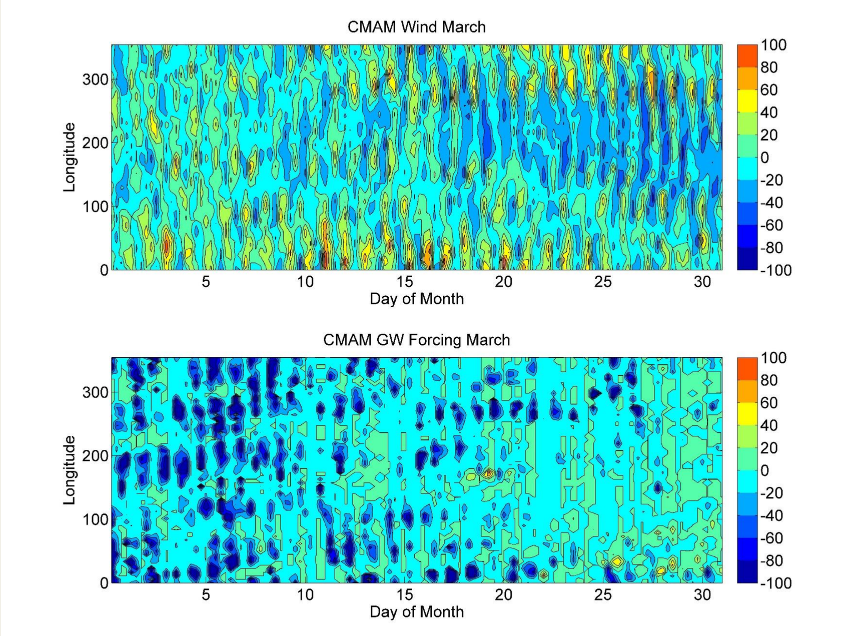


Figure 7: Monthly Mean Winds (m/s) and GW Forcing (m/s/day) in WACCM at 35° latitude



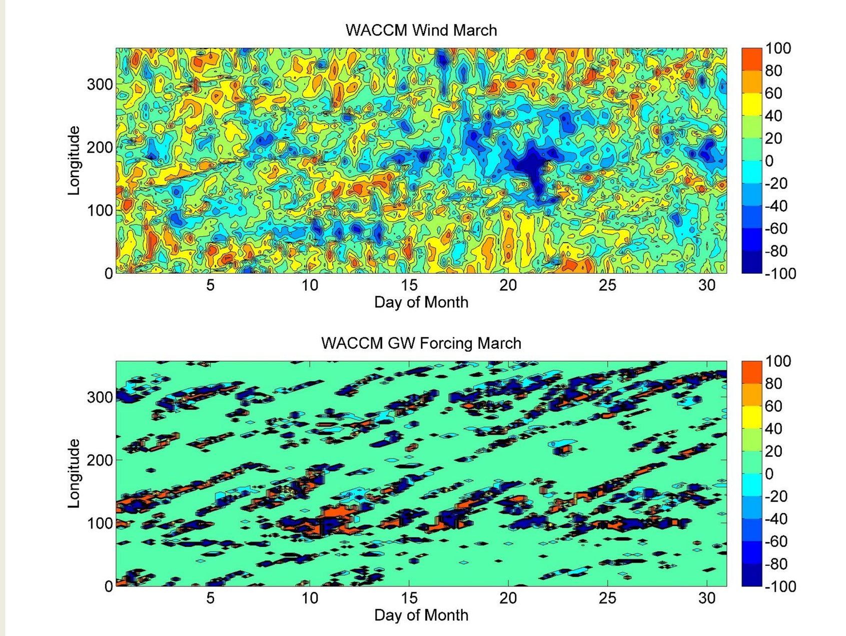
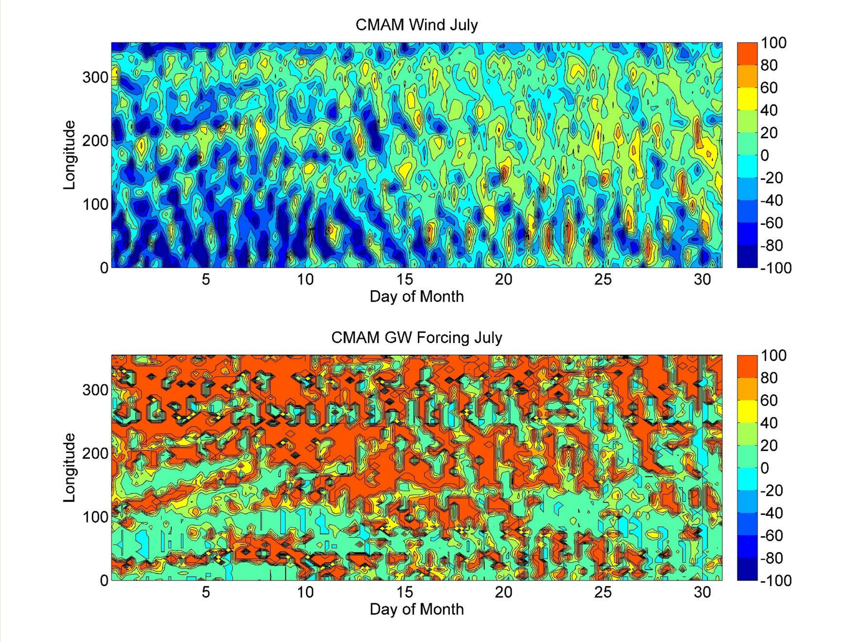


Figure 8: Zonal Wind (m/s) and GW Forcing (m/s/day) at 35° latitude and 84km in CMAM (Left) and WACCM (Right) in March



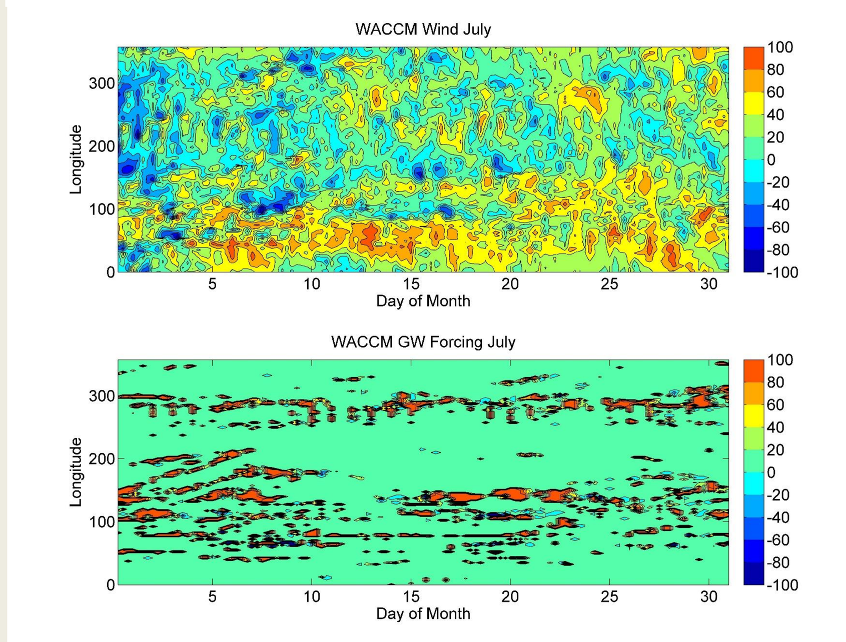


Figure 9: Zonal Wind (m/s) and GW Forcing (m/s/day) at 35° latitude and 84km in CMAM (Left) and WACCM (Right) in July

- Figures 8 and 9 show the longitude-time cross section of the GW forcing and the wind at 84km and 35° latitude.
- The diurnal variations are clearly visible in the wind field in CMAM for March whereas it is noisier in WACCM.
- The GW field in CMAM also shows modulation by the tide in both months that is not clearly visible in WACCM.
- In WACCM, GW's are only present when a certain event occurs to activate a trigger function in the source region.
- The time and location of GW drag in WACCM depends highly on the source region. This is why there is not a clear modulation of GW's by the tide at the upper altitudes.
- The Hines GW parameterization scheme in CMAM assumes a broad spectrum of waves are always present. As the GW spectrum propagates upward, the linearity of the spectrum breaks down and a tail is formed spreading the energy into the wider spectrum. The waves in the tail of the spectrum are assumed obliterated after some cutoff vertical wavenumber and their energy deposited into the background.
- The change in the spectrum is dependent on the background wind conditions at the altitude around where the wave is obliterated which explains why the forcing can have a clearer modulation.

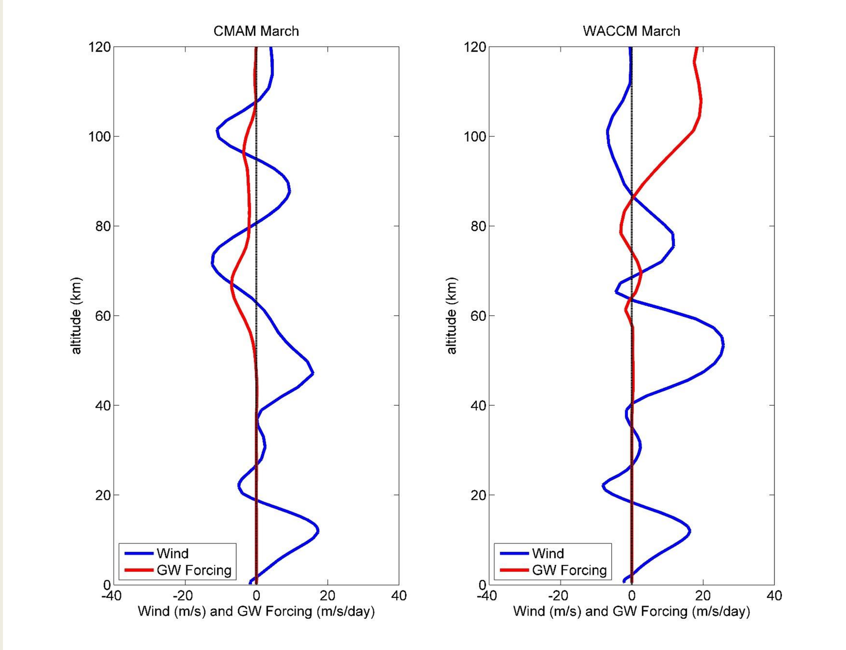


Figure 10: Mean Zonal Winds (m/s) and GW Forcing (m/s/day) in March between -40° and 40°

Mean Wind and GW Forcing Profile

- Figure 10 shows the mean winds and GW forcing in March for both models between -40° and 40° latitude.
- A wavelike structure that is most likely the DW1 tide is seen in the winds above 70km in CMAM. The GW forcing also shows a weak wavelike signature at the same altitudes that is about 90° out of phase with the wind. This is why the amplitude rate on the tide by GW's are not strong at these latitudes.
- A similar DW1 signature is seen in the WACCM winds and GW forcing between 70km and 90km. This is also approximately 90° out of phase. The winds also show a much shorter vertical wavelength.
- The major difference is above 90km where the GW forcing in WACCM greatly increases. This is also where the DW1 tide is greatest. The increased GW forcing in WACCM changes the vertical wind structure so that the DW1 signature is much weaker and has a shorter vertical wavelength.

Summary and Conclusion

- The strongest regions of the DW1 component of the GW forcing do not overlap very much with the strongest regions of the DW1 winds in March except at higher latitudes and altitudes. This indicates that the DW1 component of the GW forcing in both models does not directly change the DW1 tide at low to mid latitudes.
- Increased GW drag in WACCM is mainly counterbalanced with a change in the Coriolis Forcing.
- The monthly mean winds and GW forcing are very similar in both models below 60km.
- The largest difference in the monthly mean winds occur at locations where the GW forcing between models are more different.
- The GW field in CMAM shows modulation by the DW1 winds that is not seen in WACCM.
- This is due to the time and location of the existence of GW's in WACCM being highly dependent on trigger functions in the source region.
- CMAM on the other hand assumes a broad spectrum of waves are always present. The forcing is dependent on the shape of the spectrum at the obliteration altitude which in turn depends on the background winds in that region.
- The increased GW drag above 90km in WACCM where the DW1 tide is strongest, changes the vertical wind structure so that the DW1 signature is much weaker. The vertical GW profile in CMAM is much smaller and is approximately 90° out phase with the DW1 winds at these altitudes. This changes the phase but not the amplitude of DW1.

Acknowledgements

- This work is supported by NSF grants AGS-1115249 and AGS-1110199.
- Thanks to Dr. Jian Du of the University of Louisville for providing the eCMAM data used for this study