Tropical Gravity Wave Observations and WACCM6 Parameterized Gravity Waves from Convection: Implications for Simulation of the QBO

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Outline & Summary

I. Observations to evaluate gravity waves (GW) and Zhang-McFarlane convection

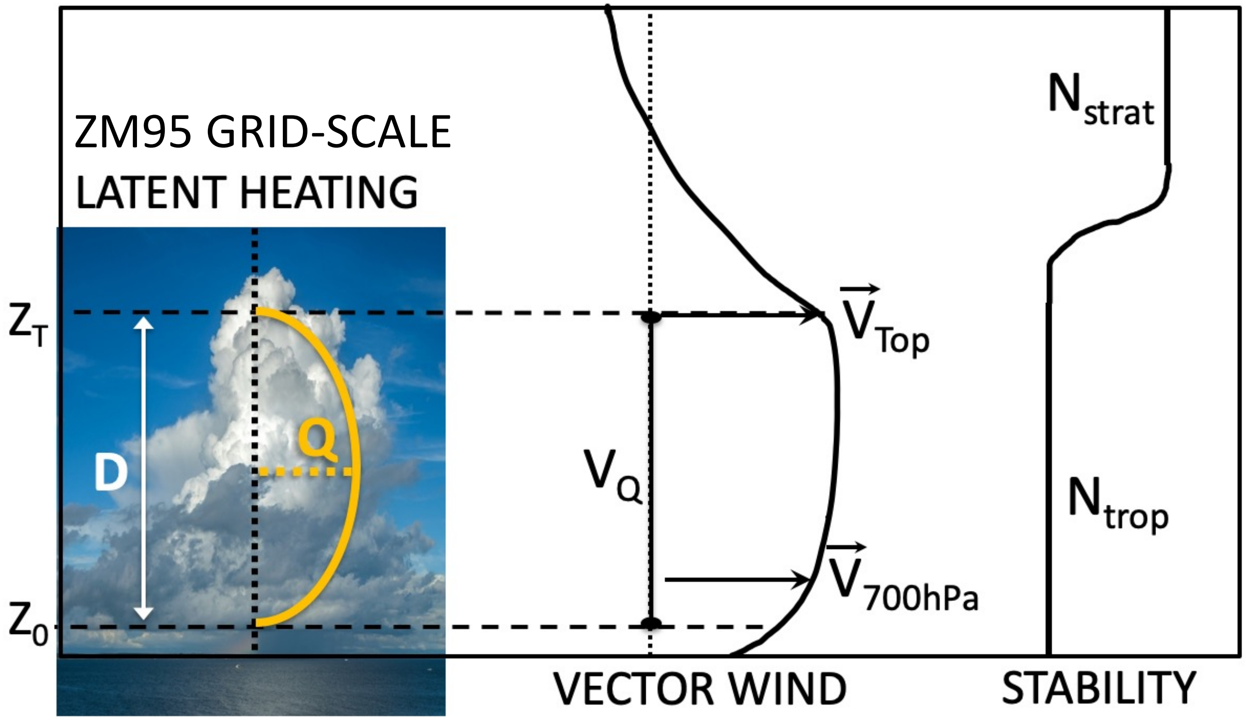
- Observations from long-duration balloons → "Beres" GW Momentum Flux
- Beres non-OGW scheme with TRMM "convective sources"
- TRMM cloud and latent heating properties → ZM convection parameters

II. Implications for GW Parameterization and Simulating the QBO

- New results from balloons on large-scale GW suggest $\Delta z \sim 200$m to resolve realistic wave-mean flow interactions
- Possible changes to the Beres non-OGW parameterization to improve representation of unresolved wave driving.

Beres Scheme for Tropical Gravity Waves

Illustration of parameters used in the application of the Beres parameterization scheme.



Sub-grid latent heating

$$Q_0 = Q/CF$$

Convective Fraction = .05 (5%)

Source momentum flux

$$M_0(c) = C_{L\tau} Q_0^2 K_{V_Q D}(c)$$

Tuning Parameter

Lookup Table

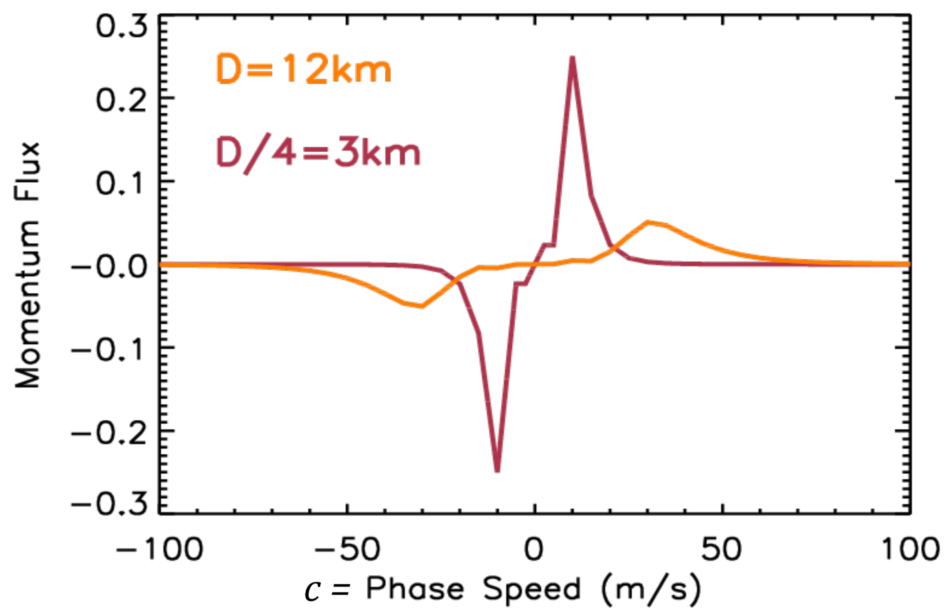
Force on the grid-scale flow

$$F(z) = \frac{-\epsilon}{\rho_0(z)} \frac{d}{dz} \left(\Sigma_j M_j(z) \right)$$

j = # of waves

WACCM6 Tuning Parameters

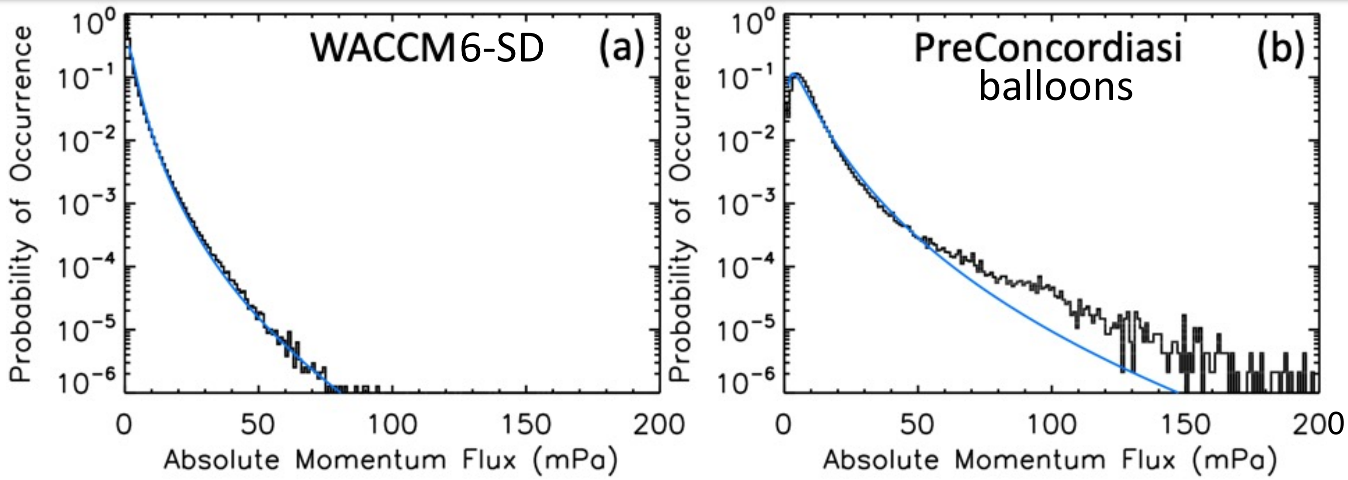
- "Convective fraction" *CF* = 5%
- WACCM5-6 uses $D/4$ to access the $K_{VqD}(c)$ lookup table in order to get a QBO.
  - $D \propto c$
  - So $D/4 \rightarrow c/4$
  - Apparently lower c and/or higher amplitudes needed for QBO
- Efficiency factor tunes the force (and QBO period)



$$F(z) = \frac{-\epsilon}{\rho_0(z)} \frac{d}{dz} \left(\Sigma_j M_j(z) \right)$$

j = # of waves

Gravity Wave Momentum Flux at 60 hPa



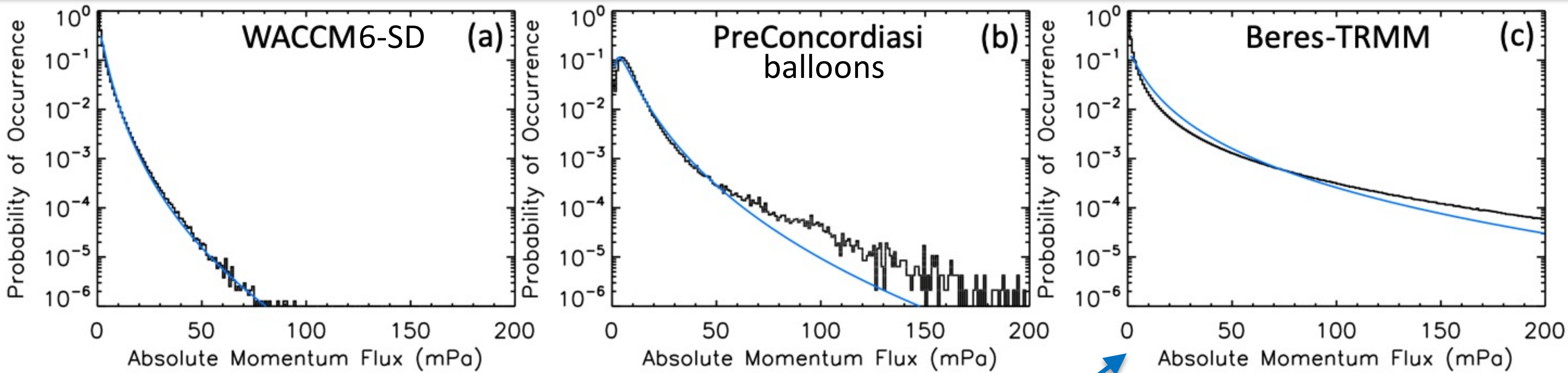
Distributions of Absolute Gravity Wave Momentum Flux comparing:

- WACCM6-SD parameterized GW
- Global measurements of high-frequency waves from super-pressure balloons Feb-May 2010

WACCM6-SD lacks the rare but very large amplitude waves in the data

- Zonal mean zonal flux in WACCM is only 1/3 of the observed flux

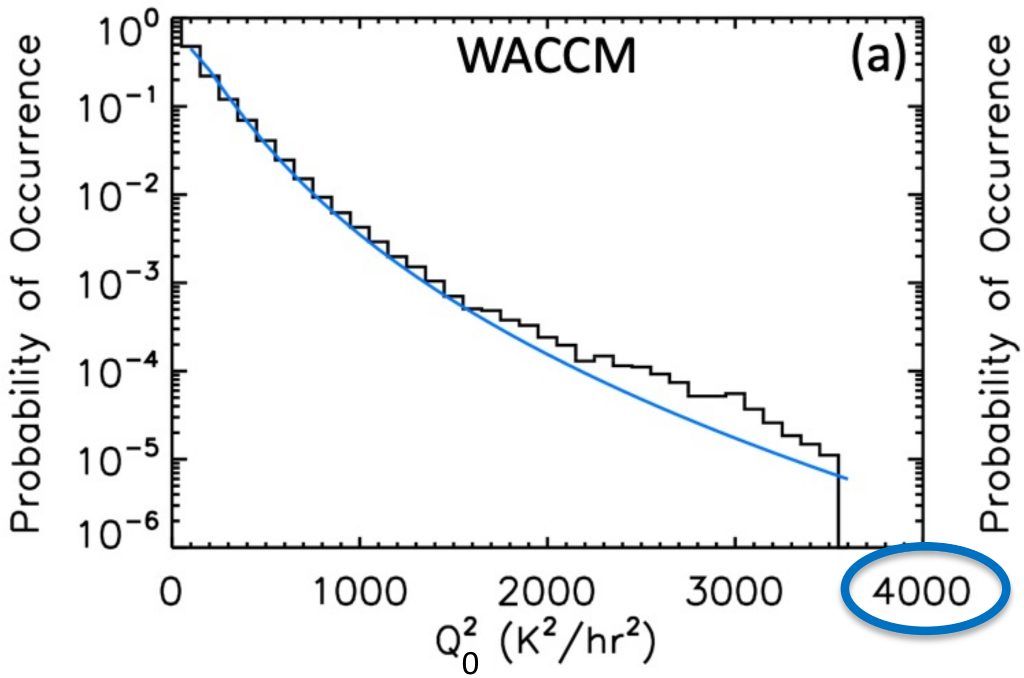
Gravity Wave Momentum Flux at 60 hPa



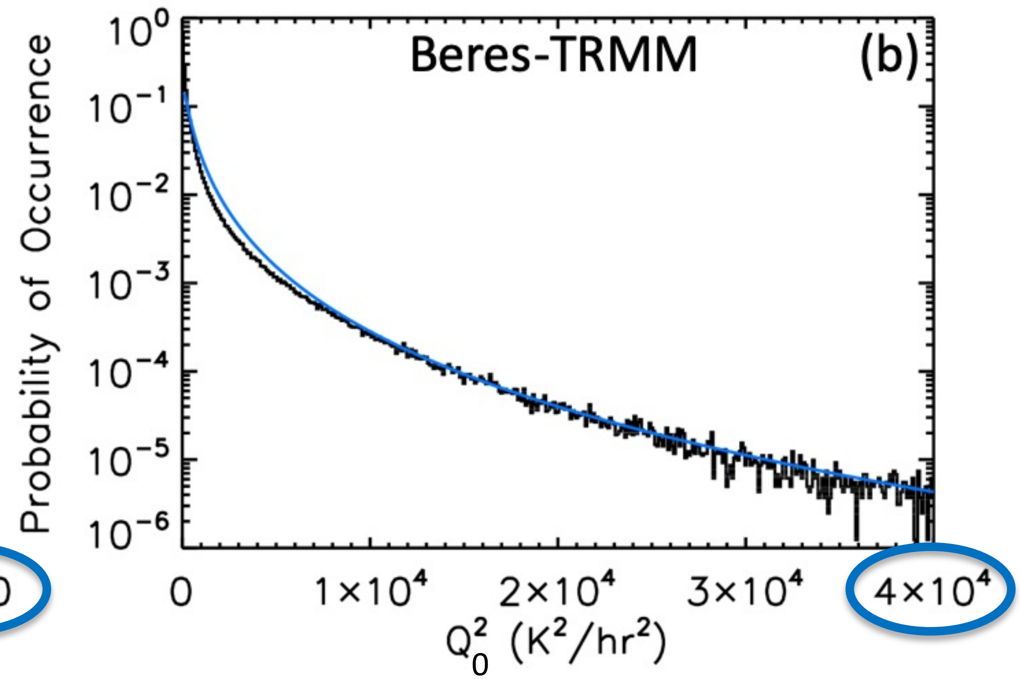
Offline calculations with the Beres scheme

- Here using D, Q_0 obtained from TRMM SLH latent heating product
- Much longer tail of high momentum fluxes
- Since Momentum Flux ~ Q_0^2 this result suggests WACCM6 Q_0 too small

Distributions of Sub-grid-scale Q_0^2



Includes CF_{WACCM}=.05

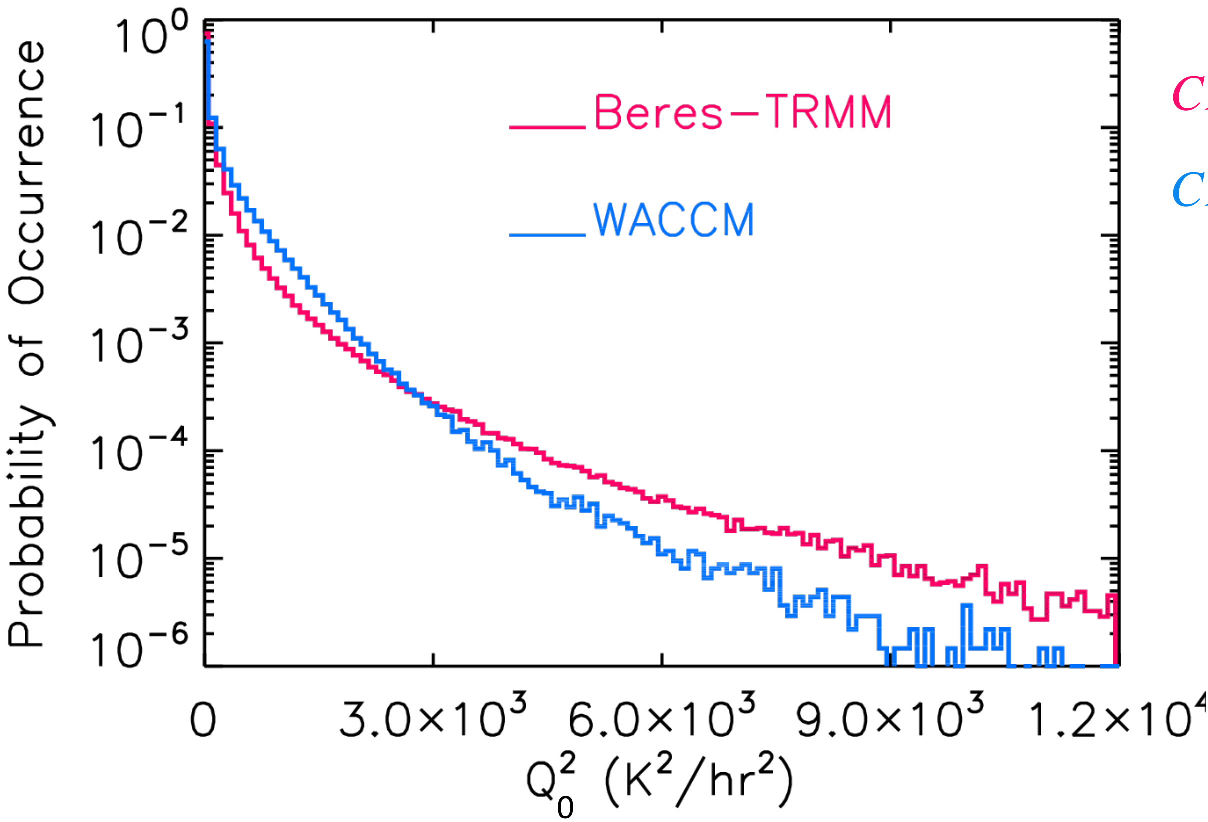


Includes $CF_{TRMM}=(\sigma_x/\Delta x_{TRMM})$

σ_x=3km, Δx_{TRMM}= 4.5km

Distributions of Sub-grid-scale Q_0^2

Simple retuning of the sub-grid-scale "Convective Fraction"



CF_{TRMM} = 1 (single pixel)

CF_{WACCM} = .03 (3%)

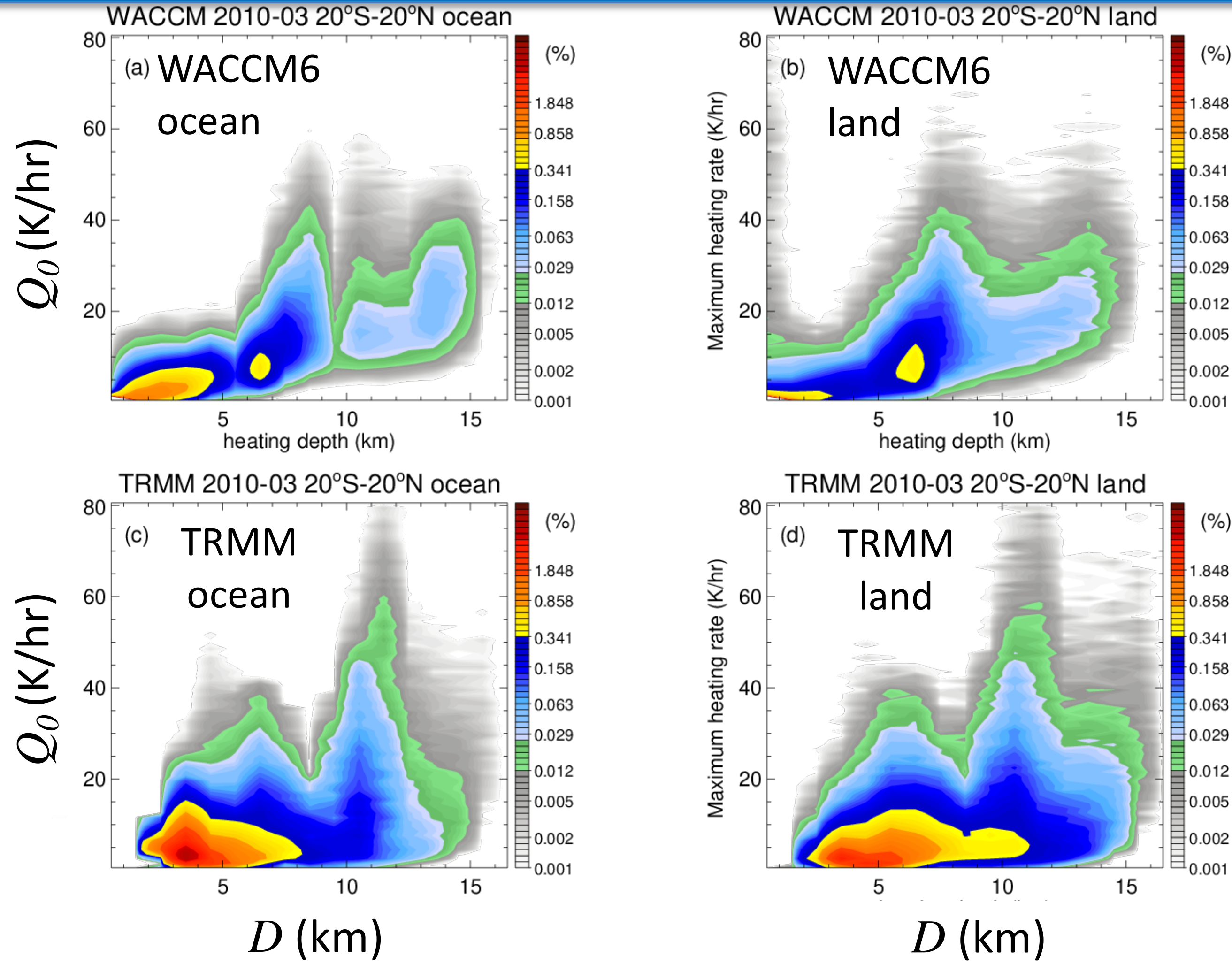
2-D Distributions of Sub-grid-scale Q_0 and D

Strongest Q_0 are most important gravity wave sources.

- Reducing WACCM CF from 5% to 3% increases Q_0 by factor 1.7.
- Momentum Flux ~ $Q_0{}^2$

Range of depths D are similar:

- TRMM comparison does not support $D/4$



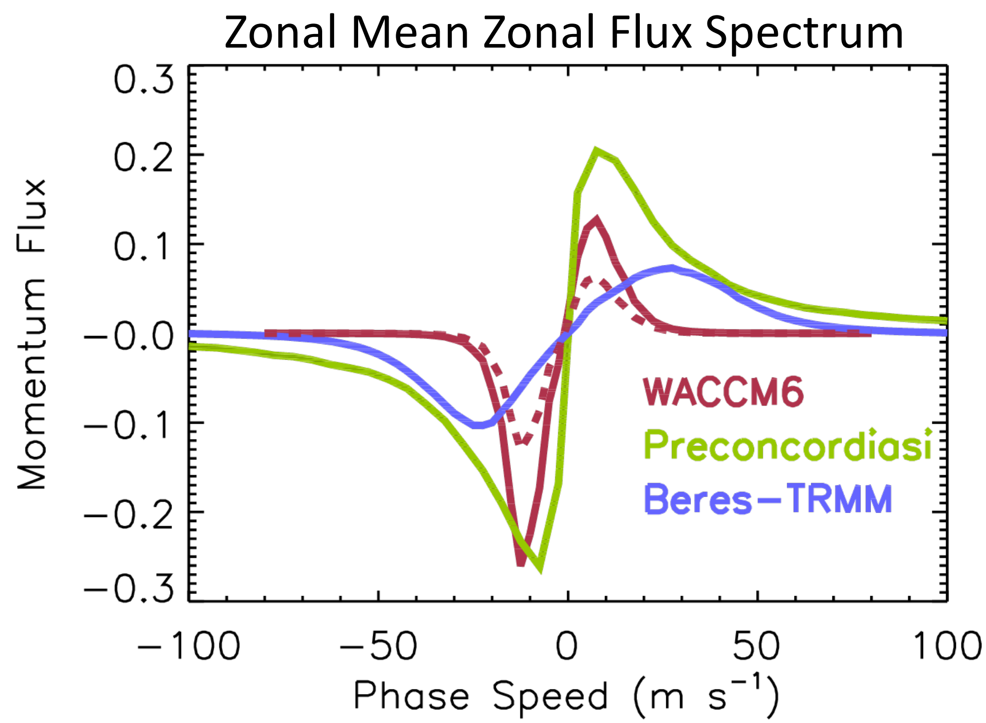
Momentum Flux Spectrum at 60 hPa

WACCM6-SD…

- Shows the effect of assuming $D \rightarrow D/4$ on the phase speed spectrum.
- Lacks the higher phase speed waves that will be important at WACCM altitudes above the QBO altitudes.

Beres-TRMM…

- Lacks low phase speed waves.



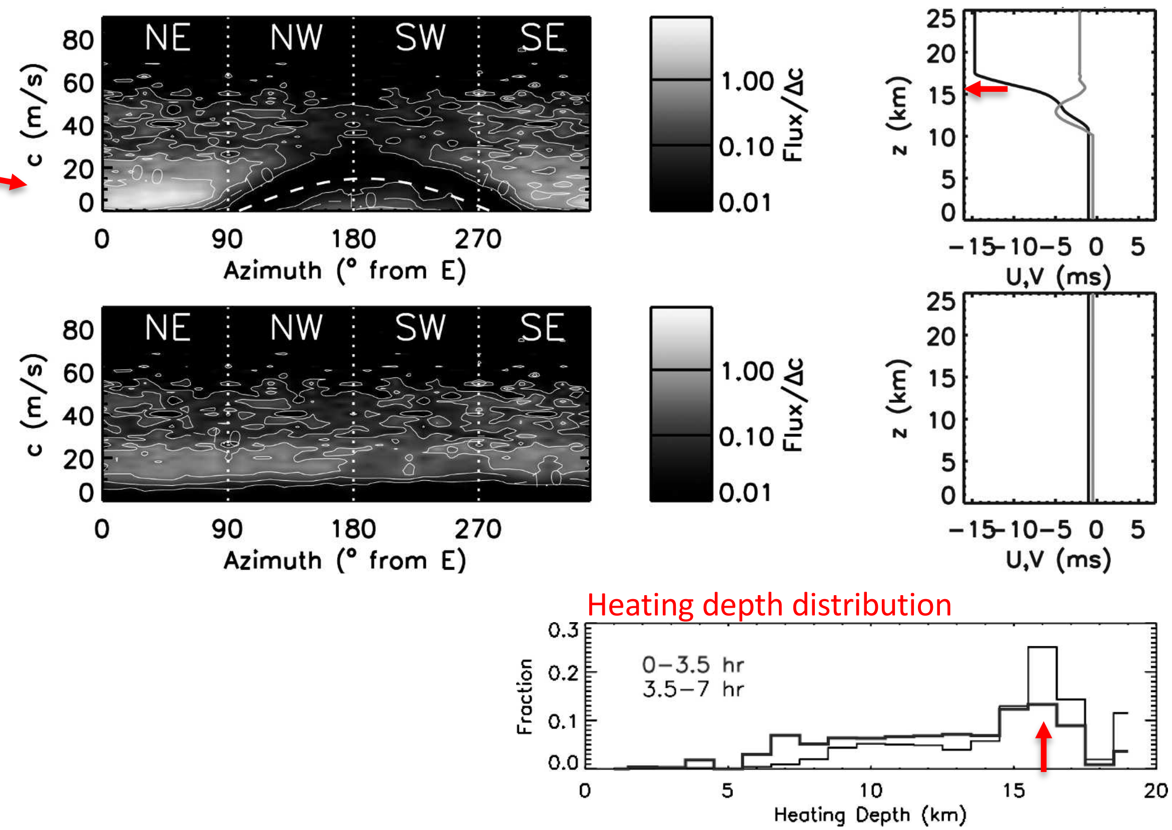
Low Phase Speed Waves to Simulate the QBO ?

- Strongest wave momentum fluxes at low phase speeds are generated when shear at the top of convection.

- Waves modeled as stationary relative to the convective heating.

- This stationary component stands out as a prominent peak in the momentum fluxes.

Gravity wave momentum flux spectrum above convection

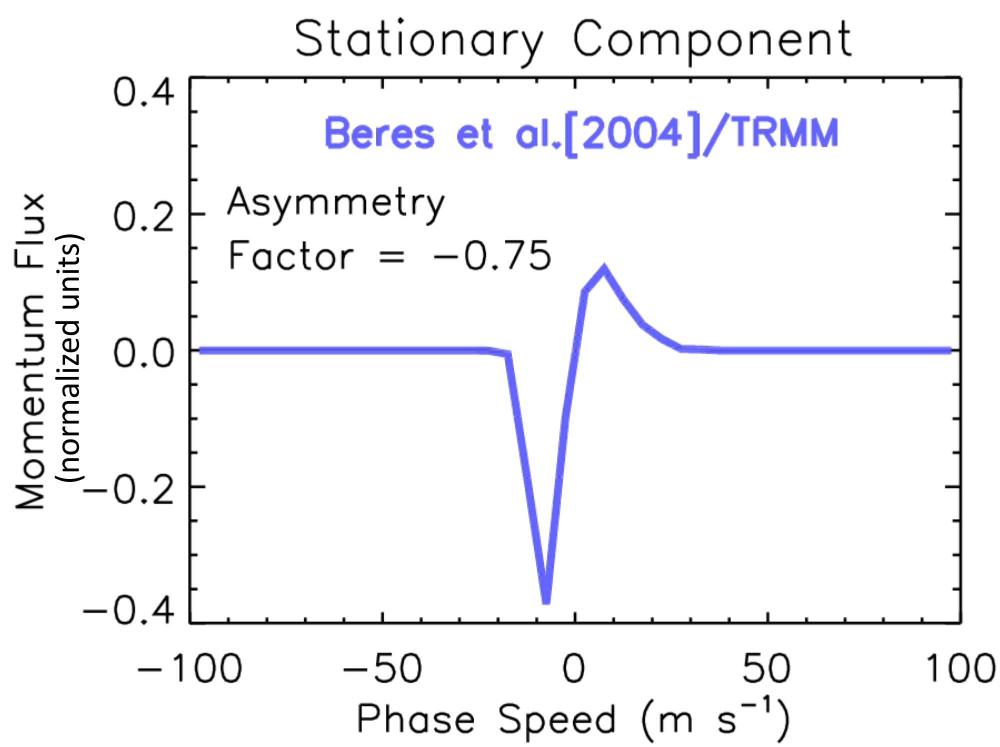


Alexander, Richter & Sutherland (2006)

Low Phase Speed Waves to Simulate the QBO ?

Beres et al. (2004) formulas for the stationary wave component with TRMM convective latent heating sources.

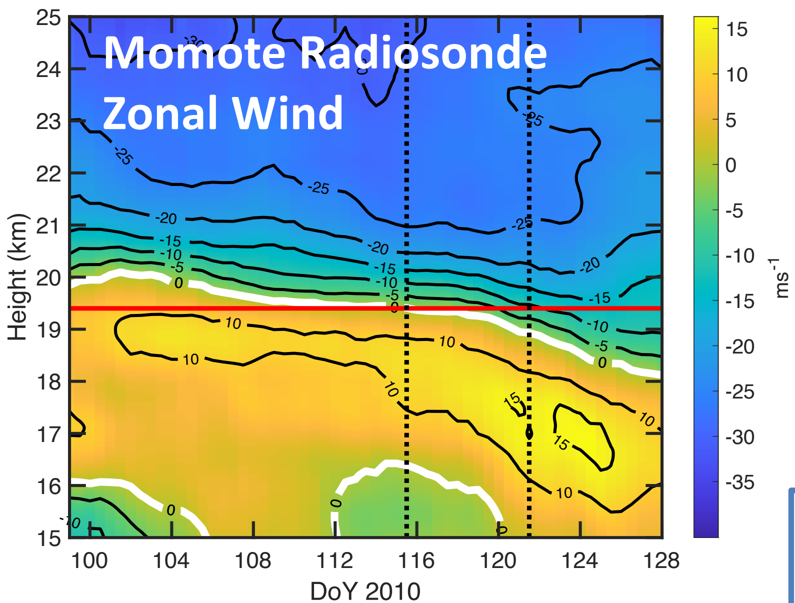
- Momentum flux spectrum peaks at c = 5-10 m/s
- Large amplitudes might force QBO descent to lower altitudes?
- Enhanced westward wave flux for improving easterly phase descent?

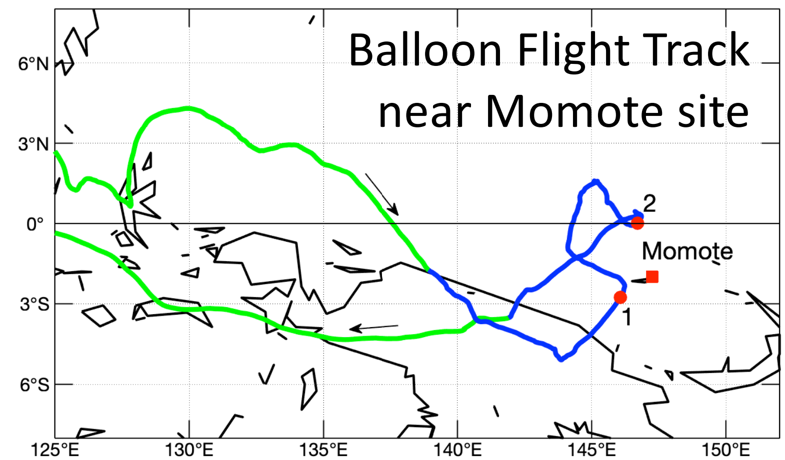


Long Period Gravity Waves: PreConcordiasi

Tropical Super-Pressure Balloon Flights, February – May 2010

Vincent and Alexander [2020]: Analysis of low-frequency 1-3 day gravity wave events





1-day wave, horizontal wavelength 1000 km:

- Dissipation within 0.6 km above balloon level
- Zonal-mean zonal force ~ –0.3–0.5 m s^{-1} day^{-1}
- Large fraction of the total needed to drive the QBO (at least for the duration of this event!)

Key Point: ***Short Vertical Wavelength (λ_z) Tropical Waves***

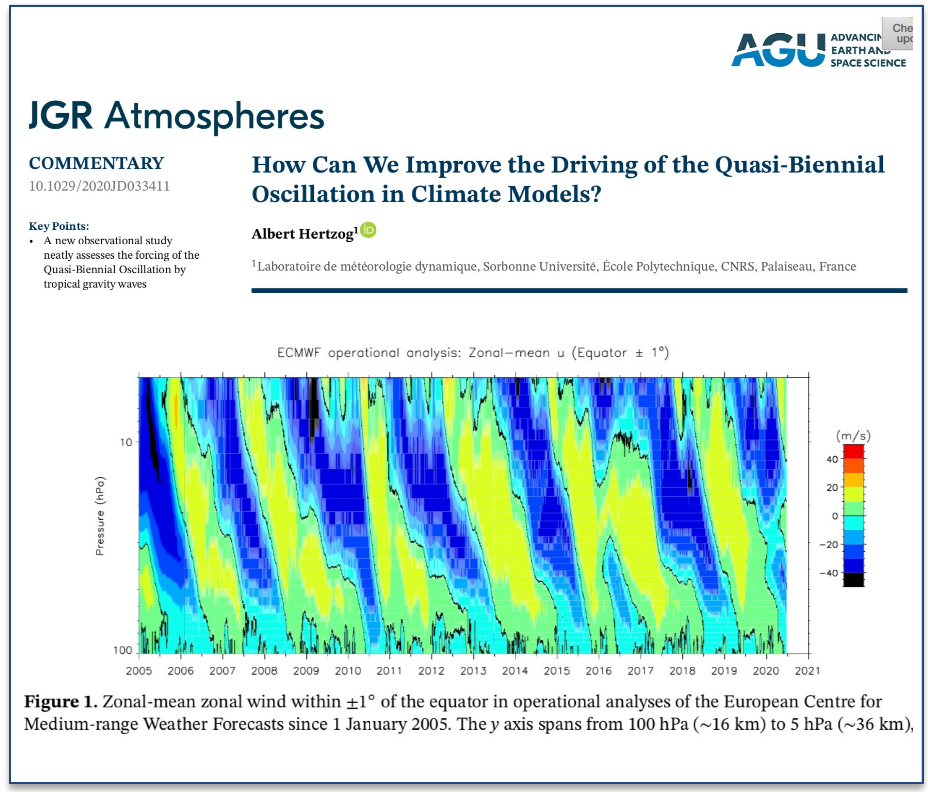
Recent results from super-pressure balloons highlight:

- *Large-scale tropical gravity waves drive the lower stratospheric QBO near wave critical levels where $\lambda_z \rightarrow 0$ [Vincent & Alexander 2020; Hertzog 2020; unpublished results from Strateole-2]*

- *Dissipation closer to critical levels gives larger forces:*

$$Force = -\frac{1}{\rho}\frac{\delta Flux}{\delta z}$$

- *Forces in models may be factors smaller than we observe!!!*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COMMENTARY
10.1029/2020JD033411

Key Points:
- A new observational study neatly assesses the forcing of the Quasi-Biennial Oscillation by tropical gravity waves

How Can We Improve the Driving of the Quasi-Biennial Oscillation in Climate Models?

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Figure 1. Zonal-mean zonal wind within ±1° of the equator in operational analyses of the European Centre for Medium-range Weather Forecasts since 1 January 2005. The *y* axis spans from 100 hPa (~16 km) to 5 hPa (~36 km),

Summary

I. Realistic forces from resolved waves require very high vertical resolution $\Delta z \sim 200$m

II. Beres scheme changes to make the tropical wave forcing of the QBO more realistic:

- *CF* → ~3%
- *D/4* → *D*
- Add stationary component (very simple to code, but would require tuning)

References (www.nwra.com/~alexand/publications.html):

- Alexander, M. J, C. C. Liu, J. Bacmeister, M. Bramberger, A. Hertzog, and J. Richter (2020): Observational validation of parameterized gravity waves from tropical convection in the Whole Atmosphere Community Climate Model. *JGR-Atmospheres*, (accepted).
- Vincent, R. A. and M. J. Alexander (2020): Balloon-Borne Observations of Short Vertical Wavelength Gravity Waves and Interaction With QBO Winds *JGR-Atmospheres*, *125*, e2020JD032779, doi:10.1029/2020JD032779