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PROGRAM

A quasi-monochromatic gravity wave parameterization for WACCM

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Motivation

Although the WACCM gravity-wave scheme has some advanced elements, candidate areas for improvement are apparent.

Actions to change the GW scheme were motivated by the following:

- Model source tuning could not be aided by comparisons with observations. This is an end-product of the use of fixed spectrum sources whose intermittency constantly varied and could never be fully determined.
- Recent observational insights had not been engendered into the scheme.
- The model did not provide an extensive set of gravity-wave information for comparison with observations.

Attempts to resolve these (and other) problems with the scheme have resulted in the developments that follow.

Outline of the talk

- The current WACCM GW parameterisation.
- Why a Quasi-Monochromatic (QMGW) scheme is indicated.
- Describe the WACCM QMGW scheme and its advantages.
- Comparison of QMGW WACCM trials with standard WACCM.
- Surface only sources and secondary gravity waves.
- Summary and conclusions.

WACCM frontal scheme

This scheme is based on Richter et al (2010)

A ‘Frontogenesis parameter’ is used to identify potential sources, and waves are launched from there.

A spectrum of momentum flux vs phase-speed has constant peak amplitude.

Phase speed orientation and centre value are related to the wind regime at the source.

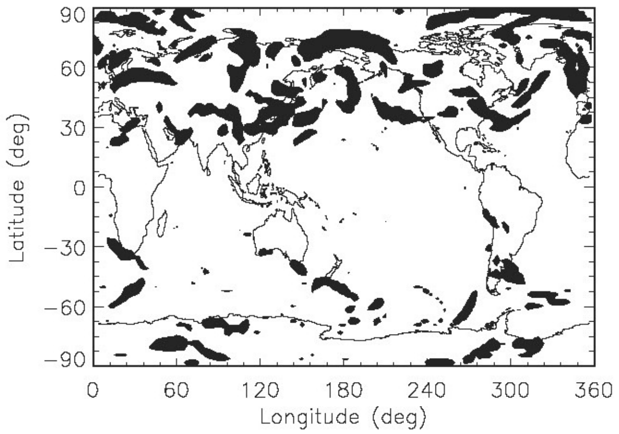
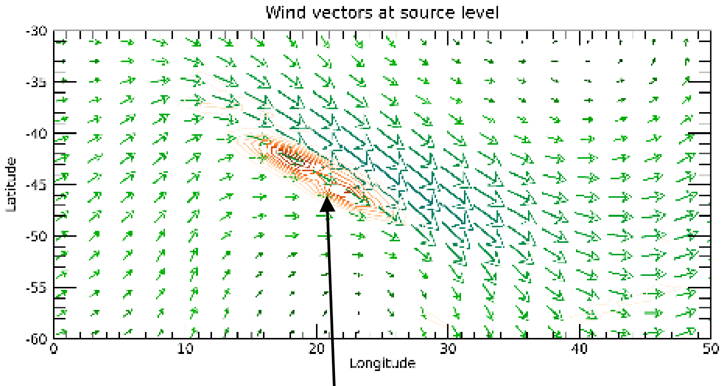
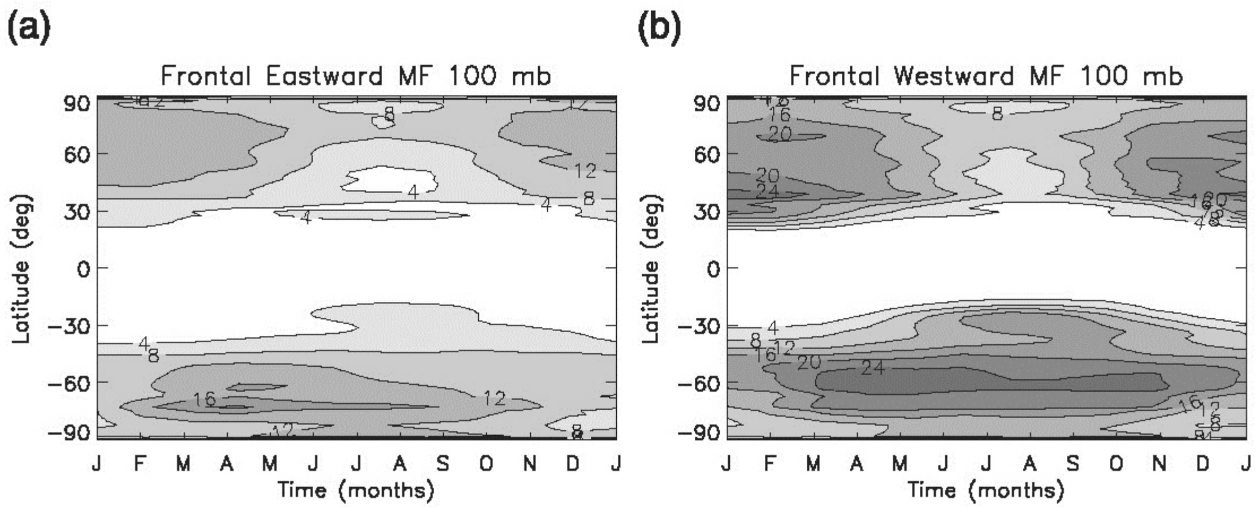


FIG. 1. Map of the regions that exceed the frontogenesis threshold on a selected day in January (depicted in black) in WACCM3.5.



WACCM Example: GWs are launched from frontal area.



Frontal scheme source momentum flux is concentrated at higher latitudes.

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WACCM Gravity Wave Drag Parameterization

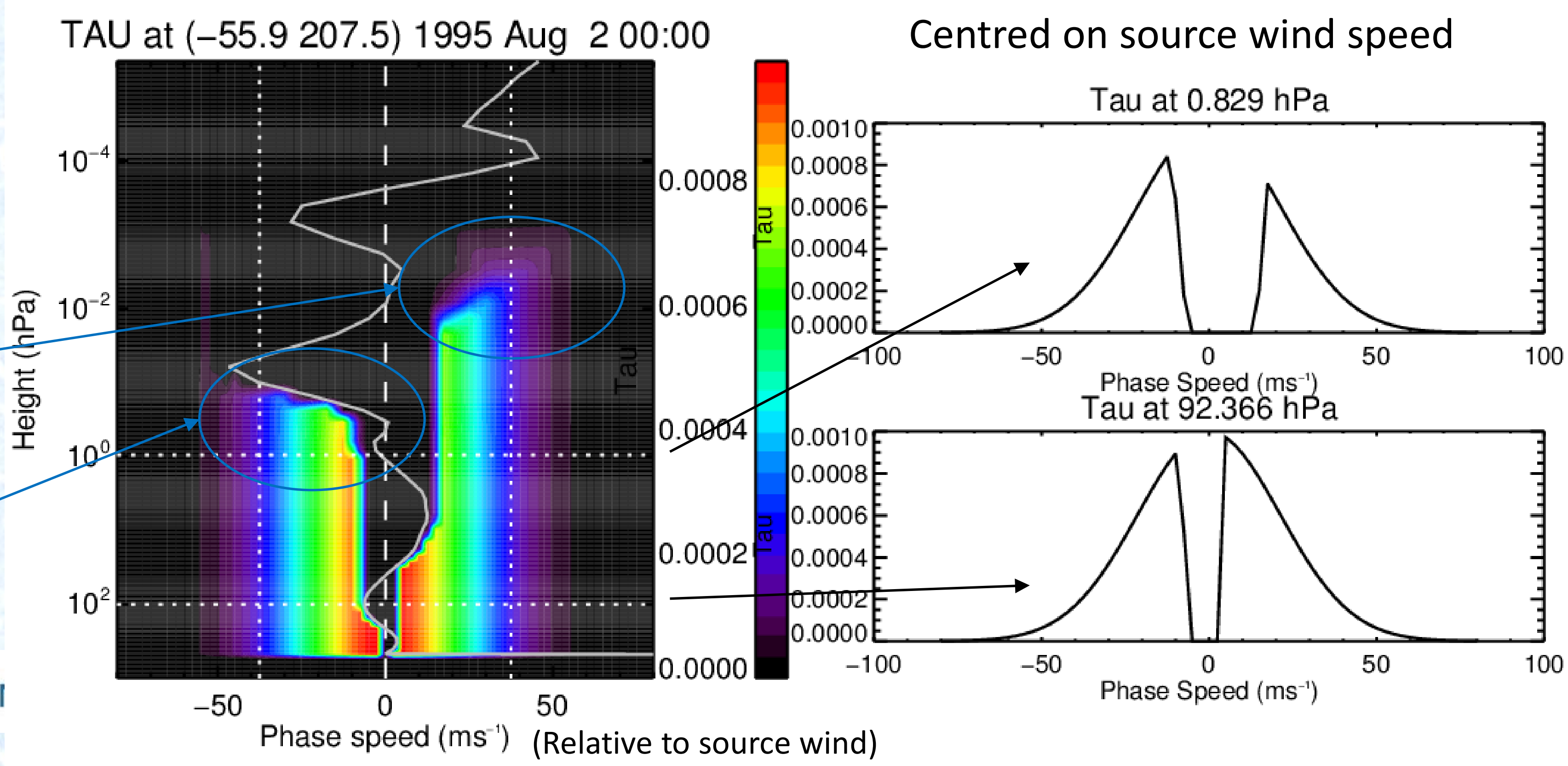
The propagation and deposition of gravity waves in WACCM is based on McFarlane [1987]

- Waves are treated as independent entities in a phase speed spectrum.
- Critical levels (where the projection of the wind equals the phase speed) remove waves from spectrum.
- Saturation leads to attenuation of wave momentum (as per Lindzen [1981]).

This figure illustrates the GW parameterization. Tau describes the momentum flux at each phase speed.

Saturation effects can be seen here

Critical level interactions can be seen here



Centred on source wind speed

(Relative to source wind)

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A log-normal distribution of momentum fluxes

A key discovery in gravity waves suggested a way forward.

Super pressure balloon measurements showed that gravity-wave momentum fluxes have a log-normal distribution.

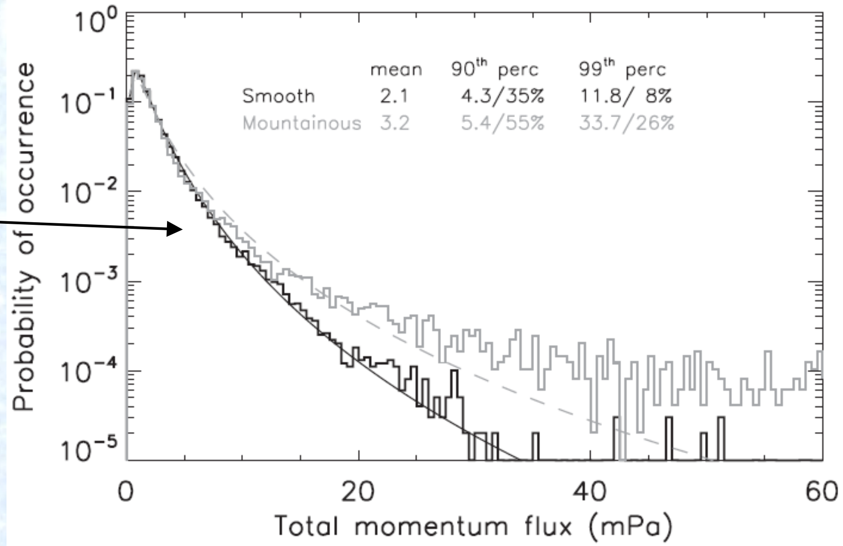
Consequently, most of the momentum flux is carried by a small number of large waves.

This is true (at least) at SPB (19 km) and polar summer mesosphere heights.

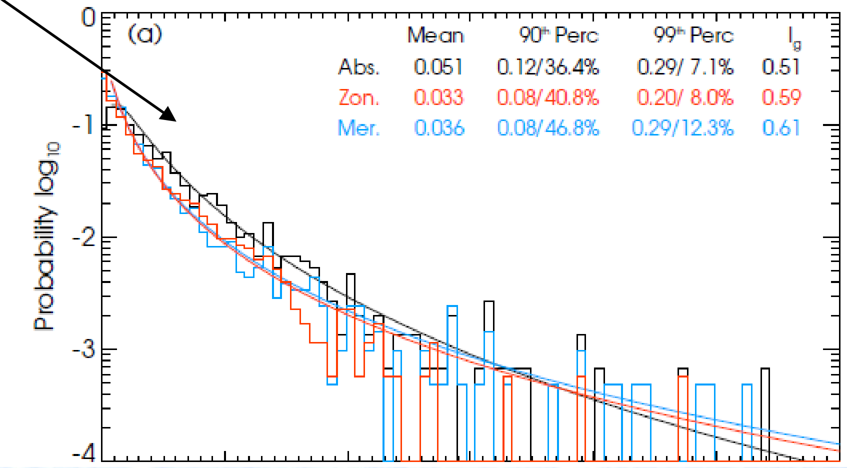
There are significant advantages in parameterizing gravity waves as individual quasi-monochromatic waves connected to known source mechanisms:

- ✓ Observed wave characteristics can contribute directly to parameterization settings.
- ✓ Influences on wave propagation (e.g. critical levels, saturation) can be represented with fewer assumptions.
- ✓ Tracked wave characteristics can be output for comparison back to observations.

Hertzog et al. (2012)



Love and Murphy (2016) for the mesosphere



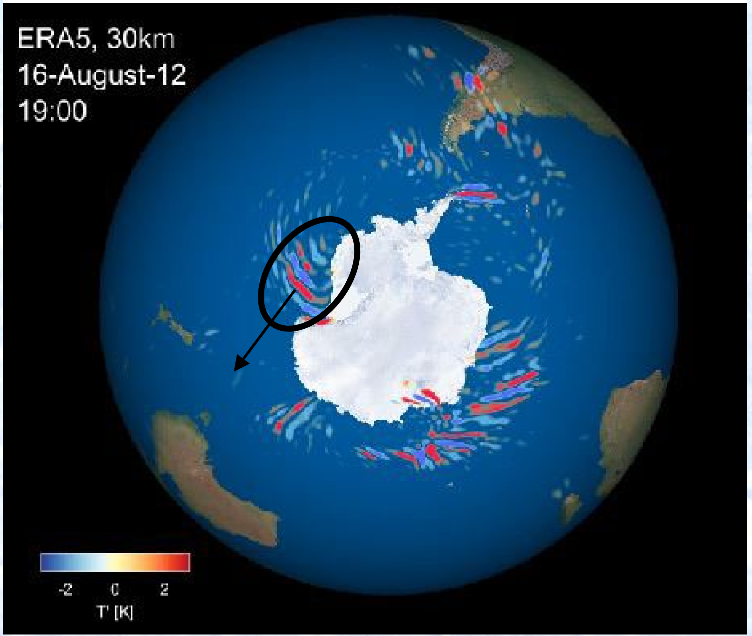
The QMGW Scheme for WACCM

- Waves are fully specified through intrinsic frequency, horizontal wavelength, propagation direction, spatial and temporal extent, and momentum flux.
- The full dispersion relation is used to relate wave parameters (i.e. calculate vertical wavenumber).
- Wave momentum flux amplitude can be variable and conforming to a log-normal distribution.
- A GW saturation scheme, based on Warner and McIntyre (1996) theory (not their parameterization) is used over the whole intrinsic frequency, vertical wavenumber range.

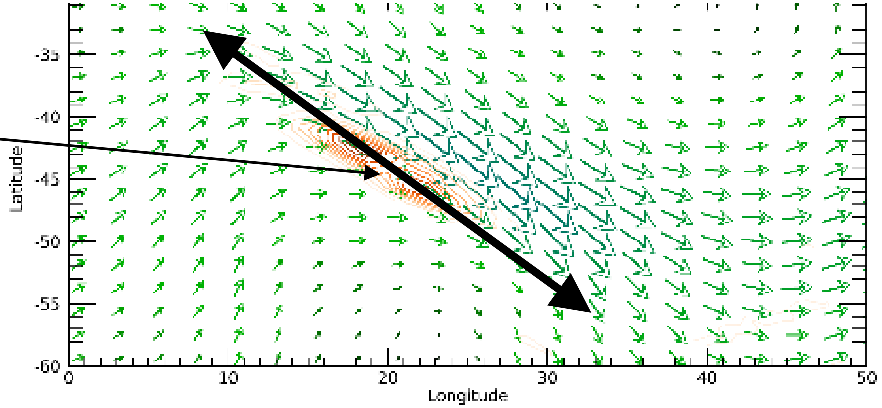
At this stage, the QMGW wave ideas:

- Are applied to the frontal source (not convective or orographic). This source is triggered when the frontogenesis parameter exceeds a threshold value at a reference height near 500hPa.
- Have a propagation direction aligned with the wind at the source level.

After Wright et al Brazil ANGWIN talk



Contour: Frontogenesis parameter
Coloured arrows: Wind direction and magnitude



QMGW parameters are directly observable

WACCM QMGW input parameters		Derived parameters		Notes
Horizontal wavelength or wavenumber	λ_h, k_h	Vertical wavelength or wavenumber	λ_z, m	
Intrinsic frequency or period	$\hat{\omega}, \hat{T}$	Intrinsic horizontal phase speed	$\hat{c}$	Convert to ground-based with BG wind.
Propagation direction	ϕ			
Momentum flux	$\rho_0 F_p$			
Horizontal extent of wave packet	$\Delta x = n_\lambda \lambda_x$	Spectral width in horizontal wavenumber	Δk	The finite horizontal extent makes the wave quasi-monochromatic
Temporal extent of wave packet	$\Delta t = n_t T$	Spectral width in frequency	$\Delta\omega$	

Source observations now have a clear path to influence model parameterization.

Saturation for Quasi-monochromatic GWs

The theoretical constructs described in Warner and McIntyre (1996) provide a framework for a saturation scheme that spans the full range of $\hat{\omega}$ and m.

The pseudomomentum flux saturation threshold that can be integrated over the widths of the QMGW to yield a threshold value: $\rho_0 F_{pStot} = \rho_0 \int_{\Delta m} \int_{\Delta \hat{\omega}} \hat{F}_{pS}(m, \hat{\omega})\, dm d\hat{\omega}$

A necessary change of variable, and integration yield a saturation threshold of:

$$\rho_0 F_{pStot} \approx X \rho_0 N \underbrace{\frac{(1-\hat{\omega}^2/N^2)^{1/2}(1-f^2/\hat{\omega}^2)^{3/2}}{(1-f^2/N^2)}}_{\text{Frequency correction to pMF}} \underbrace{\frac{1}{\hat{\omega}^{2/3}} \frac{1}{km^2}}_{\text{Spectral form}} \underbrace{\Delta k \, \Delta \omega}_{\text{Spectral width}}.$$

Normalization constant

m is calculated using the full dispersion relation

Note that the Jacobian changes the spectral index on m and brings in k

The spectral widths are derived from the number of wave cycles present in the QMGW packet:

$$\Delta k = \frac{k}{n_\lambda} \qquad \Delta \omega = \frac{\omega}{n_T}$$

n_λ is the number of horizontal wavelengths in the QMGW packet.

n_T is the number of wave periods in the QMGW generation lifetime.

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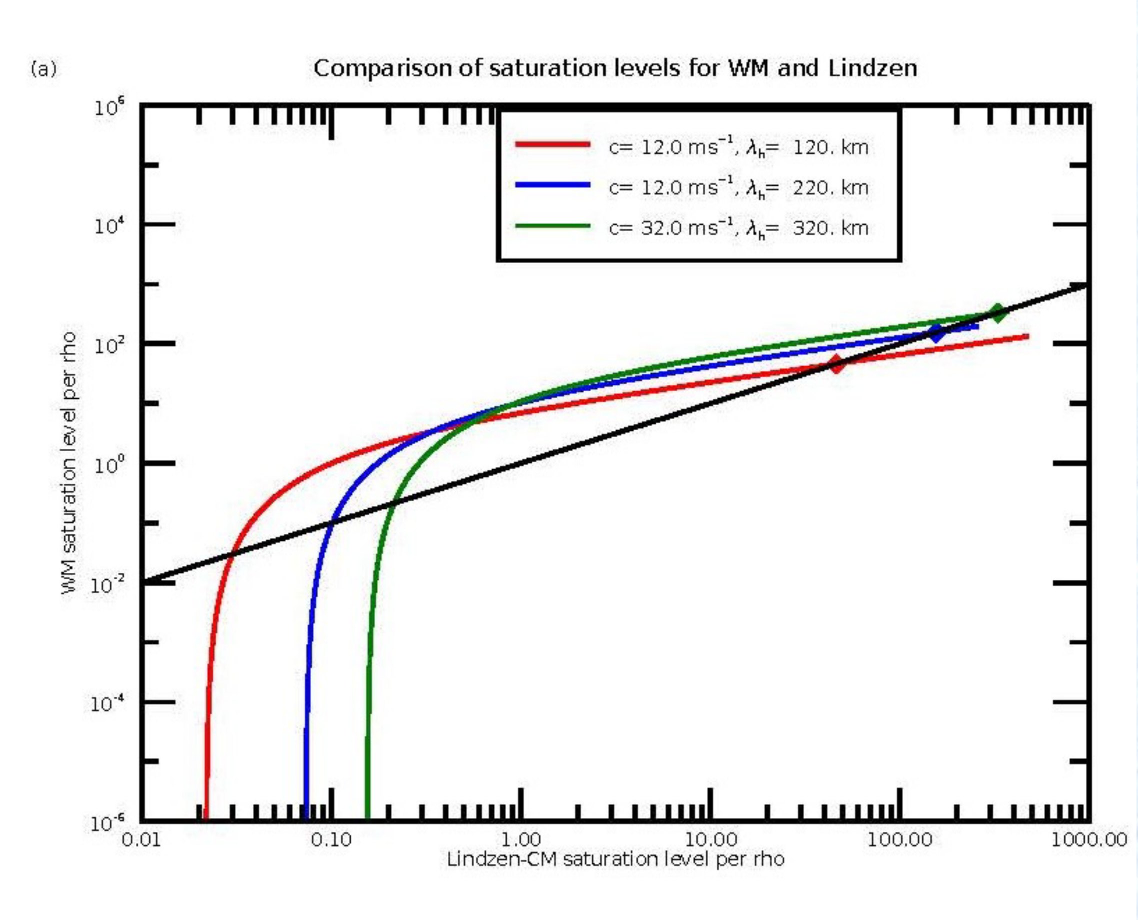
Normalisation

The normalisation constant X is chosen such that, at the source and at a reference intrinsic period (1 hour), the current WACCM parameterization (which uses the Lindzen scheme) and the QMGW version developed here would agree if the source wave conditions were the same.

Note that the normalisation constant here (and in the WM 1996 formulation) has dimensions that ensure the resulting saturation psuedomomentum flux has the correct units (Pa).



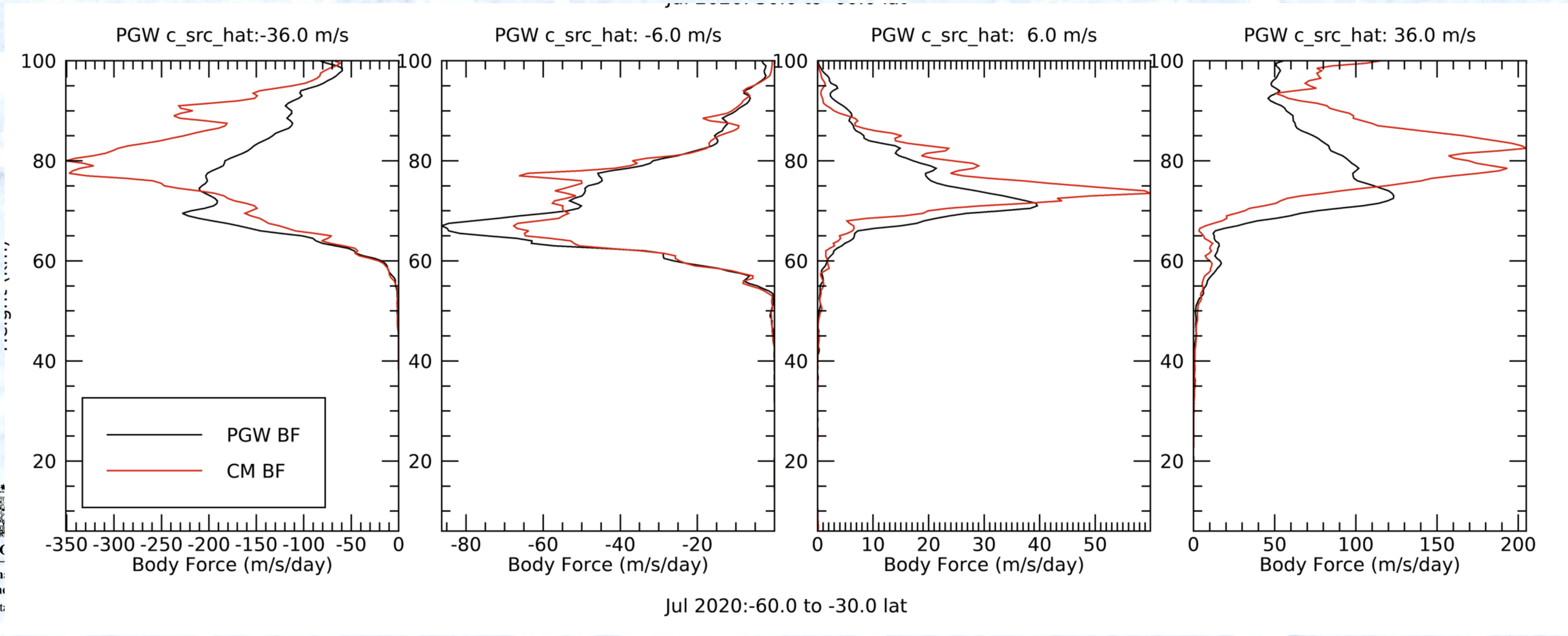
The range of saturation values is generated by varying ubar.

Comparisons between standard WACCM and QMGW schemes

An offline simulation has been developed to compare the WM96 and Lindzen parameterization schemes.

These simulations:

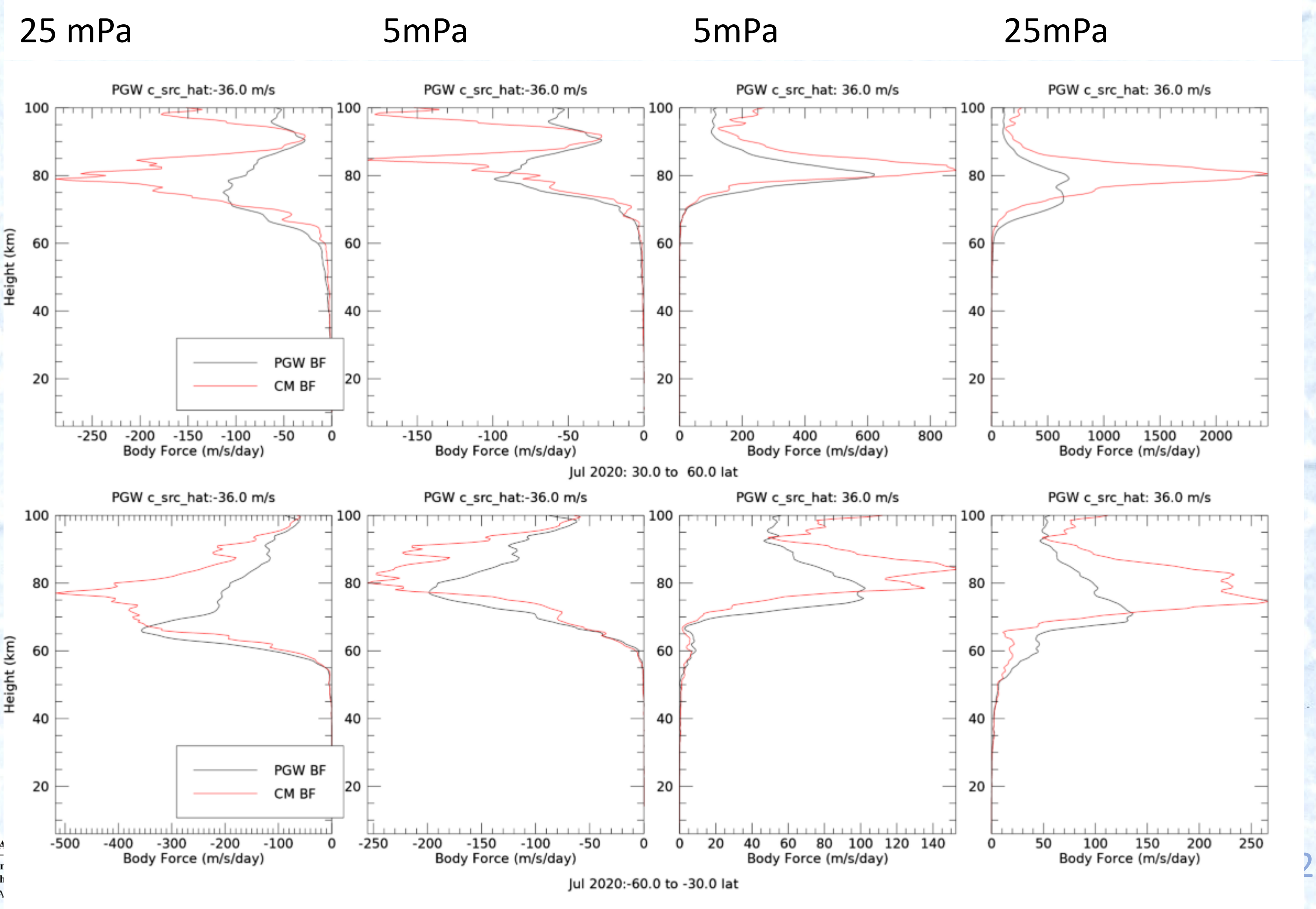
- Define a set of source gravity waves
- Propagate the waves through a set of WACCM wind fields
- Calculate the momentum flux and average the dynamical forcing they would generate.



Southern Hemisphere
July 2020
30-60 deg latitude
10mPa source MF
~120km hor. wavelength

For small intrinsic phase speeds, forcing is similar for both methods.
When $(\overline{u} - c)$ becomes large, the Lindzen scheme gives higher forcing.

Comparisons – Source amplitude



- Both Hemispheres
- +/- 36 m/sec phase speed
- July 2020
- 30-60 deg latitude
- 25 and 5mPa source MF

- GW forcing is largest for standard WACCM.
- Highest forcing when ubar is furthest from c (NH Positive; SH Negative phase speeds).
- Larger MF breaking is lower in altitude

Secondary Gravity Wave Parameterization

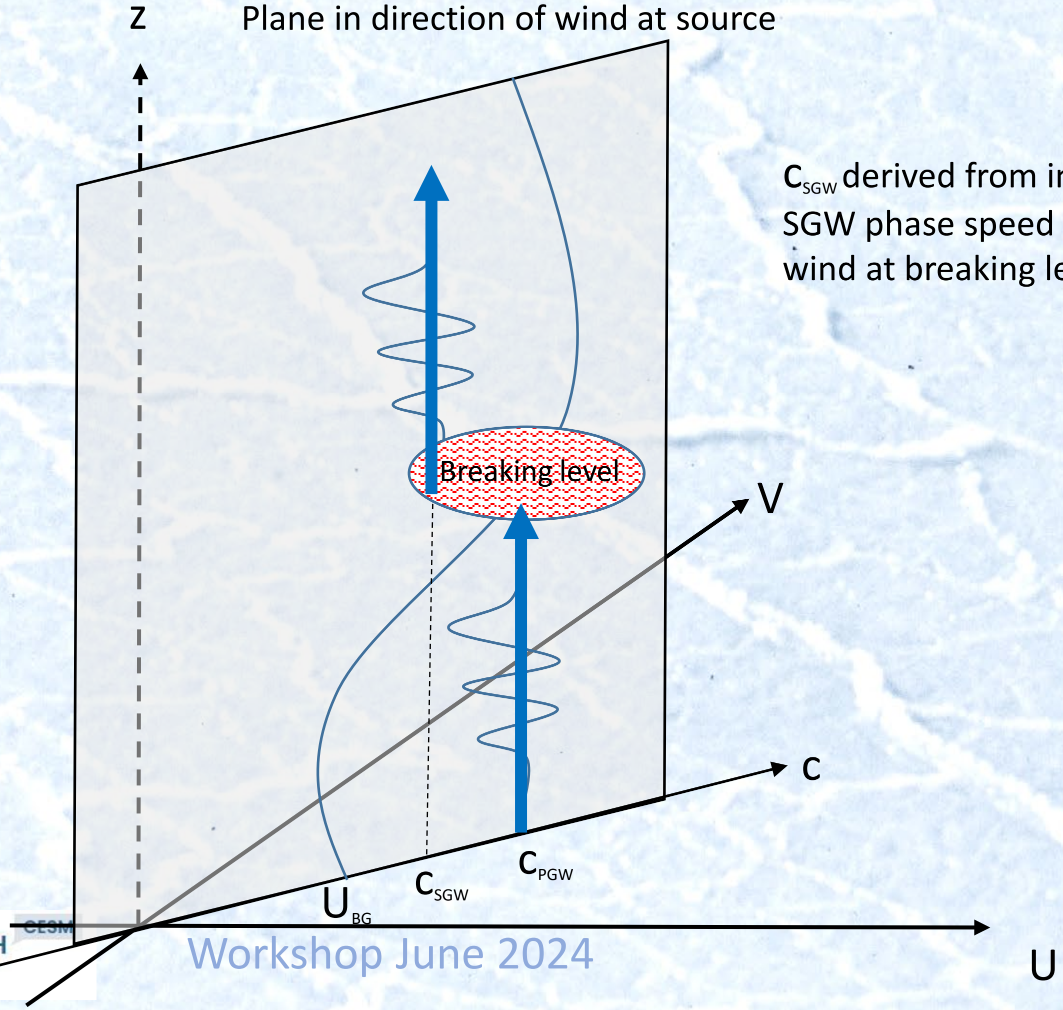
A SGW component has been added to the QMGW parameterization scheme.

For critical level approaches and for strong breaking, a SGW is added into the vertical column and propagated upwards.

The wave whose phase speed is away from the shear is chosen.

SGW characteristics are derived from the PGW characteristics.

Trials are still underway around the PGW-SGW transform parameters



C_{SGW} derived from intrinsic SGW phase speed and wind at breaking level.

Conclusions

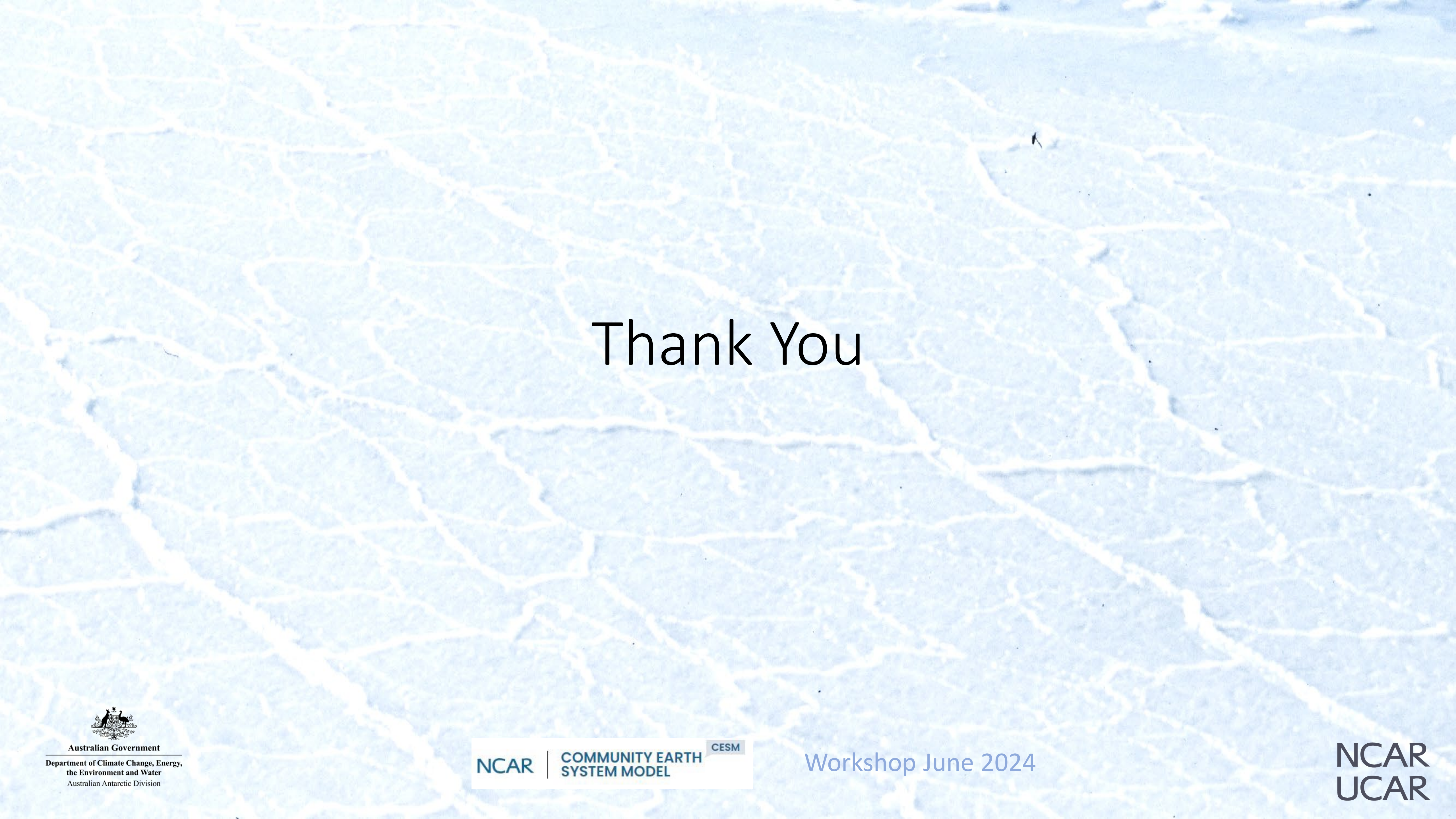
Trials of a Quasi-Monochromatic Gravity Wave parameterization scheme are continuing using the WACCM model an offline simulations.

This scheme, which connects individual quasi-monochromatic waves to known source mechanisms, has the advantages that:

- ✓ Observed wave characteristics can contribute directly to parameterization settings.
- ✓ Influences on wave propagation (e.g. critical levels, saturation) can be better represented.
- ✓ Tracked wave characteristics can be output for comparison back to observations.

It is also

- ➢ Enhancing the realism of the GW parameterization (which should make tuning the model easier).
- ➢ Enabling the inclusion of secondary gravity waves into the scheme.



Thank You

GW parameters

Source parameters				
Intrinsic phase speed	-36 m/sec	-6 m/sec	+6 m/sec	+36 m/sec
Horizontal wavelength	129.6 km	119.68*	119.68*	129.6 km
Intrinsic frequency	2pi/3600	2.5 f	2.5 f	2pi/3600
Momentum Flux	25, 10, 5mPa	10mPa	10mPa	25, 10, 5mPa