Representing the missing gravity wave forcing in the SH winter stratosphere

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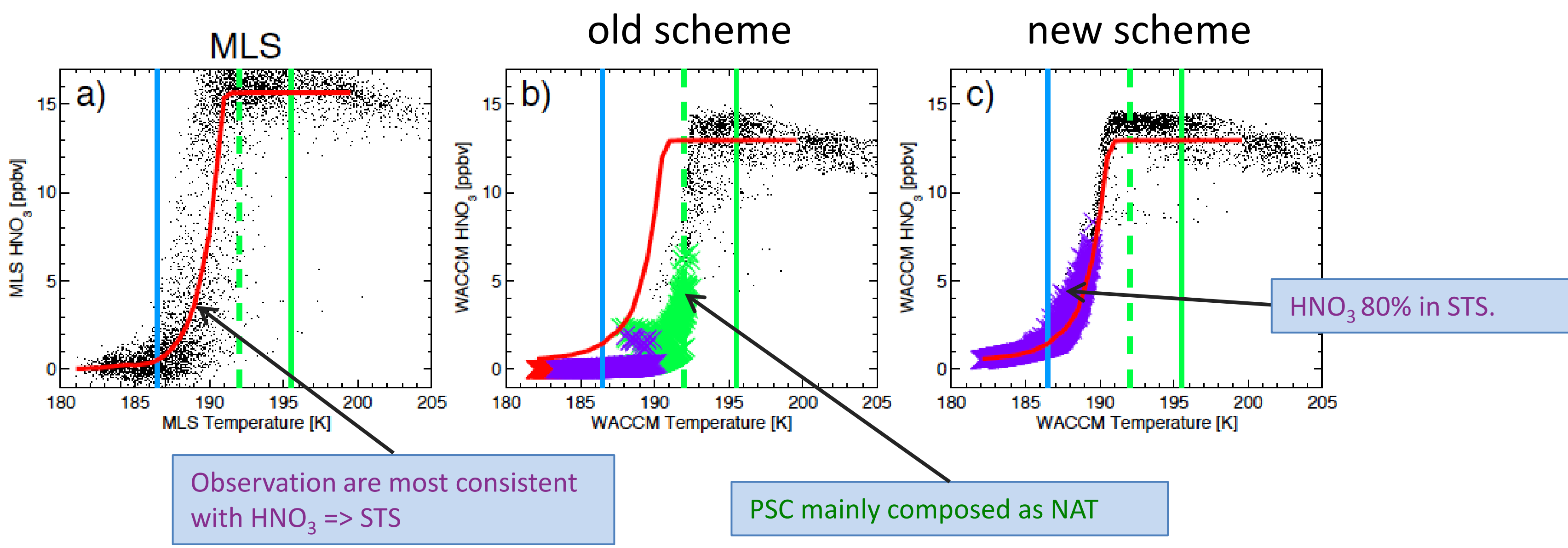
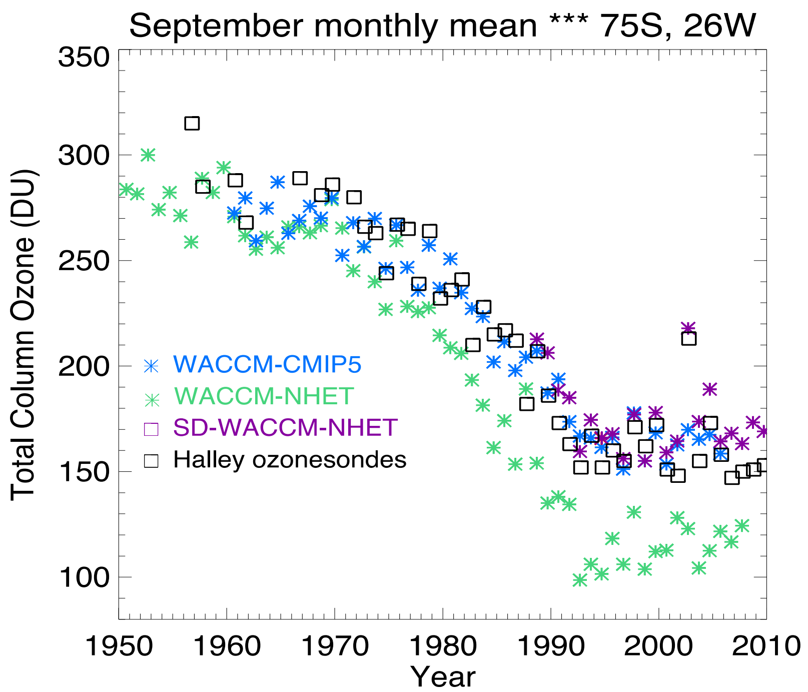
motivation: implementation of new heterogeneous chemistry module in WACCM

Updated het chemistry changes partitioning of condensed-phase HNO_3 between Nitric Acid Tri-hydrate (NAT) and Supercooled Ternary Solution (STS) [see Wegner et al., JGR, 2013.]



- Updated het chemistry decreases the amount of irreversible denitrification by decreasing NAT and increasing STS
- Less denitrification allows reformation of $ClONO_2$ in Spring ➔ continued heterogeneous halogen activation
- Heterogeneous rate for halogen activation on STS is very T-dependent (the colder, the faster)
- Both these factors **require a more accurate representation of model winter/spring LS polar temperatures**

which leads to a problem…



Observed and Calculated Ozone at Haley Bay

- model with **old chemistry** (**blue**) was reasonably consistent with observations
- model with **new chemistry and specified dynamics** (**purple**) gives good results
- model with **new chemistry and free running dynamics** (**green**) produces unrealistically low ozone column because new heterogeneous chemistry module is very sensitive the cold temperatures

the ultimate cause of the problem

SH polar cap T climatology: 1980-2010

WACCM4

MERRA

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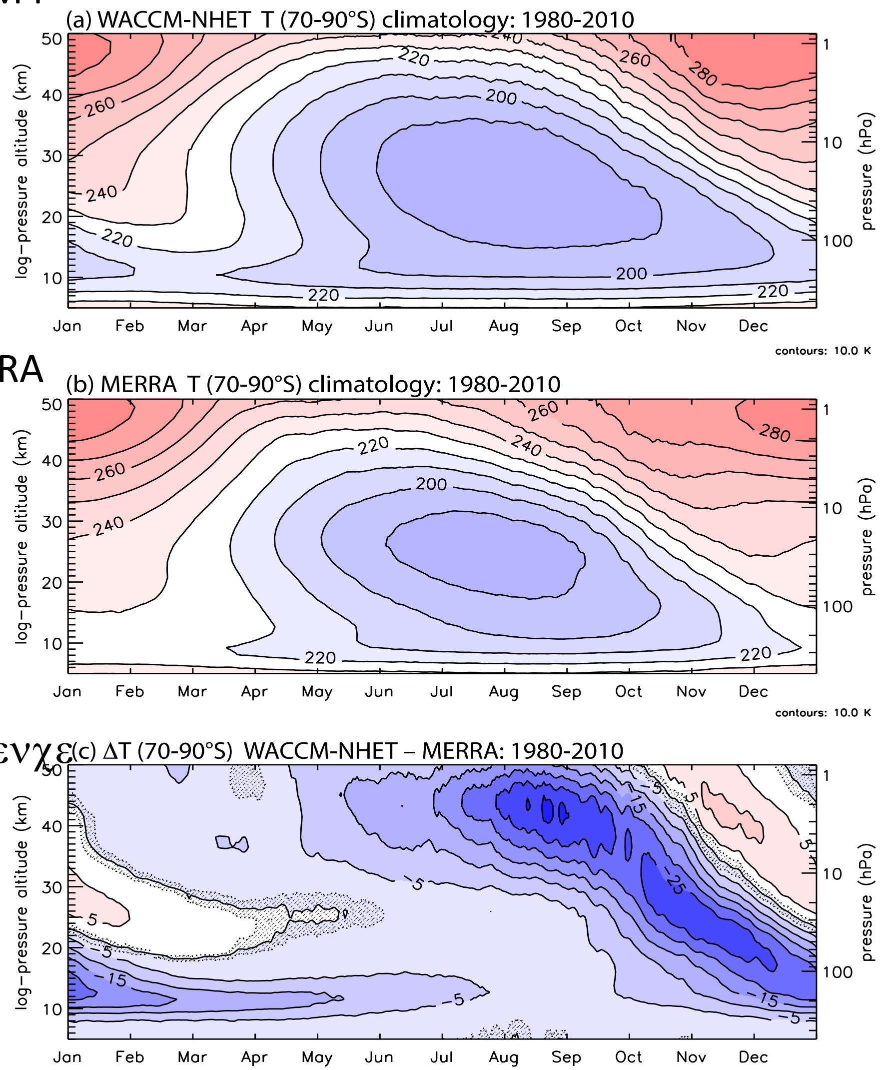


- standard version of WACCM4 has a **"cold pole" bias** in the SH (70°-90°S)
- T in ozone hole region/season is as much as 5-10 K colder than observed

components of a possible solution

- polar temperatures are sensitive to wave-induced downwelling; this suggests that wave forcing is too weak in the SH

- *resolved wave* amplitudes and dissipation are not easily adjustable

- *parameterized gravity wave* forcing is adjustable, but “tuning” the existing parameterization to make GW break in the stratosphere degrades the simulation in the mesosphere

- parameterized non-orographic GW in WACCM4 are “mesoscale” (typical L_X = 100 km); however, any physically confined source actually excites a (“red”) spectrum in wavenumber

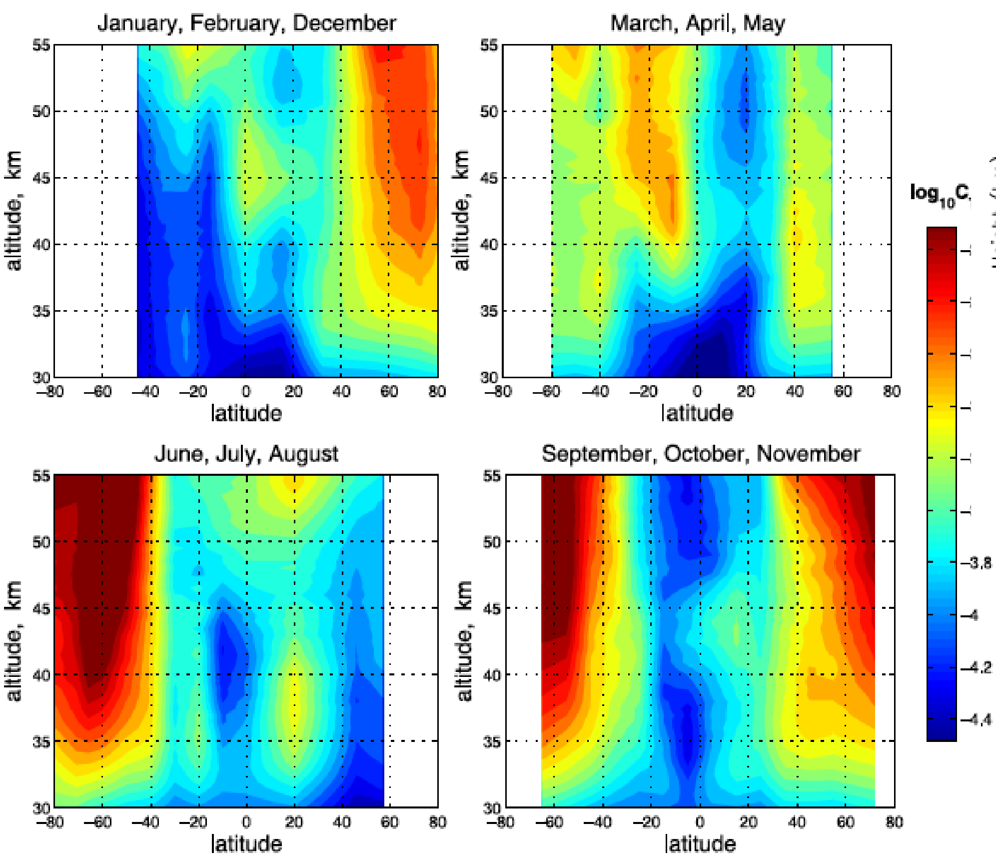
- add a second spectrum of waves, with L_X ~ 300 km (typical of the inertia-gravity range, IGW) to represent the effects of longer waves

- the longer IGW should have larger source amplitudes so that they can break in the stratosphere for reasonable values of the source stress

- orographic gw sources are fixed but it the momentum forcing can be tweaked by adjusting the “efficiency” (an intermittency factor, currently set at 0.125)

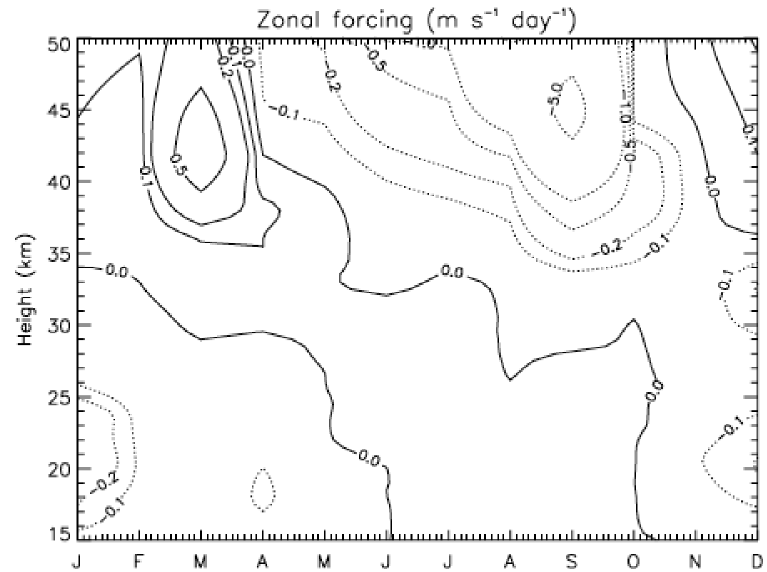
observational support for gw momentum forcing in the SH winter stratosphere

scintillation from stellar occultation
-> a measure of turbulence
-> signal not well correlated with topography



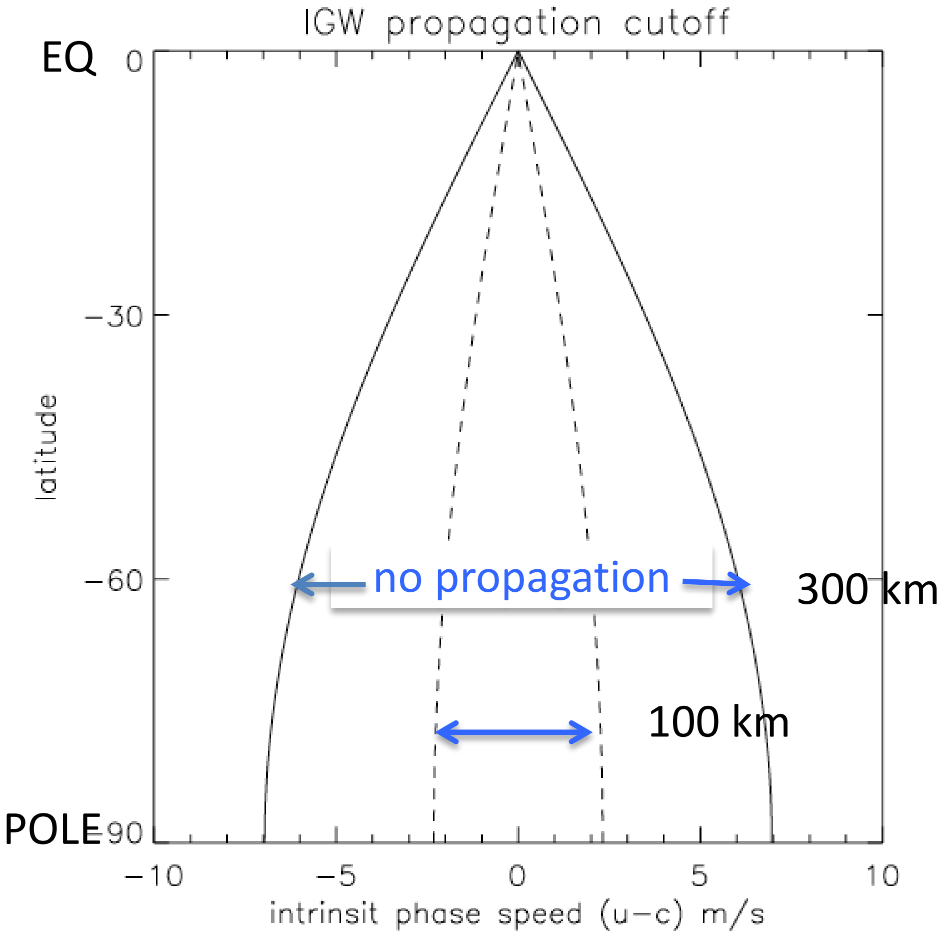
Gurvich et al, GRL, 2007

momentum forcing derived from radiosondes at 55°S



Zink and Vincent, JGR, 2001

Limits to propagation for inertia-gravity waves



dispersion relation in terms of vertical wavenumber *m*

$$m^2 = \frac{N^2}{(u-c)^2 - \frac{f^2}{k^2}}$$

This means that waves must satisfy the following in order to propagate ($m^2>0$)

$$(u-c) < -\frac{f}{k}$$

$$(u-c) > \frac{f}{k}$$

The cutoff is applied to the wave after it is launched. Note that the limit is not applied to mesoscale or orographic GW.

1st complication: four GW parameterizations

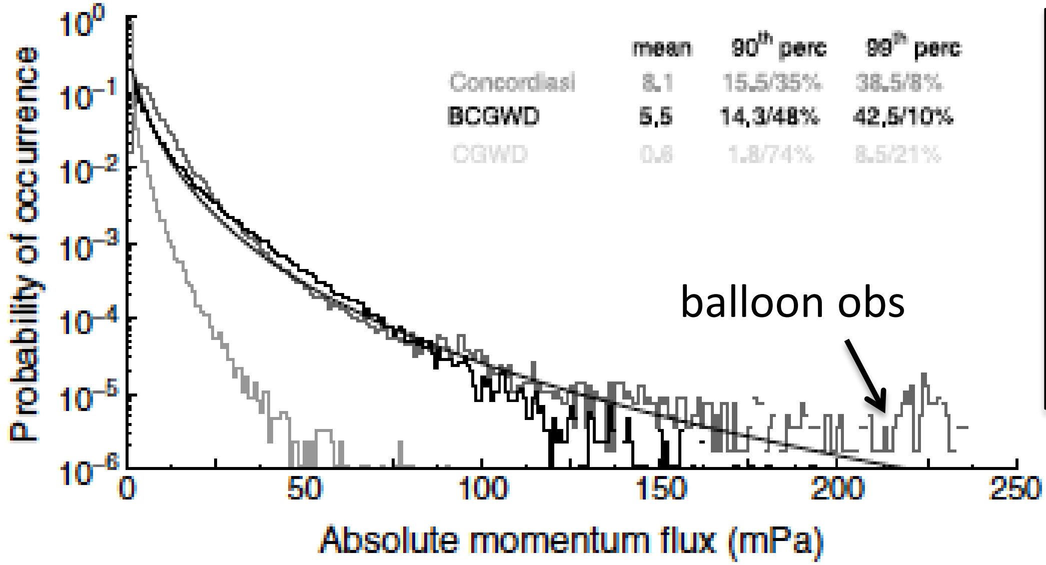
- *convective* - assumed to have no role in polar forcing
- *spectral frontal* – drive mesosphere summer to winter circulation
- *orographic* – momentum forcing in winter stratosphere
- *new inertia gravity waves* – goal is to have momentum forcing in winter SH stratosphere that does not have much impact on the NH winter, the summer of either hemisphere, or the mesosphere

Each parameterization interacts with the background winds and therefore they affect one another and also the momentum forcing by resolved waves.

SOLUTION: much tuning

2nd complication: upward wave flux at source

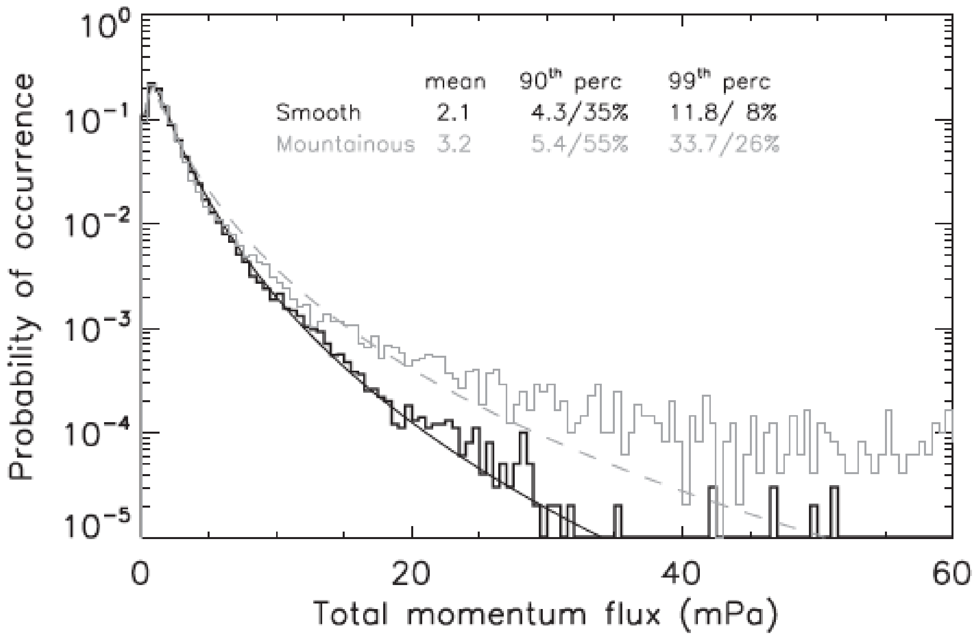
observations from lower stratosphere over Antarctica
(de la Cámara et al., JGR, 2014)



We want parameterization to be compatible with obs but waves with these values of momentum flux break high (middle mesosphere)

SOLUTION: use a low efficiency but fairly high momentum flux for spectral waves

3rd complication: orographic vs non-orographic



Herzog et al., JAS, 2012

These obs show that wave fluxes are higher over mountainous terrain than over smooth.

However, other obs suggest momentum flux and/or forcing is tied to stratospheric jet.

SOLUTION: use both, with increased efficiency for orographic GW

4th complication: winter & summer forcing

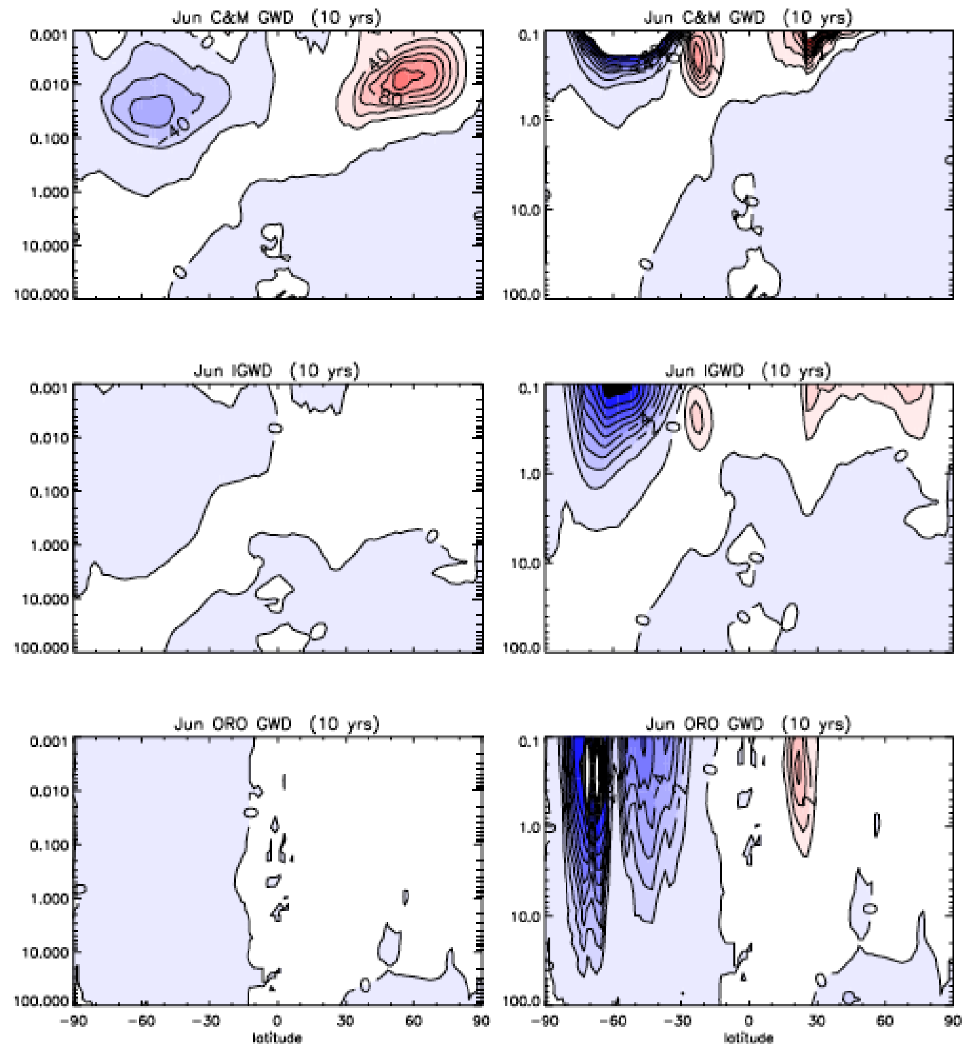
Some waves in the spectrum warm the winter lower stratosphere while others reduce the wind shear in the summer mesosphere and therefore warm the summer mesopause.

SOLUTION:

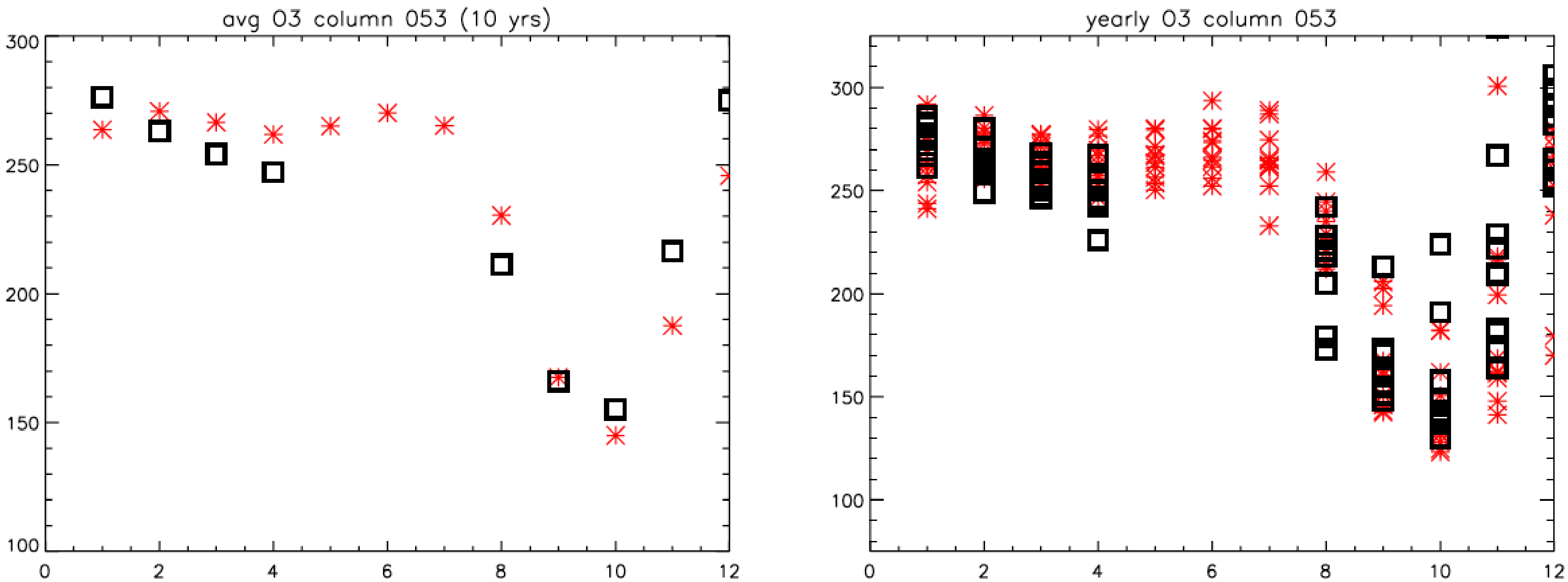
- high momentum flux to concentrate wave forcing in the stratosphere
- orographic waves affect winter but have little impact in summer

100 – 0.001 hPa

100 – 0. 1 hPa



monthly column ozone: WACCM vs Halley Bay



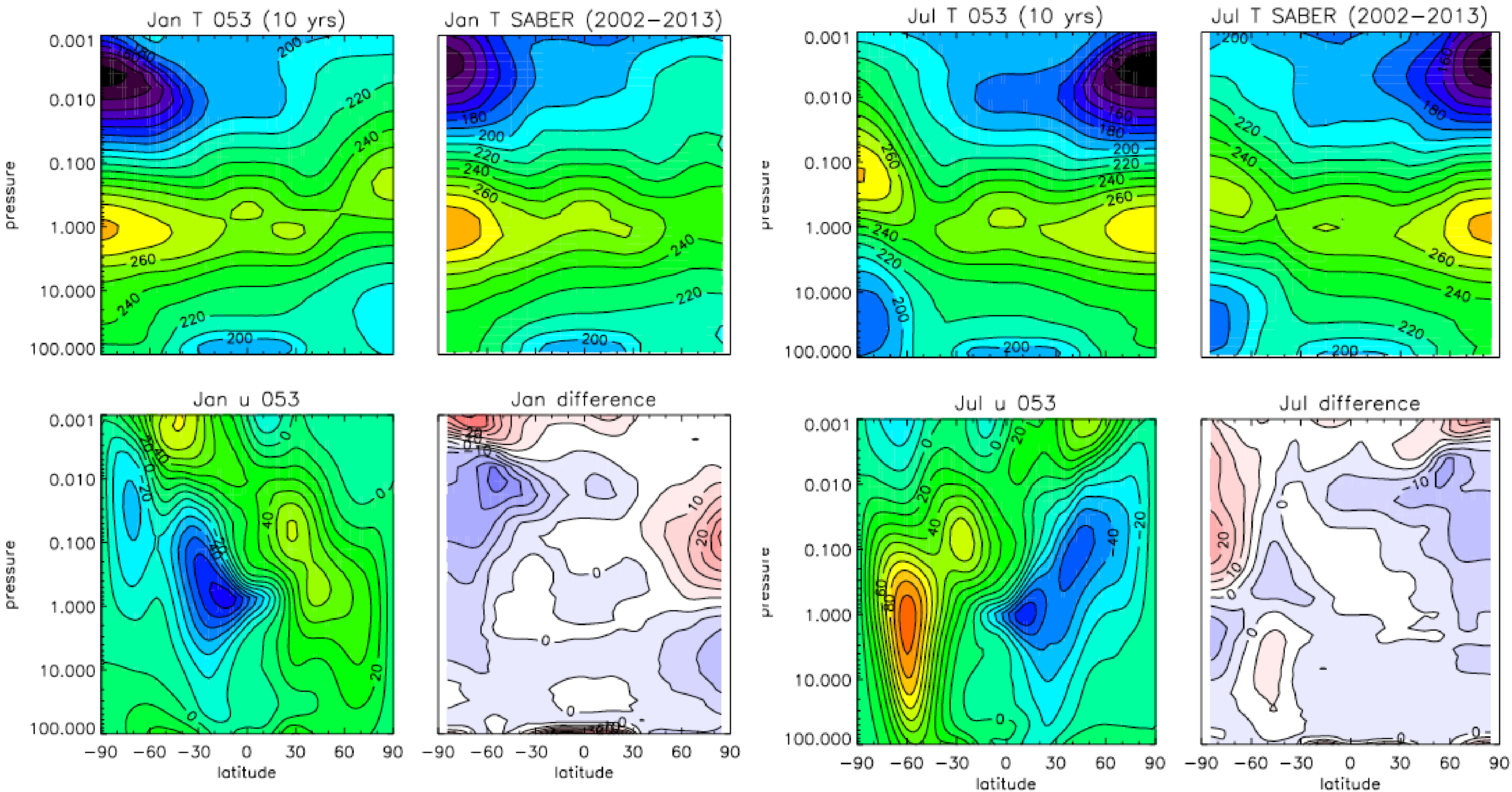
annual cycle 1995-2004

black: obs
red: WACCM

monthly T: WACCM vs SABER

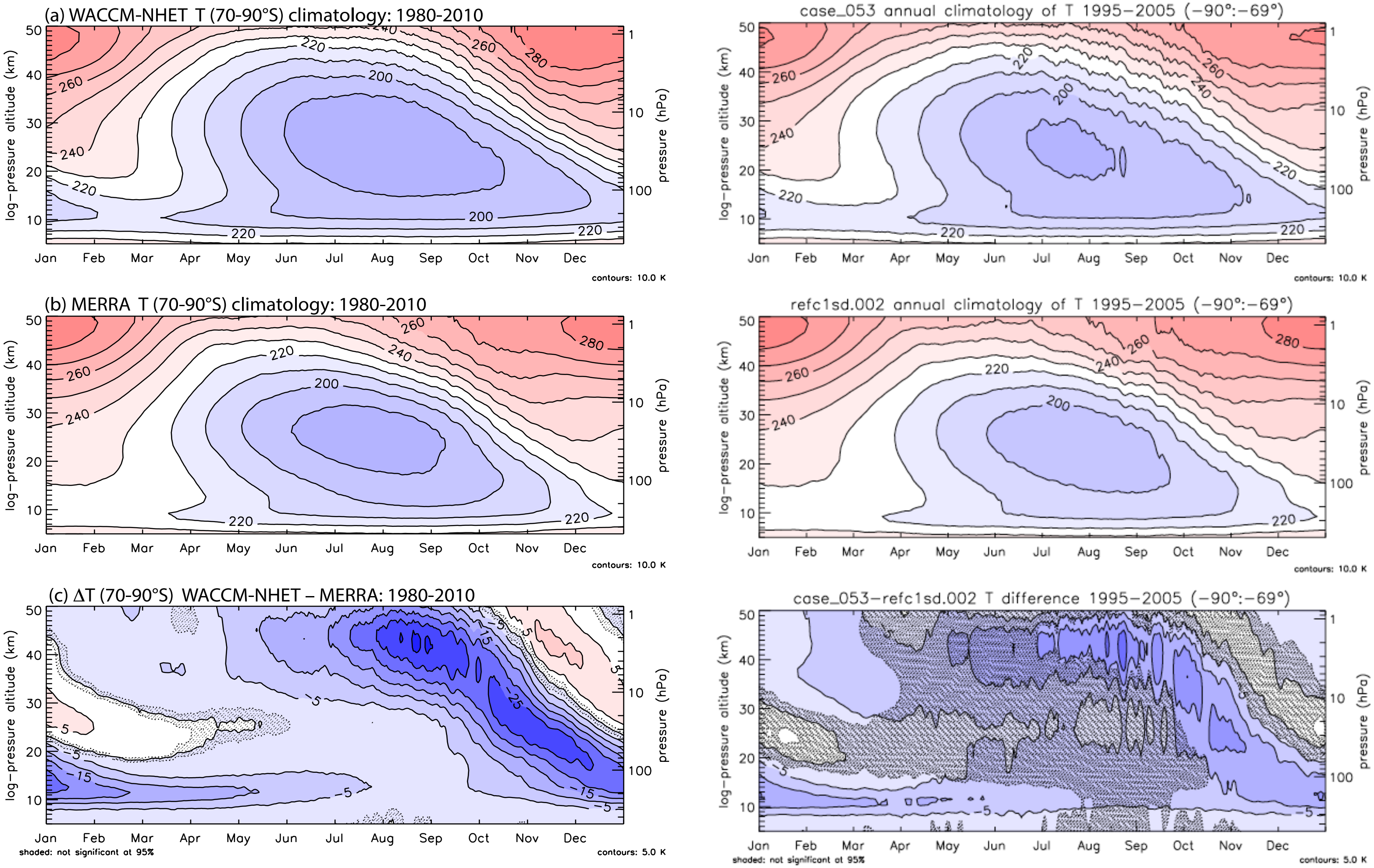
January

July



seasonal evolution with new settings

OLD (30 years) | NEW (10 years)



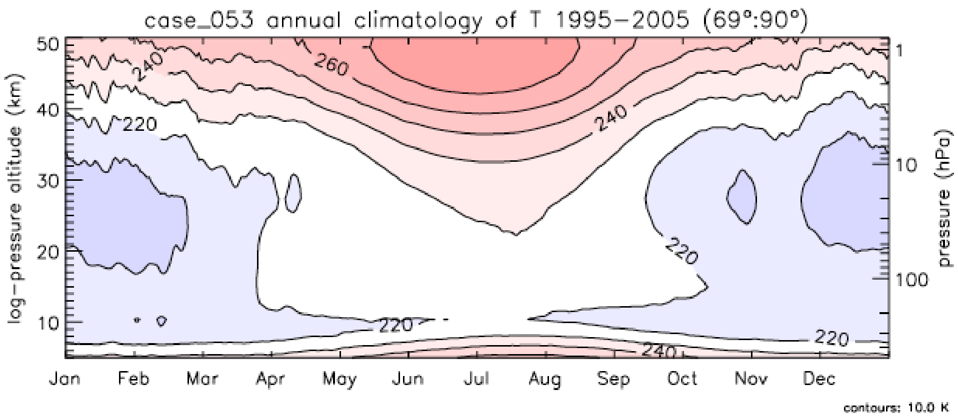
WACCM

MERRA

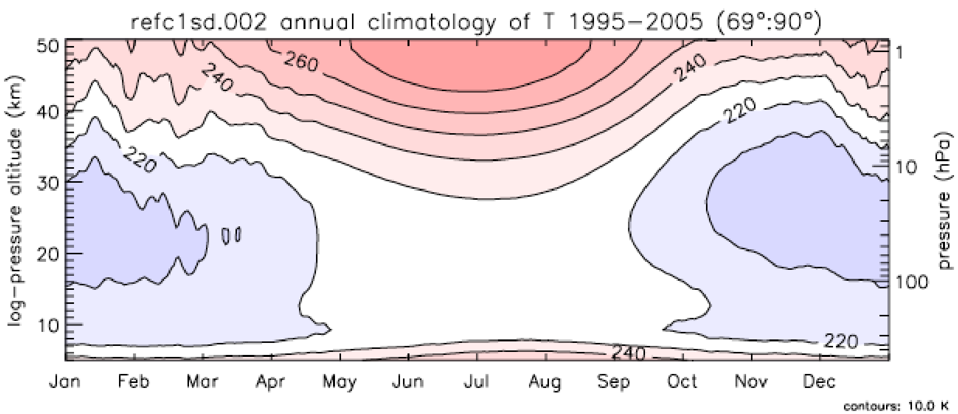
difference

- much improvement of temperature bias in winter, early spring
- late circulation reversal improved but still persists

impact on NH



WACCM



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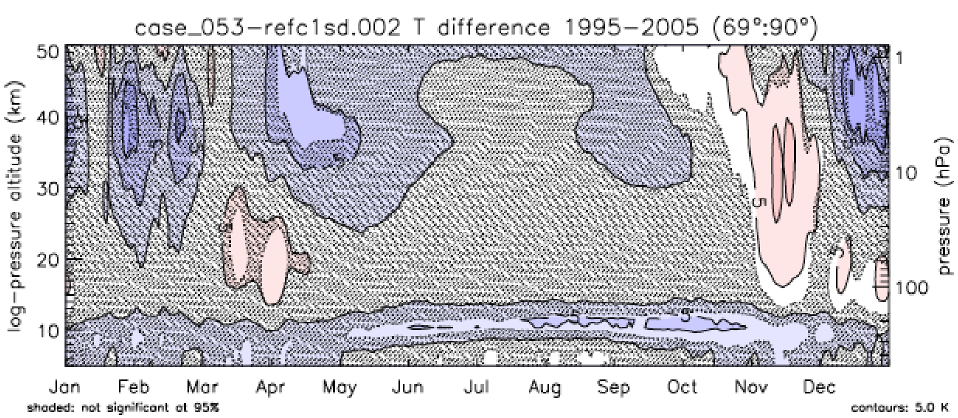

difference

climatology still looks good

new settings? – currently being evaluated

component	**change**
orographic	increased efficiency (x 2)
convective	no change
mesoscale	reduced upward flux changed threshold for frontal trigger
inertial	NEW launched at fronts Lx=300 km wave speed spectrum as in mesoscale gw very low efficiency