Extension of the WACCM gravity wave parameterization: motivation and results

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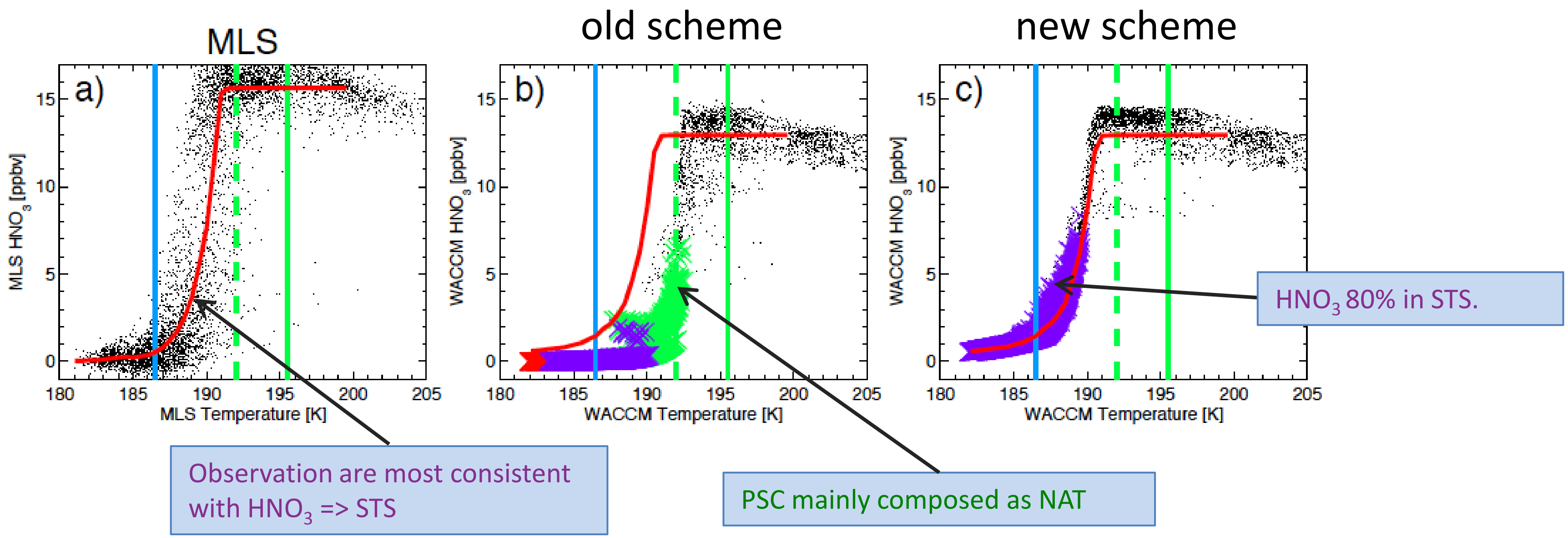
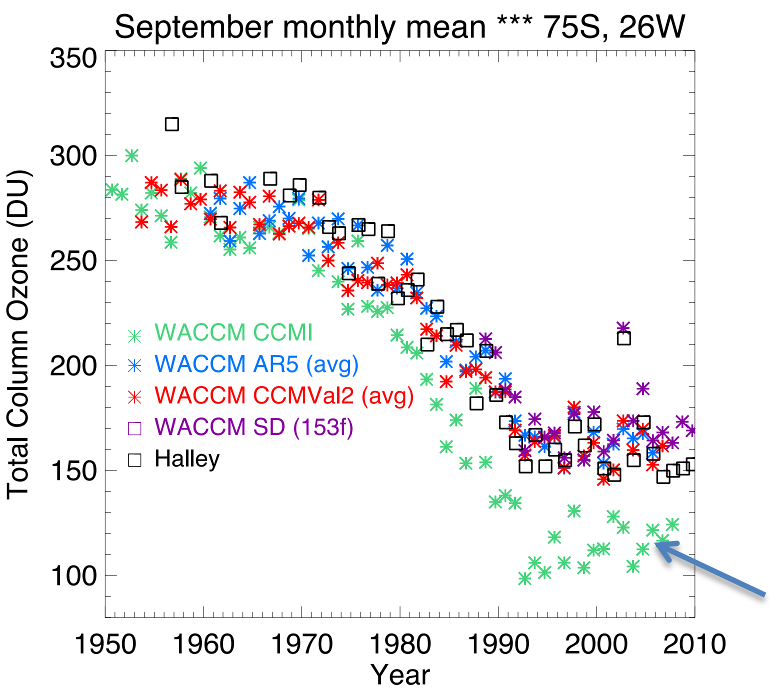
motivation: implementation of new heterogeneous chemistry module

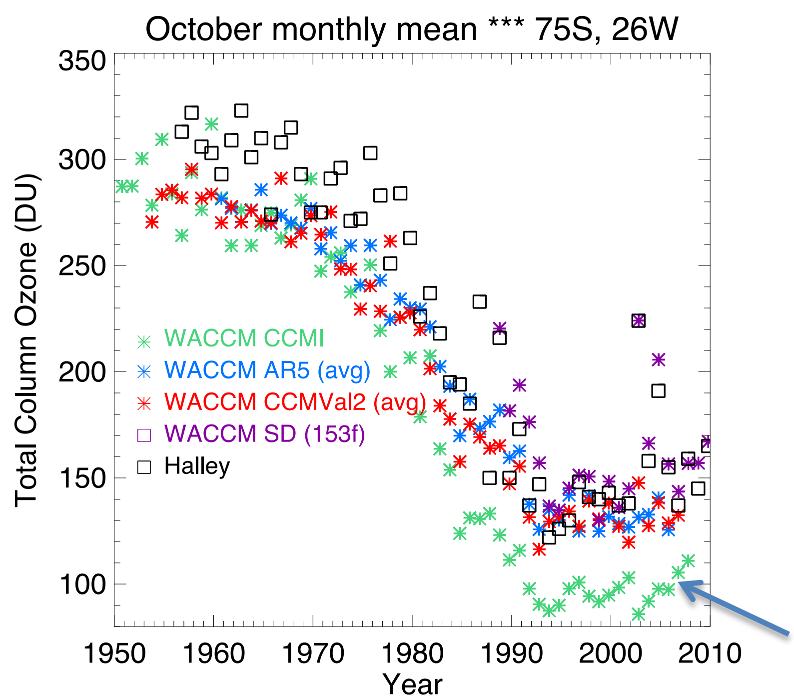
Updated het chemistry changes partitioning of condensed-phase HNO_3 between Nitric Acid Tri-hydrate (NAT) and Supercooled Ternary Solution (STS) [see Wegner et al., JGR, 2013.]



- 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



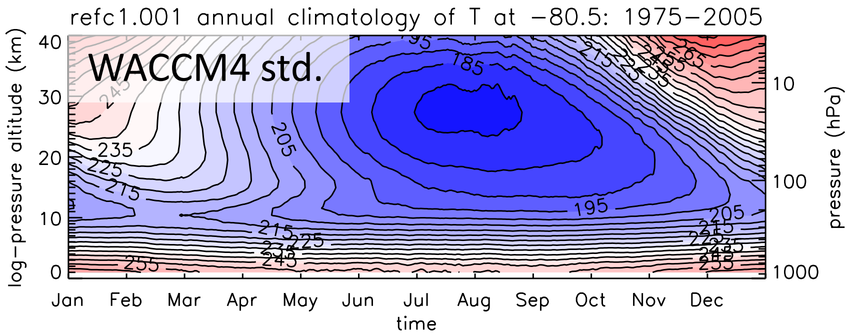


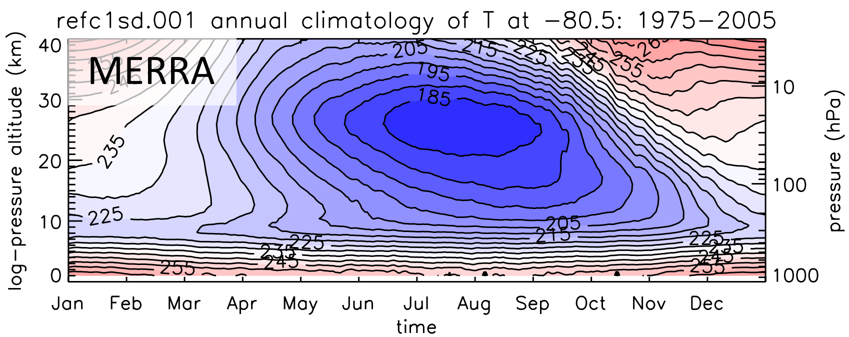
Observed and Calculated Ozone at Haley Bay

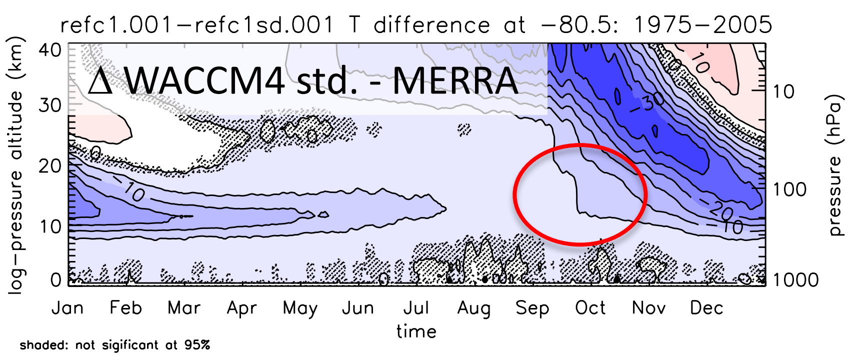
- model with **old chemistry** (red, blue) was reasonably consistent with observations
- model with **new chemistry** (green) produces unrealistically low ozone column because new het chemistry module is very sensitive the cold T

the ultimate cause of the problem

<T> (80°S) seasonal climatology 1975-2005





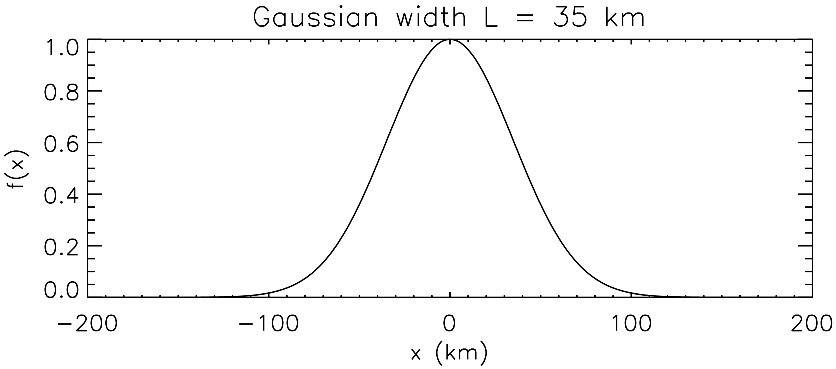


- standard version of WACCM4 has a **“cold pole” bias** in the SH
- T in ozone hole region/season is as much as 5-10 K colder than observed

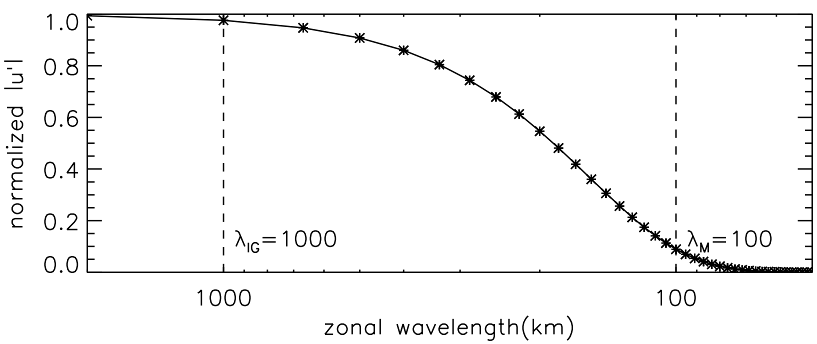
a possible solution

- polar temperatures are sensitive to wave-induced downwelling via adiabatic warming; 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 parameterization to make GW break in the stratosphere degrades the simulation in the mesosphere
- parameterized GW in WACCM4 are “mesoscale” (L_X = 100 km); however, any physical source should excite a (“red”) spectrum in wavenumber
- ➔ add a second spectrum of waves, with L_X ~ 1000 km (typical of the inertia-gravity range, IGW) to represent the effects of longer waves
- the longer IGW will have larger source amplitudes that can break in the stratosphere for reasonable values of the source stress

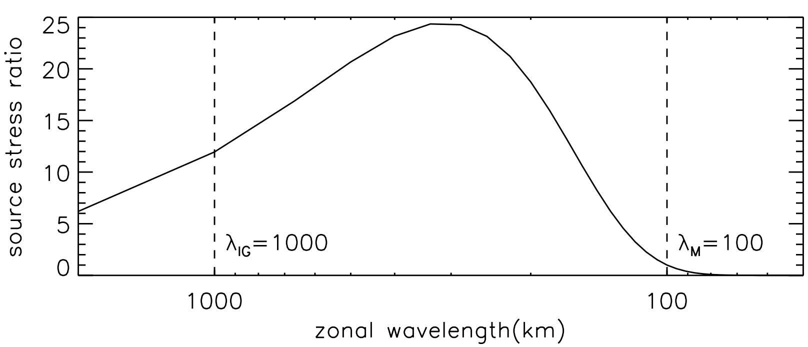
wavenumber spectrum



consider GW excitation by a “front”, idealized here as a Gaussian obstacle of width L: *w’* = <U> d*h’*/dx and, therefore, |*u’*| = *m* <U> |*h’*|



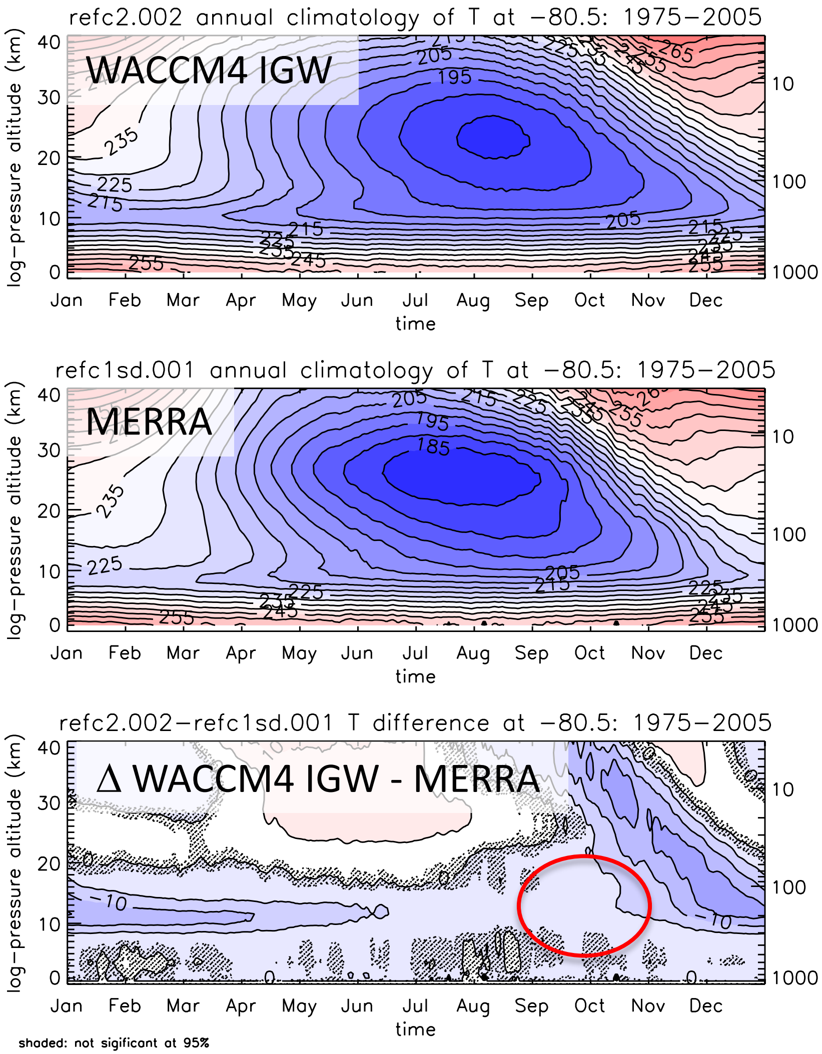
produces a Gaussian “red” spectrum in wavenumber (shown here as a function of horizontal wavelength); spectral amplitude |u’| falls of rapidly at small wavelenghts (large wavenumber, *k*)



the fall-off of spectral amplitude with decreasing wavelength means that longer waves tend to have larger source stress, $\tau = \rho\,(k/m)|u'|^2$, than mesoscale waves ➔ they break at lower altitude

<T> (80°S) with additional IGW spectrum

<T> (80°S) climatology 1975-2005

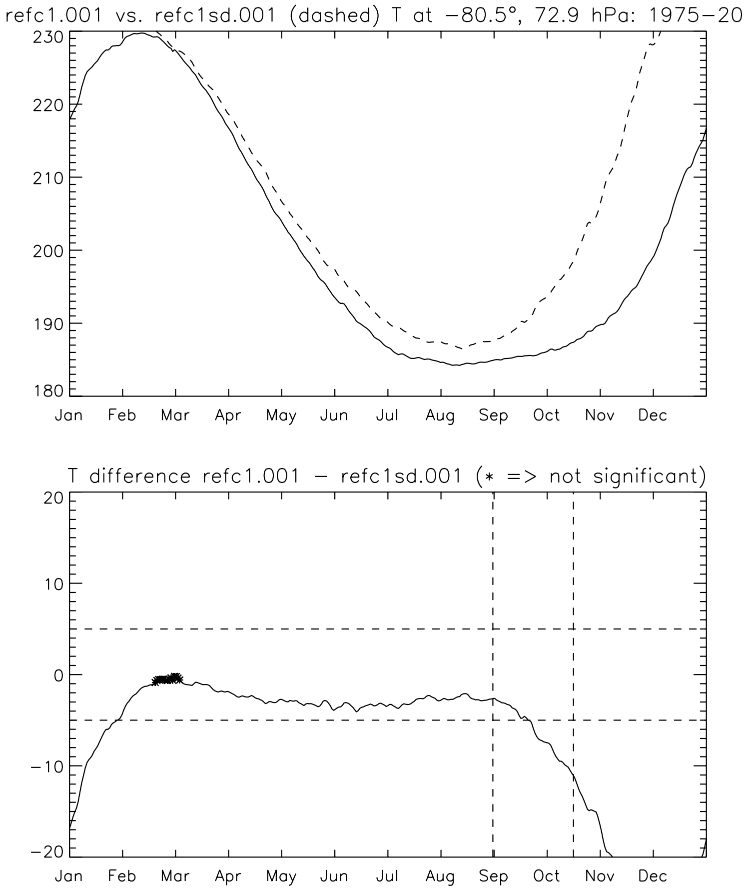


IGW spectrum uses source stress
$\tau = 8 \times 10^{-3}$ Pa
mesoscale GW spectrum uses
$\tau = 1 \times 10^{-3}$ Pa
these values are consistent with simple theoretical arguments outlined in previous slide

T in ozone hole region in SH spring is now much warmer

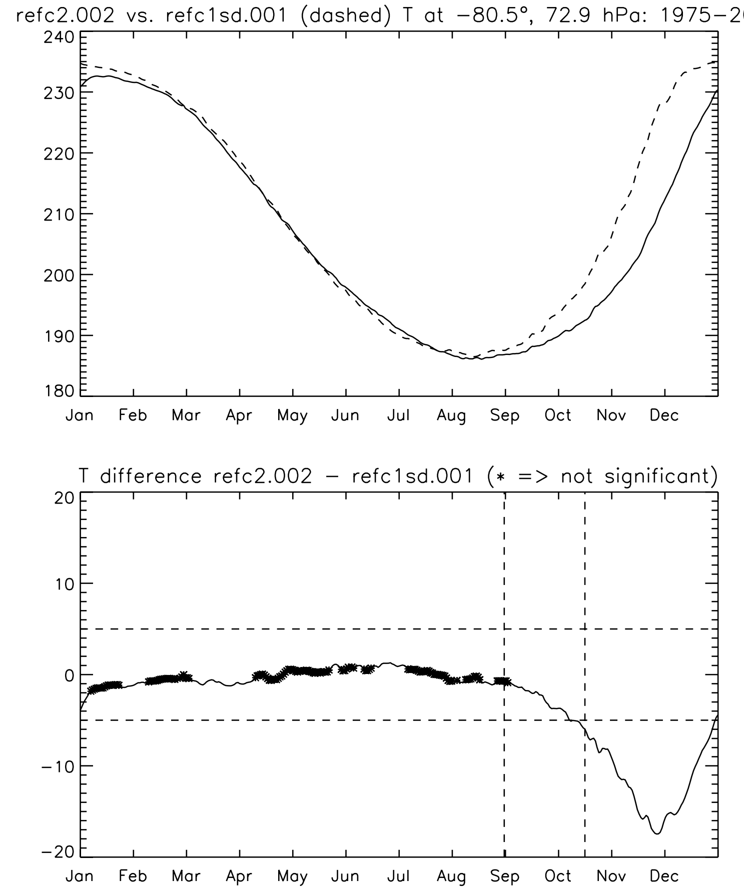
<T> @ 70 hPa, 80°S

WACCM4 std. vs. MERRA



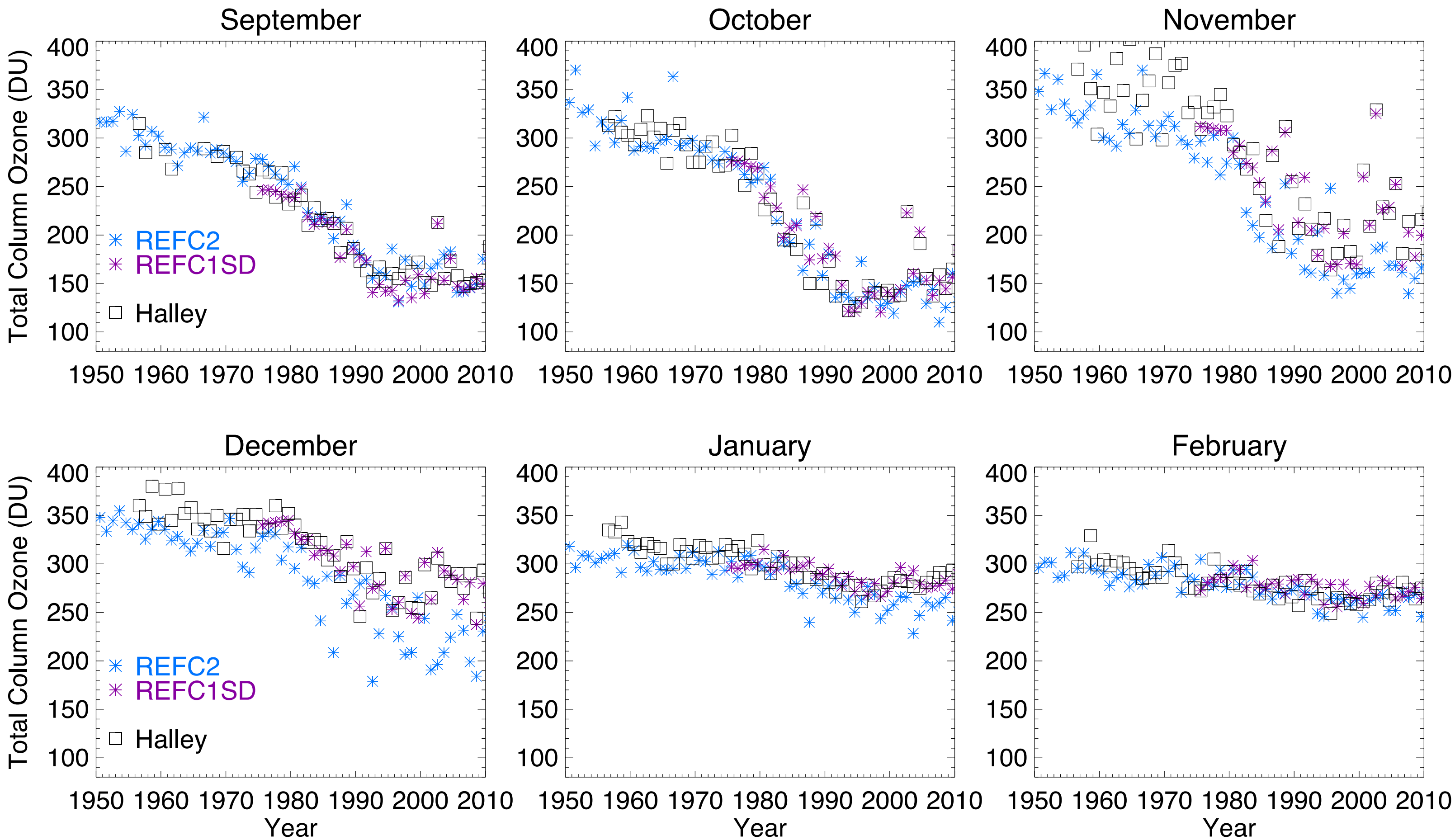
std. model is 5-10 K colder than MERRA from mid-September on

WACCM4 IGW vs. MERRA



model with IGW is within 5 K of MERRA through mid-October

ozone column in WACCM4 IGW



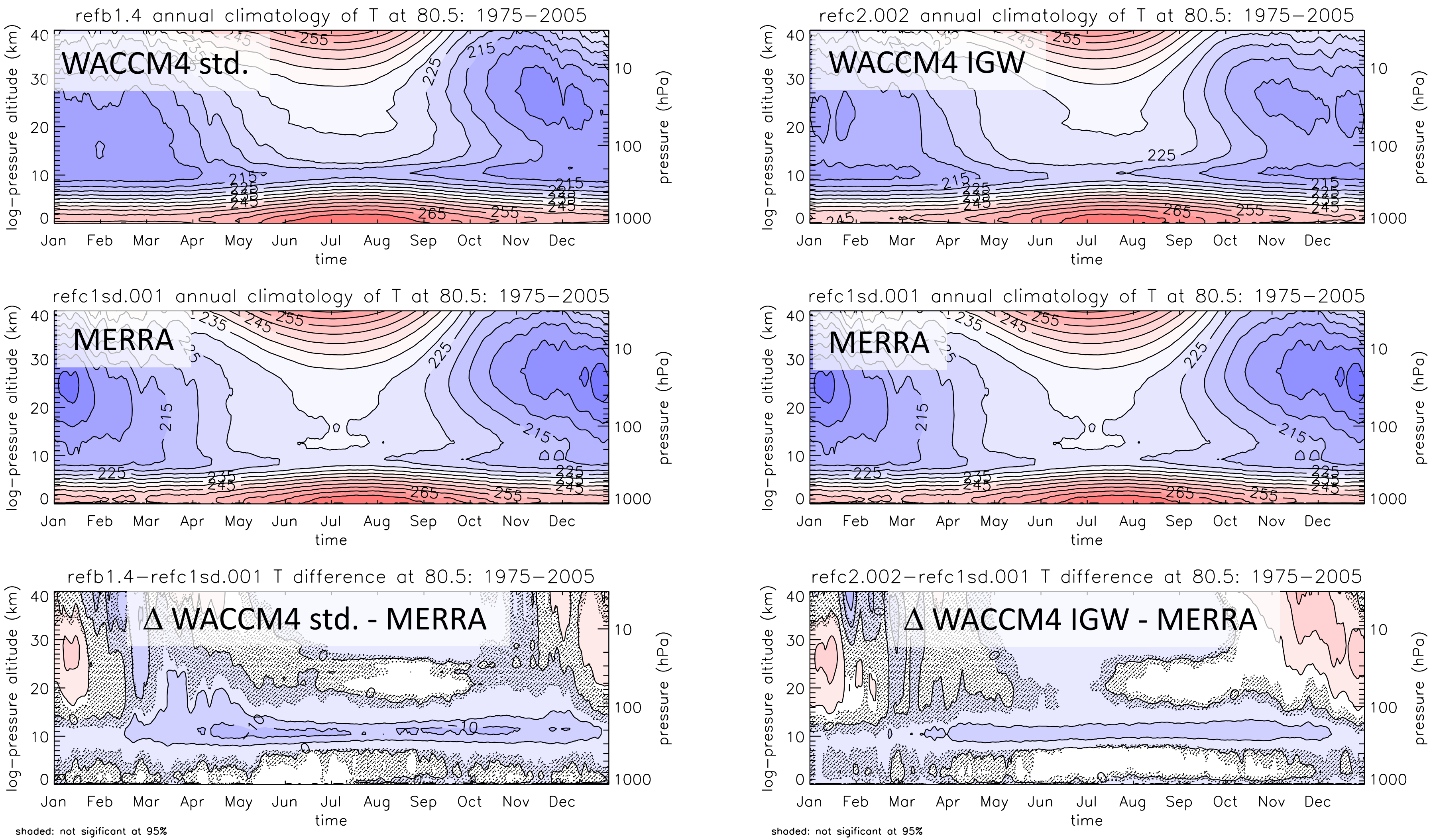
"REFC2": WACCM4 IGW, free-running

"REFC1SD": WACM4 constrained with MERRA dynamics

including IGW "solves" the low ozone problem

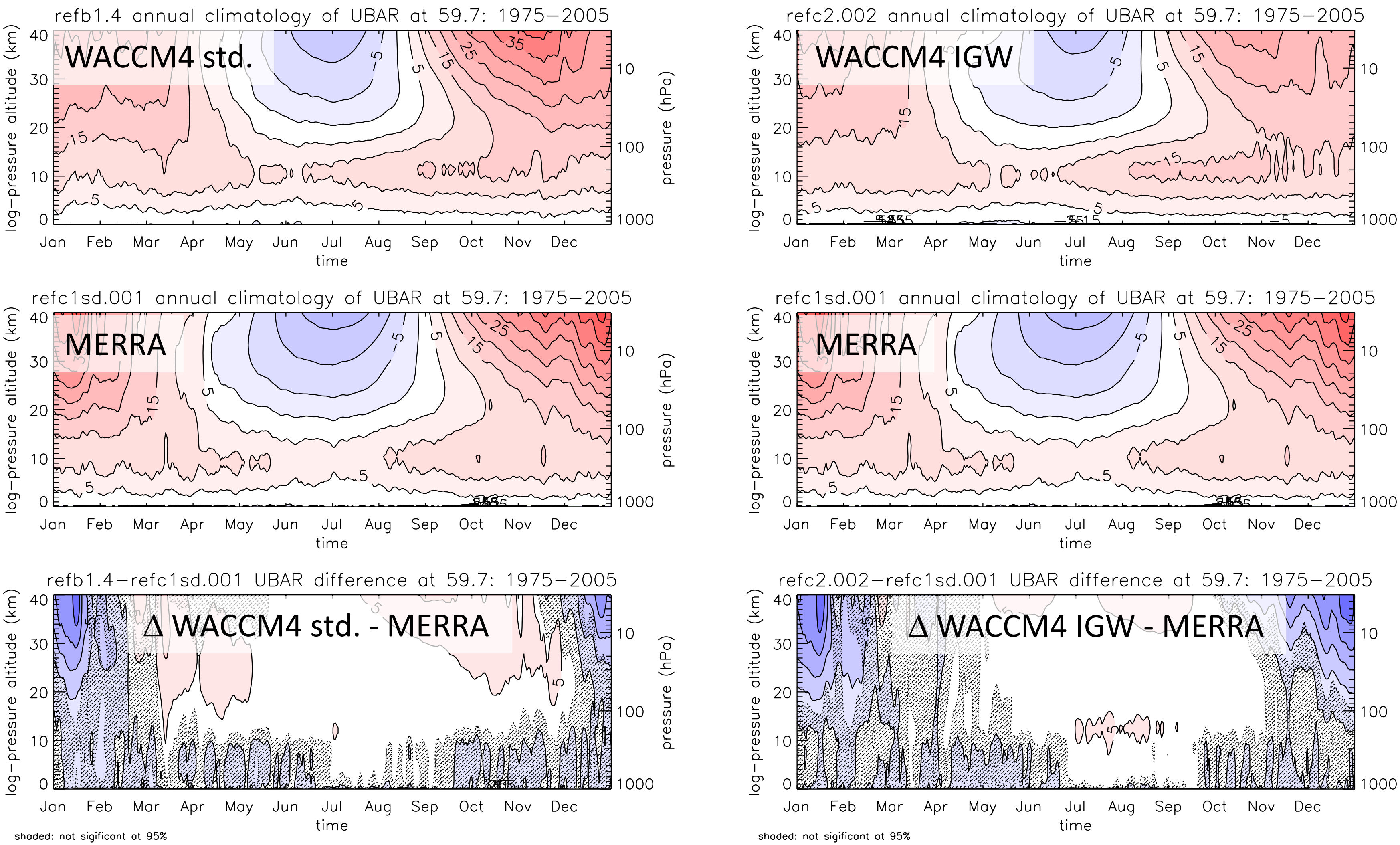
(except in December, because *final vortex breakdown is still too late*)

but what about T in NH winter?



differences in <T> (80°N) with respect to MERRA are small in both WACCM4 std. and WACCM4 IGW, although the latter is slightly warmer

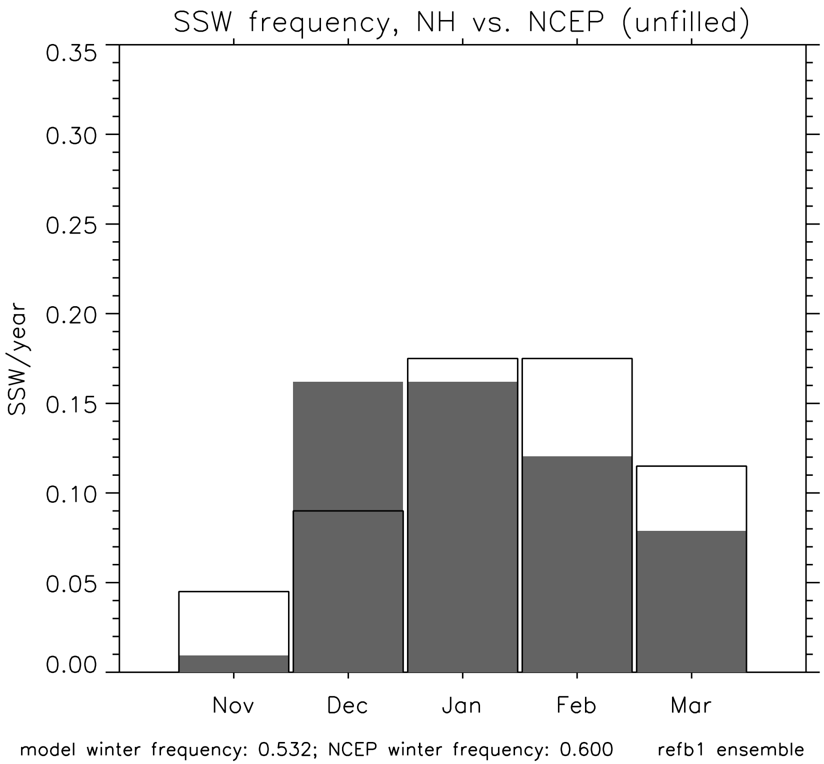
similarly for the mean zonal wind at 60°N



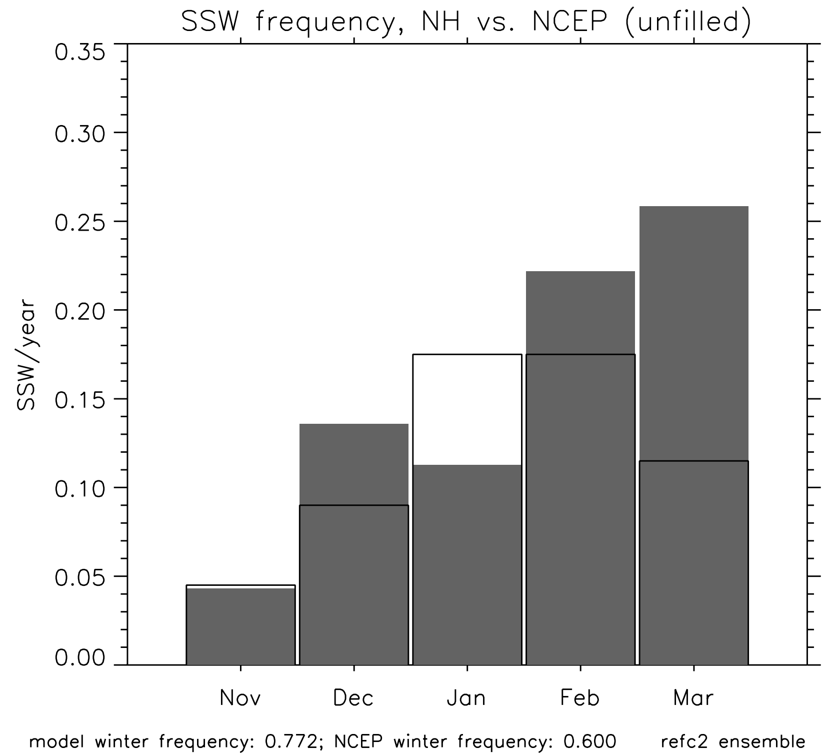
small differences overall, all of which suggests small impact of IGW in the NH. **However…**

SSW statistics: WACCM4 std. and IGW

WACCM4 std. 1975-2005
ensemble statistics

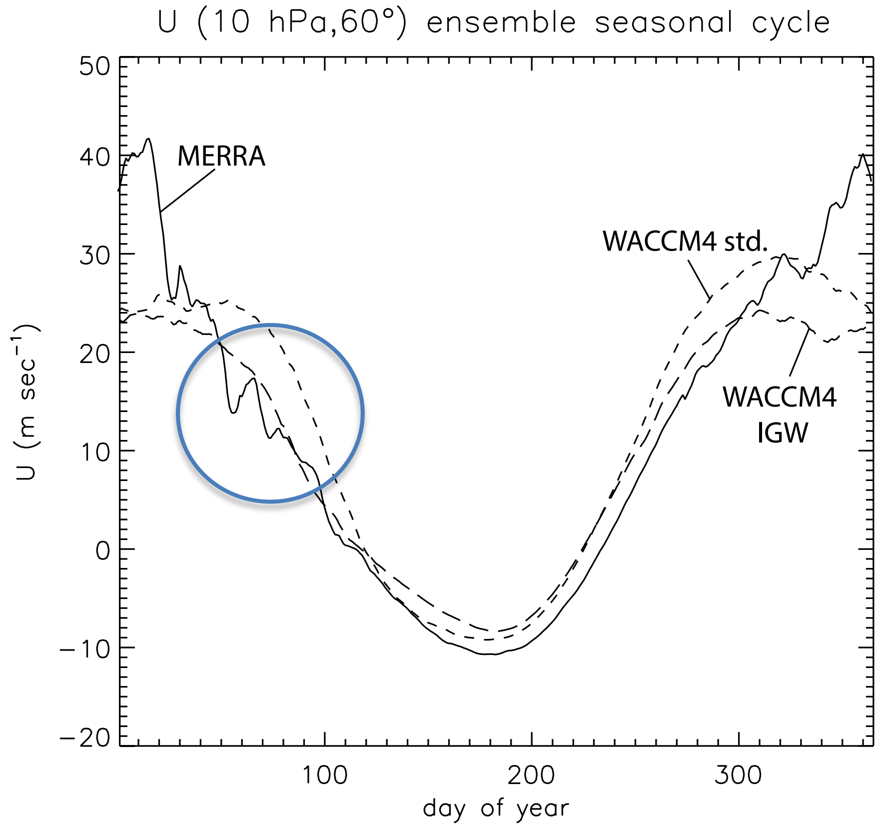


1975-2005 WACCM4 IGW
ensemble statistics



- WACCM4 IGW produces too many SSW late in the season (especially March)
- statistics are for a 3-member ensemble, so unlikely to arise by chance

a closer look at seasonal climatology: <U> (10 hPa, 60°N)



- U(10 hPa, 60°S) is stronger in MERRA than in either WACCM4 run in midwinter
- U(10 hPa, 60°S) is somehwat stronger overall in WACCM4 std. than in WACCM4 IGW and is noticeably stronger in NH spring (*but actually closer to MERRA*)

conclusions

- the addition of a second spectrum of parameterized gravity waves, in the IGW range, is physically resonable
- it ameliorates the **SH** cold-pole problem problem sufficiently to allow realistic simulation of Antarctic ozone with the updated heterogeneous chemistry module
- it produces relatively minor changes in <U> and <T> in the **NH** compared to the standard version of WACCM4
- it agrees with MERRA data for the NH at least as well as the standard version
- **however**, it produces too many late-season SSW—this aspect of the simulation needs further study