Extension of the WACCM gravity wave parameterization: motivation and results

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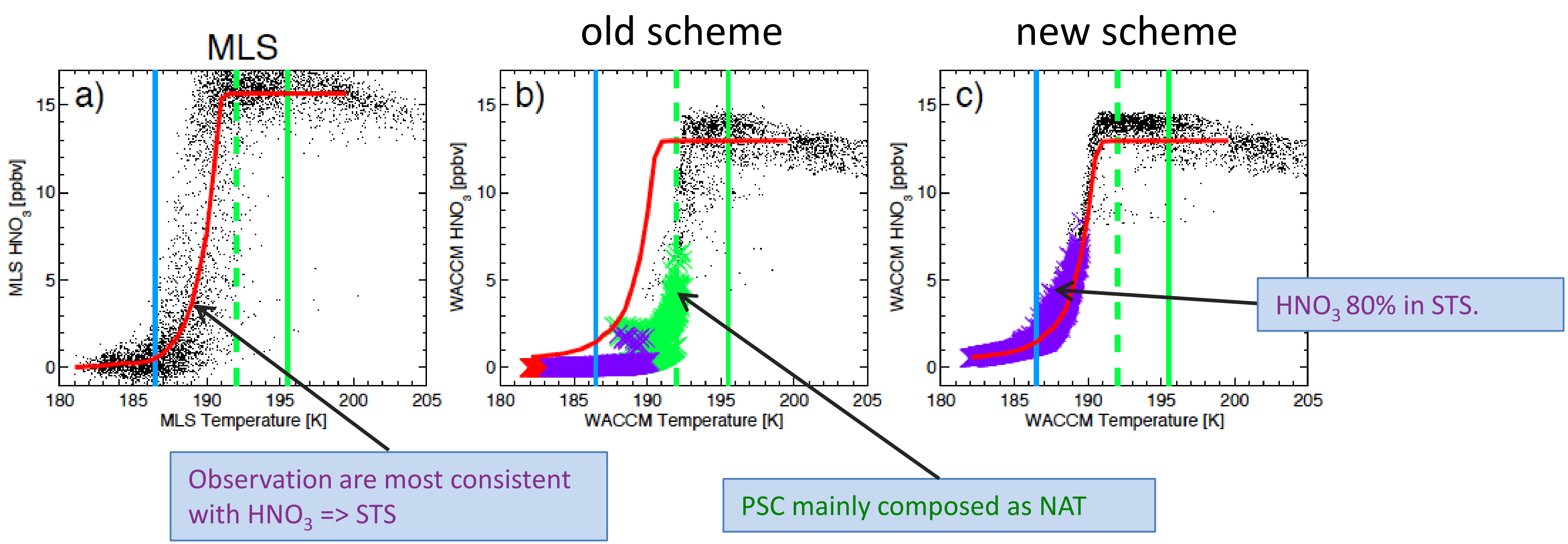
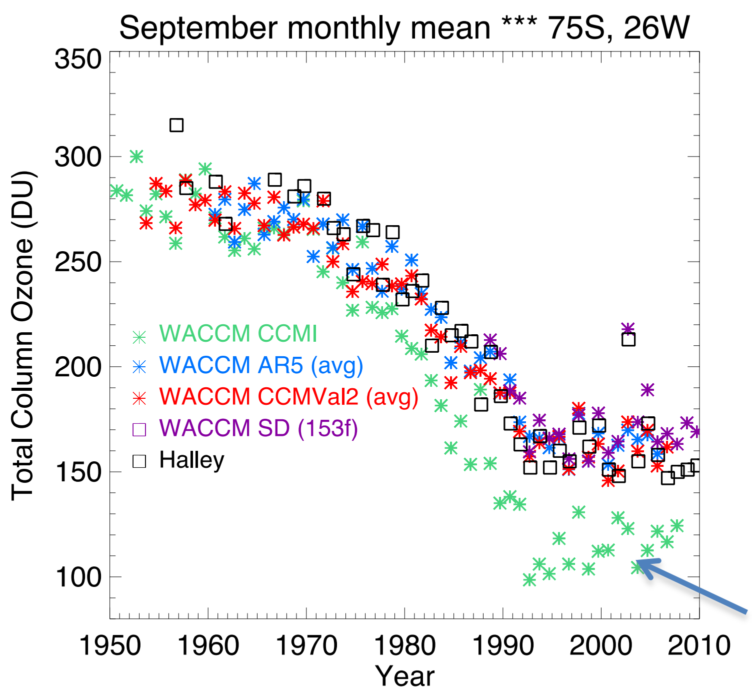
motivation: new heterogeneous chemistry module

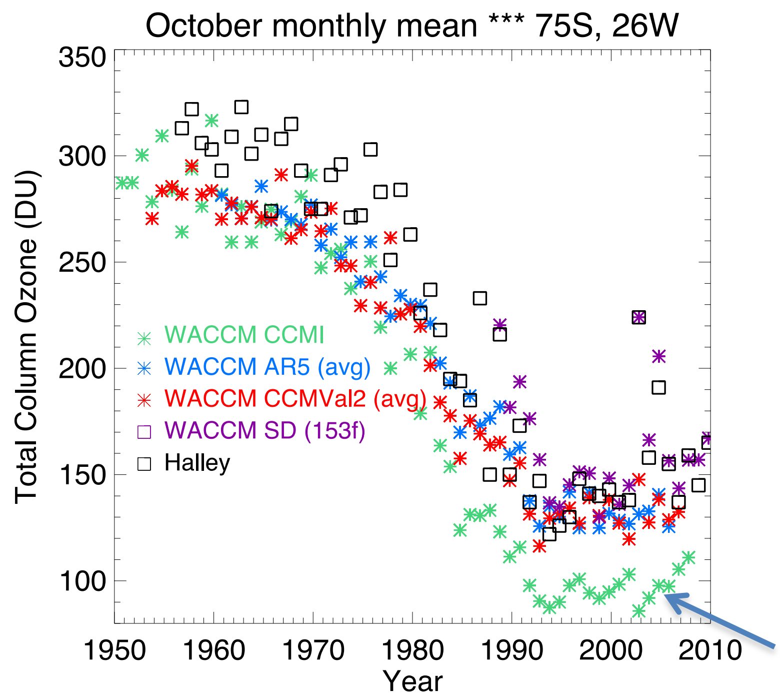
Updated heterogeneous chemistry changes partitioning of condensed-phase HNO_3 between Nitric Acid Tri-hydrate (NAT) and Supercooled Ternary Solution (STS) [Wegner et al., *JGR*, 2013.]



- Updated heterogeneous chemistry decreases irreversible denitrification by decreasing NAT and increasing STS
- Less denitrification allows reformation of $ClONO_2$ and continued heterogeneous halogen activation in Spring
- Heterogeneous rate for halogen activation on STS is very T-dependent (colder ➔ faster)
- This **requires a more accurate representation of SH winter/spring polar temperature** in the lower stratosphere

which leads to a problem



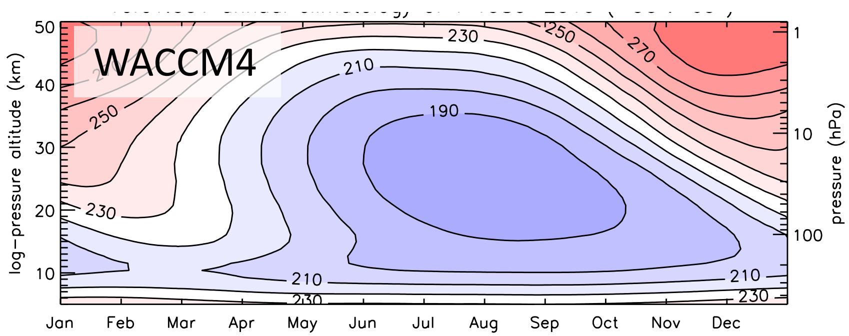


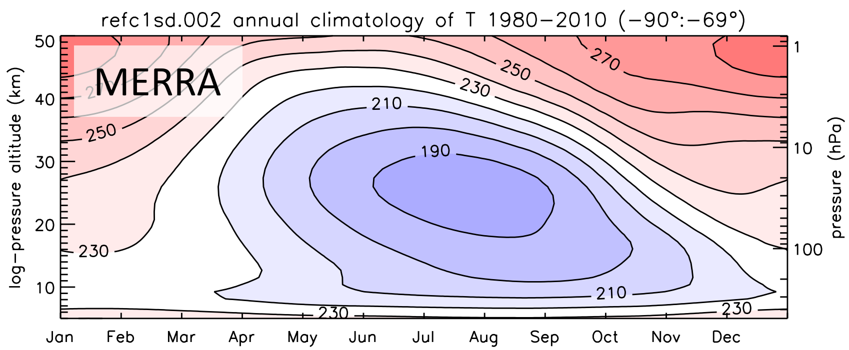
Observed (square symbols) and calculated ozone at Haley Bay

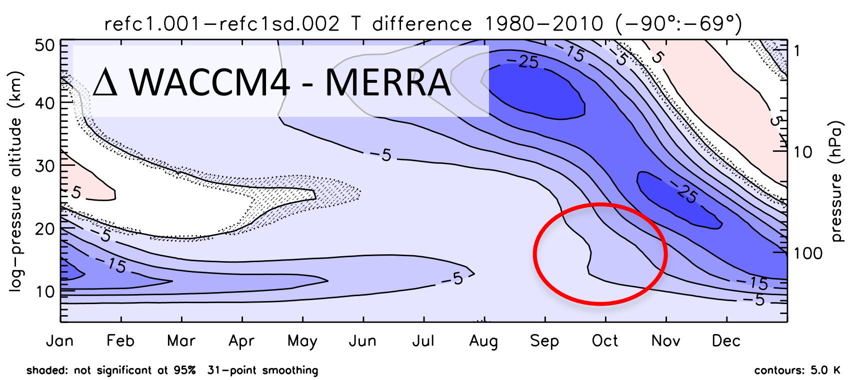
- WACM4 with **old chemistry** (red, blue, purple) is reasonably consistent with observations
- WACCM4 with **new chemistry** (green) produces unrealistically low ozone column because the new heterogeneous chemistry parameteriztion is **very sensitive to cold temperatures**

SH polar temperature bias in WACCM4

SH polar cap (70° -90° S) T climatology: 1980-2010







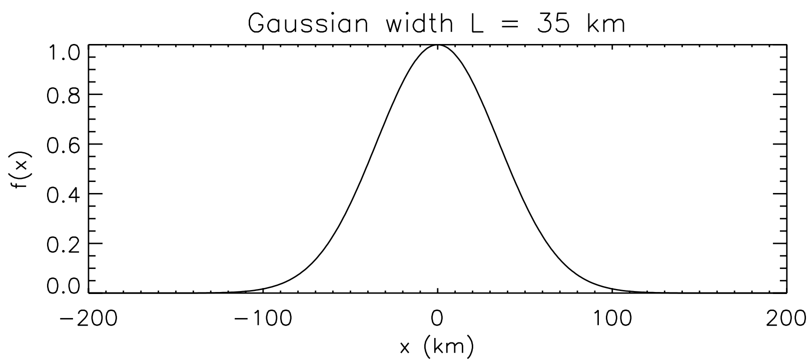
The ozone problem is ultimately due to the seasonal evolution of temperature in the SH in WACCM4

- 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

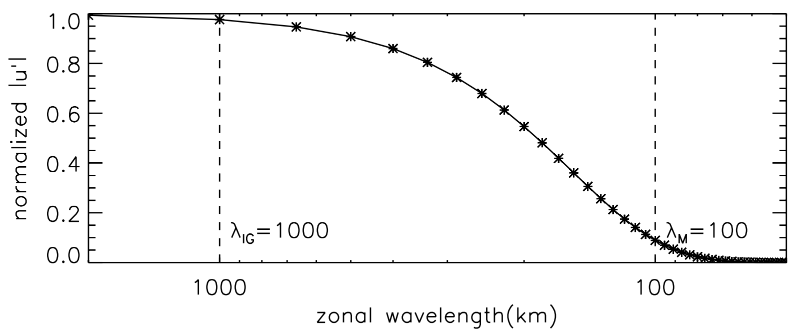
a possible solution

- polar temperatures are sensitive to wave-induced downwelling; 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 at lower altitudes degrades the simulation in the mesosphere
- ➔ add a spectrum of waves, with wavelength typical of the inertia-gravity range (IGW; Fritts and Alexander, *Rev. Geo.*, 2003), to represent the effects of longer GW

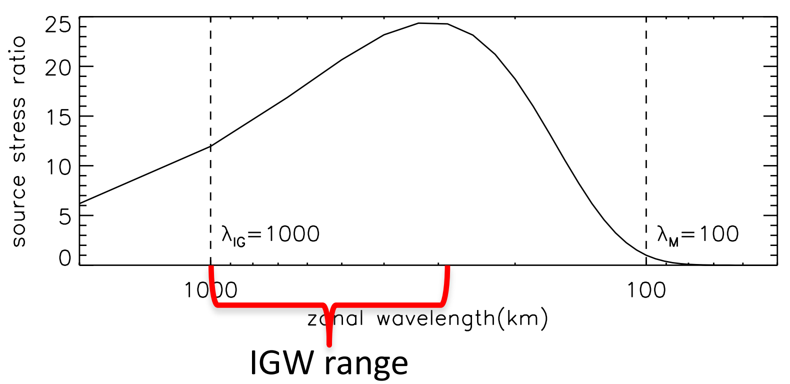
horizontal wavenumber spectrum



- consider GW excitation by wind U flowing across a Gaussian obstacle h':
- $w' = U\, dh'/dx \sim k\, U\, h'$



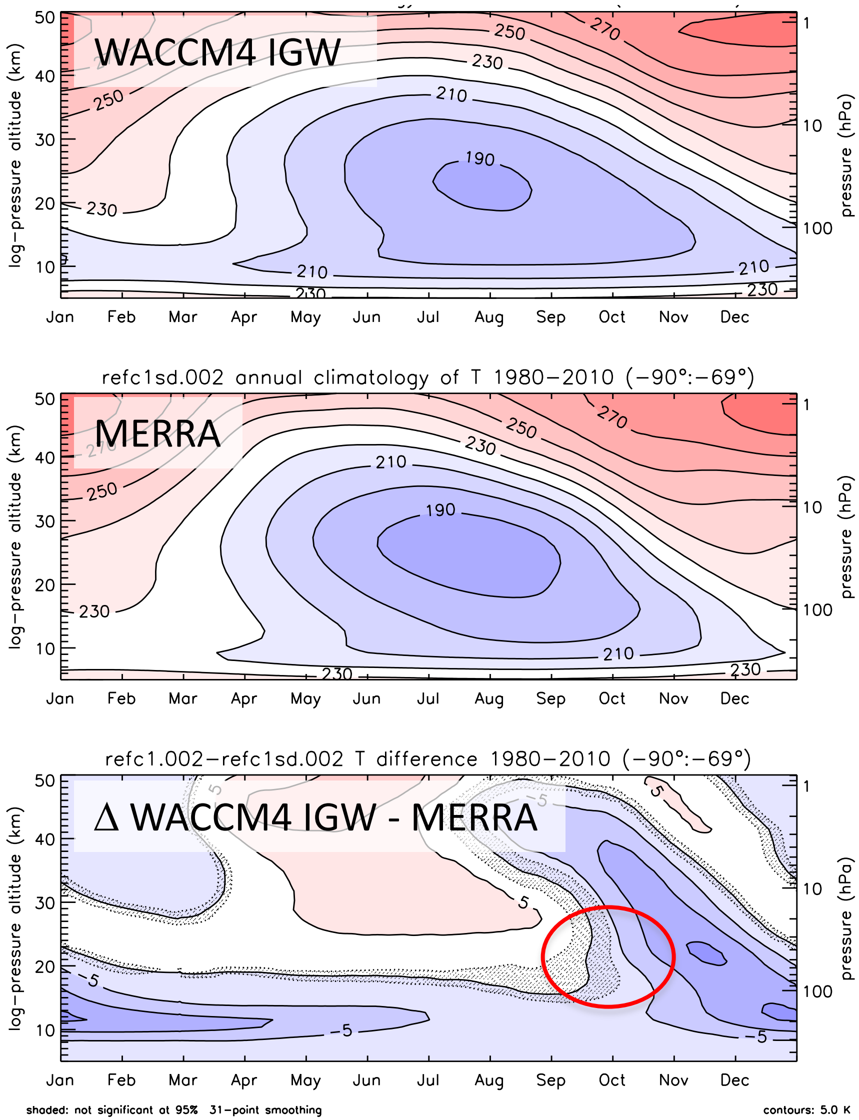
- this produces a Gaussian wavenumber spectrum of $u' = -(m/k)\, w' \sim m\, U\, h'$
- for obstacles of reasonable width, *L, the* spectral amplitude of *u'* decreases rapidly with increasing wavenumber (decreasing wavelength)



- this implies that IGW tend to have larger source stress, $\tau = \rho\, (k/m)|u'|^2$, than mesoscale GW
- ➔ they break at lower altitude

WACCM4 with IGW: SH polar cap T climatology

SH polar cap T climatology: 1980-2010



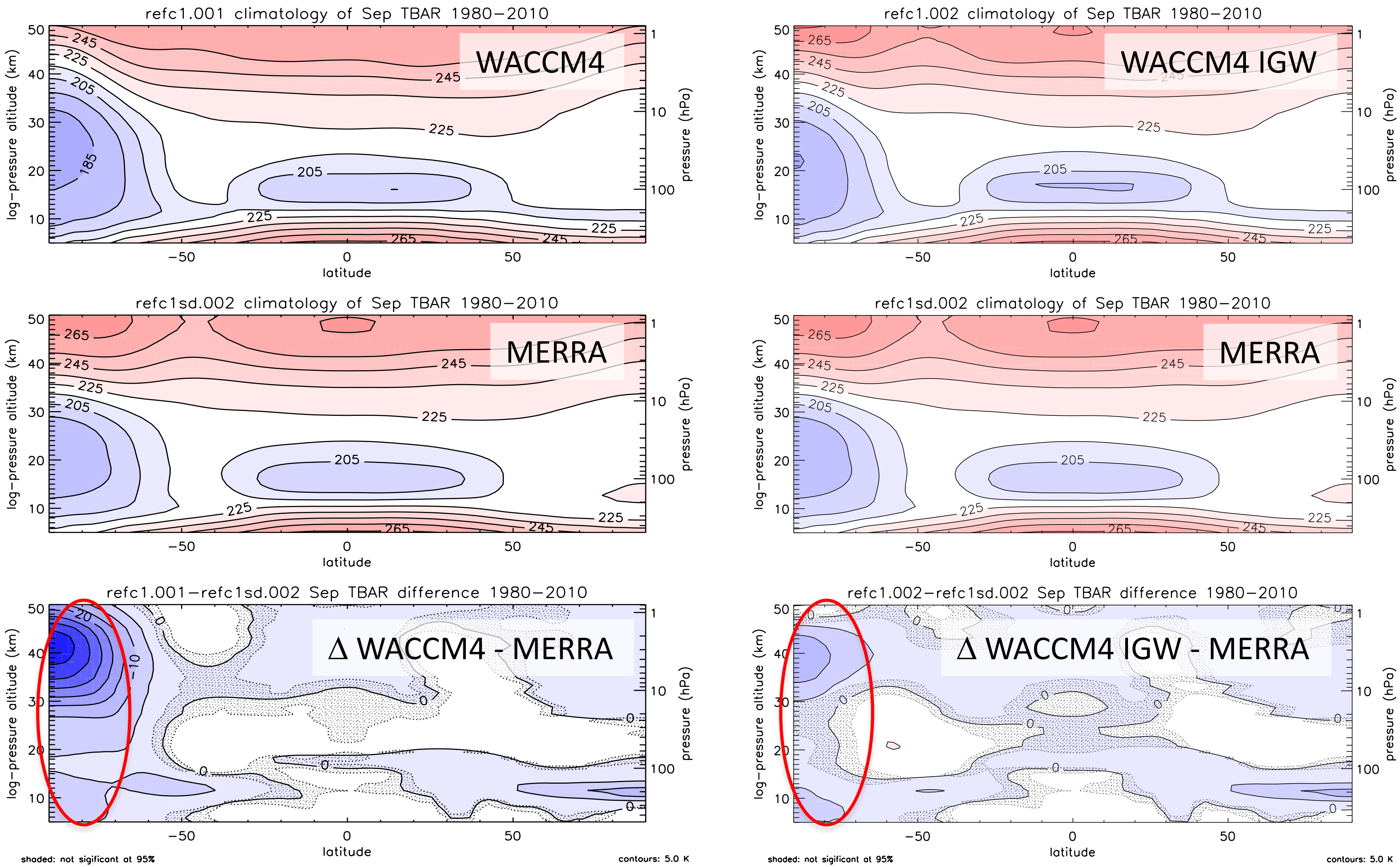
- WACCM4 run with IGW using typical λ_x =1000 km
- IGW spectrum uses source stress

  τ = 8 x 10^{-3} Pa
- mesoscale GW spectrum uses

  τ = 1 x 10^{-3} Pa
- these values are consistent with the simple theoretical arguments outlined in previous slide

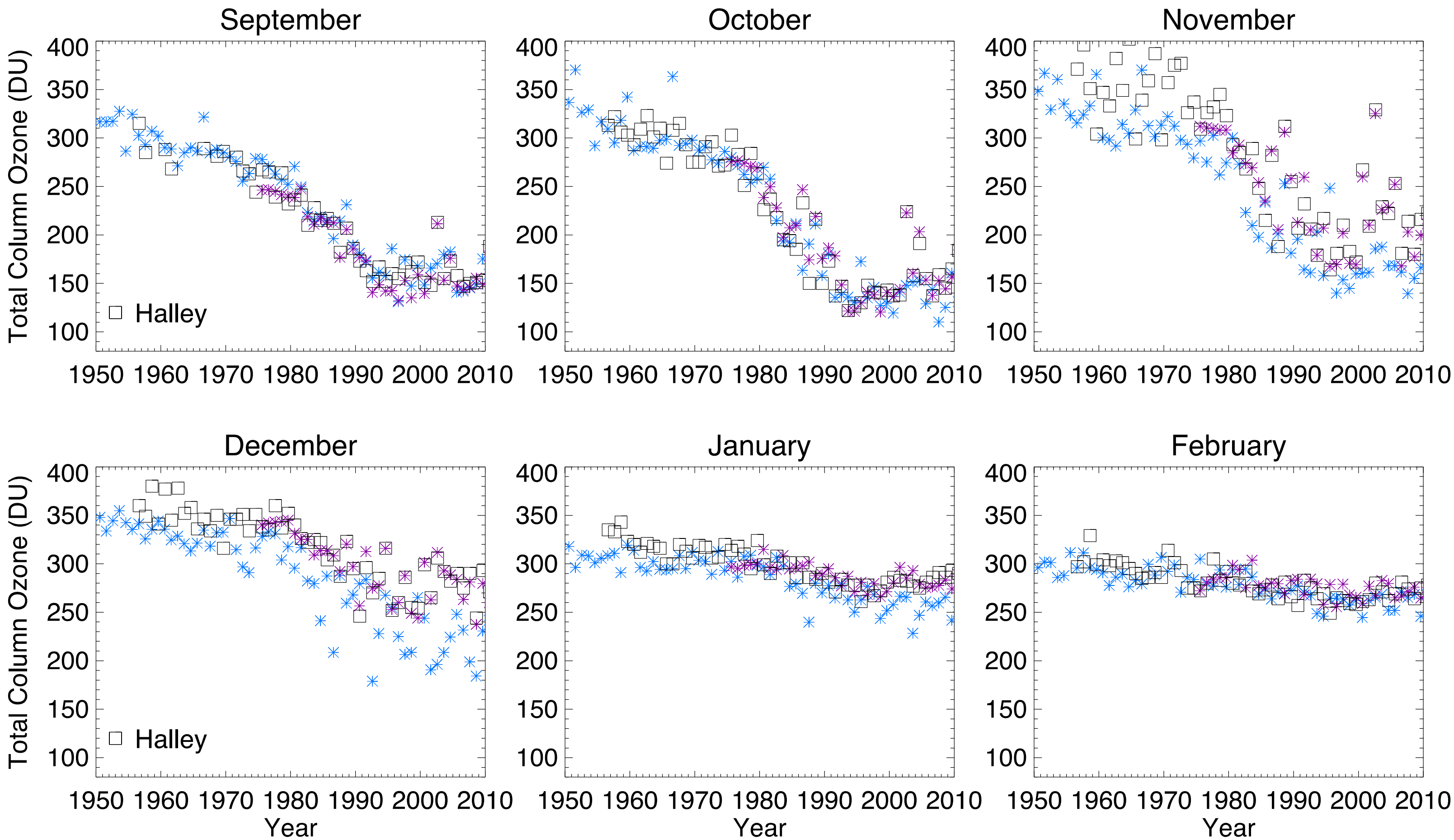
T in ozone hole region in SH spring is now much warmer

climatological T in September: effect of IGW



SH polar cold bias is much reduced by introduction of IGW

ozone column in WACCM4 with IGW



blue: WACCM4 IGW, free-running, new het chemistry

purple: WACM4 constrained with MERRA dynamics, new het chemistry

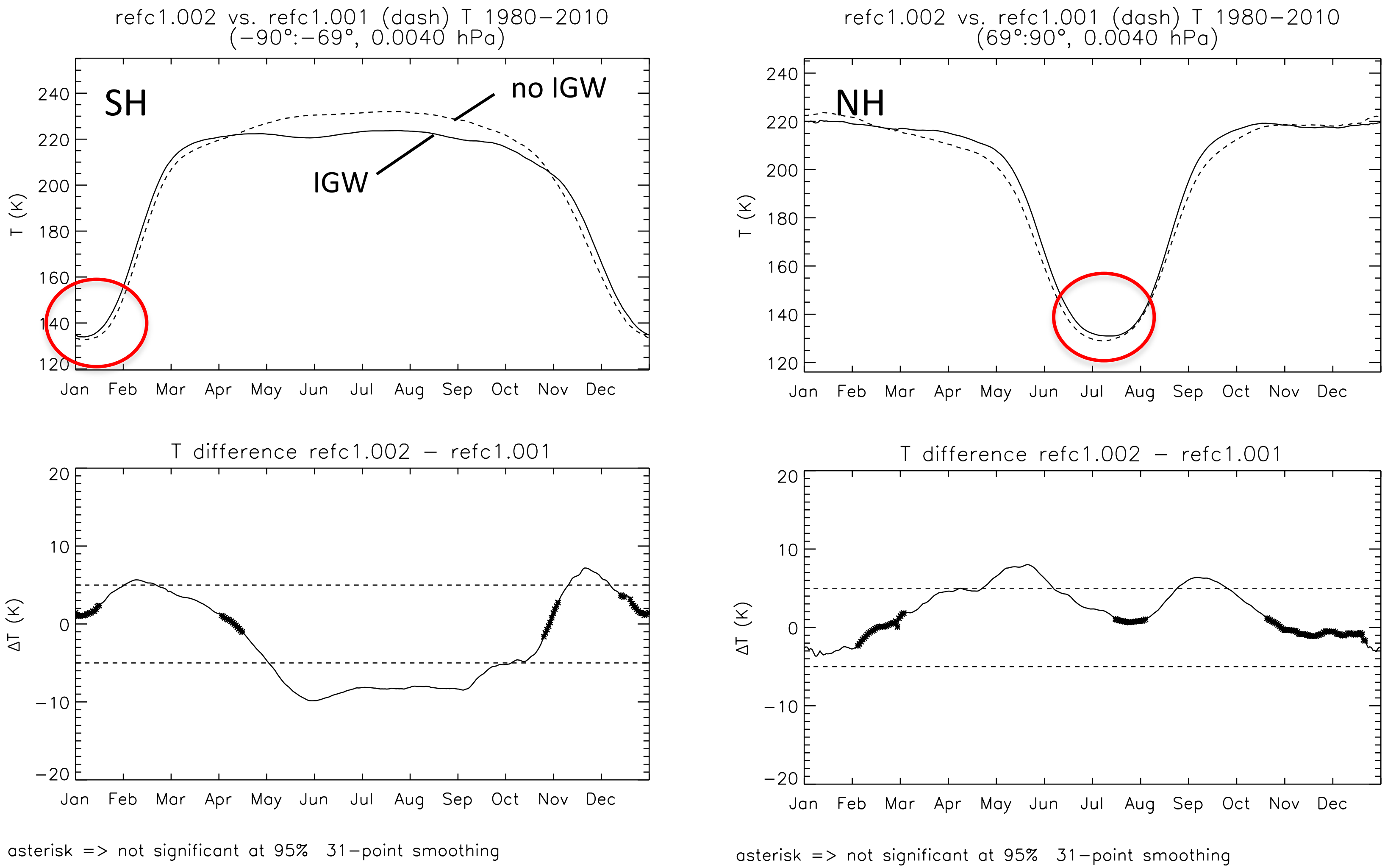
including IGW "solves" the low ozone problem

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

- addition of IGW improves the climatology of T and ozone in the SH lower stratosphere

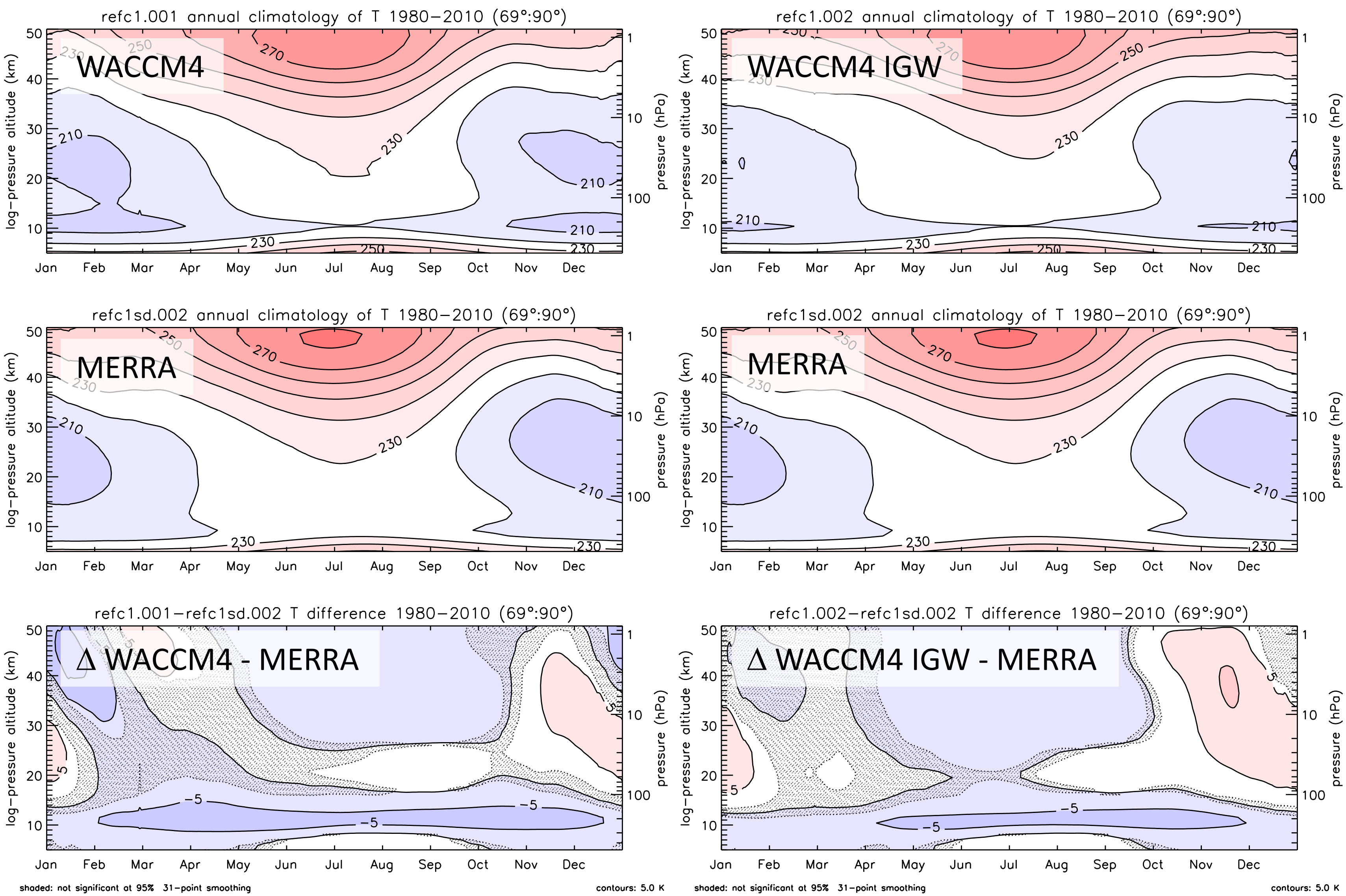
- does it preserve other, desirable aspects of the model's climatology elsewhere?

mesopause T climatology is preserved



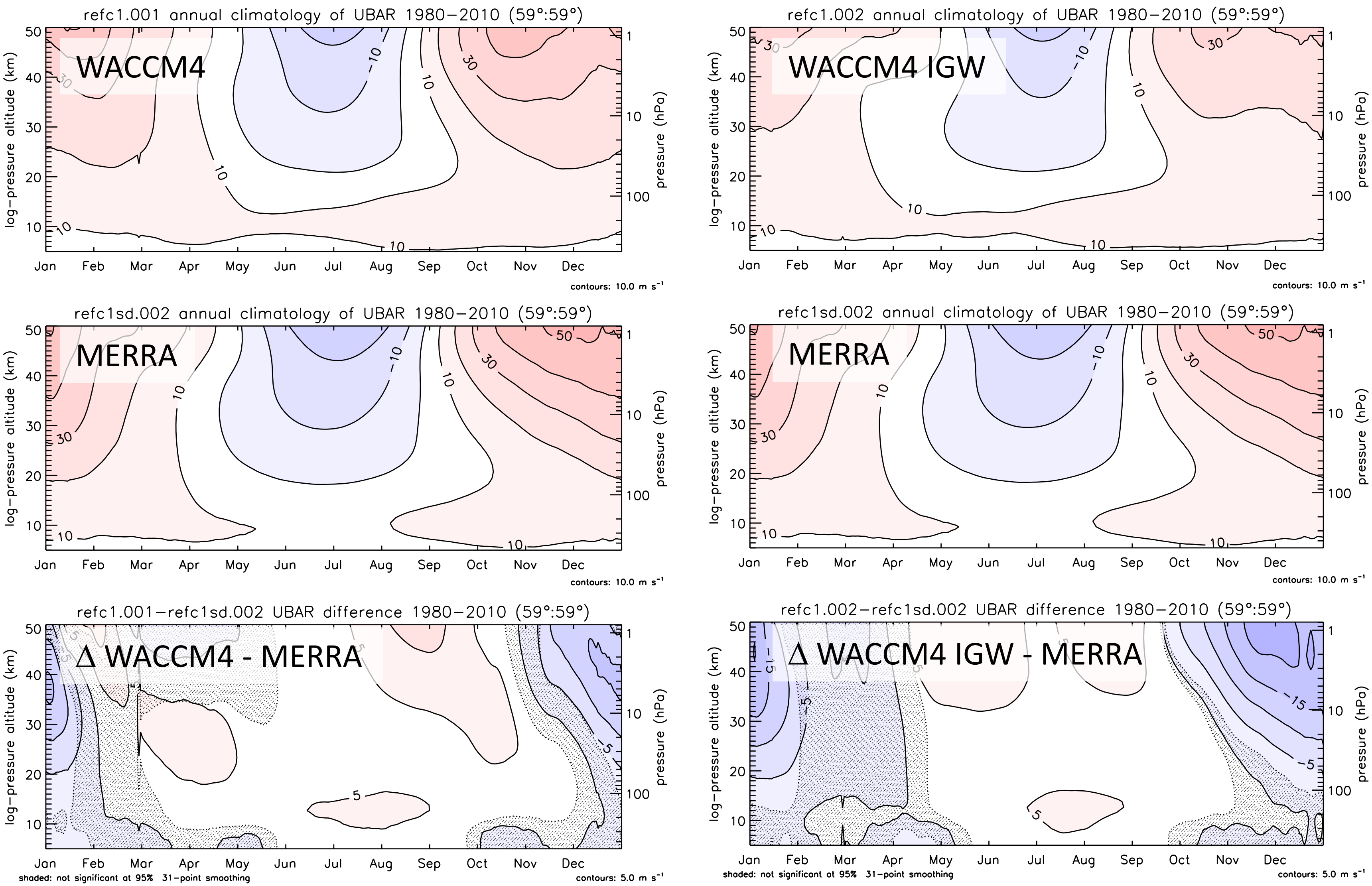
in either hemisphere, summer mesopause T changes < 3 K

stratospheric T in the NH



differences with respect to MERRA are relatively small in both WACCM4 and WACCM4 IGW

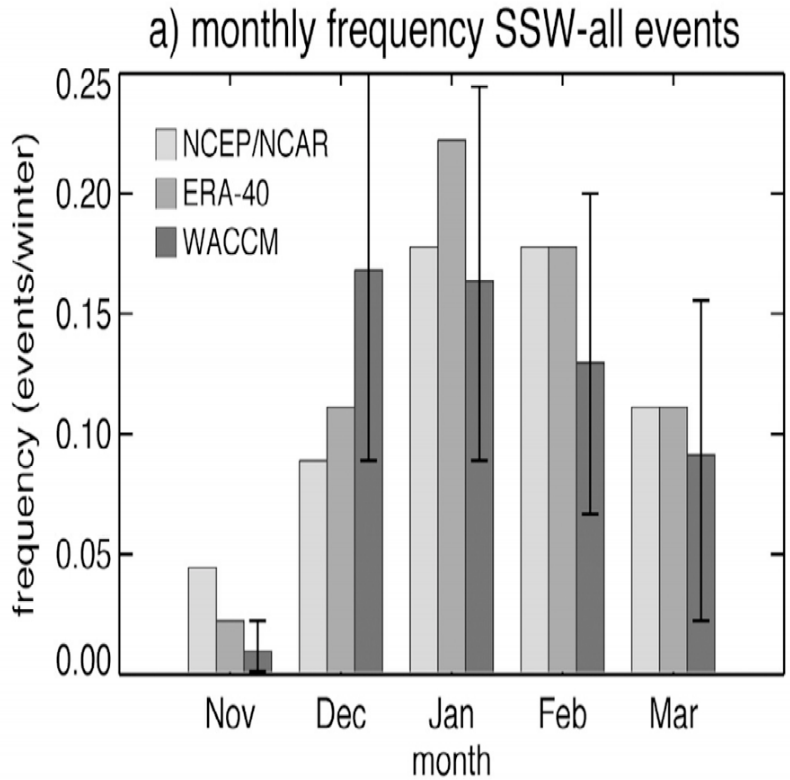
subpolar U (60°) in the NH



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

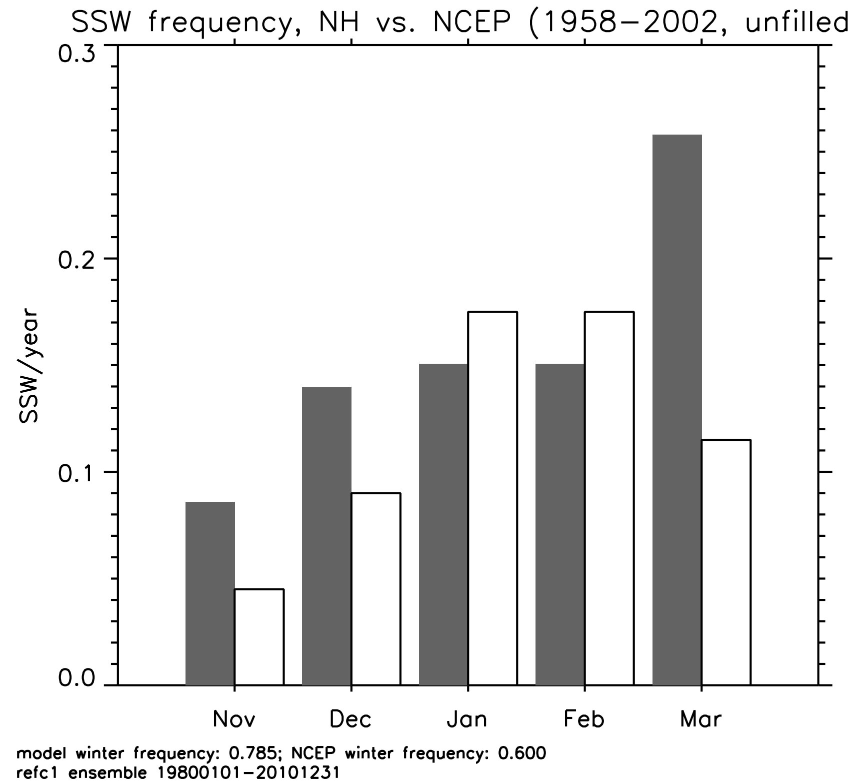
SSW statistics: WACCM4 and WACCM4 IGW

previous WACCM4 and observations



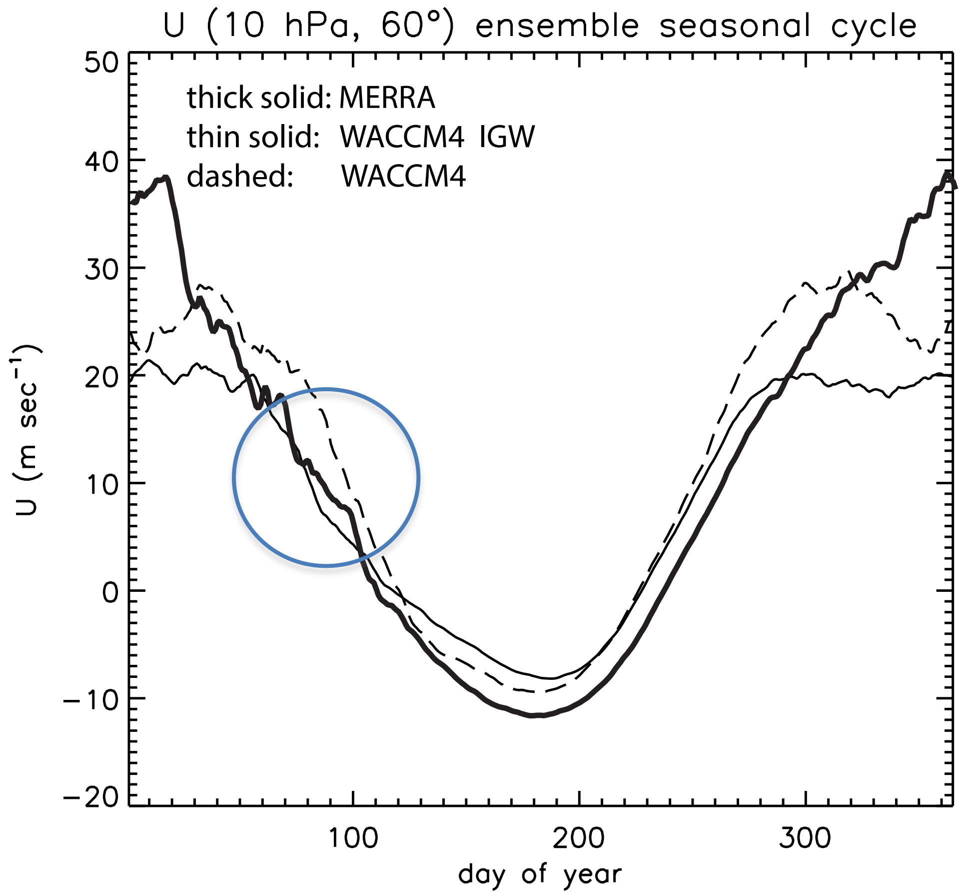
de la Torre et al. (JGR, 2012)

WACCM4 IGW 1980-2010
ensemble statistics



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

a closer look at U climatology (10 hPa, 60° N)



- In NH winter, U is stronger in MERRA than in either WACCM4 version in midwinter
- In NH winter, U is overall weaker in WACCM4 IGW than in WACCM4 in winter
- In NH spring, U is weaker in WACCM4 IGW than in WACCM4, *but closer to MERRA*

conclusions

- the addition of a second spectrum of parameterized gravity waves, in the IGW range, is physically reasonable
- it ameliorates the **SH** cold-pole problem problem and allows realistic simulation of Antarctic ozone with the updated WACCM4 heterogeneous chemistry module
- it preserves the climatology of the MLT, in particular the temperature and altitude of the summer mesopause
- it produces relatively minor changes in U and T in the **NH** and agrees with MERRA data for the **NH** at least as well as the standard version of WACCM4
- **however,** it still does not produce an early enough final warming in the **SH**
- **and** it produces too many late-season SSW in the **NH**—this aspect of the simulation needs further study