QBO, gravity wave, and deep convection responses to surface warming in GFDL AM5 simulations

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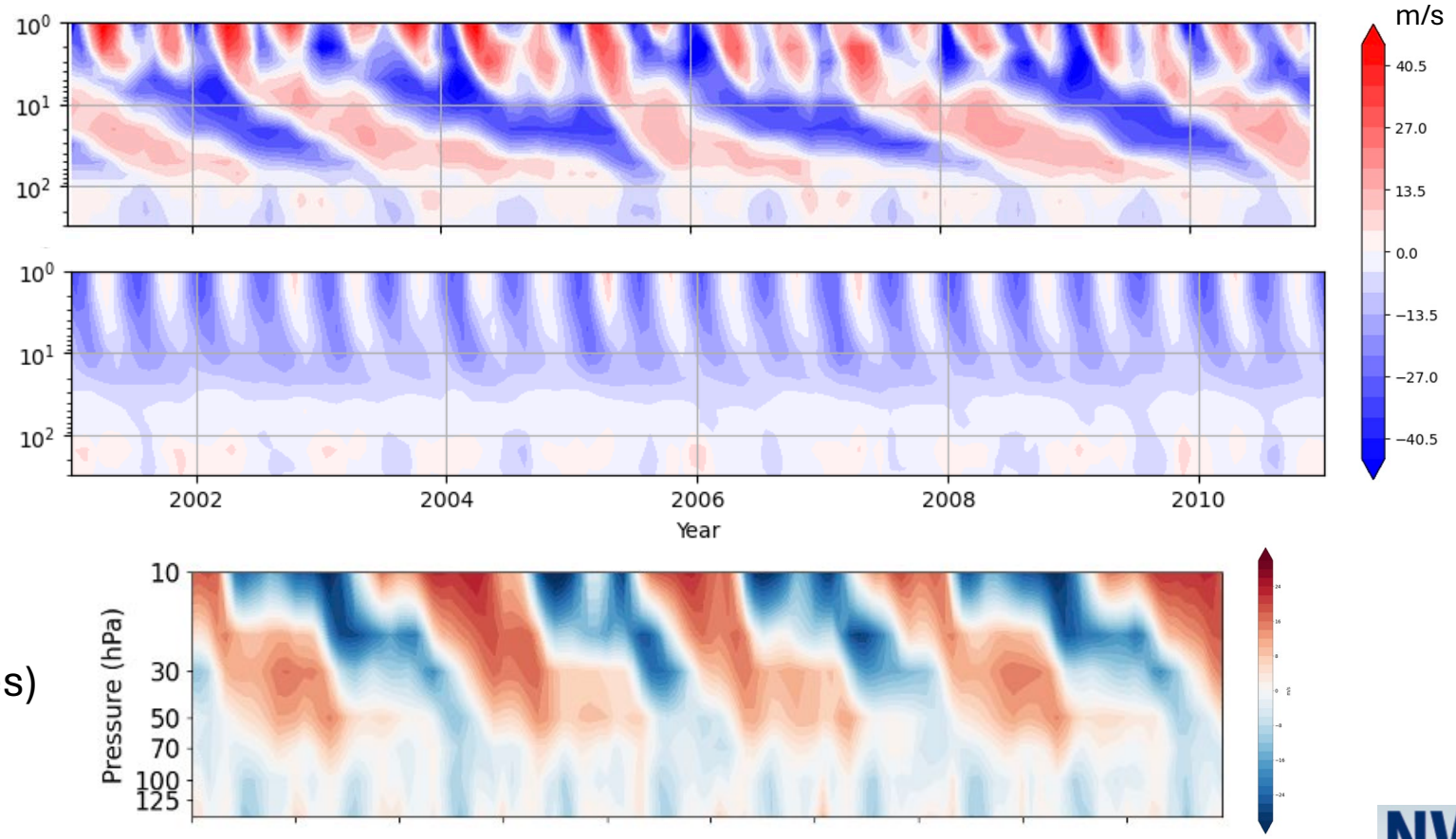
No QBO in the earlier version (AM4)

ERA5

AM4
(AD99)

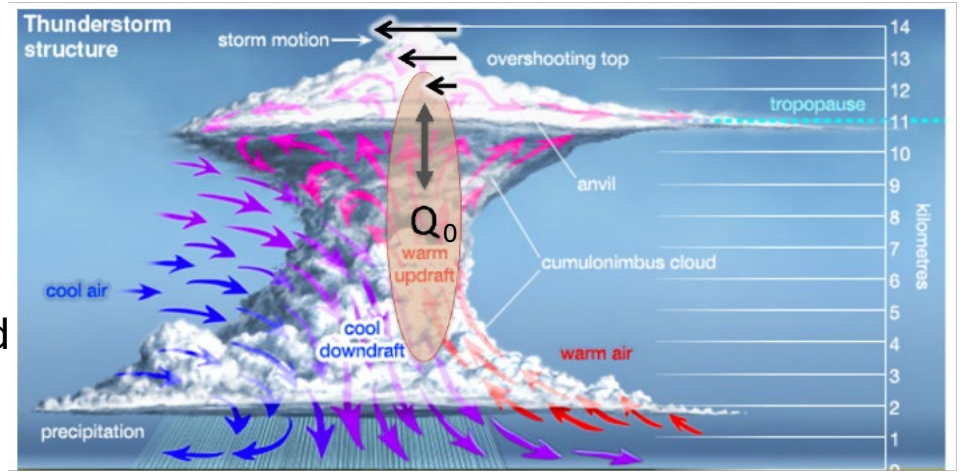
AM5(Beres)



Beres Scheme

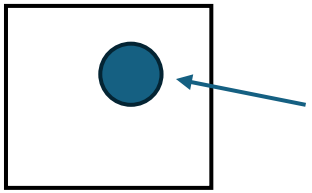
H=depth

V_Q =averaged wind in the heating layer



Model grid

100km



Heating confined within small area

Sub-grid latent heating

$$Q_0 = Q/CF$$

Convective Fraction

Source momentum flux

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

Tuning Parameter

Lookup Table

CAM: CF is fixed at 0.05
WACCM: CF is fixed at 0.05
AM5: tuned fixed case has the CF set to 0.1, with additional simulations use the prognostic updraft area

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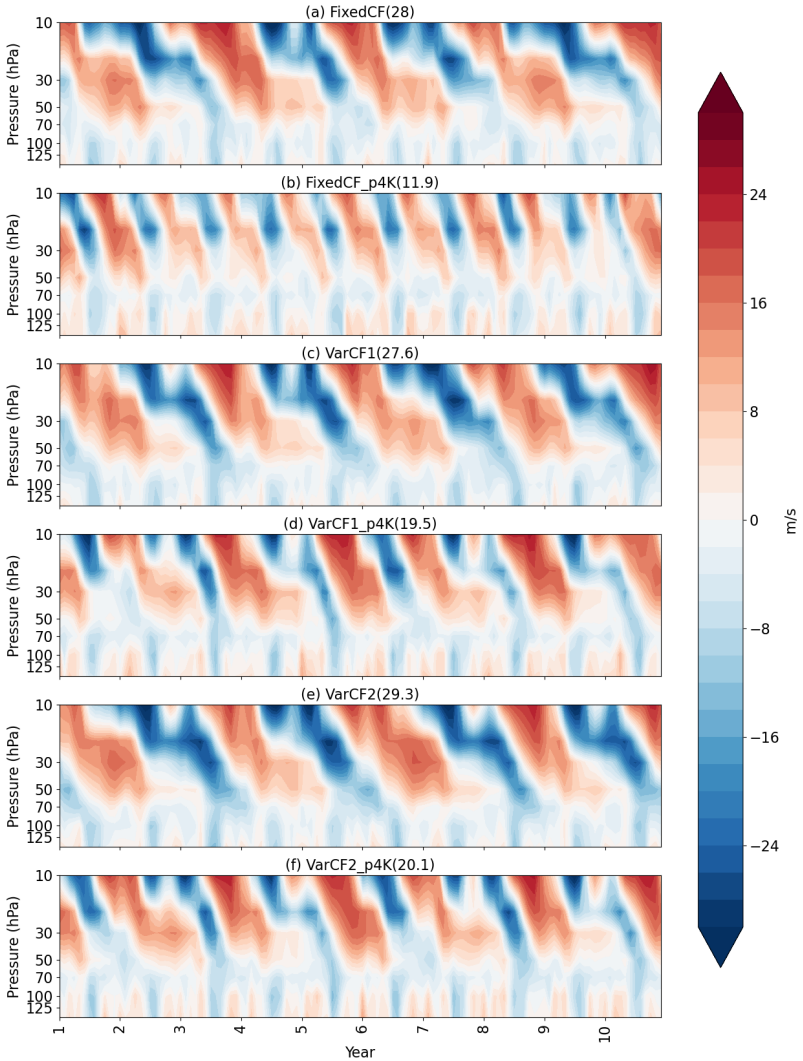
AM5 Simulations

Model input: 2010 climatology and increased 4K SST

Experiment Name	EFF	CF	QBO period	QBO period +4K SST
FixedCF	0.4	10%	28 mon	11.9
VarCF1	0.36	Variable1*	27.6	19.5
VarCF2	0.565	Variable2*	29.3	20.1

*prognostic updraft area is applied

AM5 uses a finite-volume cubed-sphere dynamical core (Harris et al., 2020). The subgrid convection is represented by two bulk plumes for shallow and deep convection (Bretherton et al., 2004). A detailed discussion about the convection parameterization can be found in Zhao et al. (2018).



Zonal mean wind (10N–10S)

QBO periods differ among different simulations:

- 4K SST simulations (b,d,f) have **shorter** QBO periods than current day simulation (a,c,e)
- 4K SST simulation of fixed convective area has the **shortest** QBO period (b)

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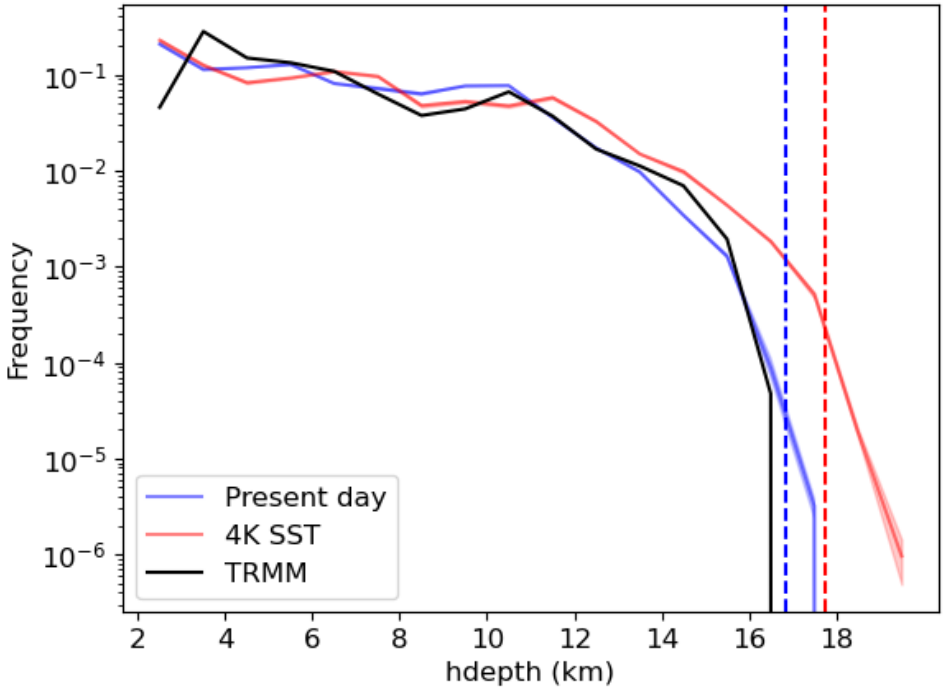
Heating depth (excluding <2km — shallow convection cases)



- Heating depth is **larger** in the 4K SST simulations than present day simulations (consistent with QBO period)
- Models and TRMM observations have similar heating depth, except models have more of the **deepest** heating depth cases than TRMM

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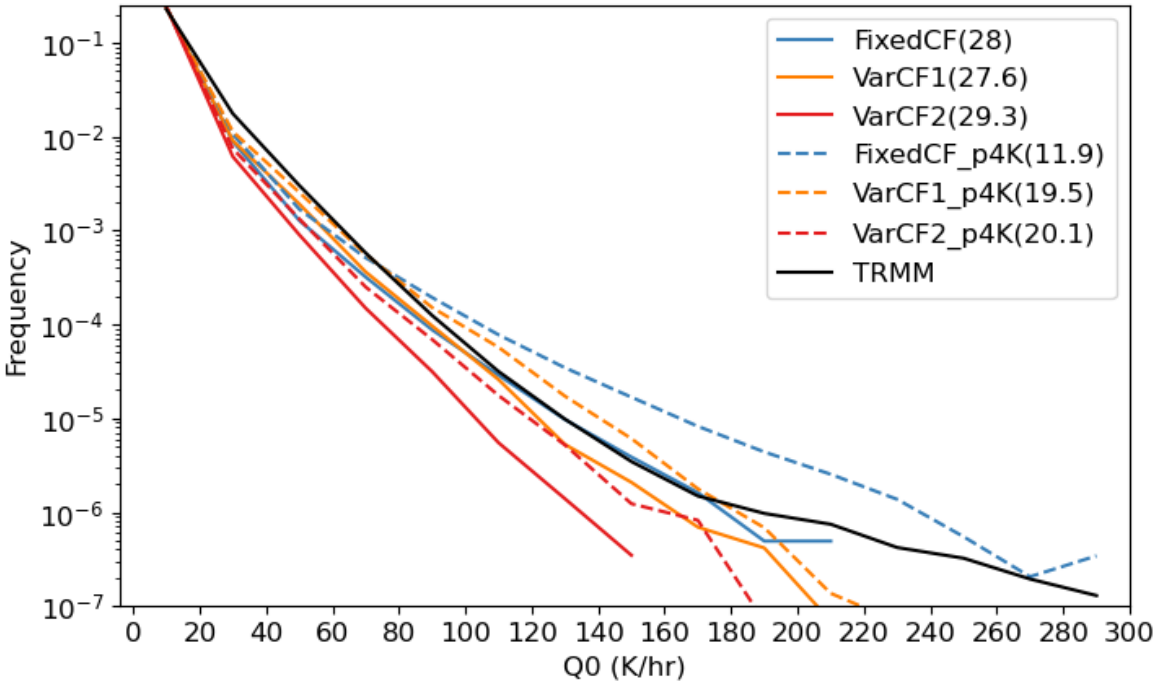
Max heating rate



- Max heating rate is **positive correlated** with QBO period, with 4K SST simulations have larger max heating rate than present-day simulations and the fixed convective area 4K SST simulation has the largest Q0
- TRMM has more **larger max heating rate** cases compared to present-day simulations

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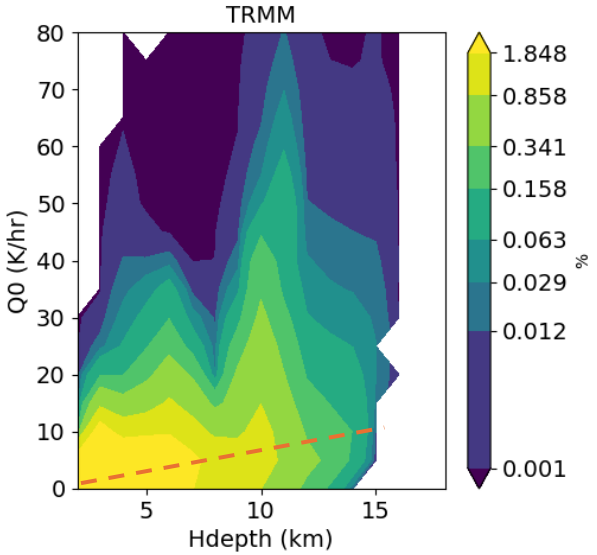
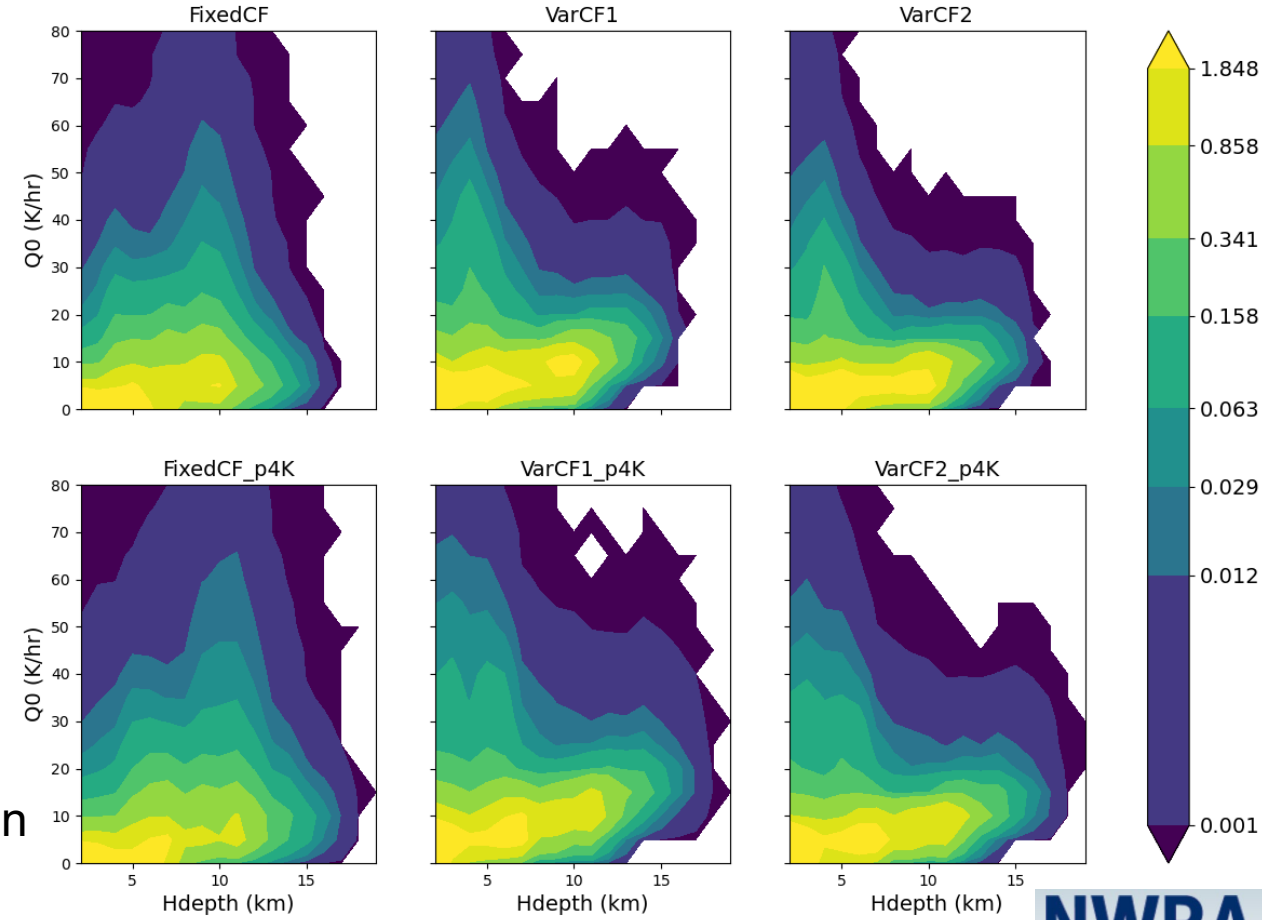
2D PDF of Max Heating (Q0) and Heating Depth (Hdepth)





- Max heating and heating depth are positive correlated
- For prognostic CF simulations, the distribution is wider at shallower depths

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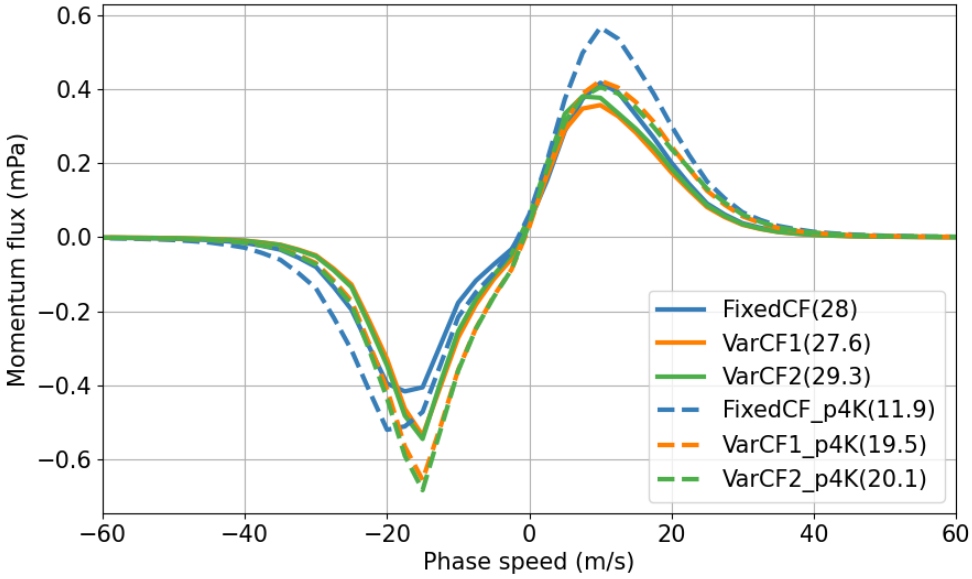
100 hPa GW zonal momentum flux phase speed spectrum



- The 4K SST simulations show a broader phase speed spectrum and more momentum flux than the present-day simulations, leading to shorter QBO periods
- The fixed convection area simulation shows a larger change in the phase speed spectrum, especially in the eastward momentum flux

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Summary

- The number of extreme deep convection events increases with the 4K SST simulation, resulting in more GW momentum flux, a broader phase speed spectrum, and thus a shorter QBO period.
- Prognostic convection area introduces less strengthening and broadening of the phase speed spectrum with the 4K SST simulation, leading to a smaller change in the QBO period compared to the fixed convection area simulation.

Thank you!