Using an Aqua-planet Model to Understand Future Changes in the Quasi-Biennial Oscillation

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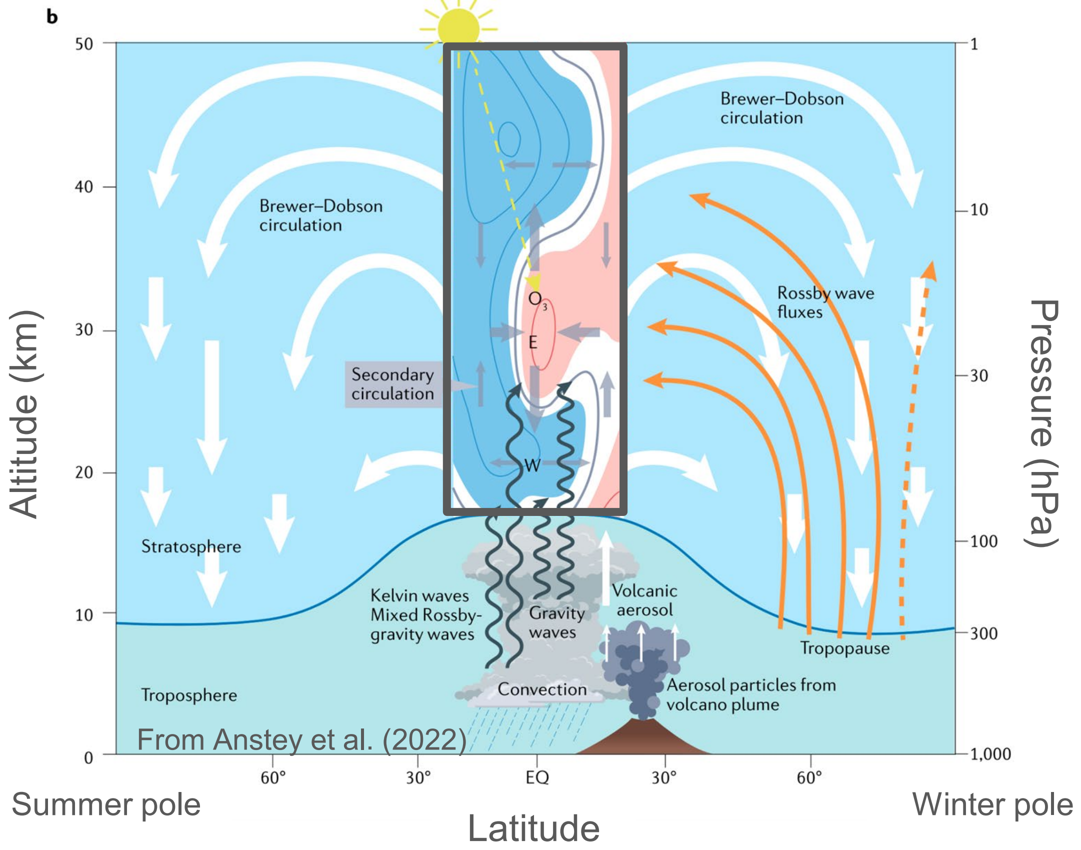
The quasi-biennial oscillation (QBO) of the stratospheric zonal winds dominates the variability of the tropical stratosphere

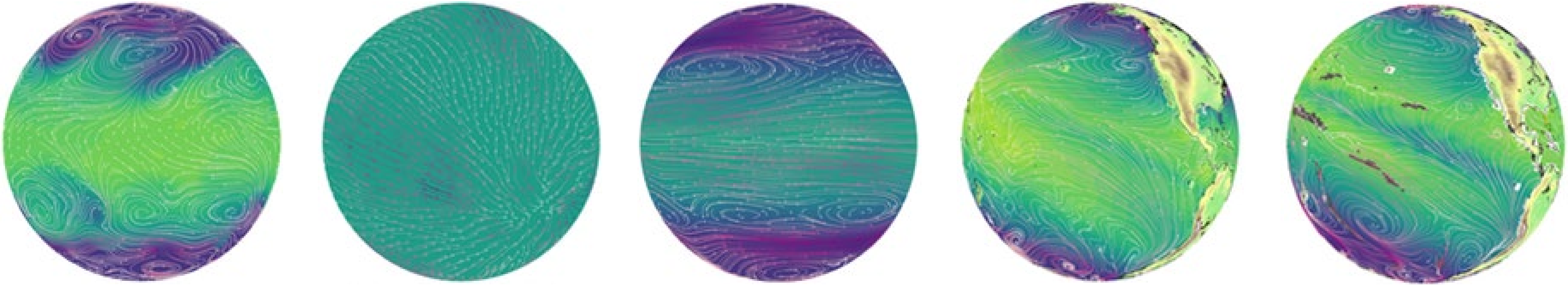


- The QBO is driven by a wide spectrum of vertically propagating equatorial waves
- The descent of the QBO zonal winds is slowed by the mean-meridional Brewer-Dobson Circulation
- The response of the QBO to increased greenhouse gas concentrations is **still uncertain**

Idealized models can improve understanding of atmospheric processes

Increasing Model Complexity

Adapted from Maher et al. (2019)



Dry dynamical core: Simplified physics (Held-Suarez)

Can simulate a QBO (Yao and Jablonowski, 2013), but not the radiative effect of CO_2

Radiative convective equilibrium: Uniform SST and insolation

Aquaplanet: Prescribed ocean with no land, ice, or seasons

This work

AMIP: Prescribed ocean and ice

QBO Initiative (QBOi)

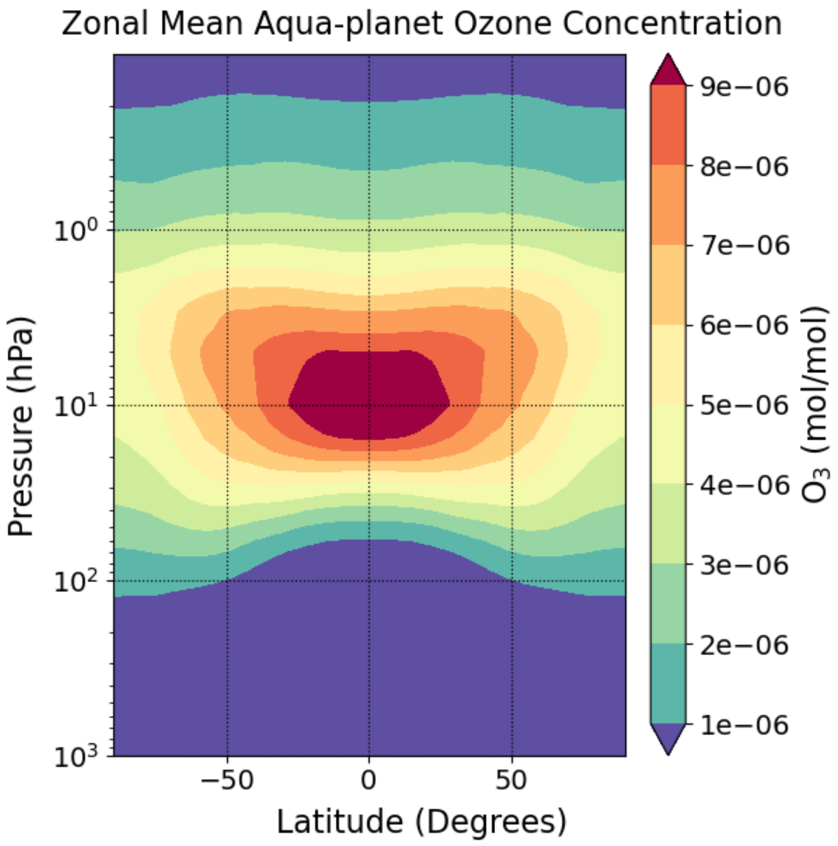
Coupled atm, land, ocean, ice, chemistry

CMIP5/6

How does the QBO respond to increasing CO_2 in an idealized model?

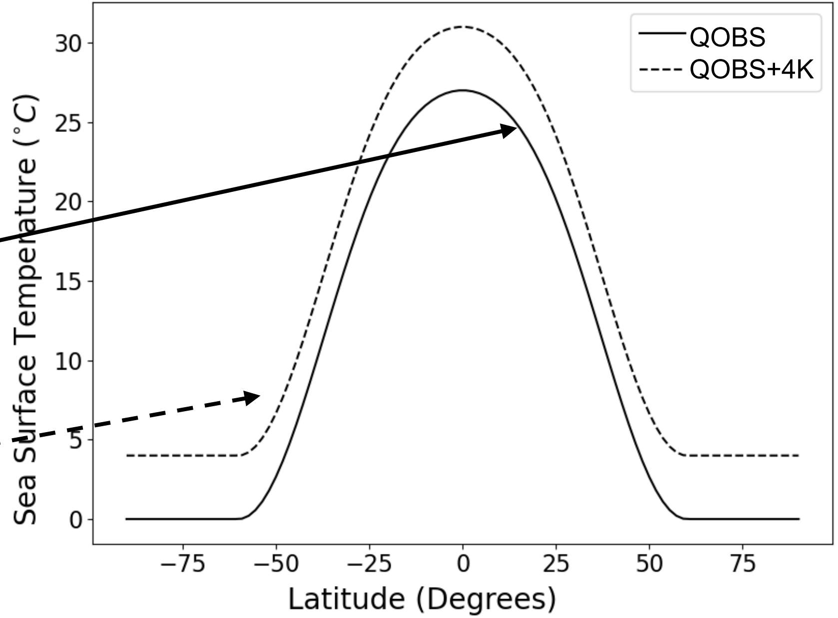
Aqua-planet Model Description

- Community Atmosphere Model version 7 (CAM7)
- Spectral Element (SE) dynamical core
- 100 km (~1°) horizontal spacing
- 72 levels with model top at 0.1 hPa (~61 km)
- Incorporates fix to convective gravity wave scheme
- Aerosol-radiation and aerosol-cloud interactions are removed (Medeiros et al., 2016)



Experimental setup

Experiment Name	CO_2 Concen-tration	SST Profile
1xCO2	348 ppmv	QOBS
4xCO2	1392 ppmv	QOBS
4xCO2+4K	1392 ppmv	QOBS+4K



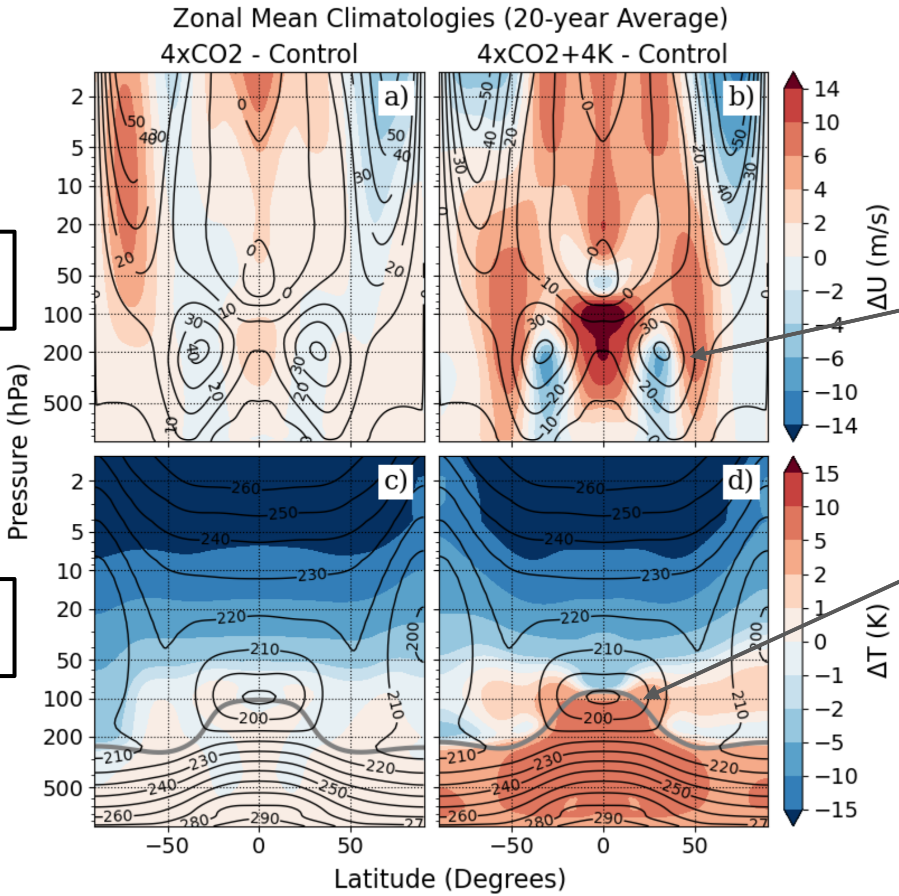
4xCO2+4K experiment incorporates idealized ocean feedback to increased CO_2

Stratospheric cooling occurs for both elevated CO_2 simulations, tropospheric warming only for 4xCO2+4K

Differences in color, control = black contours

Zonal wind

Temperature

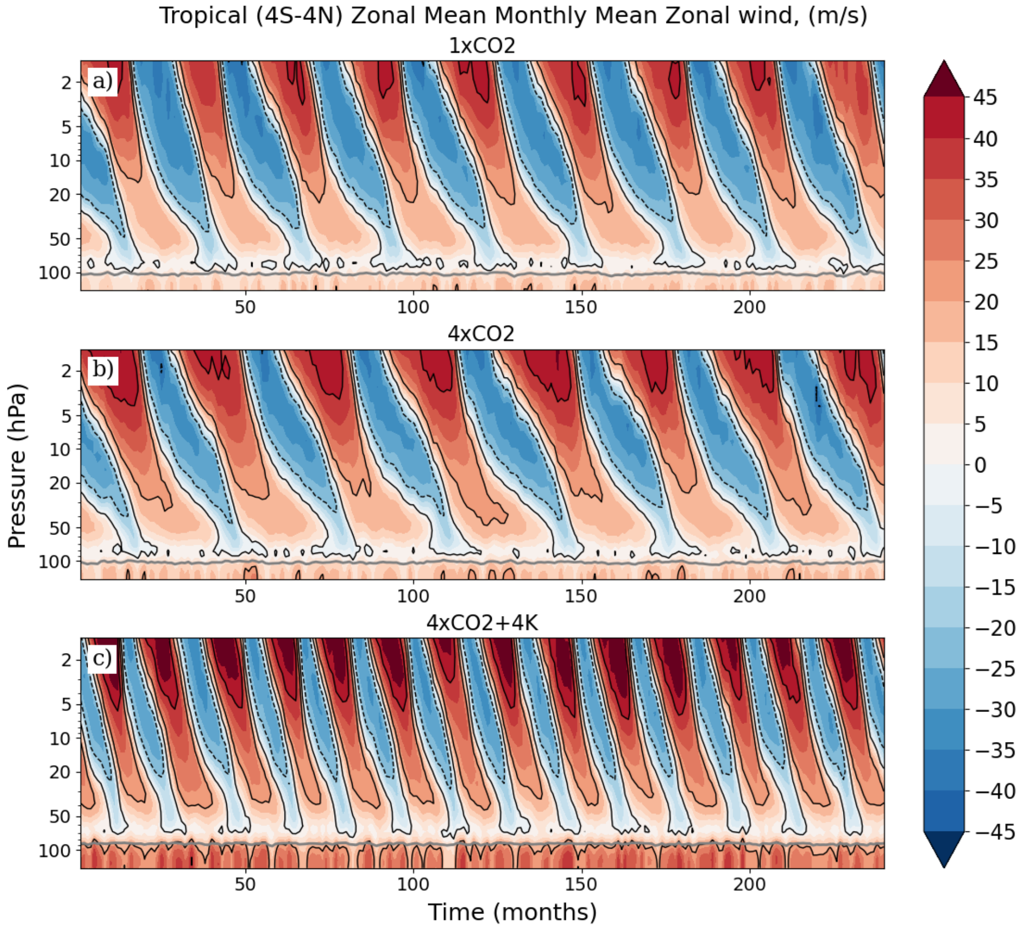


Poleward shift in the zonal jet

Tropopause height increases in 4xCO2+4K (tropospheric expansion)

4xCO2 period increases; 4xCO2+4K period and amplitude decrease*

Since SAO is not generated, QBO amplitude continues (unrealistically) to increase with height above 10 hPa



Period: 27.7 months
Amplitude: 24.0 m/s

Period: 31.3 months
Amplitude: 23.9 m/s

Period: 16.8 months
Amplitude: 21.3 m/s

*using transition times method at 20 hPa

Response of QBO to climate change can be explained using the Transformed Eulerian Mean (TEM) Framework

Residual Velocities

$$\bar{v}^* \equiv \bar{v} - \left(\overline{v'\theta'}/\bar{\theta}_p\right)_p$$
$$\bar{\omega}^* \equiv \bar{\omega} + (a\cos\phi)^{-1}\left(\cos\phi\overline{v'\theta'}/\bar{\theta}_p\right)_\phi$$

Transformation from conventional Eulerian mean (zonal-average) hydrostatic primitive equations

Zonal Momentum Equation:

$$\bar{u}_t = \bar{v}^*\left[f - (a\cos\phi)^{-1}(\bar{u}\cos\phi)_\phi\right] - \bar{\omega}^*\bar{u}_p + \frac{\nabla\cdot\mathbf{F}}{a\cos\phi} + \mathbf{GWD} + \bar{X}$$

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Advection by residual circulation contribution (ADV)

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Resolved wave contribution, Eliassen-Palm Flux Divergence (EPFD)

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Parameterized wave contribution (GWD)

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Advection by residual circulation contribution (ADV)

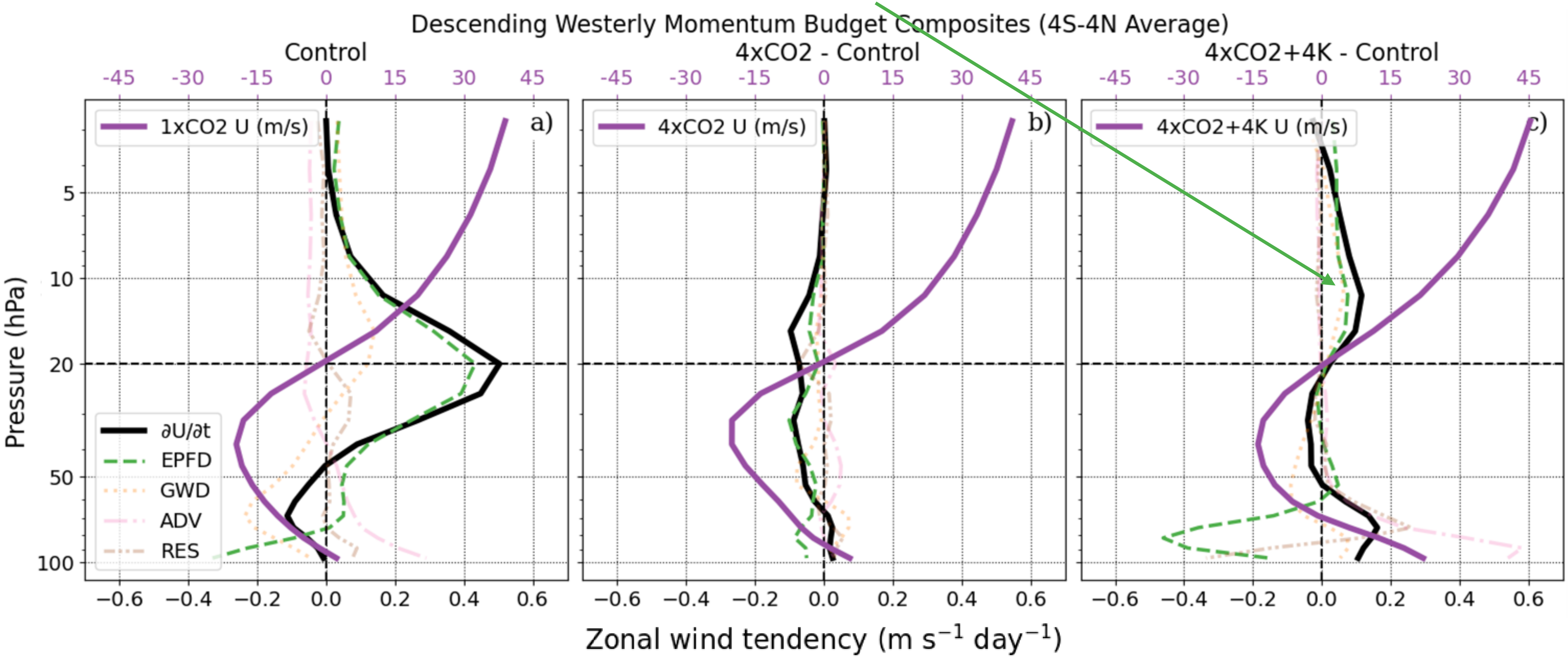
Resolved wave contribution, Eliassen-Palm Flux Divergence (EPFD)

Parameterized wave contribution (GWD)

Numerical diffusion contribution (RES)

EPFD

Increased resolved wave forcing in descending westerly phase **decreases** 4xCO2+4K period

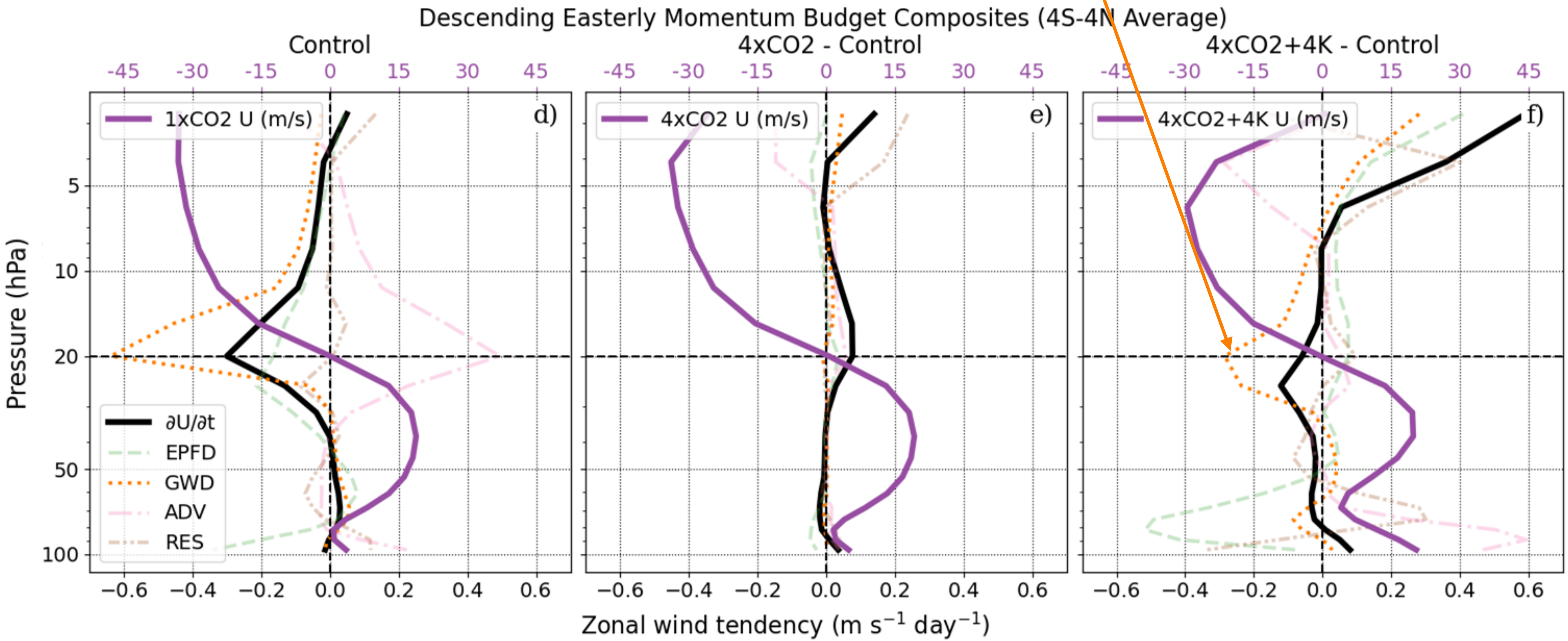


EPFD = resolved wave forcing

*composite => average over all times when u = 0 at 20 hPa

GWD

Increased parameterized wave forcing in the descending easterly phase **decreases** 4xCO2+4K period

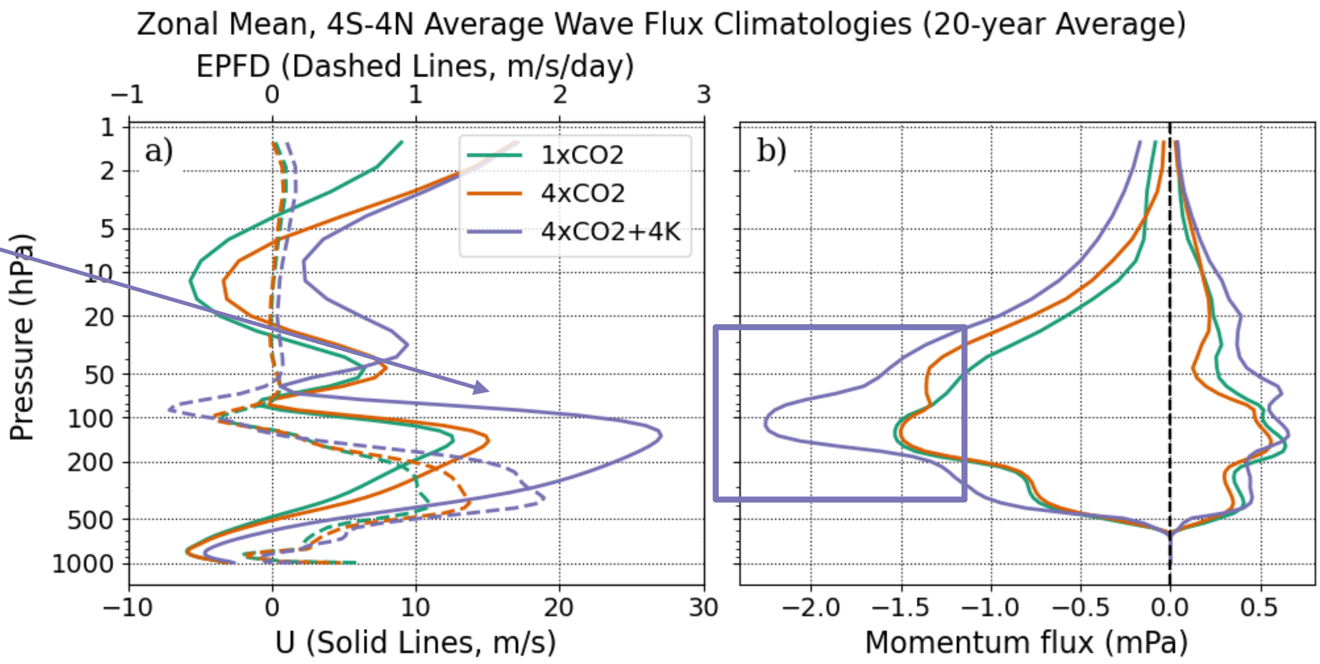


GWD = parameterized wave forcing

GWD

Changes in parameterized GW forcing in 4xCO2+4K are likely caused by changing zonal wind profile

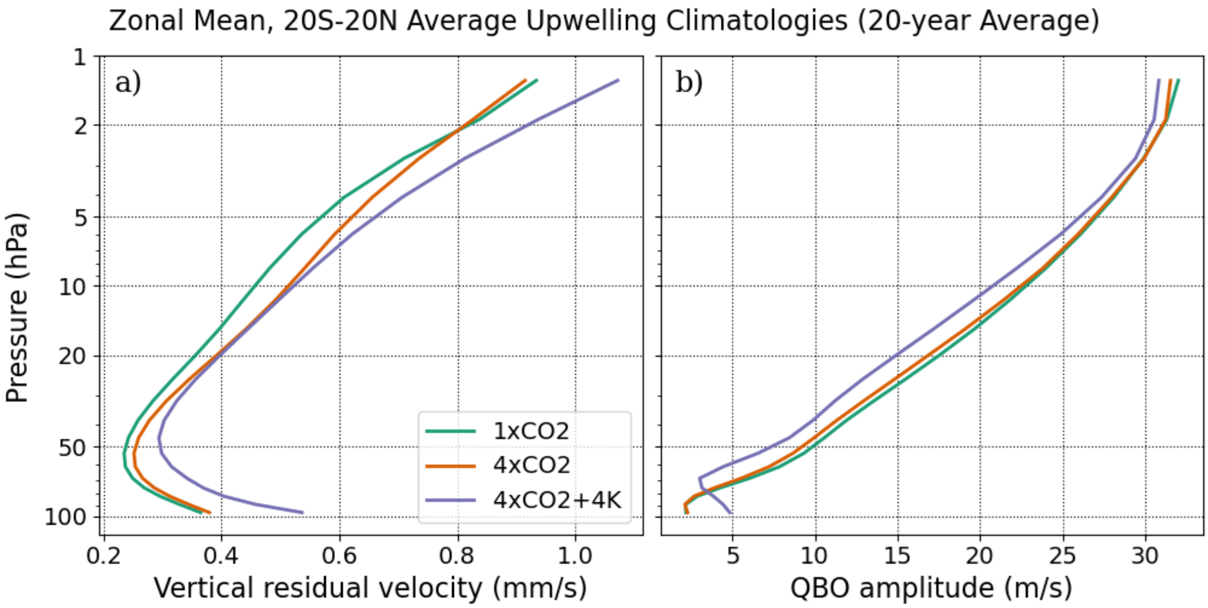
Increased tropical westerlies introduce more asymmetry into GW flux (has been observed before in Beres scheme)



ADV

Increased tropical upwelling **decreases** the QBO amplitude in the lower stratosphere

- Increased upwelling is consistent with a stronger Brewer-Dobson Circulation
- The "**buffer zone**", where the QBO dissipates despite sufficient wave forcing, is shifted upwards by upwelling



The aqua-planet QBO response qualitatively agrees with comprehensive climate models

- In a climate change simulation with increased SSTs and carbon dioxide (4xCO2+4K) a shorter QBO period is a result of increased resolved (Kelvin) and parameterized wave driving ✓
- Increased gravity wave driving in 4xCO2+4K is not a result of more intense convection, but of stronger tropical westerlies ✗
- Weaker 4xCO2+4K amplitude corresponds with strengthened tropical upwelling. ✓

✓/✗ = **agrees**/**disagrees** with comprehensive model results (QBOi,CMIP5/6)