The Quasi-Biennial Oscillation (QBO) in a Changing Aquaplanet Climate

Aaron M. Johnson (aaroj@umich.edu), Christiane Jablonowski, and Mark G. Flanner
Department of Climate and Space Sciences and Engineering
University of Michigan, Ann Arbor

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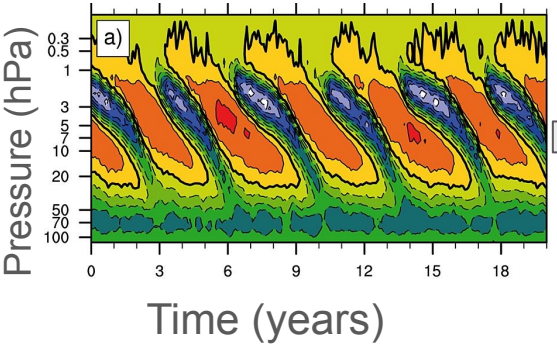
Goal: Explore QBO response to CO_2 in an idealized model

Model Complexity

Dry Held Suarez

Zonal Wind at Equator (m/s)

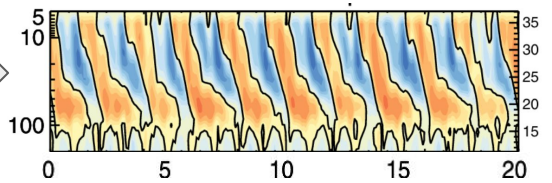


Yao and Jablonowski (2013, 2015)

Aquaplanet

Fully-Coupled

Zonal Wind at Equator (m/s)



Richter et al., 2020 - QBOi Experiment

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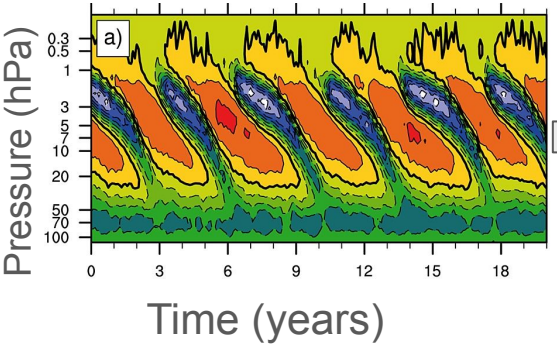

Yao and Jablonowski (2013, 2015)

Aquaplanet

Water-covered Earth with prescribed Sea Surface Temperatures (SSTs), no seasons

Fully-Coupled

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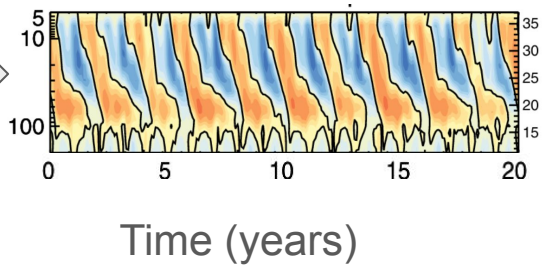
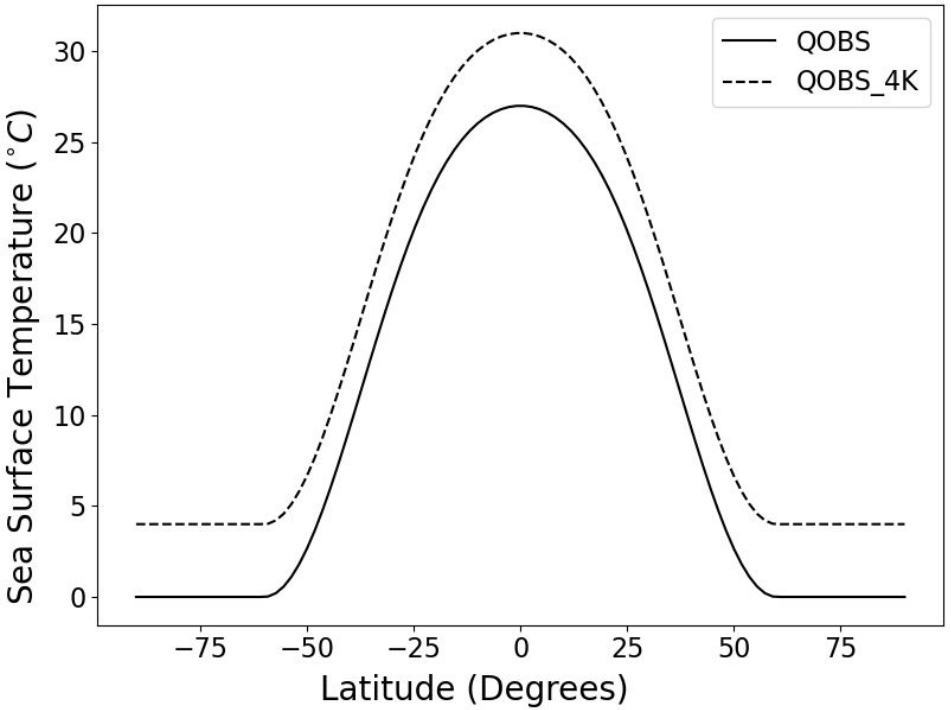


Richter et al., 2020 - QBOi Experiment

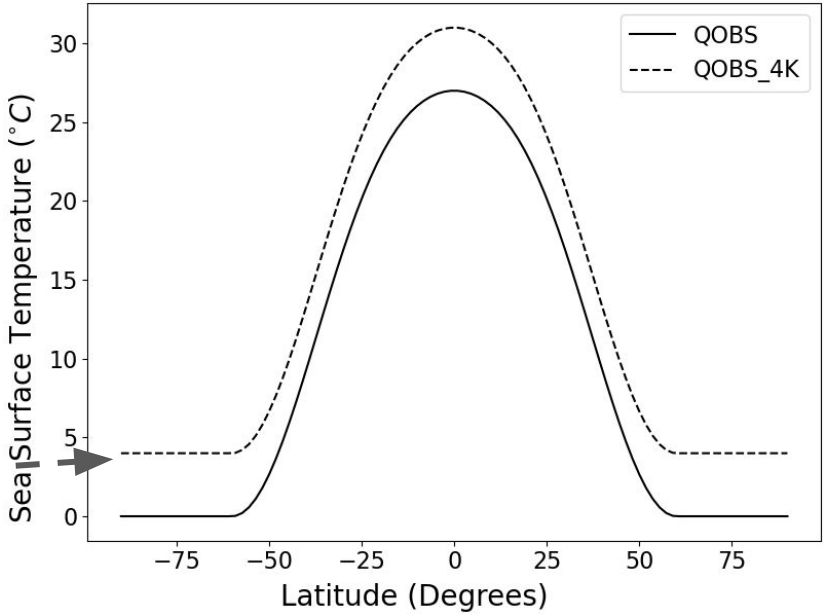
Aquaplanet Experimental Setup

- National Center for Atmospheric Research (NCAR) Community Earth System Model version 2 (CESM2) with the Community Atmosphere Model (CAM)
- Finite Volume (FV) dynamical core
- CAM4 physics package
- 200 km (~2°) horizontal spacing
- 72 levels with model top at 0.1 hPa (~61 km)

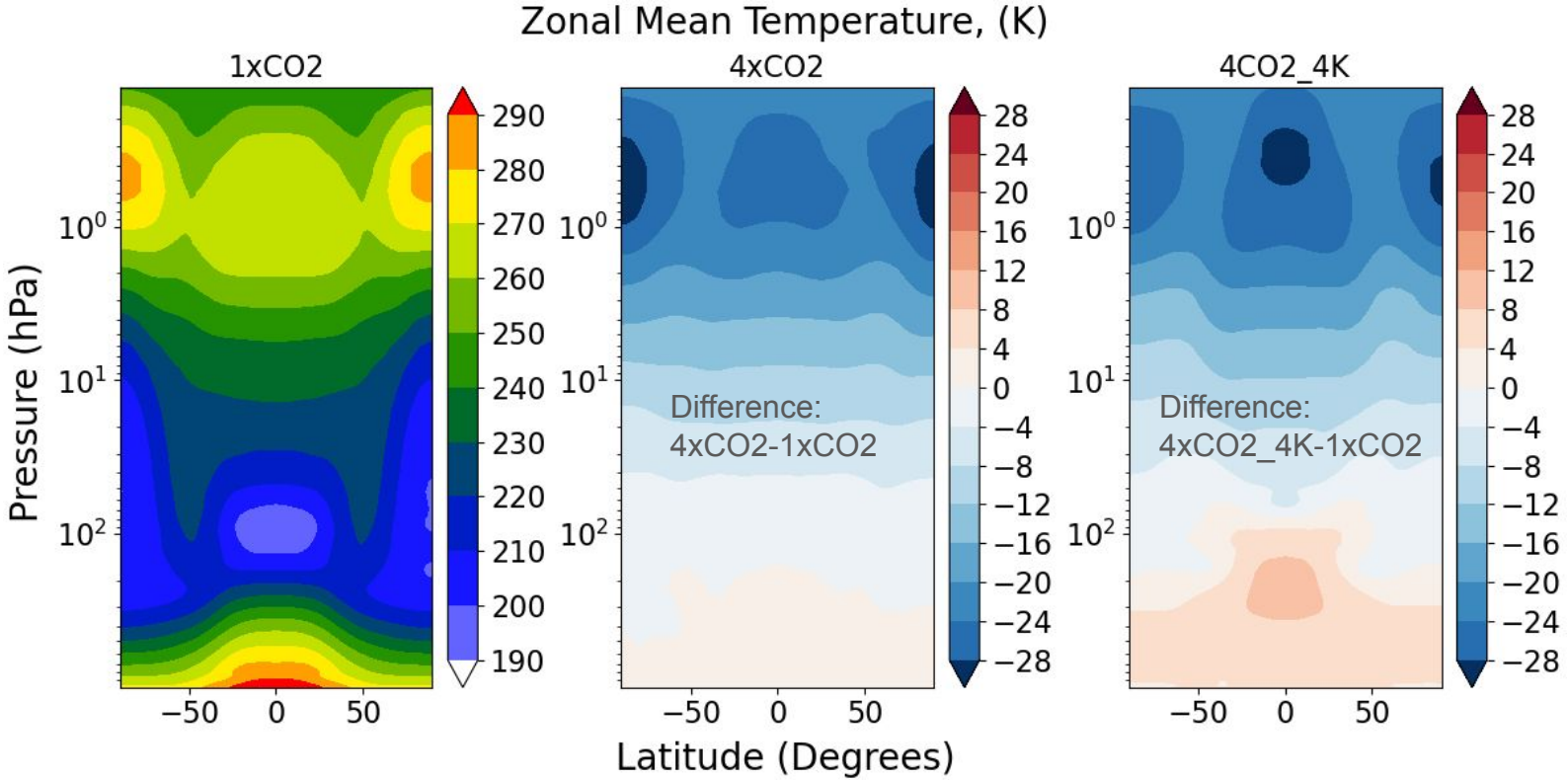


Aquaplanet Experimental Setup

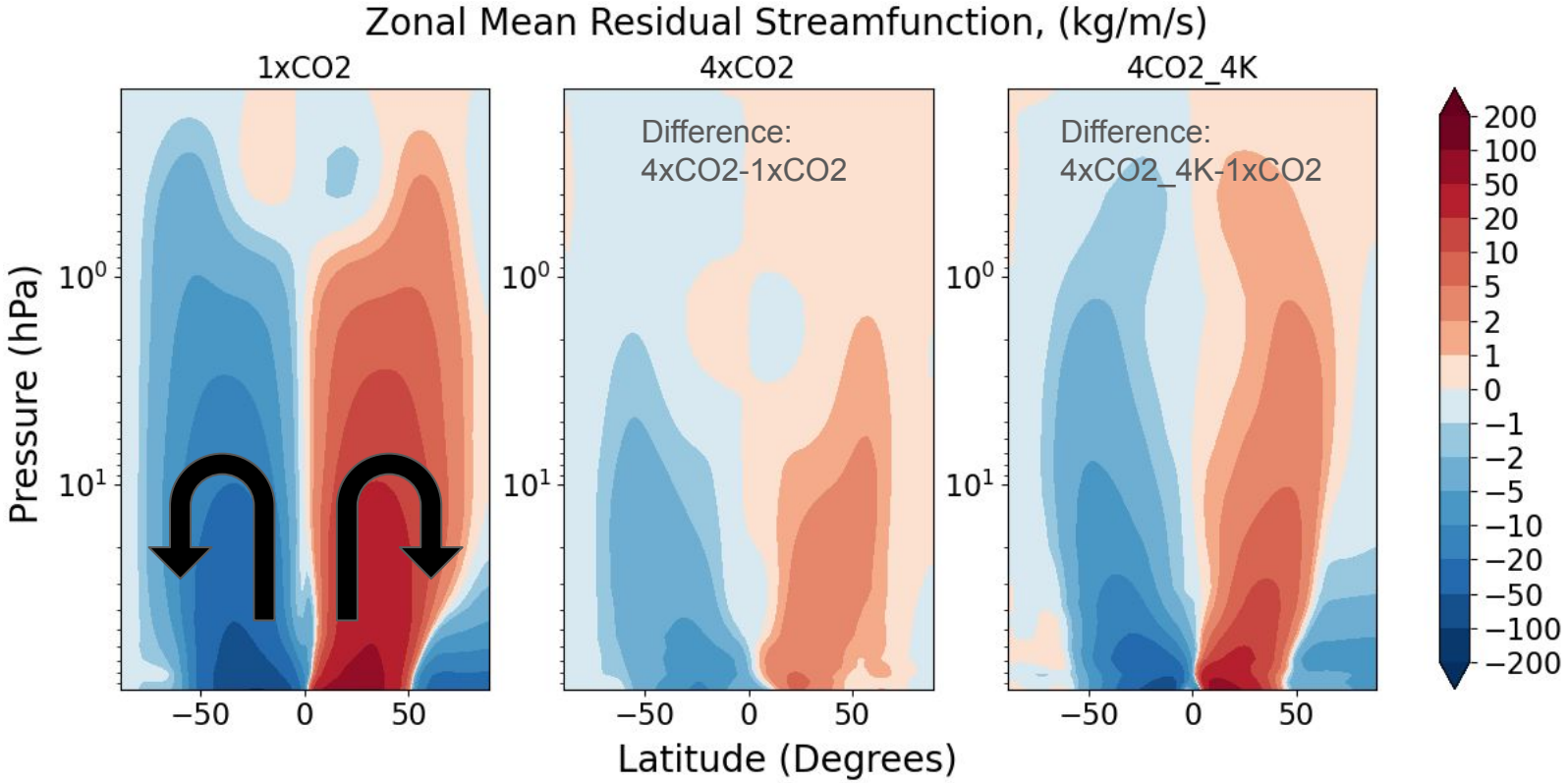
Experiment Name	CO_2 Concentration	SST Profile
1xCO2	348 ppmv	QOBS
4xCO2	1392 ppmv	QOBS
4xCO2_4K	1392 ppmv	QOBS_4K



Mean aquaplanet climate response to CO_2 is **stratospheric cooling** and **tropospheric warming**

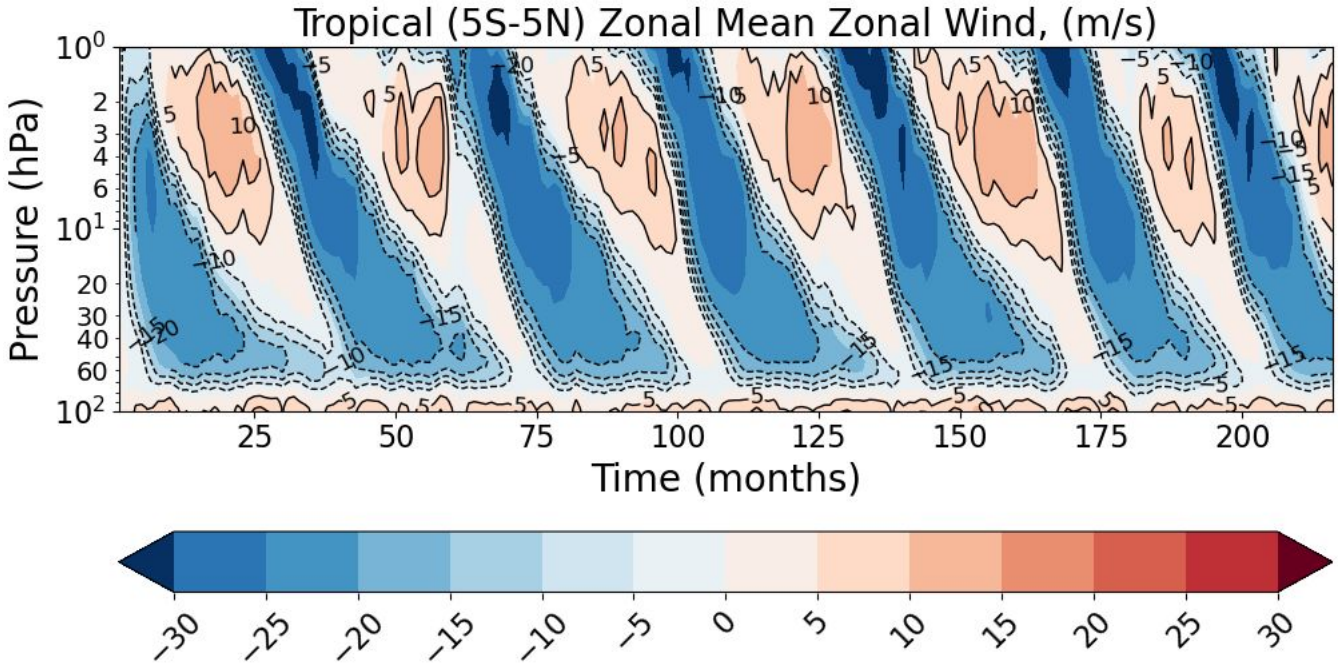


Mean aquaplanet climate response to CO_2 is a **strengthened Brewer-Dobson Circulation (BDC)**



A quasi-realistic aquaplanet QBO is simulated

1xCO2



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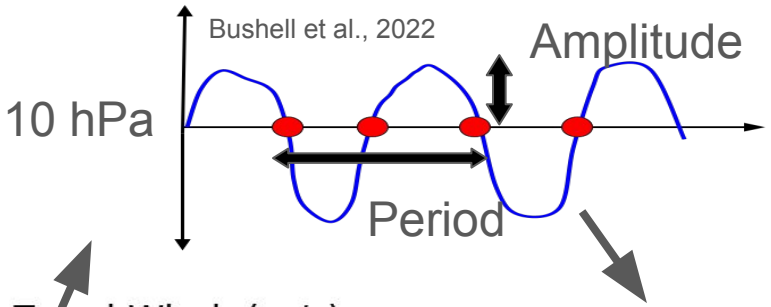

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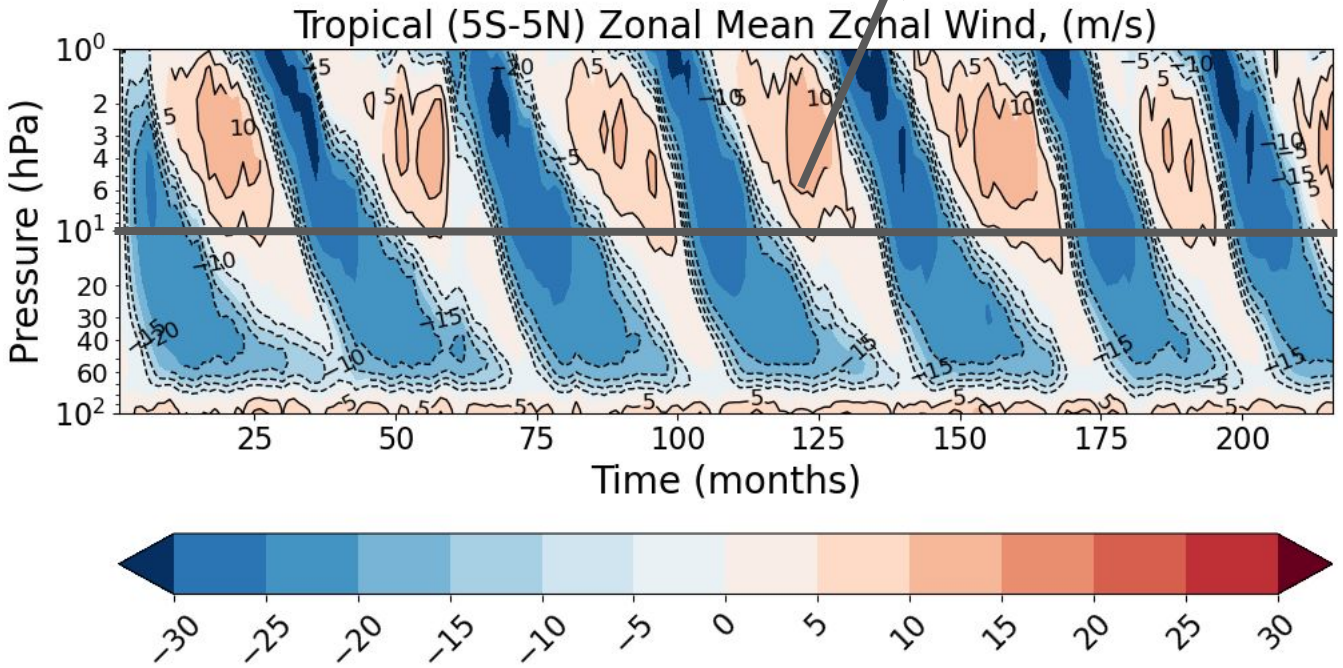
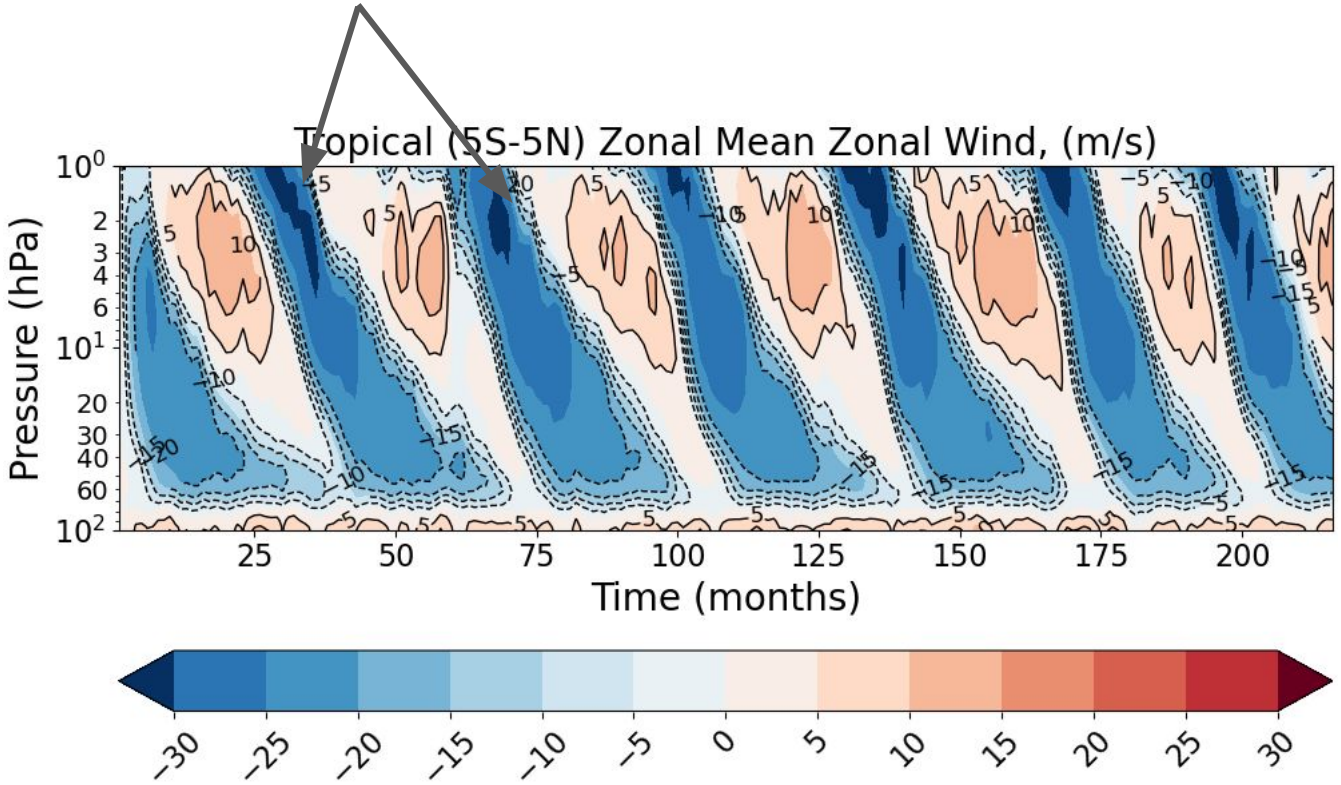


Period: 33.8 months

Amplitude: 17.6 m/s

Observed asymmetry between the QBO phases (stronger easterlies; e.g. Naujokat, 1986) is **reproduced**

1xCO2



Period: 33.8 months

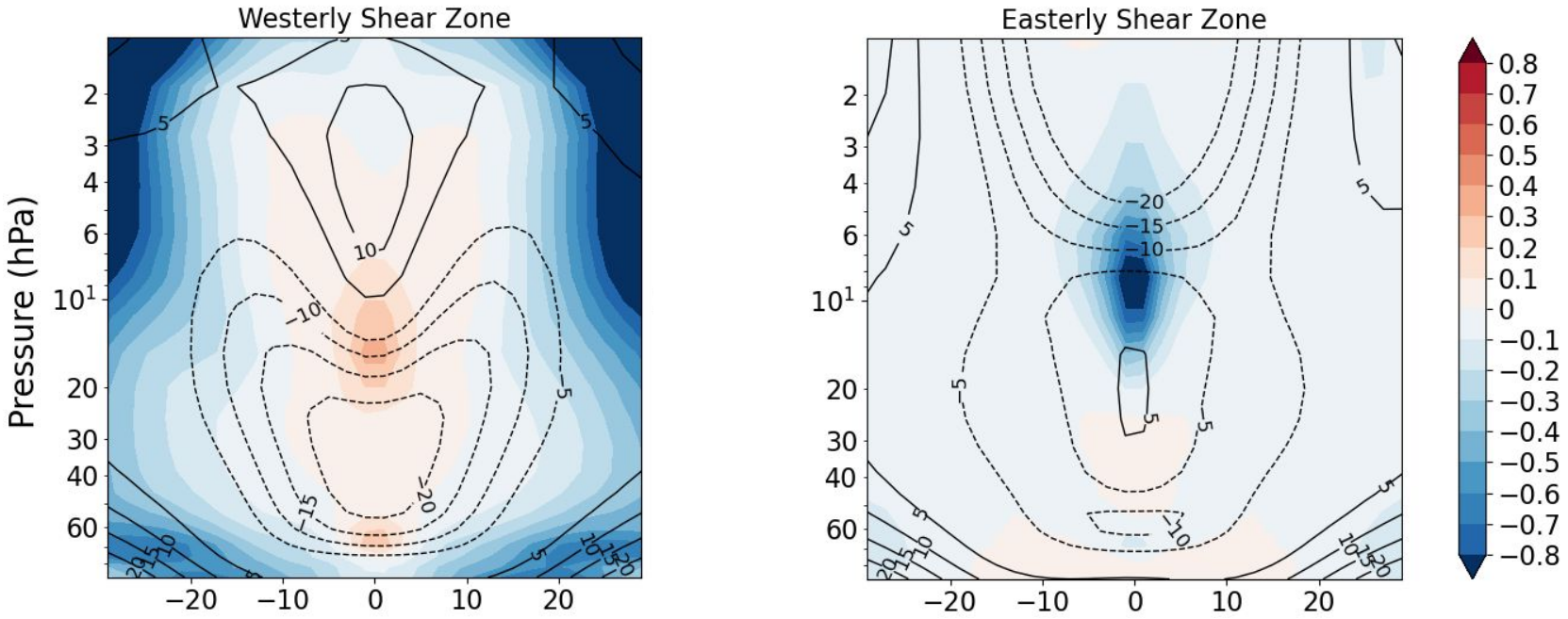
Amplitude: 17.6 m/s

The aquaplanet QBO is driven by resolved and parameterized waves

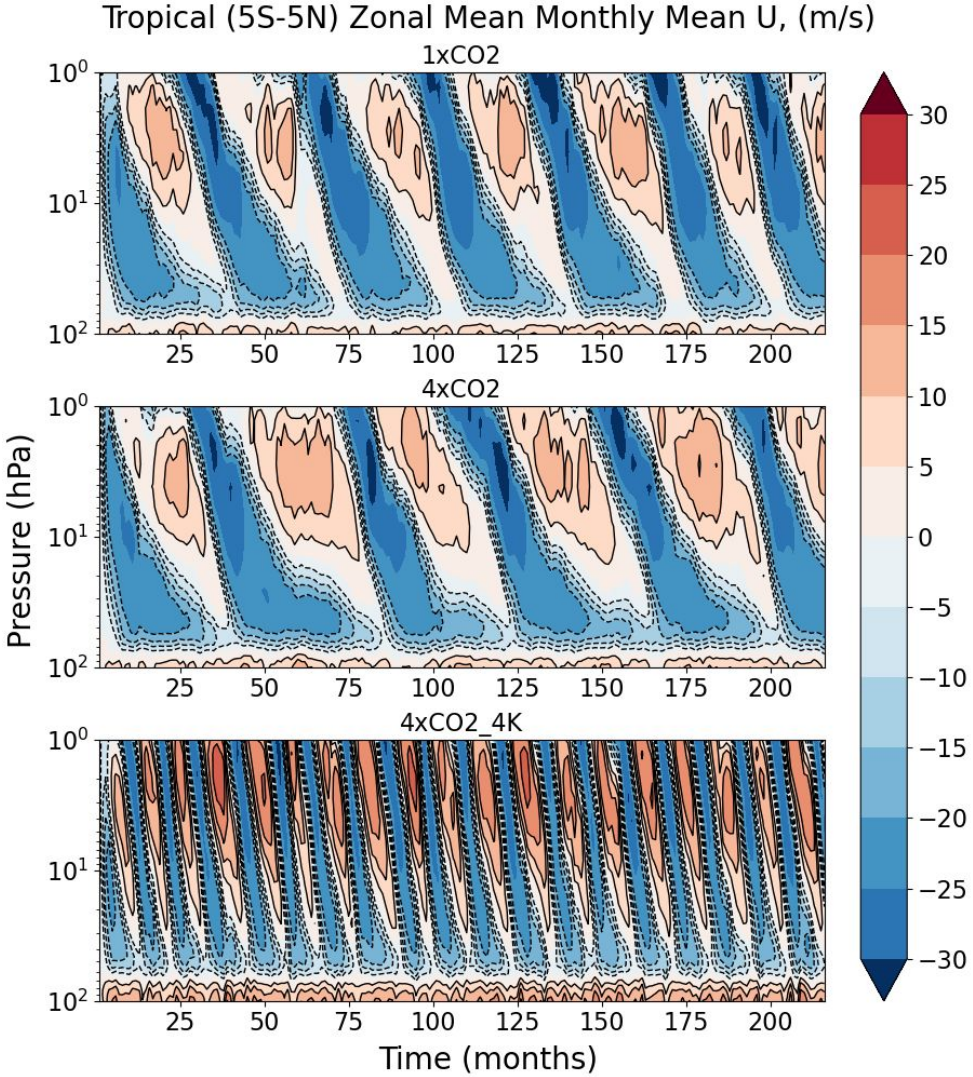
$$\bar{u}_t = \bar{v}^*[f-(a\cos\phi)^{-1}(\bar{u}\cos\phi)_\phi]-\bar{w}^*\bar{u}_z+(\rho_0 a\cos\phi)^{-1}\nabla\cdot\mathbf{F}+\mathbf{GWD}+\bar{X}$$

Forcing due to the resolved Eliassen-Palm (EP) flux divergence (m/s/day)

Forcing due to parameterized gravity wave drag (GWD) (m/s/day)



The QBO period is sensitive to increasing CO_2

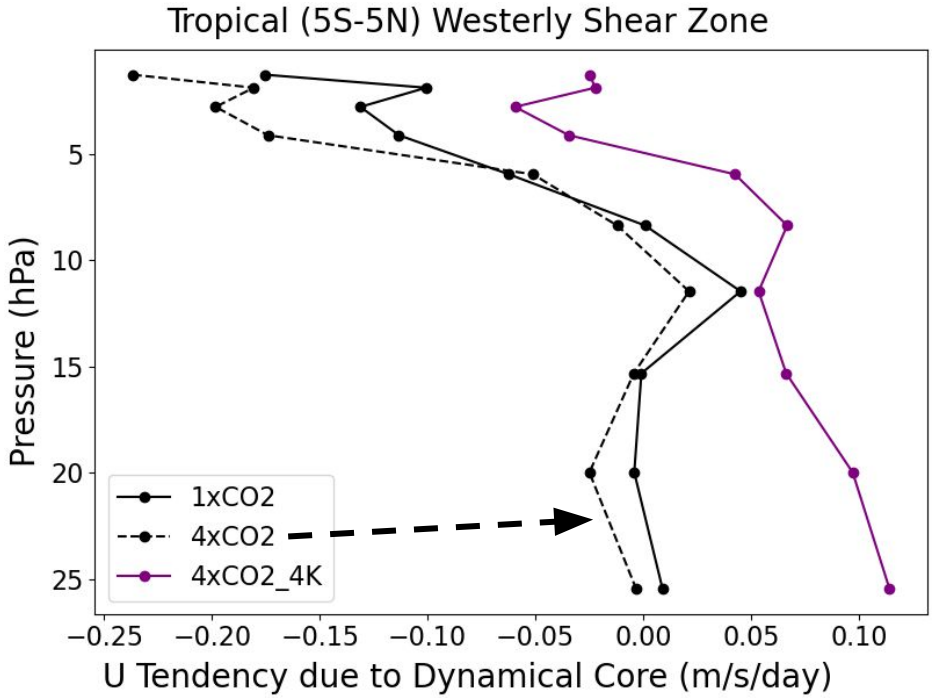


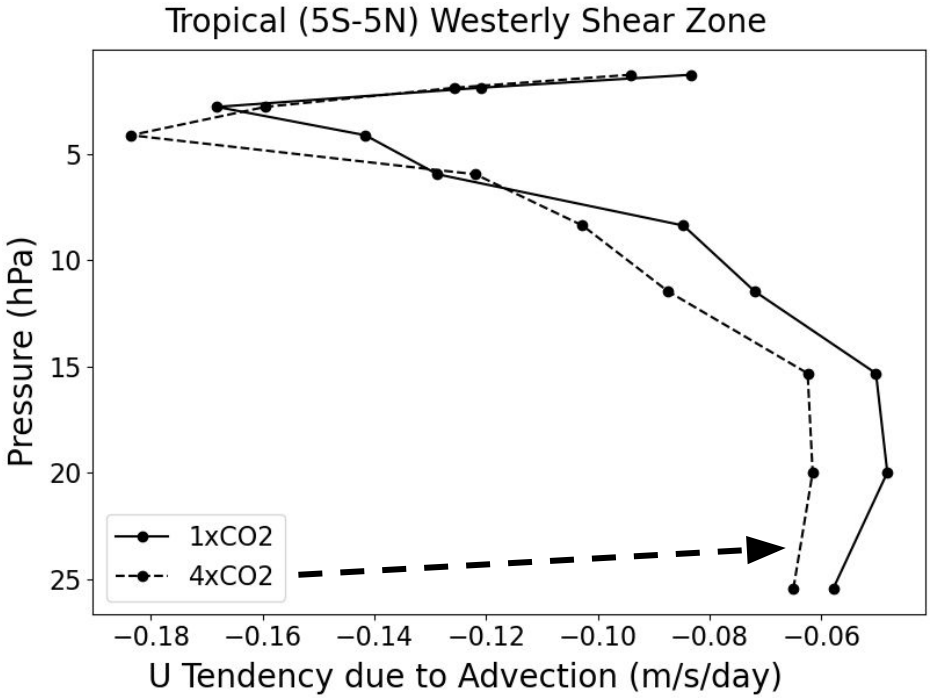
Period: 33.8 months
Amplitude: 17.6 m/s

Period: 39.5 months
Amplitude: 17.8 m/s

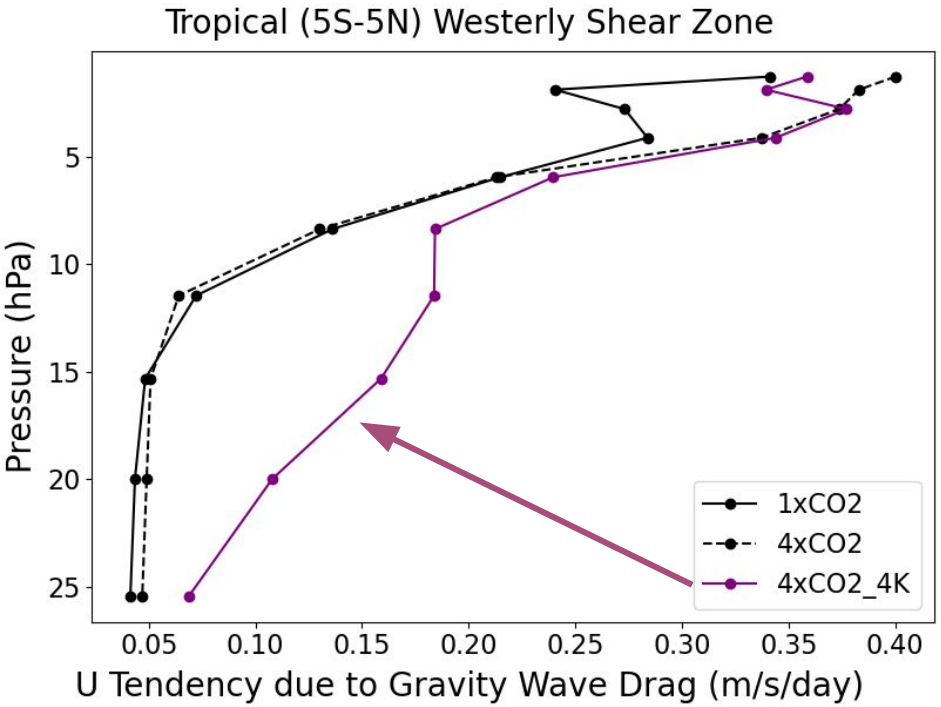
Period: 11.2 months
Amplitude: 14.7 m/s

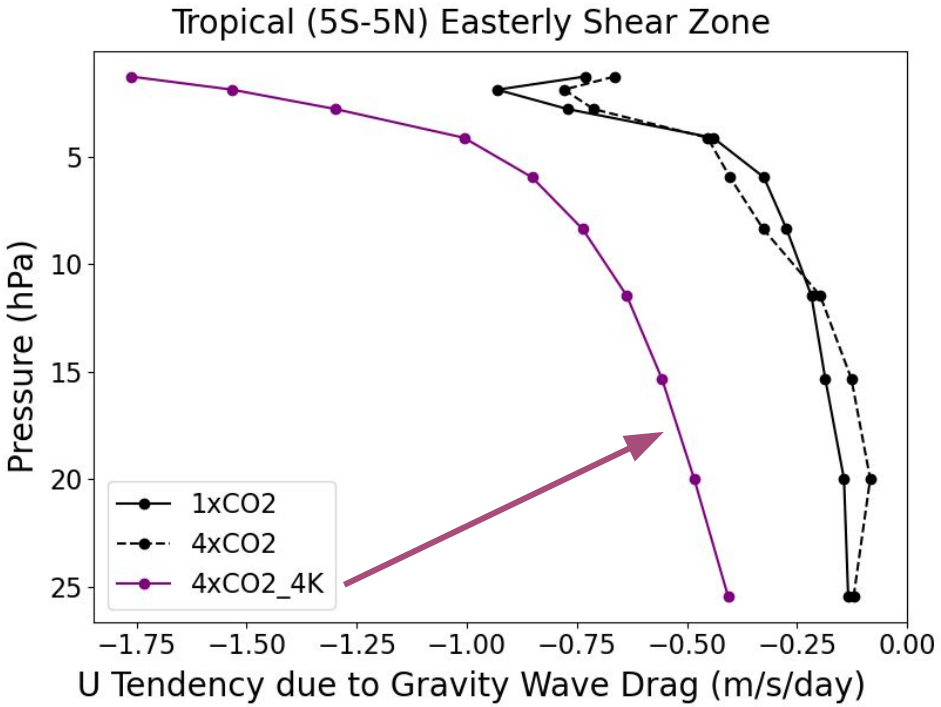
Advection is primary driver of 4xCO2 QBO period lengthening



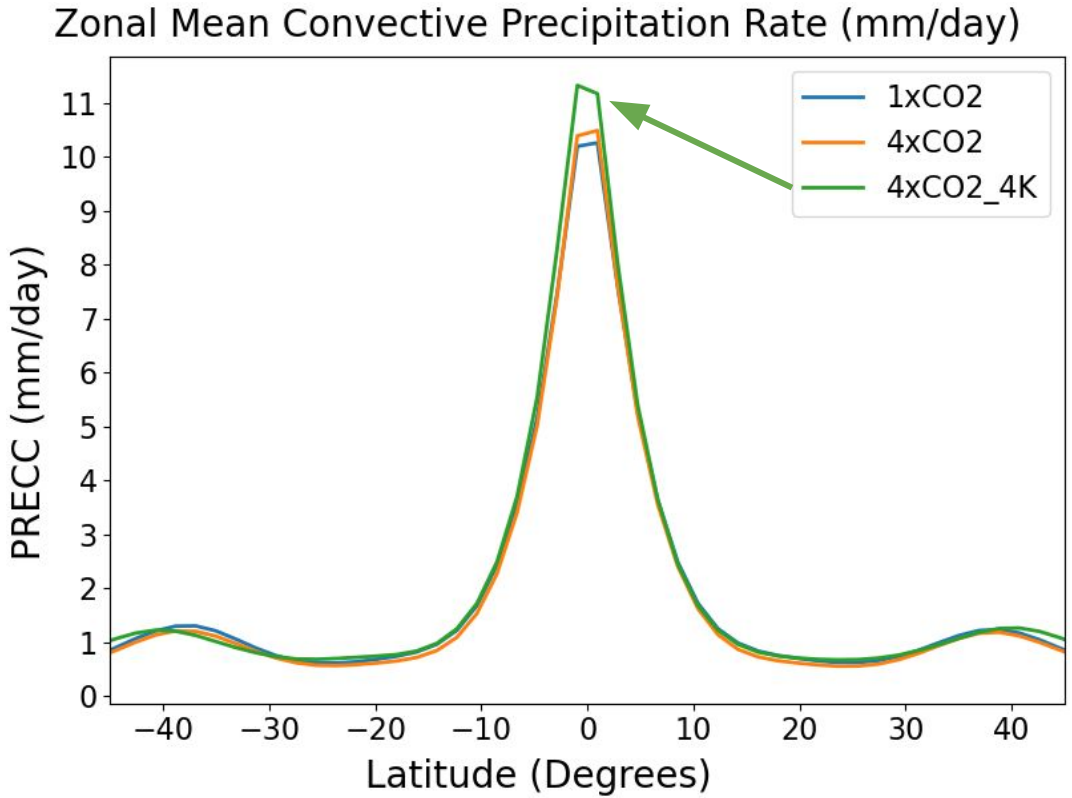


Increased gravity wave drag is primary driver of shorter 4xCO2_4K QBO period





Increased tropical convection causes intensified GW drag in 4xCO2_4K: CAM's GWD strength depends on convective heating



Conclusions

- Aquaplanet QBO period is strongly sensitive to GW drag forcing
  - Large QBO period change with respect to control in 4xCO2_4K
  - Much smaller period change in 4xCO2
- Under constant SSTs, advection is primary driver of period change
- Aquaplanet with shifted SSTs is a useful simplified framework for testing the response of the stratosphere to radiative forcing.