# Tuning the QBO in CESM3-WACCM7

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NSF National Center for Atmospheric Research (NSF NCAR)
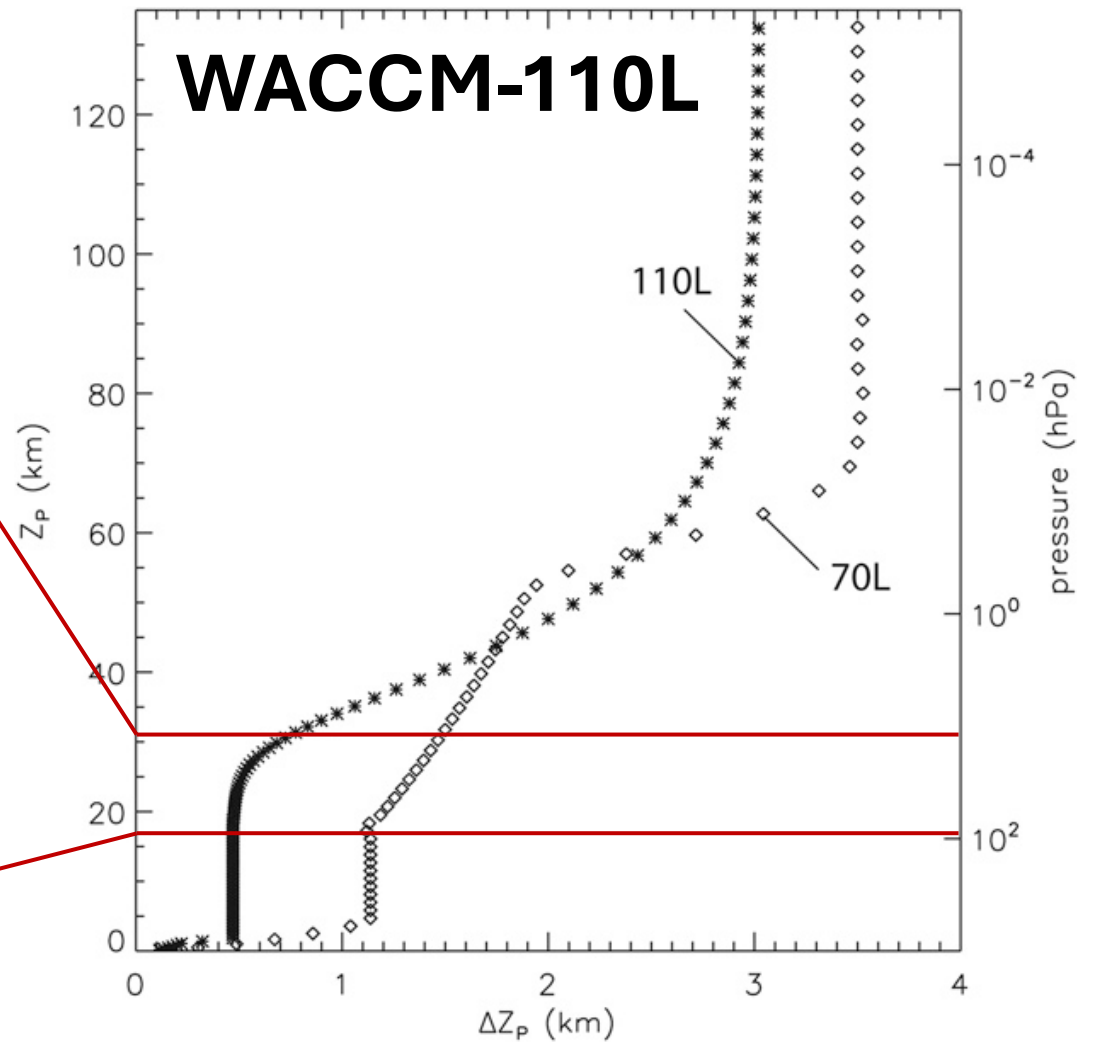
Special thanks to Nick Davis

CESM Winter Working Group Meeting, February 3-6, 2025

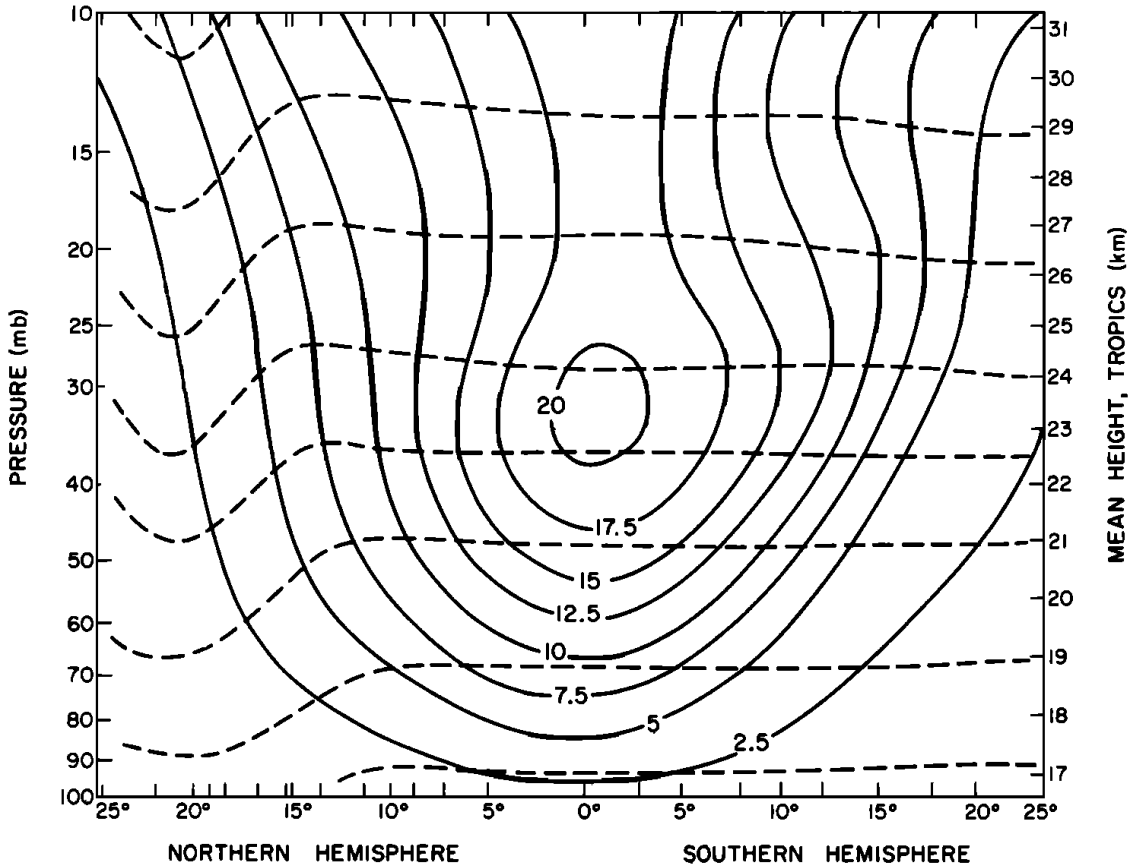# Quasi-Biennial Oscillation (QBO)

Wallace, 1973

WACCM-110L
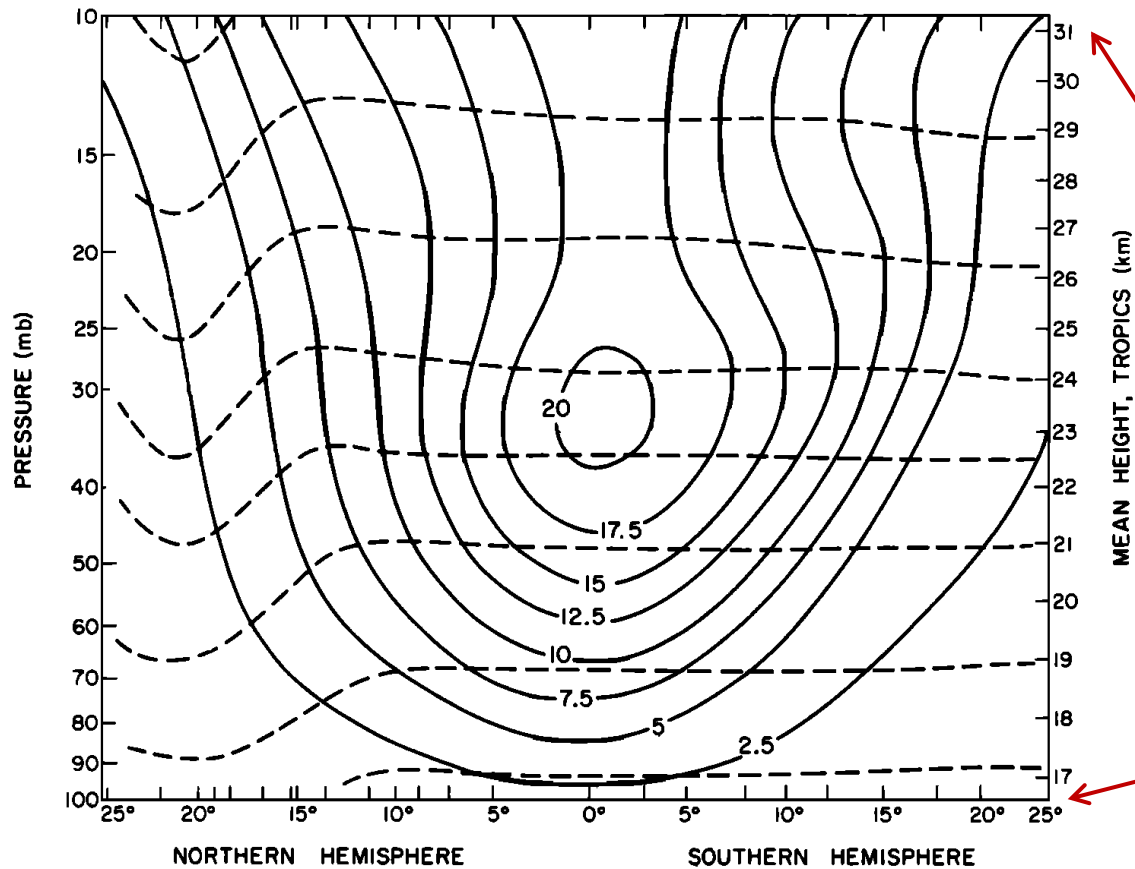
Garcia & Richter (2019)

QBO amplitude max (~ 30 hPa)

The vertical resolution is 500 m above the boundary layer and through the lower stratosphere, and then decreases slowly with altitude.

QBO Teleconnection
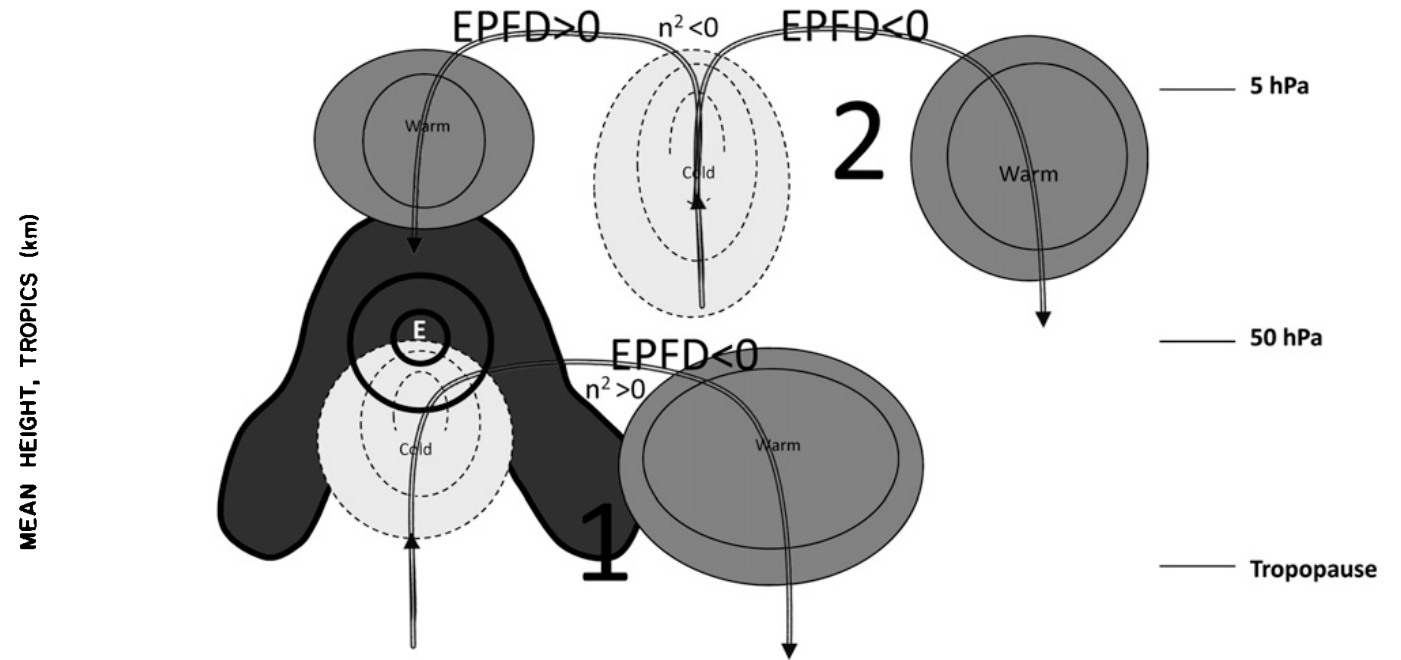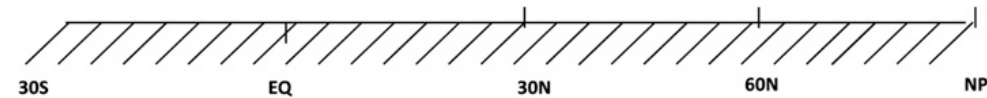

Wallace, 1973
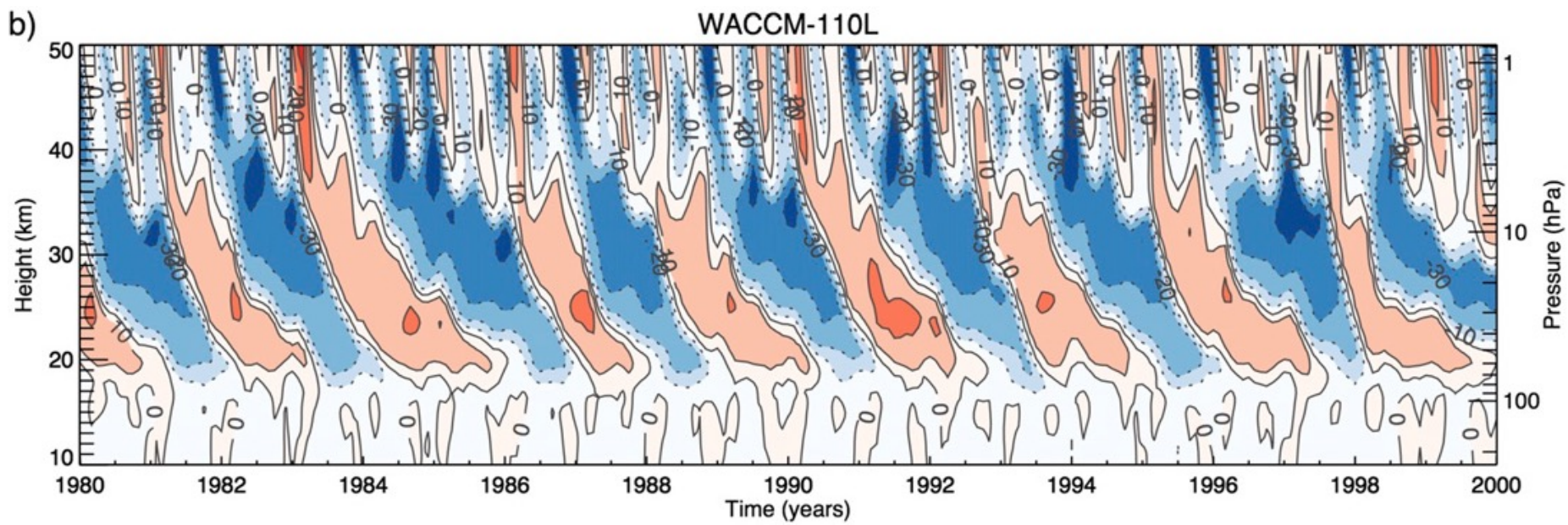
cf. (Holton-Tan effect)

Fig. 1 Garfinkel et al. (2012)

Cf) EPFD -> index of refraction -> eddies from troposphere -> TEM circulation -> warms the midlatitude lower stratosphere
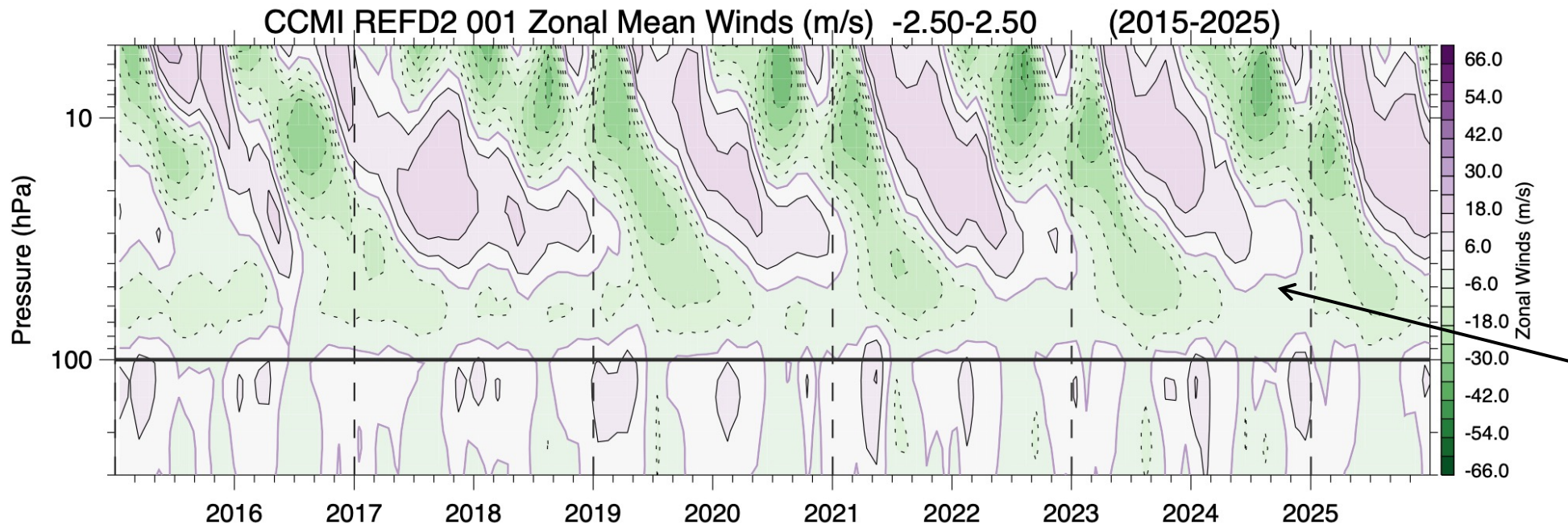
QBO in WACCM

WACCM-110L

WACCM 5.4-110L, 1°
(0.95°×1.25°)

(Garcia and Richter, 2019)

Successful simulation of the QBO: adequate horizontal and <u>vertical resolution</u>, a realistic simulation of tropical convection and a means of describing the effects of mesoscale gravity waves.
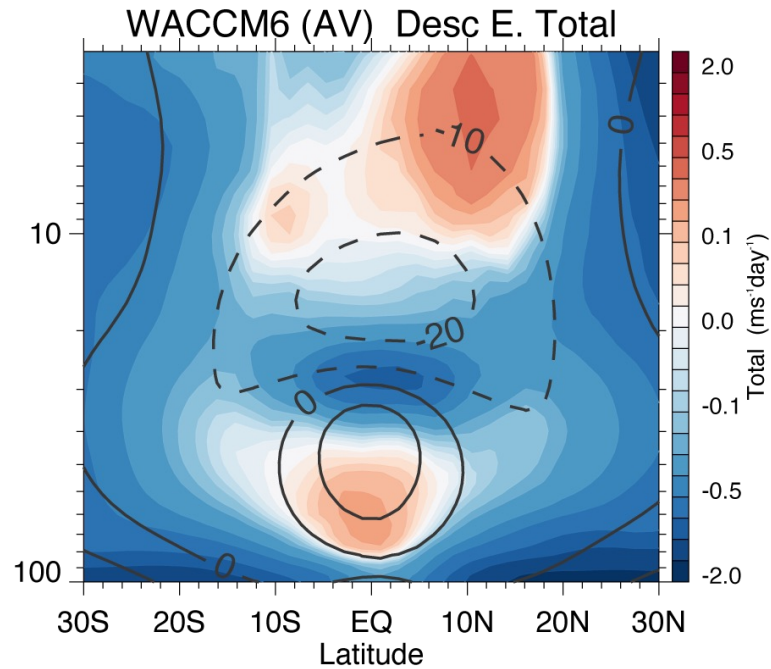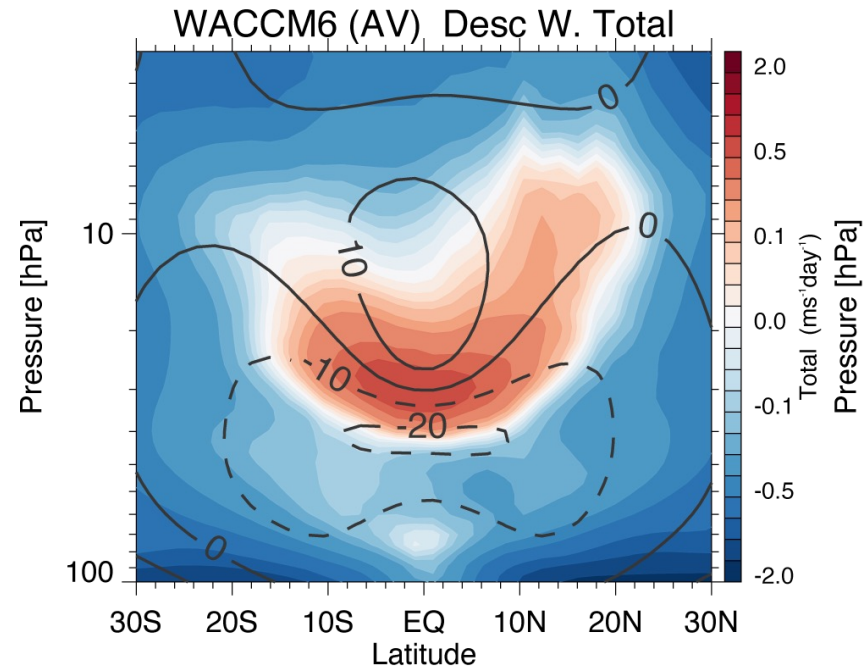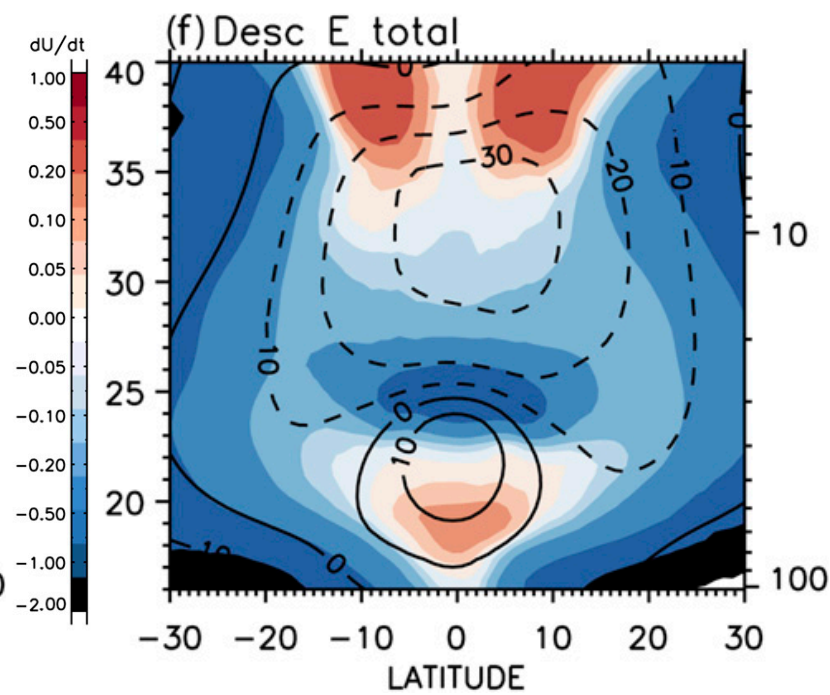

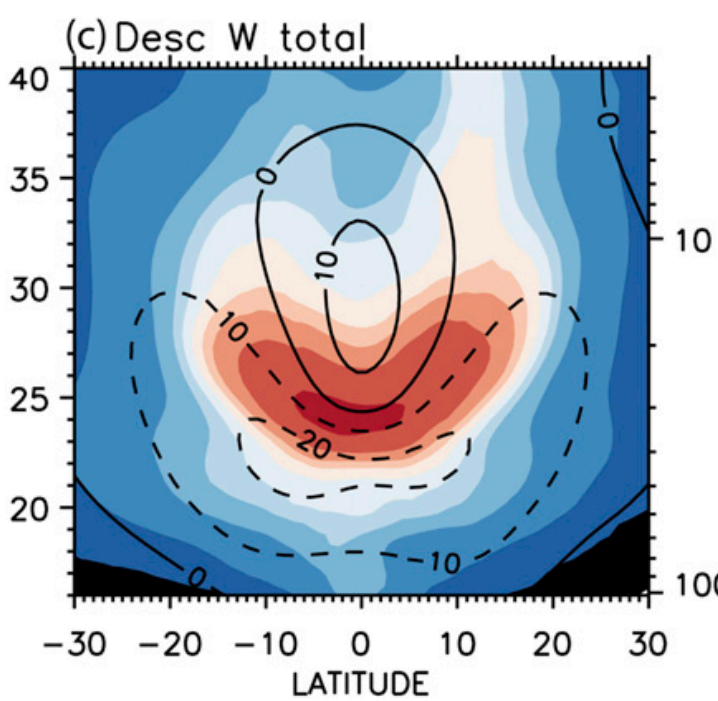CCMI REFD2 001 Zonal Mean Winds (m/s)   -2.50-2.50   (2015-2025)

WACCM6-70L, 1°
(0.95°×1.25°)

The QBO westerly does not come down to lower altitudes.

Can we run WACCM 2° to simulate the QBO?

WACCM 5.4-110L, 1° (0.95°×1.25°)

(Garcia and Richter, 2019)

WACCM6-110L, 2° (1.95°×2.25°)

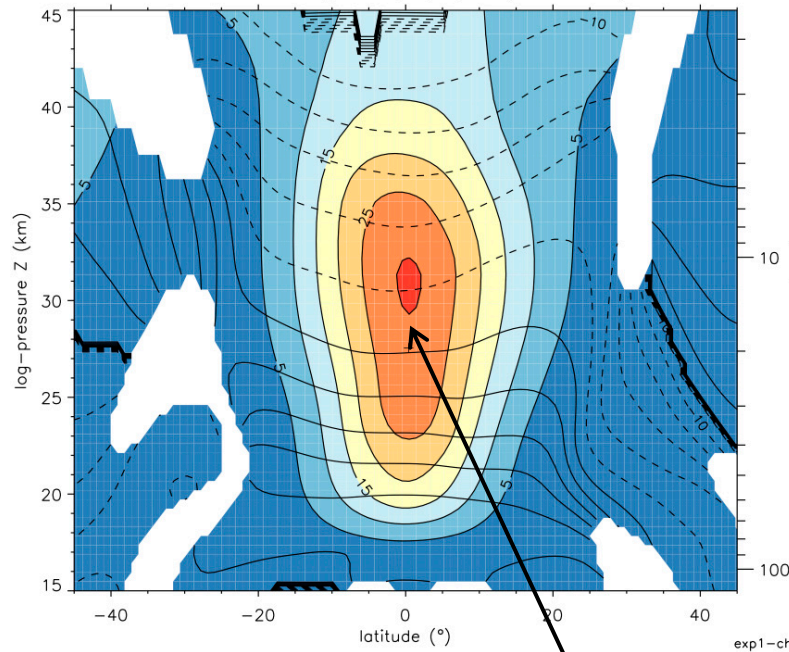Composites of acceleration (due to EP flux divergence + parameterized GW drag)

QBO amplitude & phase   **WACCM6-110L *vs.* 135L**

WACCM6-110L-1°   **WACCM6-110L-2°**   **WACCM7-135L-SE-2°**

U (m s⁻¹) Amp/Phi: (0.019−0.067) cpm; (15.0−51.4) mo;
1980−2010sig: 95%, bp: (0.5°, 20.2 hPa)

U (m s⁻¹) Amp/Phi: (0.019−0.066) cpm; (15.0−51.6) mo;
1980−2010sig: 95%, bp: (0.9°, 20.2 hPa)

U (m s⁻¹) Amp/Phi: (0.017−0.067) cpm; (15.0−60.0) mo;
1980−2010sig: 95%, bp: (0.5°, 20.0 hPa)

Stronger amplitude (1°)
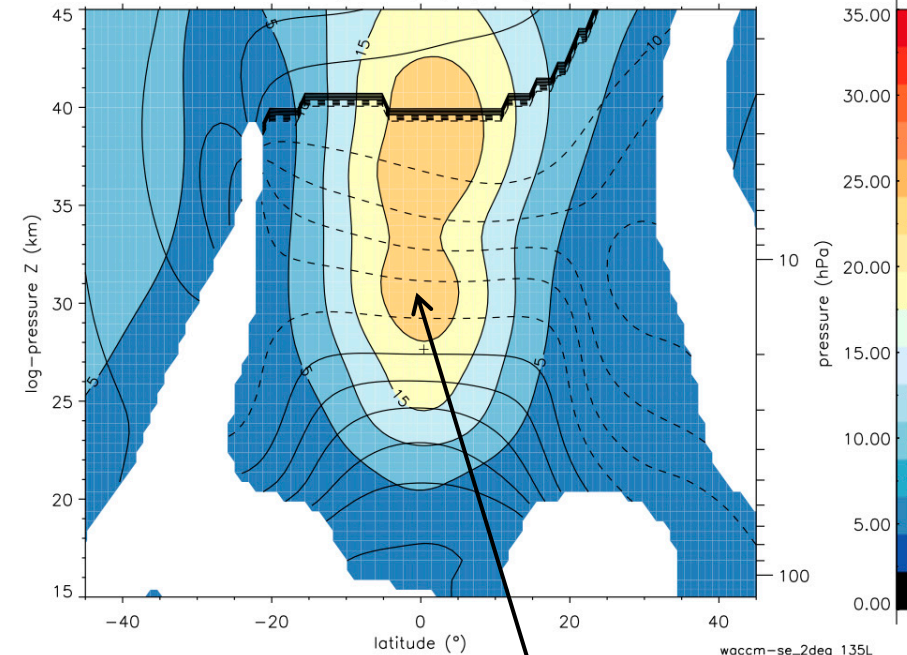
Much weaker amplitude (30-40 km)

QBO amplitude & period (WACCM-110L *vs.* 135L)

U Amp/Phi: (−10.5°,10.5°) 1980−2010

U Power Spectrum (−10.5°,10.5°) 1980−2010 27.8 km

erai
exp1
waccm−se_2deg

FV-110L-1°
SE-135L-2°
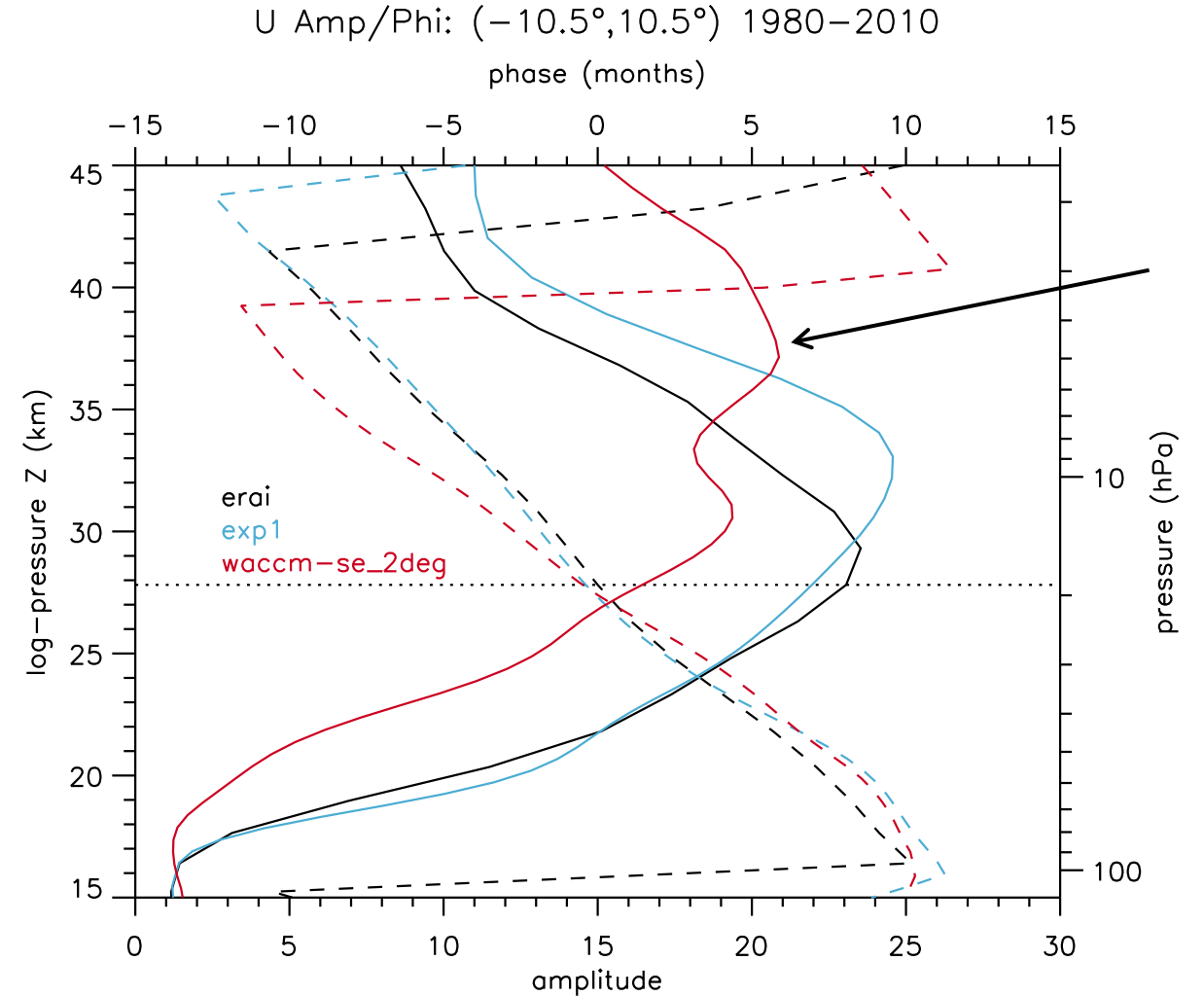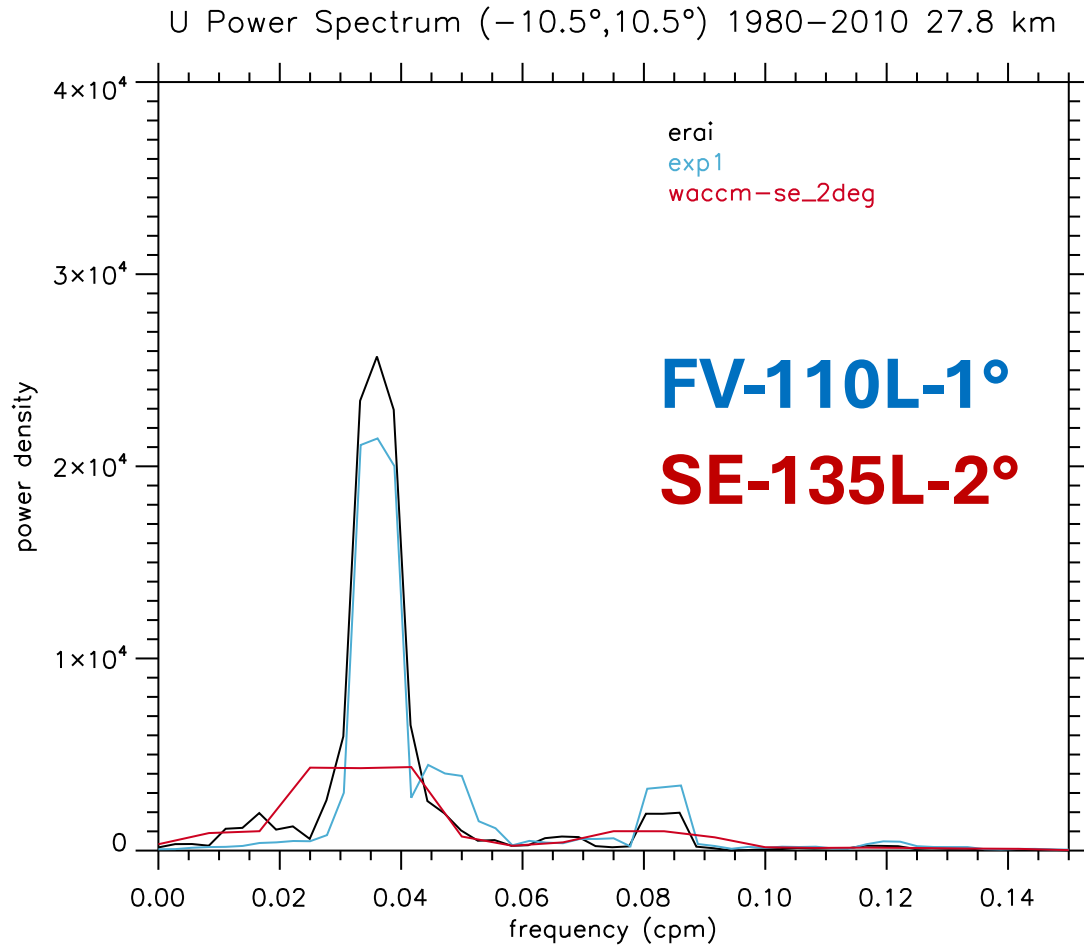
QBO (SE-135L) – Reasonable period, weak amplitude with max at 5 hPa.

Effect of HB diffusion (Holtslag and Beljaars, 1989)
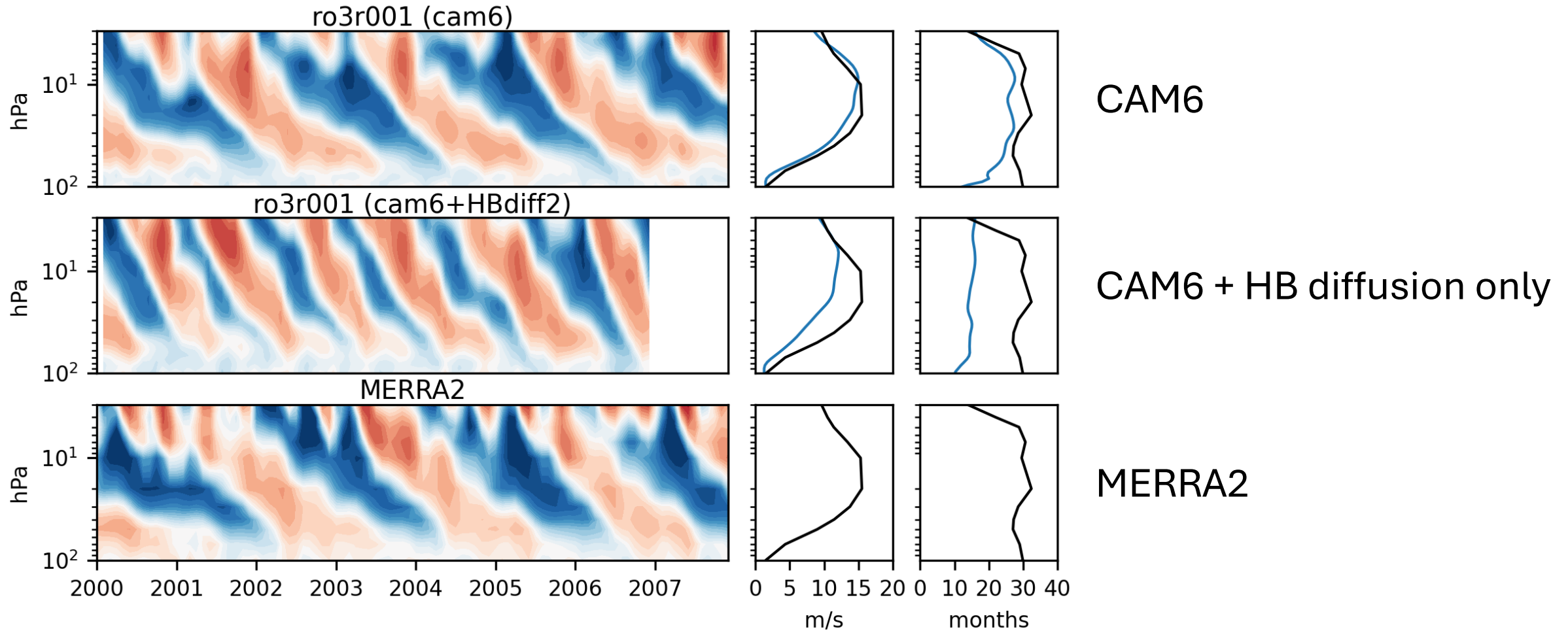
The effect of adding HB diffusion was unexpected: QBO was severely degraded

Holtslag, A. A. M. and Beljaars, A. C. M.: 1989, 'Surface Flux Parameterization Schemes: Developments and Experiences at KNMI',*Proceedings of the ECMWF Workshop on Parameterization of Fluxes Over Land Surface*, ECMWF Reading UK, pp. 121–147. (Also available from KNMI as Sci. Rep. 88-06, De Bilt NL, 27 p.)

Sep-07-2023 WAWG

Exp: CAM7+HB diffusion   (HB diffusion off 50 levels, 5 levels)
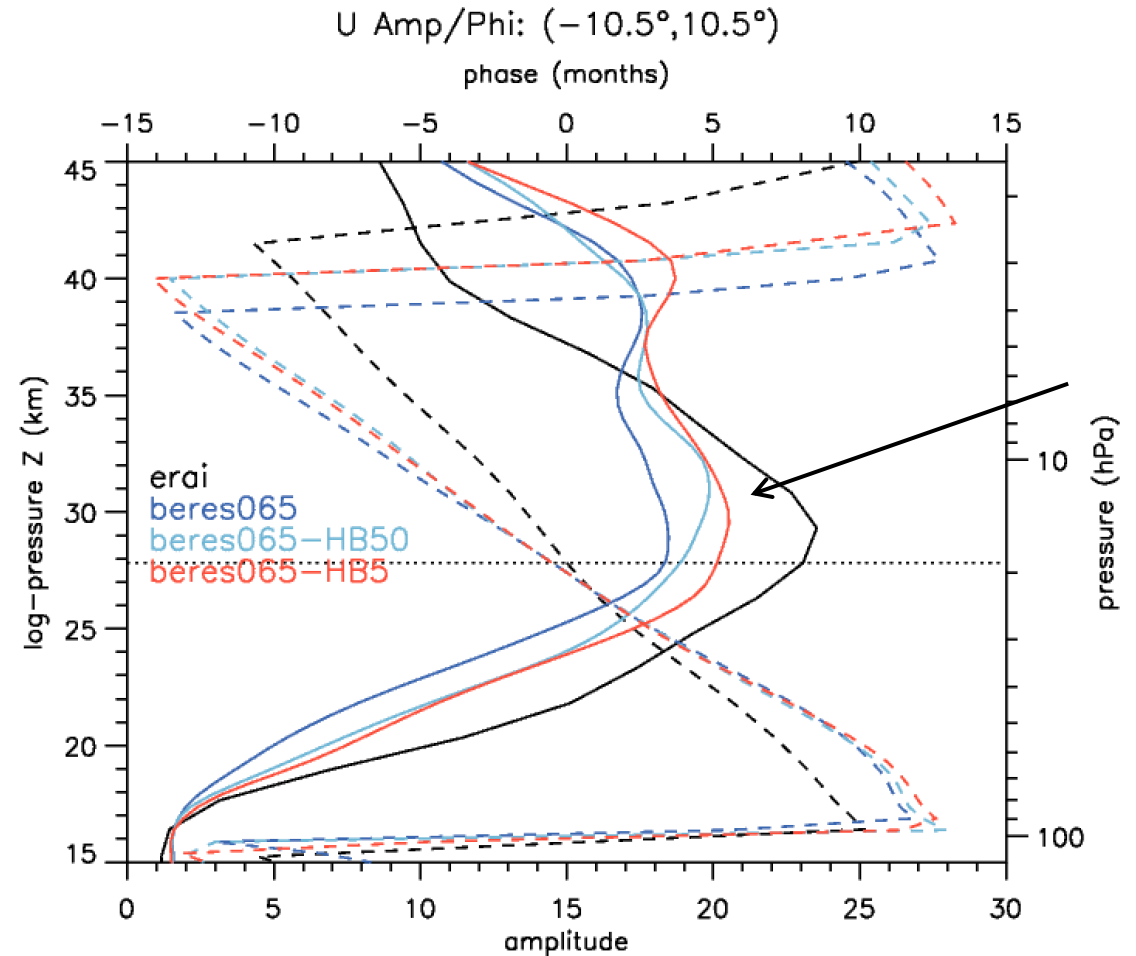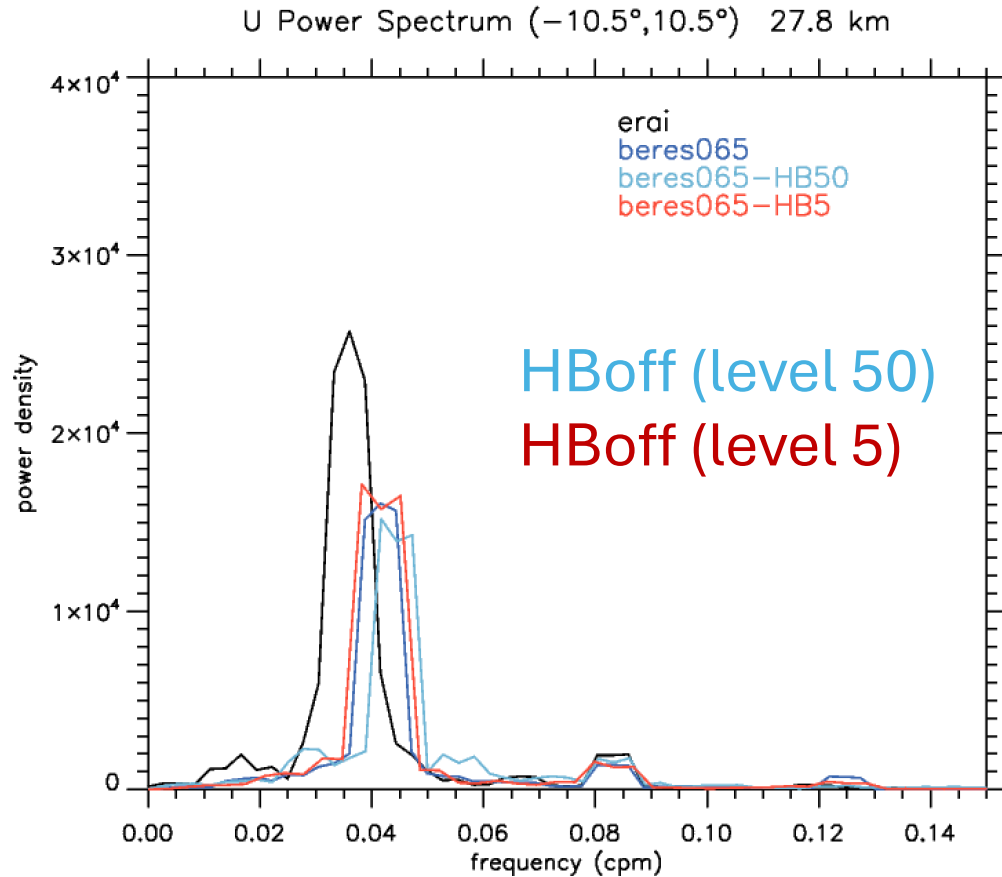
Changing the range of altitude where HB diff operates does not change the QBO period
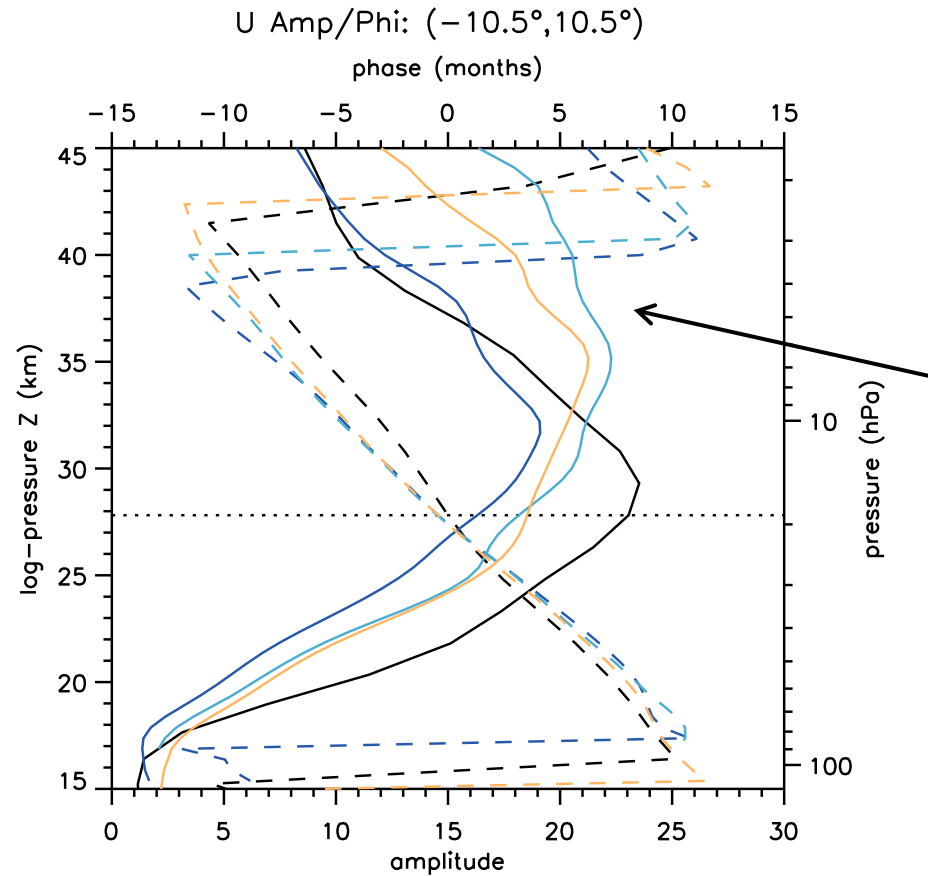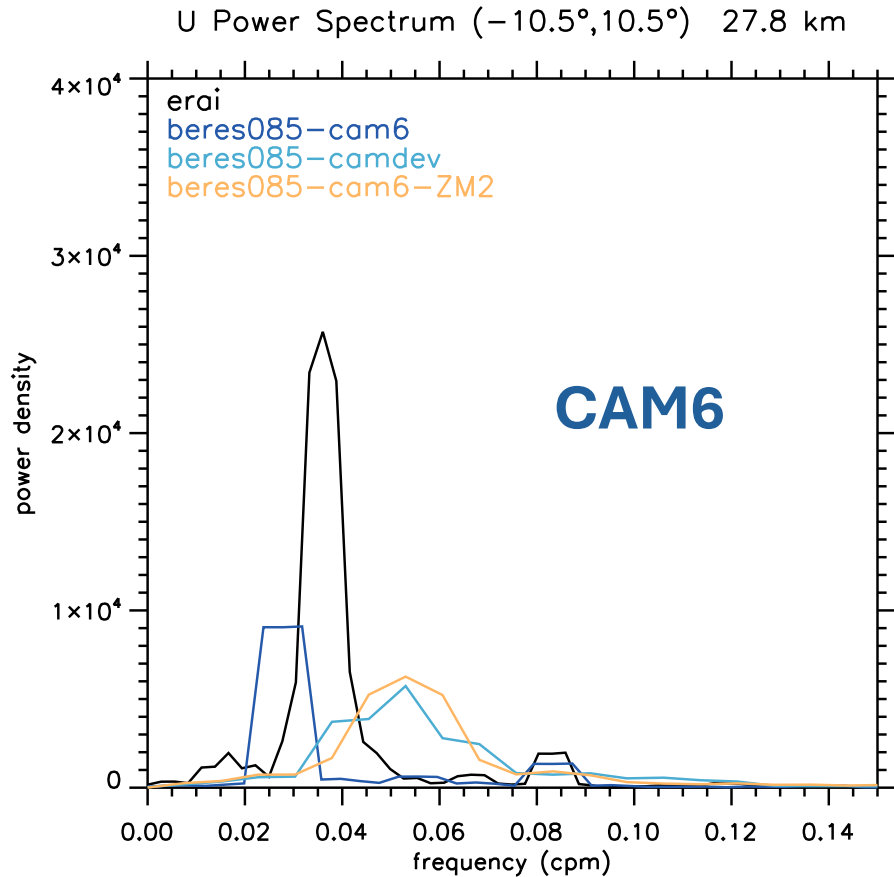Limiting HB diffusion to the sponge layer slightly increases the QBO amplitude
Remove background and stable mixing (HB diffusion on Ri ≤ 0)

The role of the Zhang & McFarlane (ZM) modification - ZM2

The high-vertical resolution grid with additional levels in the PBL, the standard version of ZM (**ZM1**) is no longer relevant. Therefore new ZM scheme (**ZM2**) is incorporated in CAM7.

U Power Spectrum (−10.5°,10.5°)   27.8 km

erai
beres085−cam6
beres085−camdev
beres085−cam6−ZM2

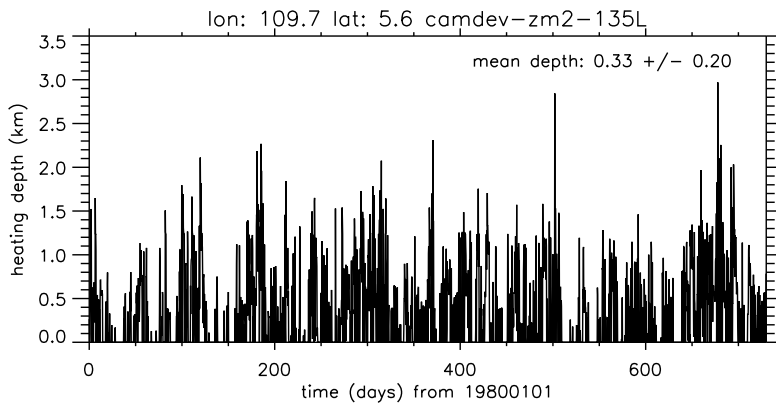**CAM6**

U Amp/Phi: (−10.5°,10.5°)

CAMDEV
CAM6+ZM2

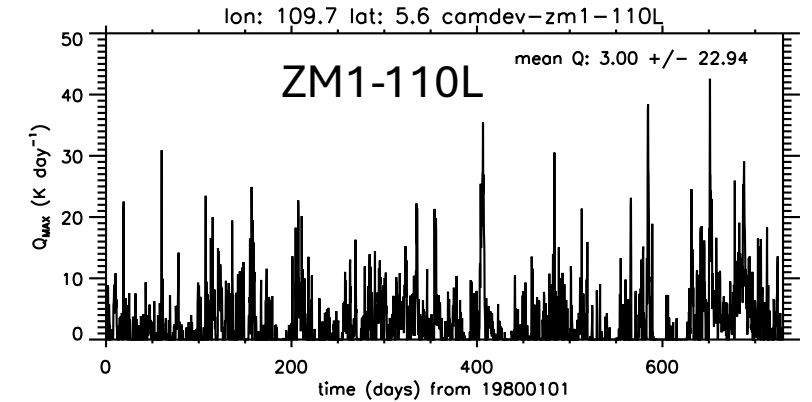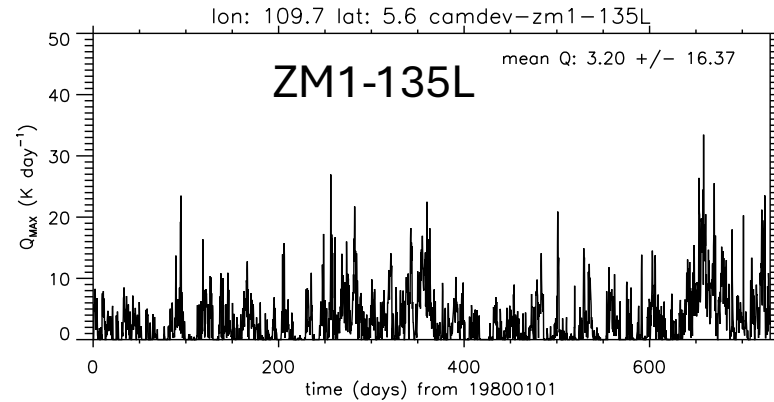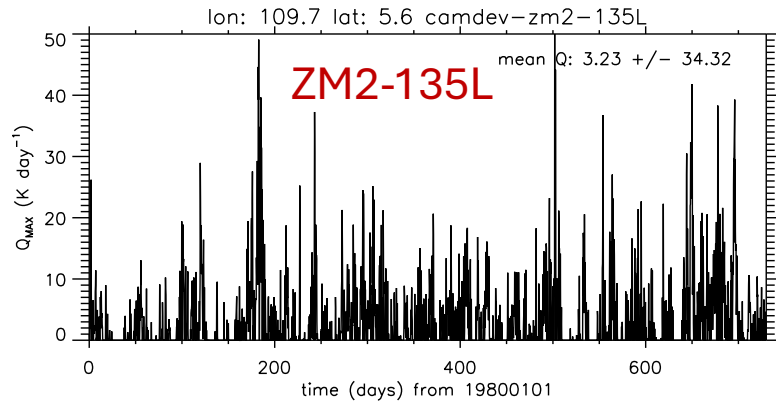Larger amplitude between 35-45km

Faster period

CAM6 physics produces QBO behavior similar to WACCM6-FV 110L

Jun-13-2024 WAWG
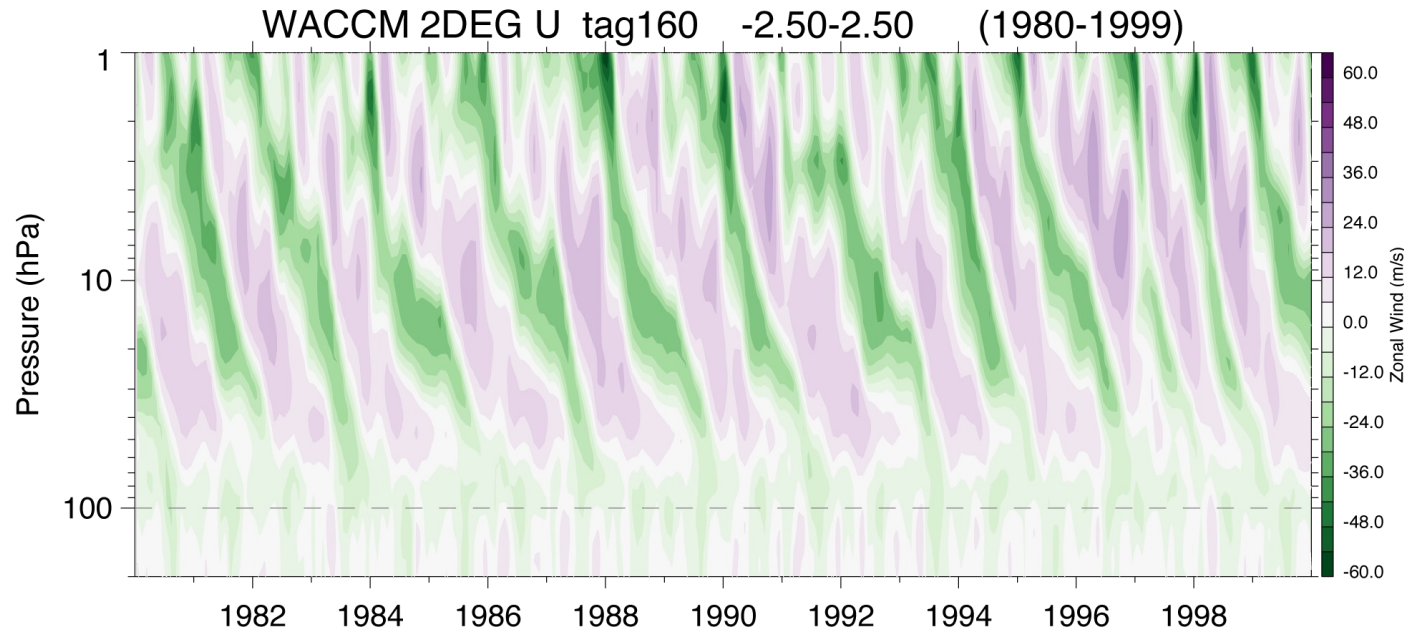
maxq$_0$ & hdepth (ZM2 *vs.* ZM1)

Top row plots (Q$_{MAX}$ (K day^{-1}) vs. time (days) from 19800101):

lon: 109.7 lat: 5.6 camdev-zm2-135L — ZM2-135L — mean Q: 3.23 +/- 34.32

lon: 109.7 lat: 5.6 camdev-zm1-135L — ZM1-135L — mean Q: 3.20 +/- 16.37

lon: 109.7 lat: 5.6 camdev-zm1-110L — ZM1-110L — mean Q: 3.00 +/- 22.94

Bottom row plots (heating depth (km) vs. time (days) from 19800101):

lon: 109.7 lat: 5.6 camdev-zm2-135L — mean depth: 0.33 +/- 0.20

lon: 109.7 lat: 5.6 camdev-zm1-135L — mean depth: 0.60 +/- 0.30

lon: 109.7 lat: 5.6 camdev-zm1-110L — mean depth: 0.43 +/- 0.22

model setup	maxq$_0$	hdepth
ZM2-135L	3.23±34.32	0.33
ZM1-135L	3.20±16.37	0.60
ZM1-110L	3.00±22.94	0.43

Mean **maxq$_0$** is similar in all three cases; ZM2-135L is more variable than the other two cases

hdepth is substantially smaller in ZM2-135L vs. ZM1-135L; in ZM1-110L, it is intermediate compared to the two 135L runs
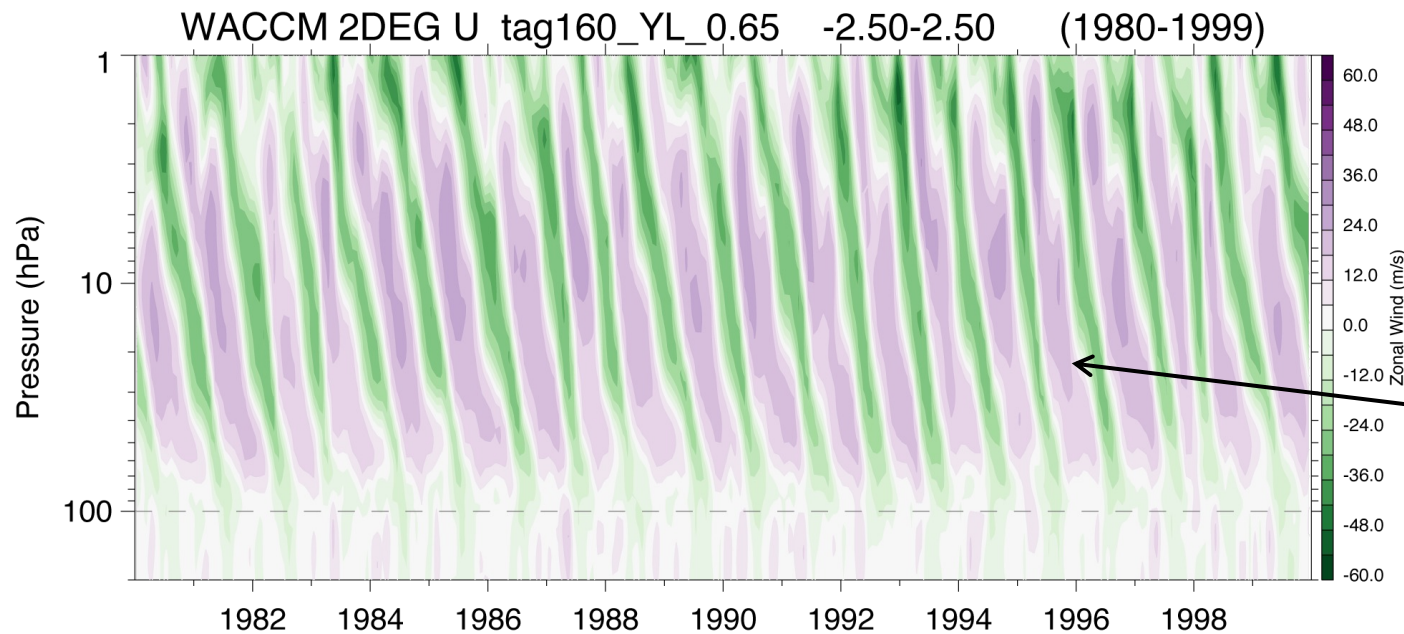
Aug-15-2024 WAWG

Gravity wave scheme (Yuanpu's fix)

WACCM 2DEG U tag160   -2.50-2.50   (1980-1999)

Before

(effgw_beres_dp=0.65)
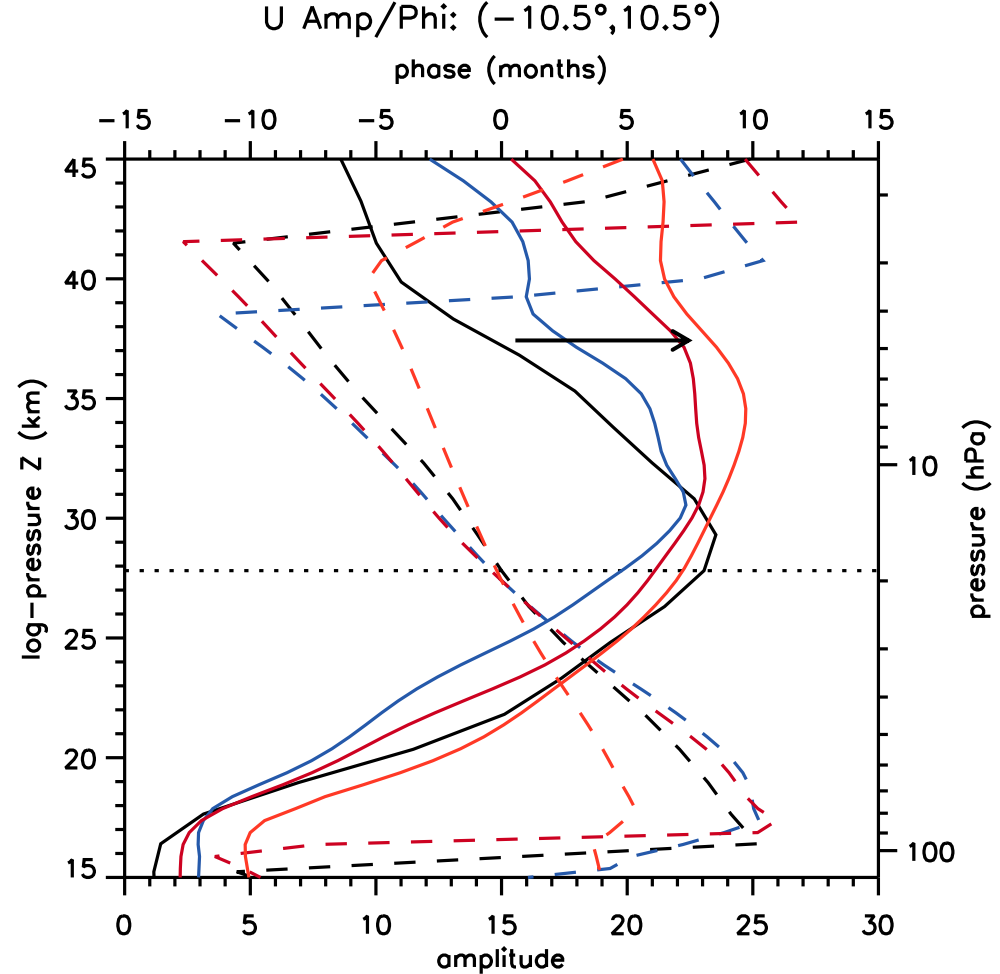
WACCM 2DEG U tag160_YL_0.65   -2.50-2.50   (1980-1999)

After

Much faster QBO

Tuning - Beres Parameter   (Yuanpu's fix)

U Power Spectrum (−10.5°,10.5°)   27.8 km

erai
tag160_beres0.20_YL
tag160_beres0.40_YL
tag160_beres0.65_YL

U Amp/Phi: (−10.5°,10.5°)
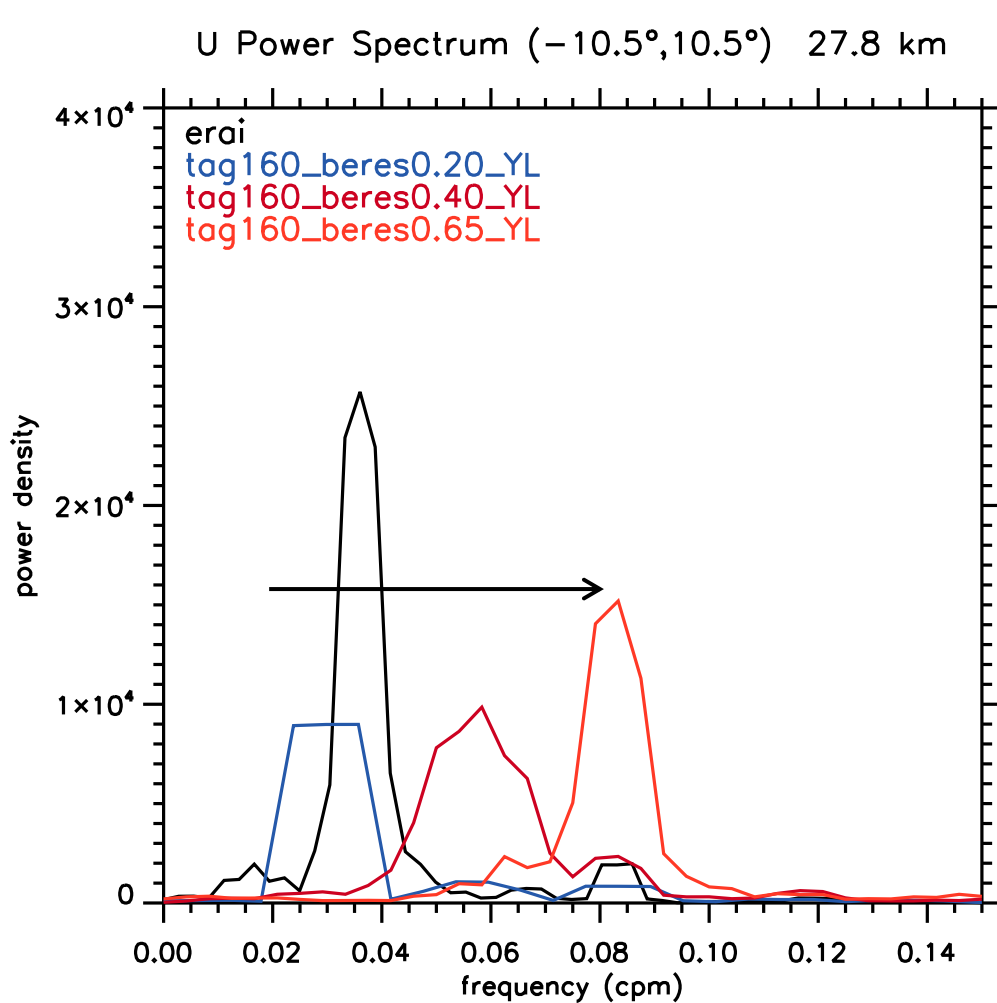
Increase in efficiency parameter increases the QBO amplitudes (more so at high altitudes) and shortens the period
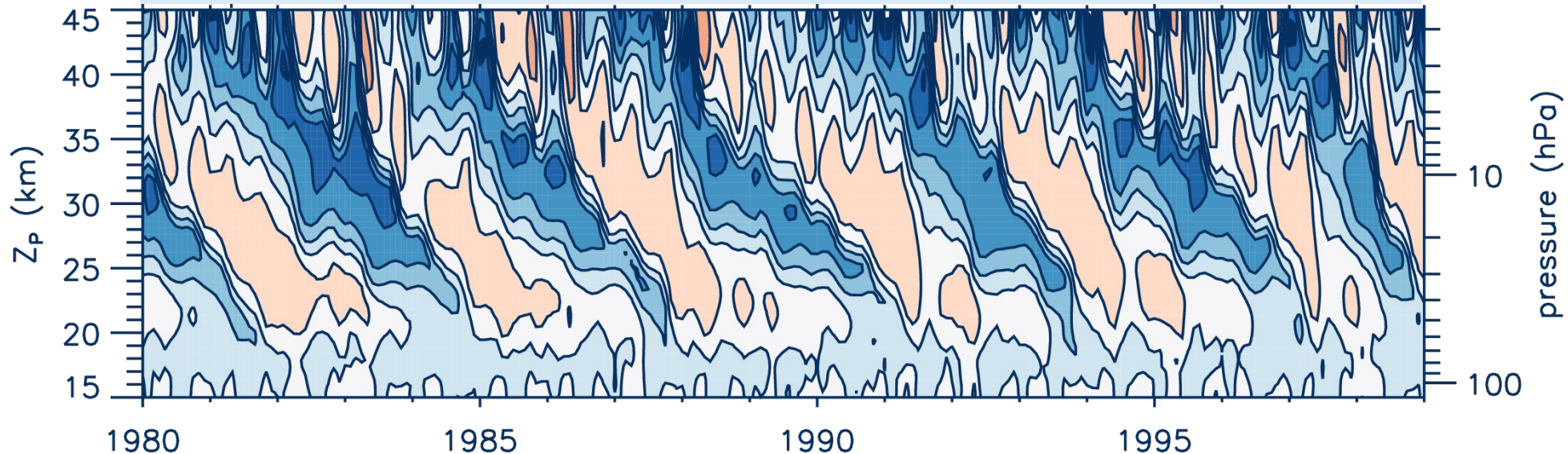
Tuning - Conversion Factor (CF)

U Power Spectrum (−10.0°,10.0°)   27.4 km

U Amp/Phi: (−10.0°,10.0°)
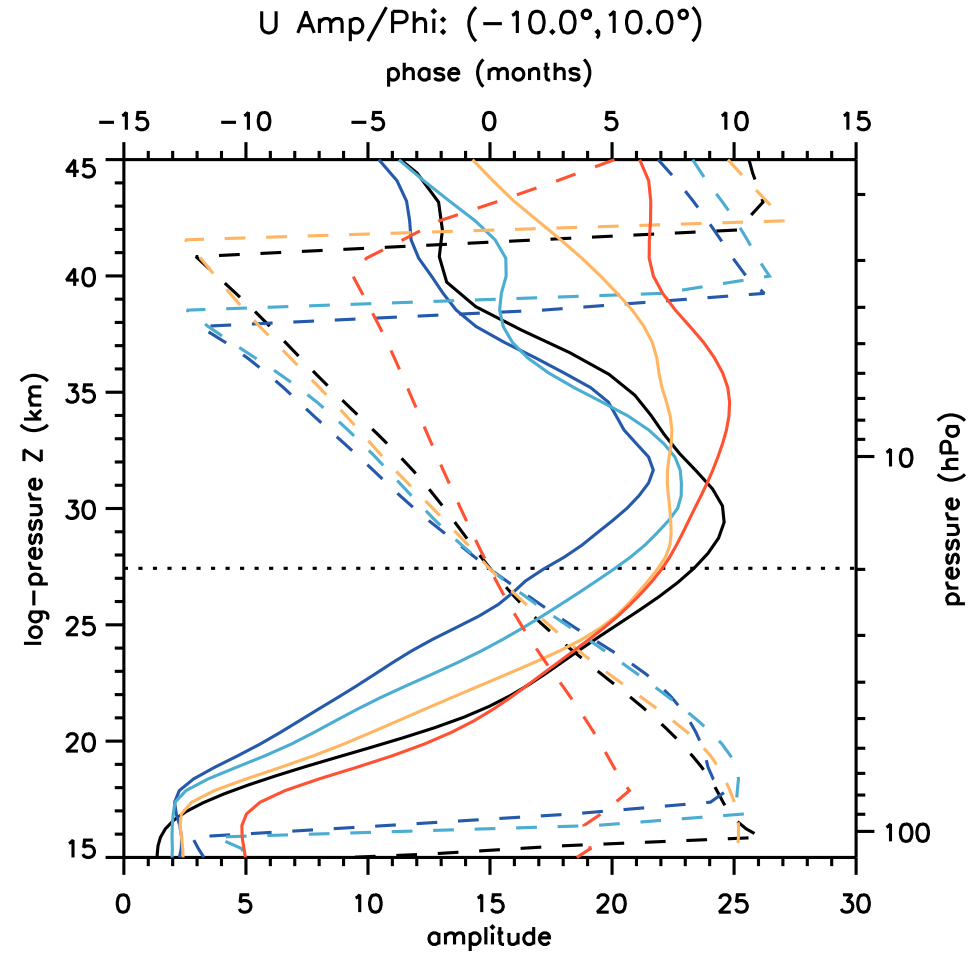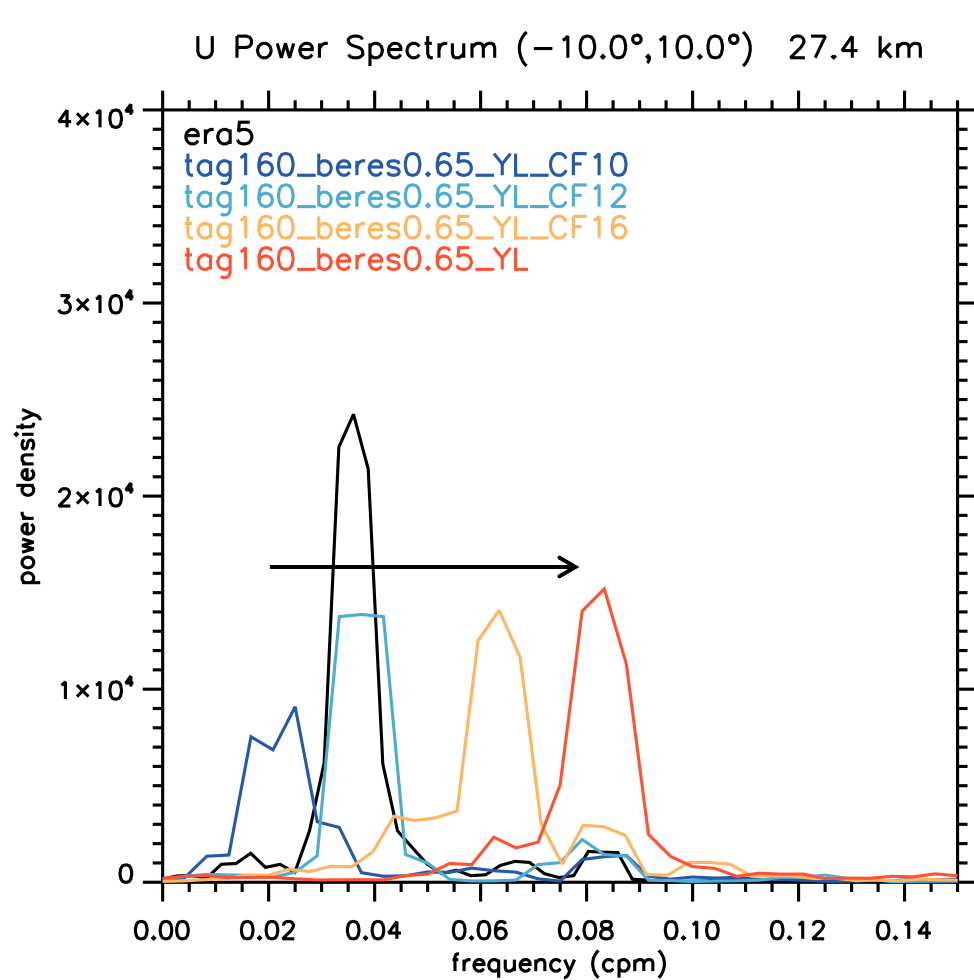
Tag160_beres0.65_YL_CF10 (slowest)
Tag160_beres0.65_YL_CF12 (right)
Tag160_beres0.65_YL_CF16 (fast)
Tag160_beres0.65_YL (CF=20, default, fastest)

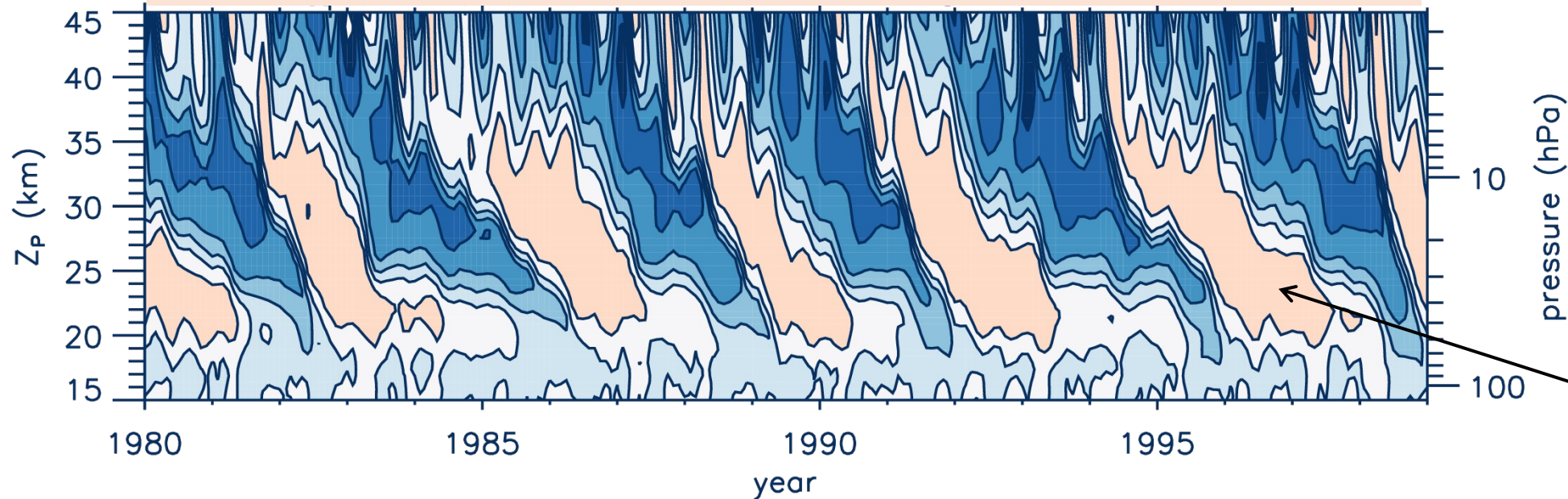Increase in CF speeds up the QBO
CF impact on QBO amplitude is not linear

WACCM7-2DEG (cam6_4_055)   135L
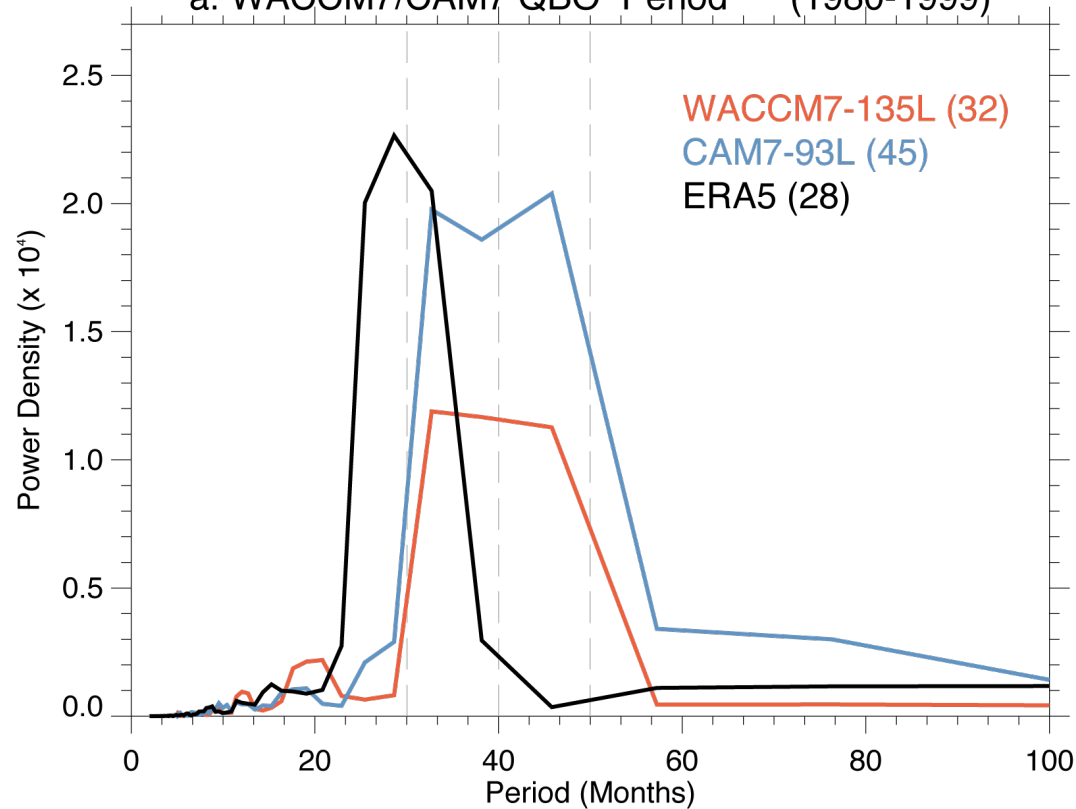
CAM7-1DEG (beta04)   Simone's run   93L

Slower QBO

NEW Tag
cam6_4_055

OLD Tag
cam6_3_160

QBO Period & Amplitude   (**CAM7-1DEG** *vs*. **WACCM7-2DEG**)
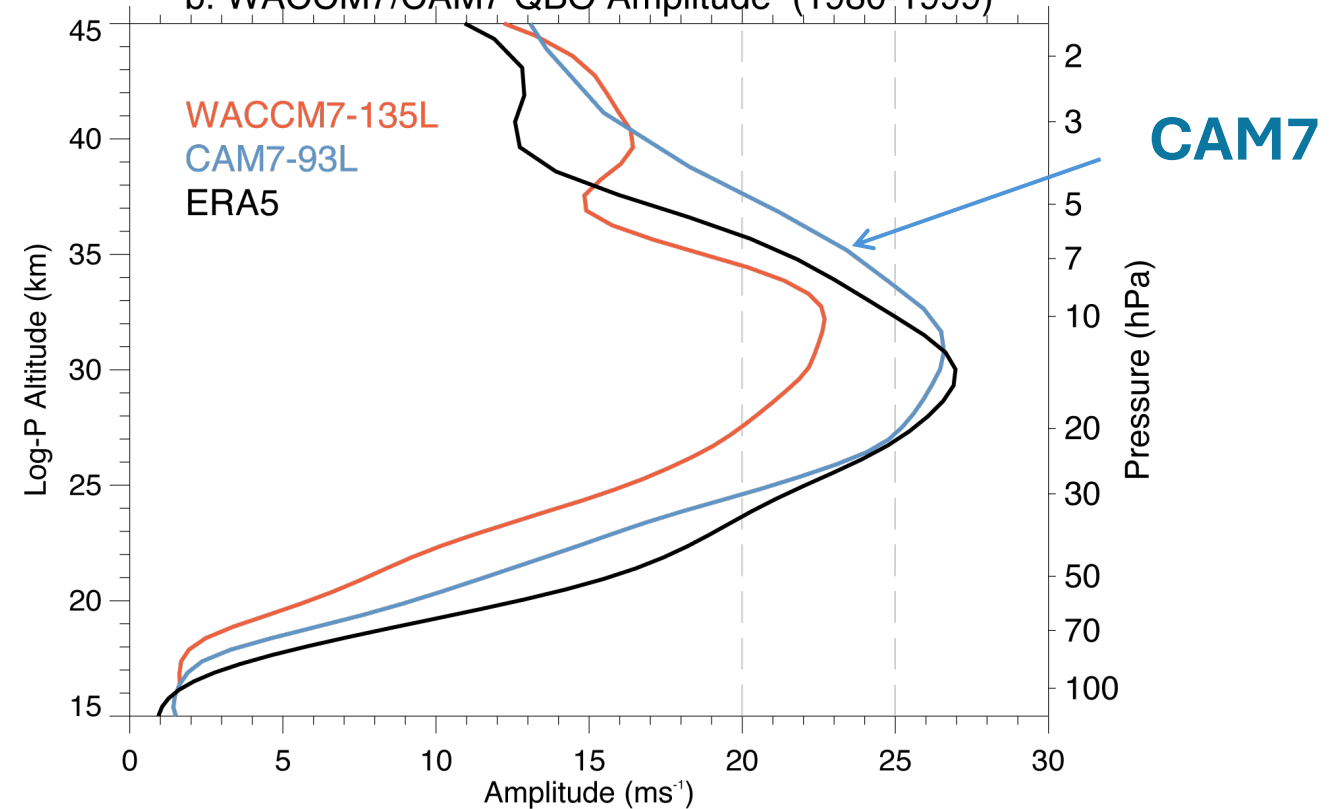
QBO is slower and its amplitude is stronger in CAM7(MT)-1DEG

atm_in

CAM7(MT)-1DEG
Simone's run (beta04)

WACCM7-1DEG
CAM6_4_055

WACCM7-1DEG
CAM6_4_055-rdg0.5

```
&gw_drag_nl
 alpha_gw_movmtn        = 0.02D0
 effgw_beres_dp         = 0.20D0


 effgw_rdg_beta         = 0.5D0
 effgw_rdg_beta_max     = 0.5D0


 front_gaussian_width   =  30.D0
 frontgfc               = 3.00D-15
```

```
&gw_drag_nl
 alpha_gw_movmtn        = 0.01D0
 effgw_beres_dp         = 0.25D0


 effgw_rdg_beta         = 1.0D0
 effgw_rdg_beta_max     = 1.0D0


 front_gaussian_width   =  30.D0
 frontgfc               = 3.00D-15
```
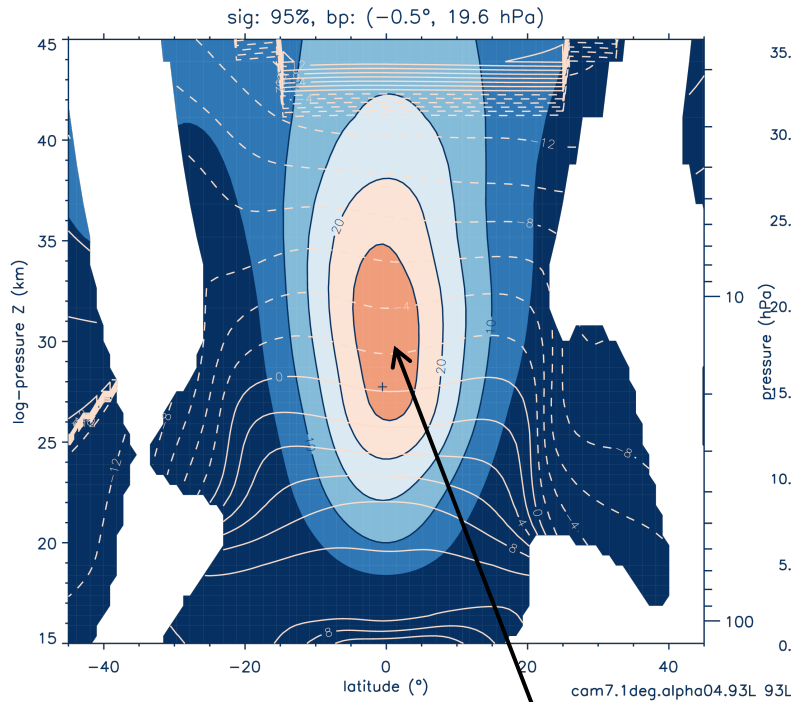
```
 effgw_rdg_beta         = 0.5D0
 effgw_rdg_beta_max     = 0.5D0
```

effgw_beres_dp (convective gravity wave efficiency)

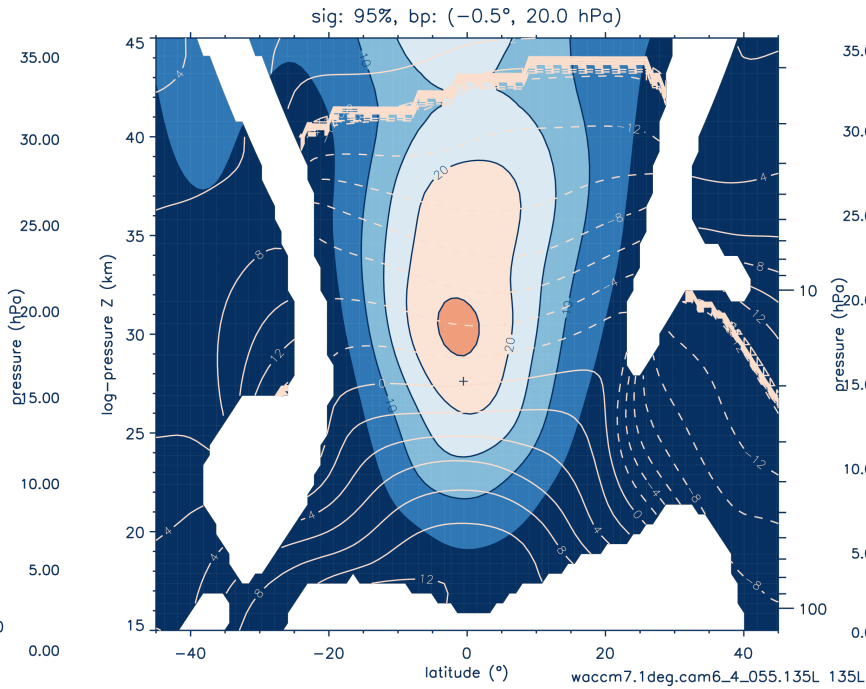effgw_rdg_beta (orographic gravity wave efficiency)

effgw_rdg_beta_max

/glade/campaign/cesm/cesmdata/cseg/runs/cesm2_0/f.e30_alpha04a.FCts4MTHIST.ne30_L93.cmip7_volc/CaseDocs/atm_in

QBO Amplitude   (CAM7 & WACCM7 1DEG)

CAM7(MT)-1DEG
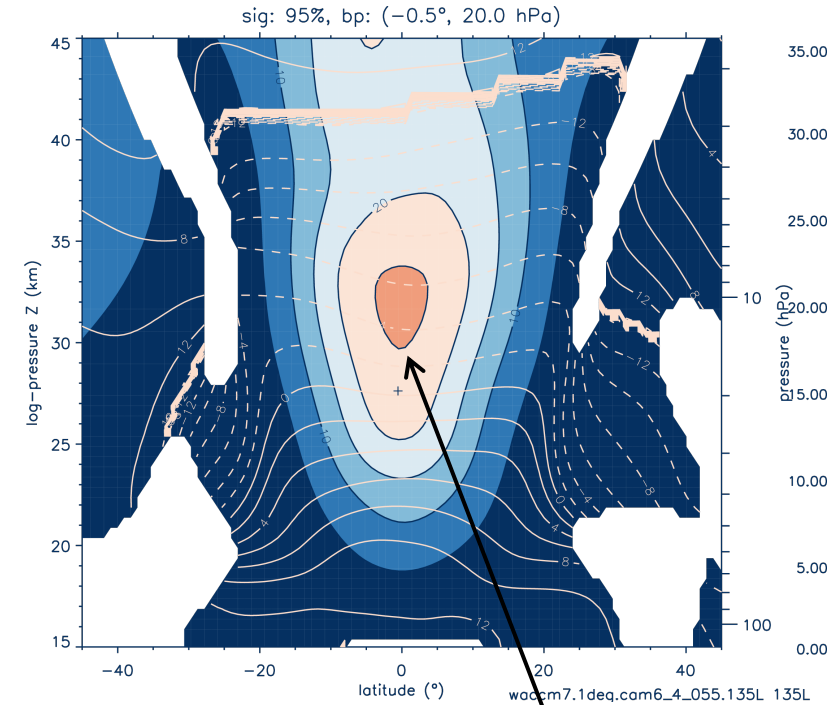### Simone's run (beta04)

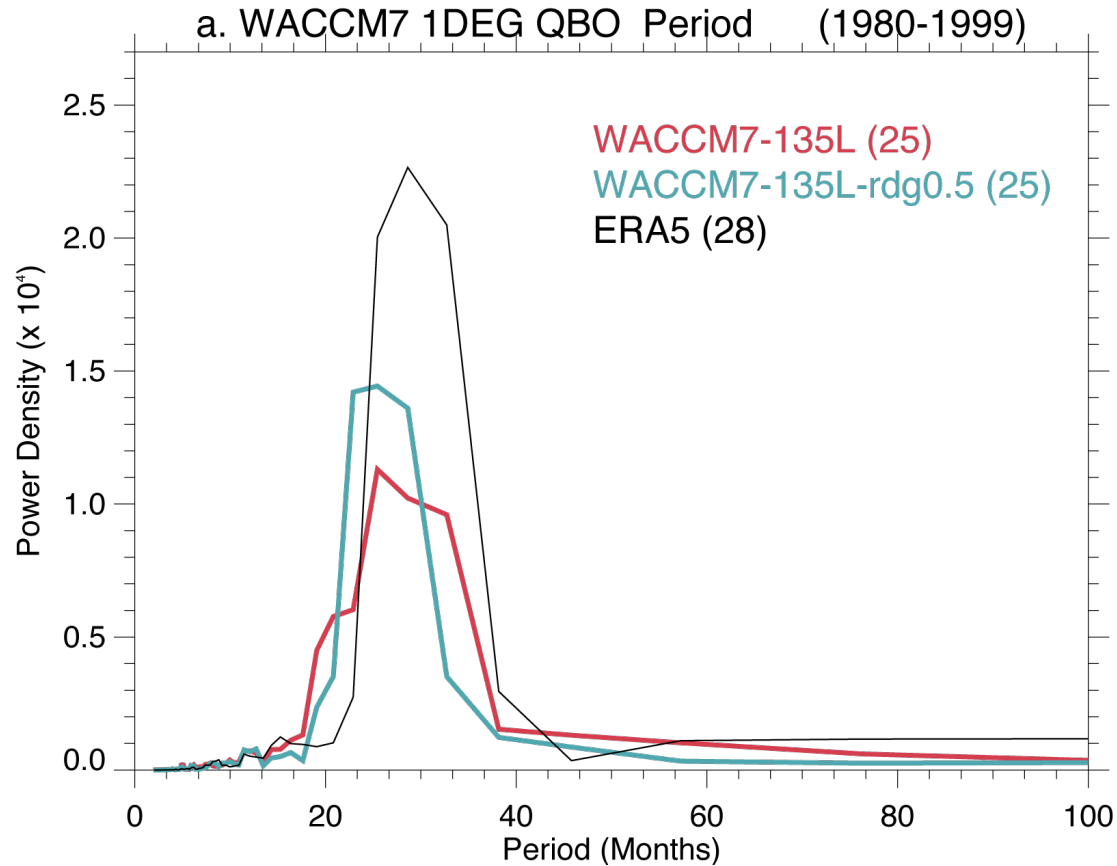### WACCM7-1DEG
CAM6_4_055

WACCM7-1DEG
CAM6_4_055-rdg0.5

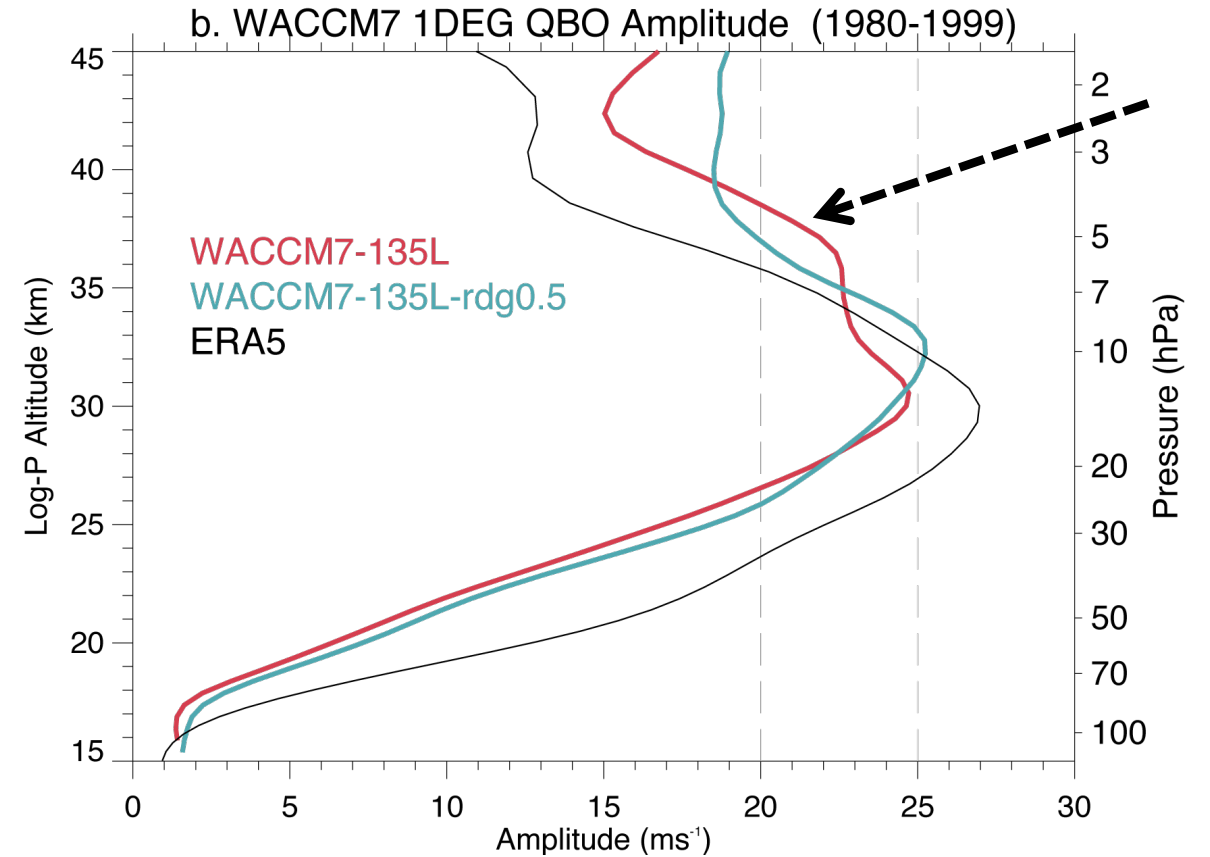CAM7 – larger amplitude

effgw_rdg_beta   = 0.5
effgw_rdg_beta_max = 0.5

QBO Period & Amplitude   (WACCM7-1DEG)

Second maximum in amplitude disappears with **effgw_rdg_beta=0.5**

Summary

1. Much improved understanding of the QBO and the physical parameters controlling the QBO in WACCM7.

2. Work is not done yet.

3. Will explore ways to improve the QBO even further.

4. Opportunity for exciting science!