Interactive QBO simulations in a warming climate

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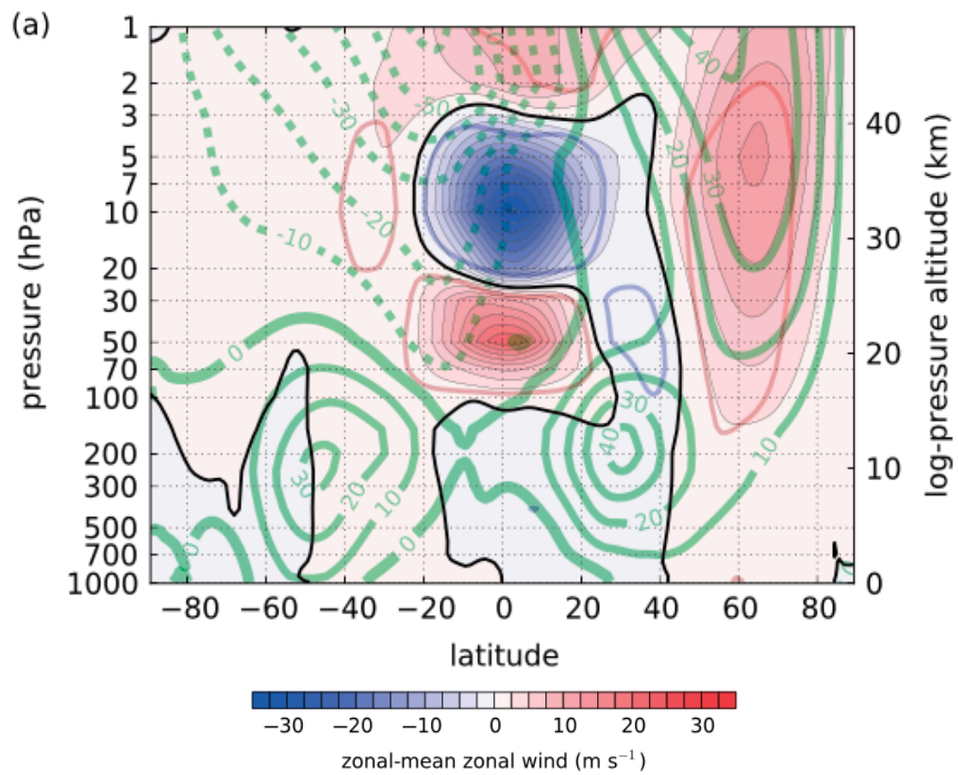
NCAR

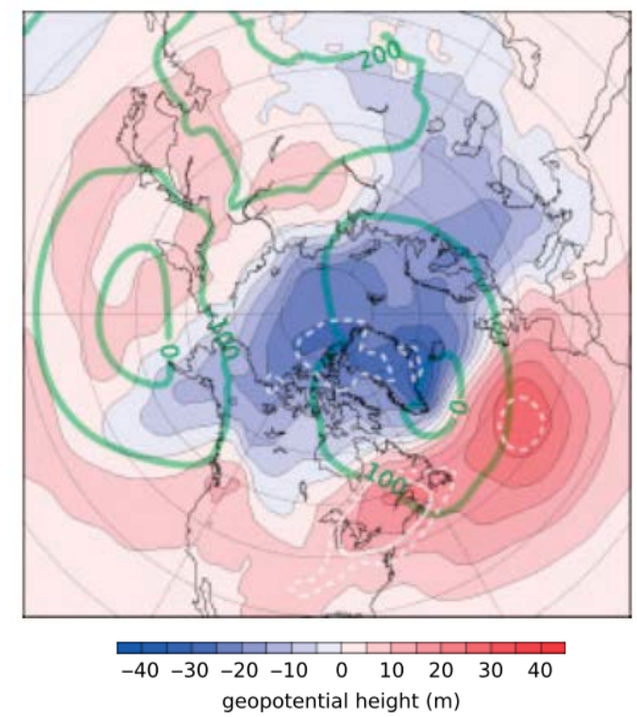
Why is QBO important?

- Primary mode of variability in the Tropical stratosphere
- Influences mean meridional circulation, temperature & transport
- Affects the strength of the polar vortex
- Affects tropospheric climate (NAO)

QBO W – QBO E
Jan Zonal Wind



QBO W – QBO E
1000 hPa Geopotential height



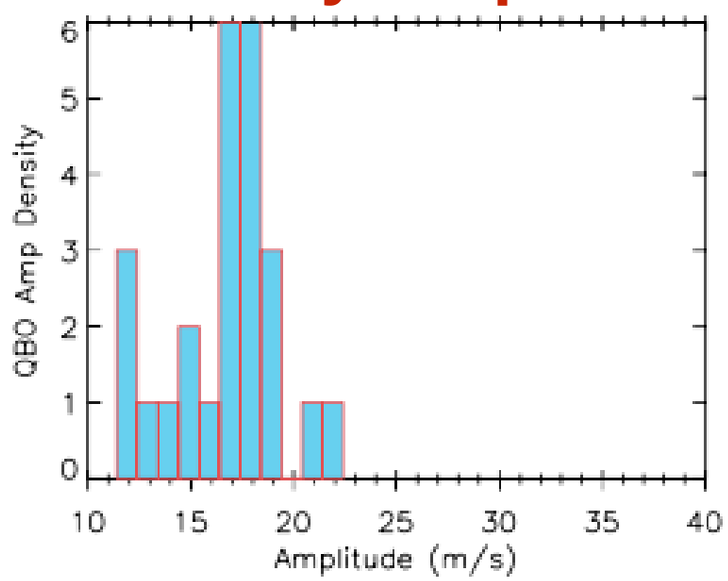
+NAO

Figures from Anstey & Shepherd (2014)

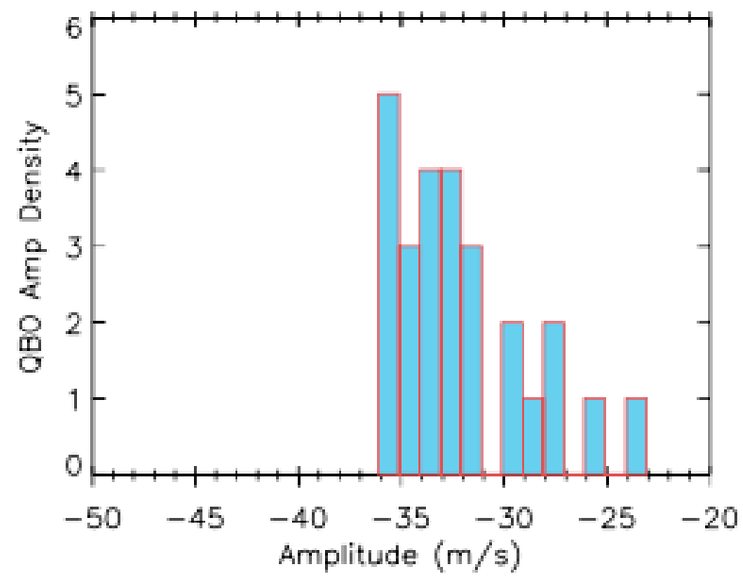
QBO Characteristics OBS:

From observations: 1952 - 2016

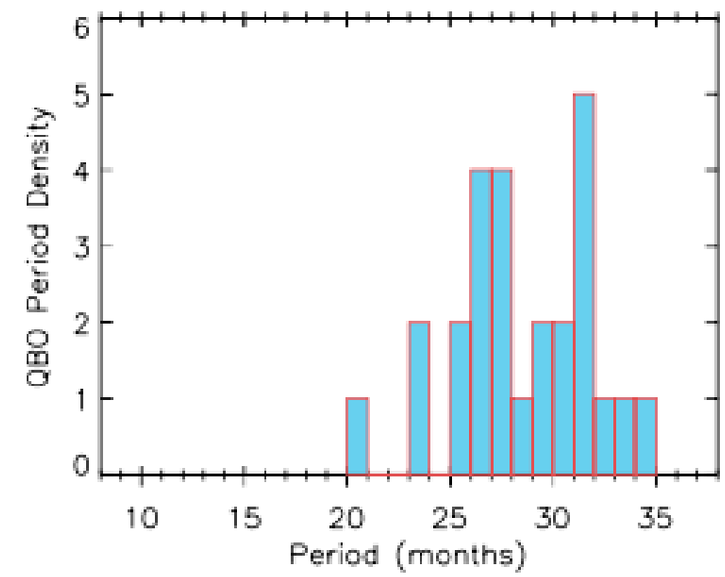
Westerly Amplitude



Easterly Amplitude



Period



Period ranges from
20 – 35 months
Mean: 28 months

QBOi: QBO Intercomparison Project

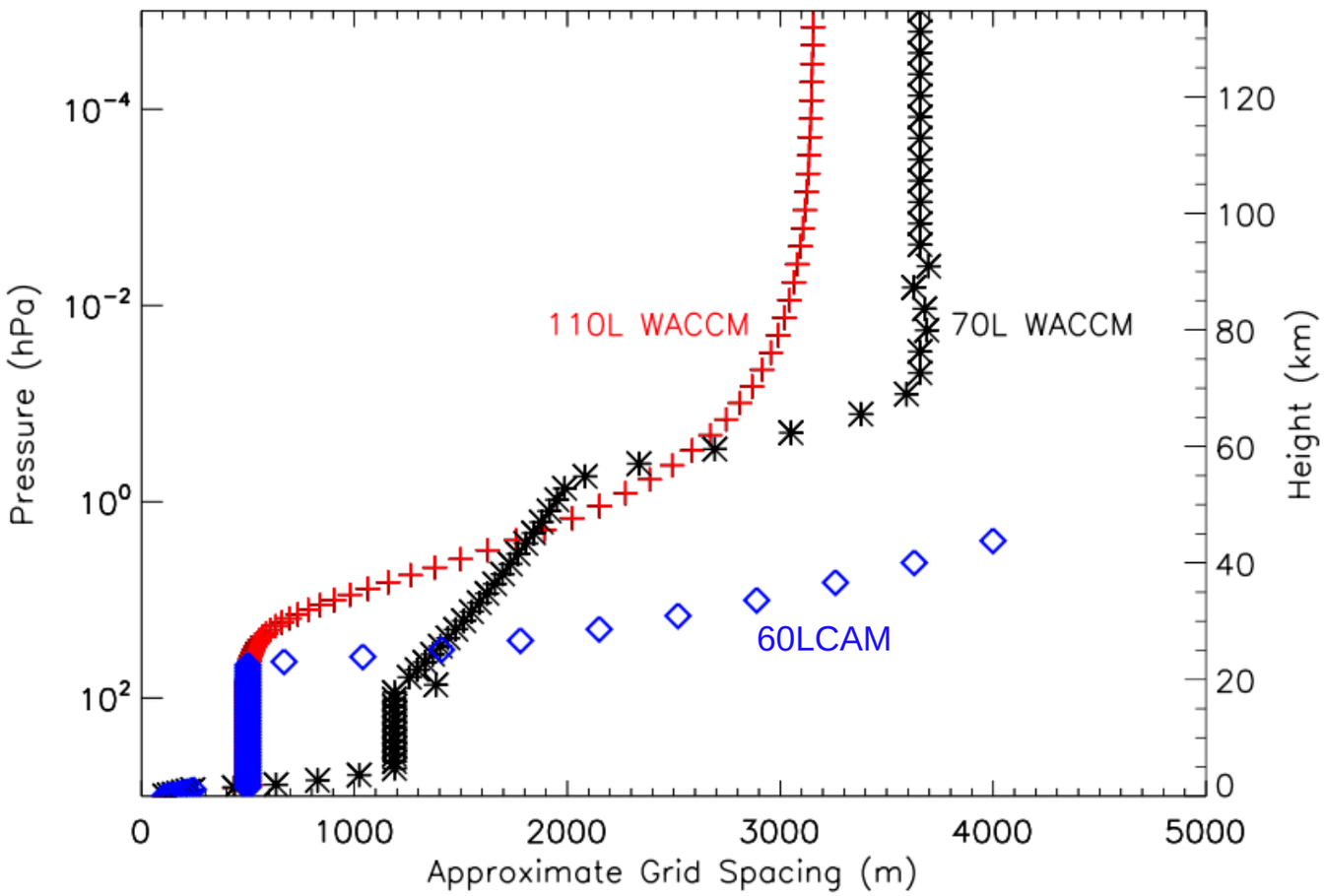
- **QBOi** is a SPARC activity to improve understanding of QBO
- Led by S. Osprey (Oxford), N. Butchart (MetOffice), & J. Anstey (CCCma)
- **First meeting:** March 2015; **2nd meeting:** September 2016
- Participating models: LMDz6 (France), HADGEM3 (UK), AGCM3-CMAM (Canada), MIROC (Japan), MRI-ESM2 (Japan), ECHAM5sh (Italy), ECMWF EC-EARTH, NRL NAVGEM,
  60L-CAM and 110L-WACCM (NCAR)

QBOi Experiments:

	SSTs	CO_2	Years
EXP1	Observed	Observed	1979-2010
EXP2	Climo 2002	2002	30
EXP3	Climo 2002 + 2K	2 x CO_2	30
EXP4	Climo 2002 + 4K	4 x CO_2	30
EXP5	Seasonal Hindcasts		

110L CESM1 (WACCM): aka 110L-WACCM

- Based on Community Earth System Model, version 1 (CESM1)
- 0.9 x1.25^{o} horizontal resolution
- CAM5.4 physics
- Zhang & McFarlane convection
- No CLUBB
- Top ~ 140 km
- 110 instead of 70 levels
- **500 m resolution** lower stratosphere
- Builds on 60-level CAM5
- Full chemistry or specified chemistry
- Additional GW parameterizations

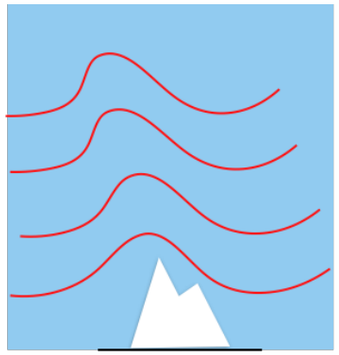


Built by J. Richter & R. Garcia for QBOi (not default CMIP6 model)

GW Parameterization: WACCM

1. Orographic GWs:

Uncertain: Efficiency

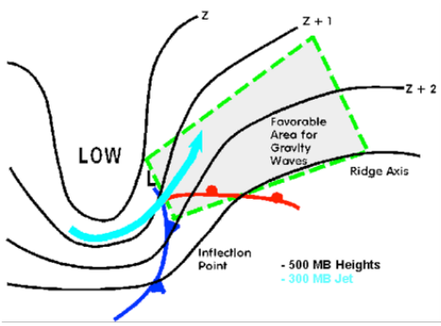


Orographic GWs:

- McFarlane (1987)
- 1 wave with c = 0
- Amplitude dependent on orography height and wean wind

2. Frontally generated GWs:

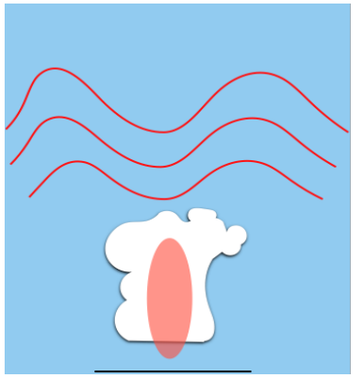
Uncertain: Efficiency, amplitude, phase speeds



- 40 waves with -100 < c < 100 m/s
- Gaussian distribution in phase speed centered at U 600 mb
- Constant wave amplitude

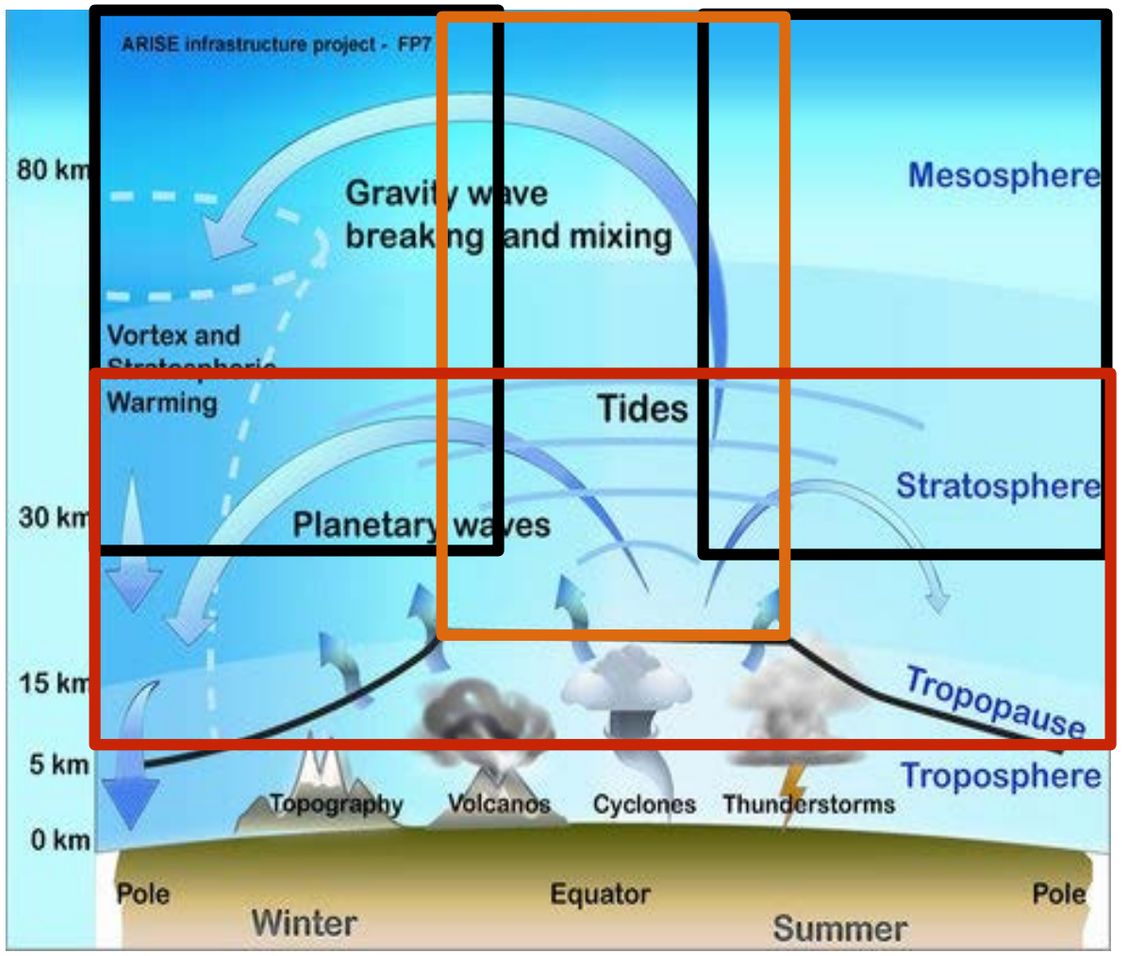
3. Convectively generated GWs:

Uncertain: Efficiency, amplitude conversion



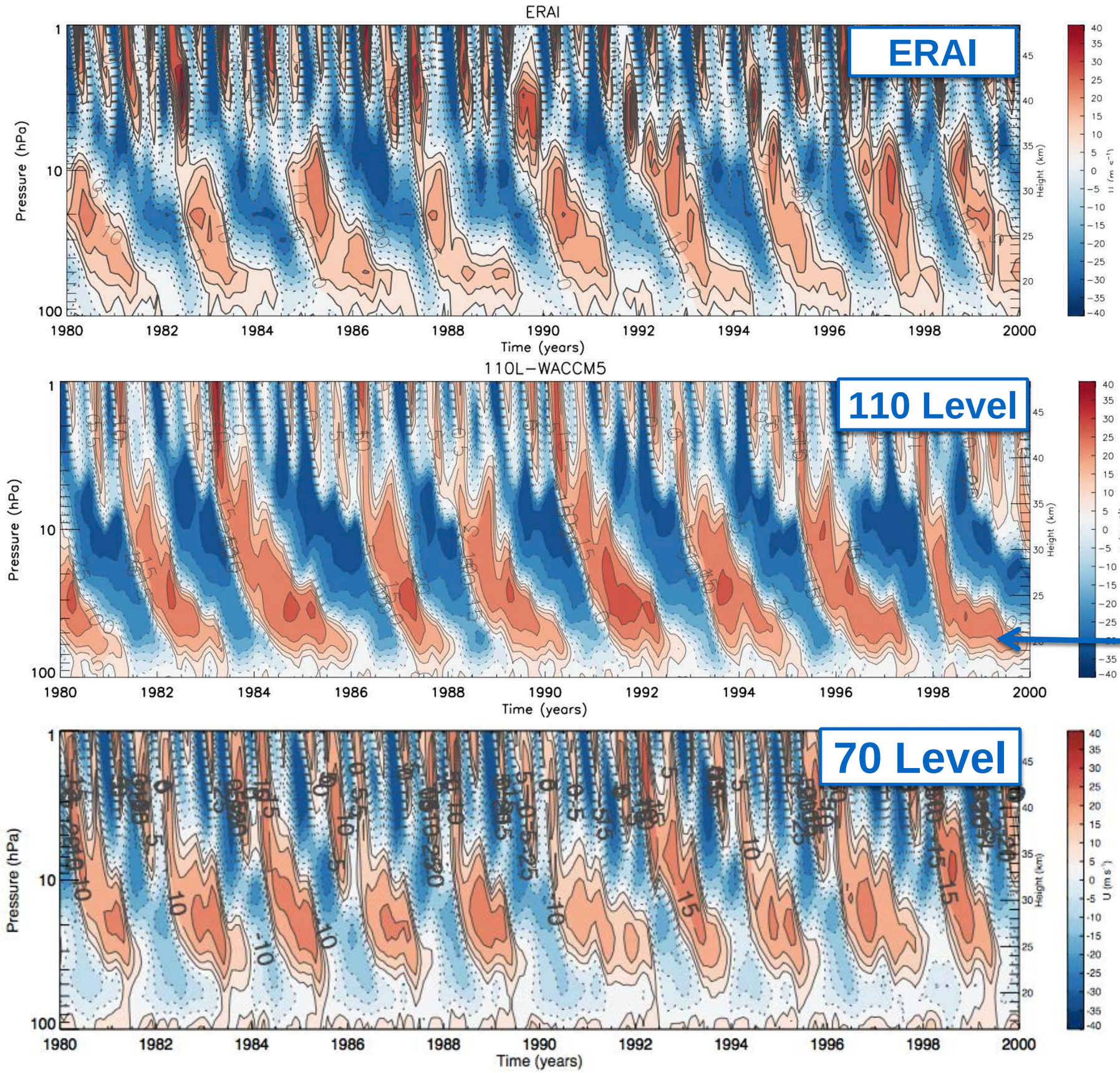
- 40 waves with -100 < c < 100 m/s
- Dominant c related to h (depth of heating)
- Wave Amplitude $\propto$ Q^2
- Wave spectrum impacted by wind in heating

Beres et al. 2004 (Beres = Richter)



Richter et al. 2010

QBO: 70 vs 110L WACCM



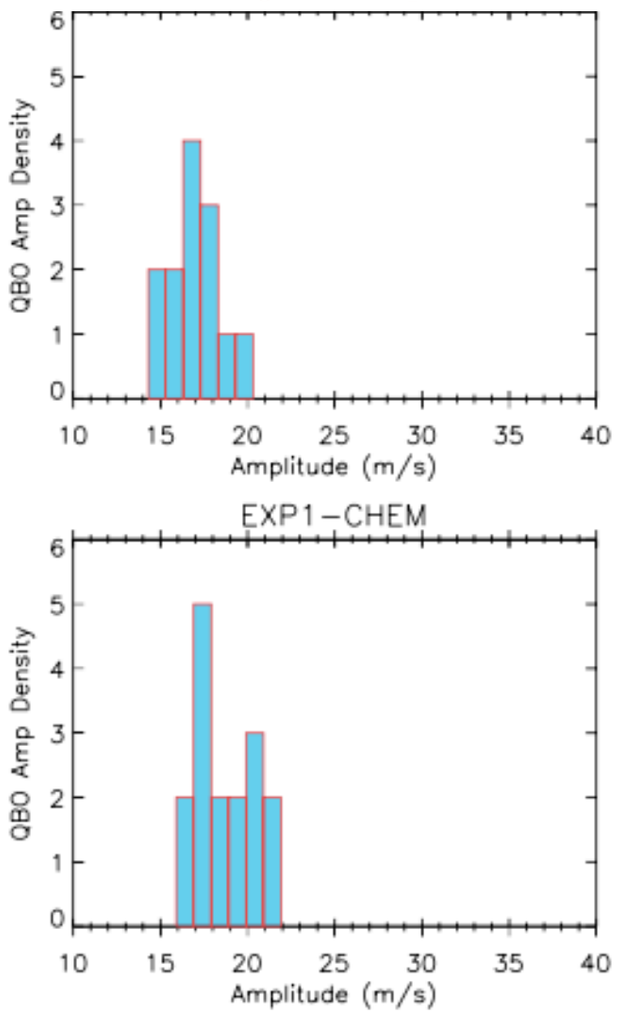
QBO descends to 100 hPa as observed (tropical Kelvin and RG waves are well resolved in the 110L model)

QBO in EXP 1: 110L WACCM @ 20 hPa

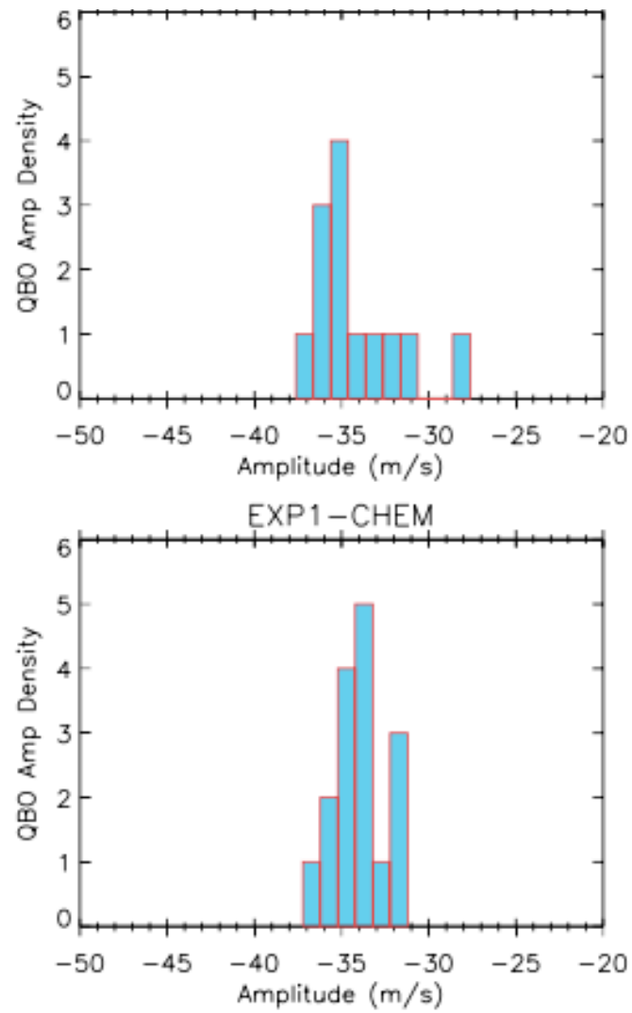
OBS

WACCM

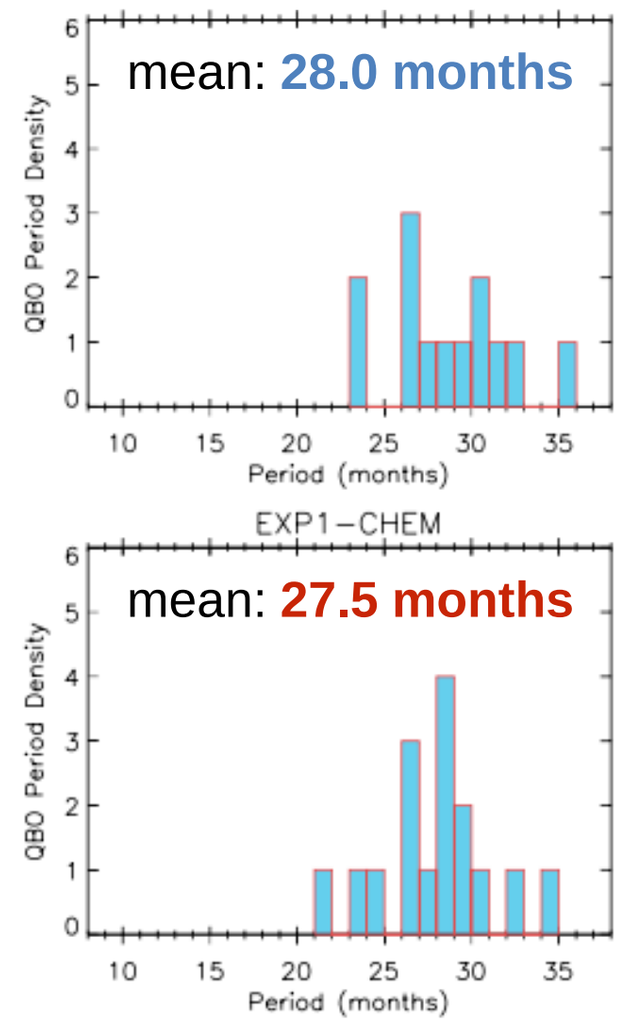
Westerly Amplitude



Easterly Amplitude

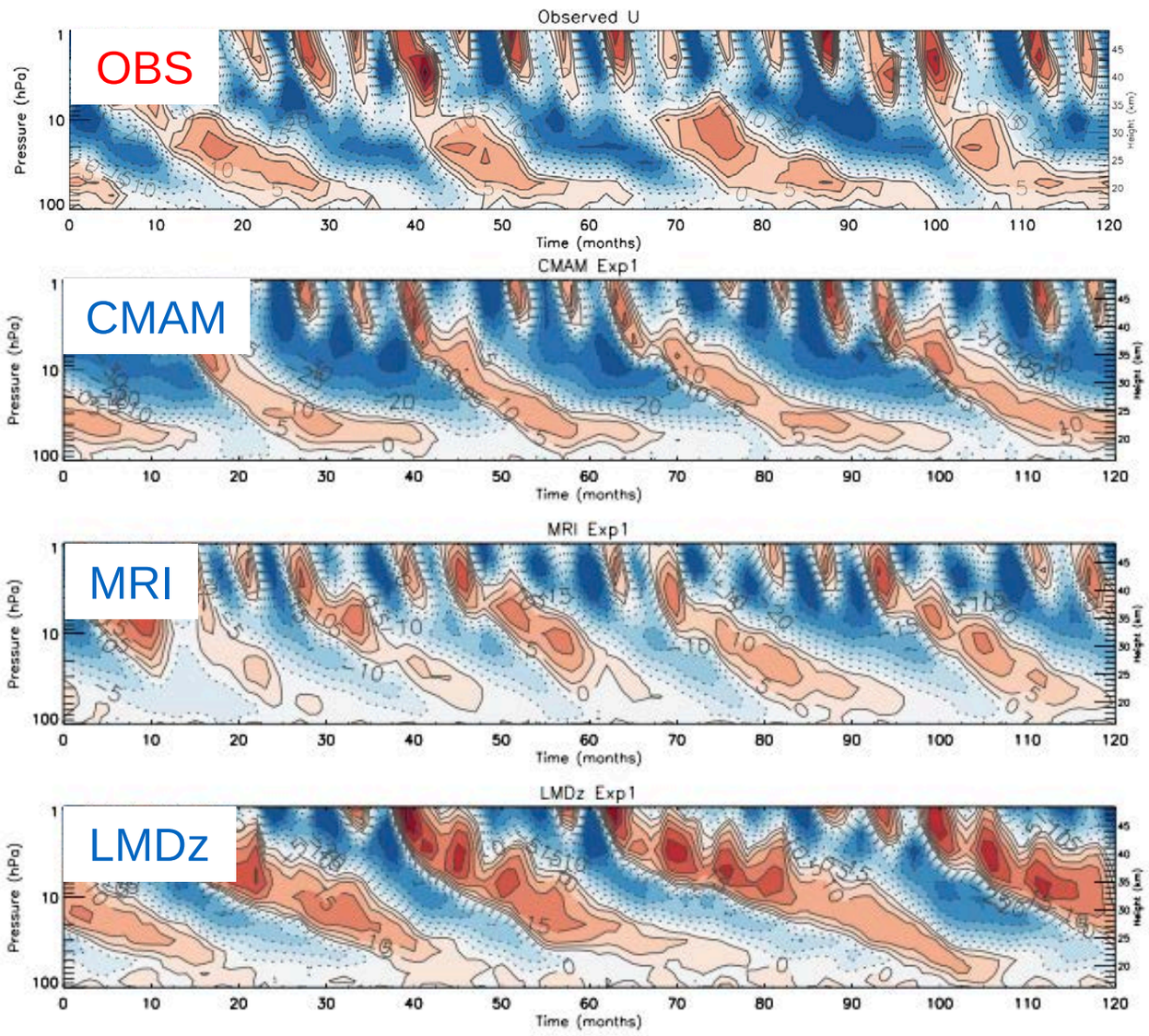


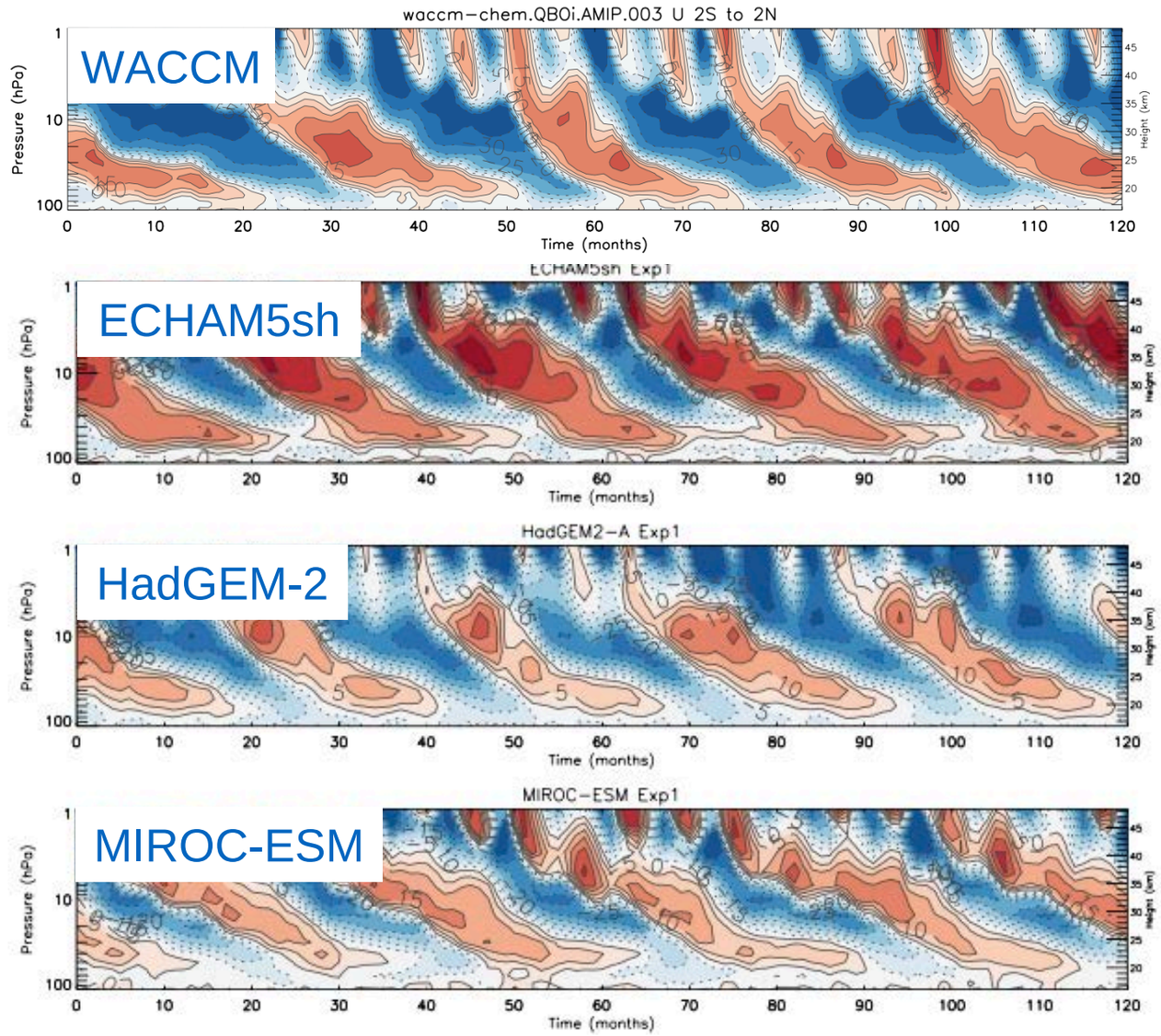
Period



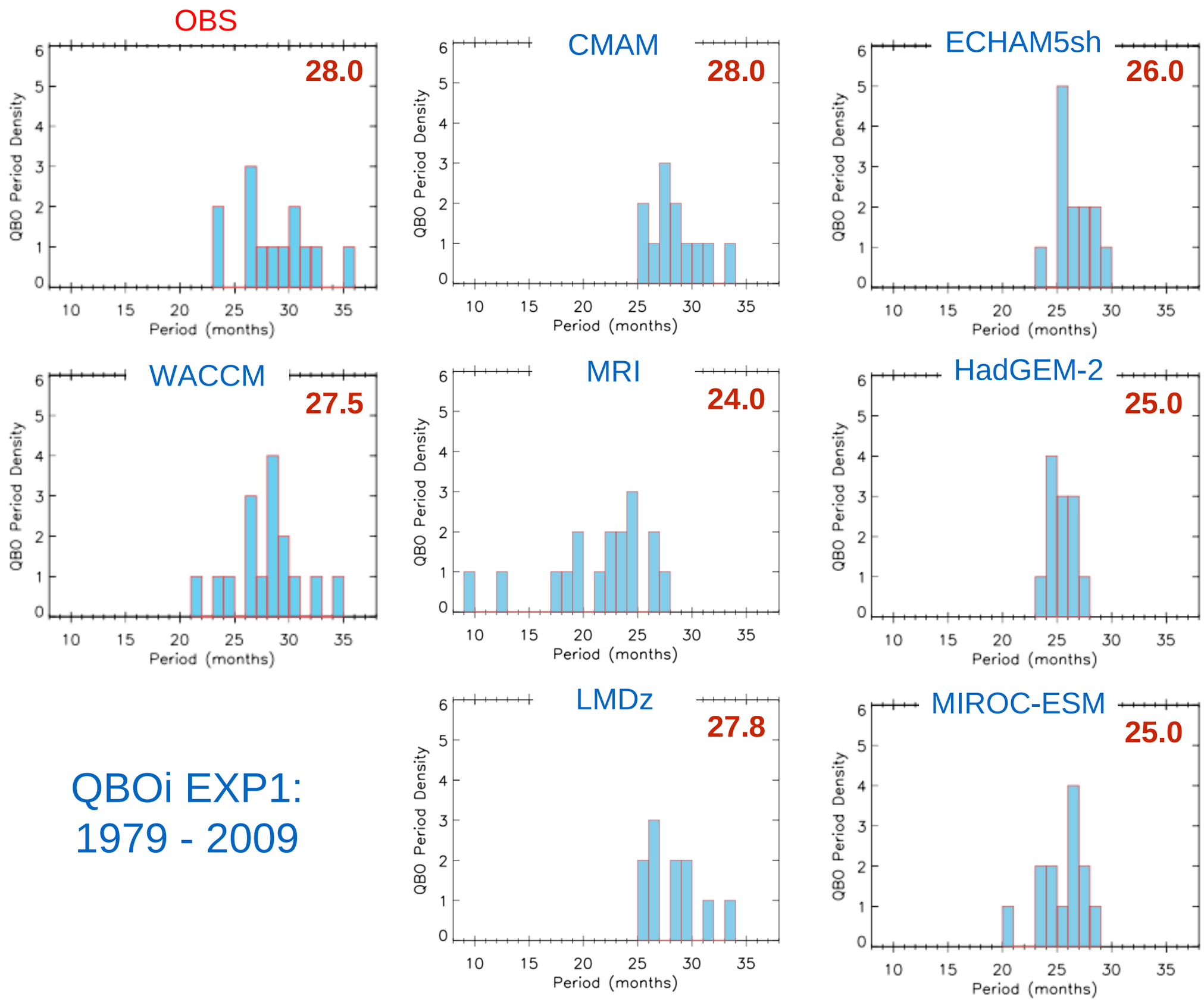
QBO in Exp 1: Other models

QBOi EXP1: 1979 - 2009





QBO in EXP 1: Other models



QBOi EXP1:
1979 - 2009

Previous Studies:

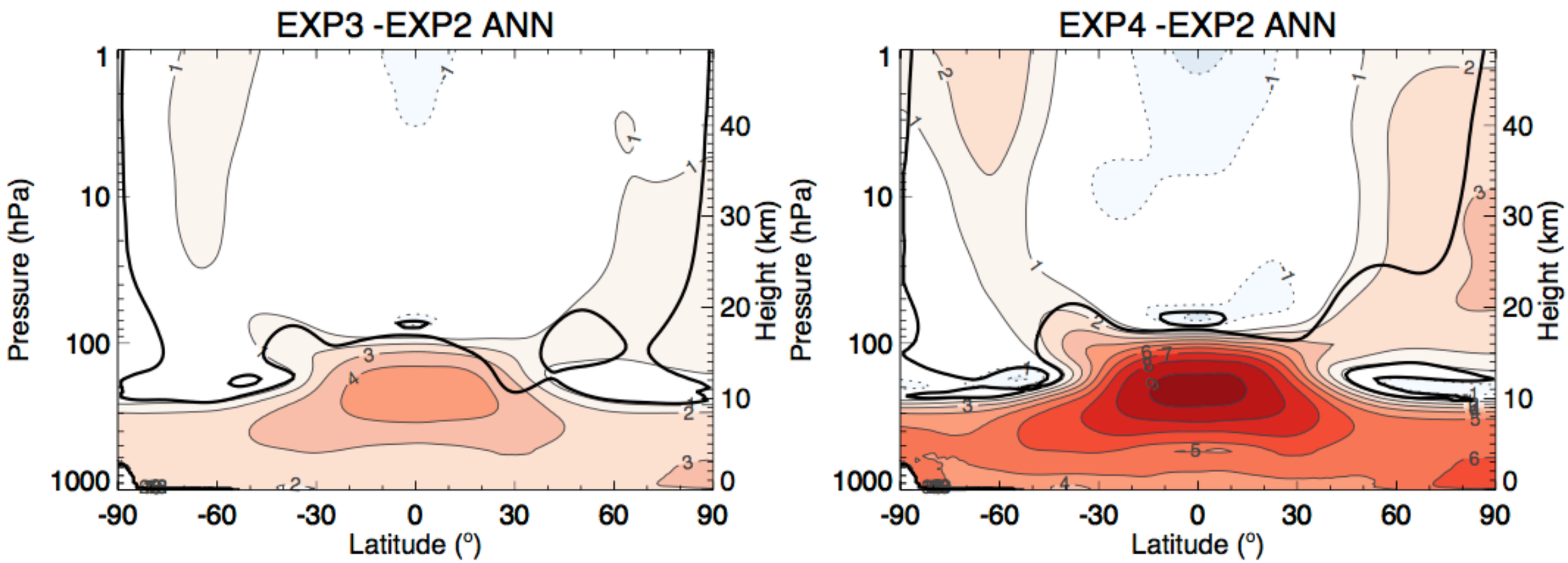
Predictions of QBO in future:

- Giorgetta & Doege (2005): shortened QBO period from 26 to 17 months (2 x CO_2)
- Kawatani et al (2011): lengthened period ~ 3 months (2 x CO_2)
- Watanabe & Kawatani (2012): lengthening ~ 3 months
- Schirber et al. (2015): Inconclusive

Increased Wave Momentum Flux → Shorter QBO period

Increased w* → Longer QBO period

WACCM: EXP 2, 3, 4

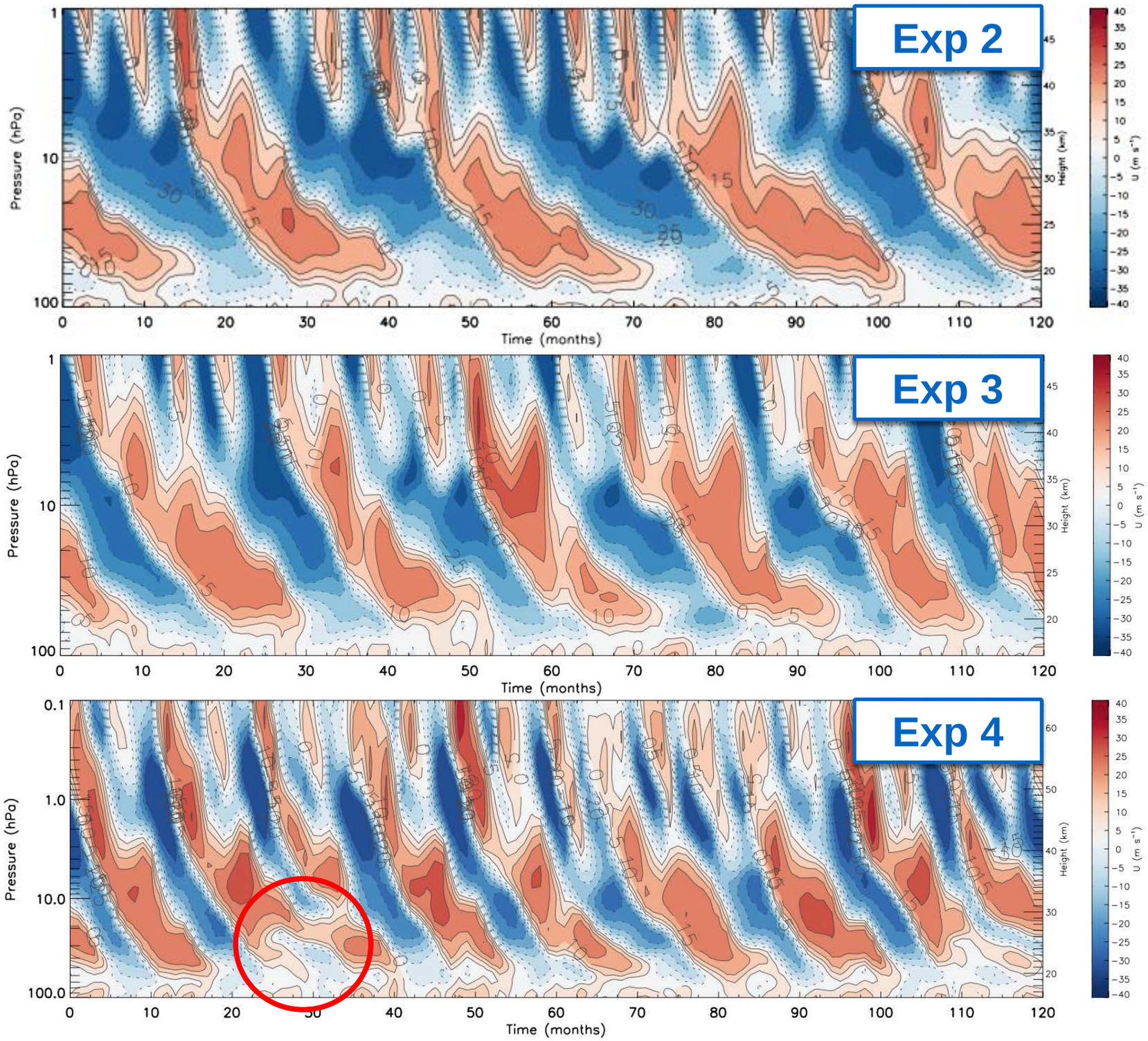


EXP2: annually-repeating SSTs, 1 X CO_2

EXP3: annually-repeating SSTs + 2K, 2 X CO_2

EXP4: annually-repeating SSTs + 4K, 4 X CO_2

WACCM: Exp 2,3, 4



Climo SST, 1 X CO_2

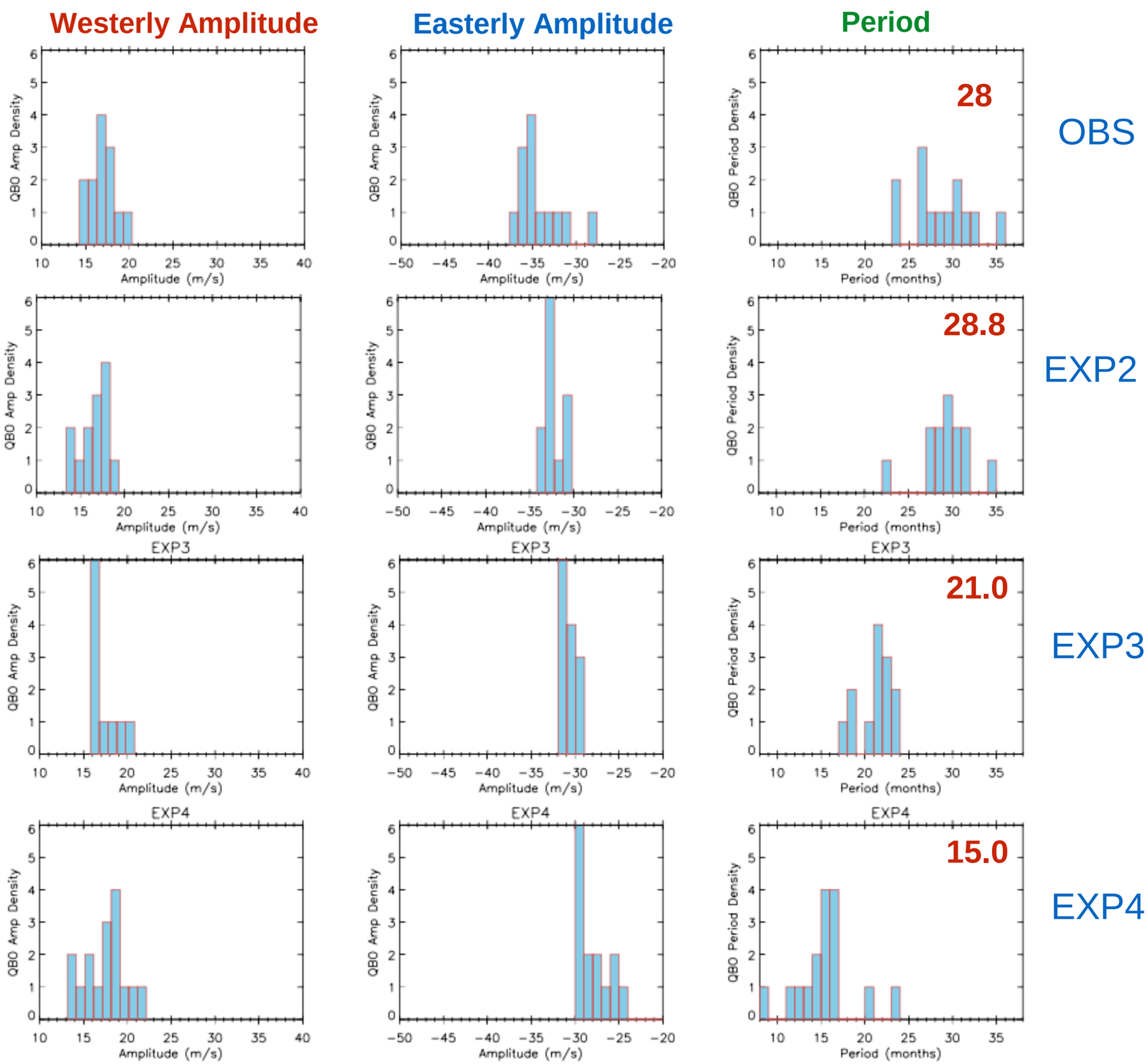
Climo SST+2K, 2 X CO_2

QBO Interruption

Climo SST+4K, 4 X CO_2

Changes due primarily to SSTs. No significant changes due to CO_2.

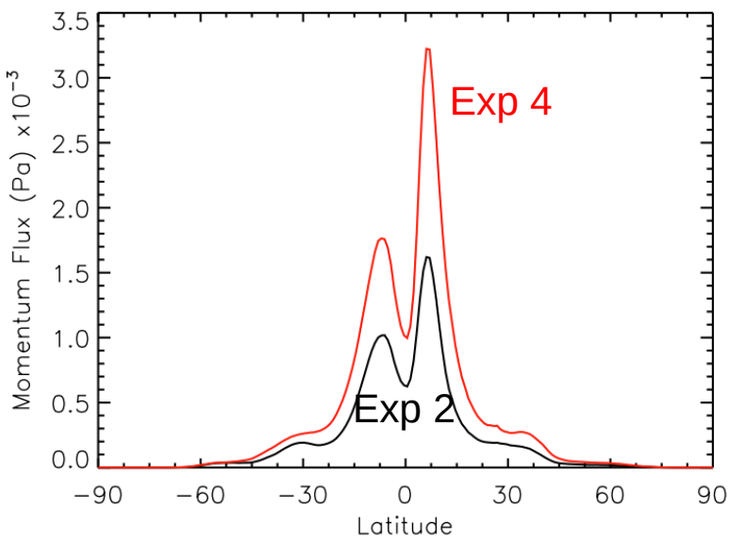
QBO amplitude and period @ 20 hPa: EXP2, 3, 4



In WACCM, QBO period decreases systematically as SSTs increase in EXP3, EXP4

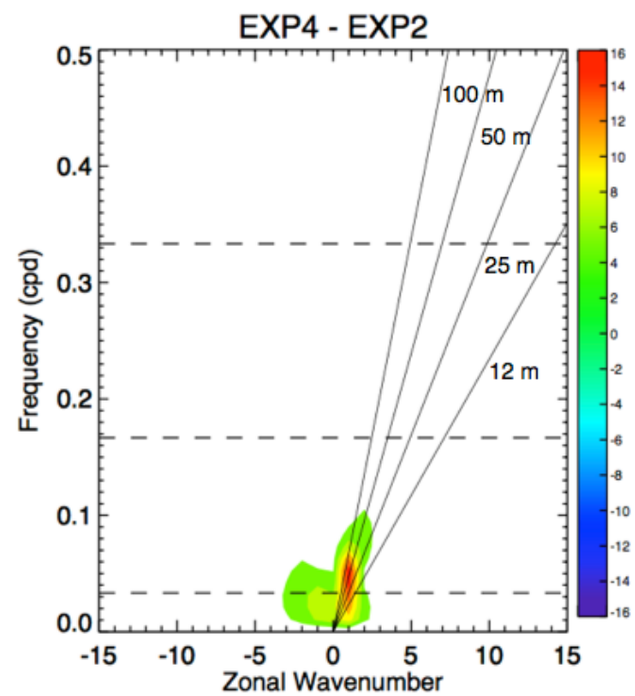
QBO Forcing: EXP2, EXP4

Westward GW Flux EXP 2, 4



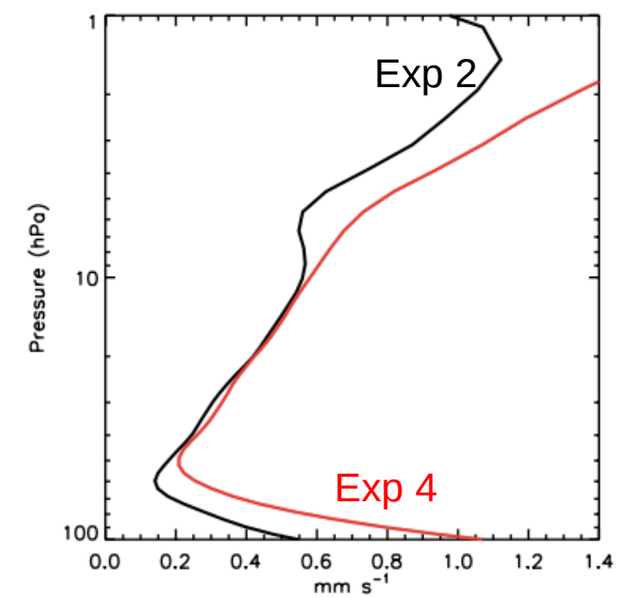
Increased GW Flux->
Shorter QBO period

Resolved waves



Increased Kelvin waves
→ shorter QBO period

Residual w*



Increased w*
→ Longer QBO period

Decrease of QBO period in EXP4 due to increased GW source momentum flux & increased Kelvin wave activity

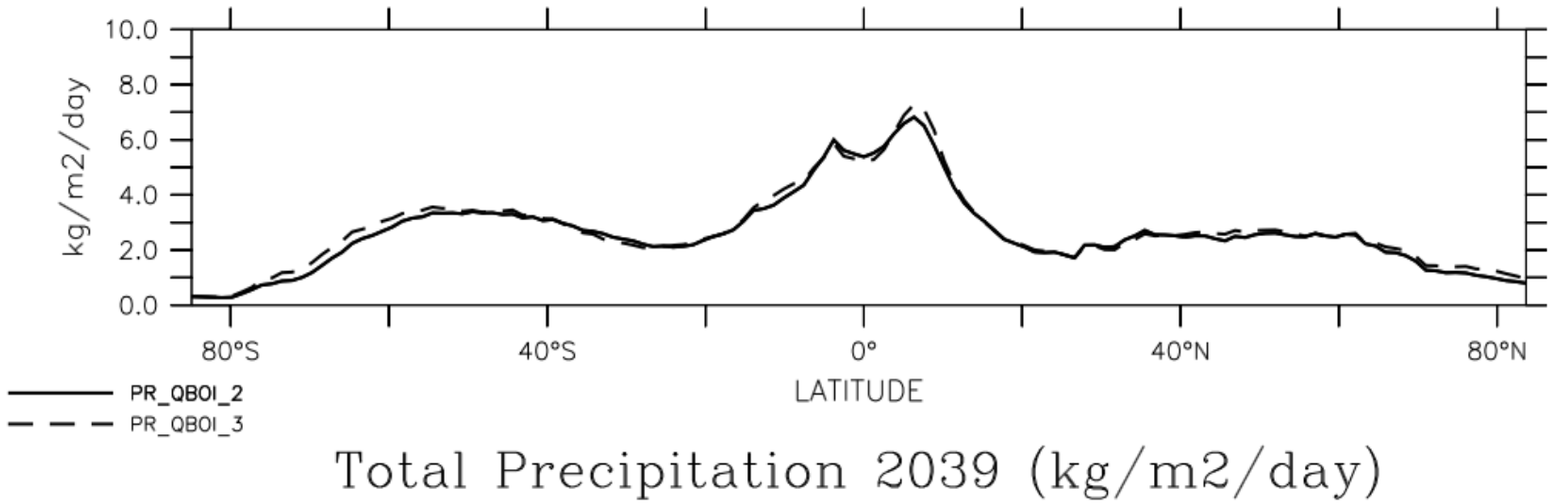
QBO Periods in EXP 2, 3, 4: Other Models

	EXP 2	EXP 3	EXP 4	GW Source
WACCM	28.8	21	15	Interactive Beres et al. 2004
CMAM	29	40	N/A	Fixed (McFarlane)
MRI	24	24+	24+	Fixed (Hines)
LMDz	28	30	100	Interactive Lott and Guez (2013)
ECHAM5sh	27	27	N/A	Fixed (Hines)
MIROC-ESM	24	26	33	Fixed (Hines)
MIROC-AGCM	19.5	20.5	23	None

Preliminary results from QBOi Paper 2 (in preparation):
Robustness of QBO's response to climate forcing: EXP2, EXP3, EXP4
Co-leads: *Yaga Richter, Neal Butchart*

LMDz Convective GW flux:

- Stochastic parameterization: frequency & wave numbers chosen randomly
- Wave amplitude is related to **precipitation**, which is converted into heating rate
- Distribute latent heat in Gaussian similarly to Beres et al. 2004 (chose ‘dz’)



Precip EXP2 ~ Precip EXP4

GW Flux EXP2 ~ GW Flux EXP4

Negligible changes in GW source momentum flux because changes in precipitation are very small

QBO in warming climate: Uncertainties

There are large uncertainties as to how the QBO will change in the future climate

- How accurate are convective parameterizations in future climates?
- Will relationships between convective heating and GWs hold in future climate?
- How will the resolved waves change?
- How will the residual circulation change?

Thank you!

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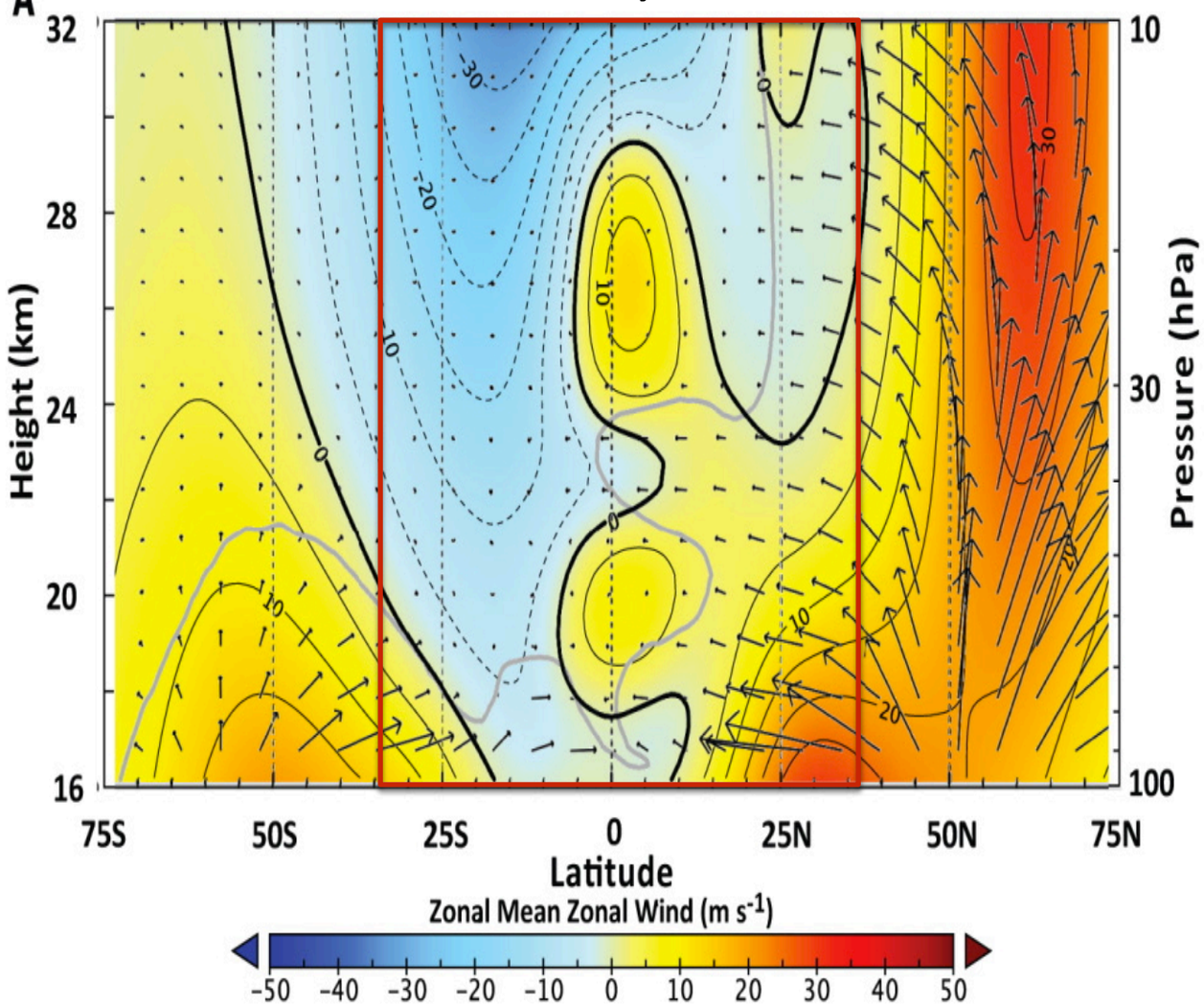
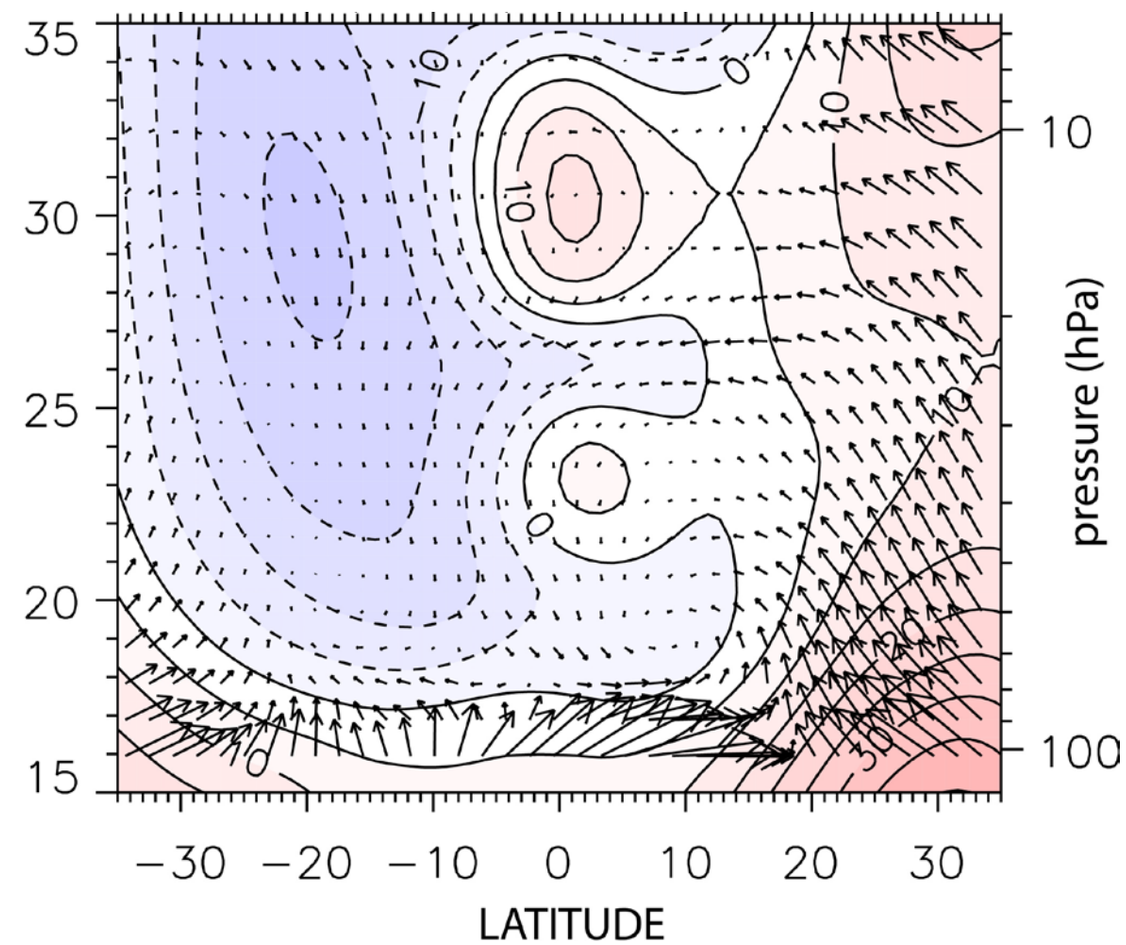
QBO interruption in EXP4

February 2016



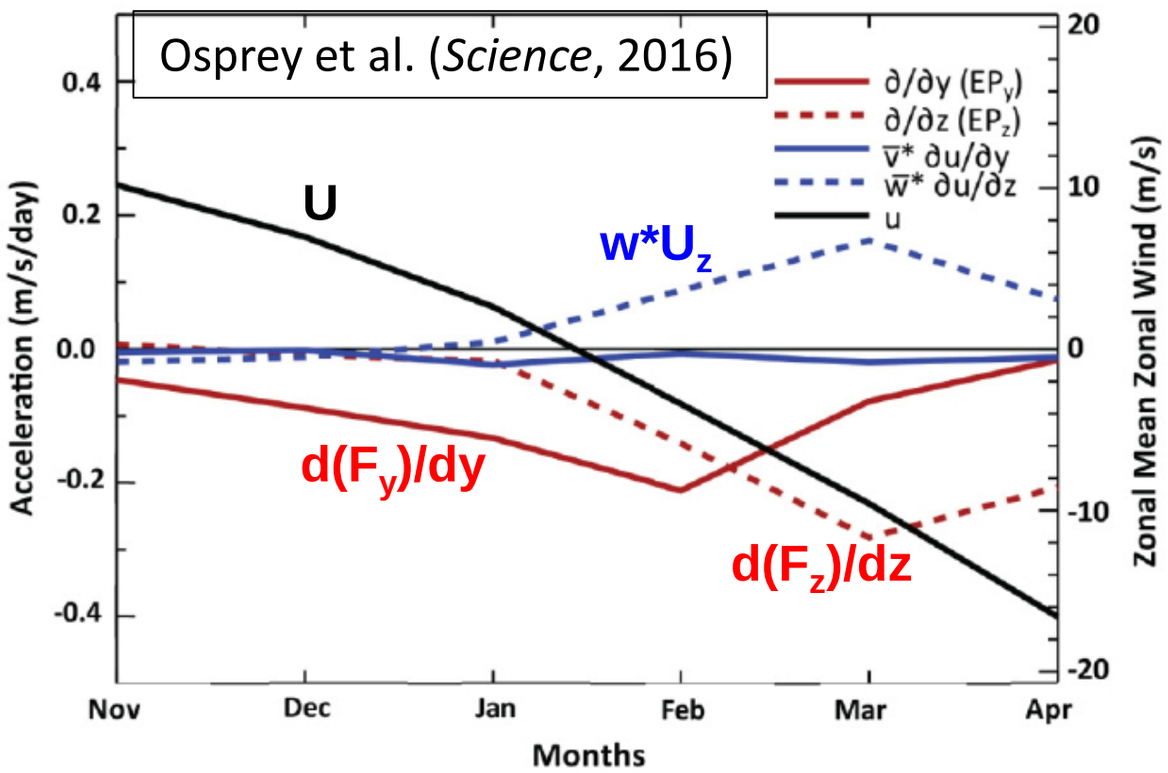
from Osprey et al. (*Science*, 2016)

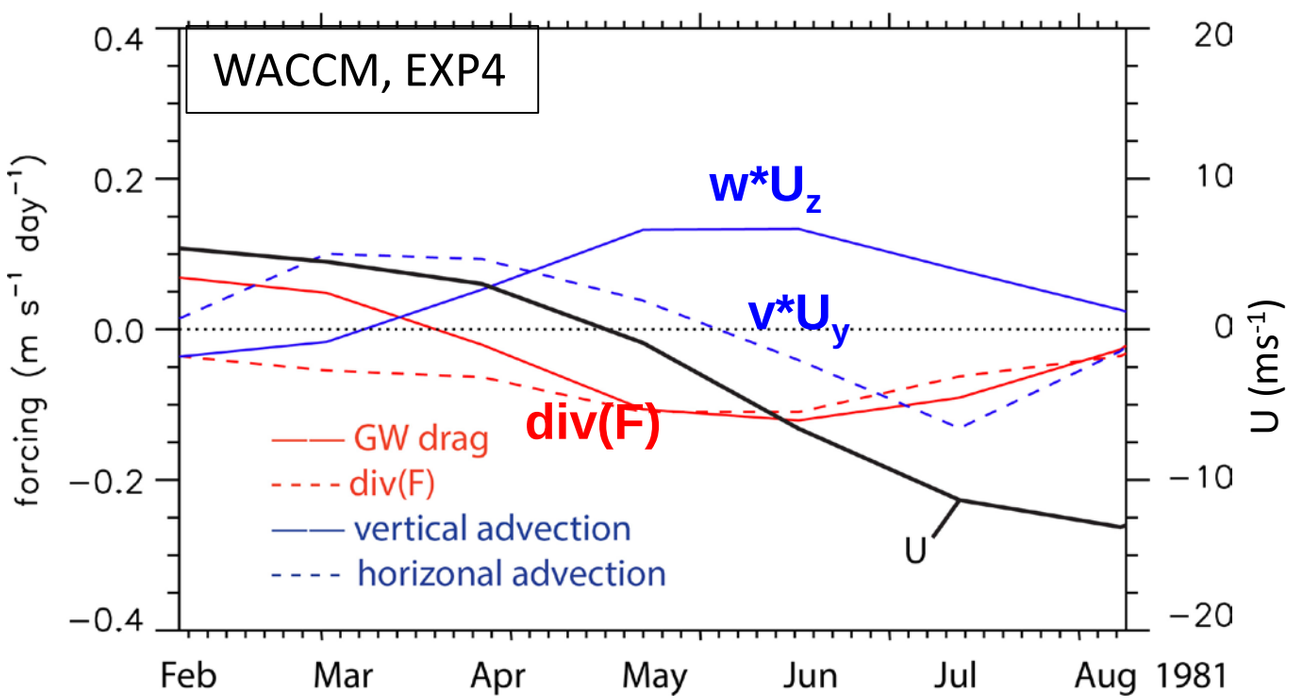
WACCM: March 1981, EXP4



- QBO morphology similar in EXP4 (3/1981) and observations (2/2016)
- Easterly EP Flux Divergence plays a role in both

TEM momentum budget at 40 hPa





- Overall behavior and magnitudes similar in WACCM and observations
- in WACCM:
  - horizontal mean advection is not negligible
  - GW drag and div(F) have comparable magnitude
- Otherwise, U, vertical advection and div(F) have comparable magnitudes in WACCM and observations