The semi-annual oscillation in WACCM and other models participating in QBOi

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framework

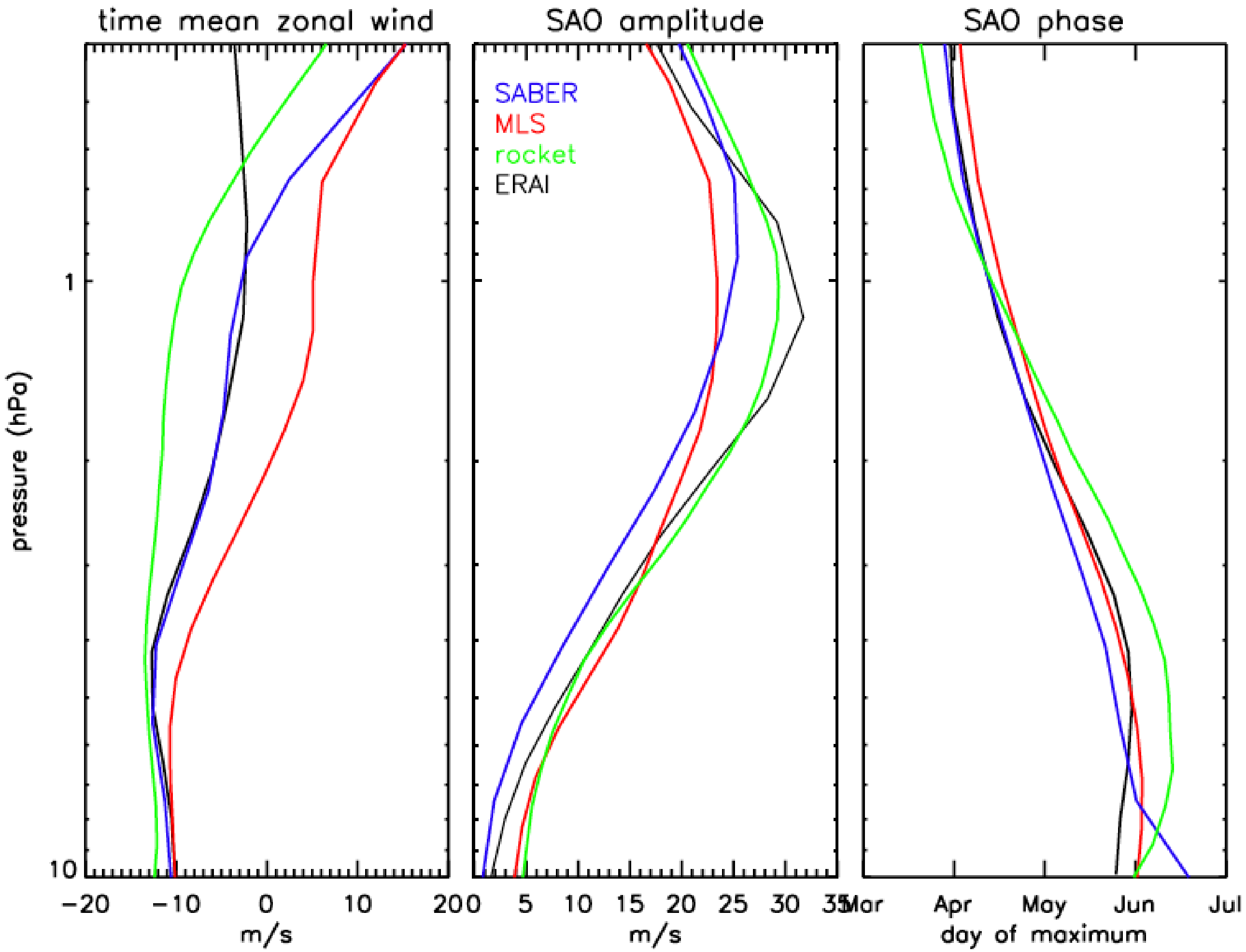
- QBOi: Quasi-Biennial Oscillation initiative
- Goal is an intercomparison of the QBO in global models that simulate a self-generated QBO
- Includes WACCM and CAM (special versions with higher vertical resolution up to the middle stratosphere).
- Most of the models have upper boundaries in or above the mesosphere.
- How well do they simulate the semi-annual oscillation (SAO)?

limitations on evaluating the SAO

- model output has been interpolated to a common grid; highest level 0.4 hPa (~55 km)
- Not all model groups supplied diagnostic products such as EP flux divergence, parameterized gravity wave drag, etc.
- Observations for validation of the SAO and the processes that drive it are scarce.

SAO

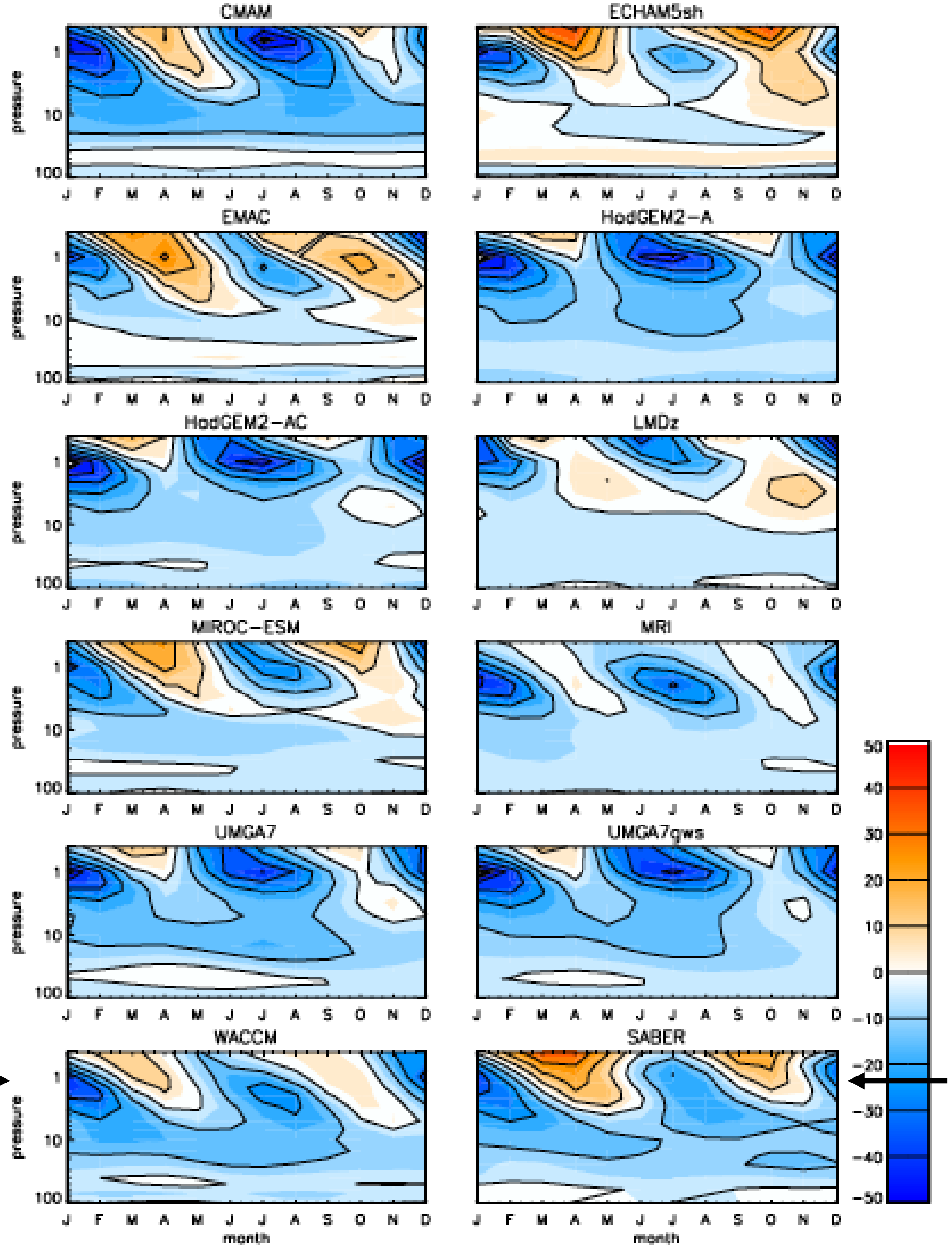
- variation of equatorial zonal mean wind extending from upper stratosphere to upper mesosphere
- poorly constrained by observations and reanalyses
- traditionally divided into stratopause SAO (focus of current analysis) and mesopause SAO



SABER: wind derived from geopotential (2002-2016)
MLS: wind derived from geopotential (2004-2016)
rocket: tropical measurements from 1960s and 1970s
ERAi: reanalysis

Seasonal wind in QBOi models (30-year average)

10 other models or model versions



WACCM

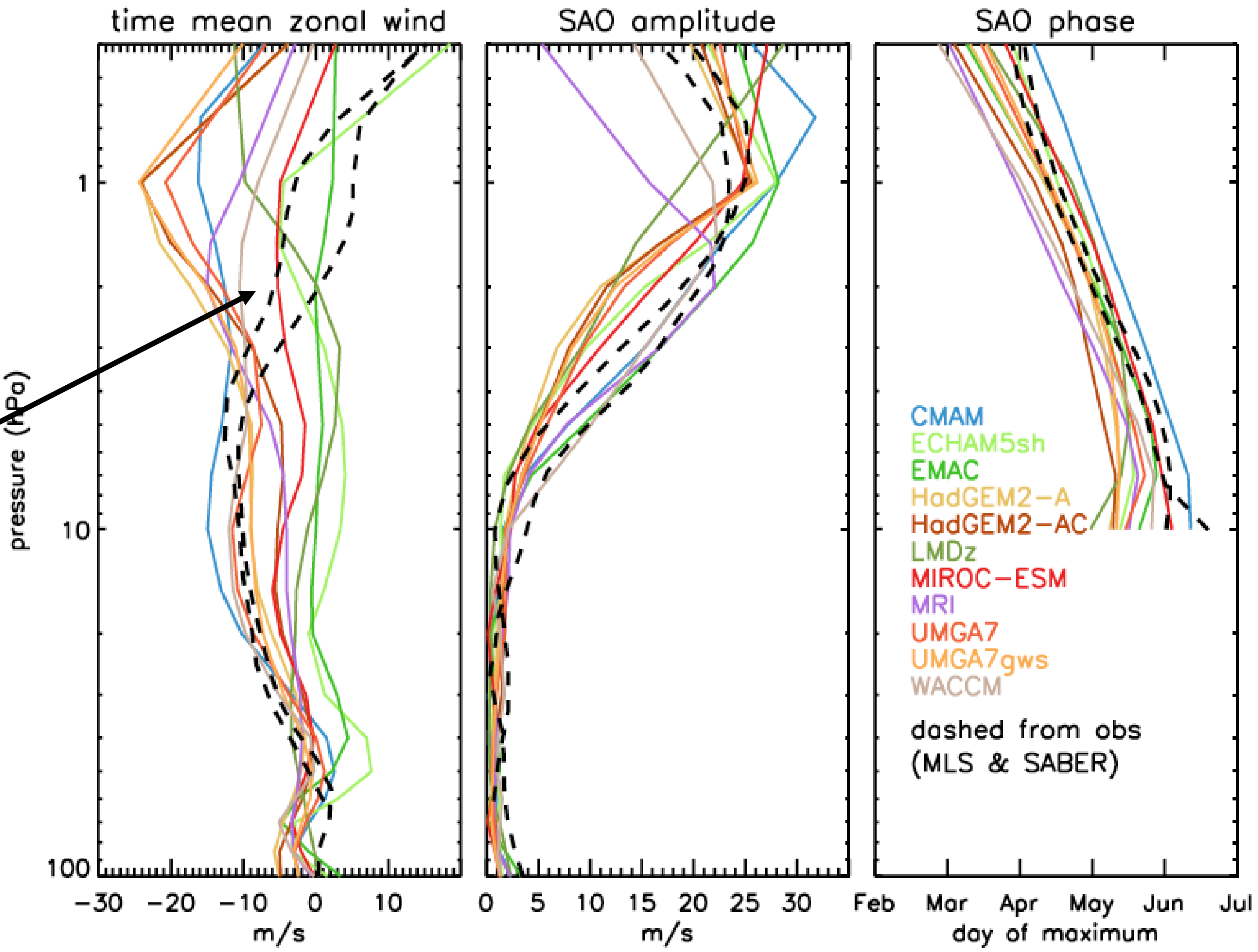
obs

All models simulate an SAO. At the stratopause, there are easterly winds at solstices, westerly (or weaker easterly) winds at equinoxes.

SAO and time-mean wind

Models do a better job with the SAO than with the time-mean wind.

Particularly, the westerly shear in the upper stratosphere is lacking.



processes driving the SAO in transformed mean

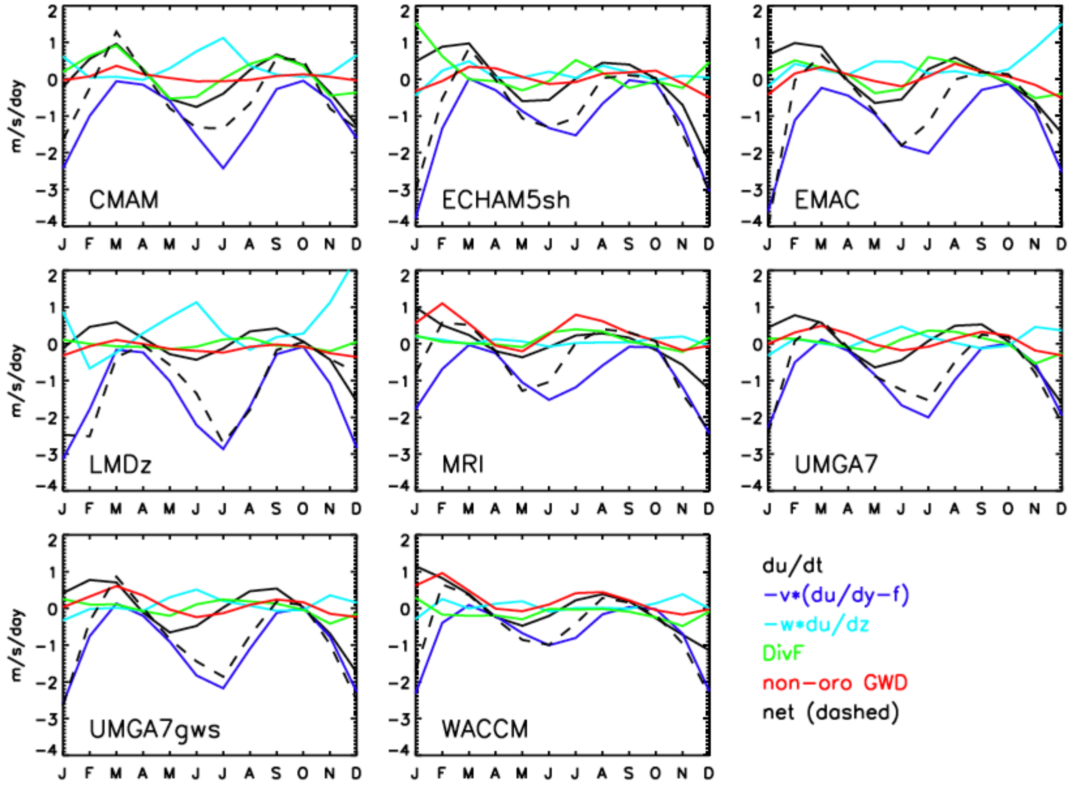
$$\frac{\partial \bar{u}}{\partial t} = \underbrace{-\bar{v}^*\left[\frac{1}{a\cos\varphi}\frac{\partial \bar{u}\cos\varphi}{\partial \varphi} - f\right] - \bar{w}^*\frac{\partial \bar{u}}{\partial z}}_{\text{advection by BDC}} + \underbrace{\frac{1}{\rho_0 a\cos\varphi}\nabla\cdot \mathrm{F}}_{\text{resolved waves}} + \bar{X}$$

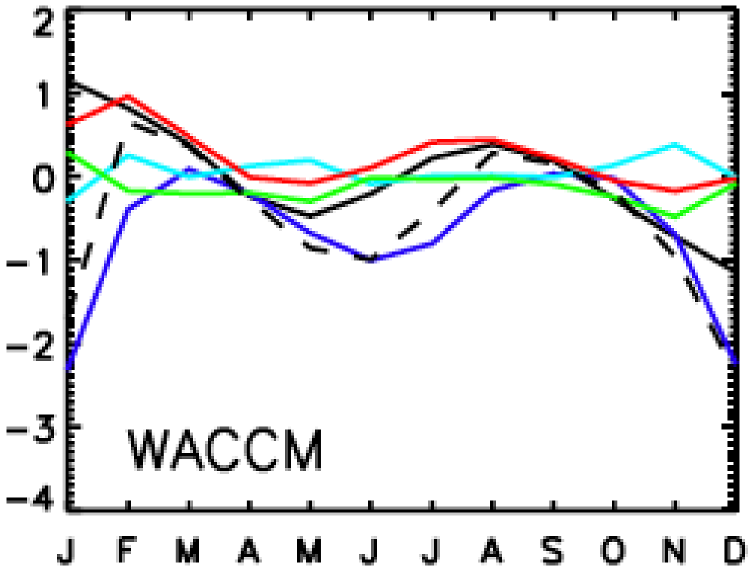
advection by BDC

resolved waves

parameterized waves

seasonal variation at 1 hPa





SAO timing controlled by BDC advection.

Net forcing by resolved waves is weak.
GW forcing is stronger but still weaker than BDC.

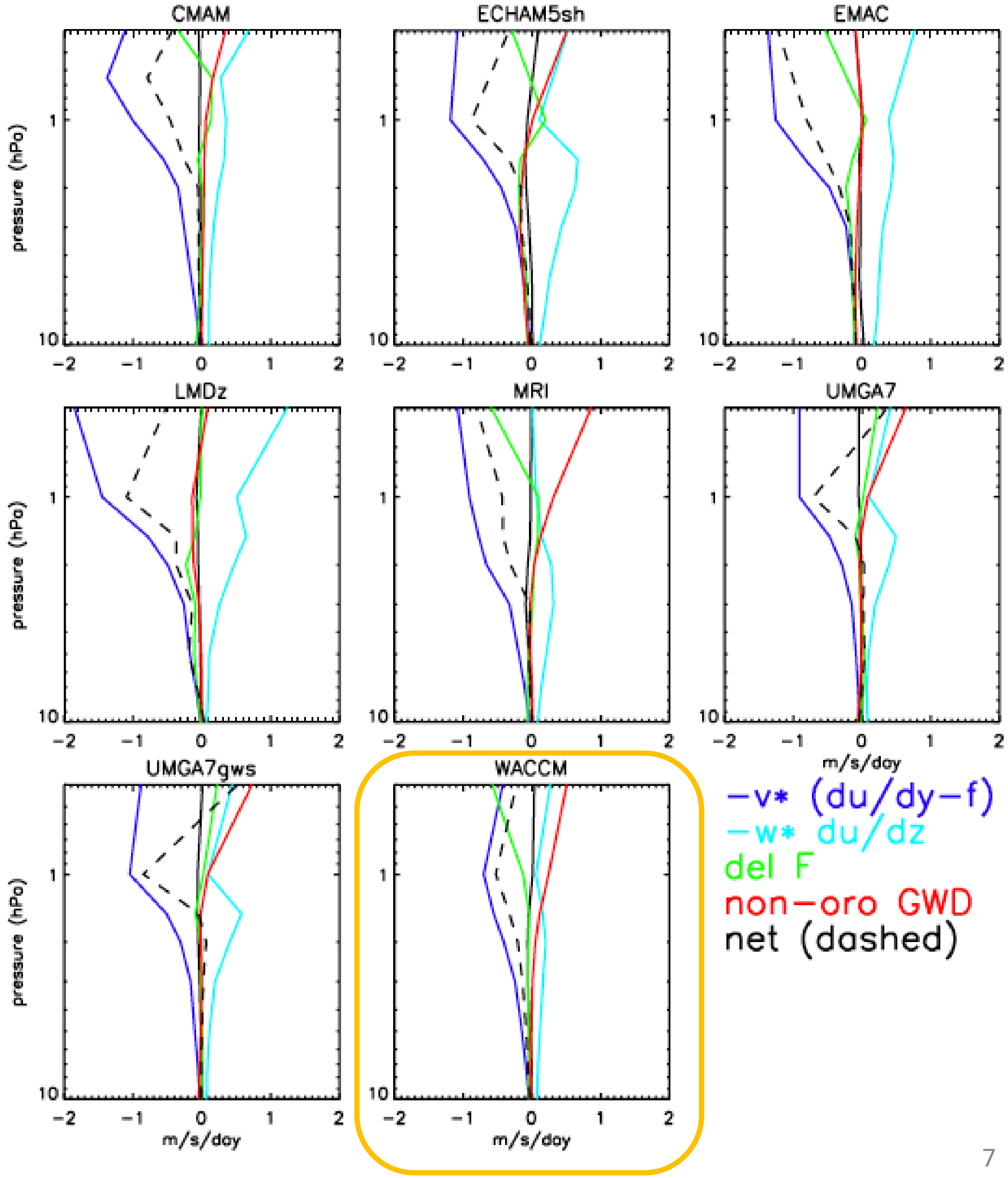
time mean forcing

imbalance due to:

- missing forcing (diffusion)?
- approximation due to interpolation to QBOi vertical grid?
- use of monthly mean for calculating BDC terms?

All models, including WACCM, have weak wave forcing. In WACCM, net EP flux divergence is negative.

Where is the forcing by fast Kelvin waves?

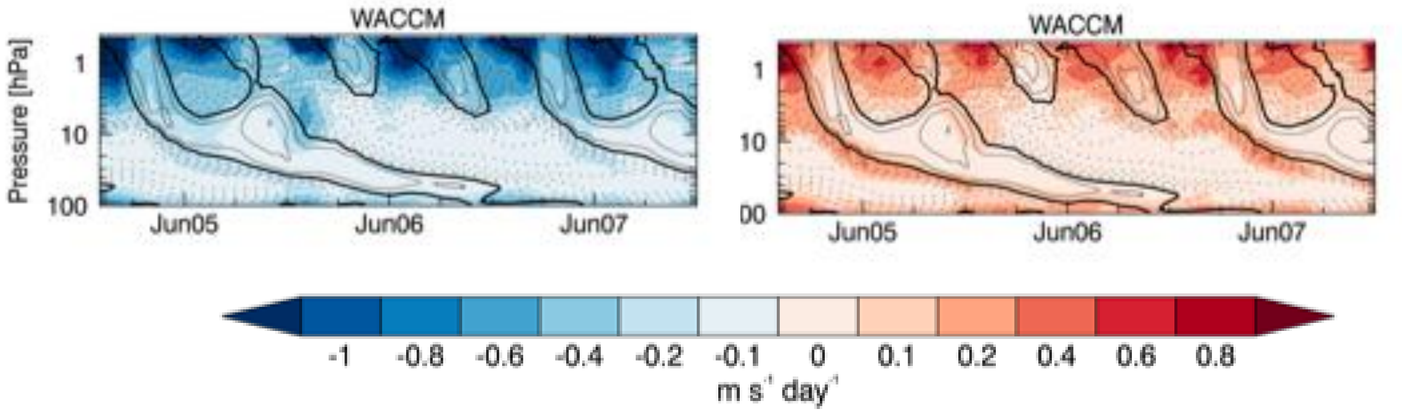


next step….

- Laura looked at wave forcing in the QBOi models using output at every 6 hrs.
- Rolando looked in detail at the wave forcing in the full WACCM output (i.e., daily; not interpolated to standard QBOi levels).

westward waves

eastward waves



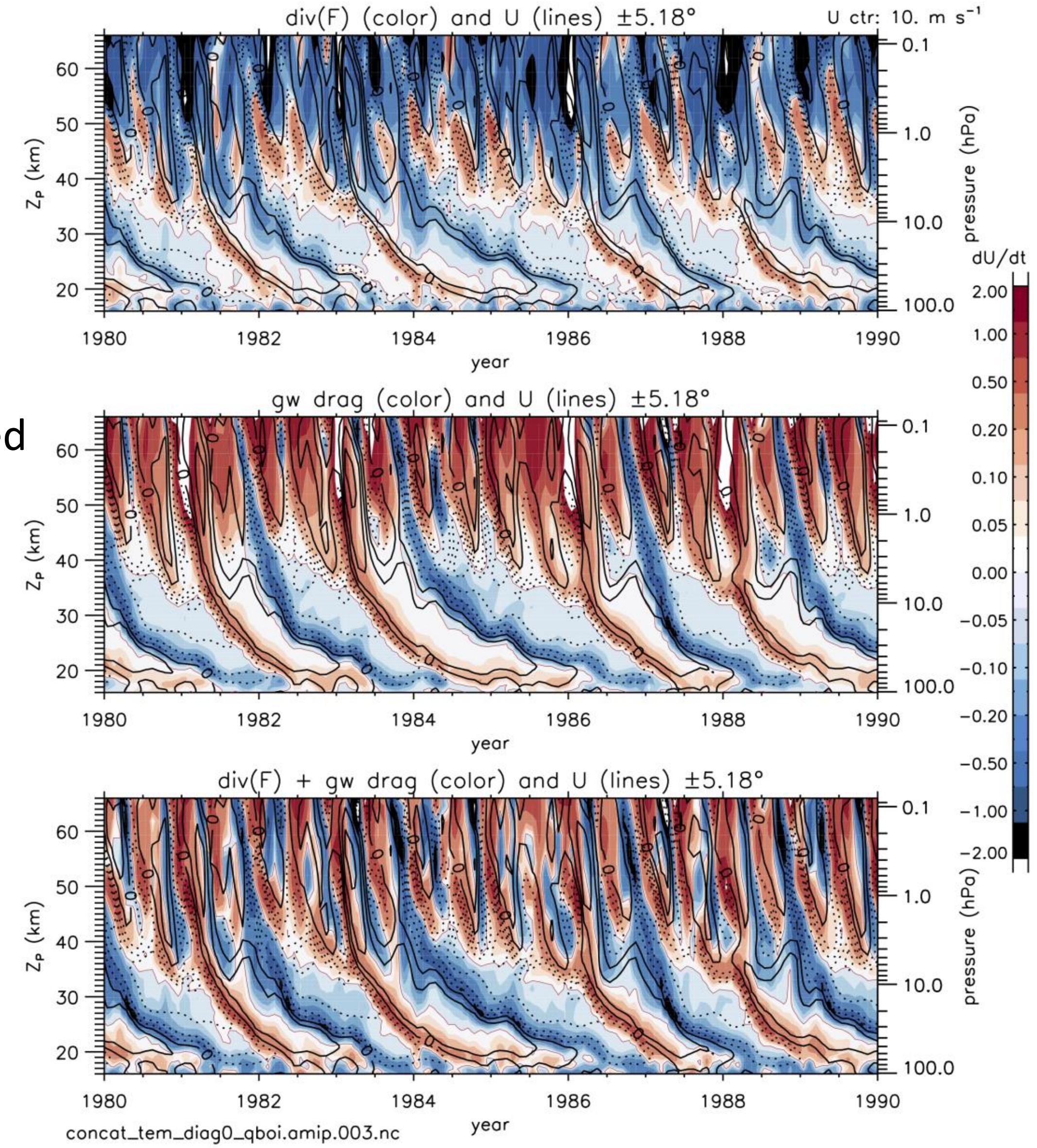
There is a high degree of cancellation since the westward & eastward waves deposit momentum at same locations and times.

WACCM wave forcing at the Equator (±5° average)

resolved waves

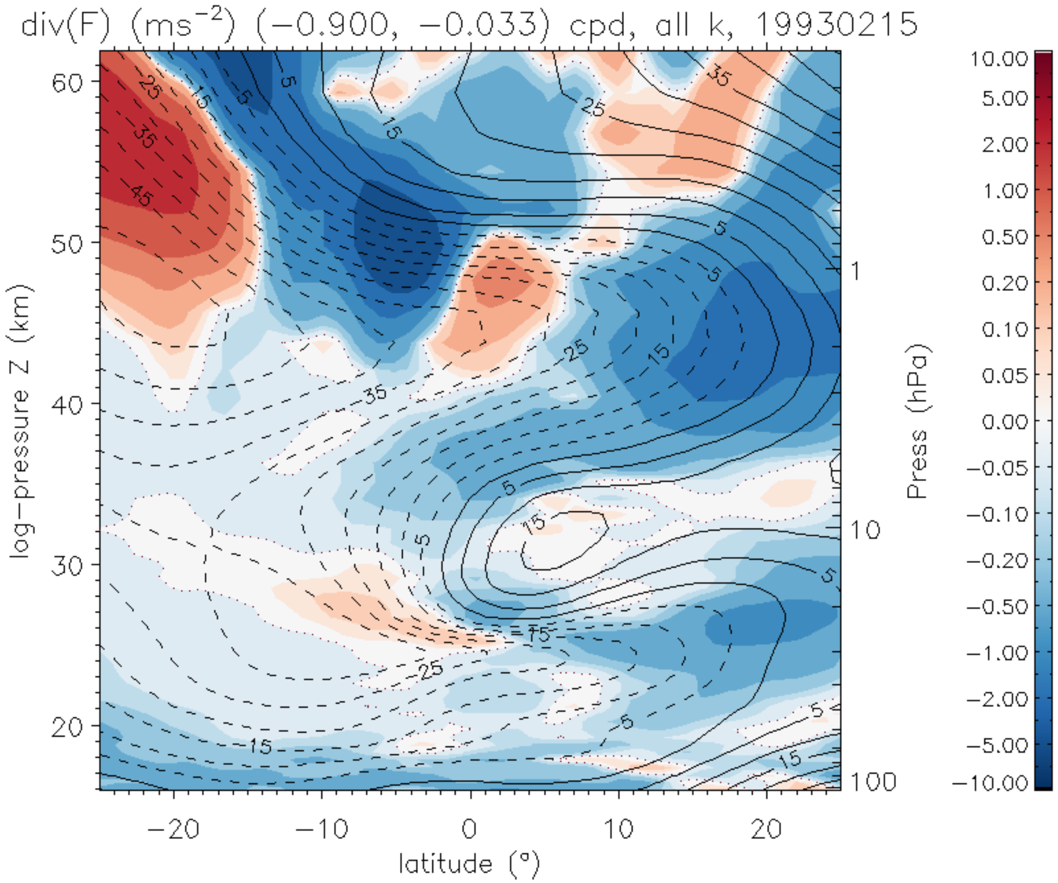
parameterized gravity waves

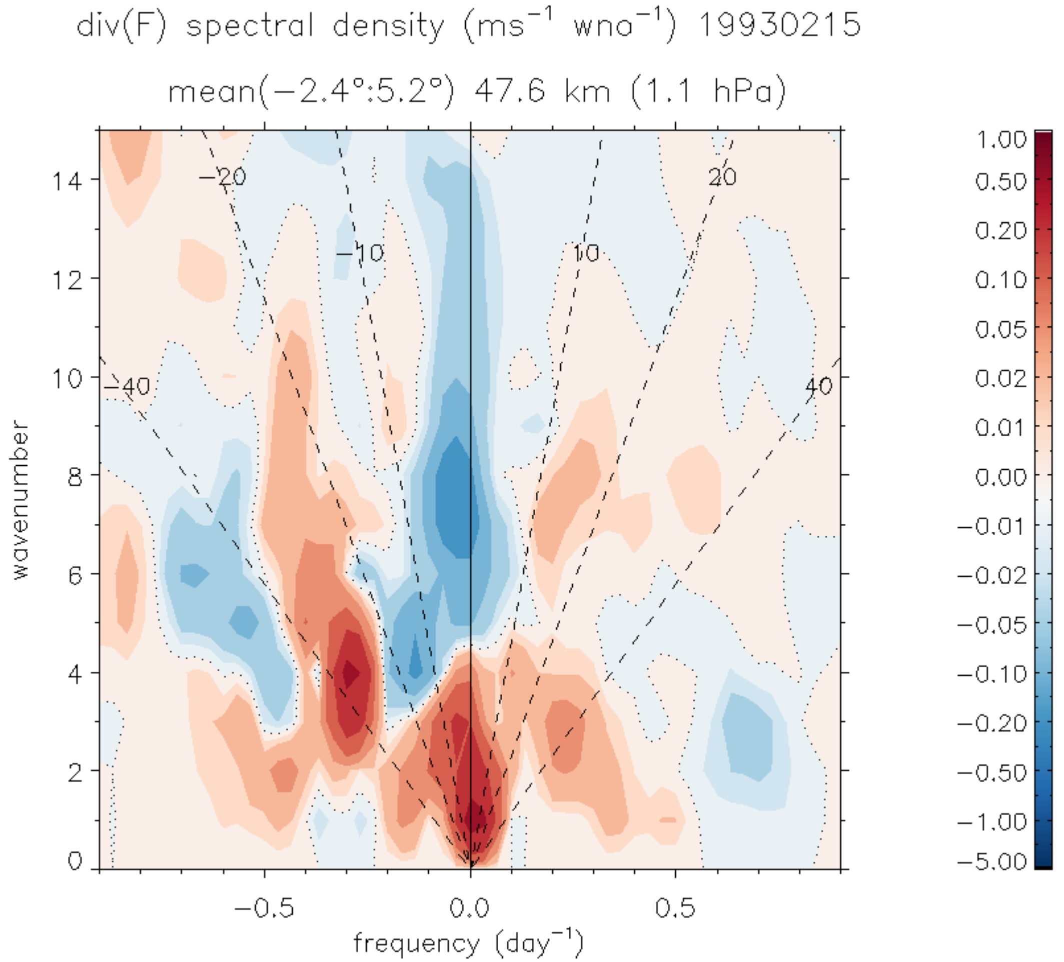
sum



- most of the eastward acceleration in the SAO region is due to GW
- above 50 km, div(F) is mainly negative
- this suggests Kelvin waves are not doing much of anything to produce the W phase of the stratopause SAO in WACCM

SAO in February 1993, WACCM-chem run

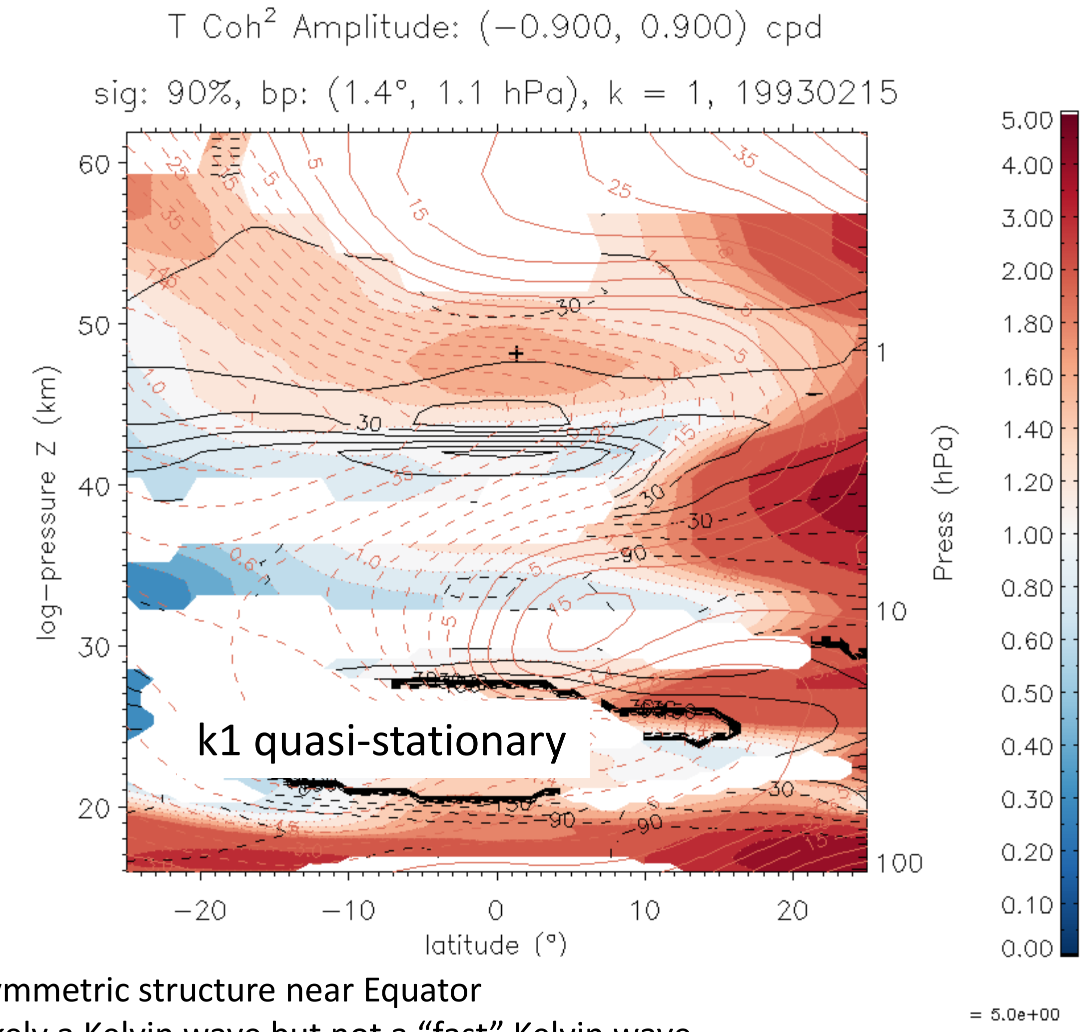


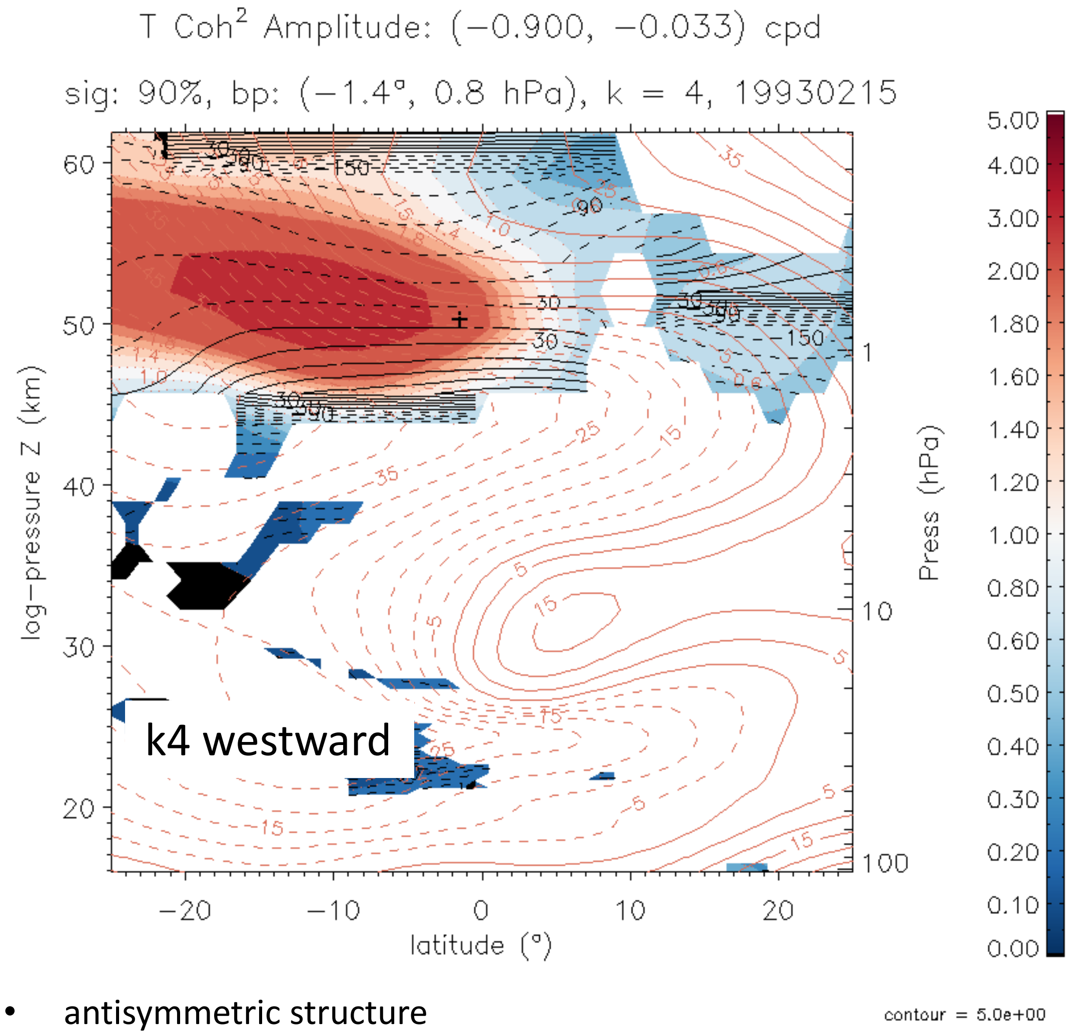


- the only near-equatorial div(F) > 0 occurs in the region of easterly wind
- this appears to be part of a broader +/-/+ acceleration pattern, centered just S of Equator
- region of positive div(F) is centered just N of Equator

- positive div(F) just N of the Equator is due mainly by quasi-stationary k=1 and 3-day westward k = 4

T' wave structures (U contours superimposed)





- symmetric structure near Equator
- likely a Kelvin wave but not a “fast” Kelvin wave
- subtropical structure looks like Rossby wave (likely unrelated to equatorial forcing)

- antisymmetric structure
- Rossby-gravity wave? not coherent with anything at lower altitude
- in situ generation?

Status

- This version of WACCM successfully simulates a good QBO. Unfortunately, the standard WACCM6 has lower vertical resolution and, as a result, the QBO has shortcomings, particularly at its lowest extension just above the tropical tropopause.
- The easterly phase of the stratopause SAO is driven by the Brewer-Dobson circulation (well-simulated).
- The westerly phase of the stratopause SAO in WACCM is driven by parameterized GW.
- Kelvin waves do not contribute much in the way of forcing to the SAO or the time-mean wind. Their contribution is weak compared to GW and even to other waves of uncertain origin.

Where do we go from here?

- MISSING: bservational evidence about which waves are actually driving the eastward acceleration or the time-mean westerly winds and shear.
- Would improved vertical resolution in the upper stratosphere change the representation of resolved waves and/or their dissipation?
- Are fast Kelvin waves not forced efficiently in the troposphere in WACCM? This lack might be a result of the Zhang-McFarlane deep convection parameterization (cf. Ricciardulli and Garcia, 1999), which has short-term variability that is unrealistically low.
- Can the gravity wave parameterization be “tuned” to provide the missing eastward forcing?