The QBO in 110L WACCM: the importance of vertical resolution

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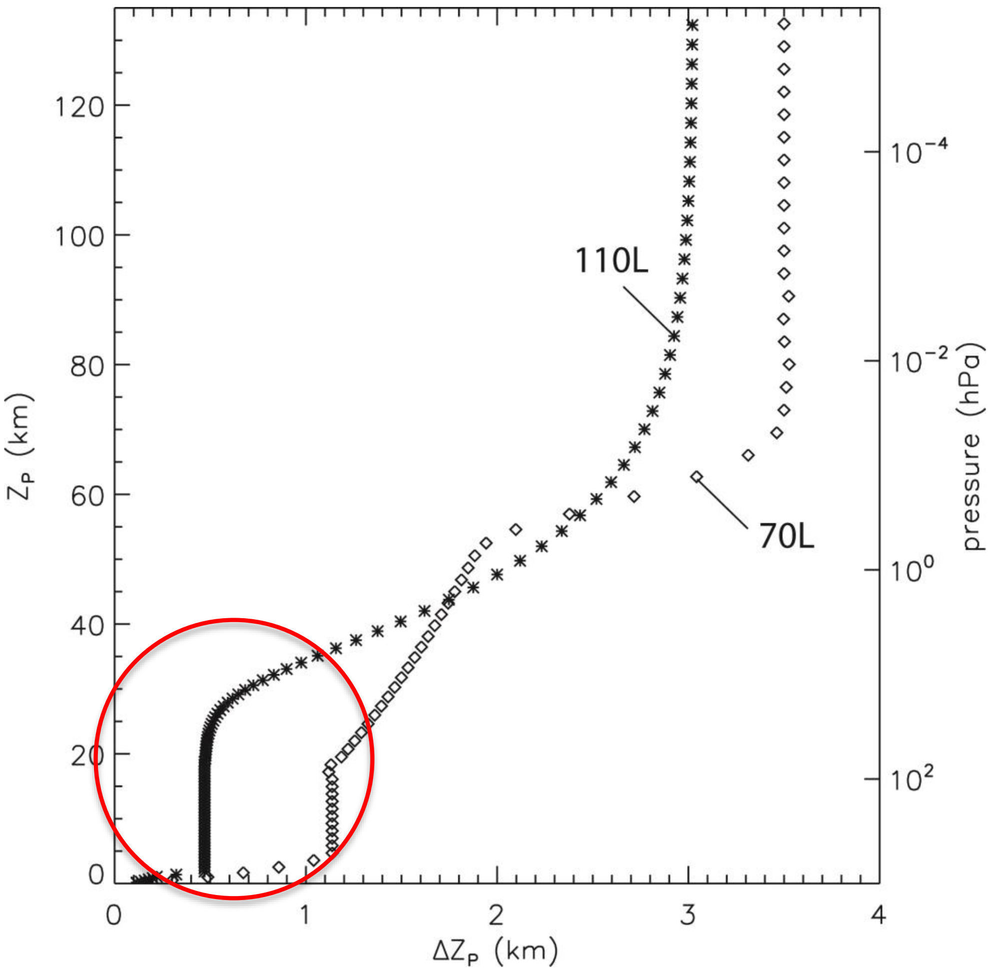
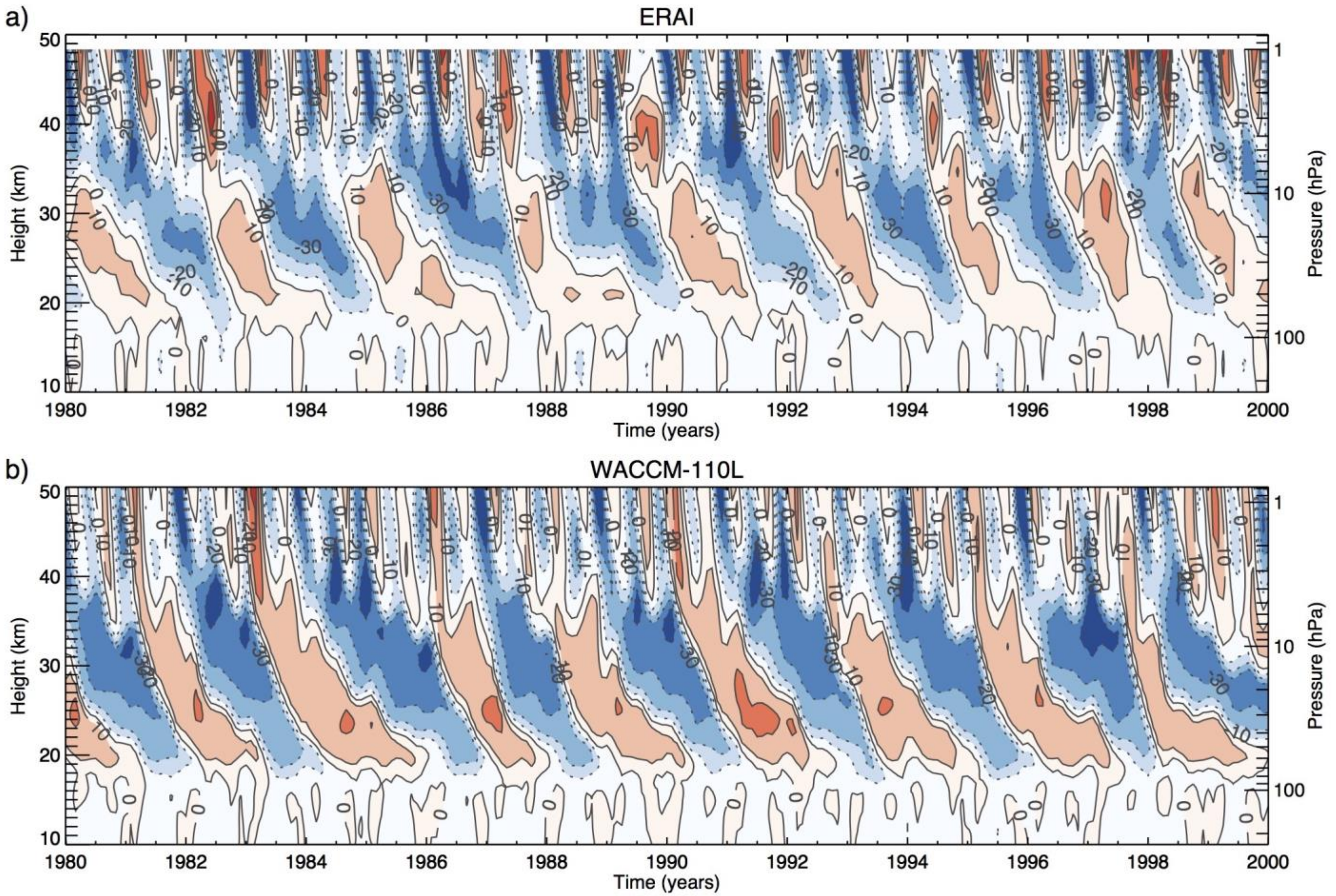
high-vertical resolution version of WACCM5.4

- QBO simulations for the period 1980-2010 using a modified version of **WACCM-5.4** (1° horizontal resolution, similar physics as WACCM6)
- tropical GW are parameterized with the Beres convective GW scheme (Beres et al., *JAS*, 2005) (GW excitation dependent on convective heating)
- the 110L model has much higher resolution than the standard, 70L WACCM from the top of the boundary layer through the middle statosphere

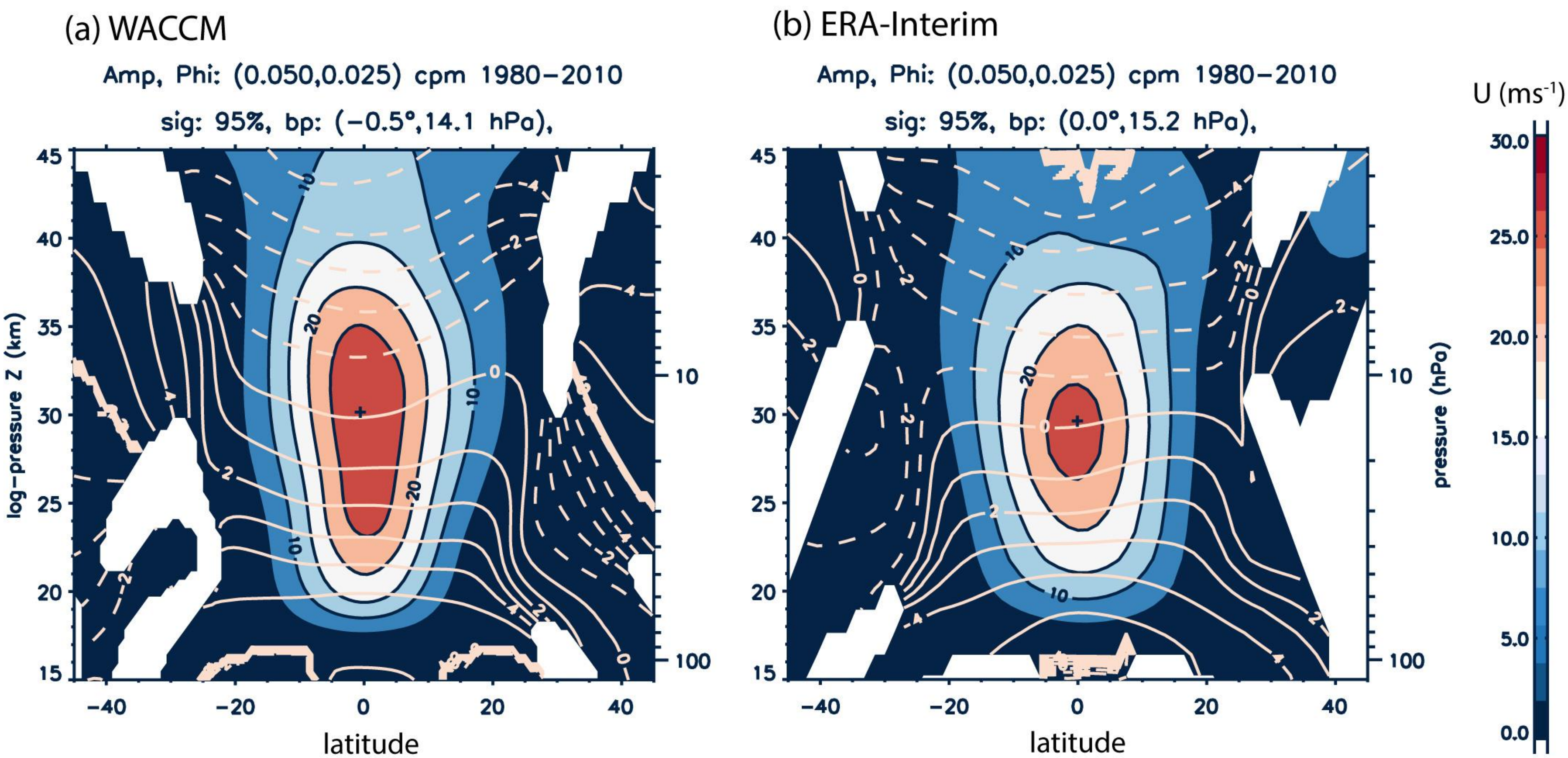


$U_{eq}(t)$: WACCM vs. ERA-Interim data



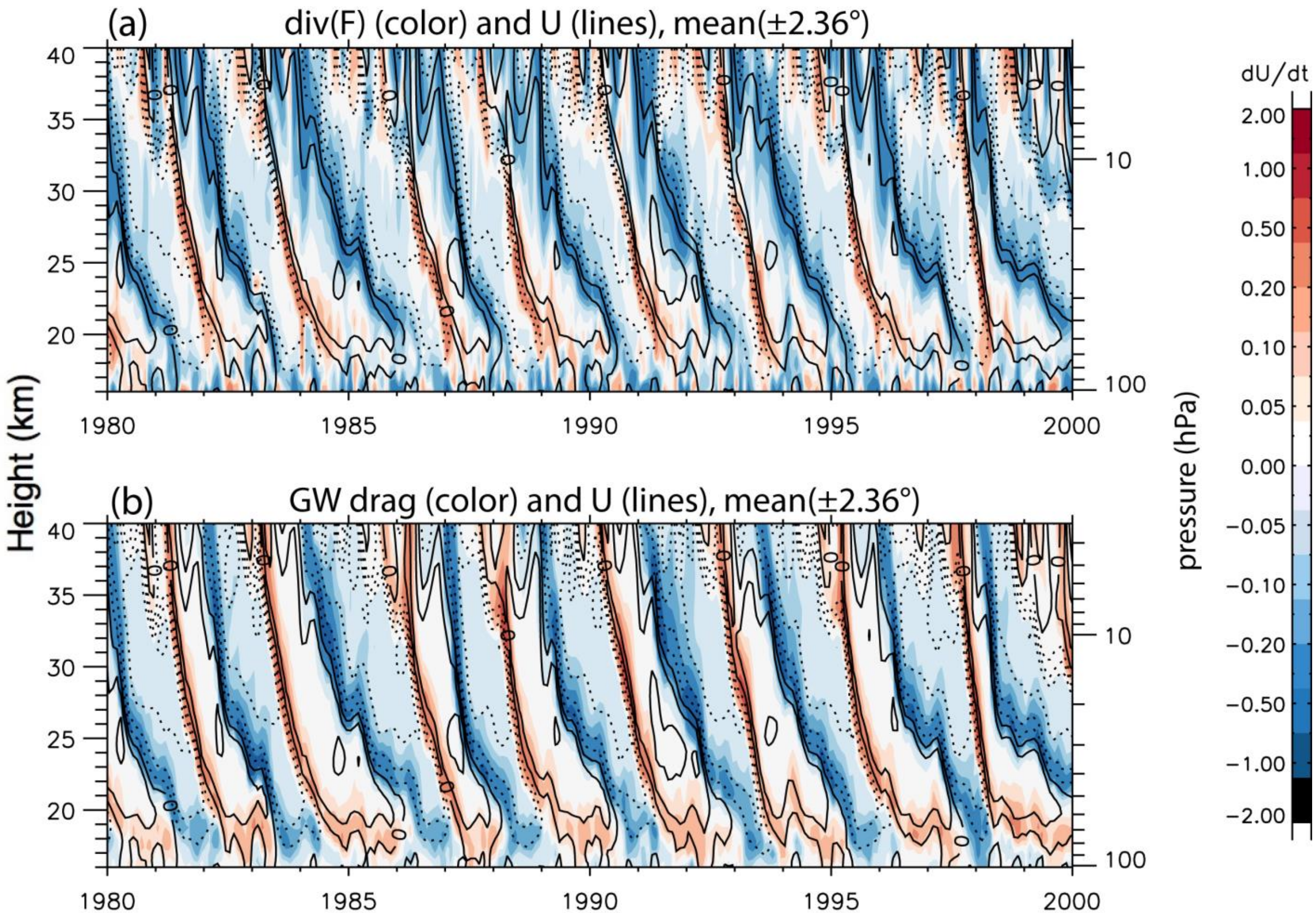
- 110L WACCM roduces a QBO in very good agreement with observations in most respects
- Observed period ~ 28 months (1952-2016); simulated period = 27.5 months (1980-2010)
- Amplitude slightly too strong compared to observations

QBO structure from Coh^2 analysis



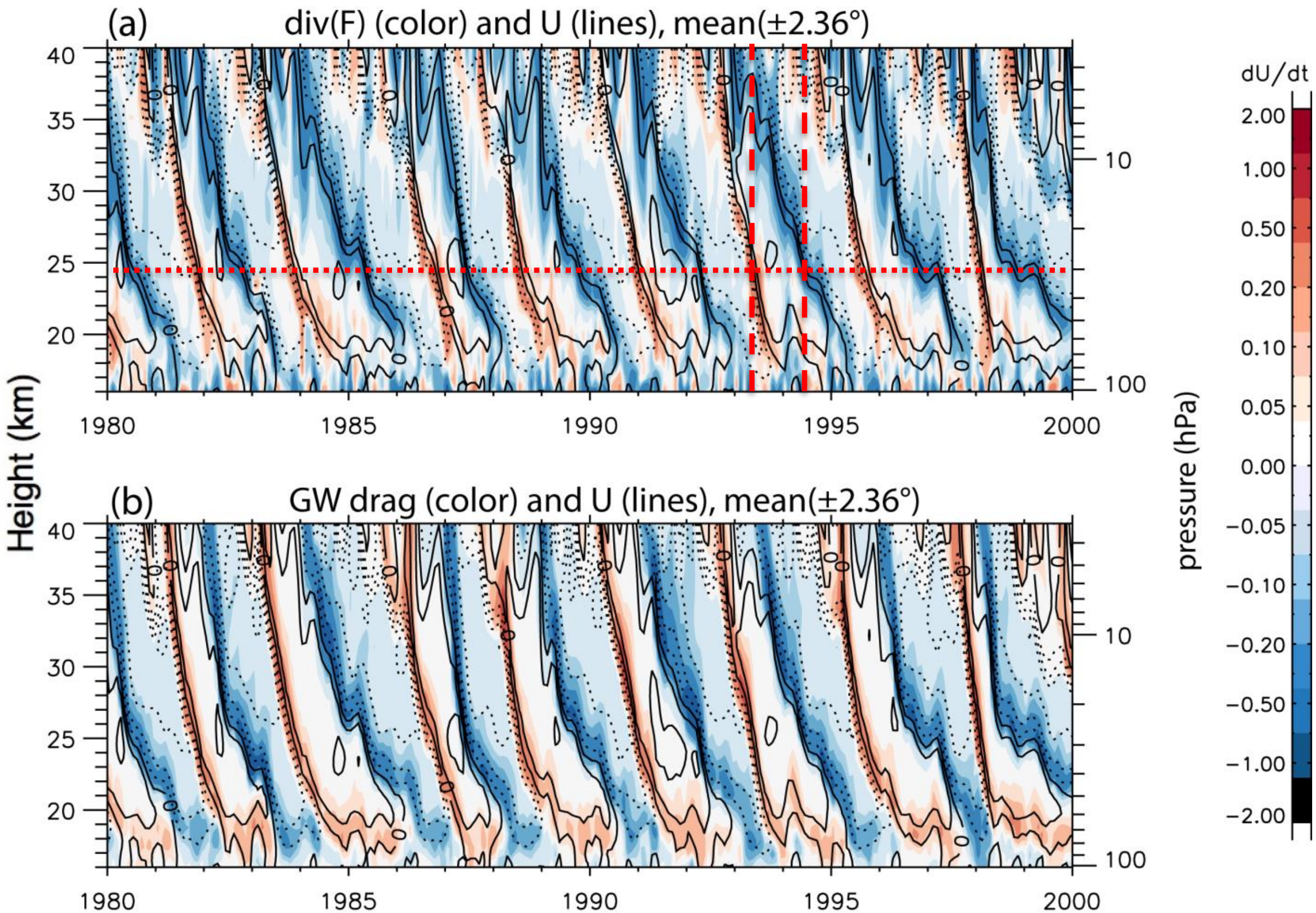
- Coh^2 analysis provides a “compact” view of the QBO
- amplitude somewhat too strong
- phase behavior in close agreement with ERA-I

div(F) and GW drag (color) vs. $U_{eq}(t,z)$ (contours)



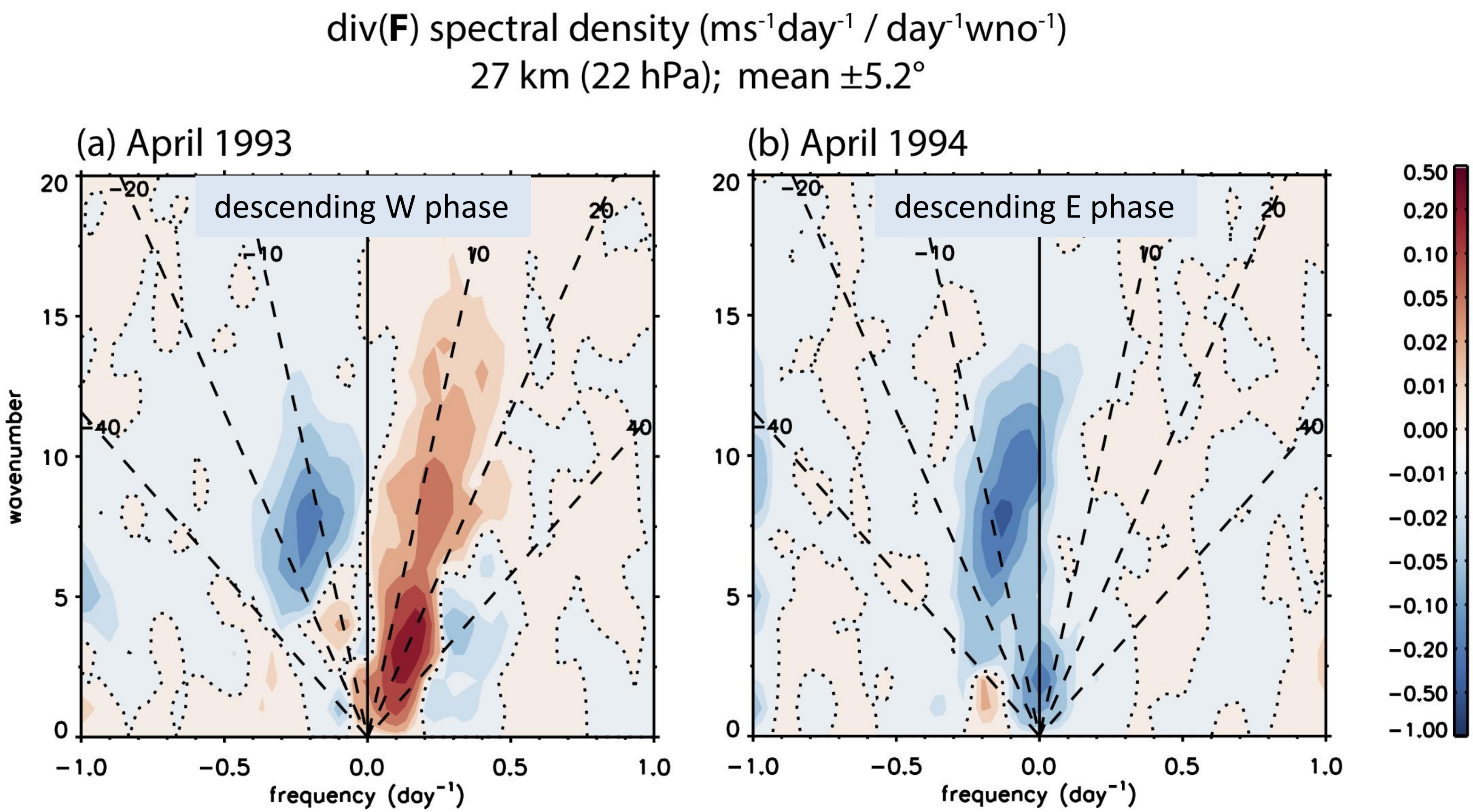
- parameterized div(**F**) and GW drag (±5° averages) contribute comparably to E and W phases
- easterly and westerly forcing are concentrated along the respective vertical shear zones
- accelerations are of order 1 m s^{-1} day^{-1}
- Next: look in detail at div(**F**) due to explicitly resolved waves

div(F) and GW drag (color) vs. $U_{eq}(t,z)$ (contours)



- look in detail at div(**F**) due to explicitly resolved waves in E and W phase

div(**F**) spectrum (±5°), W and E phase

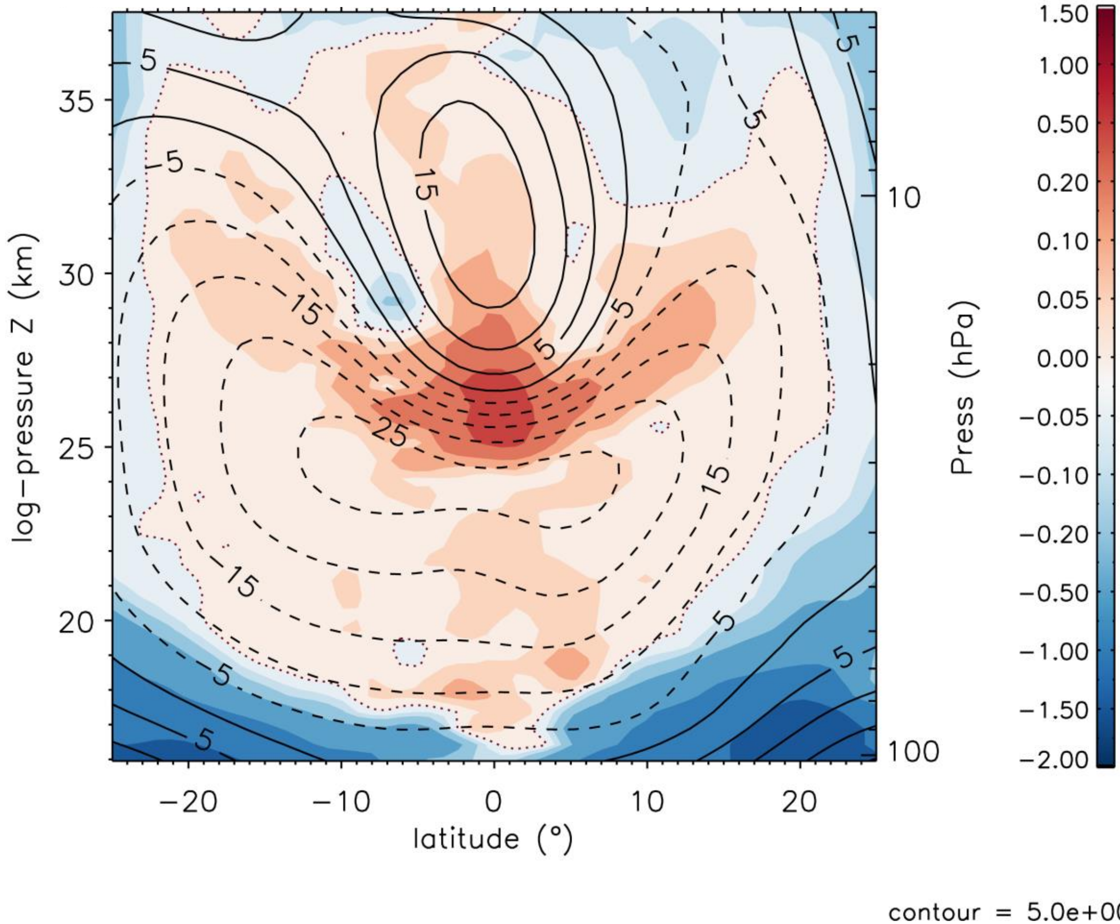


- eastward div(**F**) strongest for k = 1-4 (but extends to k > 15), present *only during W phase*
- westward div(**F**) strongest at k = 5-10, centered on k ~ 7-8, present *in both W and E phases*

div(**F**) of eastward waves

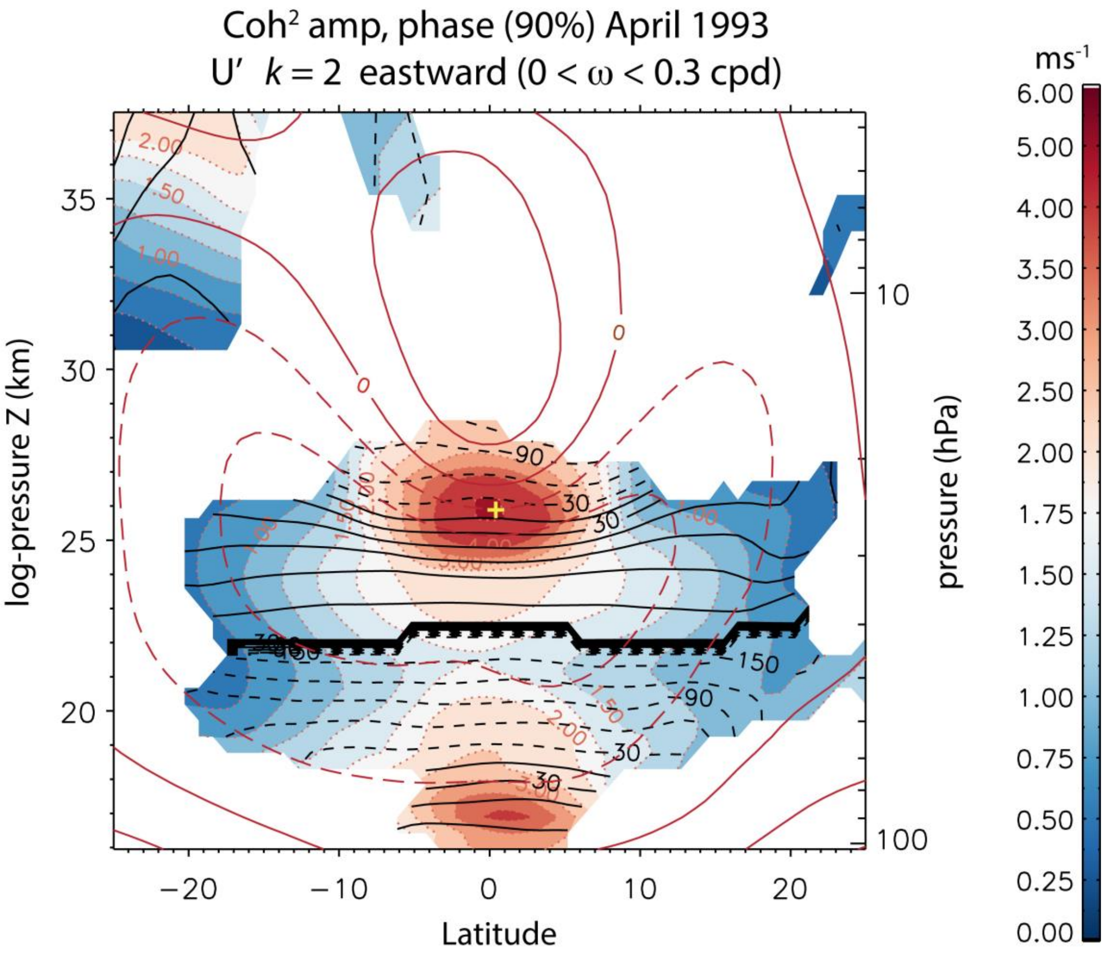
- strongest along Equator, during descending W phase
- uniformly weak at other times (not shown)
- consistent with expected forcing by *Kelvin waves*

April 1993: descending W phase at 25 km



eastward wave structure

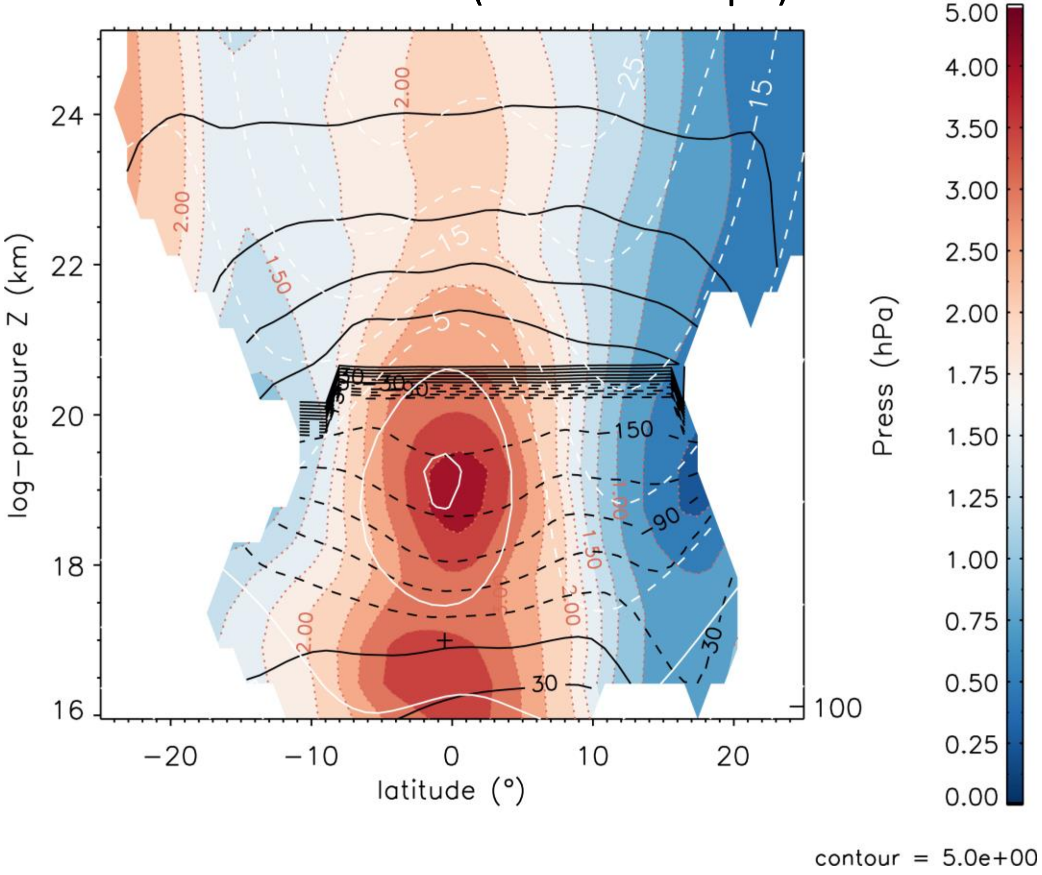
- structure via Coh^2 analysis (eastward frequencies; base point: cross)
- present in W phase only
- largest amplitudes at planetary scales (*k* = 1-4); example shown is *k*=2
- u' >> v' (only u' shown here)
- Kelvin wave structure (similar structures found at other *k*)
- *consistent with expectations* for div(**F**) in the W phase of the QBO



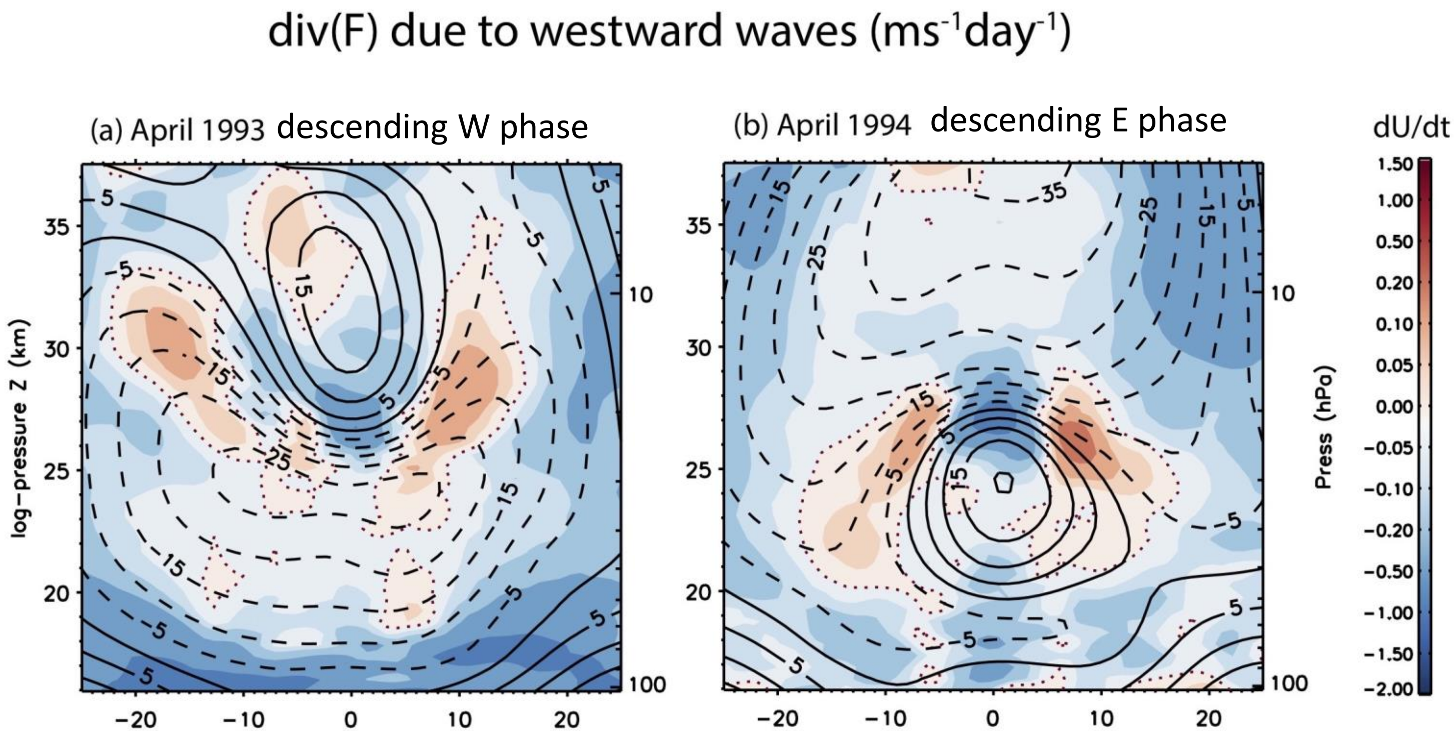
eastward waves: lowermost stratosphere

- structure via Coh^2 analysis (eastward frequencies; base point: cross). Note reduced vertical domain.
- in this example, the W jet is approaching the tropopause
- this k = 2 Kelvin wave has low frequency, narrow horizontal scale and short vertical wavelength
- $\lambda_Z \sim 6$ km → *need for high vertical resolution* to represent properly

Coh^2 amp, phase (90%) October 1993
U’ k = 2 eastward ($0 < \omega < 0.3$ cpd)



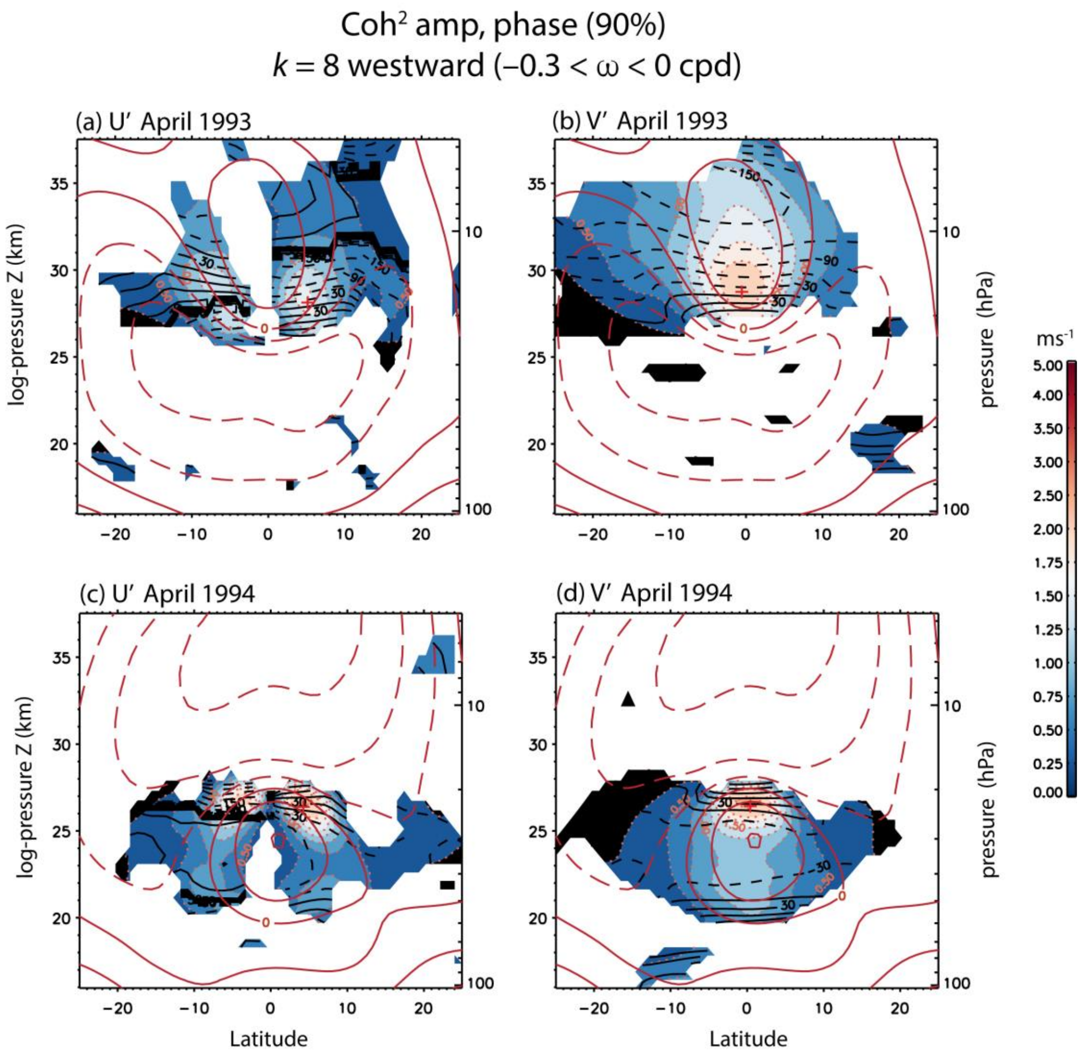
div(**F**) of westward waves



- present during both descending W phase and descending E phase
- characteristic pattern of alternating sign, with negative acceleration near the Equator and positive on either flank

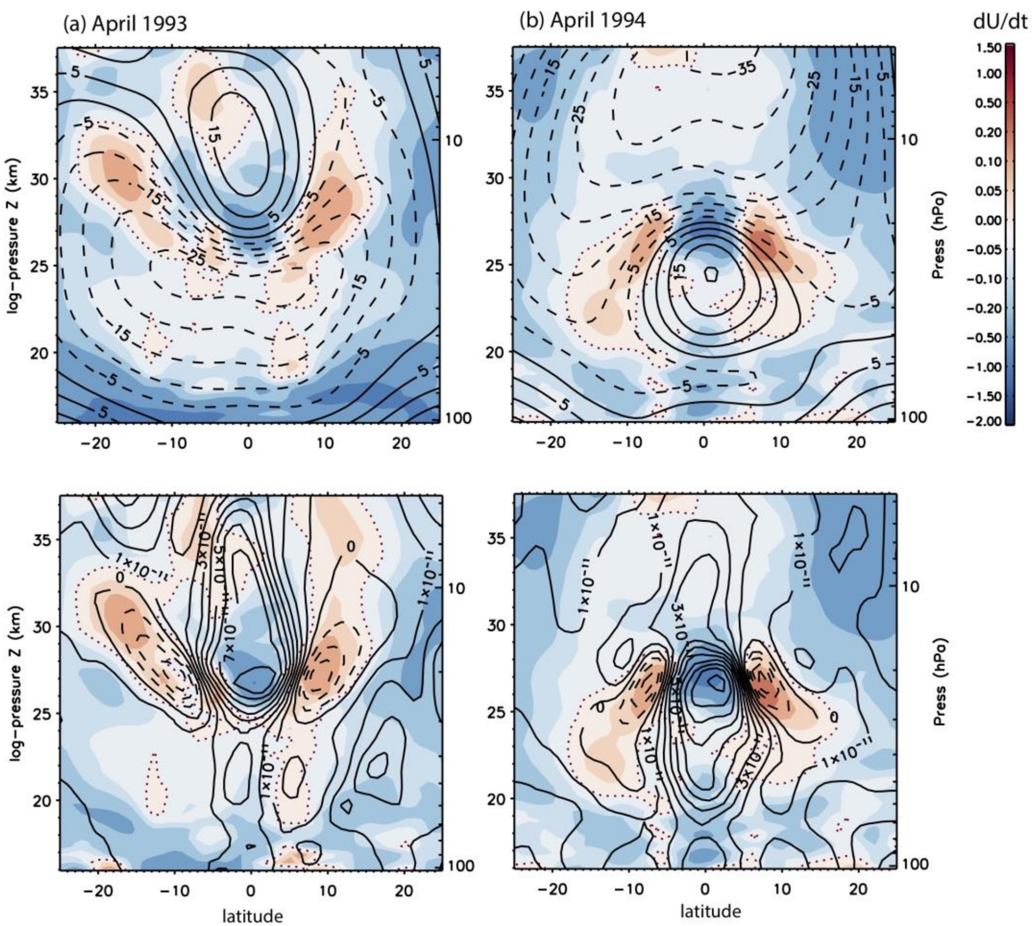
westward wave structure

- structure via Coh^2 analysis (westward frequencies; base point: cross).
- u' and v' (shown in this example for k = 8) are of comparable magnitude
-
- structure is consistent with RG waves; note very short vertical wavelength, λ_z ~ 4-5 km → *need high vertical resolution*
- waves are confined to the vicinity of the "nose" if the QBO westerly jet
- turns out these waves are generated locally due to barotropic instability of the (bottom or top side) of the QBO westerly jet (cf. Hamilton, 1984, 2001; Shuckburgh et al., 2001). *This is a new (unexpected) finding* in the context of QBO modeling



barotropic instability

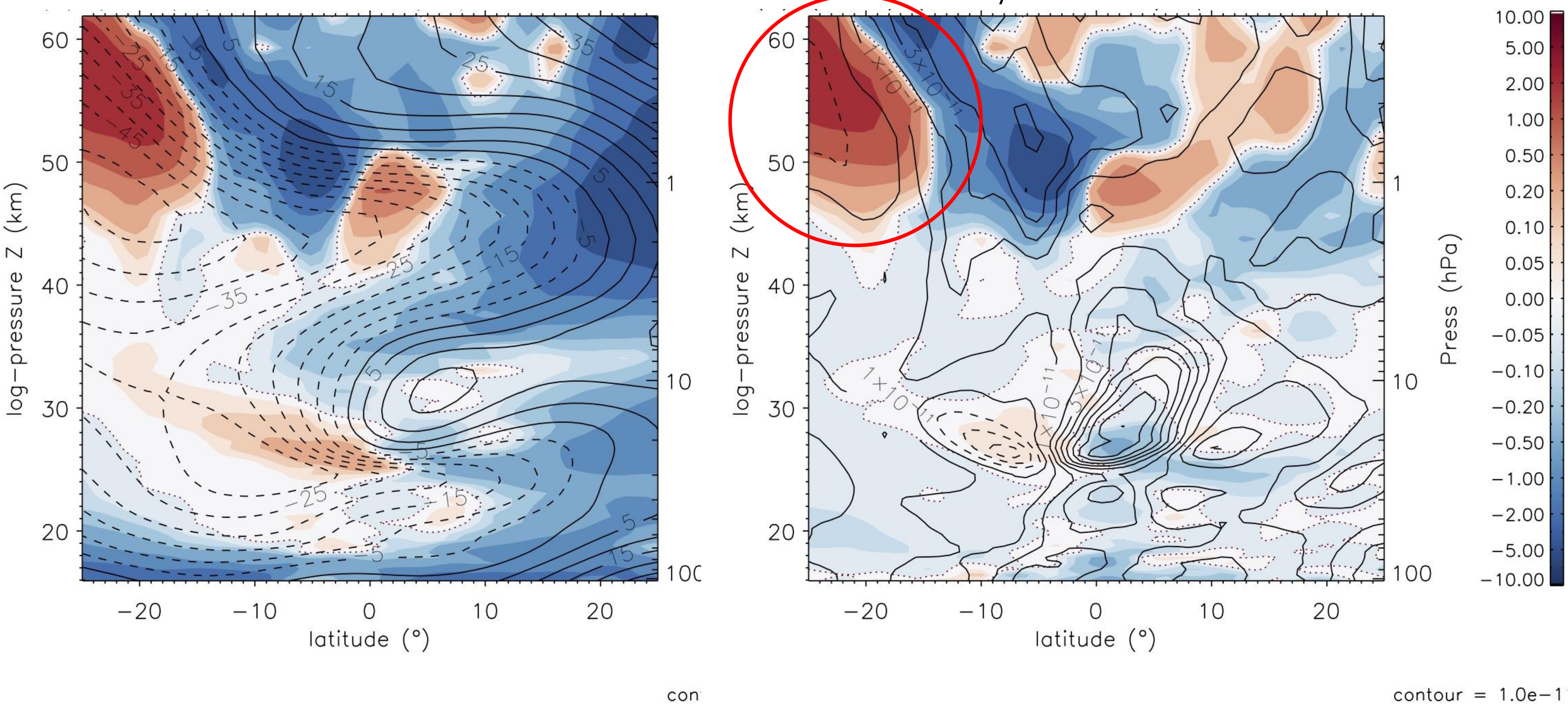
div(F) due to westward waves ($ms^{-1}day^{-1}$)



- div(**F**) with contours of zonal-mean zonal wind *U* superimposed (top row)
- div(**F**) with barotropic vorticity gradient $\zeta_y = \beta - U_{yy}$ superimposed in bottom row
- ζ_y meets the necessary condition for barotropic instability (gradient reversal)

upper stratosphere (SAO W phase)

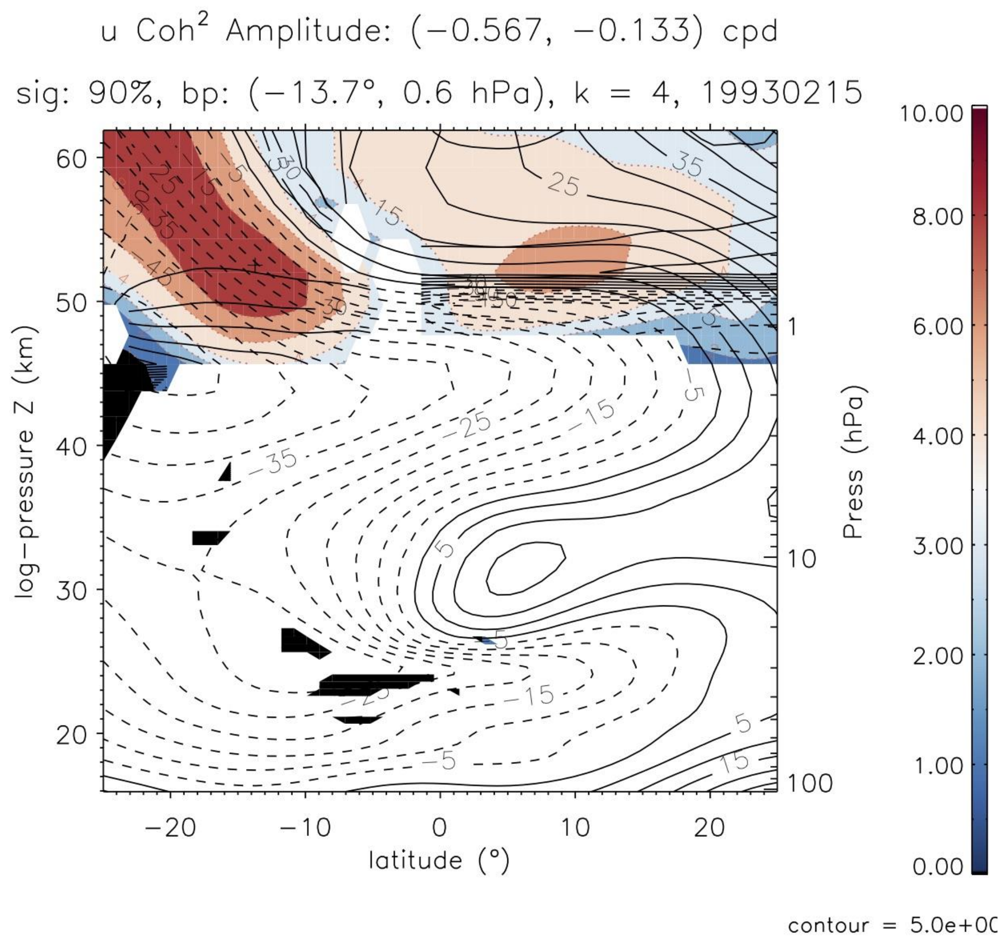
div(**F**) with U contours superimposed　　div(**F**) with Z_y contours superimposed



- div(**F**) pattern associated with SAO W phase (Feb-Mar) alternates in sign with latitude
- ζ_y meets the necessary condition for instability off Equator
- broader patterns than found in QBO region: how might this depend on vertical resolution?

wave structure in the upper stratosphere

- structure for u′ at *k* = 4 *westward* (largest amplitude found in spectral analysis—not shown)
- broad structure suggestive of RG or Rossby waves
- how would finer vertical resolution impact this result?



Summary

- high-vertical resolution 110L WACCM generates a realistic QBO
- div(**F**) in descending W phase is due mainly to large-scale (k = 1-4) Kelvin waves
- div(**F**) in descending E phase due to smaller-scale (k > 5) RG waves, apparently excited *in situ* by barotropic instability
- other, apparently unstable waves are present in connection with the W phase of the SAO at the stratopause—how are these impacted by coarser vertical resolution at that altitude?
- → high resolution WACCM simulations allow studies of previously inaccessible features of tropical dynamics

more details: Garcia and Richter, *JAS* (January 2019)