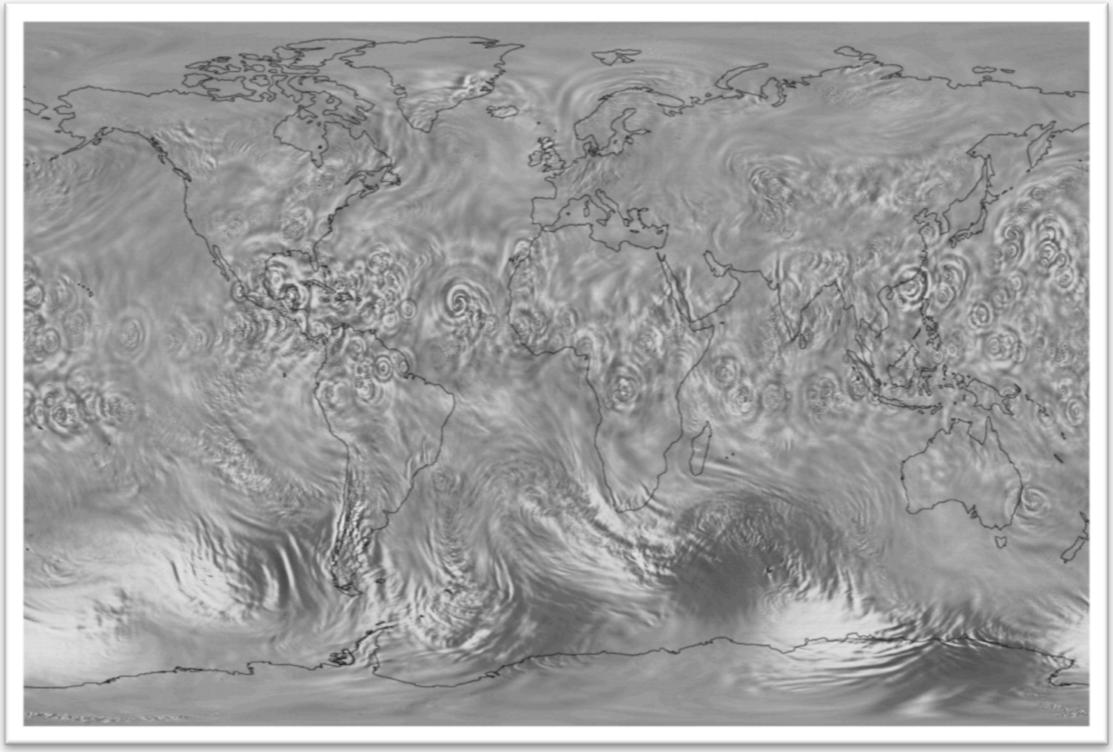
QBO dynamics in a 7-km global climate simulation



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Outline

- Motivation: Why understanding the QBO is important
- 7-km GEOS-5 Nature Run (NR)
- Evidence of realistic tropical waves in NR
- What drives the QBO in the NR?
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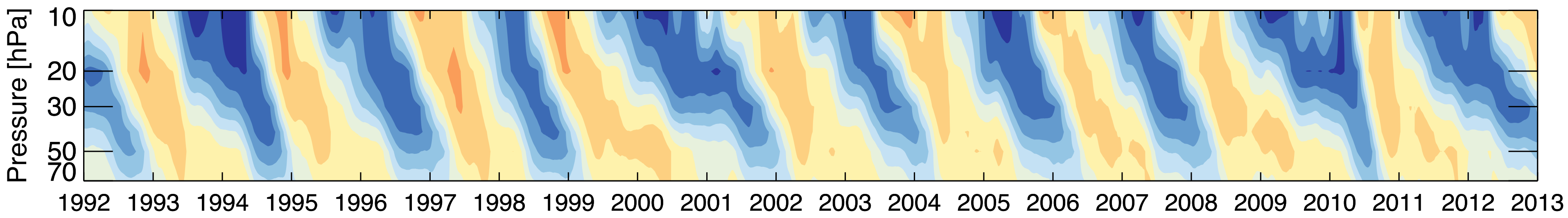
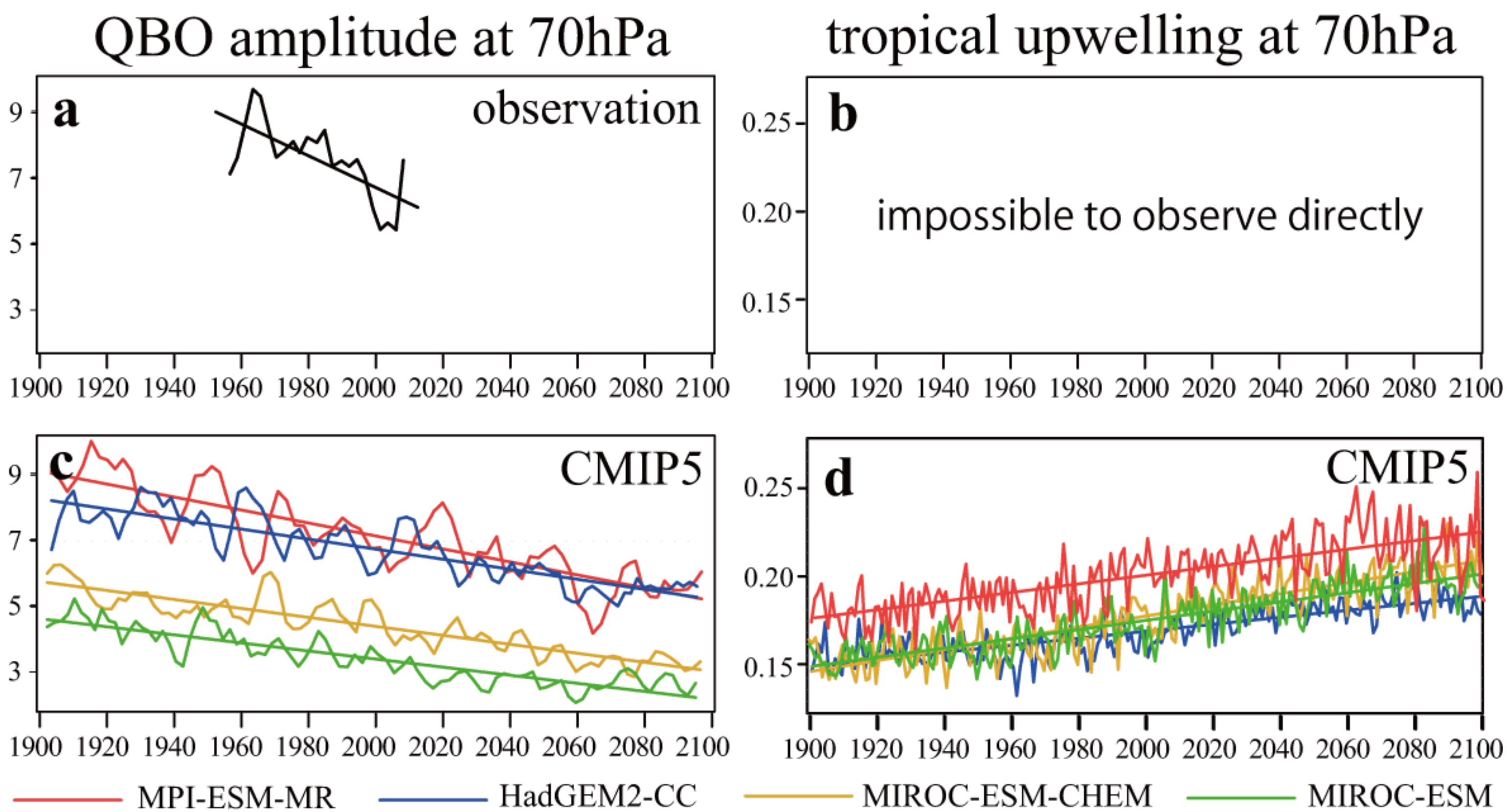
Quasi-biennial oscillation in tropical lower stratosphere winds



- Influences tropical-extratropical teleconnections and seasonal forecasts of the North Atlantic Oscillation [Scaife et al. 2014] and tropical cyclone activity (e.g. Camargo and Sobel [2010])
- Differences in wave forcing and/or QBO winds in the lowermost stratosphere could affect tropical upwelling
- Driven by continuum of waves, with more than half of forcing due to gravity waves that must be parameterized by GCMs
- Model QBOs are very sensitive to changes to many parameters, including resolution, GW parameterization, and dynamical core
- How will QBO change with climate? Implications?

Evidence the QBO is changing with warming climate

Kawatani and Hamilton [2013]:

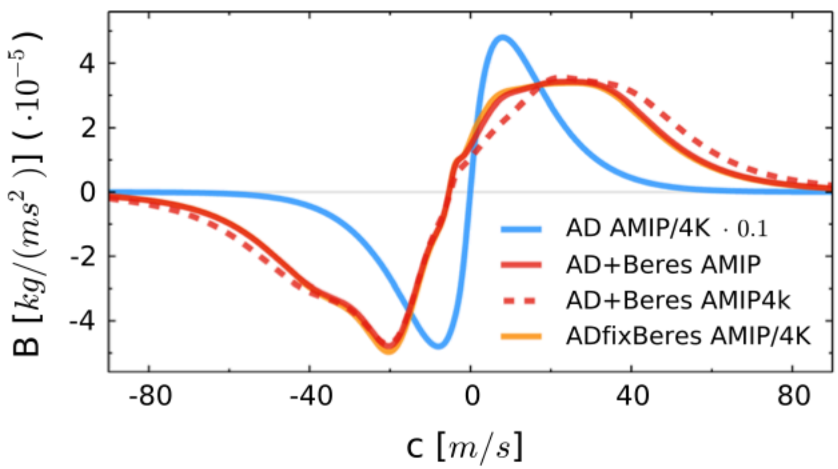


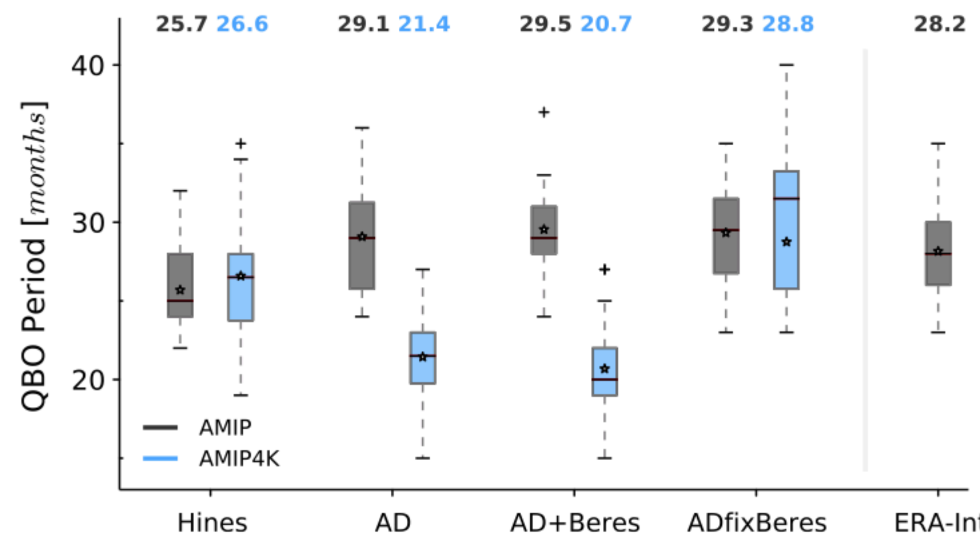
- Evidence that QBO winds near tropopause have grown weaker with time
- Consistent with model predictions that the Brewer-Dobson circulation is growing stronger, and will continue to do so in the future

The quasi-biennial oscillation in a warmer climate: sensitivity to different gravity wave parameterizations

Schirber et al [2014]

Effects of changes to the model's gravity wave scheme on the simulated QBO.





- Subtle changes in the gravity wave parameterization details gave different predictions for changes in the QBO in a warmer climate.
- A previous study predicts a lengthened future QBO period, but here many experiments gave a shorter period.

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7-km GEOS-5 Nature Run

- 2-year run produced with GEOS-5
- Cubed sphere, finite volume numerics
- Free running atmosphere
- 7-km horizontal resolution
- Between 1 – 2 km vertical resolution in stratosphere
- Non-hydrostatic
- Time step: 10 s dynamics, 300 s fast physics
- Non-orographic parameterized gravity wave drag (after Garcia and Boville, 1994)
- 2nd order divergence damping
- Relaxed Arakawa-Schubert moist physics scheme

7-km GEOS-5 Nature Run

Tropical Storm winds 39-73 mph	Hurricane winds 74-111 mph	Major Hurricane winds 112+ mph

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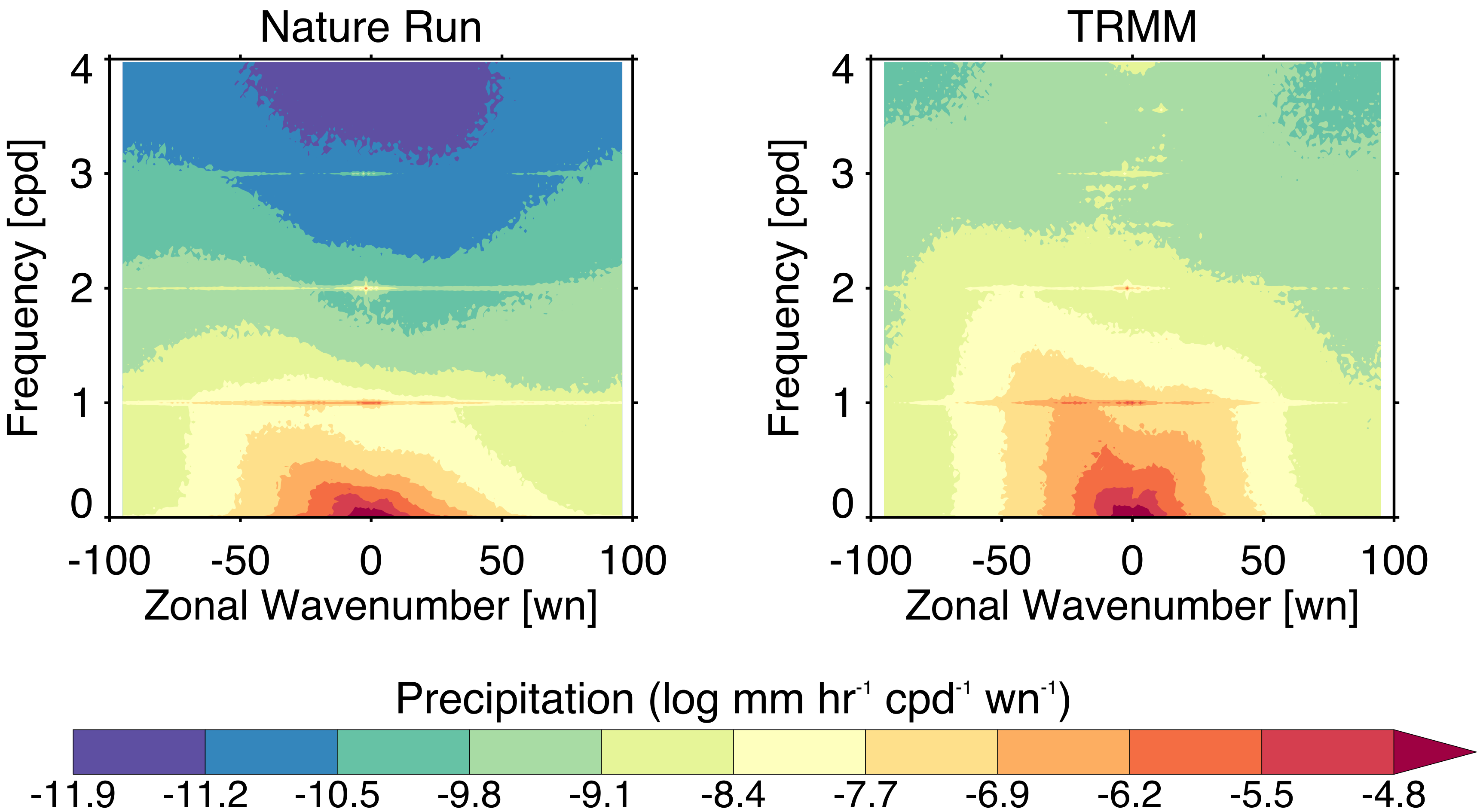
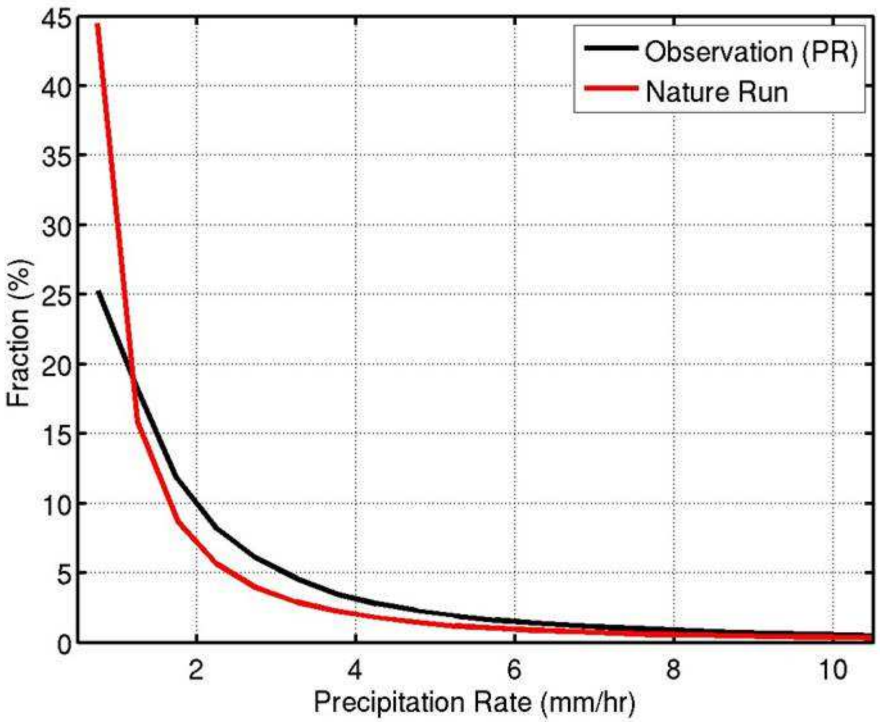
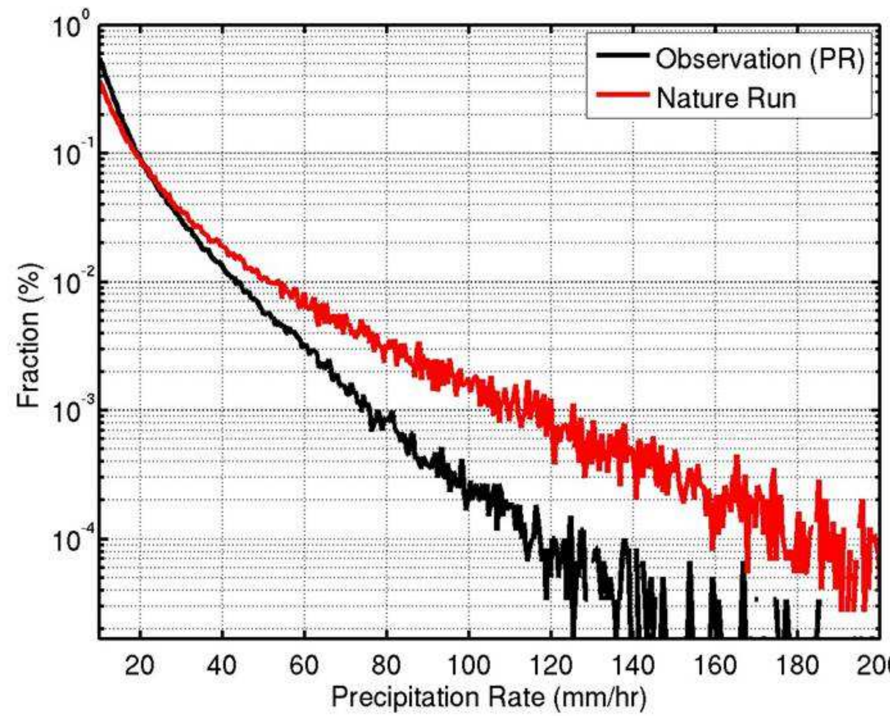
NR reproduces broad range of convectively coupled waves



TRMM spectrum reproduced from Kim and Alexander, 2013

Probability Distribution of Surface Precipitation Compared to TRMM

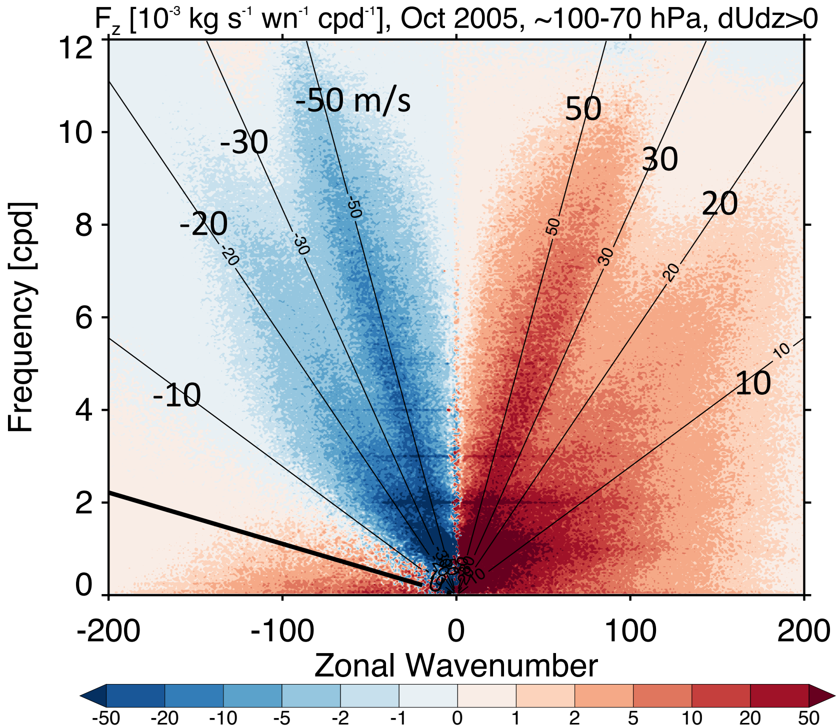




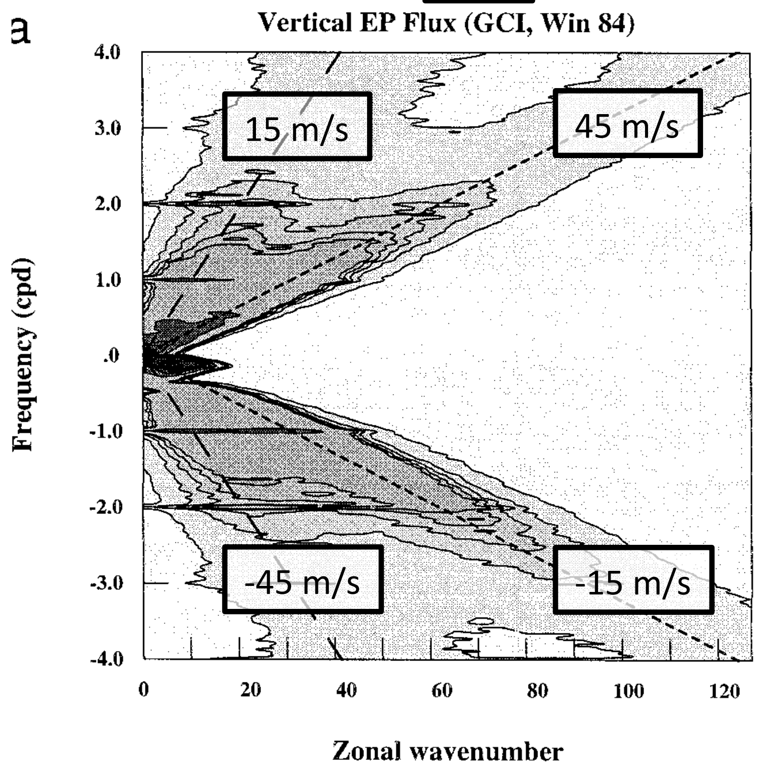
- NR > TRMM for light precipitation (<1 mm/hr) and heavy precipitation (> 20 mm/hr)
- NR < TRMM for precipitation between 1 and 20 mm/hr

NR Vertical EP-Flux Compared to that derived from Global Cloud Imager

NR



GCI

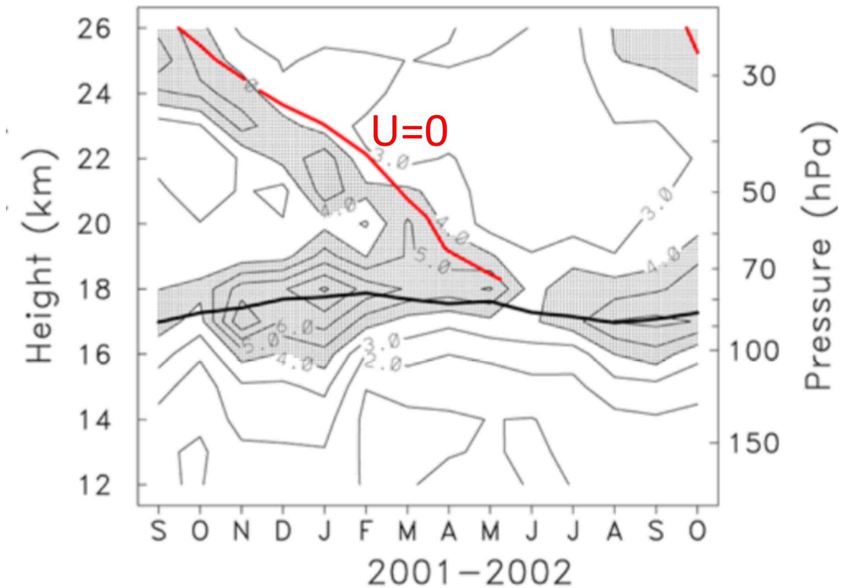


- Double lobe structure is present in NR
- NR captures the high phase speed lobe

Ricciarduli and Garcia, 2000 JAS

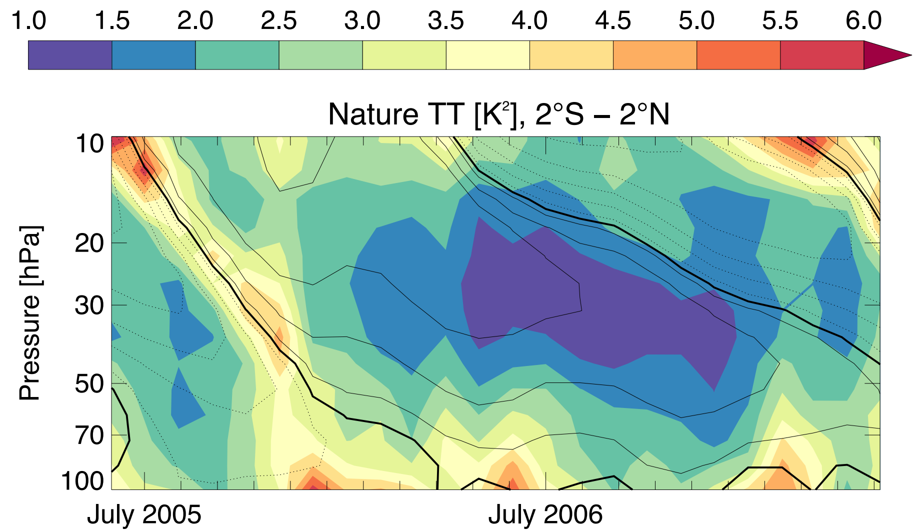
Small-scale temperature variance

GPS radio occultation T'^2



Randel and Wu, 2005 JGR

NR T'^2



- Small-scale waves drive tropopause T variance
- Interaction between small-scale waves and u=0 region

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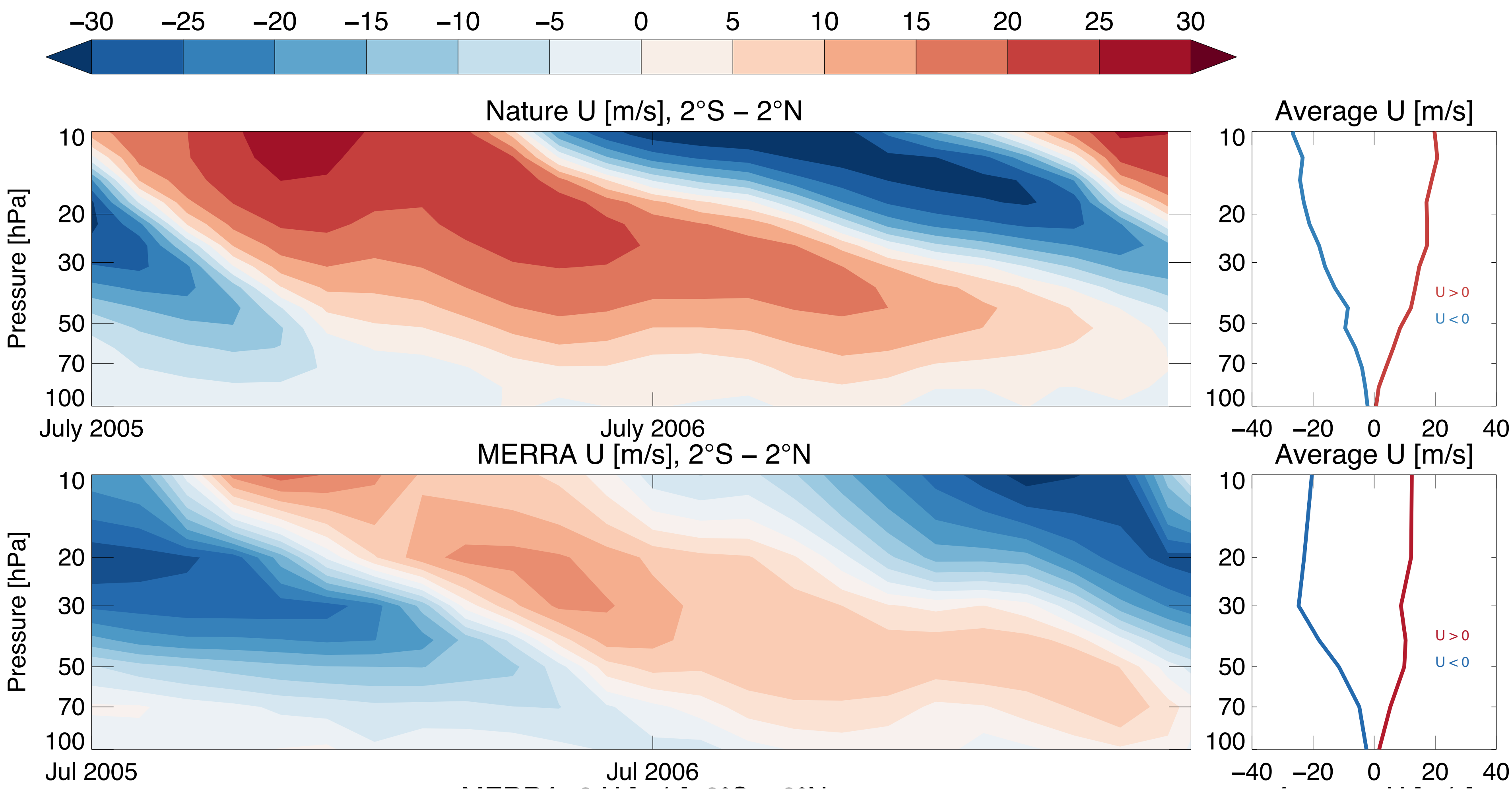
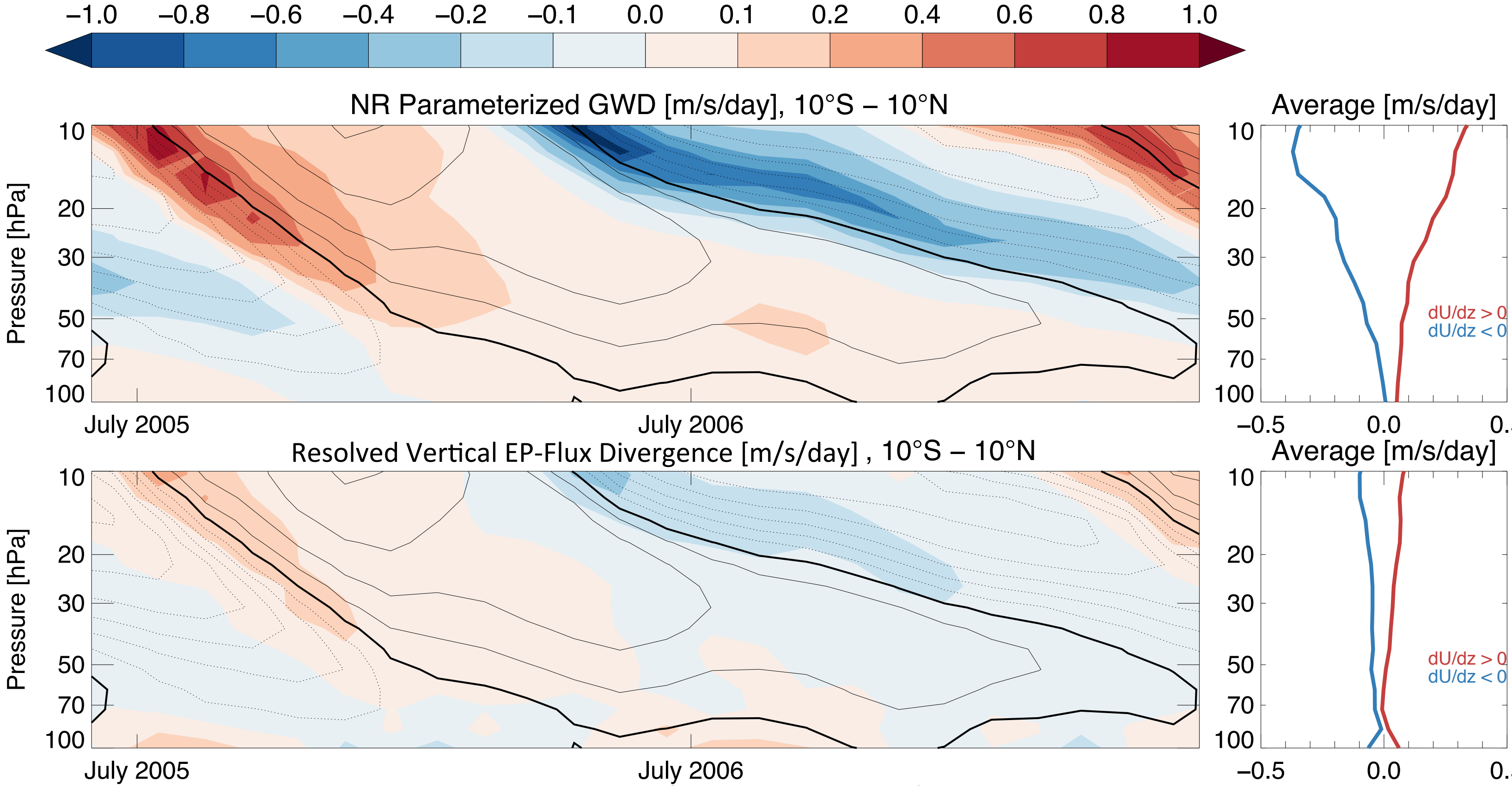
NR and MERRA QBO



NR Parameterized GWD and Resolved EP-Flux Divergence



Resolved EP-Flux divergence < 25 % of parameterized GWD

QBO balance equation

$$\frac{\partial \bar{U}}{\partial t} + \overline{w}^{*} \frac{\partial \bar{U}}{\partial z} = \bar{\mathrm{X}} + \left(\rho_0 a \cos\phi\right)^{-1} \vec{\nabla} \cdot \vec{F}$$

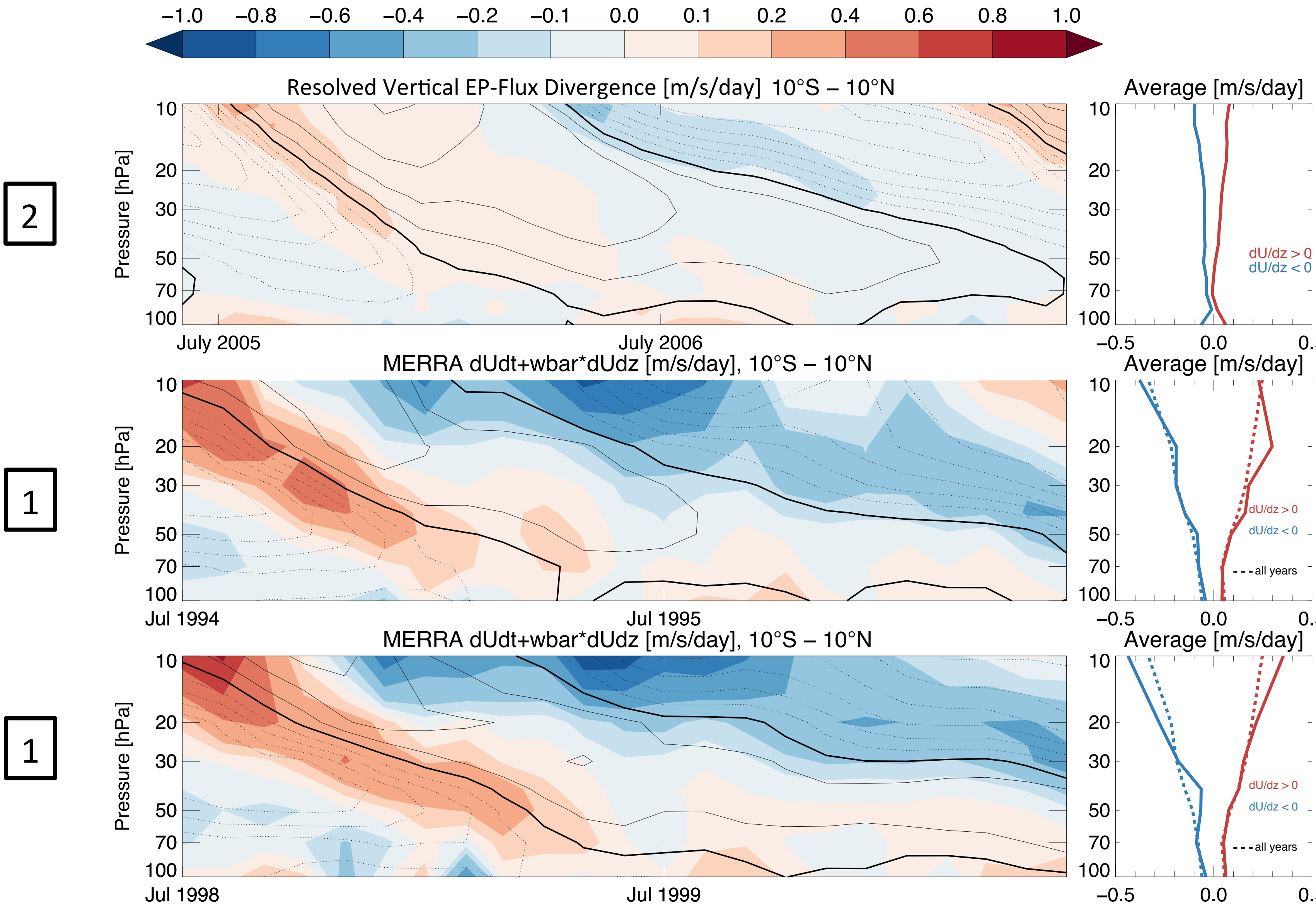
1

$$\vec{\nabla} \cdot \vec{F} = \left(a \cos\phi\right)^{-1} \frac{\partial F_{\phi} \cos\phi}{\partial \phi} + \frac{\partial F_z}{\partial z}$$

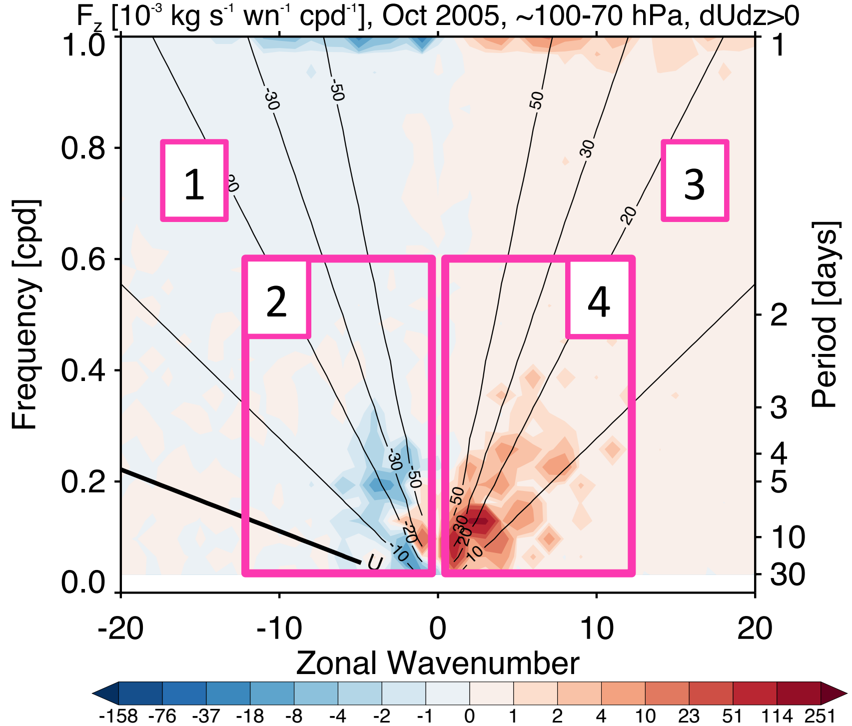
$$\frac{\partial F_z}{\partial z} = \frac{\partial}{\partial z}\left\{\rho_0 a \cos\phi \left\{\left[f - \left(a \cos\phi\right)^{-1} (\bar{u}\cos\phi)_{\phi}\right] \frac{\overline{v'\theta'}}{\bar{\theta}_z} - \overline{u'w'}\right\}\right\}$$

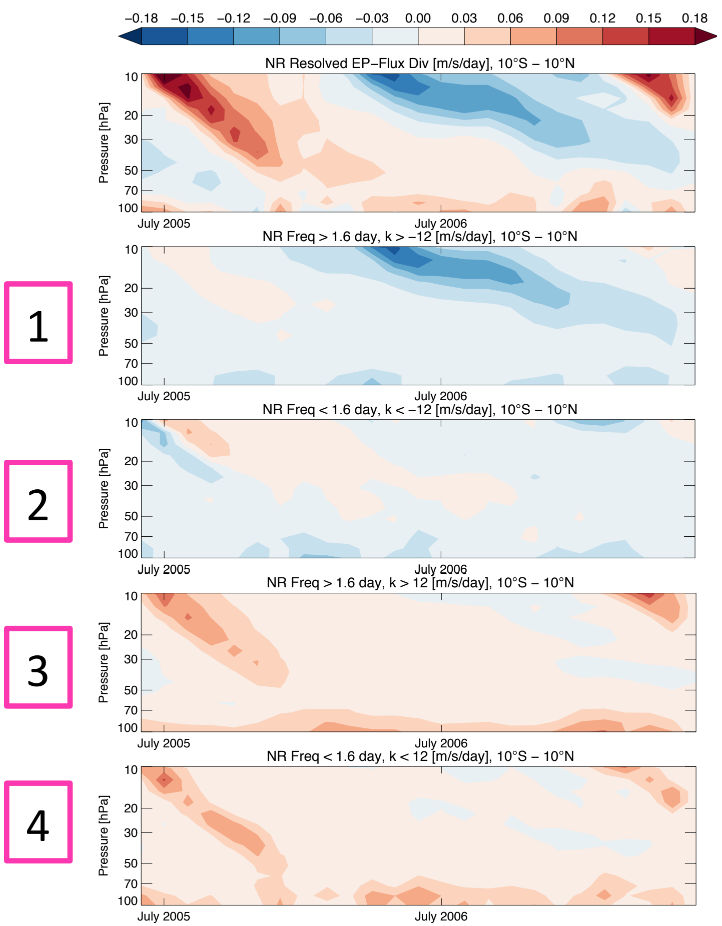
2

NR vertical EP-flux div compared to MERRA total zonal forcing



NR vertical EP-Flux divergence from different wavenumber-frequency bins

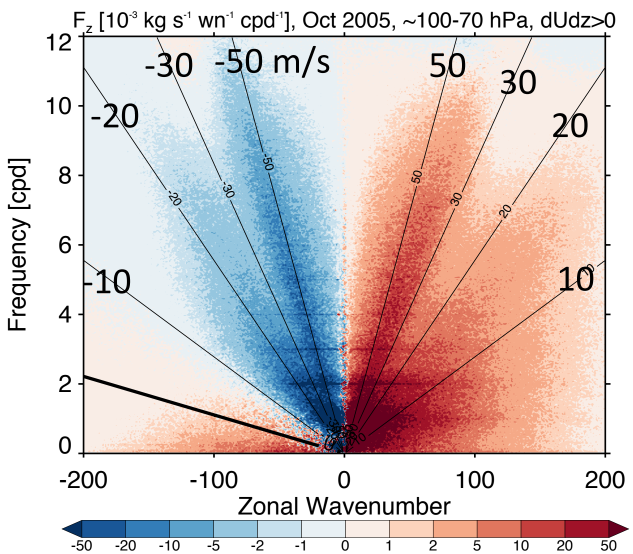




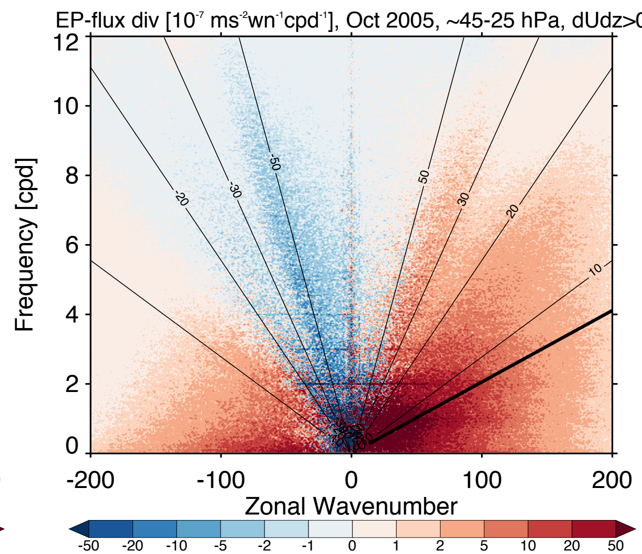
- High-frequency, small scale GWs dominate during easterly shear phase
- Kelvin waves provide half of the forcing in westerly shear phase
- In agreement with previous studies (e.g. Kawatani et al., 2010)

Too much dissipation?

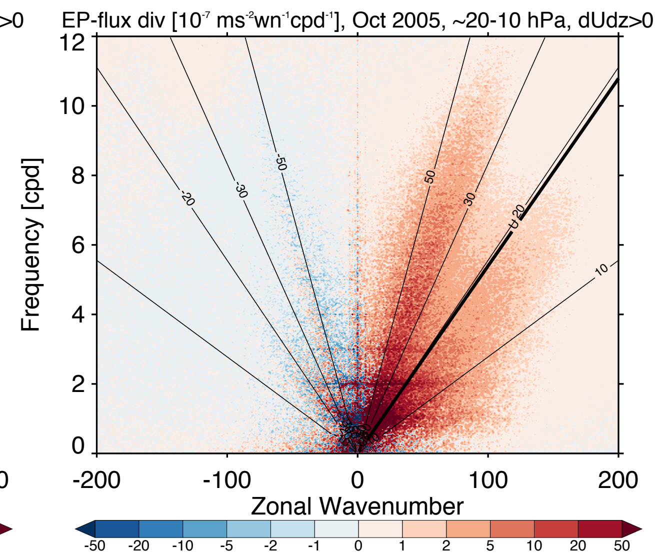
EP-Flux from ≈100-70 hPa



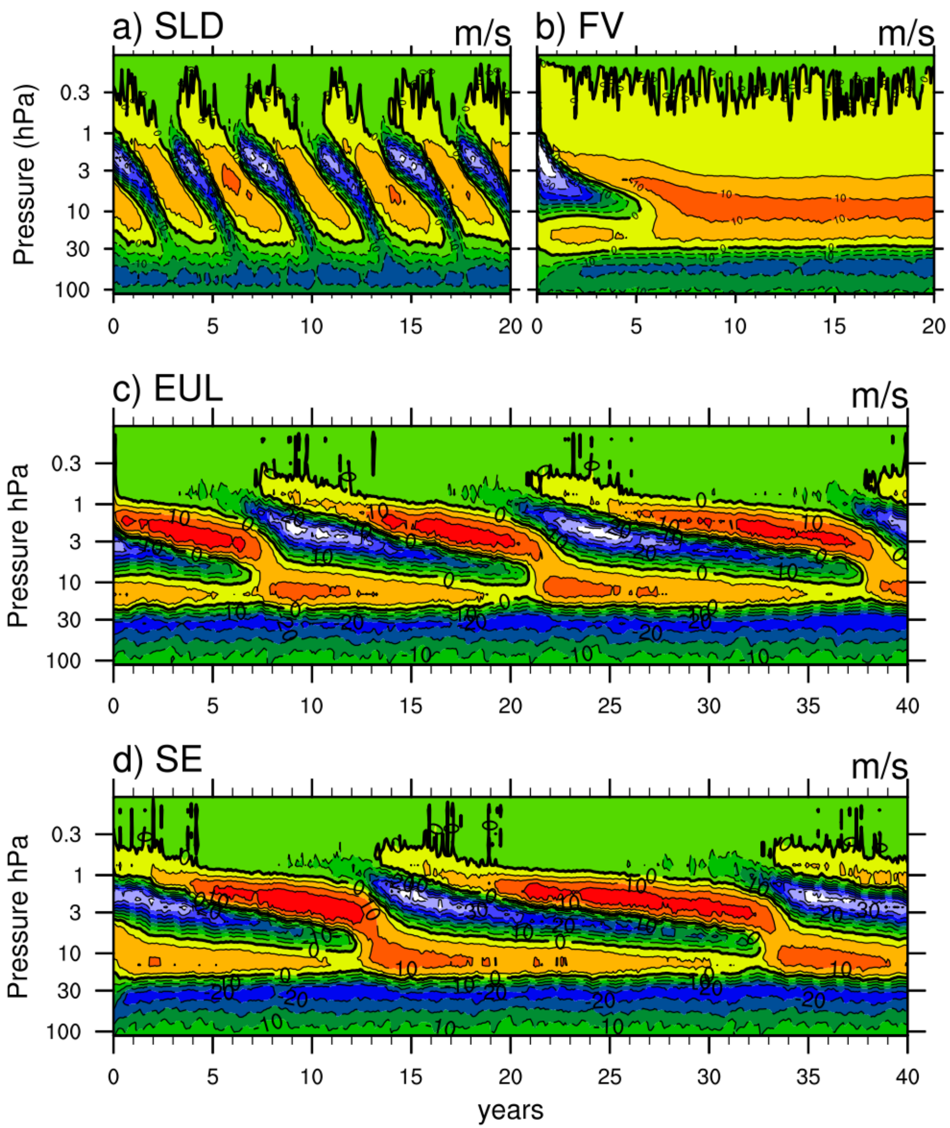
EP-Flux div from ≈45-25 hPa



EP-Flux div from ≈20-10 hPa



Influence of dynamical core choice?



- Dry GCM dynamical cores
- QBO-like oscillations in all but FV
- Measures of wave activity much lower in FV

Yao and Jablonowski, 2015 JAS

Conclusions

- Resolved small-scale waves in NR are well-represented and behaving realistically
- Resolved waves in NR contribute about 25% of zonal force for QBO
- Still need parameterized GWs to get QBO
  - Higher vertical resolution?
  - Too much dissipation/damping? Dynamical core?

Thank You