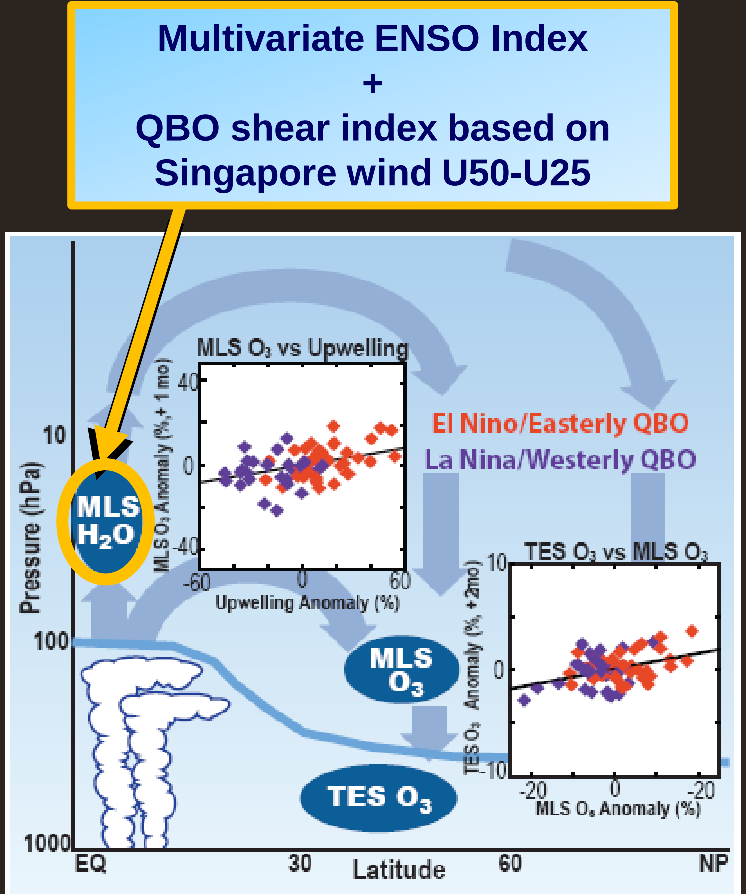
Comparing QBO and ENSO impacts on stratospheric transport in WACCM-SD and -FR

CESM Chemistry WG Meeting

Boulder, CO | February 10, 2016

Jessica L. Neu[1], Douglas Kinnison[2], Sasha Glanville[2], Meemong Lee[1], Thomas Walker[1]

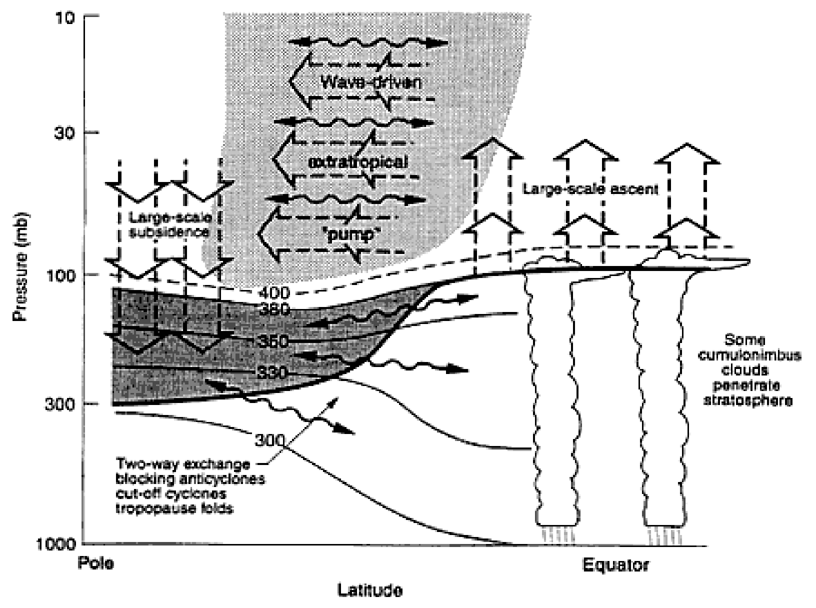
[1]NASA Jet Propulsion Laboratory/Caltech, Pasadena, CA; [2] National Center for Atmospheric Research, Boulder, CO



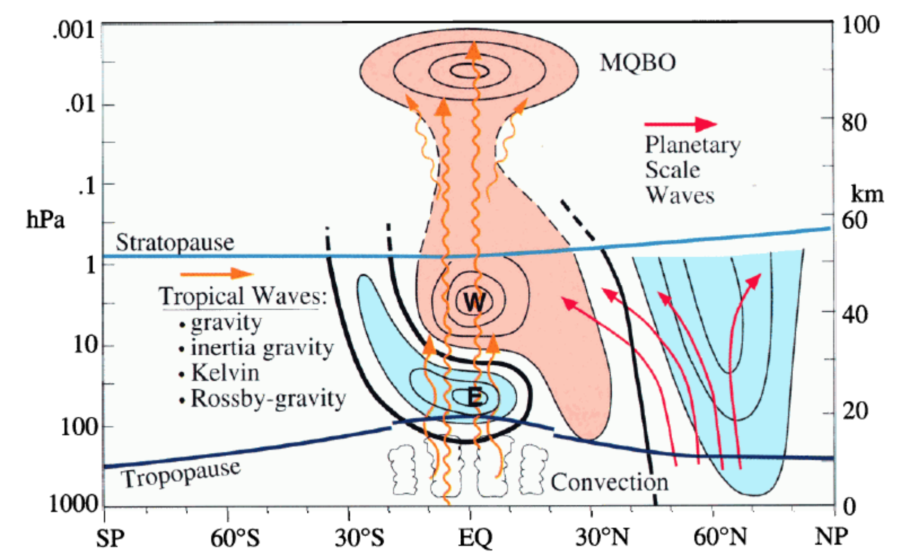
Multivariate ENSO Index
+
QBO shear index based on Singapore wind U50-U25

Neu et al., *Nature Geoscience*, 2014

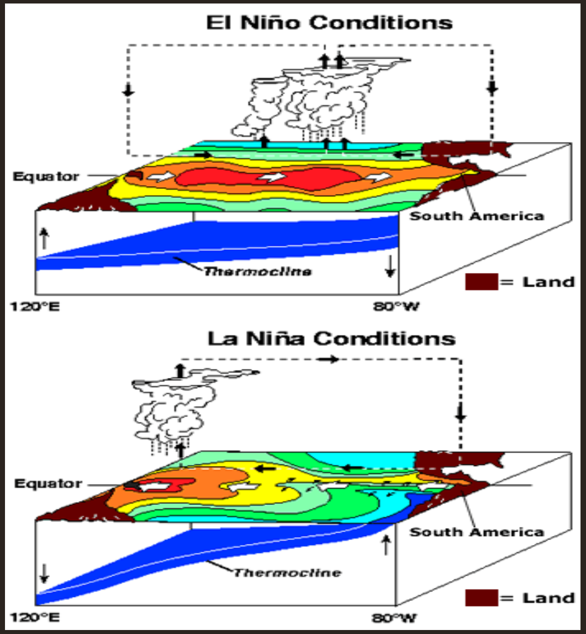
The Wave-Driven Circulation



QBO Zonal Wind Shear
Free Univ. of Berlin, B. Naujokat



ENSO Changes in Convection and the Walker Circulation

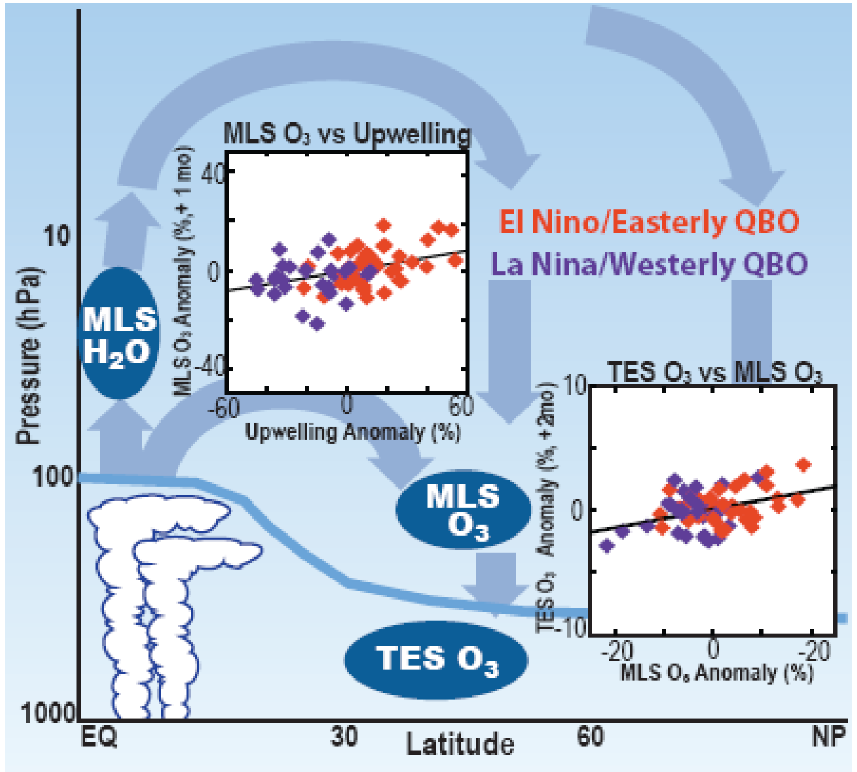


- Both QBO and ENSO also alter the circulation by modulating the propagation and dissipation of the waves that drive circulation (e.g. Dunkerton and Baldwin JAS, 1991; Calvo et al., JAS, 2010)
- The QBO also drives a secondary meridional circulation via thermal wind balance, with relative upwelling at the equator during the easterly shear phase and relative downwelling during the westerly shear phase (Plumb and Bell, QJRMS, 1982). During the solstices, the circulation extends deep into the winter hemisphere (Kinnersley, JAS, 1999).
- QBO and ENSO may interact nonlinearly to modulate the circulation (e.g. Garfinkel and Hartmann, JGR, 2007).

Natural variability in the stratospheric circulation allows us to empirically derive the response of tropospheric ozone to changes in the circulation

- El Nino/Easterly QBO increase the strength of the stratospheric circulation and transport from the ozone maximum down to the midlatitude lower stratosphere
- This leads to increased STE and increased midlatitude tropospheric ozone
- La Nina/Westerly QBO are associated with decreases in the strength of the circulation, STE, and O_3
- Focus on 2005-2010, NH

datasets used in this study



Multivariate ENSO Index (Wolter and Timlin 1993, 1998)
QBO shear index based on Singapore wind U50-U25
(Free Univ. Berlin, updated from Naujokat 1986)

Microwave Limb Sounder Water Vapor
Microwave Limb Sounder Ozone

Tropospheric Emission Spectrometer Ozone

Neu et al., *Nature Geoscience*, 2014

Why do we need to more fully understand the tropospheric ozone response to changes in the stratospheric circulation?

Chemistry-climate models robustly predict strengthening of the large-scale stratospheric circulation and stratosphere-troposphere exchange (STE) in response to increasing greenhouse gases, with uncertain consequences for tropospheric ozone.

We use the WACCM Chemistry-Climate Model in both specified dynamics (SD) and free-running (FR) modes to investigate how ENSO & QBO impact…

1. Transport circulation (total) vs the residual circulation (w*) in the tropics
2. Deep branch transport
3. Stratosphere-to-troposphere O_3 transport in the NH mid-latitudes

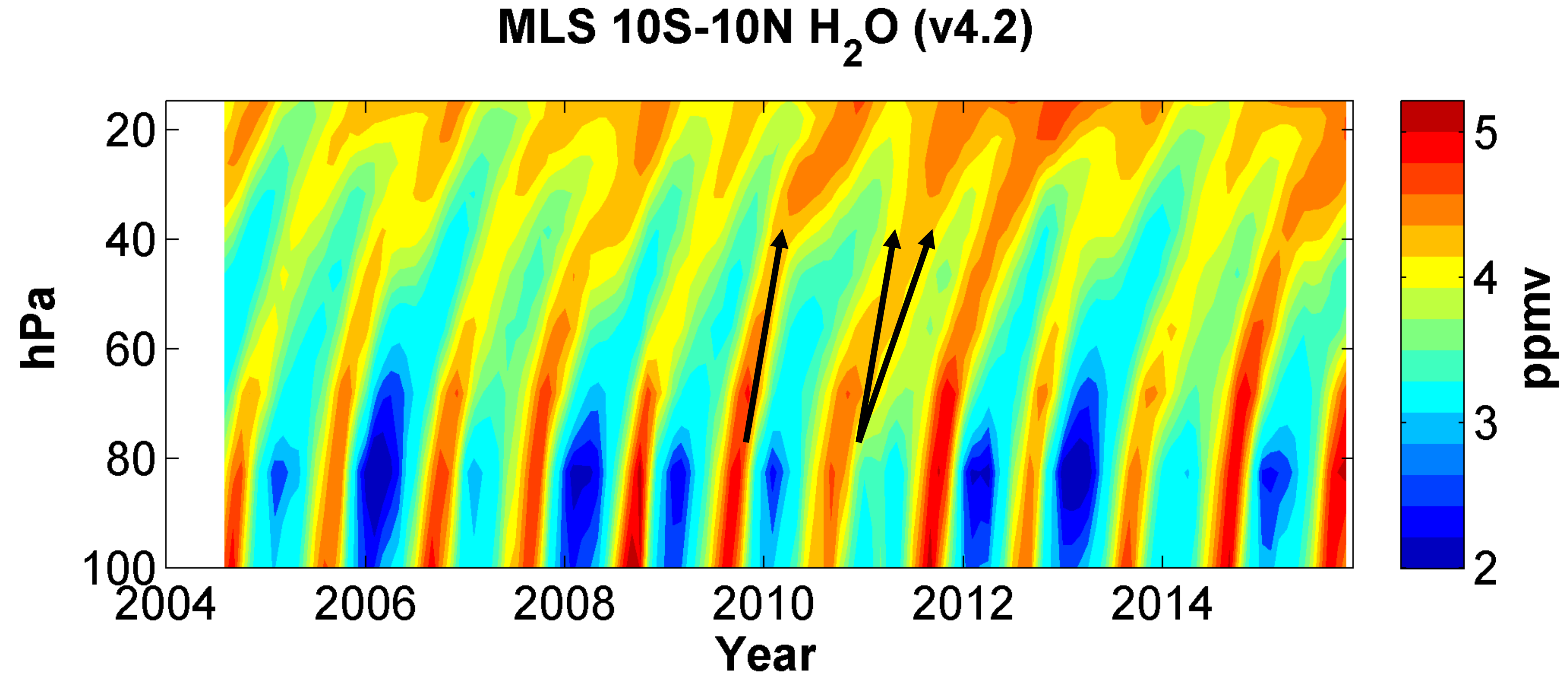
→ **comparing observations to WACCM**

Because water vapor is conserved after passing through the cold point, it's like a sound recorded on a tape…

Tape Recorder velocity (w_{TR})

method based on Schoeberl et al., 2008 and Niwano, 2003

an effective velocity that measures $\overline{w}^*$ + vertical mixing + horizontal mixing

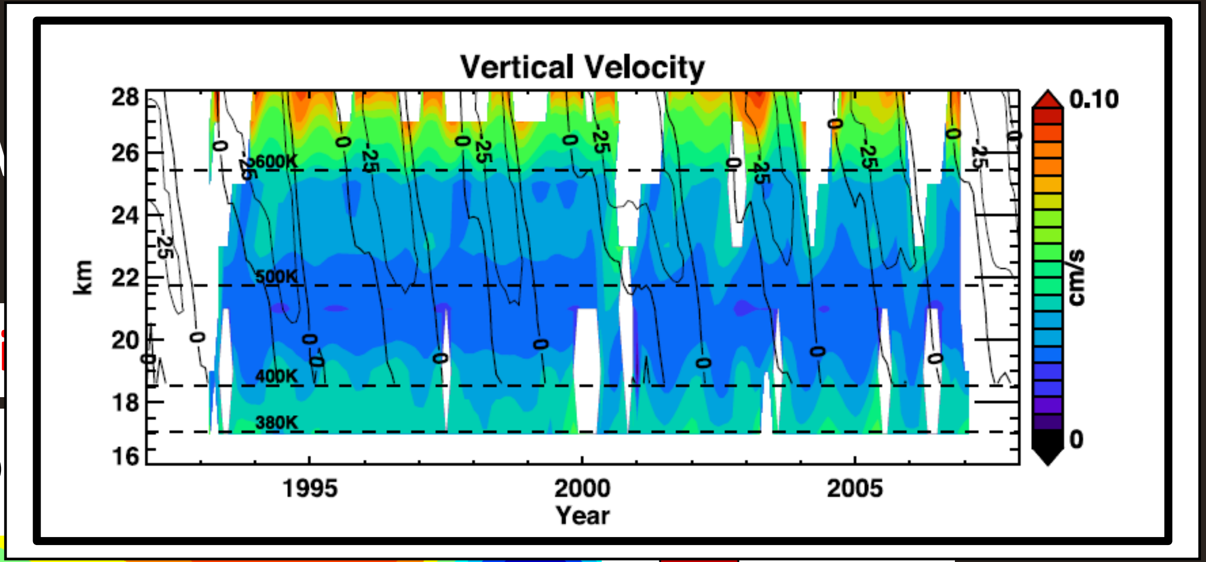


Because water vapor is conserved after passing through the cold point, it’s like a sound recorded on a tape…

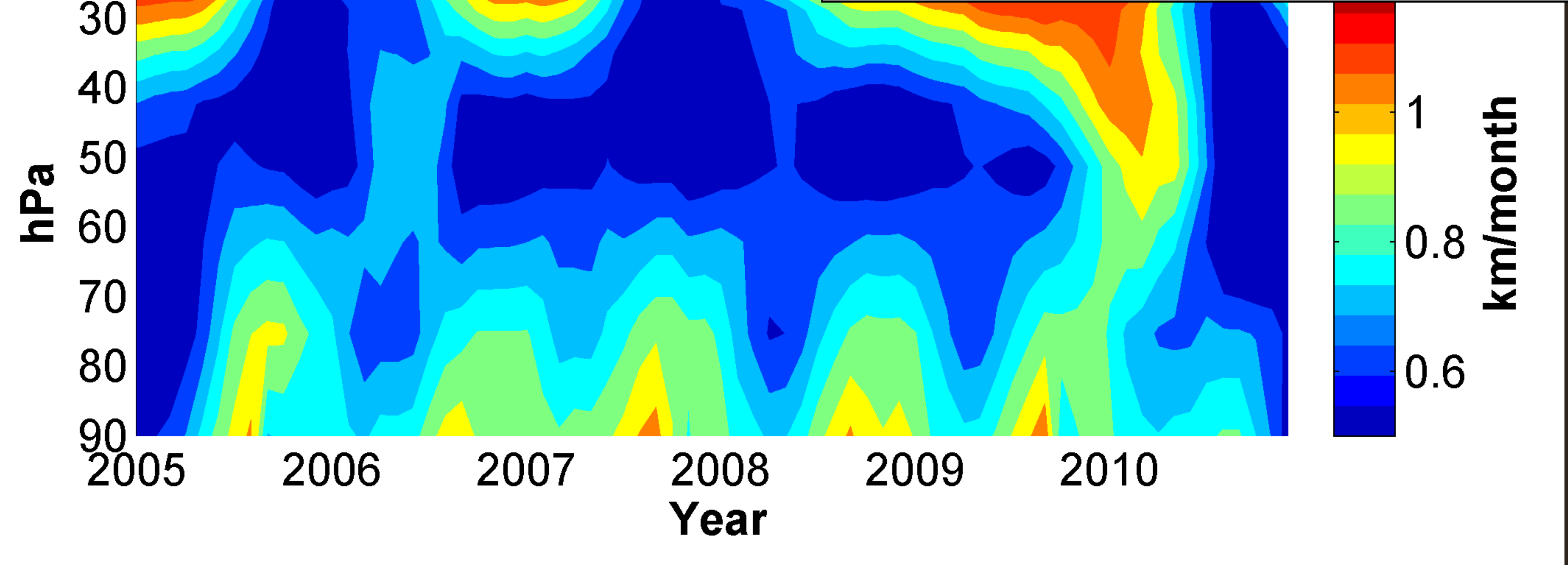
Tape Recorder velocity (w

method based on Schoeberl et al., 2008 and

total transport velocity = $\bar{w}^*$ + verti

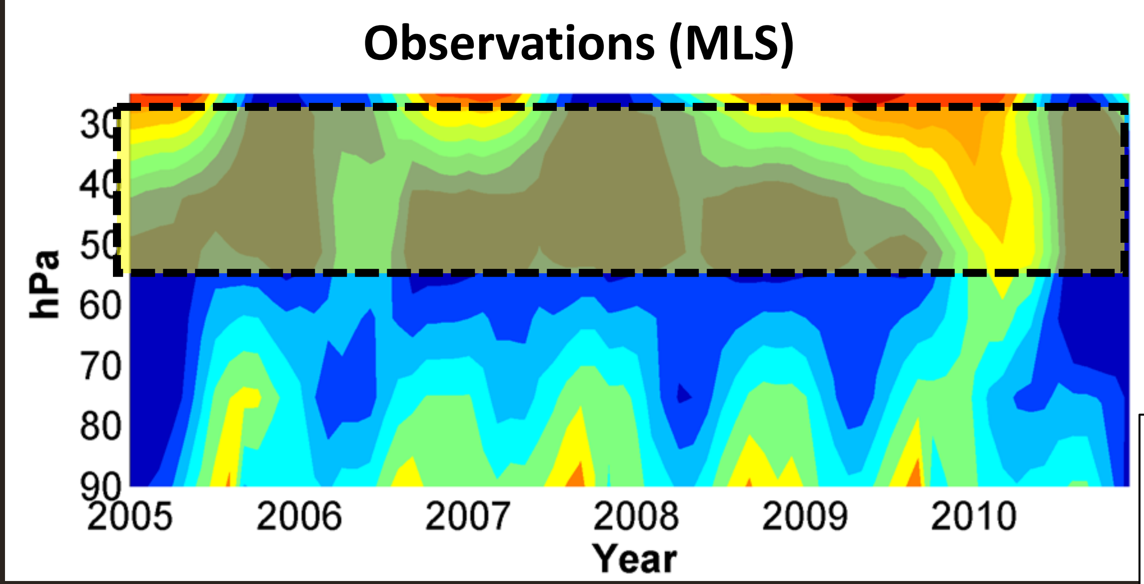


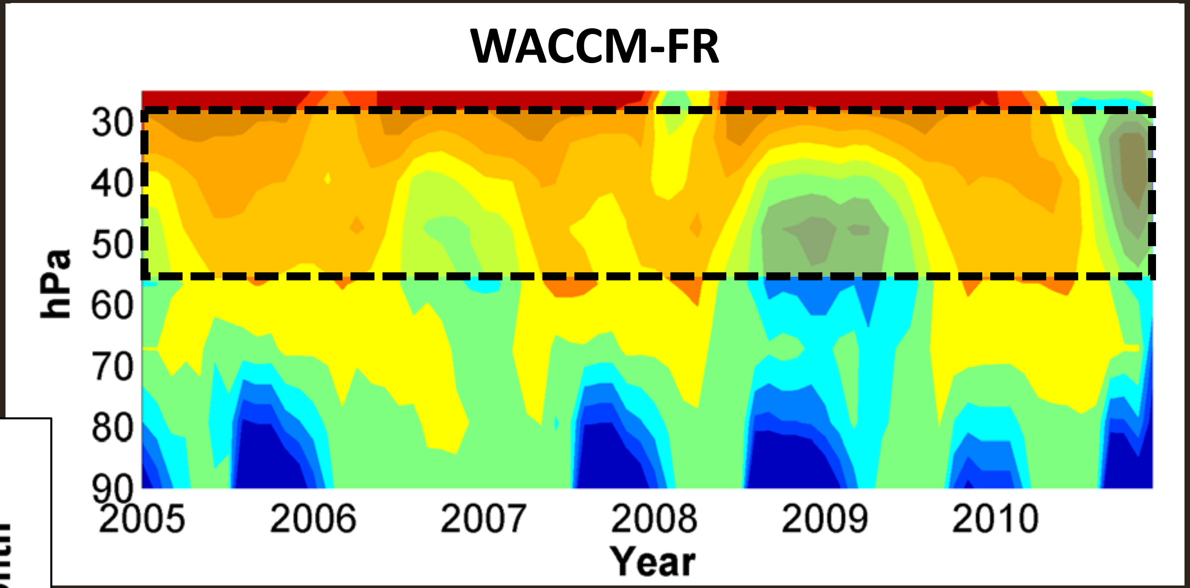
10S-10 Tape Reco

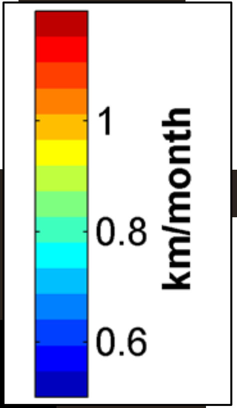


Tape Recorder velocity w_{TR}

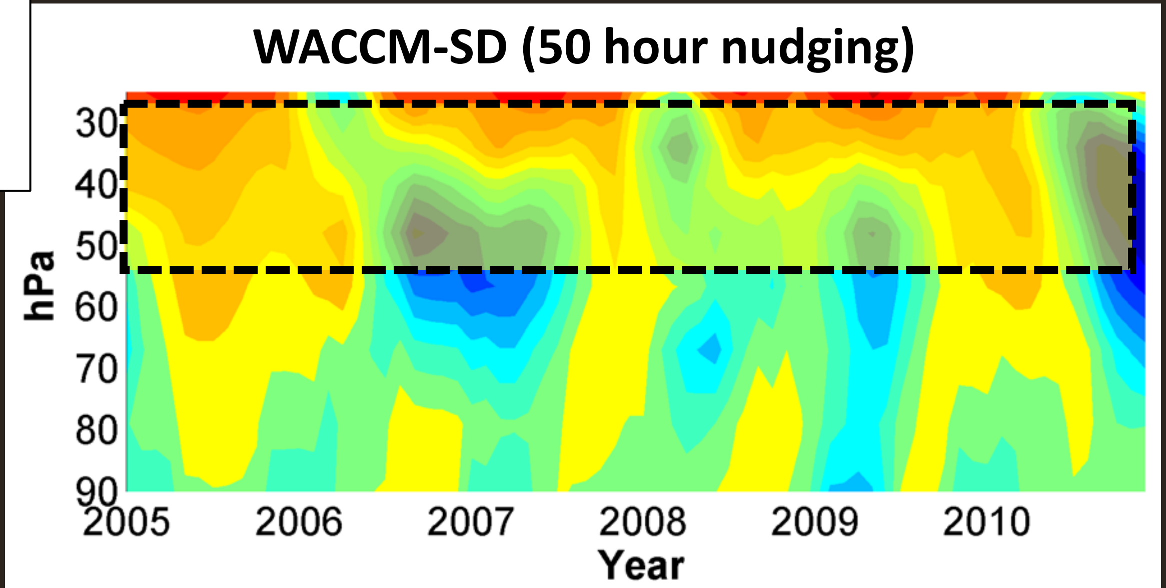
Fourier transform results
~75 day lead at 50 hPa


Observations (MLS)


WACCM-FR



In each simulation, the **dry signal moves too fast** (esp. during May/June) while the wet signal matches MLS very well


WACCM-SD (50 hour nudging)

~45 day lead at 50 hPa

Upwelling in the Tropics

total transport vs residual circulation

w_{TR} **Total Circulation**

$\bar{w}^*$ **Residual Circulation**

Tropical vertical transport response to ENSO and QBO

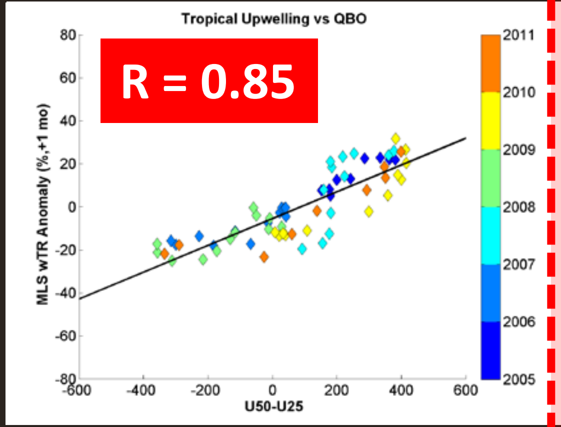
for 2005 thru 2010
QBO/ENSO R = 0.67

Observations

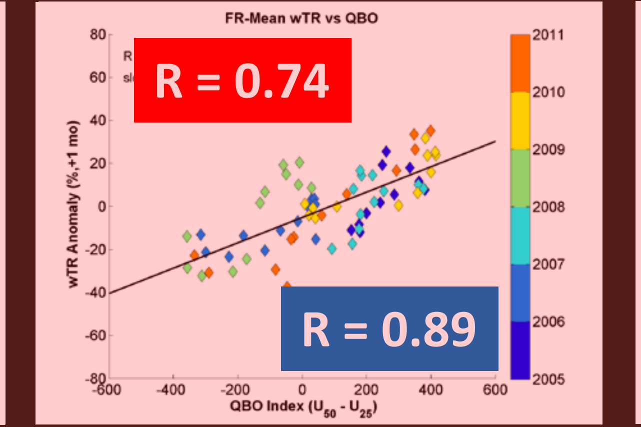
WACCM-FR

WACCM-SD (50hr)

w_{TR} vs QBO

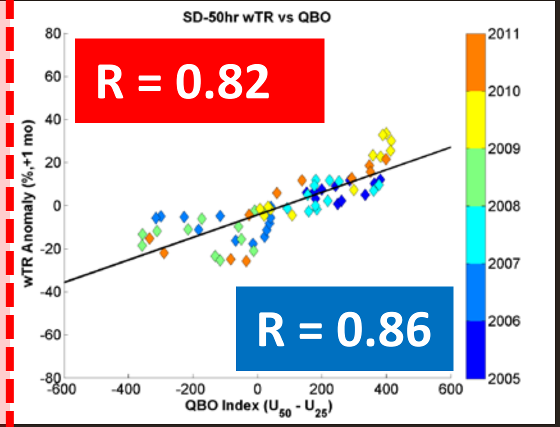

Tropical Upwelling vs QBO

R = 0.85


FR-Mean wTR vs QBO

R = 0.74

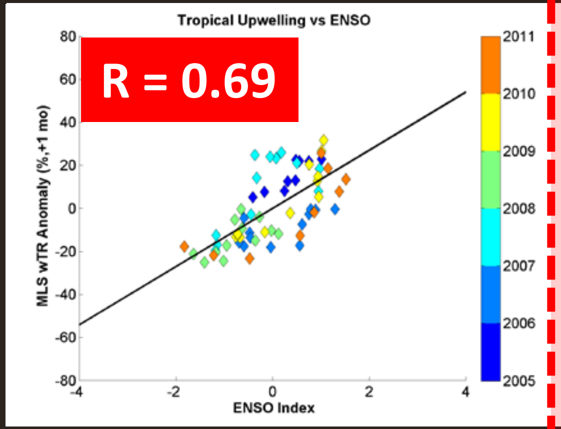
R = 0.89


SD-50hr wTR vs QBO

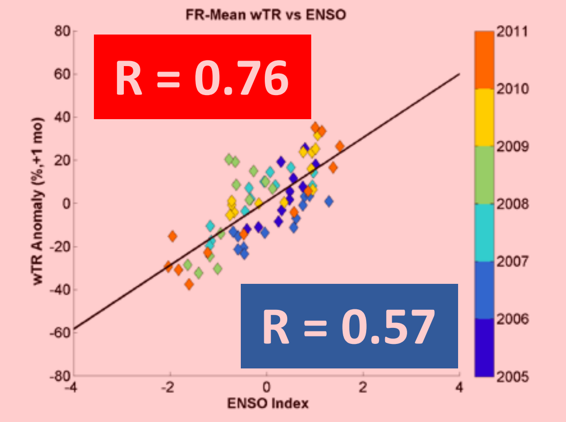
R = 0.82

R = 0.86

w_{TR} vs ENSO

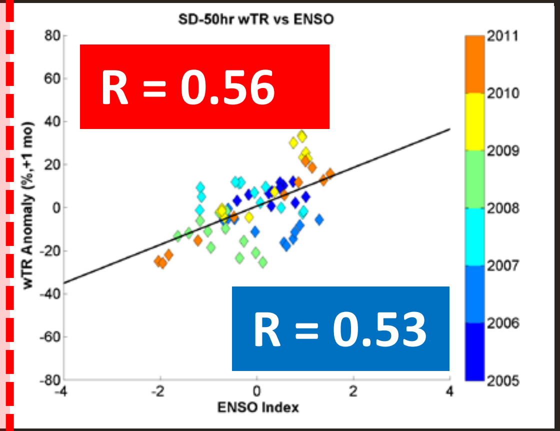

Tropical Upwelling vs ENSO

R = 0.69


FR-Mean wTR vs ENSO

R = 0.76

R = 0.57


SD-50hr wTR vs ENSO

R = 0.56

R = 0.53

Note: w_{TR} anomalies taken between 56-25 hPa

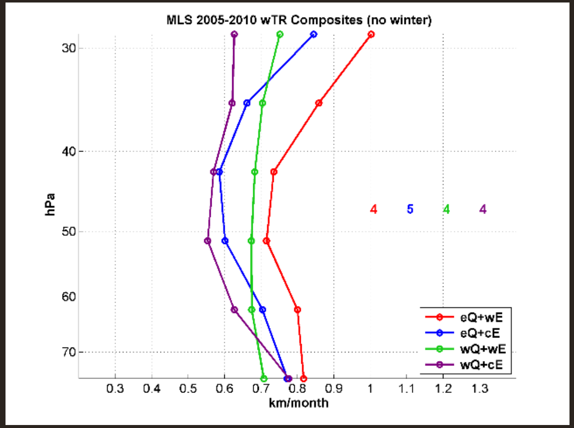
Tropical vertical transport composites

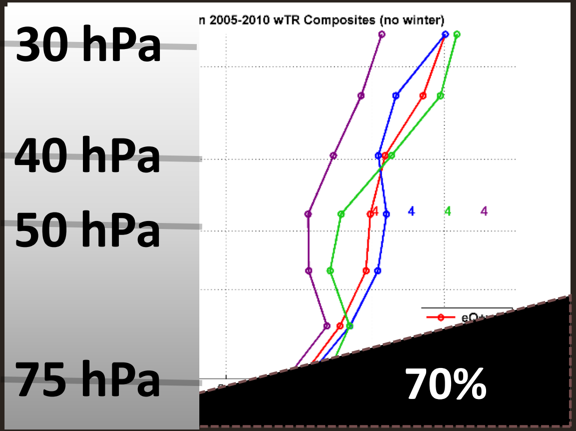
for different QBO/ENSO combinations

for 2005 thru 2010
QBO/ENSO R = 0.67

warm ENSO dominates	**?**	**easterly QBO dominates**
Observations	**WACCM-FR**	**WACCM-SD (50hr)**

w_{TR}





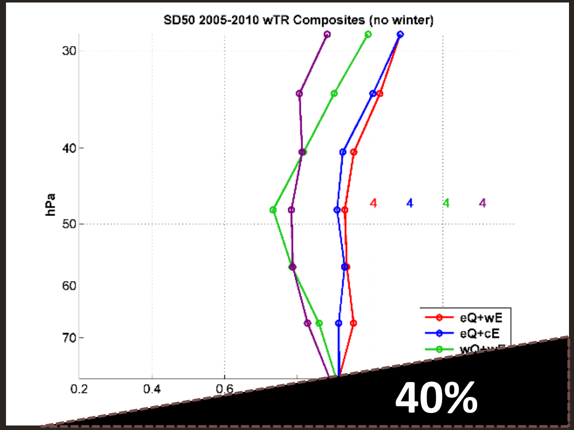
30 hPa

40 hPa

50 hPa

75 hPa

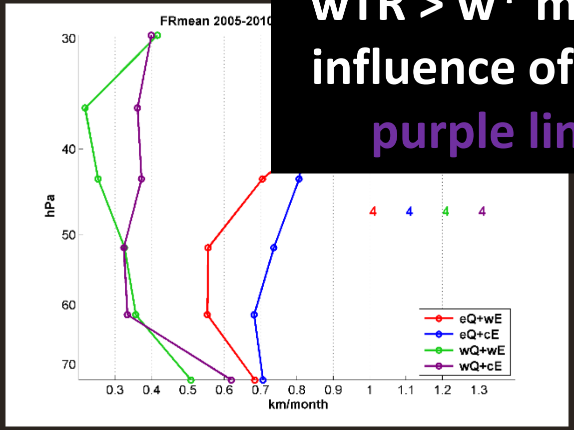
70%

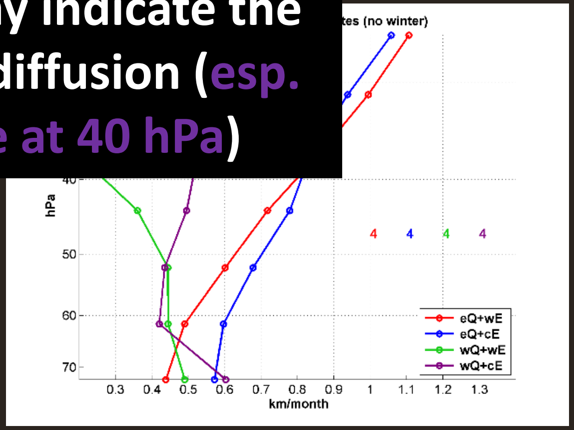


40%

- 🟥 easterly QBO + warm ENSO
- 🟦 easterly QBO + cold ENSO
- 🟩 westerly QBO + warm ENSO
- 🟪 westerly QBO + cold ENSO

$\overline{w}^*$





wTR > w* may indicate the influence of diffusion (esp. purple line at 40 hPa)

30 hPa

40 hPa

50 hPa

75 hPa

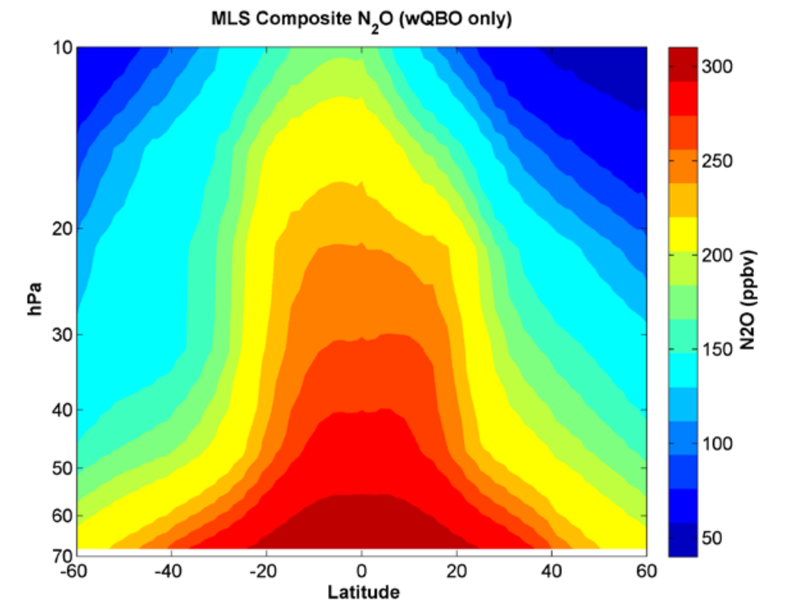
Deep Branch Transport

using N_2O

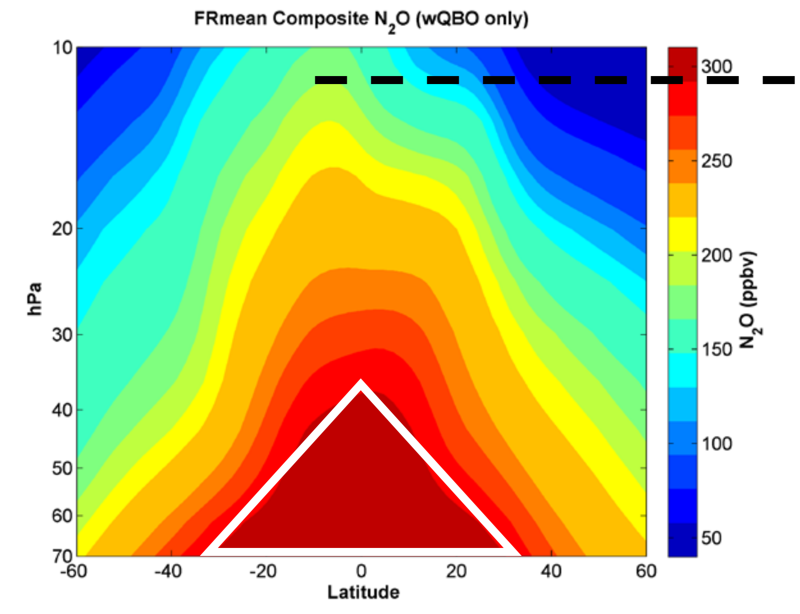
N_2O Composites for westerly QBO

for 2004 thru 2014
QBO/ENSO R = 0.47

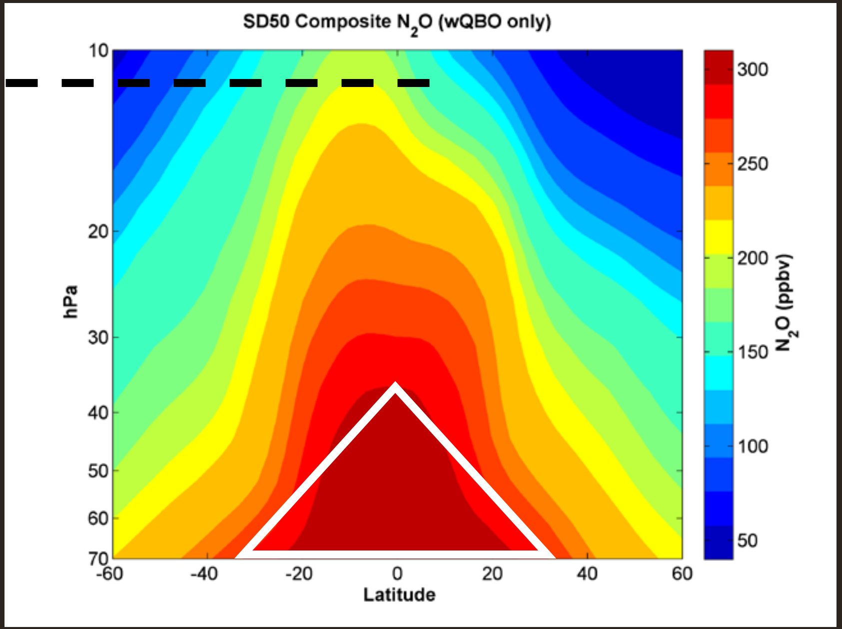
Observations



WACCM-FR



WACCM-SD (50hr)



w_{TR} **Total Circulation**

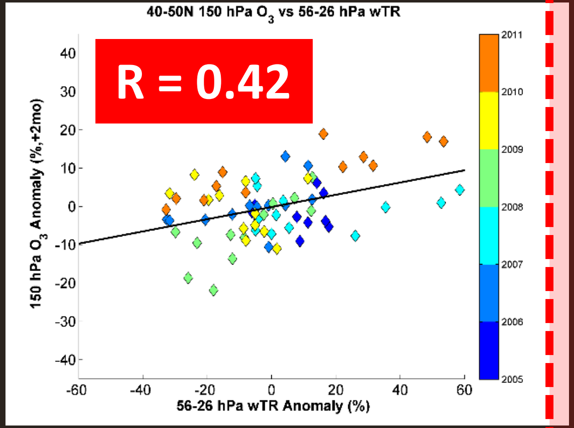
$\overline{w}^*$ **Residual Circulation**

Midlatitude (40N-50N) stratospheric (150 hPa) ozone response to wTR

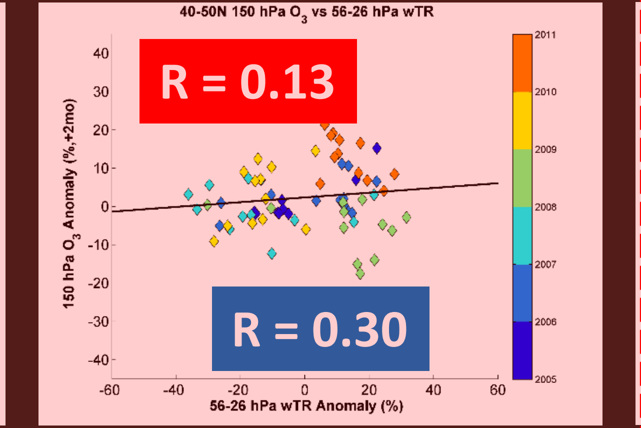
for 2005 thru 2010
QBO/ENSO R = 0.67

Observations | **WACCM-FR** | **WACCM-SD (50hr)**

w_{TR} vs midlatitude O_3

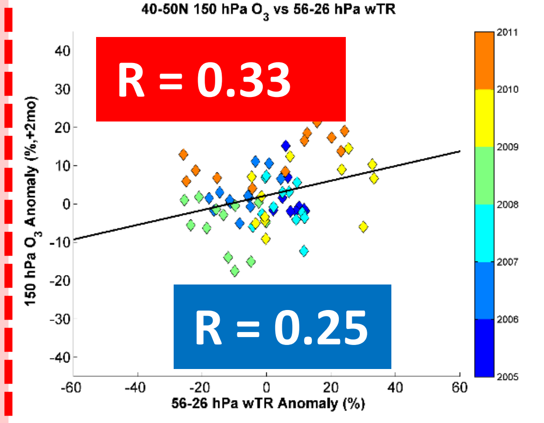

40-50N 150 hPa O_3 vs 56-26 hPa wTR

R = 0.42


40-50N 150 hPa O_3 vs 56-26 hPa wTR

R = 0.13

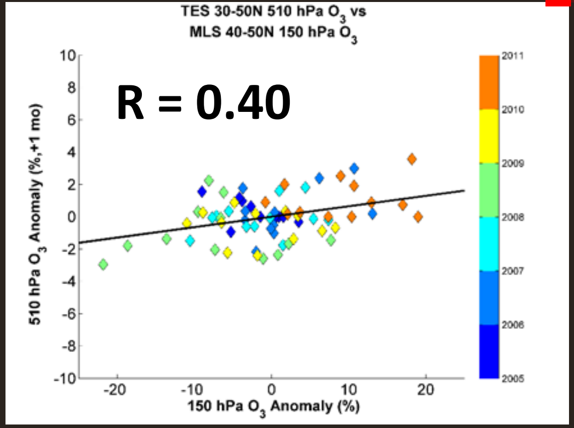
R = 0.30


40-50N 150 hPa O_3 vs 56-26 hPa wTR

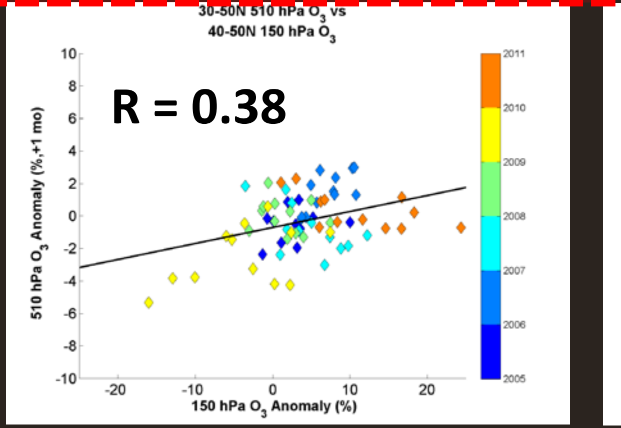
R = 0.33

R = 0.25

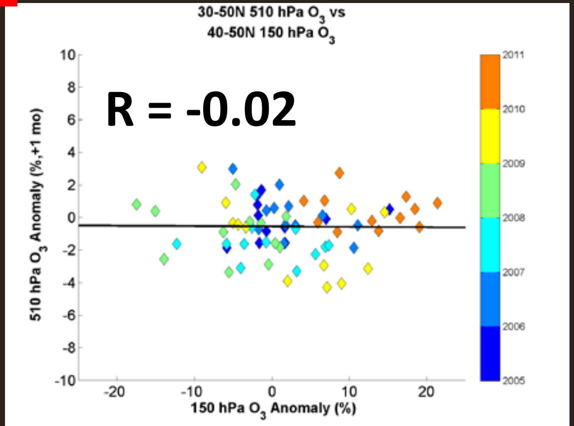
150 hPa O_3 vs 510 hPa O_3


TES 30-50N 510 hPa O_3 vs MLS 40-50N 150 hPa O_3

R = 0.40


30-50N 510 hPa O_3 vs 40-50N 150 hPa O_3

R = 0.38


30-50N 510 hPa O_3 vs 40-50N 150 hPa O_3

R = -0.02

Note: w_{TR} anomalies taken between 56-25 hPa

Conclusions

- Both ENSO and QBO drive year-to-year changes in the circulation, but model/observation agreement depends on your location
  - Tropical Upwelling: FR and SD
  - Deep Branch Transport: SD
  - Midlatitude Ozone Flux: FR (Neu's talk)
- **Middle-stratosphere tropical total transport (wTR) variability**
  - **FR is driven equally by QBO and ENSO**
  - **SD is driven more by QBO (~30%) than ENSO**
  - **Observations are driven more by QBO (~20%) than ENSO**
- **On all measures, there is a larger wTR vs w* difference in the FR**
  - Meaning potentially more vertical or horizontal diffusion in FR
  - Westerly phase of QBO reaches further poleward in FR → RW could propagate further equatorward → more mixing between the tropics/subtropics and midlatitudes (between 50-70 hPa)

Tropical vertical transport driven by different waves

Downward control calculations show significant differences in the wave-driven response to ENSO and QBO in FR and SD

Note: Downward control taken over 22S-22N

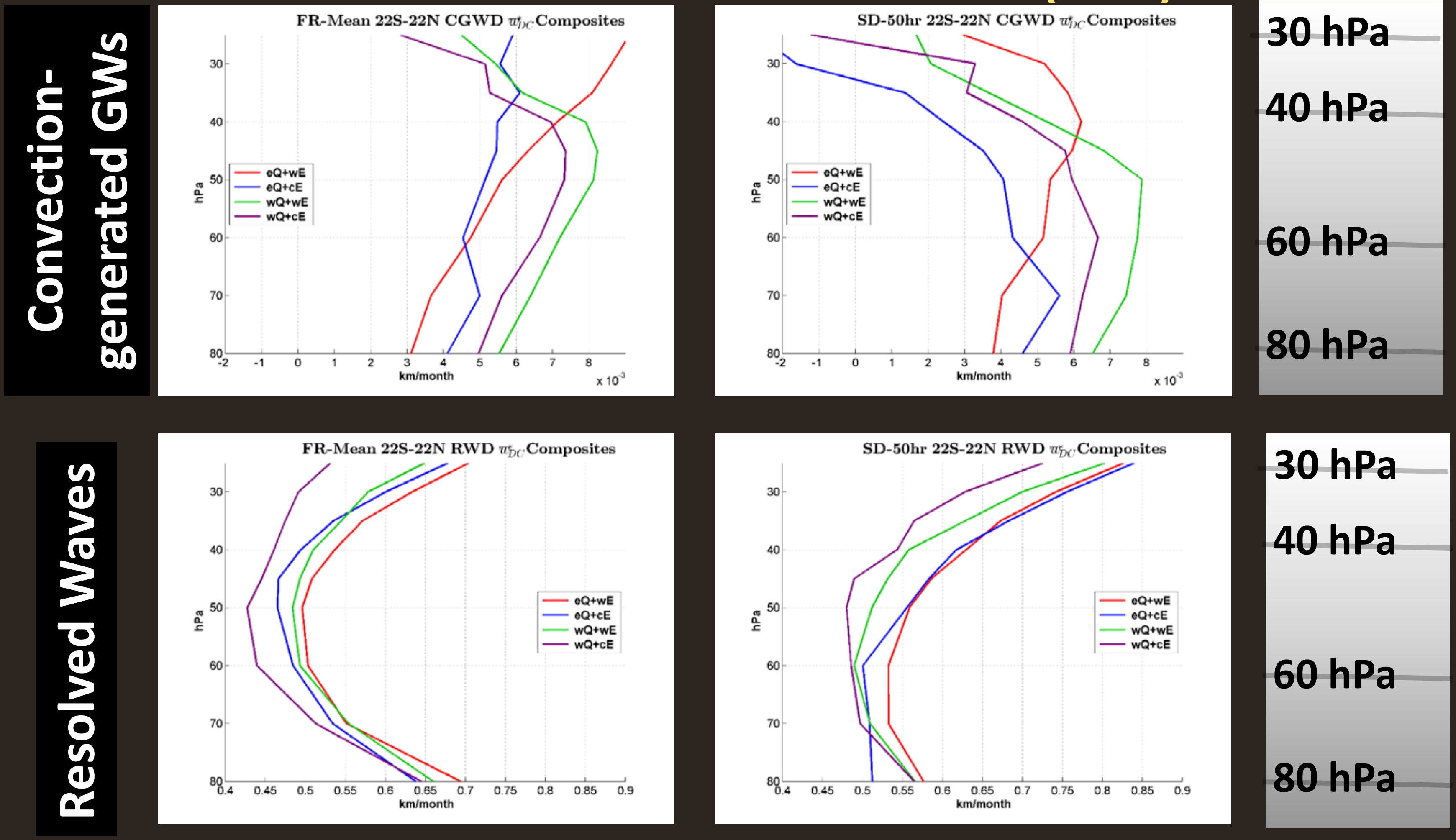
easterly QBO + warm ENSO

easterly QBO + cold ENSO

westerly QBO + warm ENSO

westerly QBO + cold ENSO

WACCM-FR **WACCM-SD (50hr)**



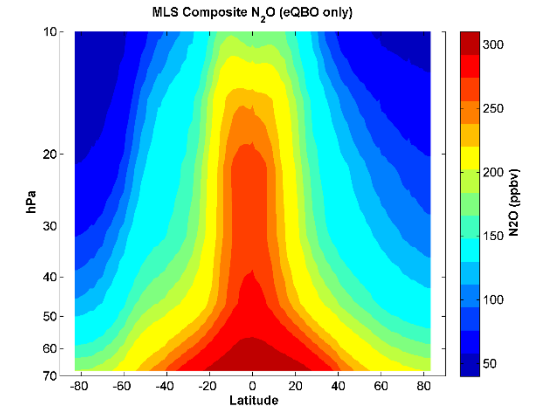
Global N_2O composit

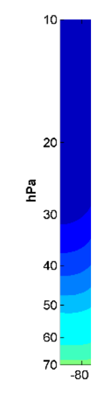
for 2004 thru 2014
QBO/ENSO R = 0.47

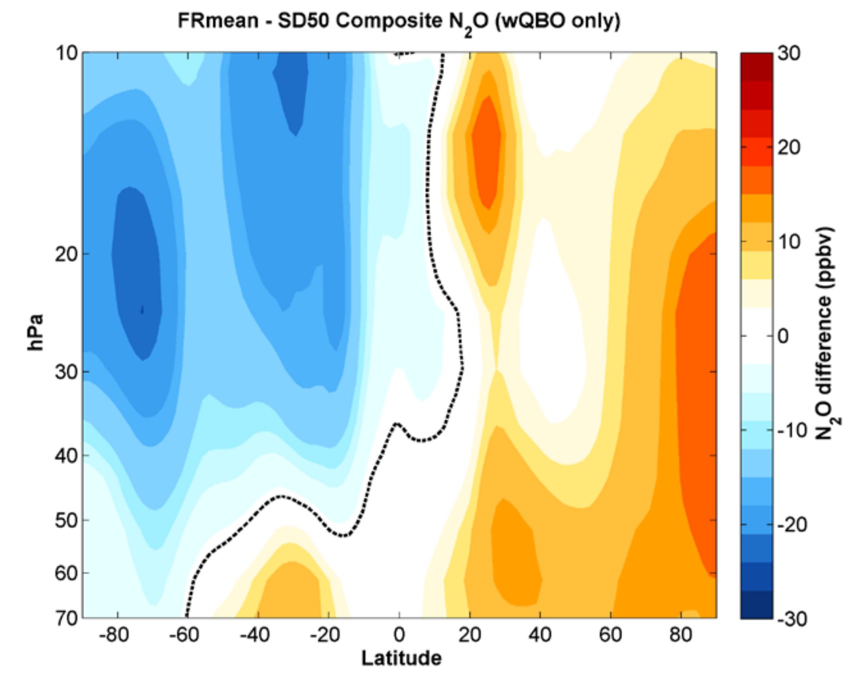
Observations

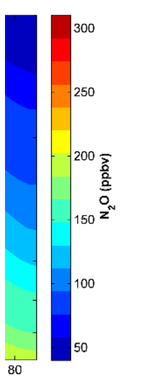
0hr)

Easterly QBO









10 hPa

20 hPa

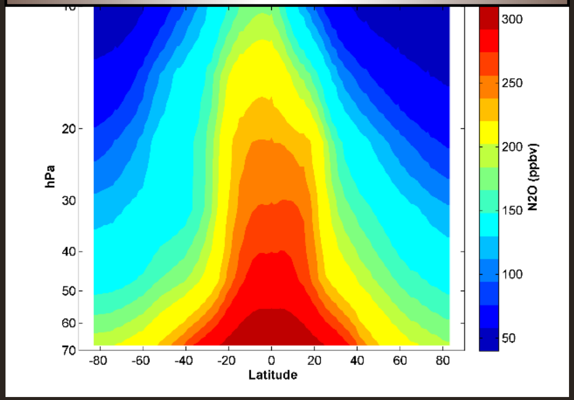
40 hPa

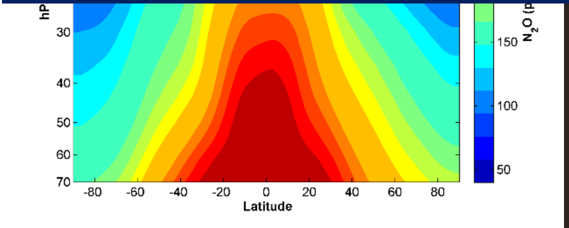
70 hPa

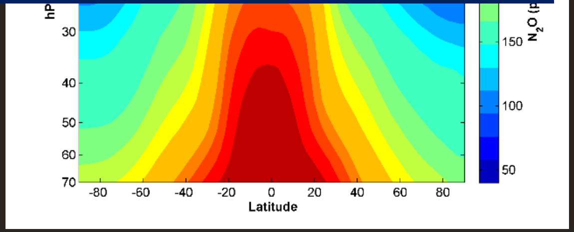
90S **0** **90N**

Westerly QBO

- NH latitudinal gradient 20% weaker in FR
- FR flux of N2O doesn't reach as high as SD/obs
- Winter residual circulation stronger bend in SD?





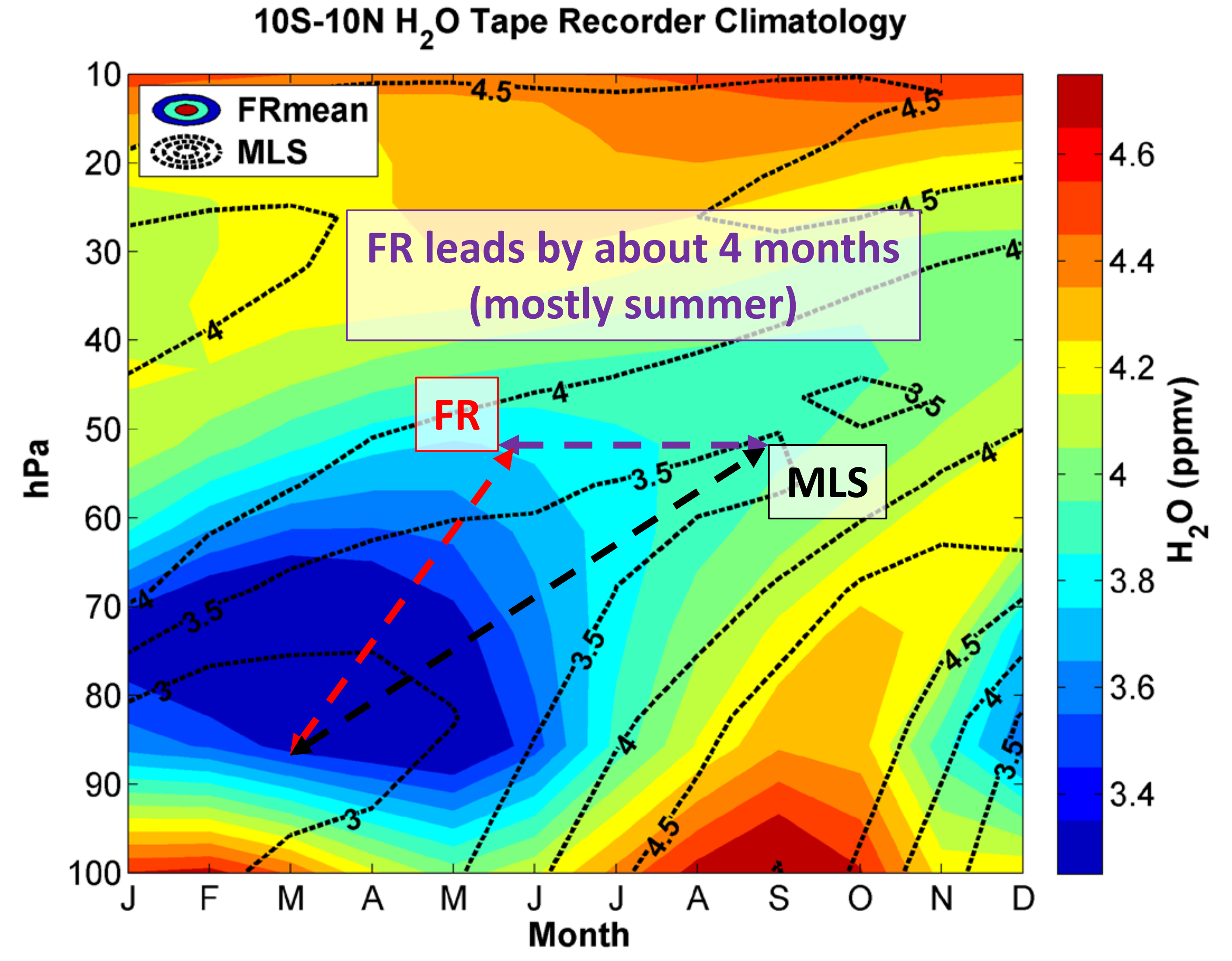


10 hPa

20 hPa

40 hPa

70 hPa



FR leads by about 4 months
(mostly summer)

Vertical advection composites

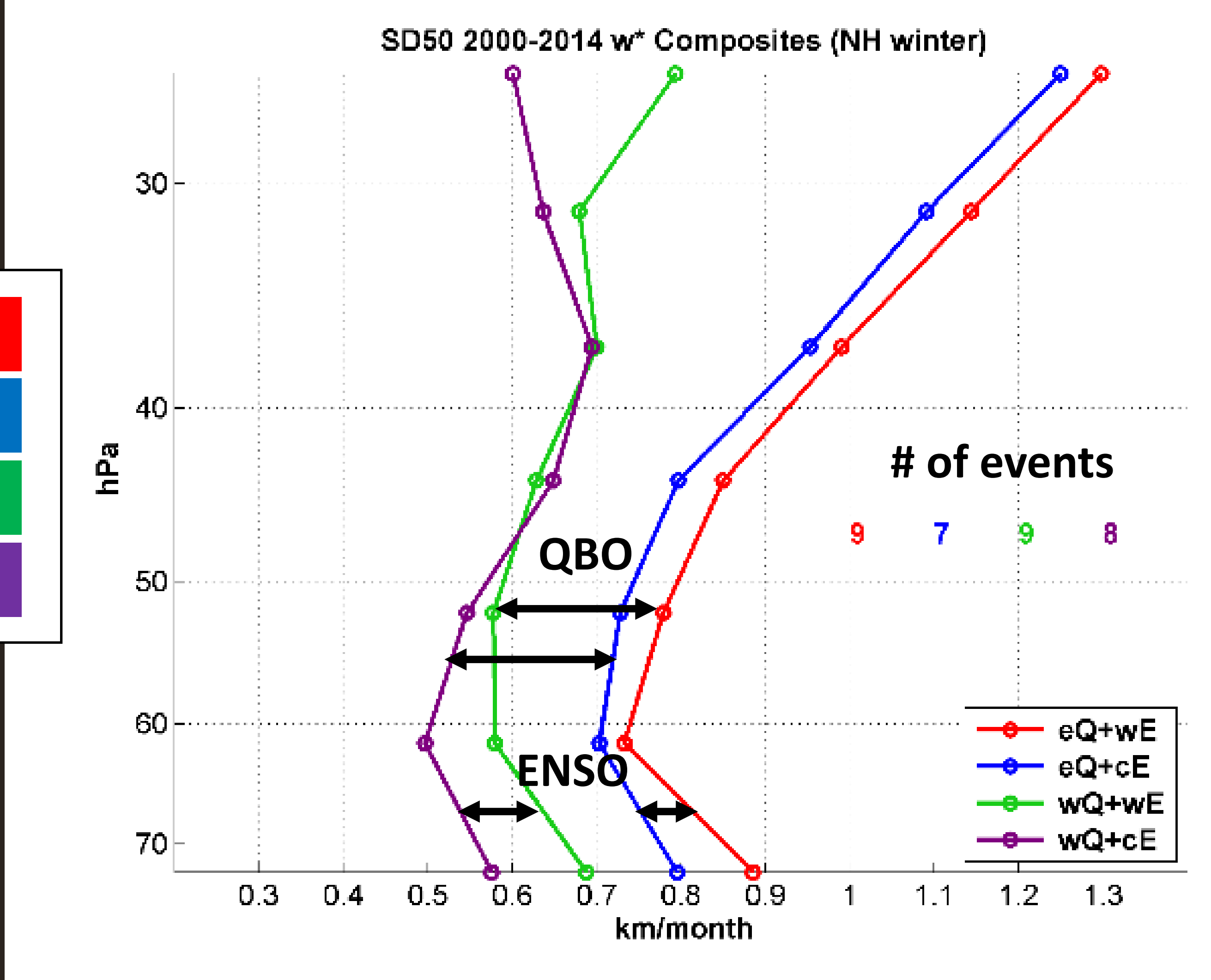
for different QBO/ENSO combinations

easterly QBO + warm ENSO

easterly QBO + cold ENSO

westerly QBO + warm ENSO

westerly QBO + cold ENSO



Tape Recorder velocity w_{TR}

with easterly winds and ENSO Index overlaid