Decadal-Scale Variability in Stratospheric Circulation and Tracer Transport

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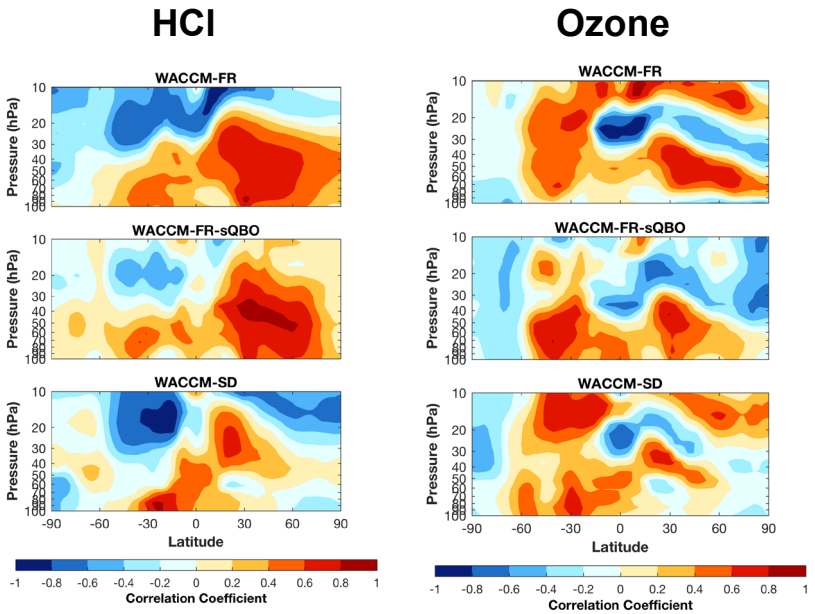
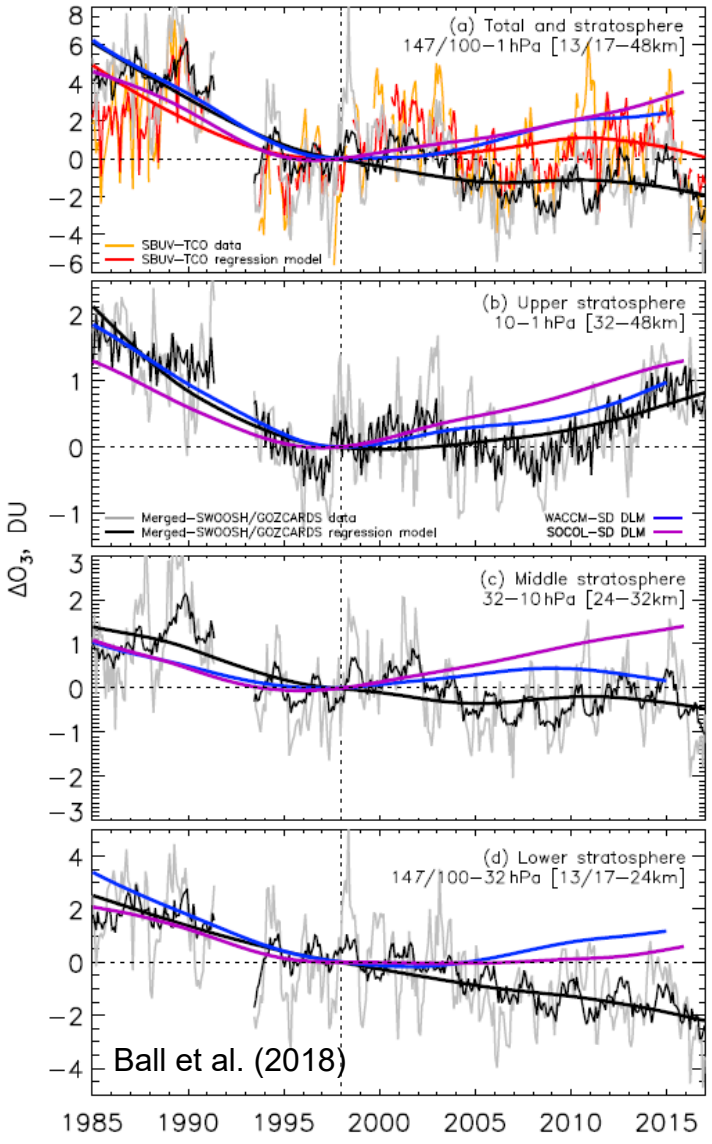
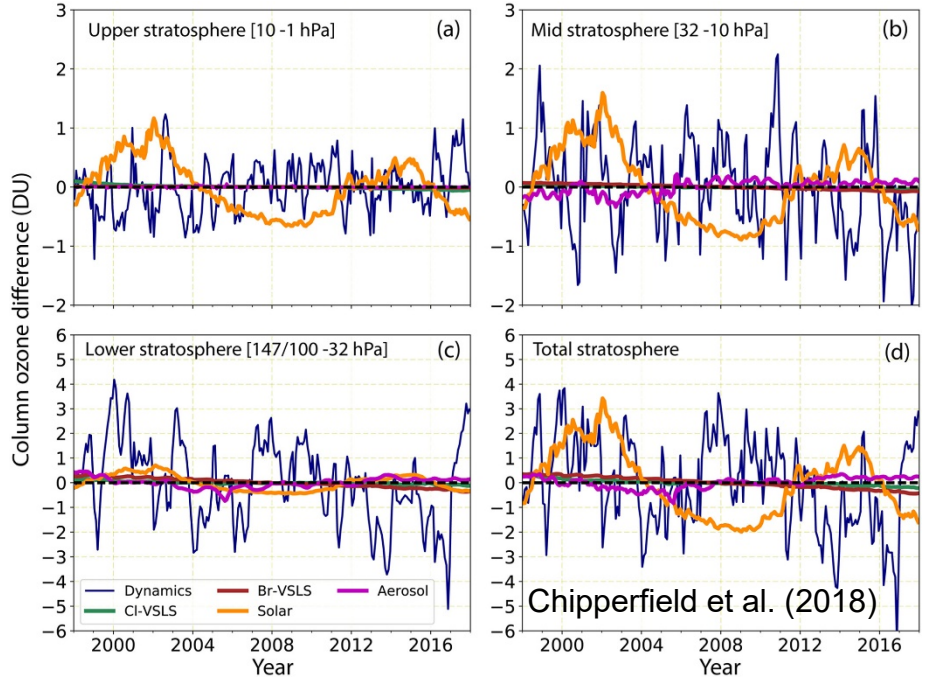


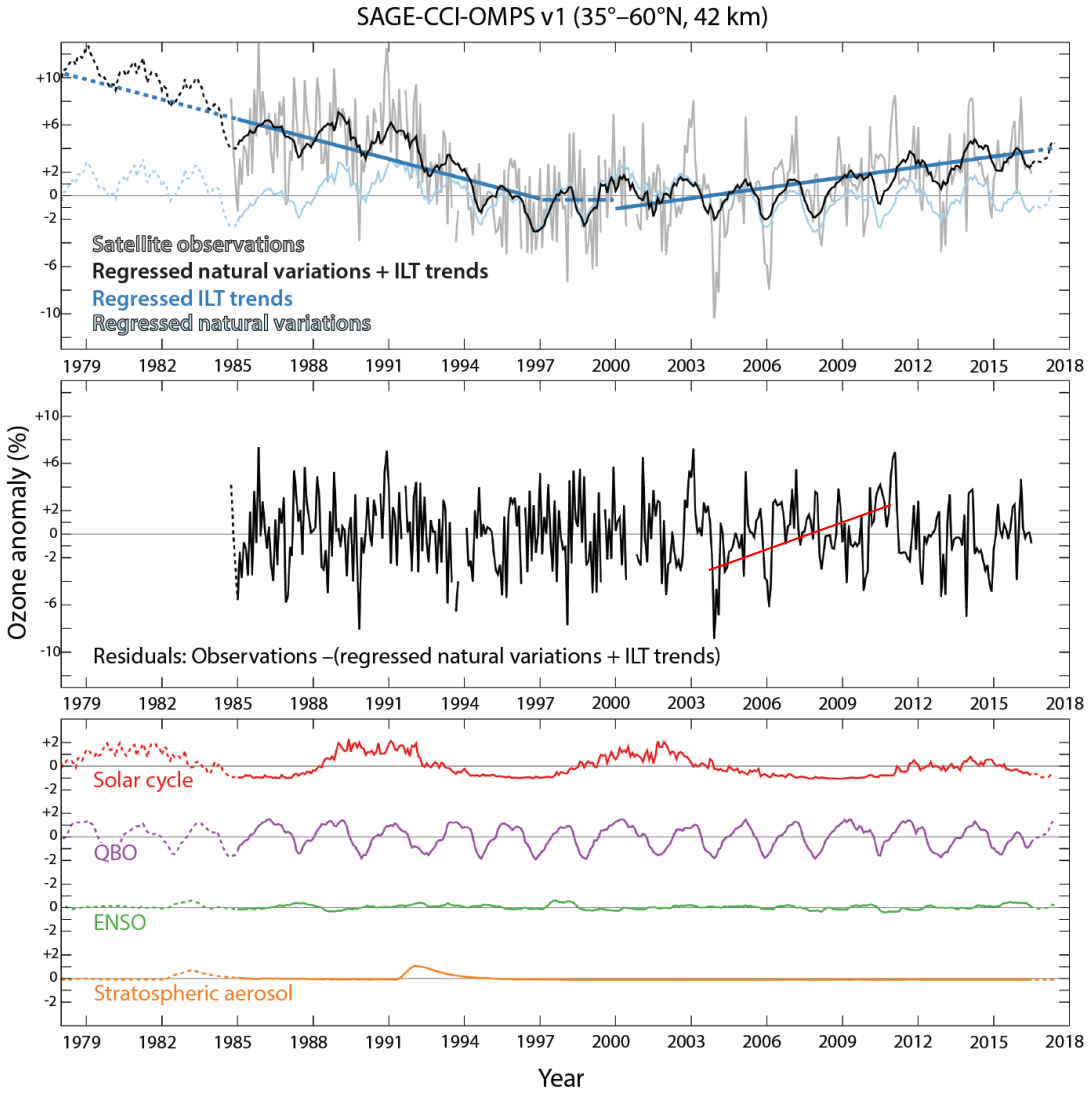
Moving Beyond Attribution to “Dynamical Variability”



- Variability and trends in stratospheric tracers are often ascribed to “dynamical variability”, without an understanding of what underlying natural processes are at work.
- If we can better understand the drivers of this dynamical variability, we can better account for it when assessing anthropogenically-driven trends.

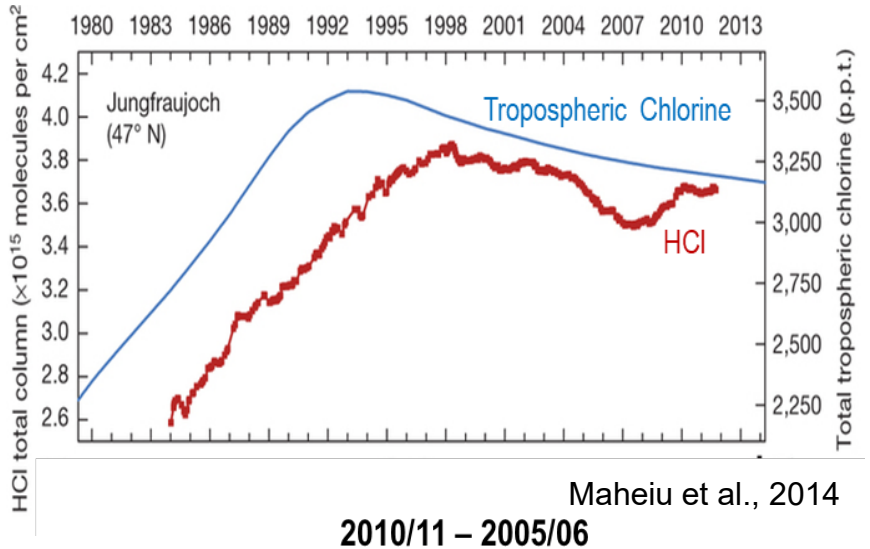


Decadal-scale variability driven by the QBO

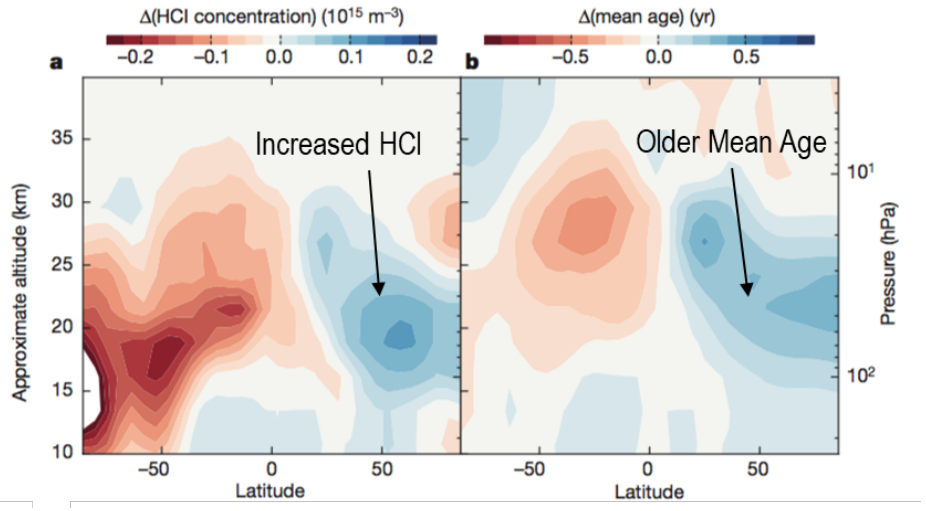


- The residuals of MLR fits to trace gas measurements in the stratosphere are large.
- We are not capturing much of the actual variability in trace gases, yet we believe it is primarily dynamically driven.

Stratospheric Trace Gases 2004-2012

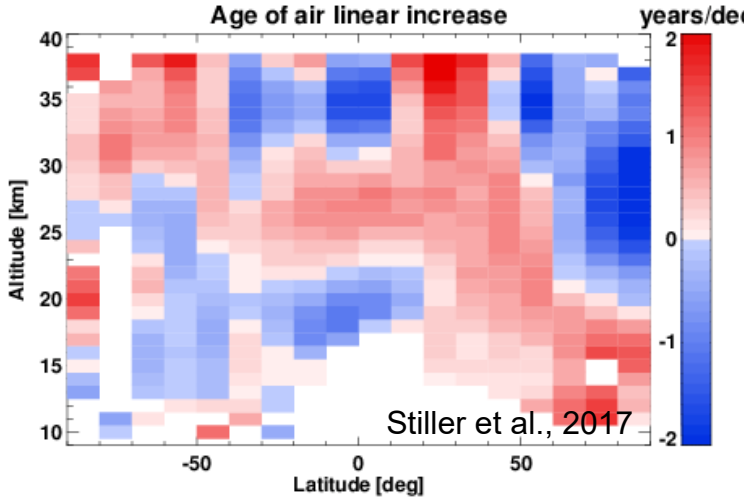


Maheiu et al., 2014



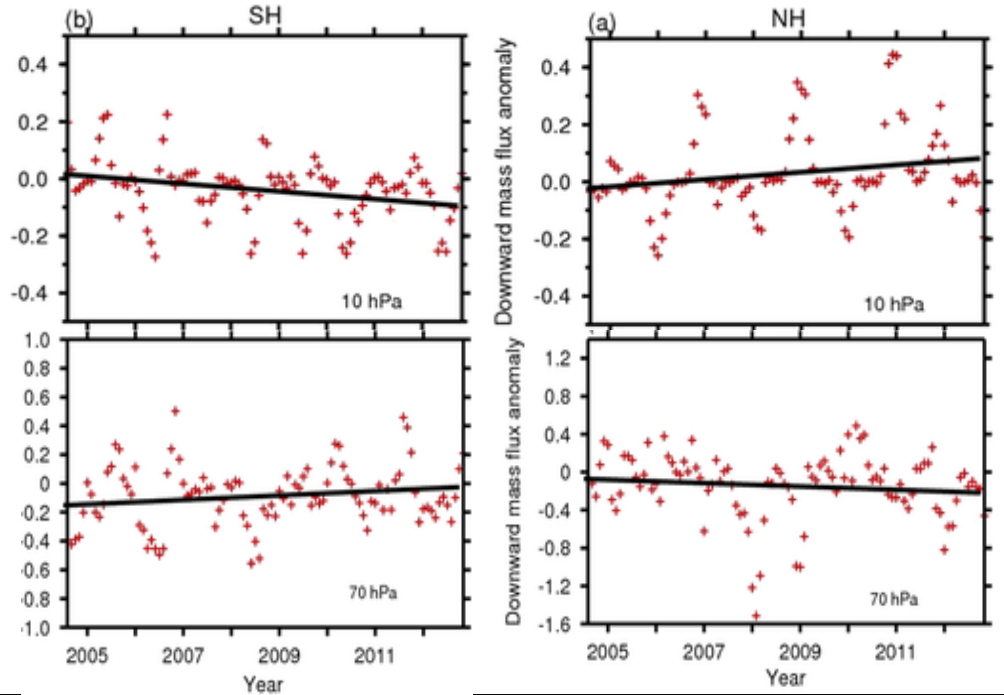
2010/11 – 2005/06

- Numerous recent studies have focused on the evolution of stratospheric trace gases from 2004-2012.



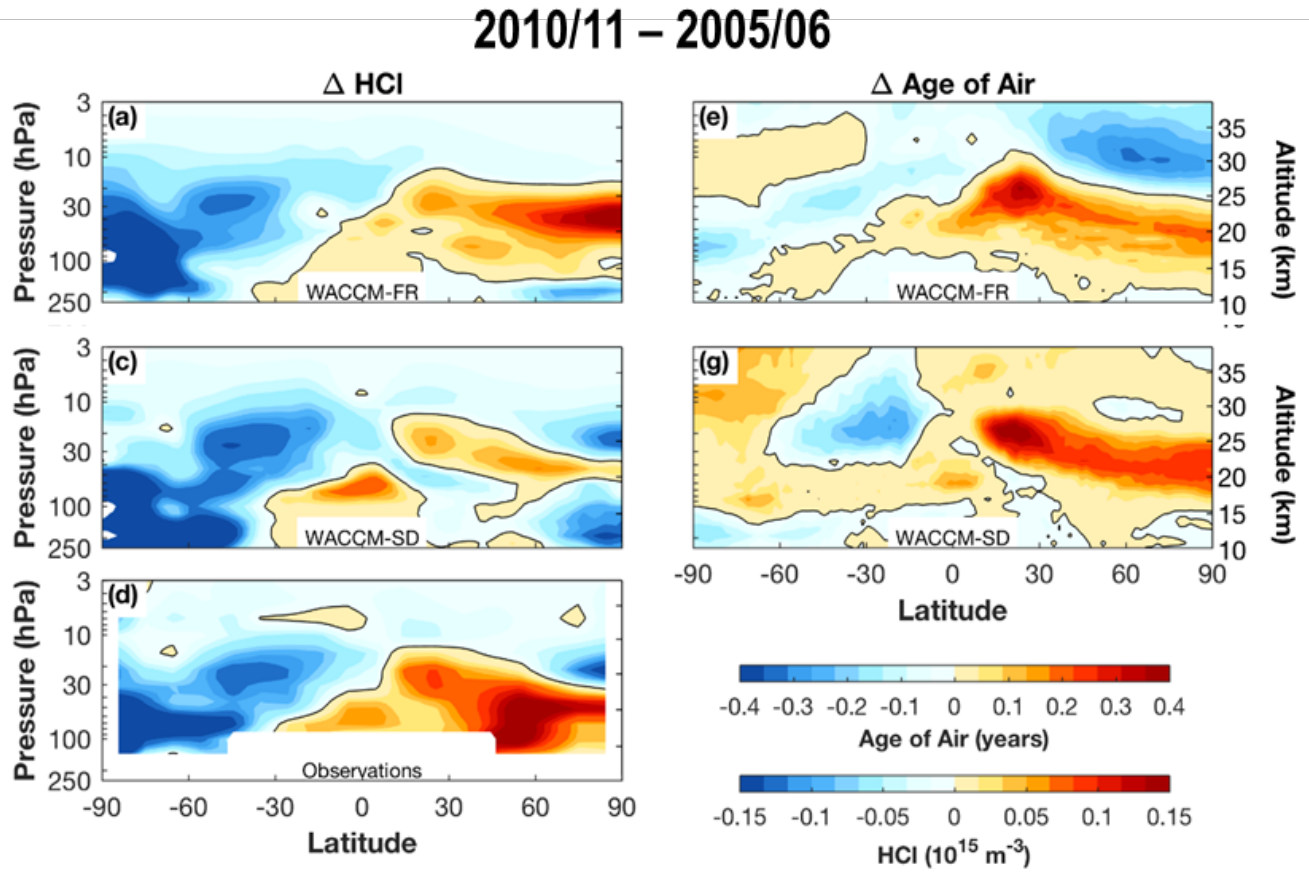
Stiller et al., 2017

Downwelling Mass Fluxes at 10 and 70 hPa



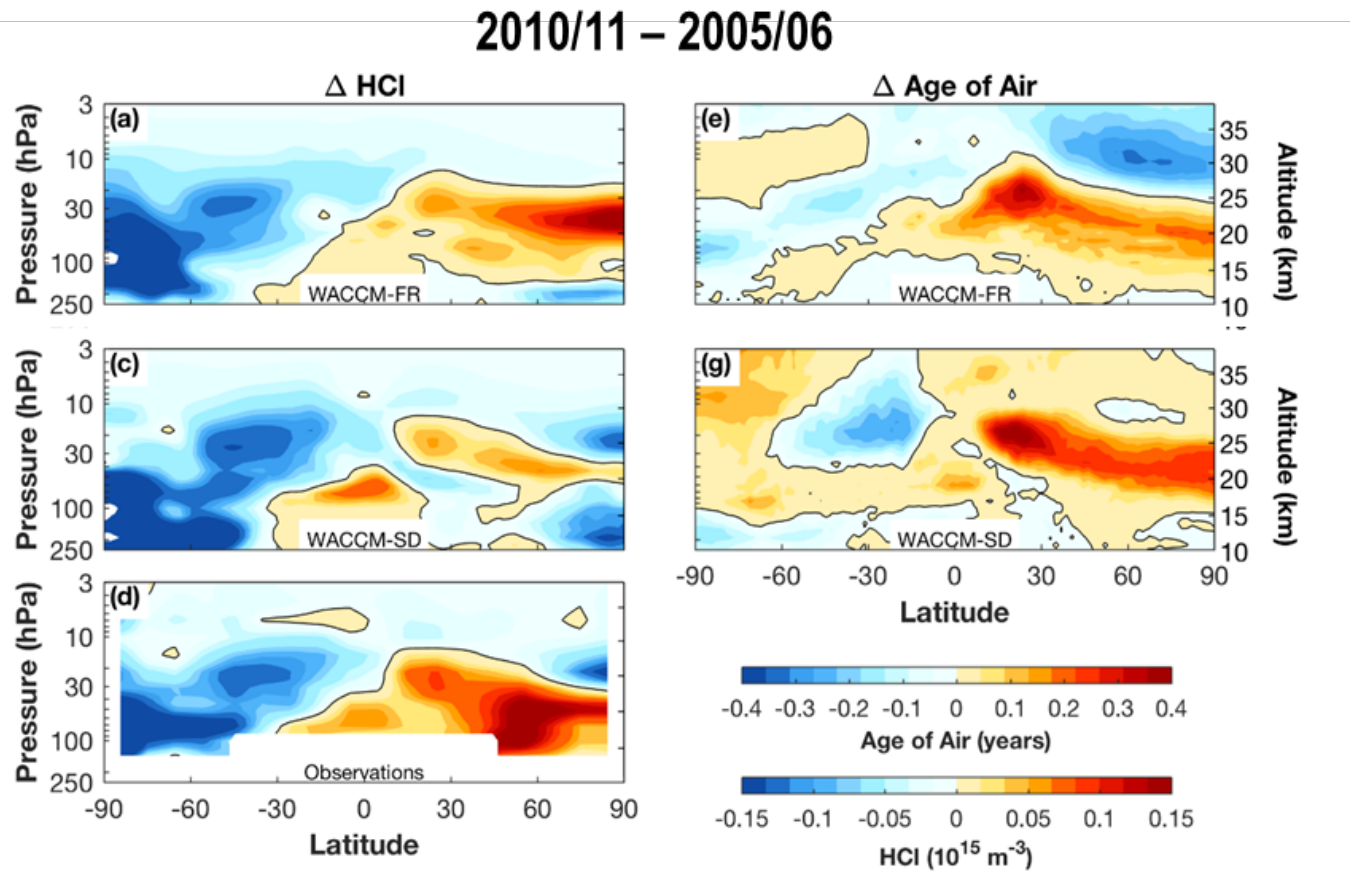
Han et al., 2018

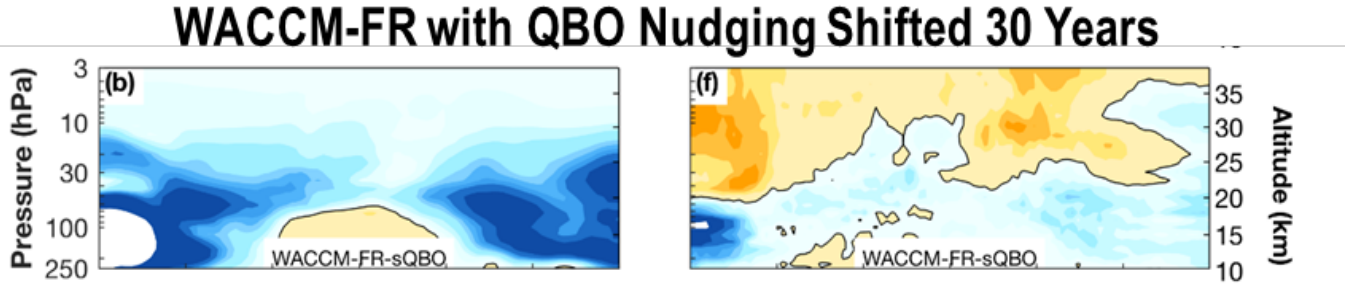
WACCM Simulations of HCl and Age of Air



- The QBO is nudged to Singapore winds in WACCM-FR, while all of the meteorology is nudged to MERRA in WACCM-SD.

What Would Have Happened With a Different QBO?



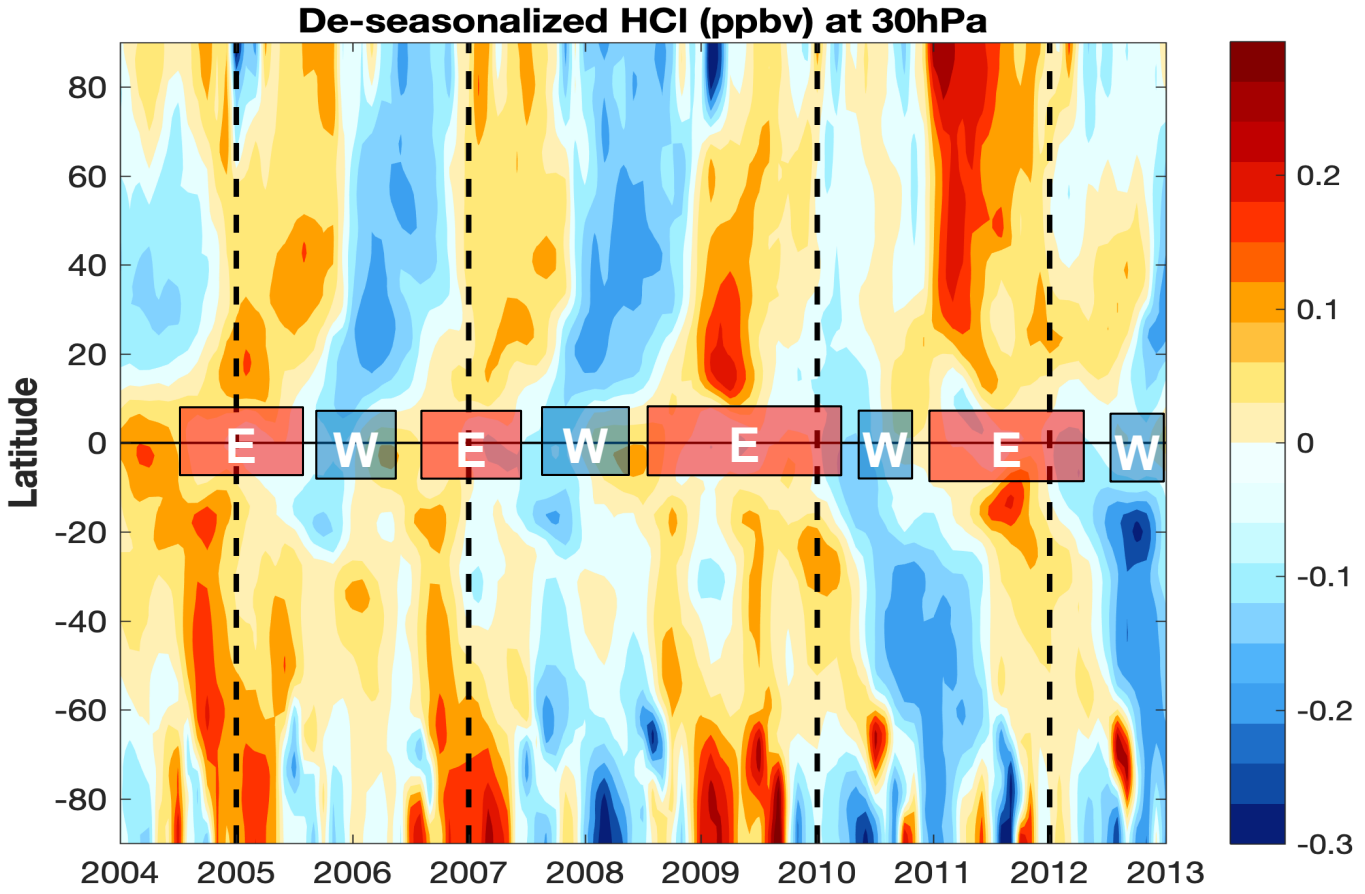


- In a simulation in which the QBO nudging in WACCM-FR is shifted by 30 years (i.e. year 2005 was nudged to the 1975 QBO), the 2005-2010 NH HCl and Age of Air changes are of the opposite sign.

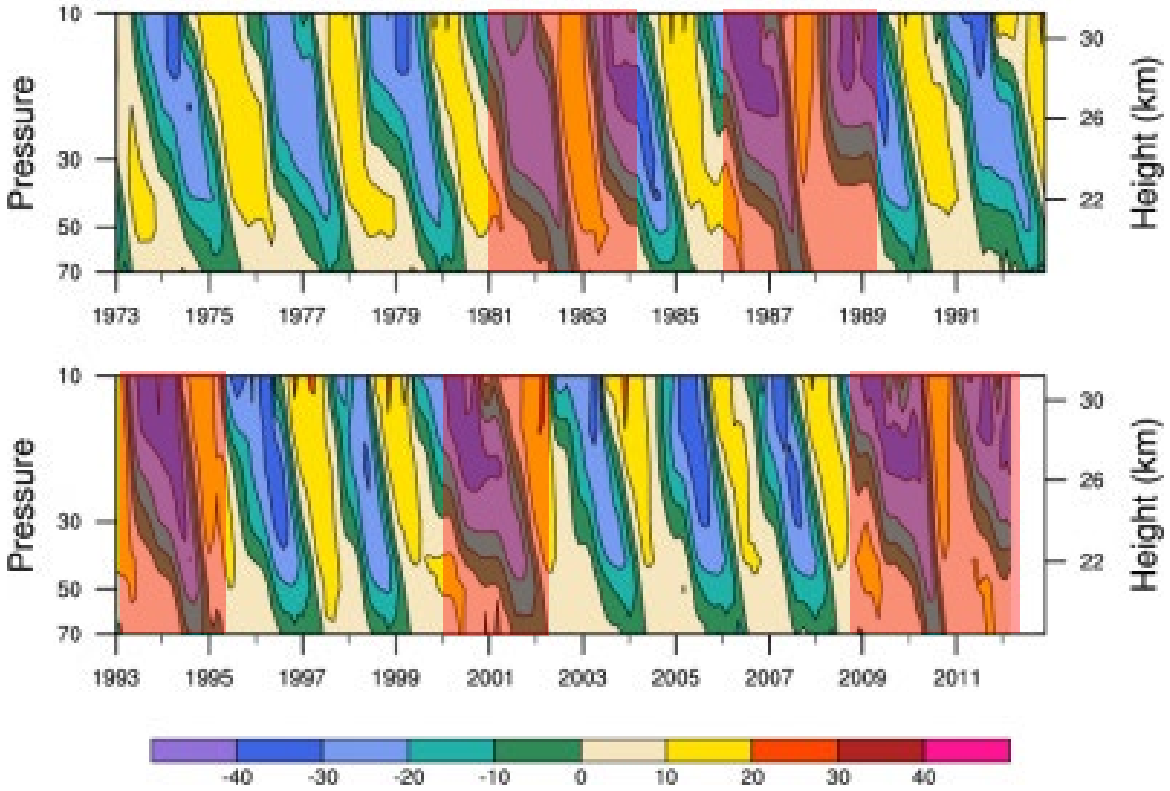
Clearly, the evolution of the QBO played a critical role in the large-scale changes in circulation and trace gases from 2004 to 2012. How and why?

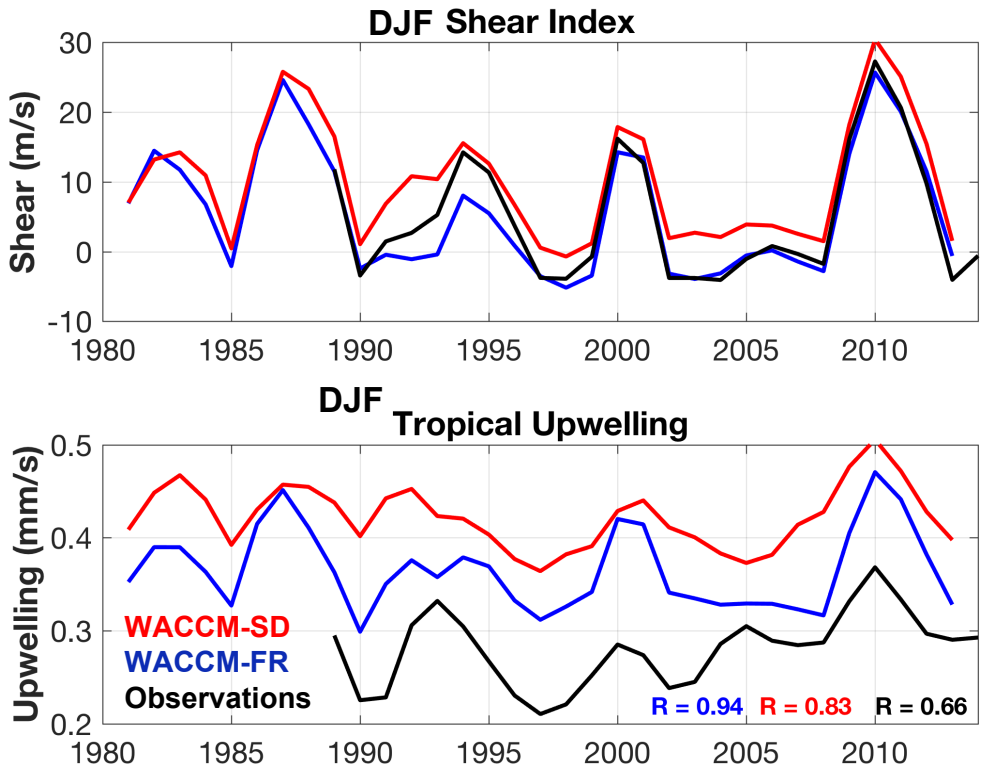
QBO Phase Length and Timing and Long-Lived Tracers

- The 2004-2012 changes in HCl are associated with a series of years in which the QBO period was relatively short and regular (2003-2008) followed by several years with extended periods of easterly shear (2009-2012).



“Extended Easterly Shear” QBO

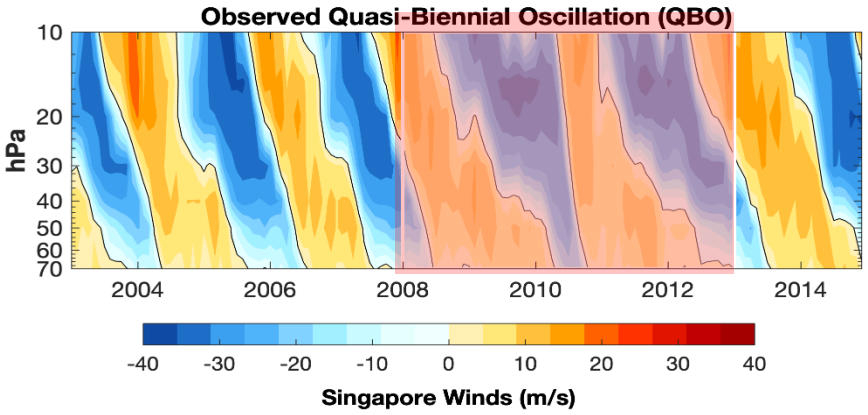


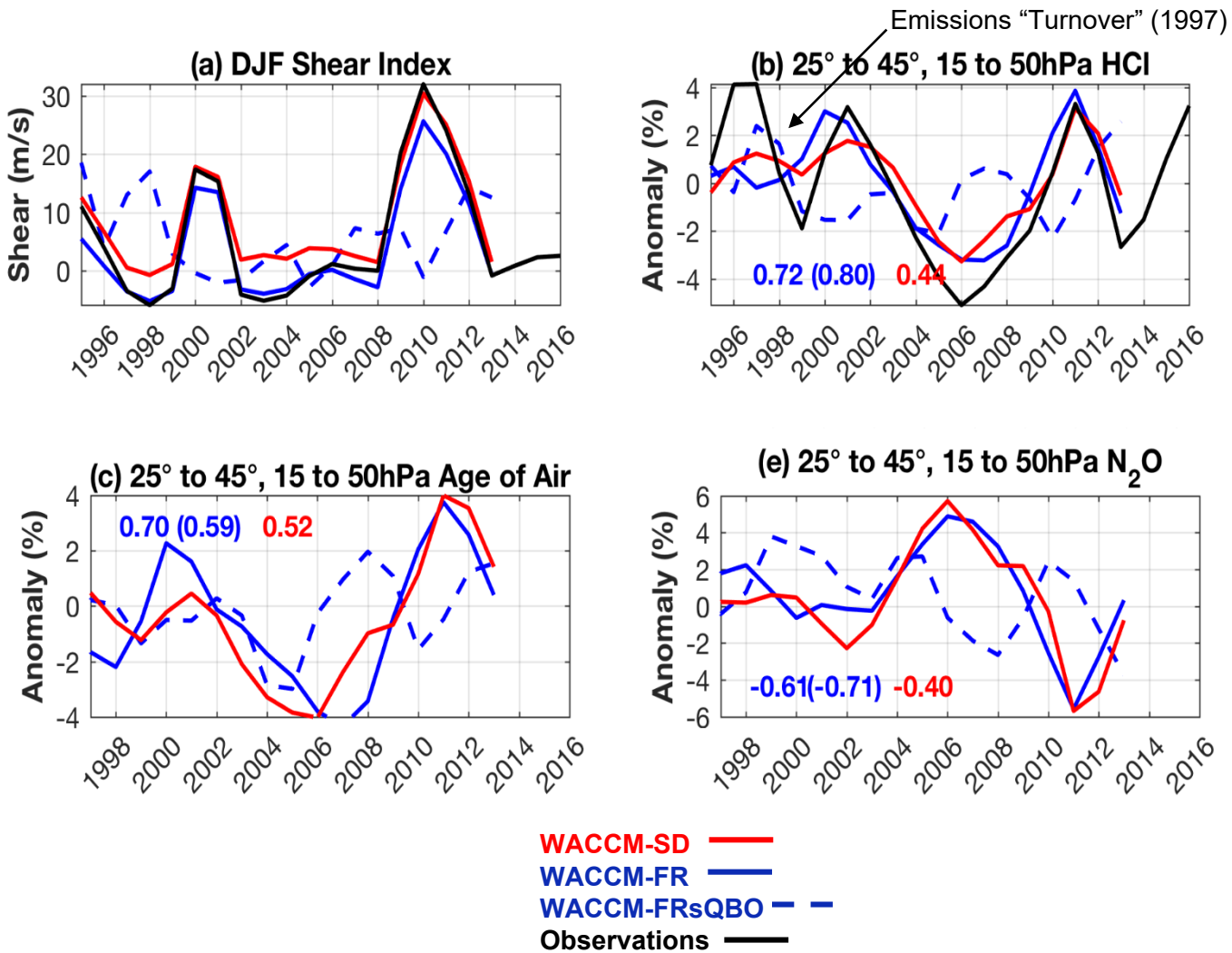


- The DJF shear index reflects changes in the relationship between the QBO and seasonal cycle driven by changes in the periodicity of the QBO.
- The corresponding variations in shear are tightly coupled to changes in tropical upwelling.

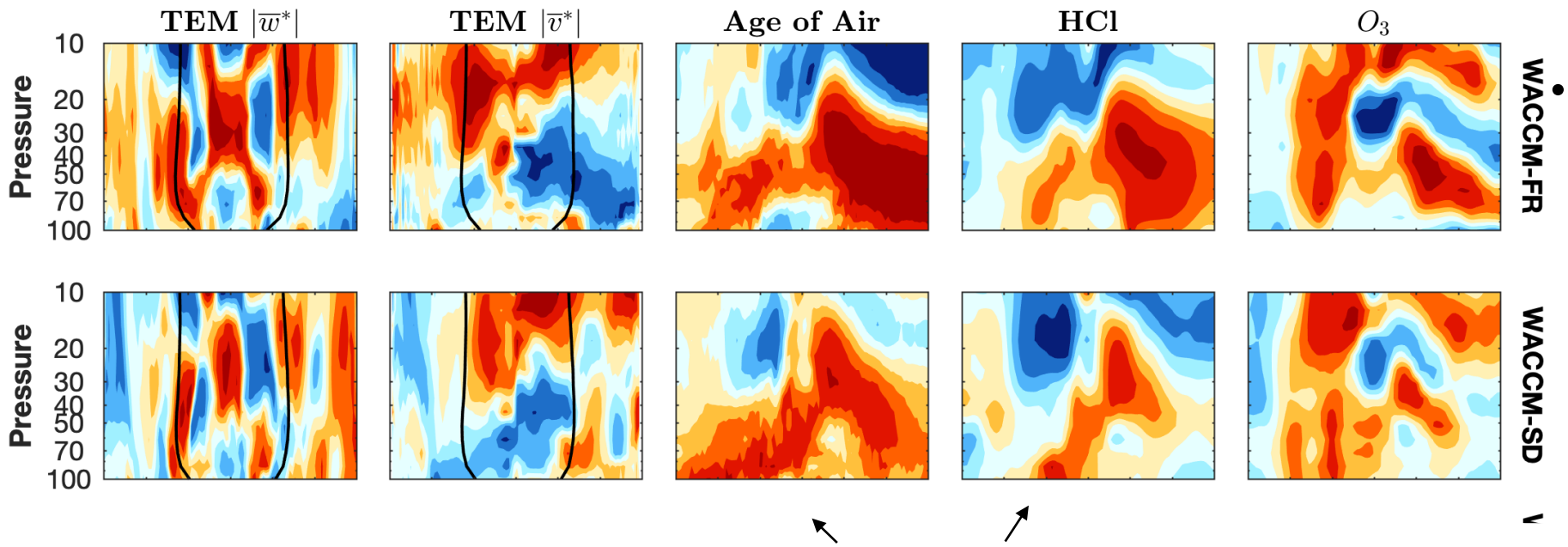
DJF Shear Index and Long-Lived Tracers

- The DJF Shear is also highly correlated with annual mean variations in long-lived tracers and Age of Air in the NH, including in the shifted-QBO simulation.
- The 2005-2010 increase in NH HCl was associated with a change in the relative lengths of the easterly and westerly phases.



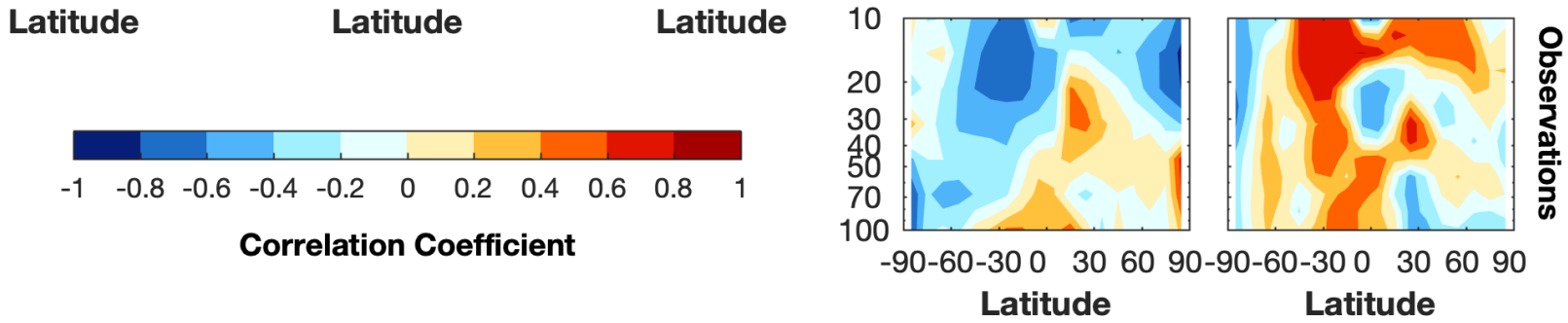


DJF Shear Index Correlation with Annual Mean Variables



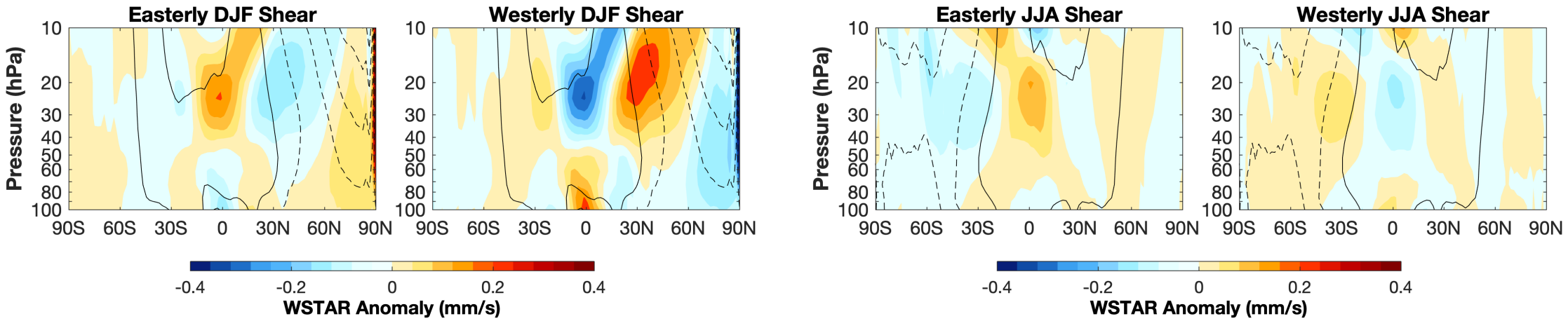
These are the same patterns as Maheiu et al. (2014) described

- The large-scale changes in the structure of the stratospheric circulation driven by changes in the periodicity and timing of the QBO can appear as multi-year “trends” in trace gases.

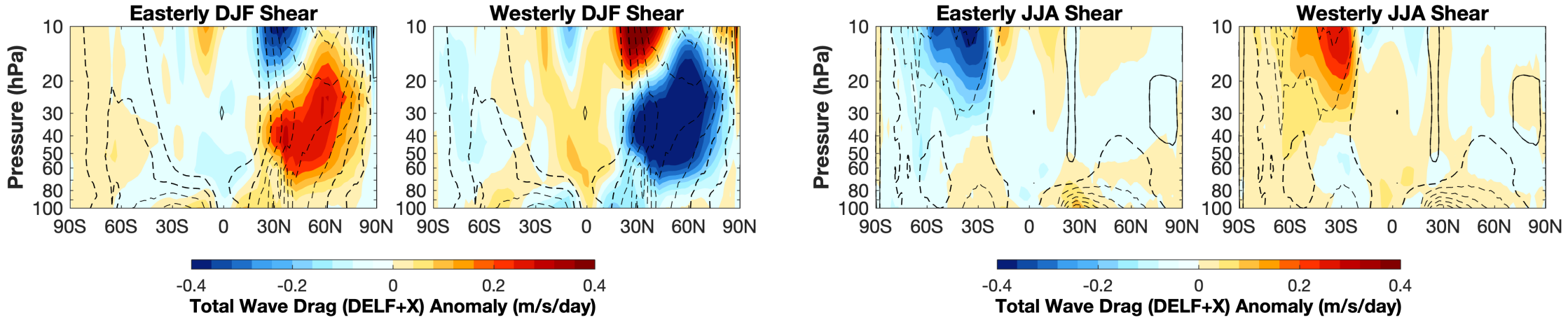


What drives asymmetries in w* and v*?

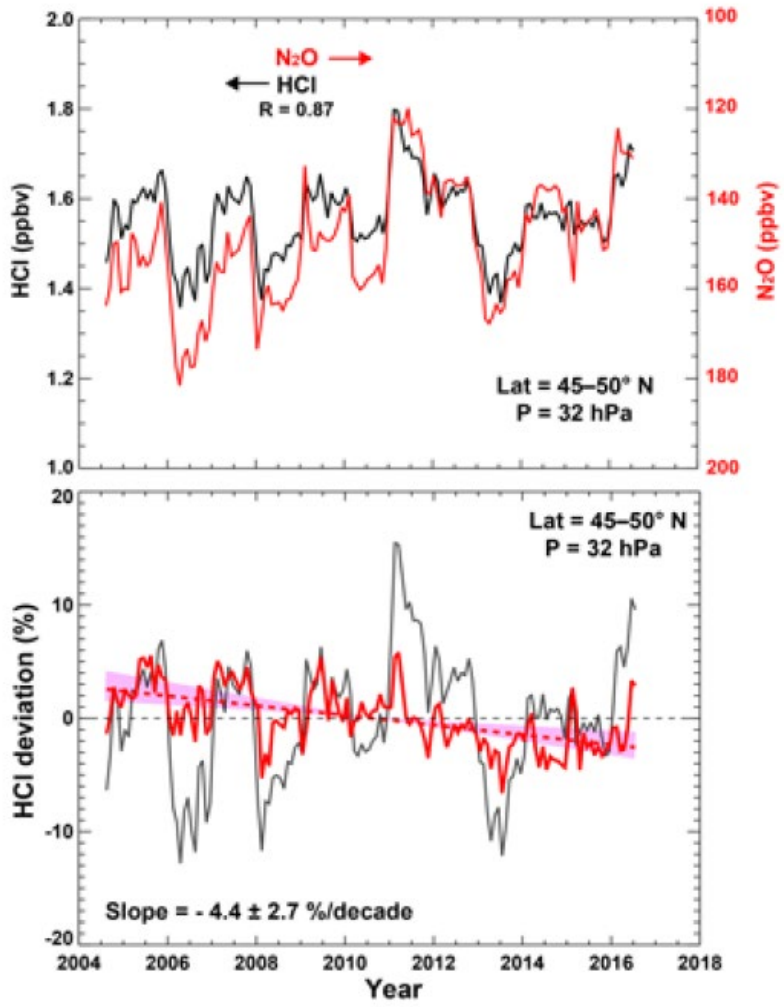
WSTAR Composites



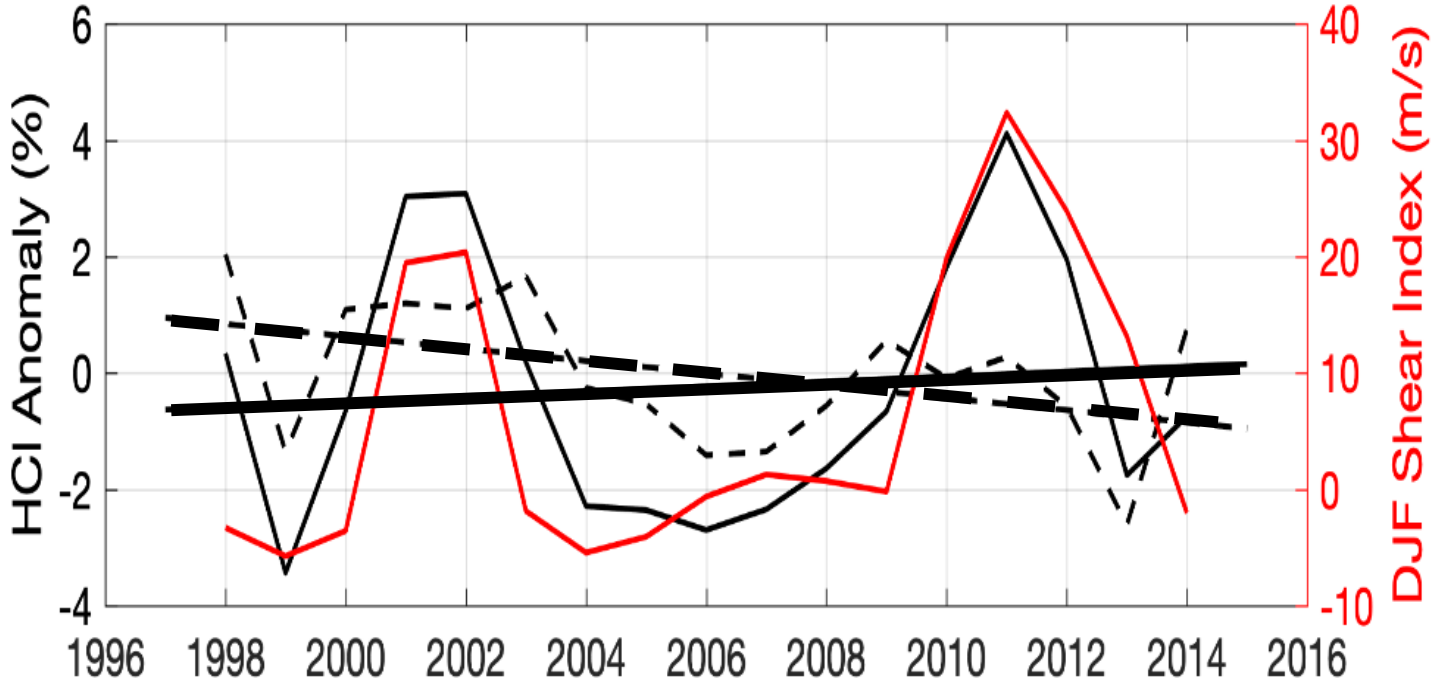
Total Wave Drag Composites



Using the DJF Shear Index in Trend Regression

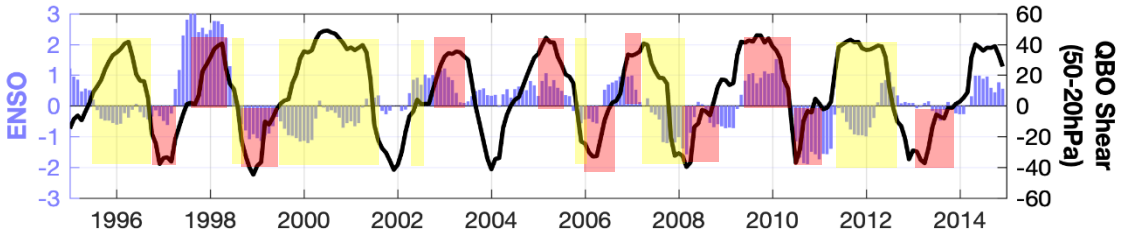


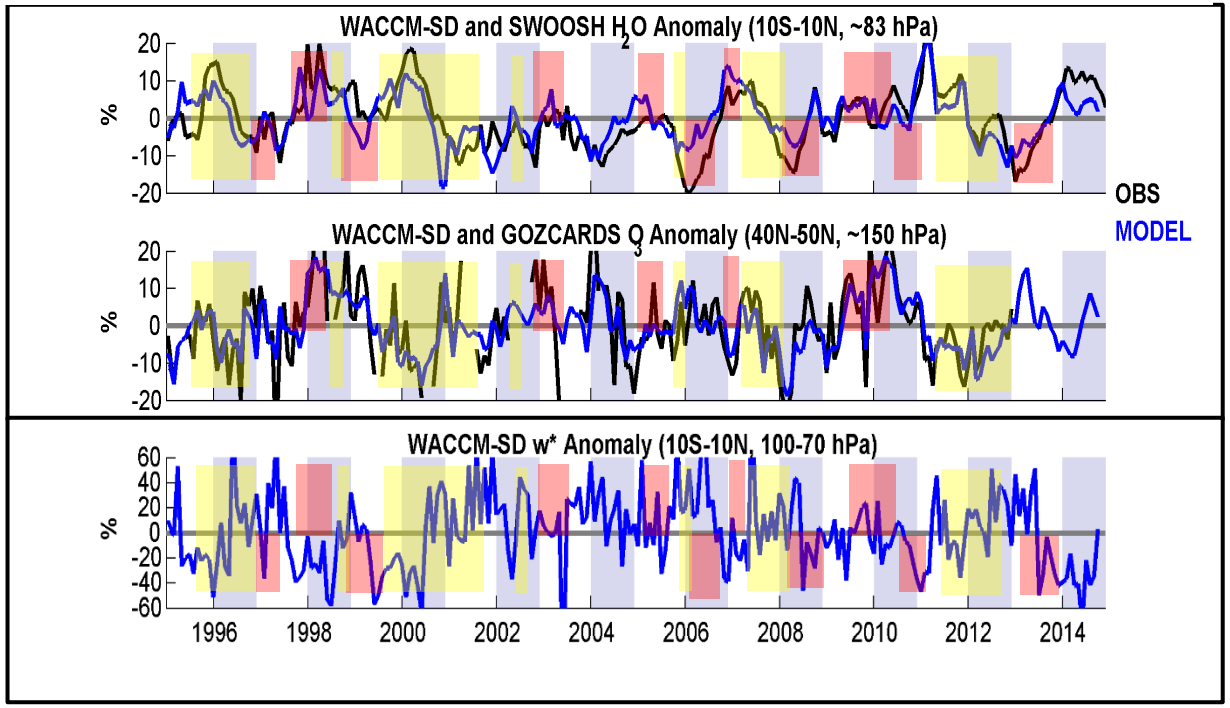
Stolarski and Douglass (2018)



- We can use the DJF Shear Index to remove decadal-scale variations from annual HCl anomalies. Doing so results in a change in the trend from positive to negative and a reduction in the uncertainty comparable to using N_2O as a regressor. Yet the Shear Index is physically-based and provides a mechanistic explanation of the variability.

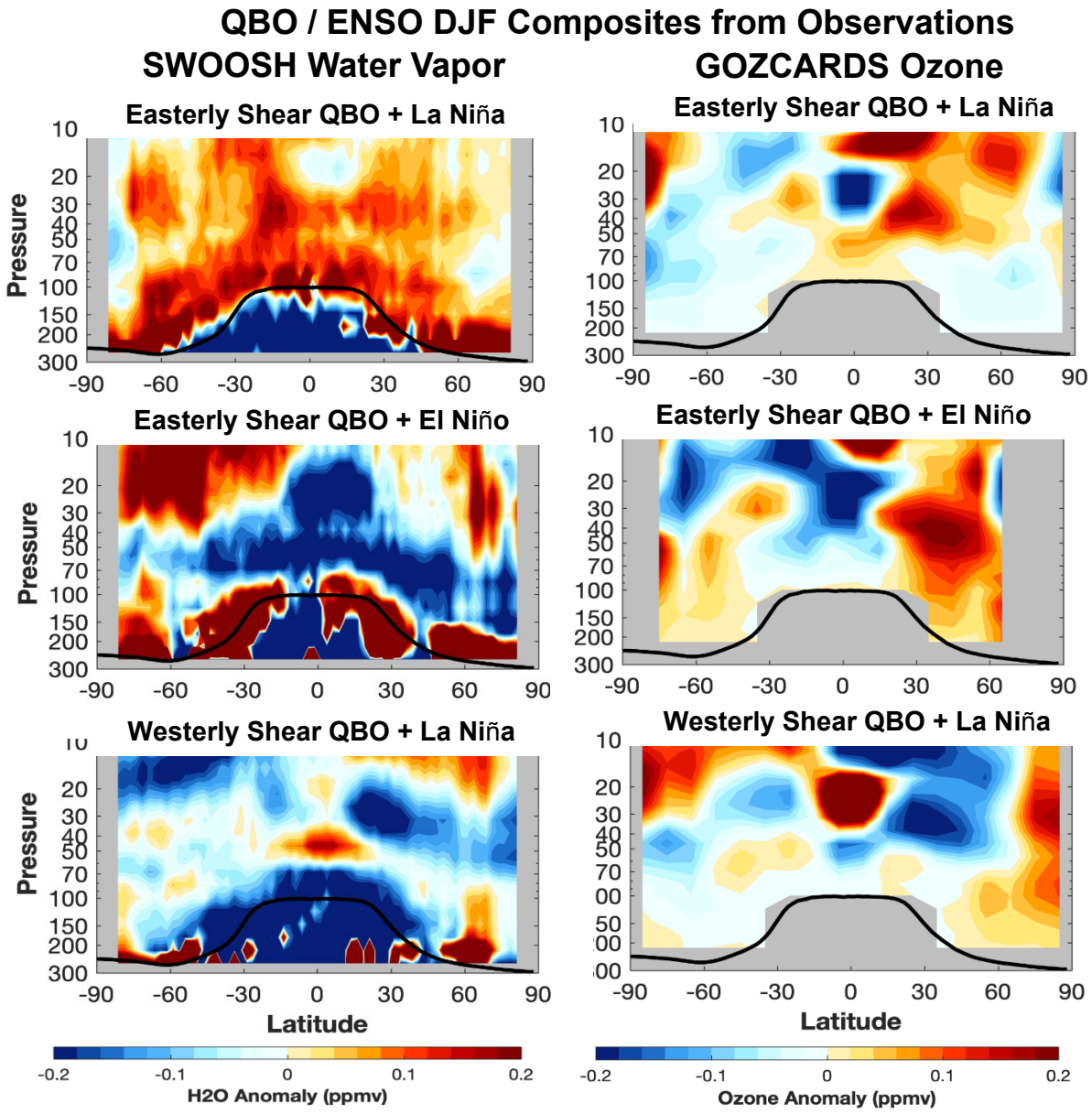
What's ENSO Got To Do With It?





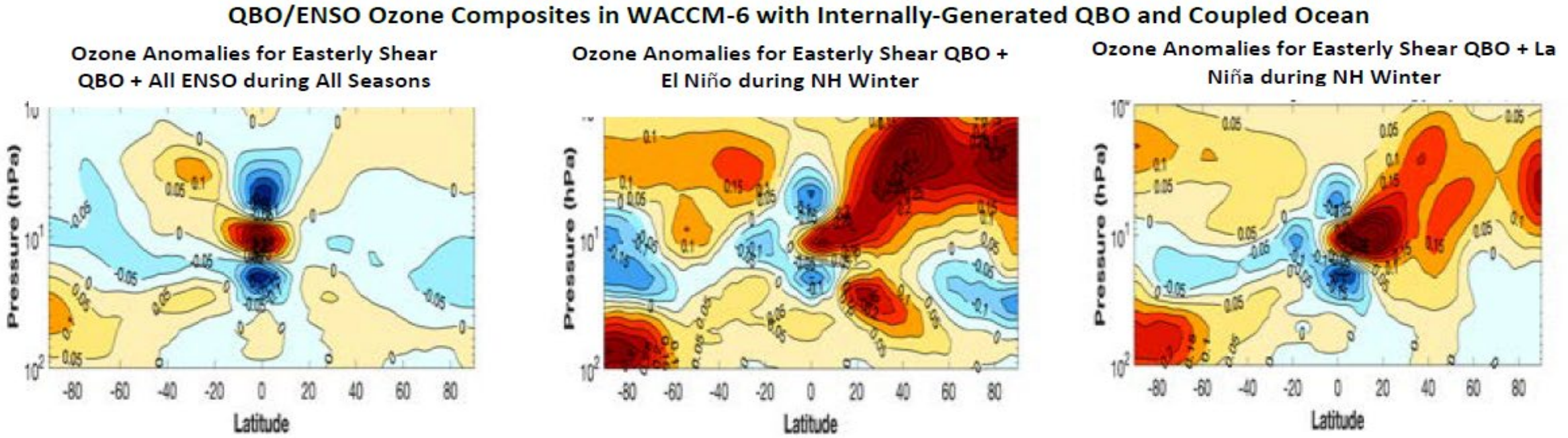
- There is never a sustained period in which El Niño and westerly shear QBO coexist. There are, however, extended periods of La Niña / easterly shear QBO.
- Every La Nina / easterly shear QBO occurrence is accompanied by an increase in lower tropical upwelling and a "drop" in tropical water vapor.
- These periods also lead to a midlatitude ozone dip and then recovery, which is also seen in tropospheric ozone.

ENSO / E-QBO Composites - Observations



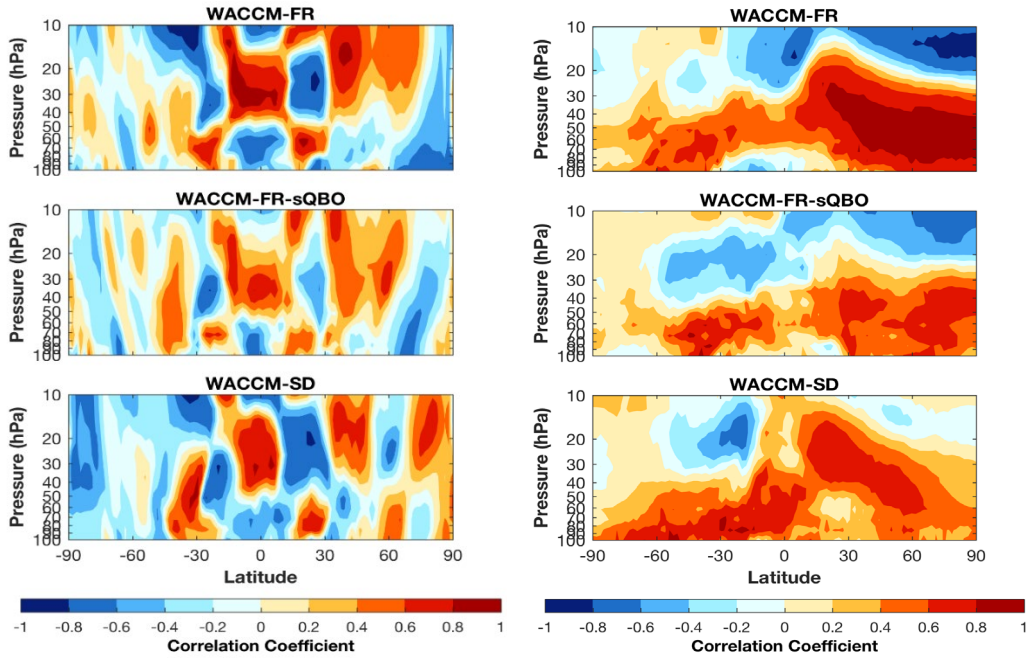
- Water vapor anomalies depend strongly on the phase of ENSO and are only positive throughout the stratosphere during La Nina + E-QBO.
- Mid-stratospheric ozone anomalies are similar for both ENSO phases during E-QBO, but lower stratospheric ozone anomalies are of the opposite sign depending on the phase of ENSO. Only La Nina + E-QBO is associated with negative ozone anomalies in the lower midlatitude stratosphere.

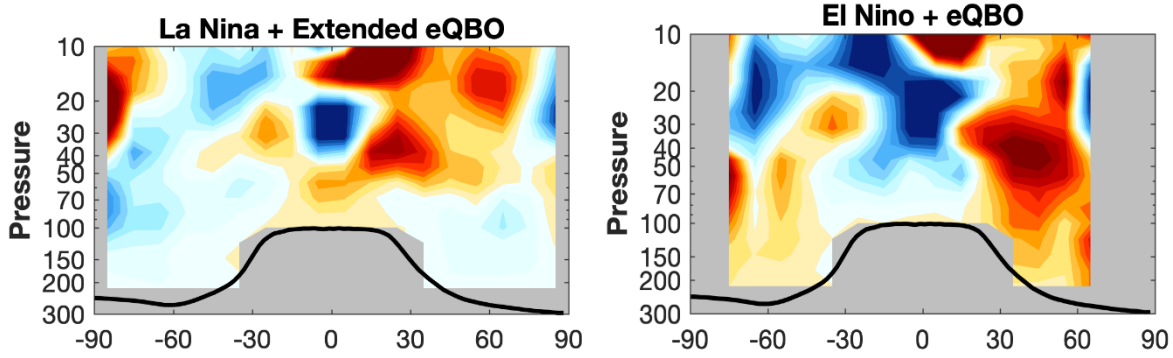
ENSO / E-QBO Composites – WACCM-6



- WACCM-6 ozone anomalies are likewise not highly dependent on ENSO in the middle stratosphere, but are of opposite sign in the lower stratosphere for El Nino vs La Nina during E-QBO.

Summary



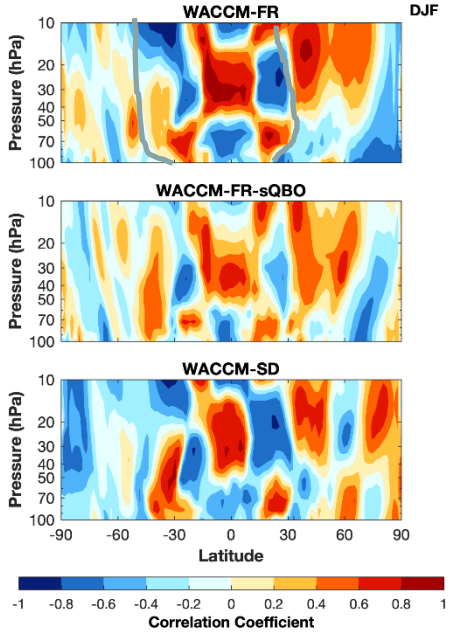


- While the QBO has long been recognized as playing an important role in year-to-year variations in stratospheric circulation and trace gases, recent work has shown its importance for tropospheric composition and for interpreting changes in the growth rate of chlorine source gases.
- Our work shows that changes in the periodicity of the QBO are responsible for decadal-scale variations in stratospheric circulation and trace gases, with a robust, hemispherically-asymmetric response to multi-year changes in the periodicity of the QBO.
- Accounting for this QBO-driven decadal-scale variability can provide reduced uncertainties on trends and their attribution to anthropogenic activity.
- The QBO time series itself, however, may depend on SSTs and there may be strong influences of ENSO / QBO phasing on lower stratospheric circulation and trace gases.

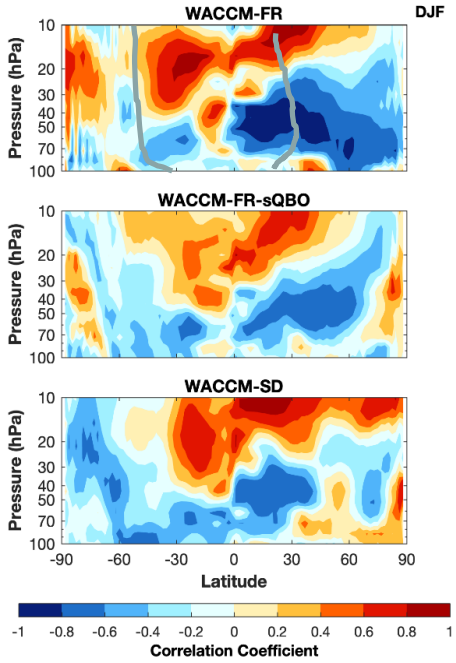
Extras

Hemispheric Asymmetry Driven By Easterly Shear During DJF

TEM $|\overline{w}^*|$

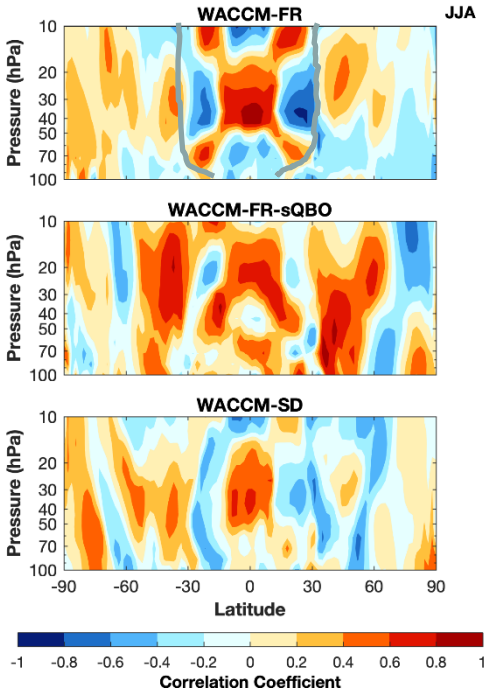


TEM $|\overline{v}^*|$

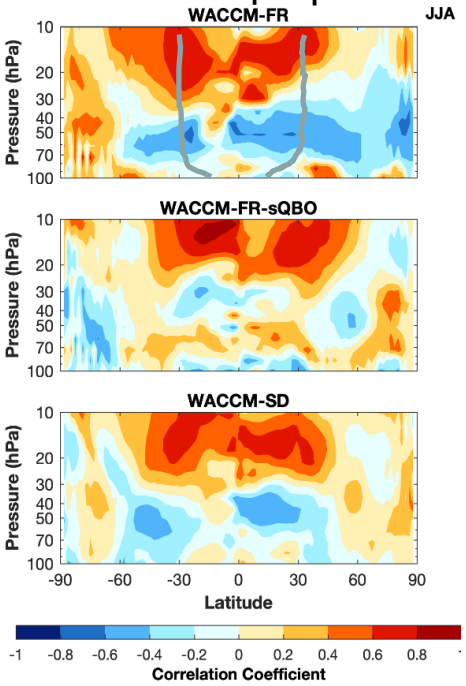


Correlation of Annual Mean Residual Circulation with DJF and JJA Shear

TEM $|\overline{w}^*|$

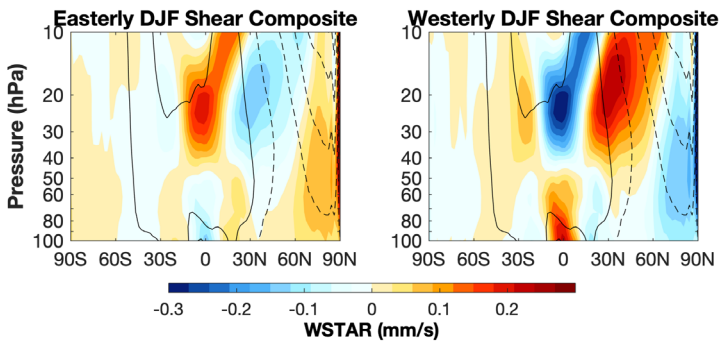


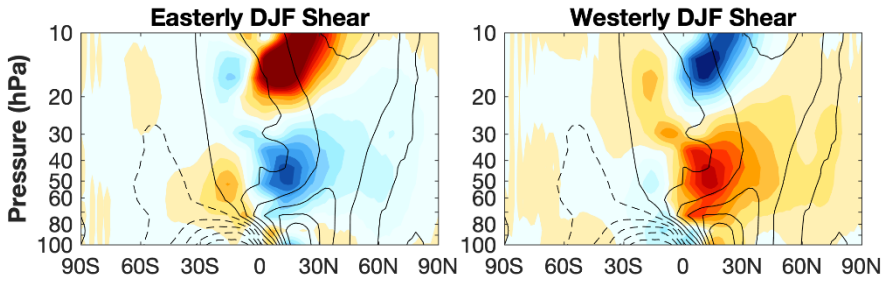
TEM $|\overline{v}^*|$

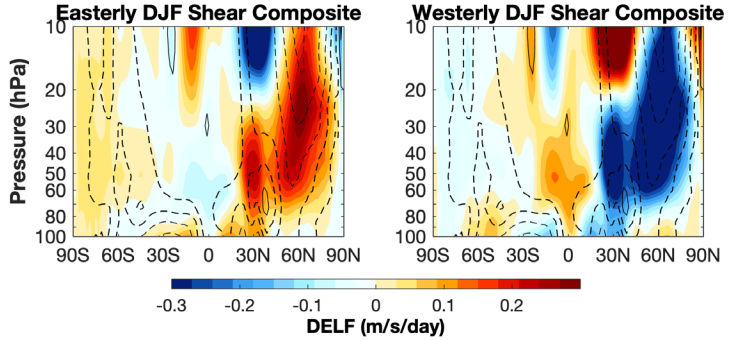


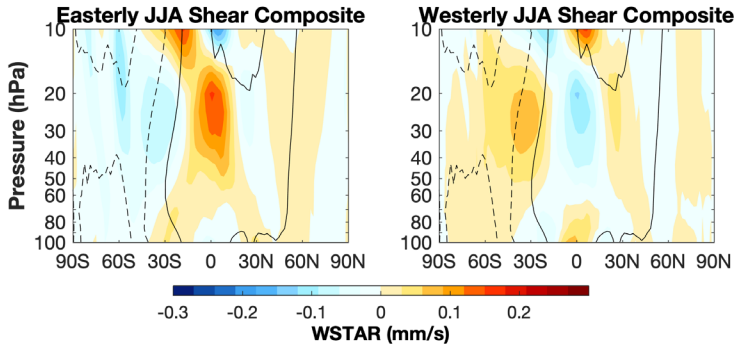
From 2009-2012, every DJF had strong easterly shear. The correlation of the residual circulation with the DJF shear index shows that the circulation response is highly asymmetric when the shear occurs during DJF. The circulation changes associated with the QBO shear are the same as those identified by Han et al. (2019), but the fact that they are also seen in the WACCM-FR-sQBO simulation indicate that they are a robust response to the QBO and not a specific feature of 2004-2012.

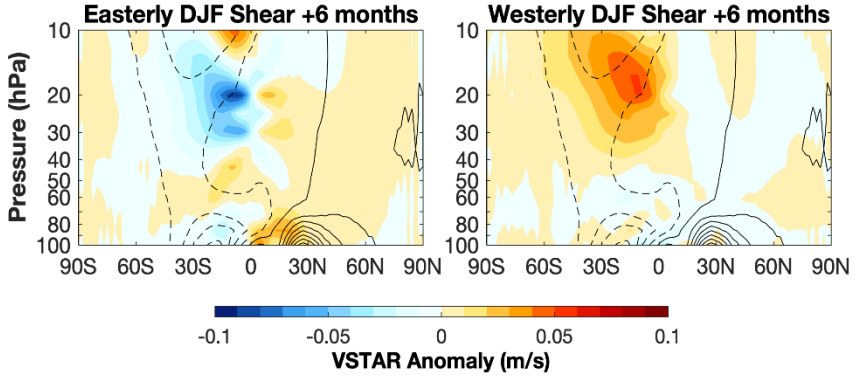
Composites

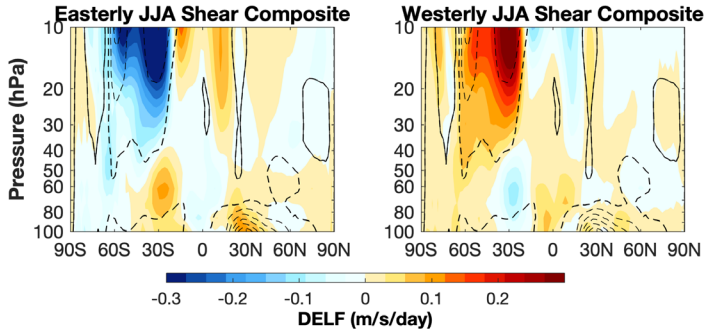

Easterly DJF Shear Composite
Westerly DJF Shear Composite
Pressure (hPa)
10
20
30
40
50
60
80
100
90S 60S 30S 0 30N 60N 90N
-0.3 -0.2 -0.1 0 0.1 0.2
WSTAR (mm/s)

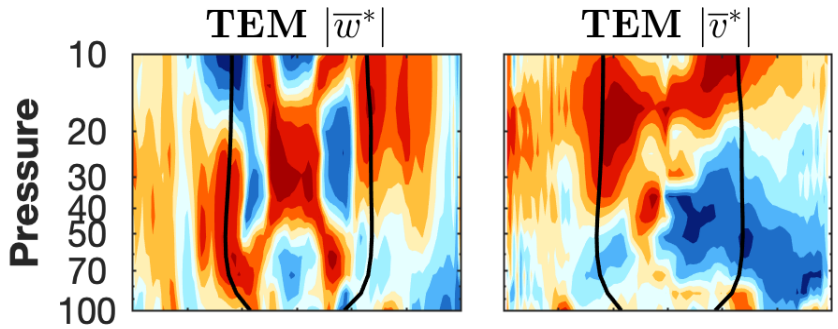

Easterly DJF Shear
Westerly DJF Shear
Pressure (hPa)
10
20
30
40
50
60
80
100
90S 60S 30S 0 30N 60N 90N


Easterly DJF Shear Composite
Westerly DJF Shear Composite
Pressure (hPa)
10
20
30
40
50
60
80
100
90S 60S 30S 0 30N 60N 90N
-0.3 -0.2 -0.1 0 0.1 0.2
DELF (m/s/day)

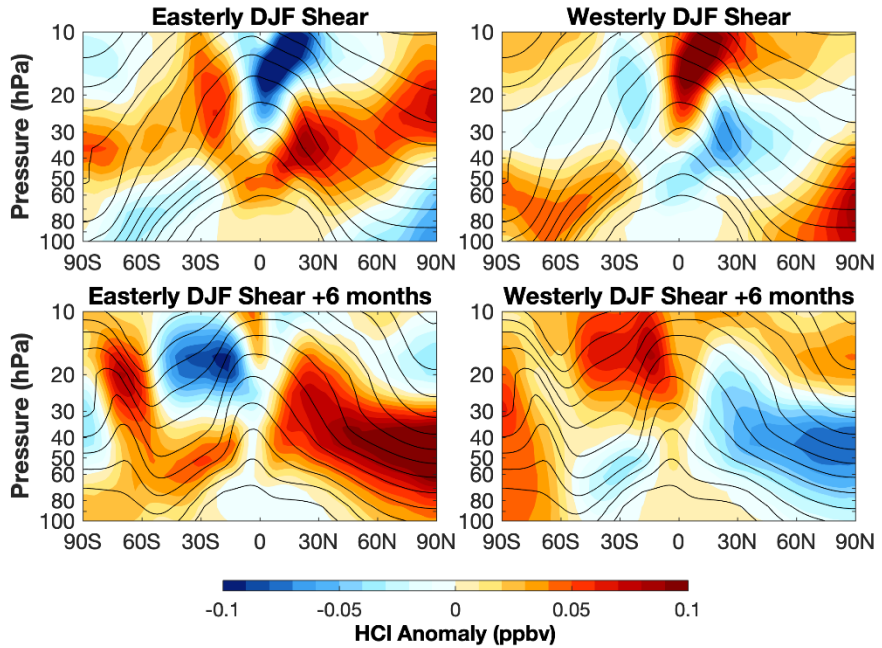

Easterly JJA Shear Composite
Westerly JJA Shear Composite
Pressure (hPa)
10
20
30
40
50
60
80
100
90S 60S 30S 0 30N 60N 90N
-0.3 -0.2 -0.1 0 0.1 0.2
WSTAR (mm/s)

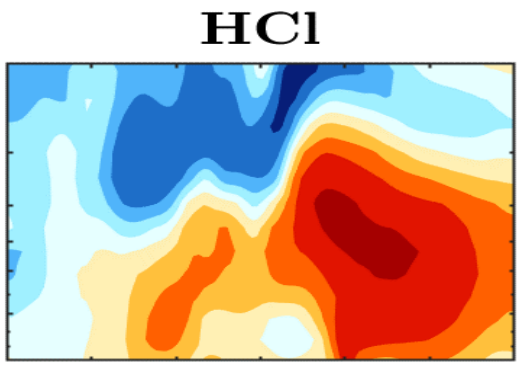

Easterly DJF Shear +6 months
Westerly DJF Shear +6 months
Pressure (hPa)
10
20
30
40
50
60
80
100
90S 60S 30S 0 30N 60N 90N
-0.1 -0.05 0 0.05 0.1
VSTAR Anomaly (m/s)


Easterly JJA Shear Composite
Westerly JJA Shear Composite
Pressure (hPa)
10
20
30
40
50
60
80
100
90S 60S 30S 0 30N 60N 90N
-0.3 -0.2 -0.1 0 0.1 0.2
DELF (m/s/day)


TEM $|\overline{w}^*|$
TEM $|\overline{v}^*|$
Pressure
10
20
30
40
50
70
100

Extras


Easterly DJF Shear
Westerly DJF Shear
Easterly DJF Shear +6 months
Westerly DJF Shear +6 months
Pressure (hPa)
10
20
30
40
50
60
80
100
90S 60S 30S 0 30N 60N 90N
-0.1 -0.05 0 0.05 0.1
HCl Anomaly (ppbv)


HCl