From the Upper Troposphere Through the Stratosphere: How Satellite Measurements Help Us Decode the Past to Better Project the Future

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Stratospheric to Tropospheric Composition and Transport: 3 Examples of Response

O_3

- The growth of the Antarctic ozone hole (late 1970s – mid 1990s) caused a dynamical perturbation to the Southern Hemisphere stratospheric circulation visible in ozone, one of our longest and best observed chemical constituents, and illustrates the connection between chemical change and the coupled radiative and dynamical response (Stolarski et al., 2006).

N_2O

- The quasi-biennial oscillation (QBO) is the dominant mode of interannual variability in the tropical stratosphere, however its impacts on stratospheric circulation and composition can be traced globally. The QBOs timing with respect to the seasonal cycle in each hemisphere is significant in understanding its impact on decadal scale variability (Strahan et al., 2015).

O_3
H_2O

- The El Nino Southern Oscillation (ENSO), which dominates tropical tropospheric interannual variability, also affects the stratosphere and its influence is visible in our growing record of stratospheric composition measurements (Oman et al., 2013).

Growth of the Antarctic Ozone Hole

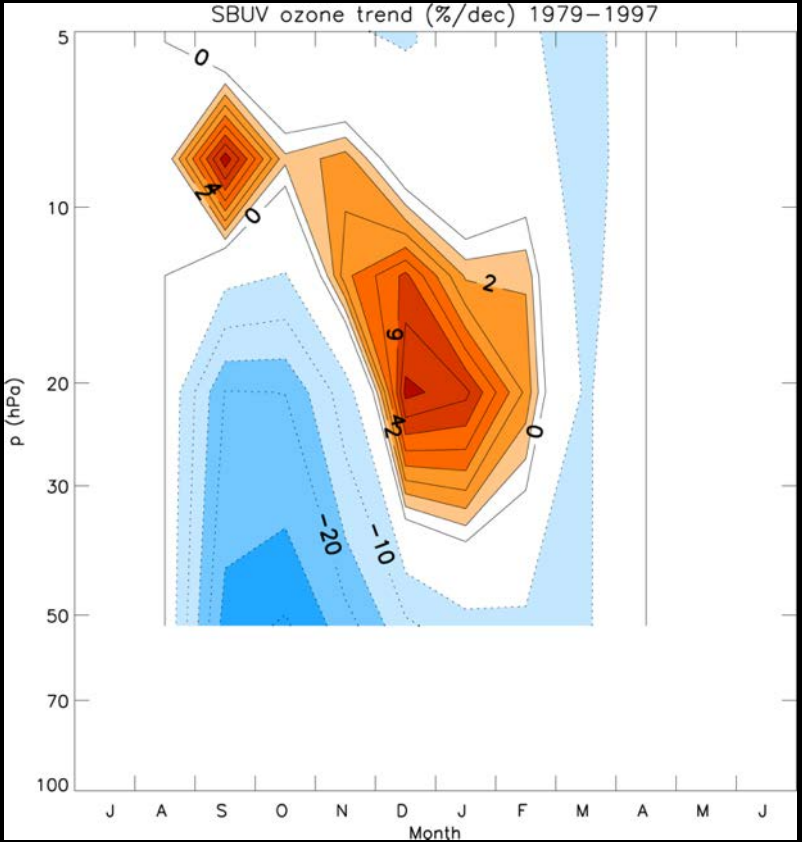
SBUV version 8.6 ozone observations from 1979-1997 only coarse vertical information

Described in Stolarski et al., 2006
Linear trend at 75-80°S in (%/dec.)

Negative trend interval 5%
Positive trend interval 1%

The negative trend is the large chemical loss due to heterogeneous chemistry in the spring polar vortex (~-30%/dec October around 50 hPa)

The positive response is dynamical indicating an increase in circulation bringing higher ozone values into the polar vortex as it breaks down
(~8%/dec December around 20 hPa)

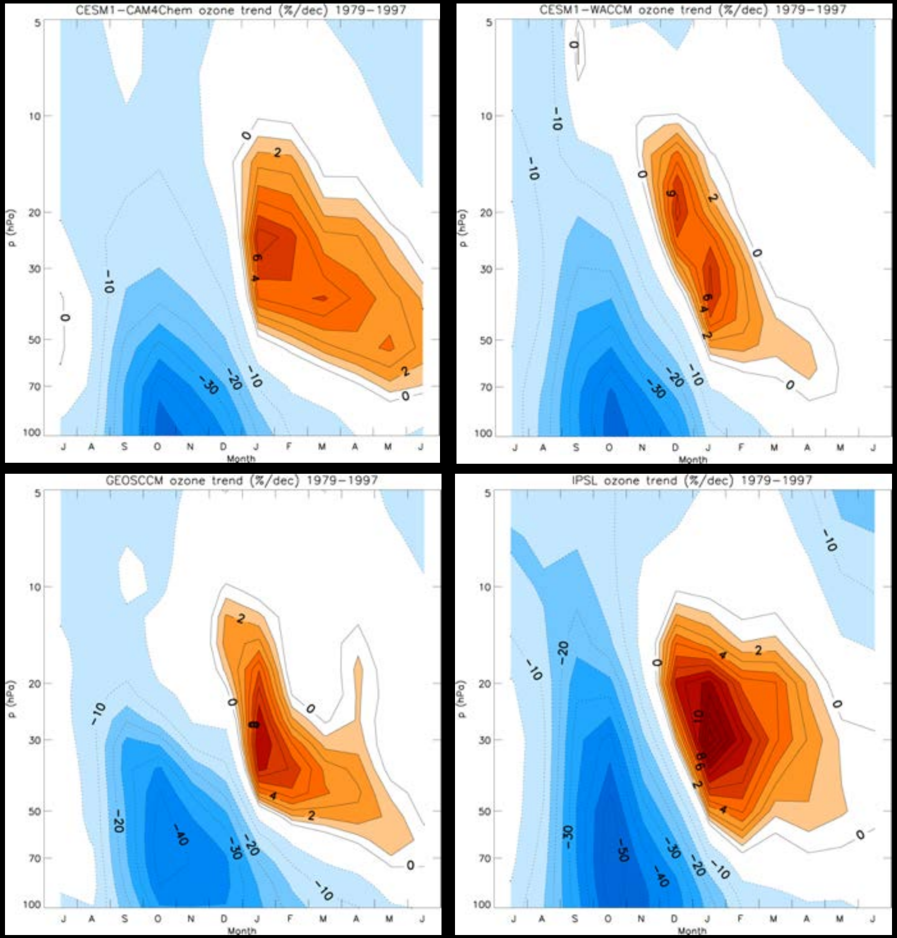


Examples from CCMI Simulations

Most models can reproduce this dynamical increase in ozone to varying degrees

Typically as many tend to have a later breakup of the polar vortex the peak increase tends to be in Jan instead of the observed Dec.

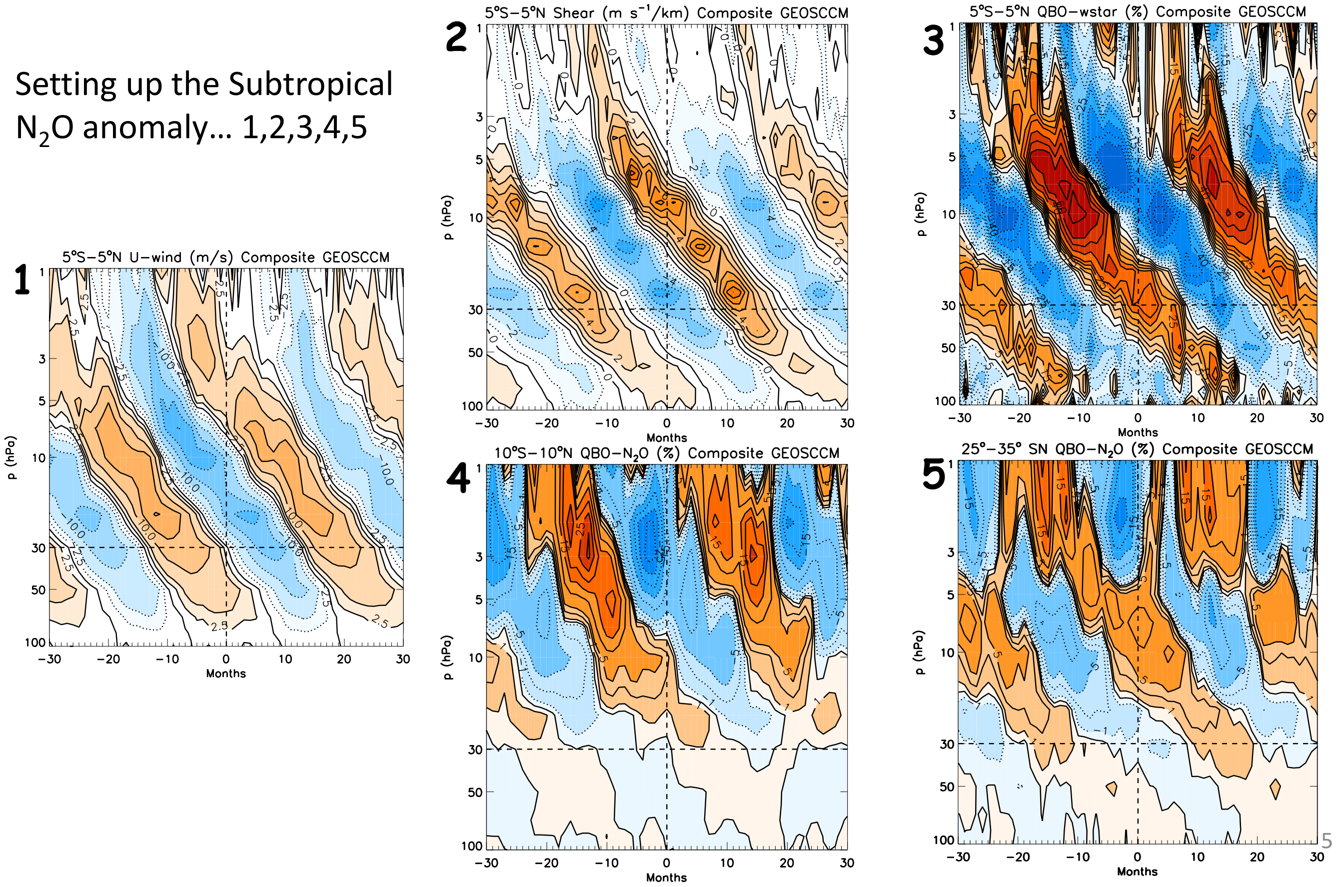
WACCM gets the timing a bit better than most



Connecting the QBO to Polar LS Composition

Described in Strahan et al. (2015) in obs. but here we show how it develops in a model

Setting up the Subtropical N_2O anomaly… 1,2,3,4,5



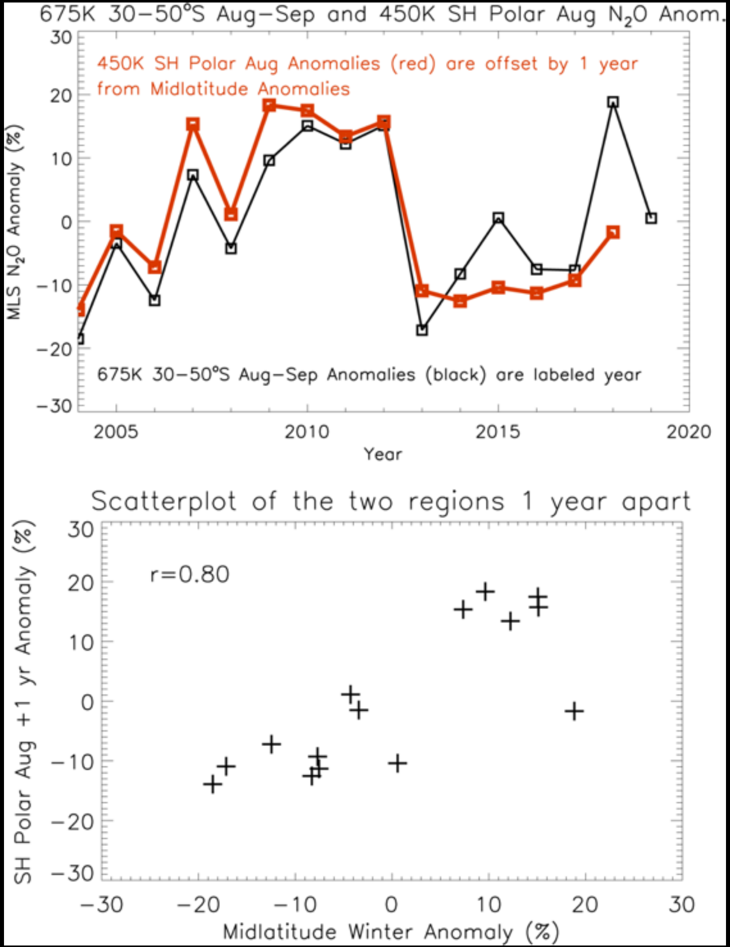
Observing the Journey on the Stratospheric Highway

Aura Satellite measurements:
Microwave Limb Sounder (MLS) v4.2
Aug. 2004 – Apr. 2020

The high correlation between late winter subtropical middle stratospheric N_2O anomalies and winter N_2O anomalies in the polar lower stratosphere 1 year later can be clearly seen in MLS observations of N_2O (updated from *Strahan et al.,* 2015)

N_2O anomalies have a direct relationship with Cl_y so this gives a prediction of polar LS Cl_y 1 year in advance.

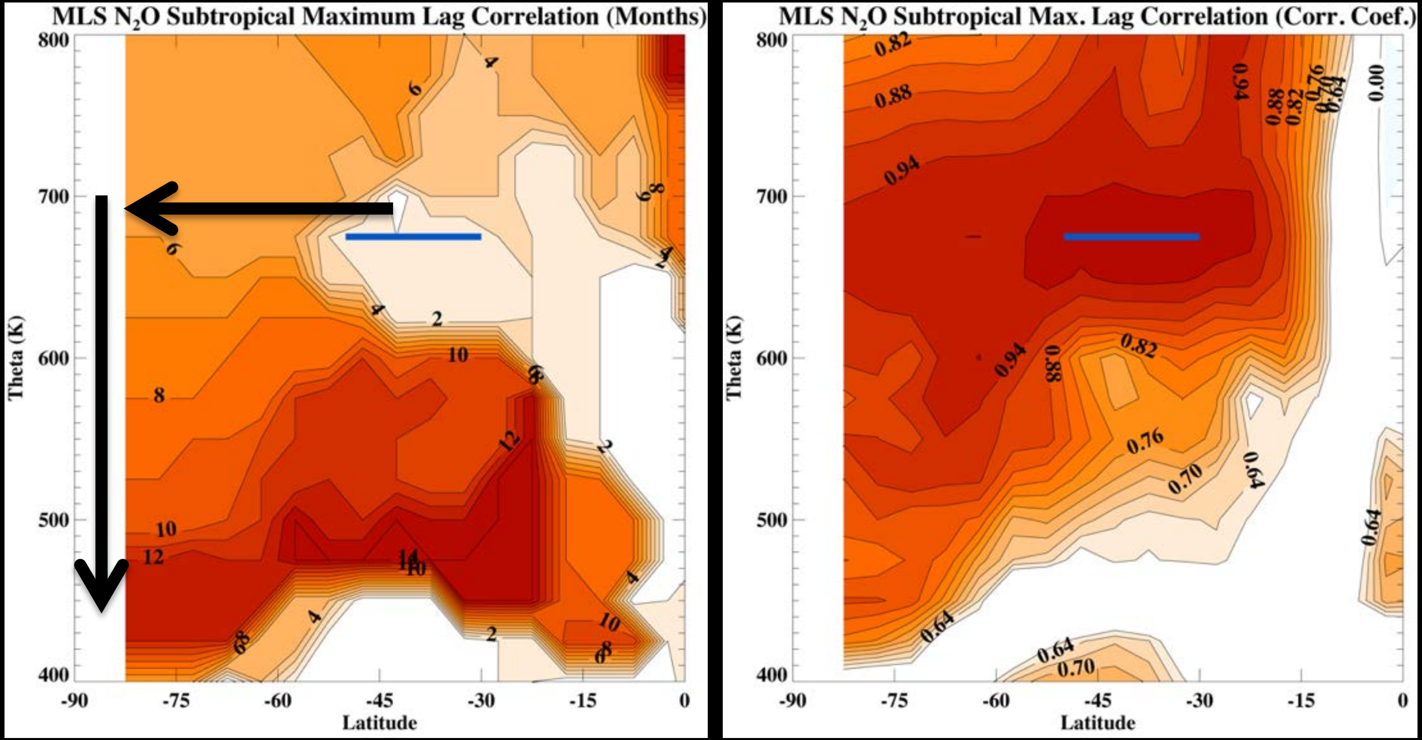
Odd QBO during 2015/2016 could have had an impact



Southern Hemisphere Transport in MLS Obs.

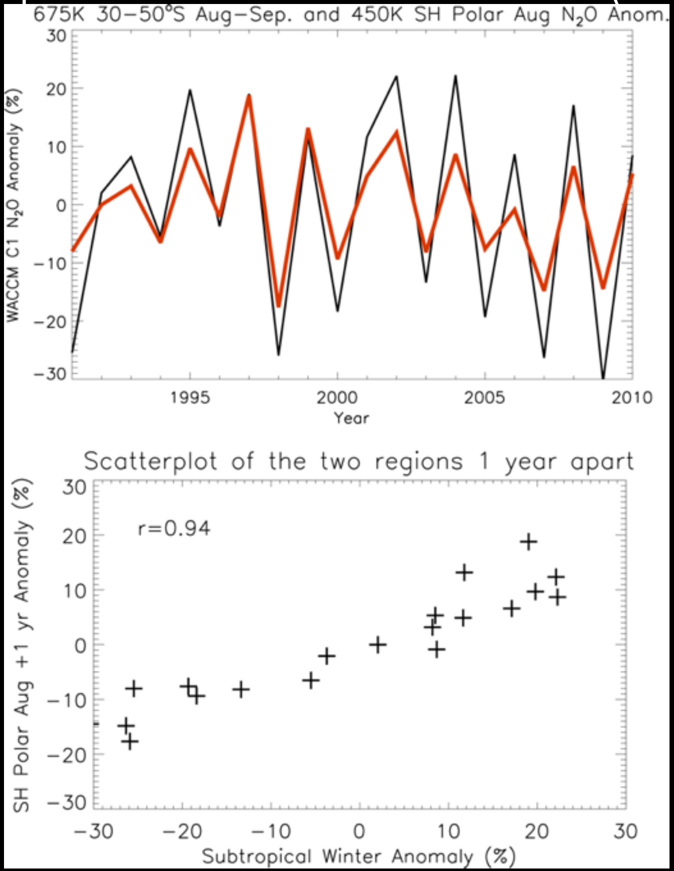
The 12 month transport timescale can be seen by examining the lag number of months each location has maximum correlation with the subtropical winter MS

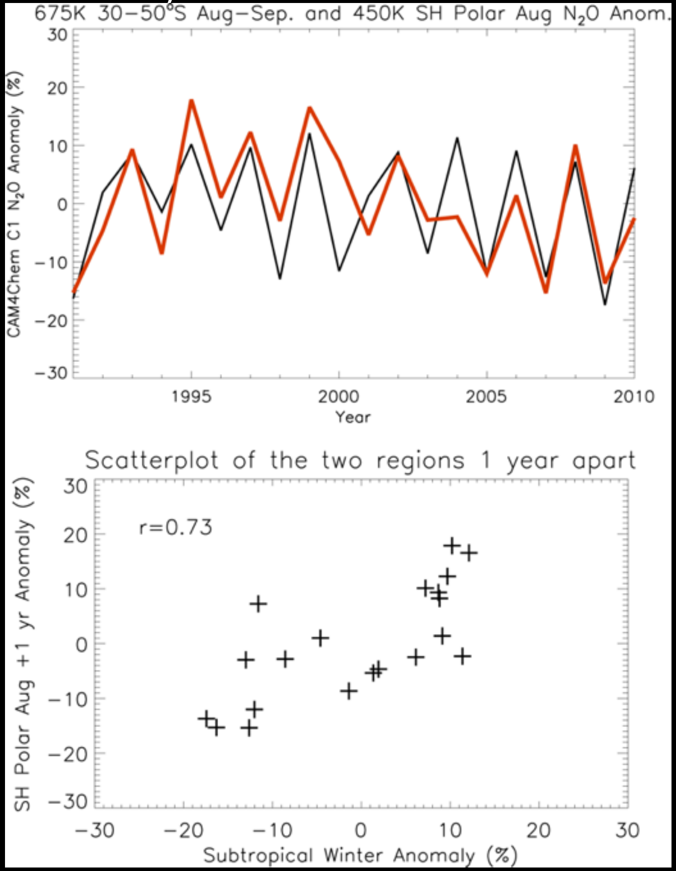
Looking at the maximum correlation shows the very high correlation throughout the journey - Similar but weaker relationship in the NH



CCMs with a nudged to observed QBO

Driving some of the observed composition variability (note black curves)
Shows response very well, polar variability tends to be smaller (horizontal res.), also note impact of different vertical resolutions (88 vs 56 levels)





A Tale of Two Tracers

MLS/TES Ozone and MLS/AIRS H_2O sensitivity avg. over the tropics

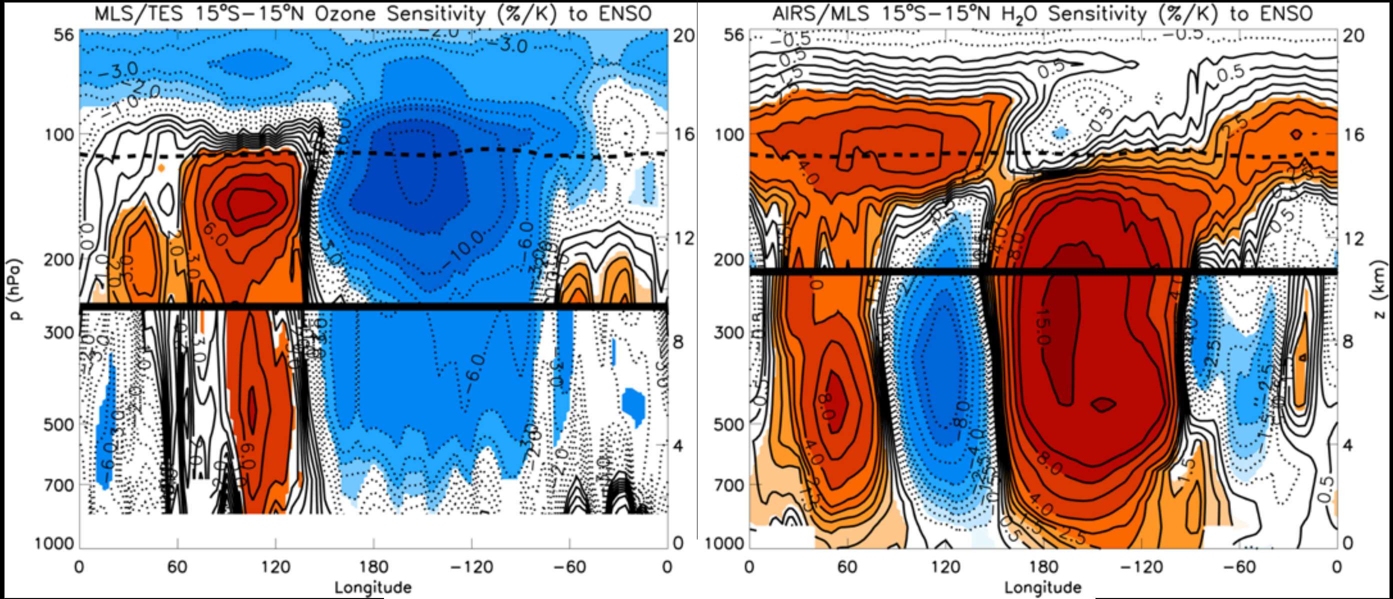
Negative ozone and positive H_2O sensitivities are seen over the eastern and central tropical Pacific troposphere, in the stratosphere decreases in ozone

Positive ozone and negative H_2O sensitivities over Indonesia, except in UT

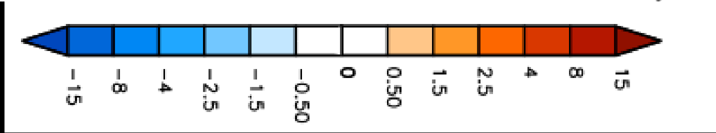
MLS v4.2 O_3 and H_2O Aug. 2004 - Apr. 2020

TES O_3 Sep. 2004 - Dec. 2009

AIRS v6 H_2O Sept. 2002 – Apr. 2020



Colored contours significant at 2 SD

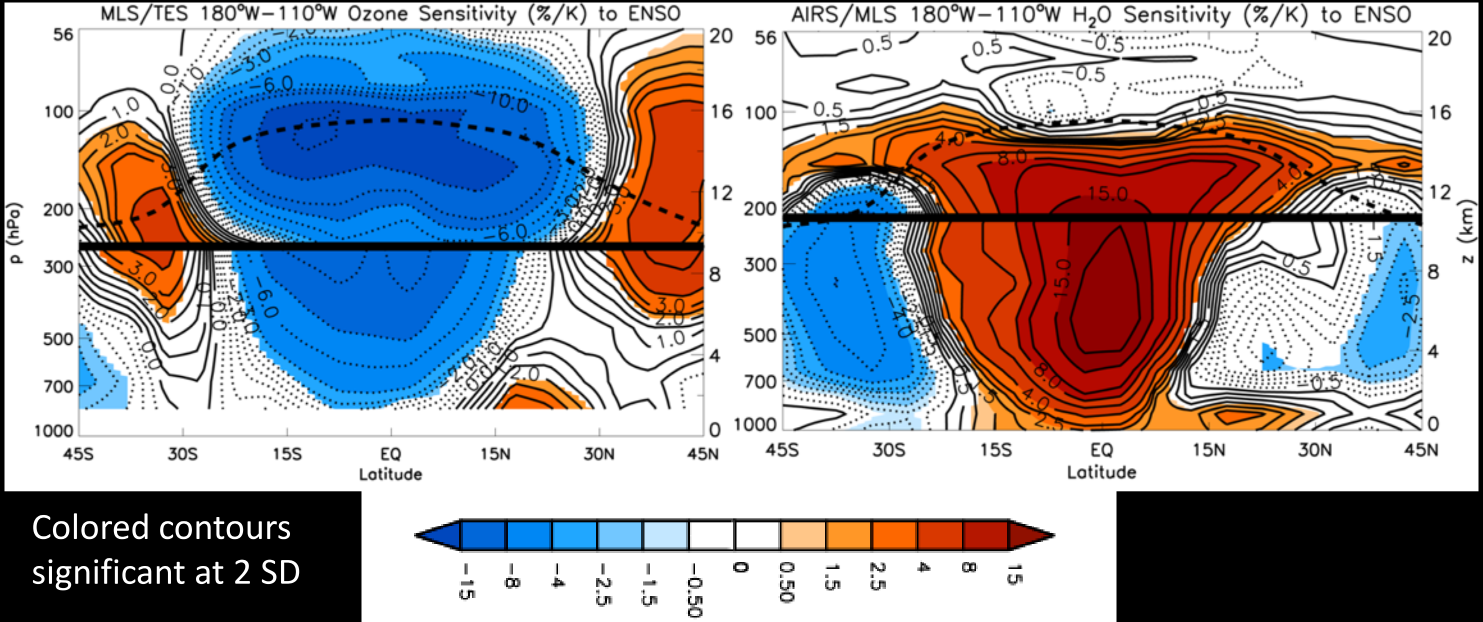


MLS/TES Ozone and MLS/AIRS H_2O sensitivity to ENSO averaged over Eastern and Central Pacific Region

In the deep tropical troposphere Ozone decreases and H_2O increases occur

In the midlatitudes increases in ozone occur in the UT/LS which continue into the troposphere in the subtropics, H_2O decreases with the increased downwelling

In the tropical LS ozone is consistent with increased circ.



Colored contours significant at 2 SD

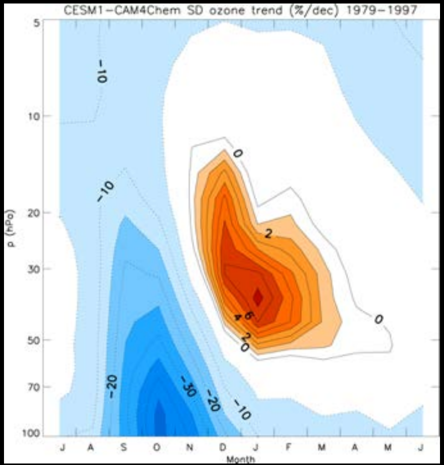
Conclusions

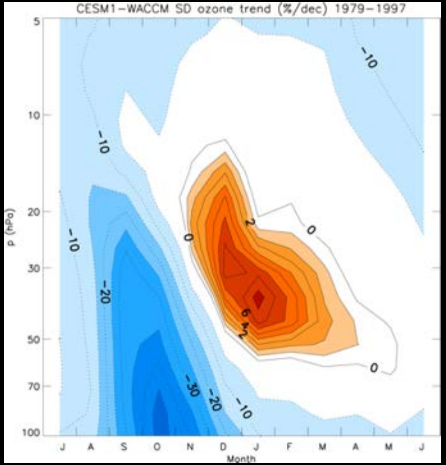
- We can look to nature to provide us with many examples of response at the intersection of transport and composition which can inform on processes and assess our modeling capabilities and future projections
- There is a dynamical response to polar ozone depletion and the reverse is expected on a slower timescale through recovery
- The impact of the QBO on polar lower stratospheric composition through an approximate 1 year transport timescale from the subtropical mid-stratosphere to polar lower stratosphere
- The impact of ENSO on the lower branch of the BDC which can be clearly seen in the signature of the ozone response

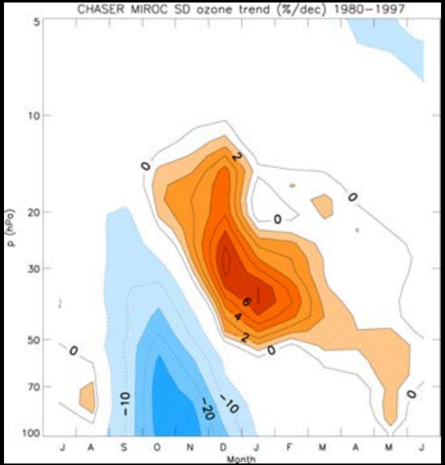
Extra Slides

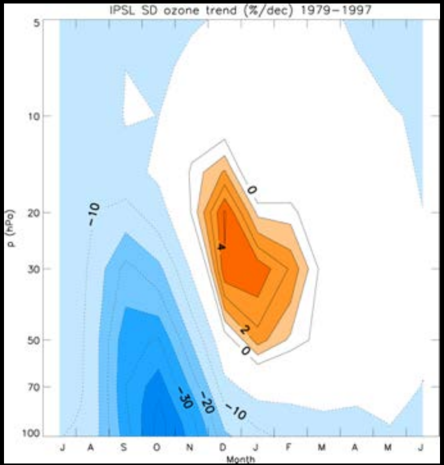
Examples in Ref C1SD Simulations

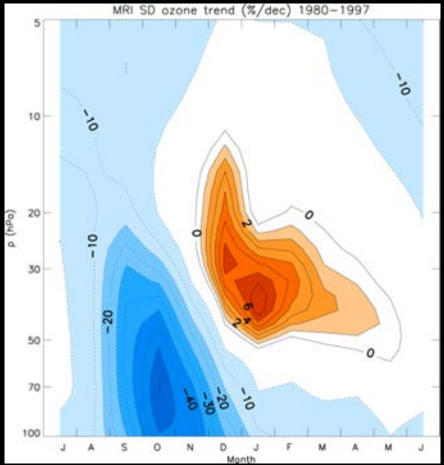
Overall models constrained by specified dynamics do a good job on this response both in the timing and magnitude







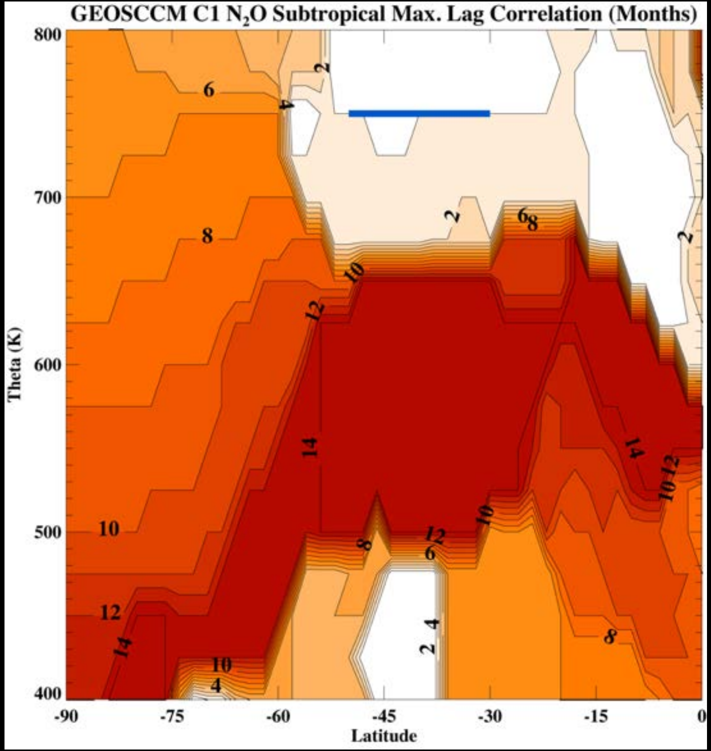


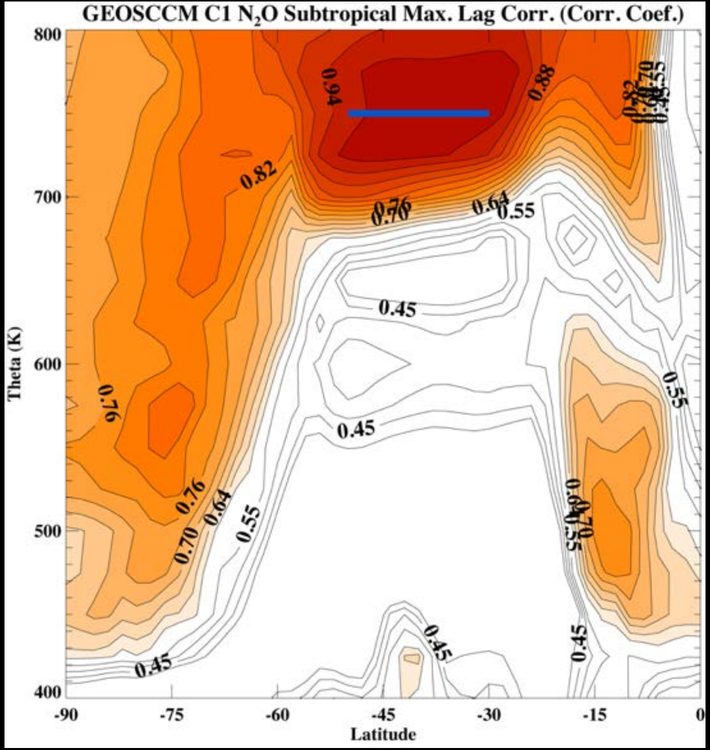


Southern Hemisphere Transport in GEOSCCM

The same 12 month transport timescale can be seen in GEOSCCM looking slightly higher

The maximum correlation while lower than in the observations again shows the very high correlation present from the subtropics to the polar lower stratosphere 1 year later





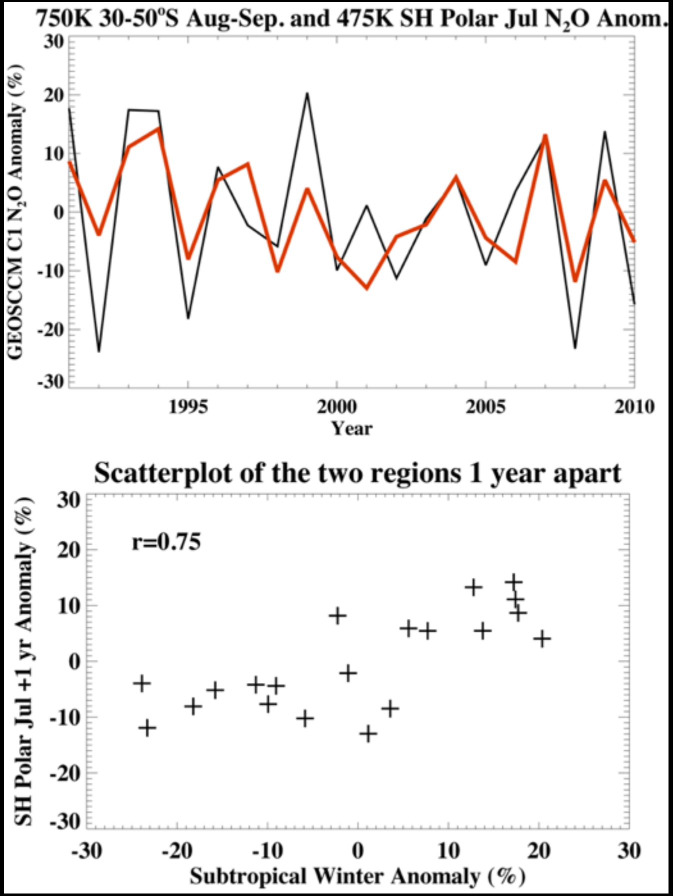
GEOSCCM with spontaneously generated QBO

The top panel shows the midlatitude MS late winter N_2O anomaly compared to the polar LS N_2O anomaly almost 1 year later

Bottom panel shows a scatterplot of the 2 regions with a reasonably high correlation but not as strong as in observations

There does seem to be some horizontal resolution dependence

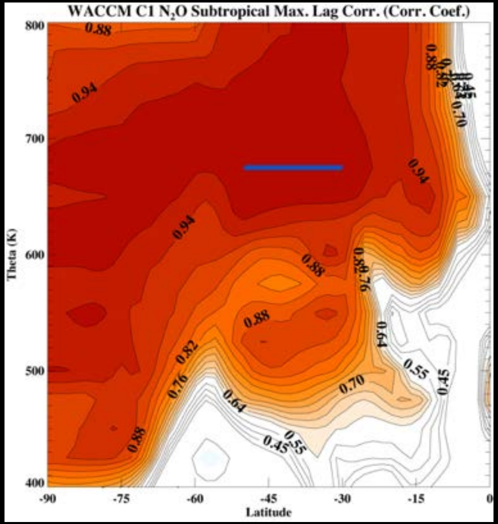
In general models that produce a spontaneous QBO you tend to need to look higher 750K vs 675K for nudged or specified dynamics simulations

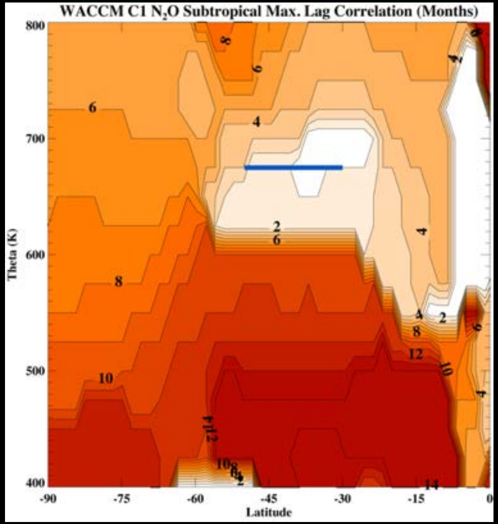


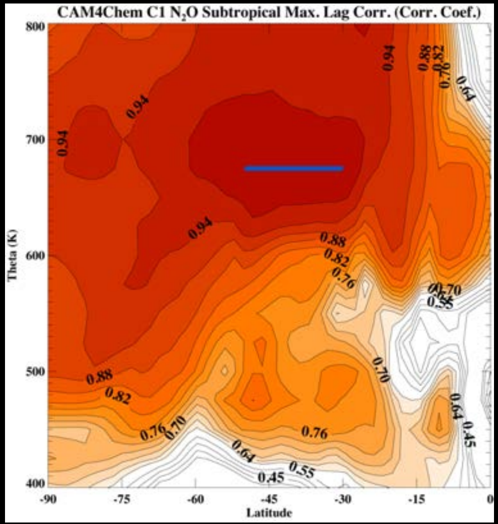
Examples from a couple of CCMs with nudged QBO

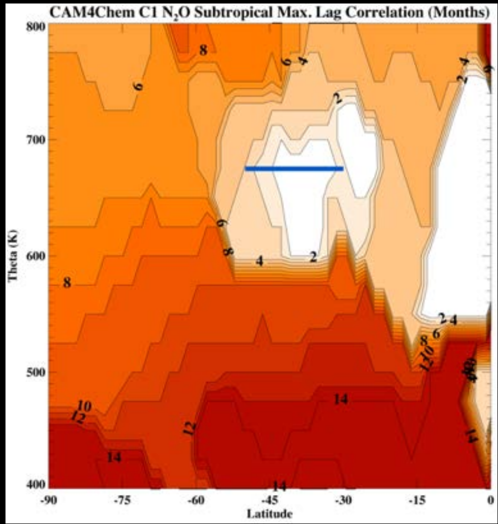
Very good examples from WACCM and CAM4Chem which show very high correlations and lag time responses

Also vertically in the right region

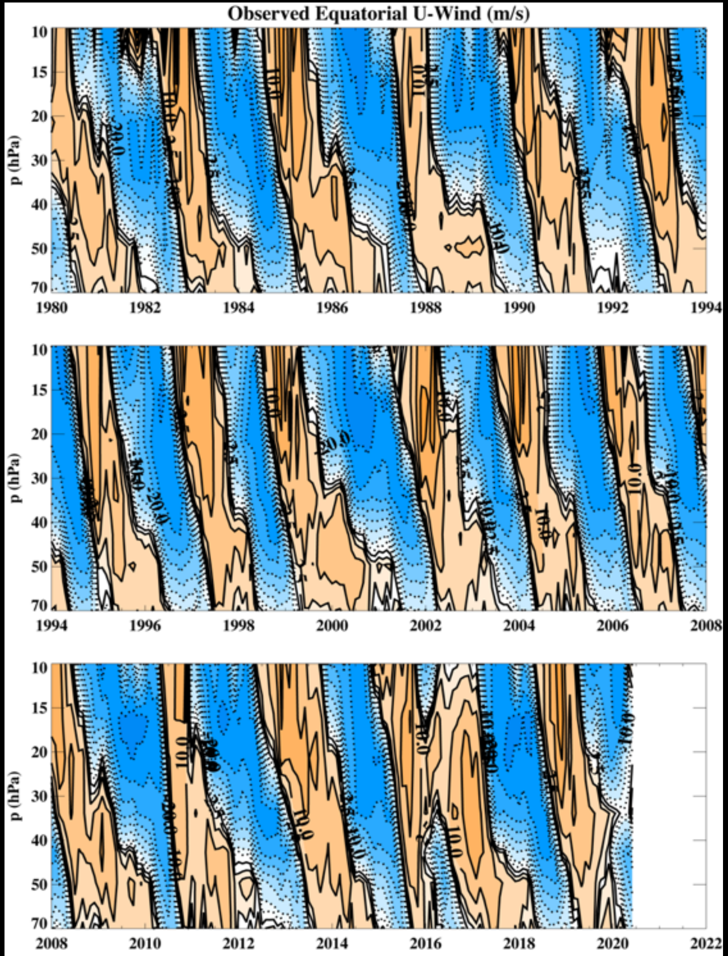








QBO


Observed Equatorial U-Wind (m/s)
p (hPa)
10
15
20
30
40
50
70
1980
1982
1984
1986
1988
1990
1992
1994
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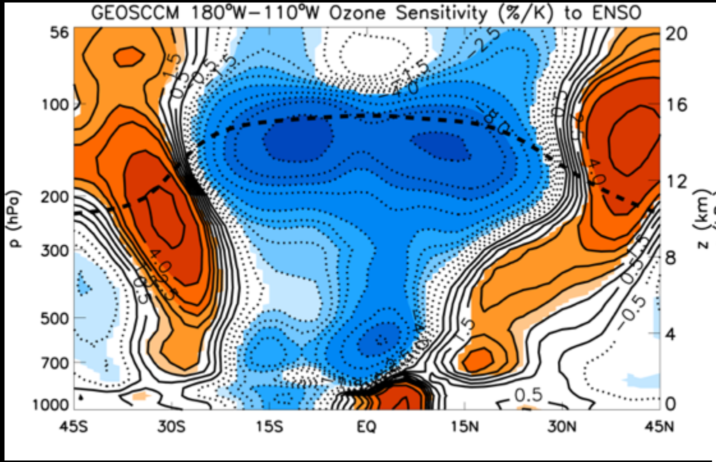
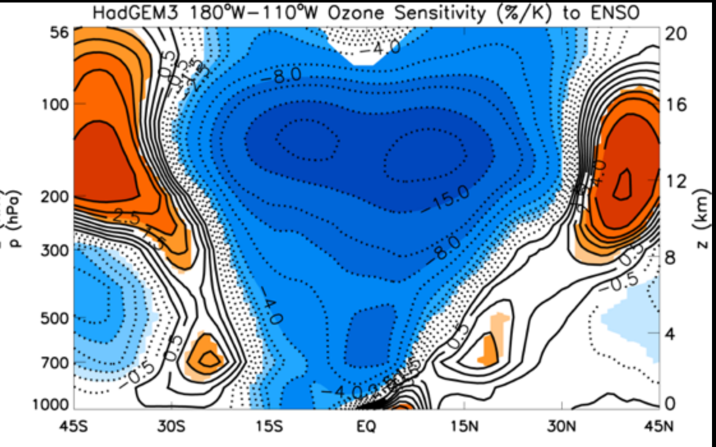
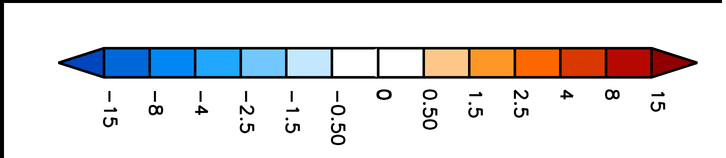
2016
2018
2020
2022

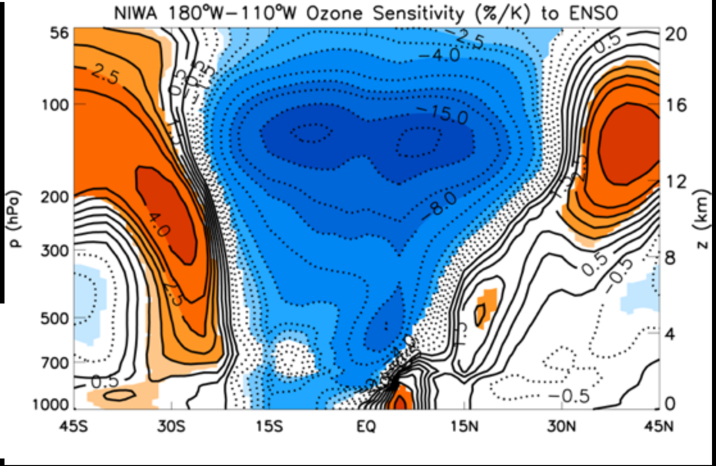
Ozone Response to ENSO in C1 simulations



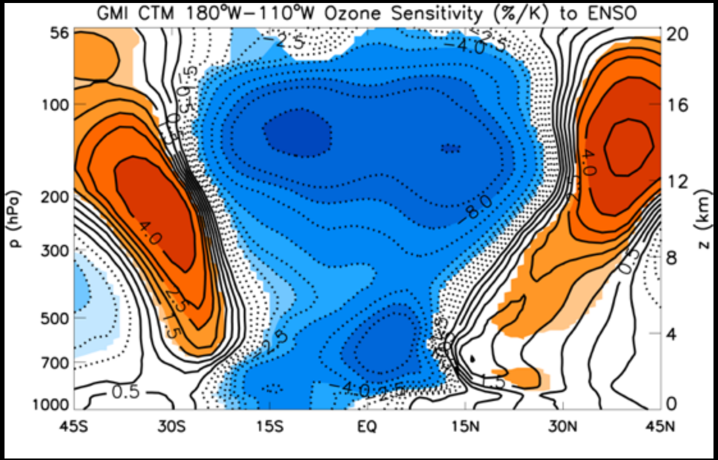


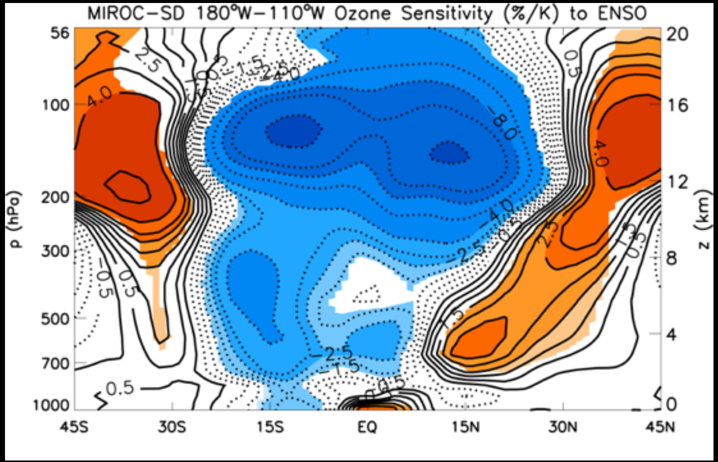
Many models do get this signature in the BDC with very comparable responses



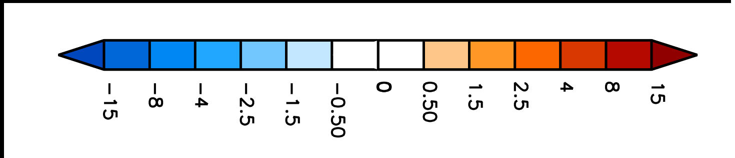


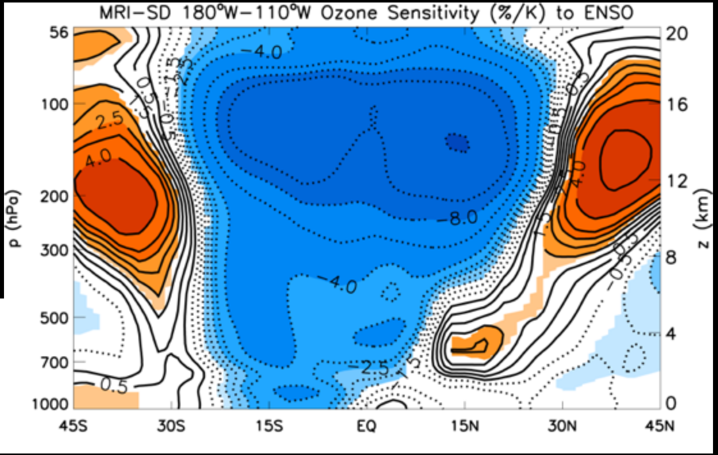
Ozone Response to ENSO in C1SD simulations



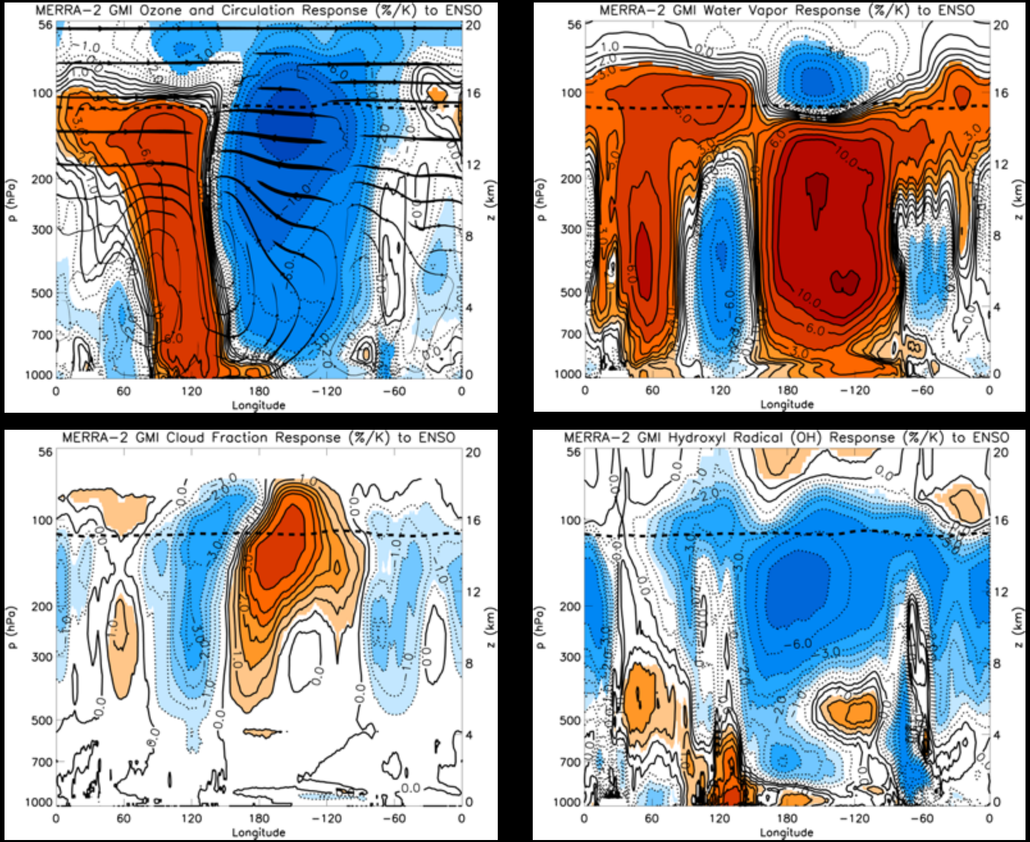


The response is also generally well reproduced in specified dynamics simulations





Response to ENSO in MERRA-2 GMI



We can use a simulation like MERRA-2 GMI to examine processes causing the response and to look at important species that are not currently observable