# Changes in stratospheric water vapor and aerosols and their relation to ozone

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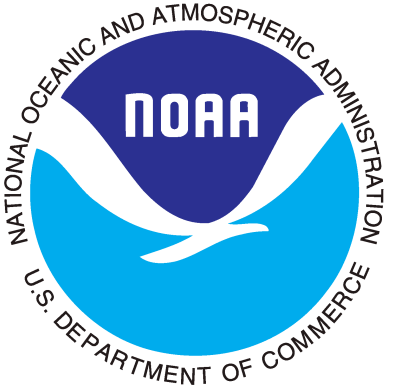



# Stratospheric $H_2O$ and $O_3$

*Impact of a stratospheric water change*

**increase $H_2O$ -> increase potential for PSCs** ⇩ **$O_3$**

(Kirk-Davidoff et al., Nature, 1999)

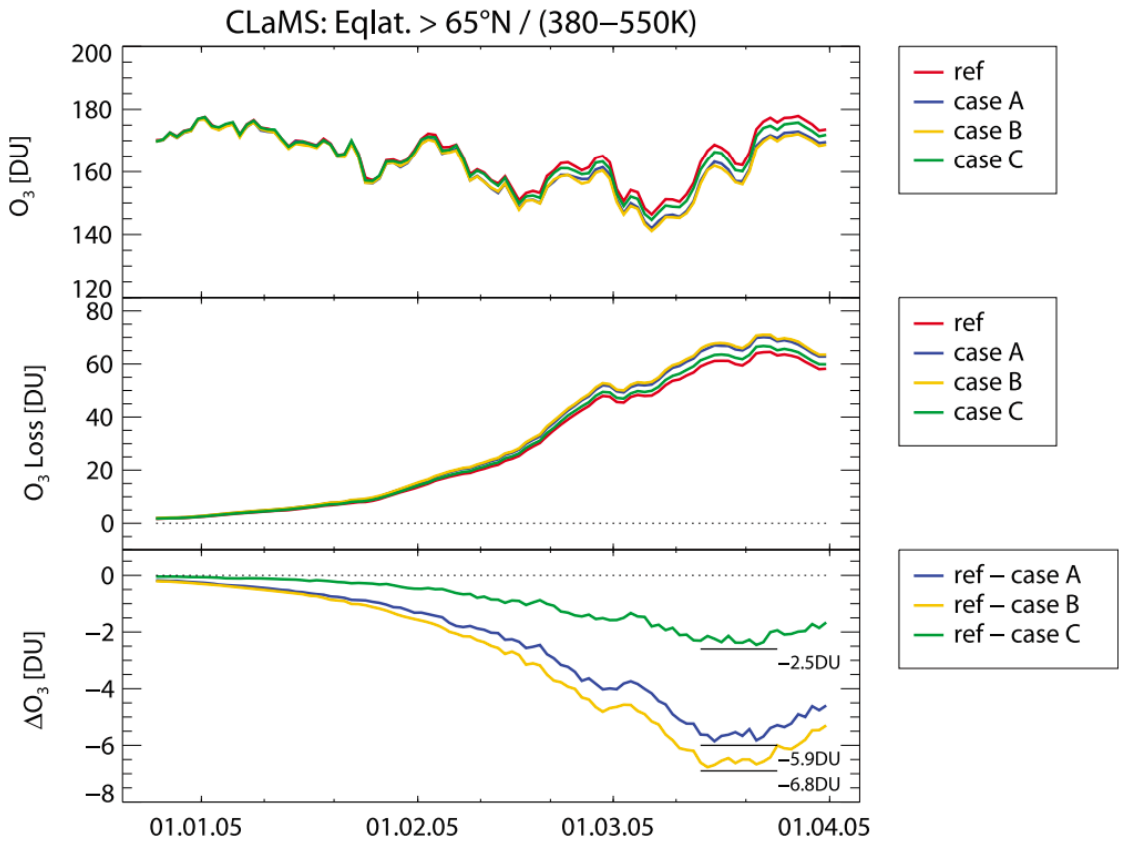



**Figure 6.** (top) Column ozone (in Dobson units) of the reference (red), with additionally increased $H_2O$ ("case A", blue), "case A" with additional decreased temperatures ("case B", yellow), and with a moderate $H_2O$ increase (including corresponding decreased temperatures, "case C", green) integrated over an altitude range from 380 K to 550 K (≈16–26 km) for equivalent latitudes poleward of 65°N. (middle) Ozone loss in DU for these model simulations. (bottom) $\Delta O_3$ due to "case A" (blue), "case B" (yellow), and "case C" (green). A higher ozone loss of up to 5.9 DU (≈10 %), 6.8 DU (≈11 %), and 2.5 DU (4 %) is found in "case A", "case B", and "case C", respectively, compared to the reference.

From Vogel et al.. JGR, 2011

# Stratospheric $H_2O$ and $O_3$

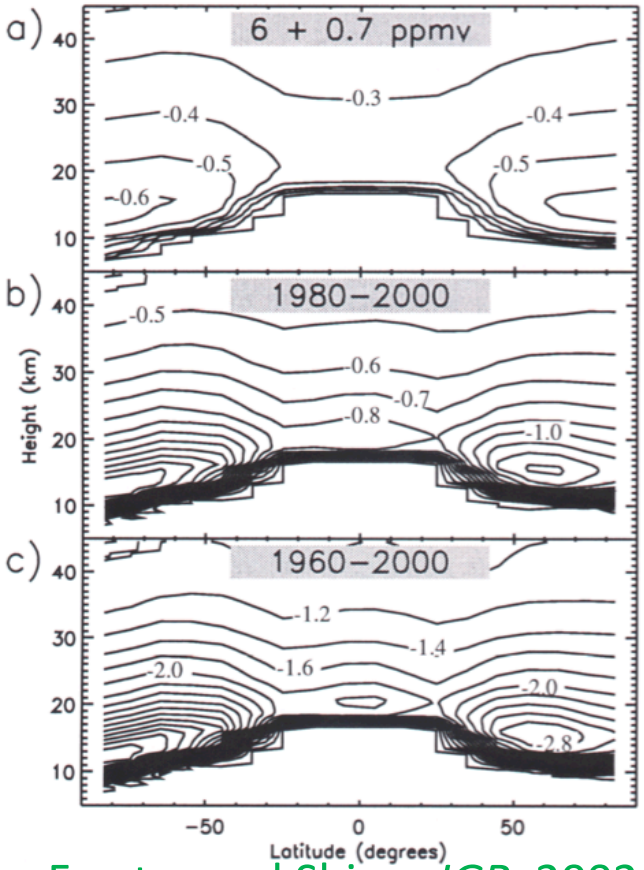
*Impact of a stratospheric water change*

**increase $H_2O$ -> increase potential for PSCs ↓ $O_3$**

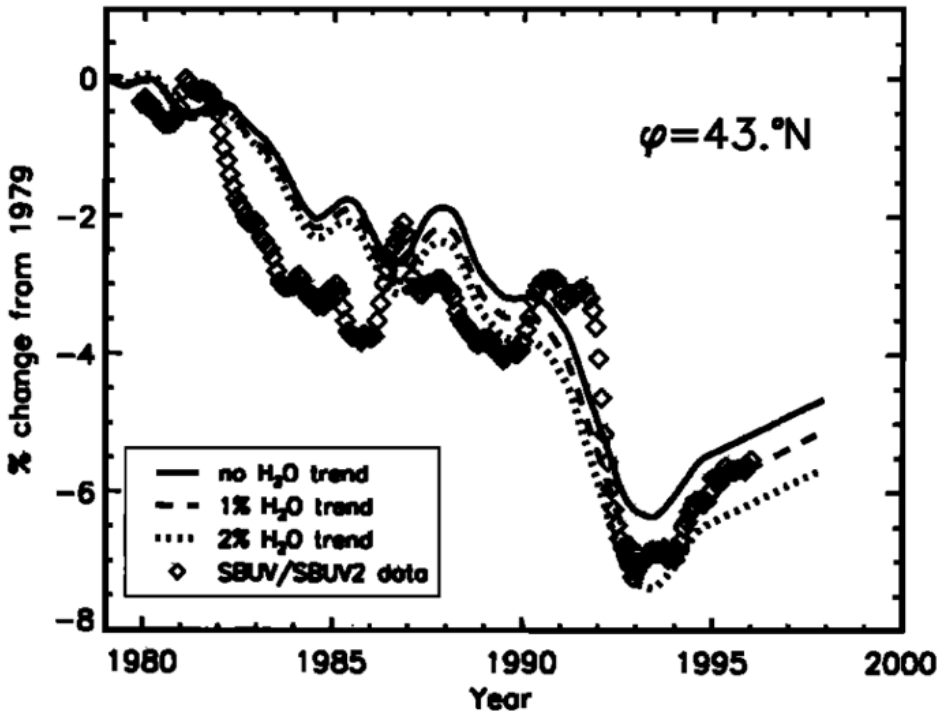
**increase $H_2O$ -> increase HOx ↓ $O_3$**

**increase $H_2O$ -> decrease stratospheric temperature**

**↑ $O_3$ where PSCs do not form, ↓ $O_3$ where there are PSCs**




Forster and Shine, *JGR*, 2002

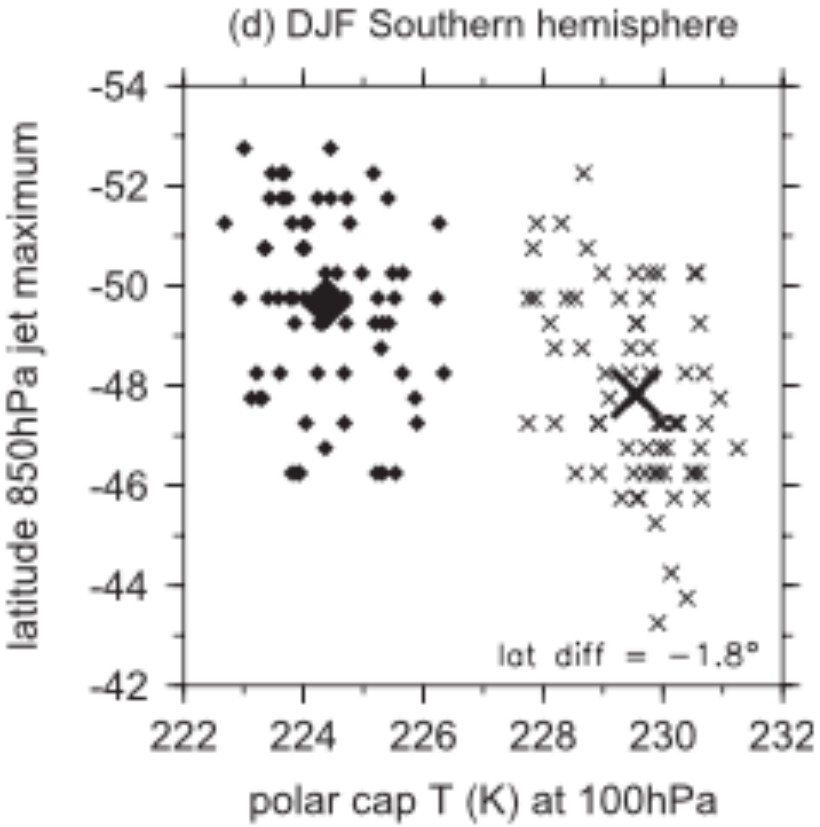



Dvortsov and Solomon, *JGR*, 2001

# Stratospheric $H_2O$ and $O_3$

*Impact of a stratospheric water change*

**A change in atmospheric circulation -> possible feedbacks on $O_3$**

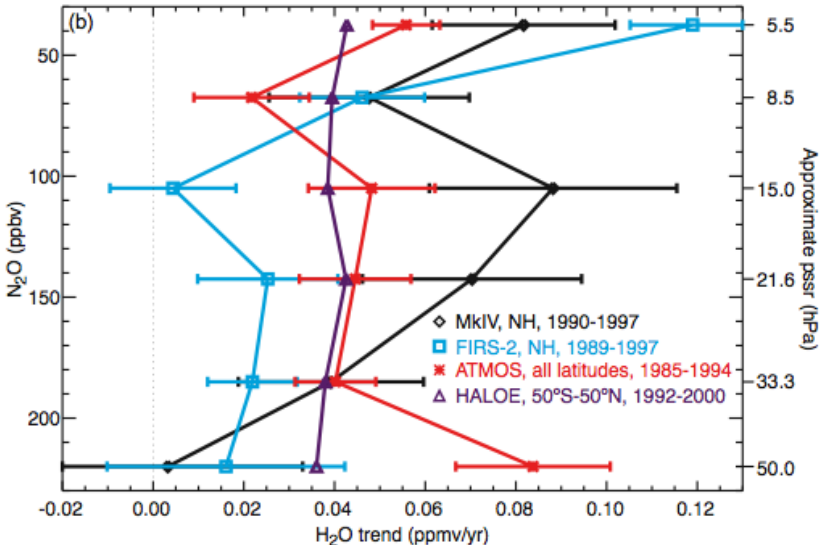


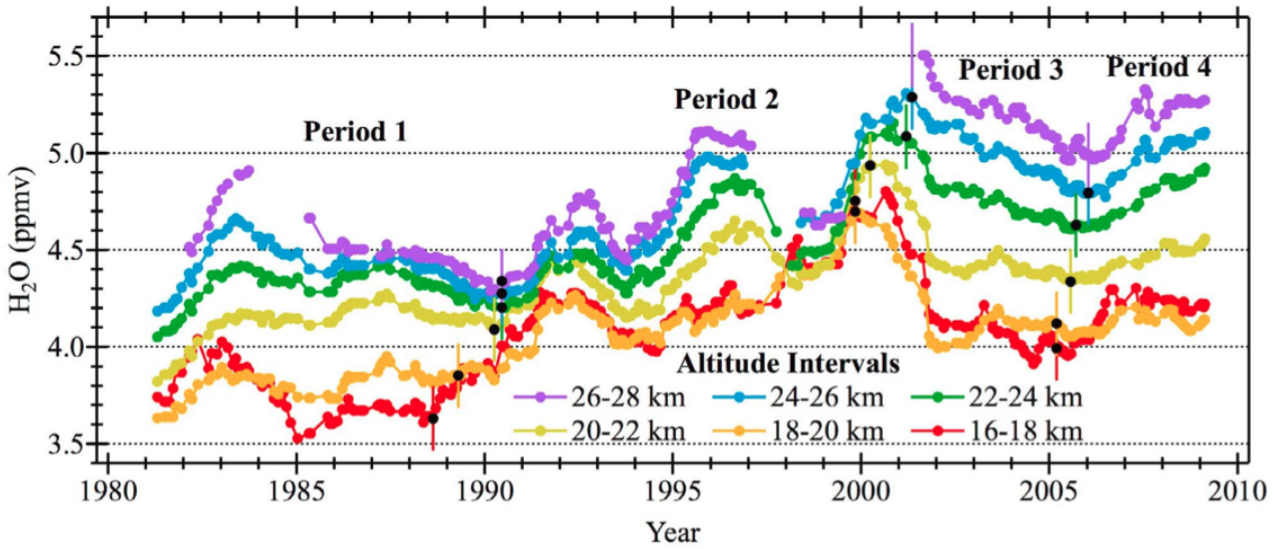

And, if the circulation changes, including tropical width changes, that can result in changes in constituent fluxes into the stratosphere

Maycock et al., *J.Climate*, 2013

# How has stratospheric $H_2O$ changed?

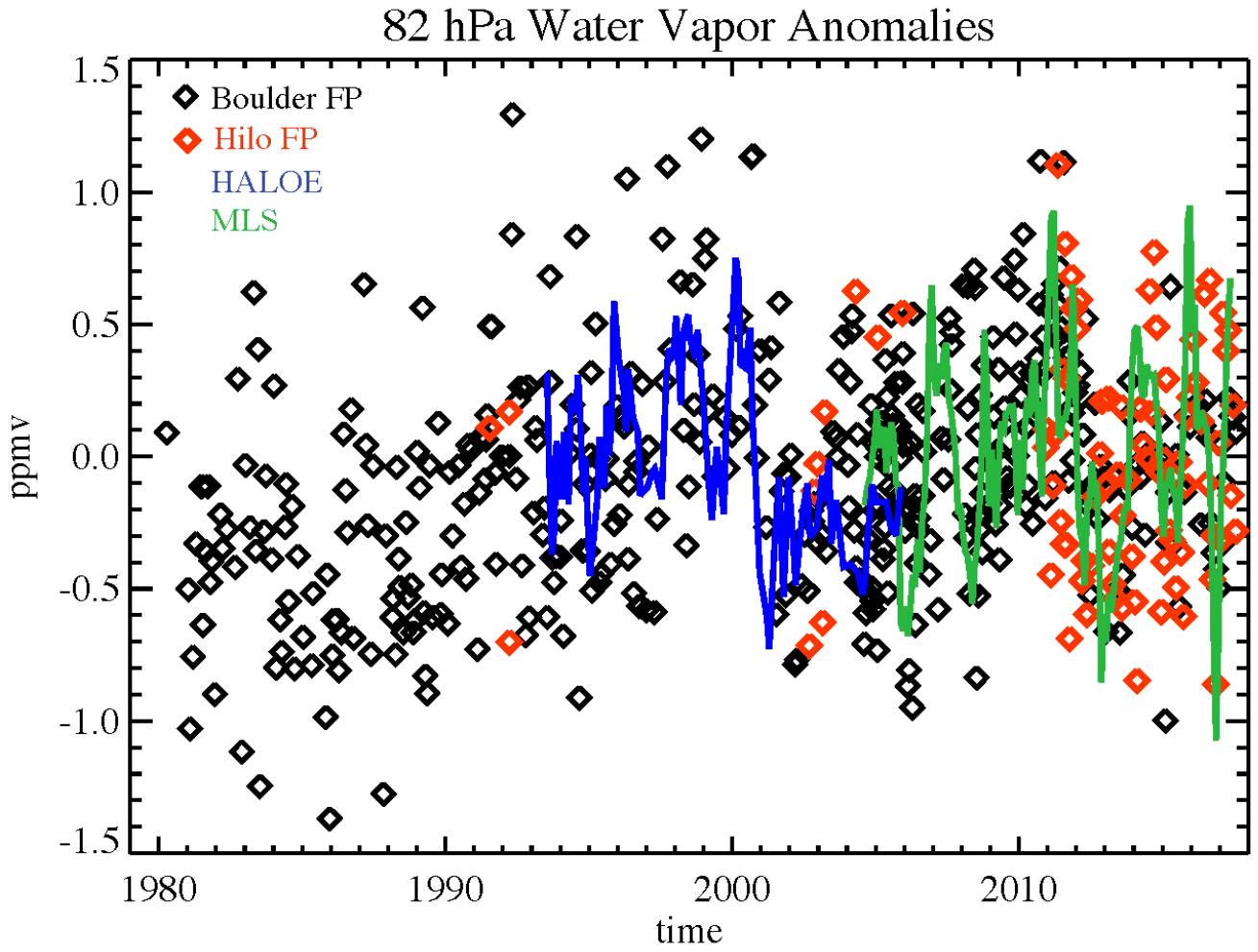
SPARC, 2000




Hurst et al, 2011, JGR

# How has stratospheric $H_2O$ changed?

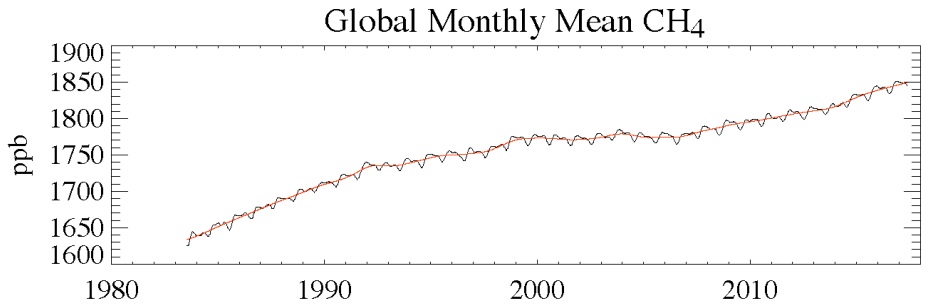


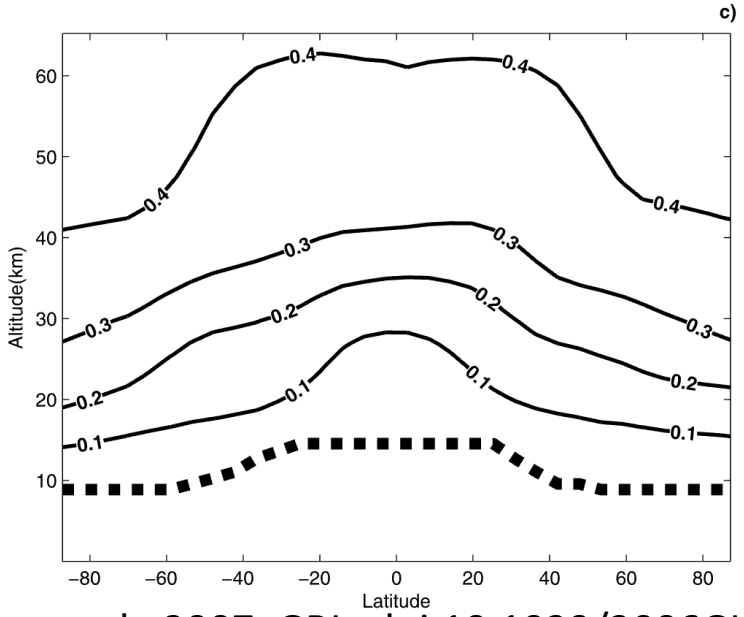

NOAA FP and HALOE and MLS tropical satellite measurements

# What causes $H_2O$ changes?

## 1) Changes in $CH_4$

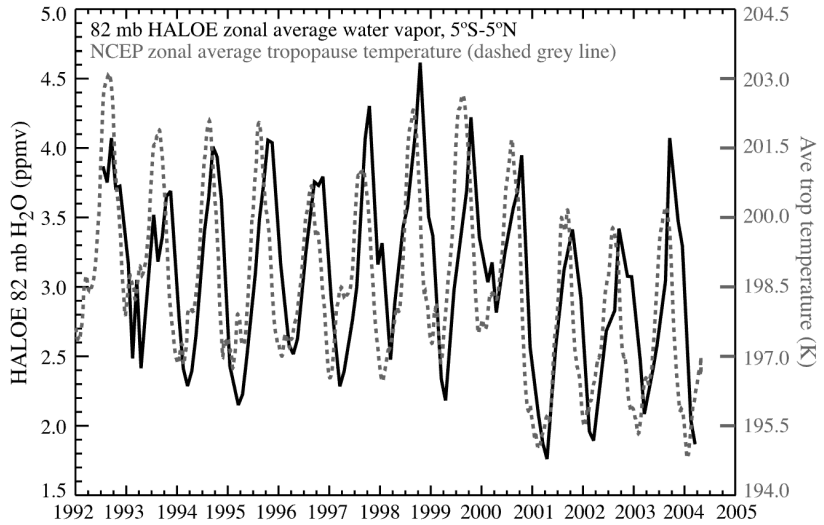
1979-2000 increase



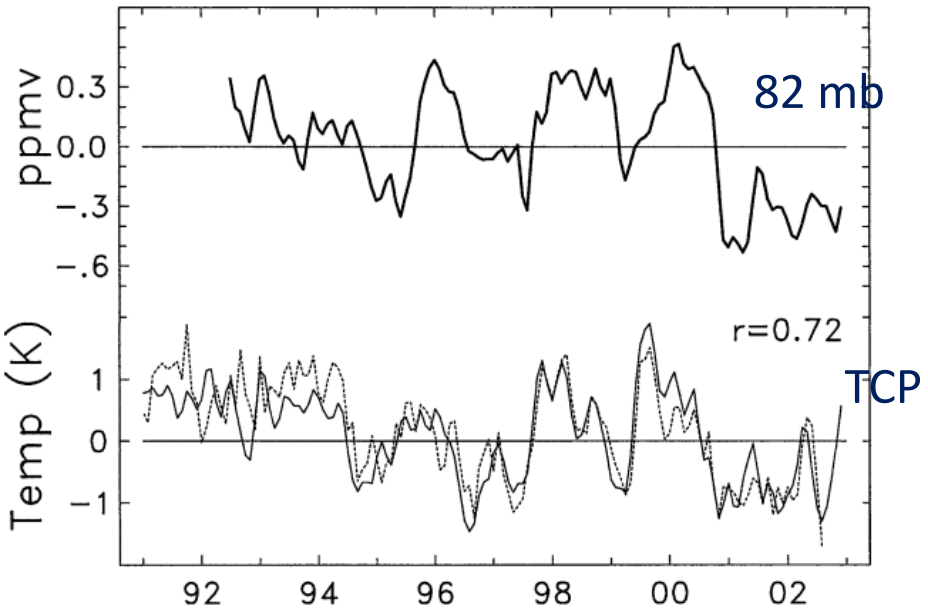




Myhre et al., 2007, GRL, doi:10.1029/2006GL027472

## 2) Changes in tropical tropopause temperatures




Rosenlof & Reid, 2008, JGR, doi:10.1029/2007JD009109




Randel et al, 2004, JAS doi: 10.1175/1520-0469(2004)

# What causes $H_2O$ changes?

## 3) Variability related to potential changes in ice input

**Geophysical Research Letters**

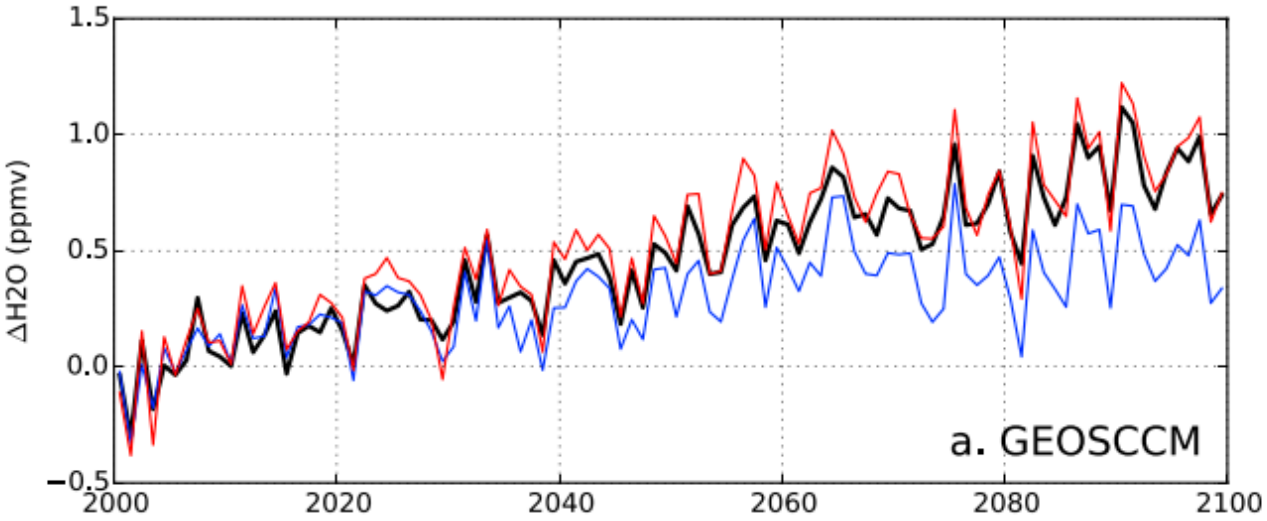
**RESEARCH LETTER**
10.1002/2016GL067991

**Key Points:**
- Models all predict water in the stratosphere will increase
- Much of this is due to warming of the tropopause
- A significant fraction, however, is due to increases in evaporation of convective ice

### Transport of ice into the stratosphere and the humidification of the stratosphere over the 21st century

**A.E. Dessler[1], H. Ye[1], T. Wang[2], M.R. Schoeberl[3], L.D. Oman[4], A.R. Douglass[4], A.H. Butler[5,6], K.H. Rosenlof[5], S.M. Davis[5,6], and R.W. Portmann[5]**

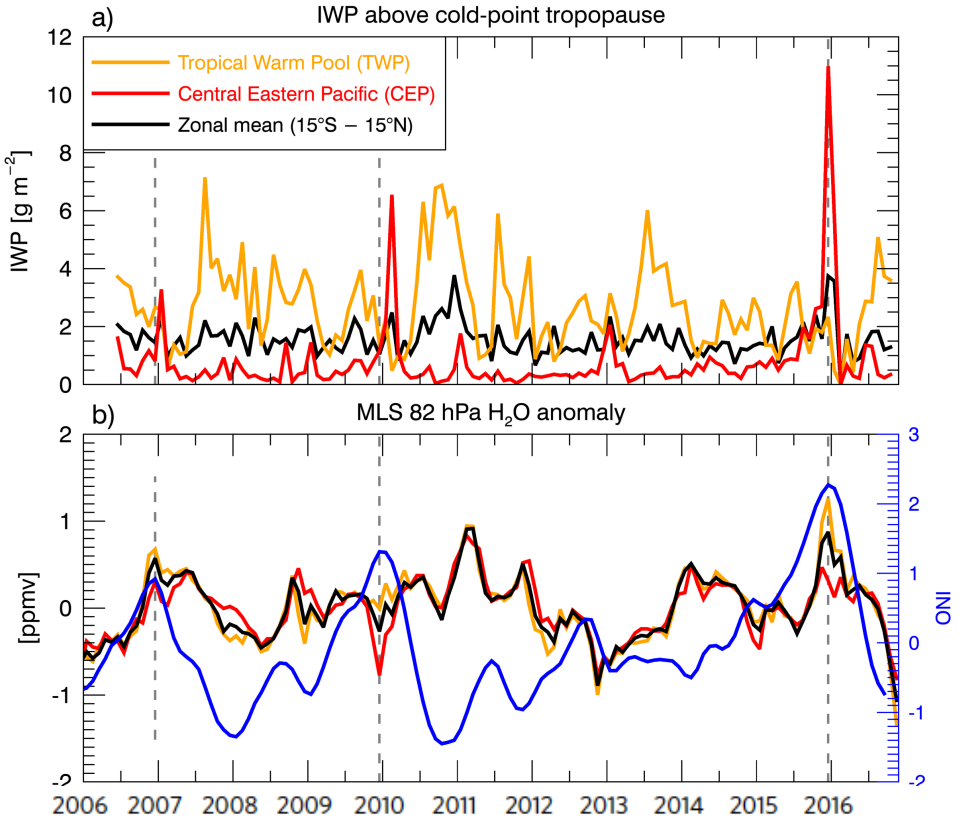
[1]Department of Atmospheric Sciences, Texas A&M University, College Station, Texas, USA, [2]NASA Jet Propulsion Laboratory/Caltech, Pasadena, California, USA, [3]Science and Technology Corporation, Columbia, Maryland, USA, [4]NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, [5]NOAA Earth System Research Lab, Boulder, Colorado, USA, [6]Cooperative Institute for Research in Environmental Sciences, University of Colorado Boulder, Boulder, Colorado, USA

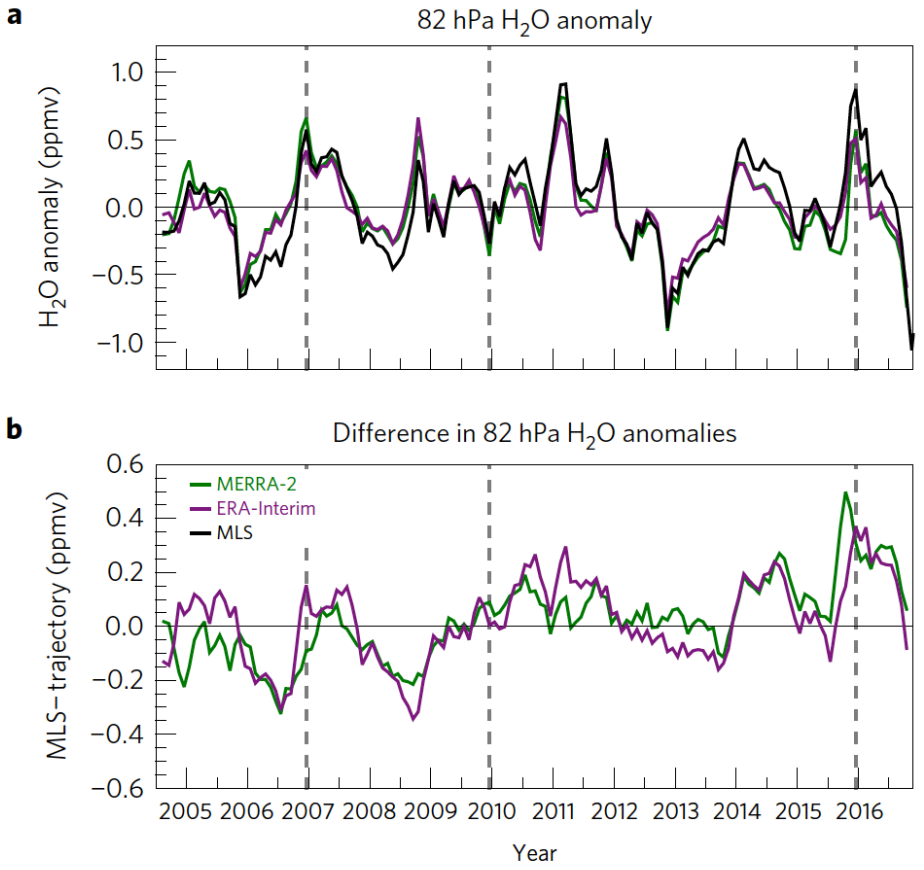



$H_2O$ entry from GEOSCCM (black), a trajectory run based on CCM temperatures (blue), and one that includes ice lofting (Red)

# What causes $H_2O$ changes?

## 3) Variability related to potential changes in ice input



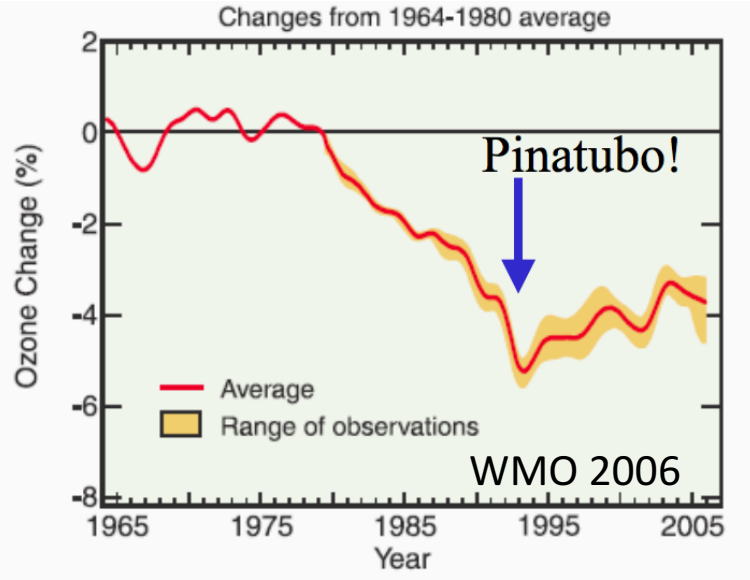



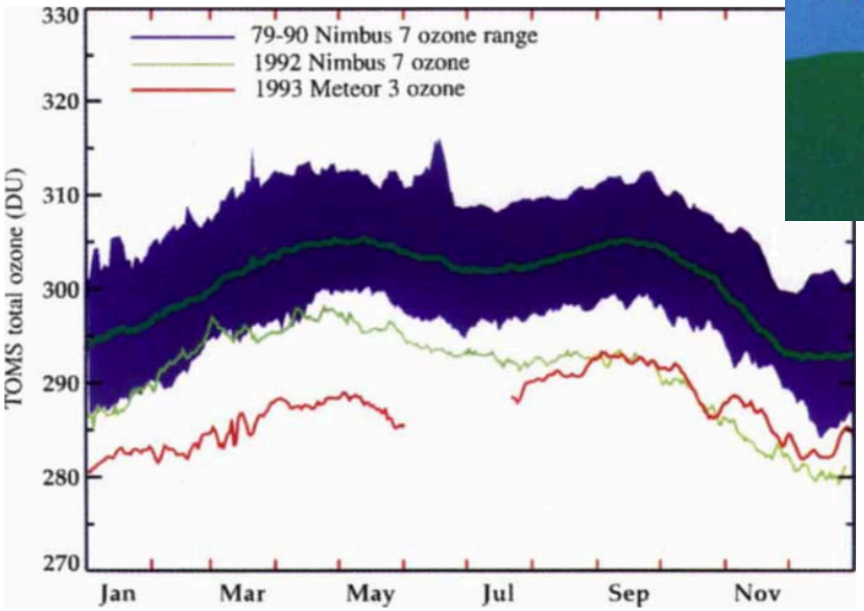

1 sample case where ice lofting is needed to reproduce observations, recent strong ENSO event.

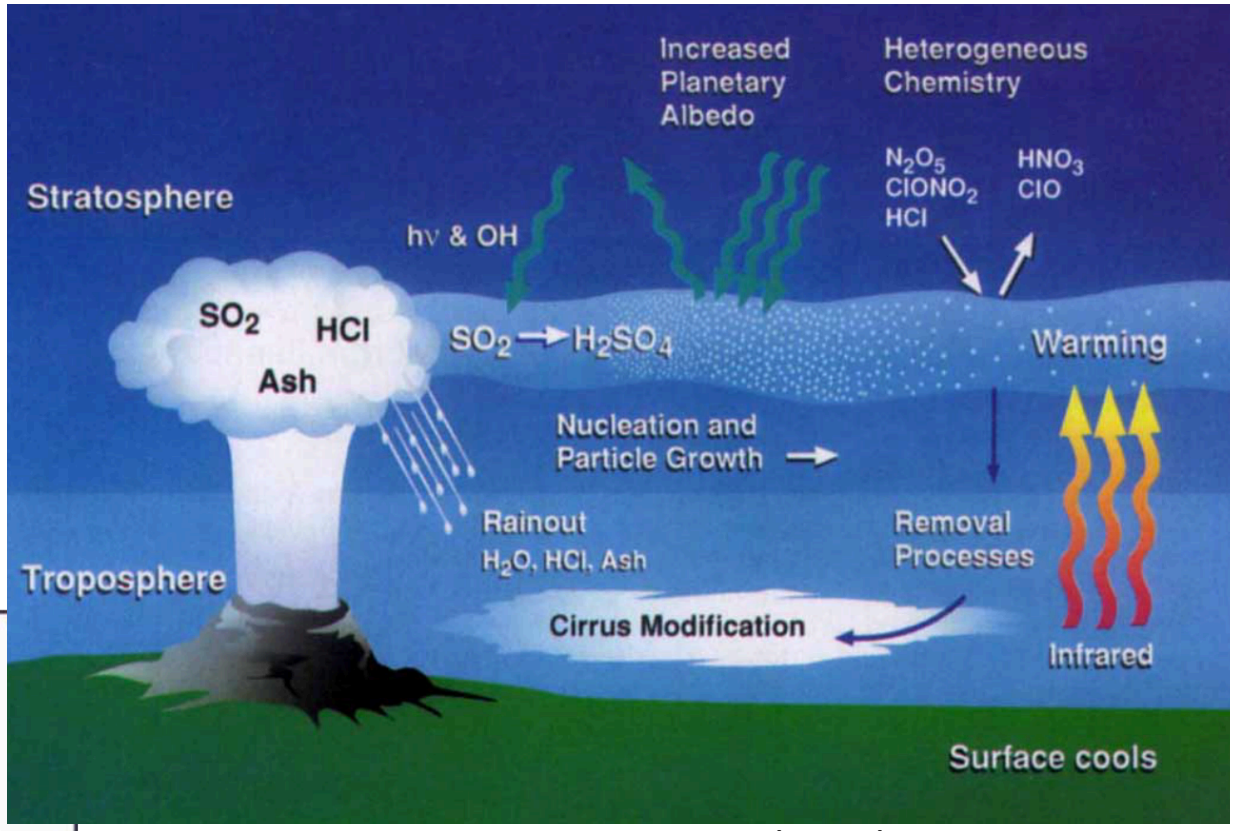
*Avery et al., 2017, Nature Geoscience, 10, 405–409, DOI:10.1038/NGEO2961*

# Stratospheric aerosol and $O_3$

*How do aerosols impact stratospheric ozone?*



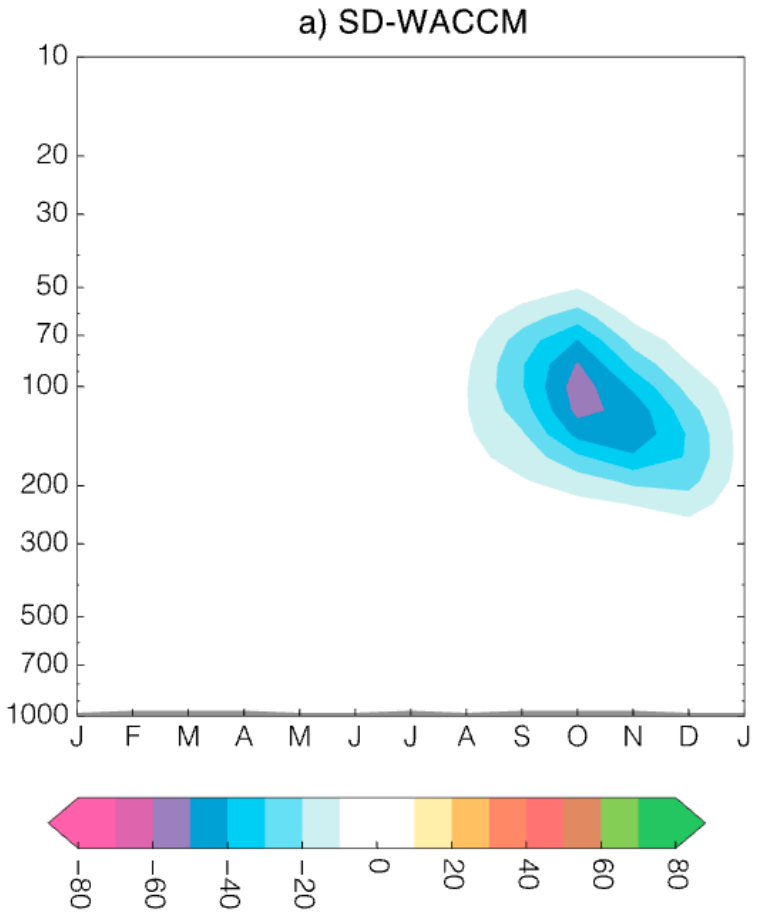

McCormick et al., Nature, 1995

Heat balance
Circulation
Heterogeneous chemistry

# Stratospheric aerosol and $O_3$

*Impact of Calbuco in 2015*

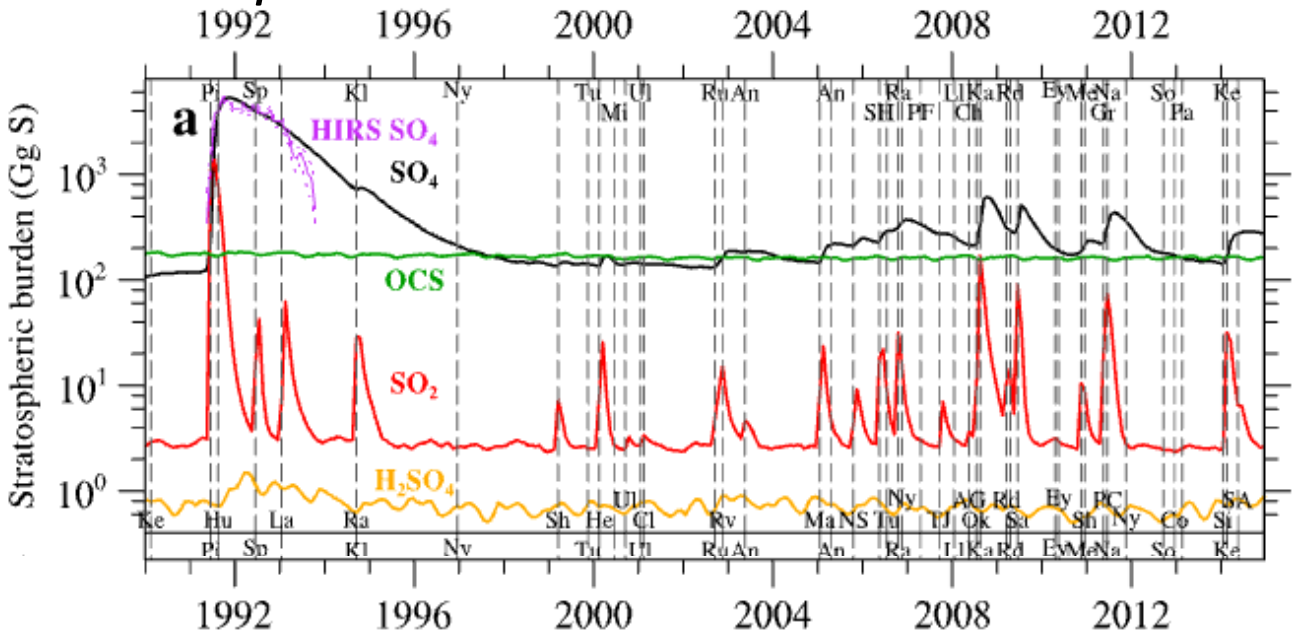
*Relative differences in polar cap averaged (63–90°S) ozone between the Volcanic and Vol-Clean WACCM simulations*




From Ivy et al. ,2017, doi:10.1002/2016GL07192

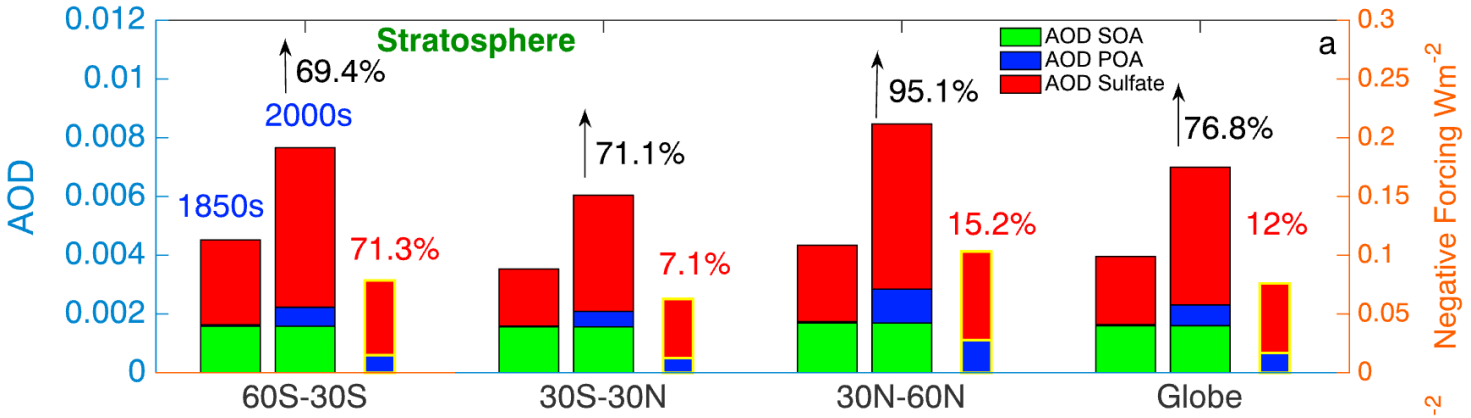
# What causes stratospheric aerosol changes?

*1) Volcanic input*



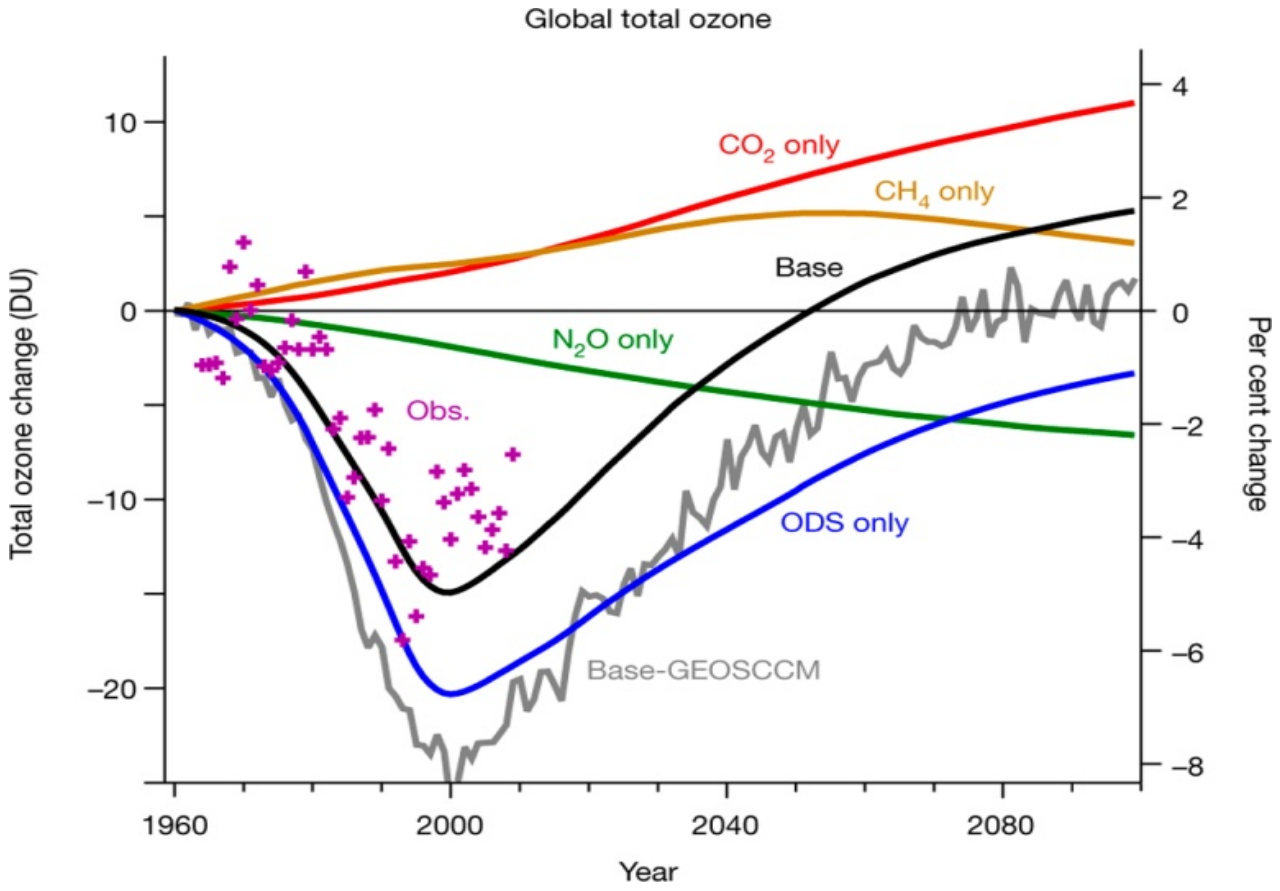

Mills et al., JGR, 2016, doi:10.1002/2015JD024290

*2) Anthropogenic source is relatively small, but has changed with time*




Yu et al., GRL, 2016, doi:10.1002/2016GL070153

# Where do these changes fit into the $O_3$ big picture?




Essentially, the aerosol and water vapor effects are encapsulated by the spread of the observational symbols on this plot.

Simulated global annual averaged total ozone response to changes in GHGs and ODSs from the GSFC two-dimensional chemistry–climate model.

M P Chipperfield *et al. Nature* **549,** 211–218 (2017) doi:10.1038/nature23681

# What could happen in the future?

## *Considering stratospheric $H_2O$*

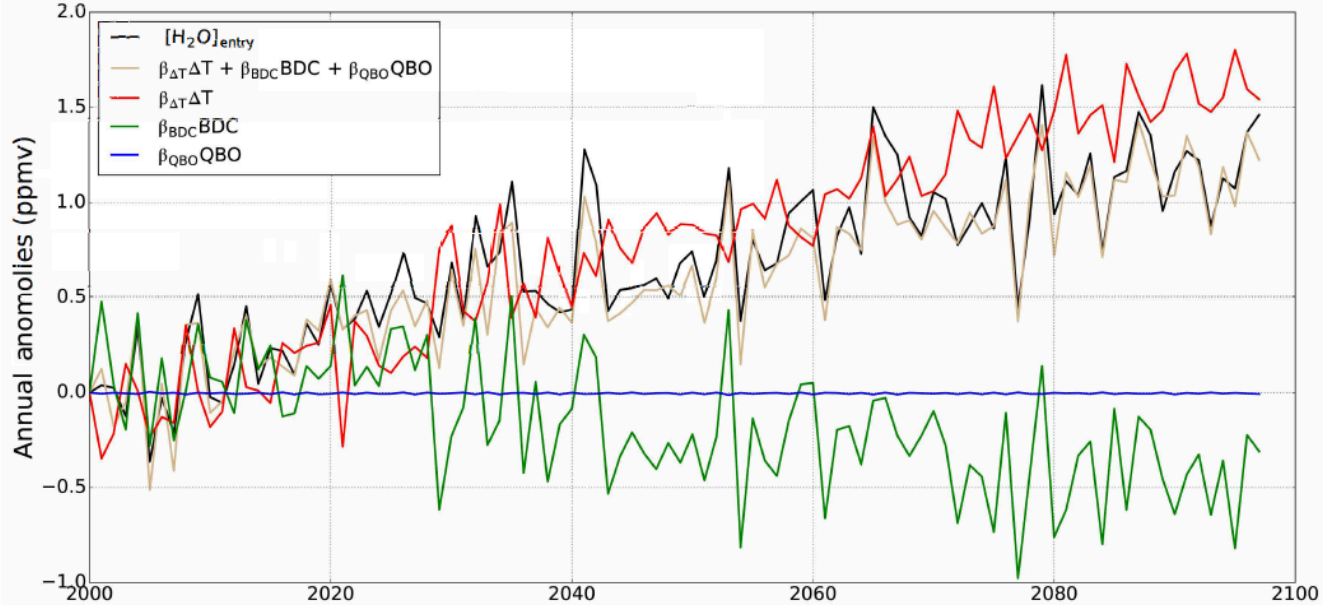



**Figure 2.** Time series of annual-averaged anomalies of $[H_2O]_{entry}$ from the MRI (black), and its reconstruction using a multivariate linear regression (brown). The red, green, and blue lines are the $\Delta T$, BDC, and QBO terms from the regression, respectively.

Future increases are attributed to tropospheric warming with an offset due to an increased strength of the Brewer Dobson Circulation

From Smalley et al., 2017, ACP

# What could happen in the future?

*Systematic changes in aerosol or water could skew the ozone evolution relative to current model estimates, possibly delaying ozone recovery by a small number of years if:*

- *Stratospheric water increases*
- *There is a large volcanic eruption*
- *There is  a new source of aerosols*

*Geoengineering? see Simone Tilmes' talk≠*