# Future evolution of water vapour

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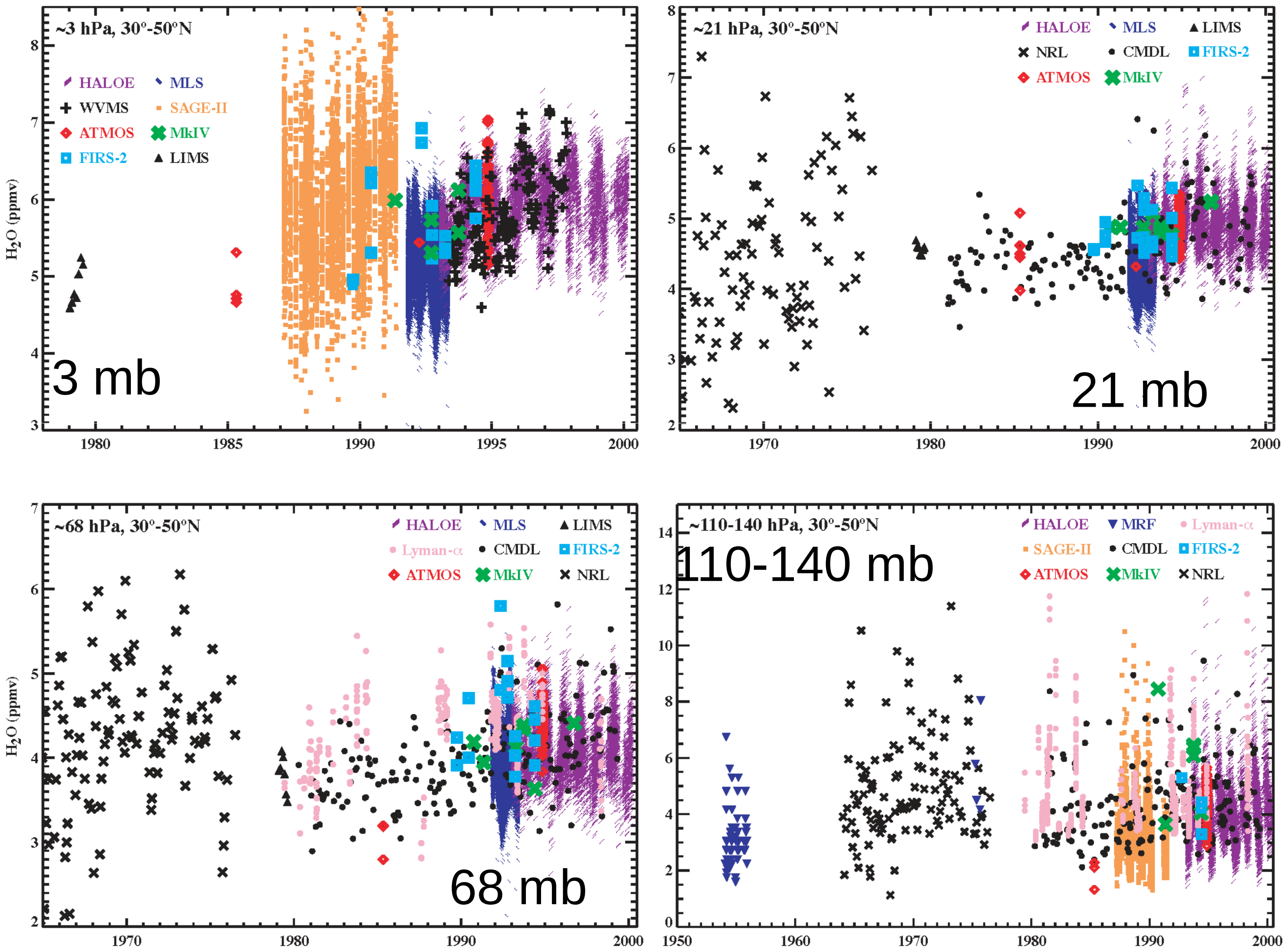
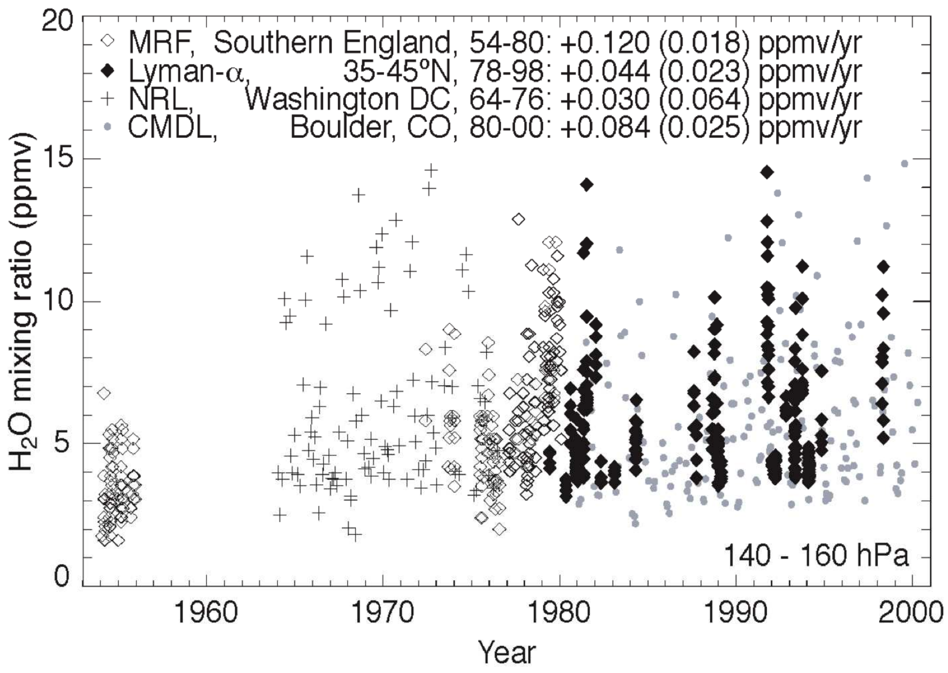
Cargèse International School
Water Vapour in the Climate System (WAVACS)
14-26 September 2009
Lecture 4 of 4

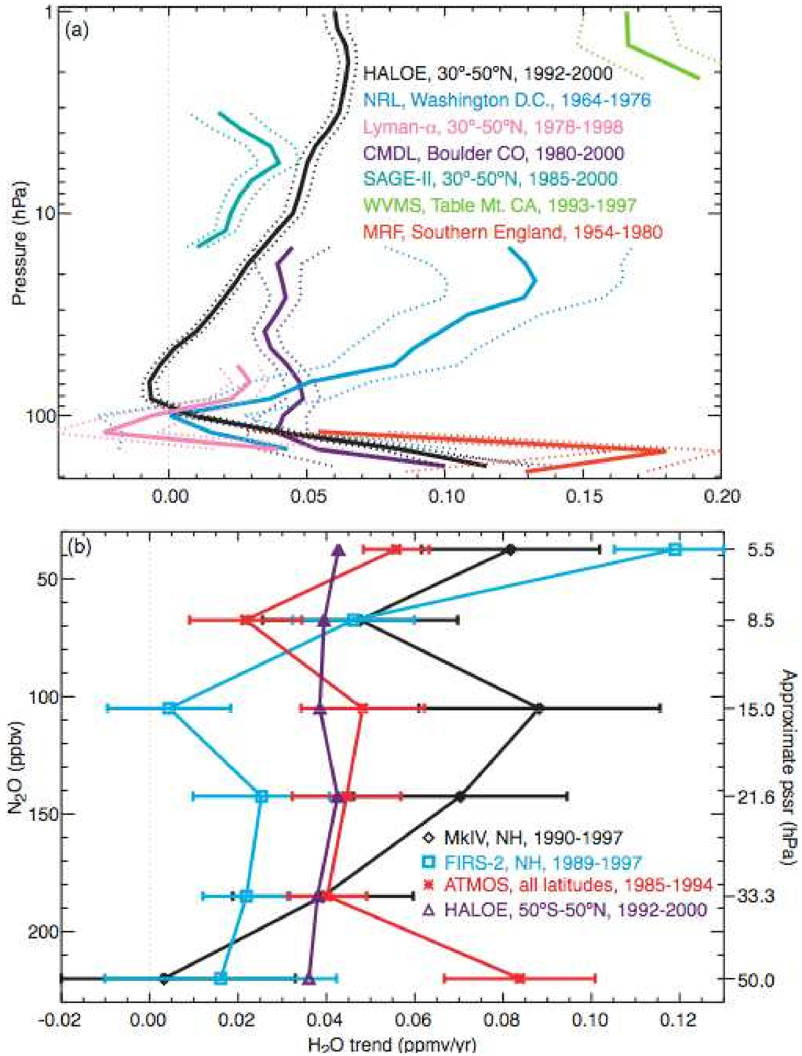
# SPARC WAVAS, 2000, 20-50ºN historical measurements

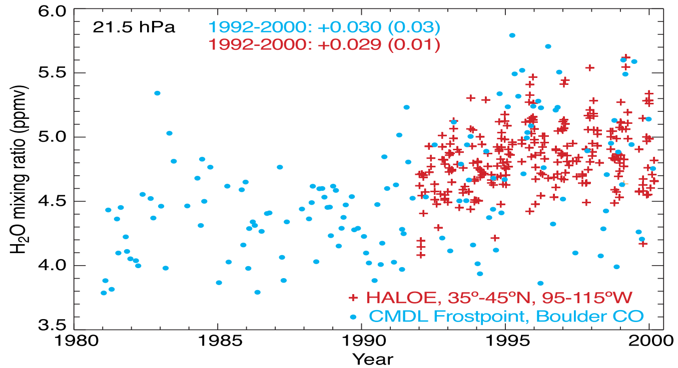


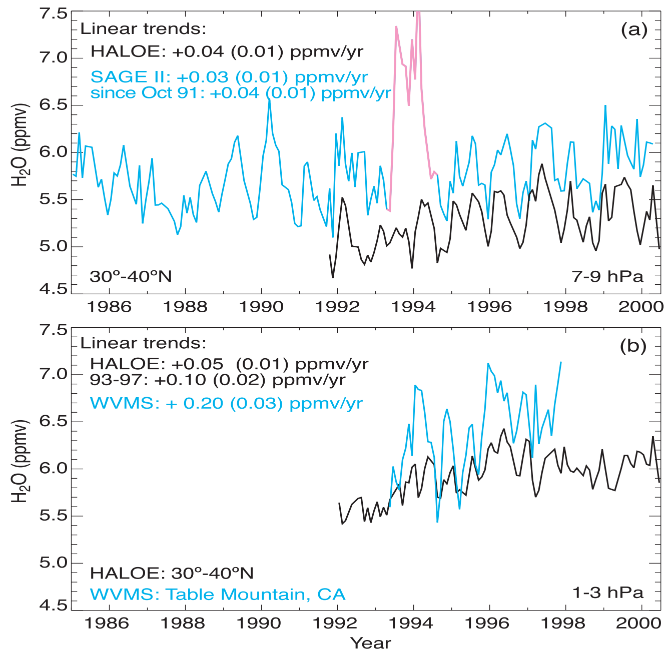


MRF, Southern England, 54-80: +0.120 (0.018) ppmv/yr
Lyman-α, 35-45ºN, 78-98: +0.044 (0.023) ppmv/yr
NRL, Washington DC, 64-76: +0.030 (0.064) ppmv/yr
CMDL, Boulder, CO, 80-00: +0.084 (0.025) ppmv/yr
140 - 160 hPa
H2O mixing ratio (ppmv)
Year
0
5
10
15
20
1960
1970
1980
1990
2000


140-160 mb




1) Linear terms largely positive: average = 0.045 ppmv/yr

2) Vertical structure in trends: minimum at 100-60 mb

3) When time periods overlap, trend calculations are similar for different data sets.

4) Over all conclusion: there was a trend over the time period considered, exact mechanism not fully understood.

*(from Rosenlof et al, 2001, GRL)*

# Boulder FP data was recently quality controlled, and bias corrections in the early period were applied



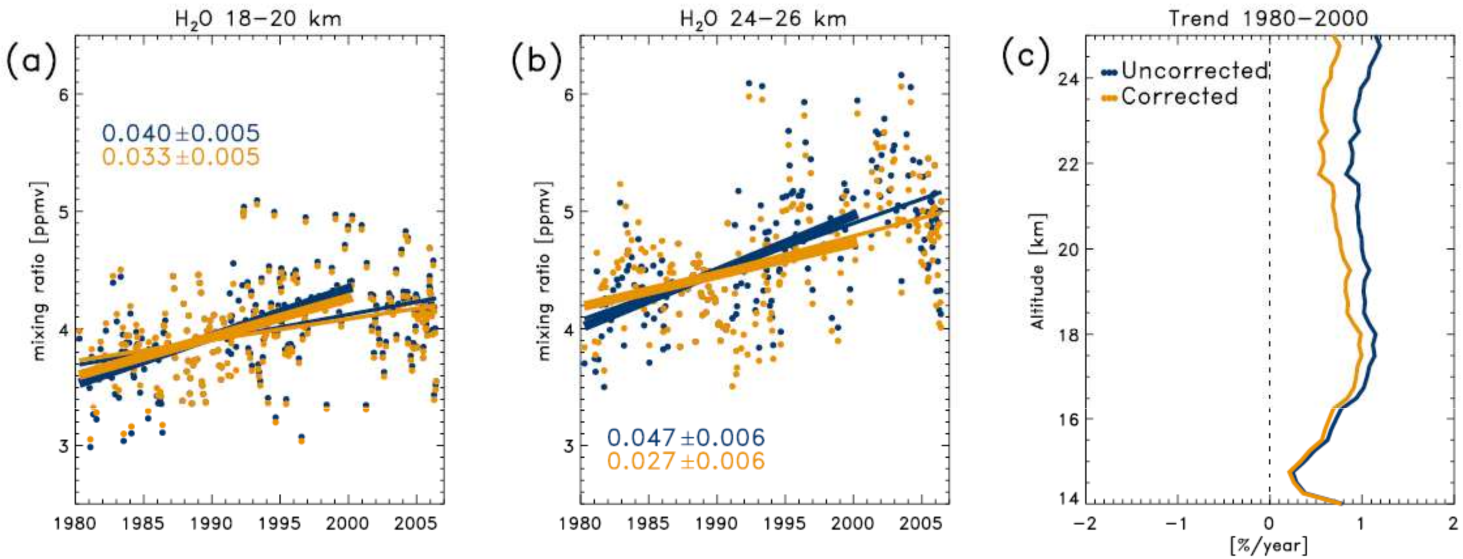



**Fig. 1.** Linear trend estimates of stratospheric water vapour from NOAA FP measurements. **(a)** For 18–20 km; **(b)** for 24–26 km; **(c)** trend profiles (in percent per year, confidence intervals omitted for clarity). Blue/yellow show uncorrected/corrected data, no correction applied for period 1987–1991. Trends for period 1980–2000 (slope and 2-$\sigma$ uncertainty printed in panels a/b) for comparison with Oltmans et al. (2000). Note trend reduction of up to 40% due to data correction.

# Magnitude of historical change

Trend in the corrected Boulder data set is is now .6% per year (~.03 ppmv/year).

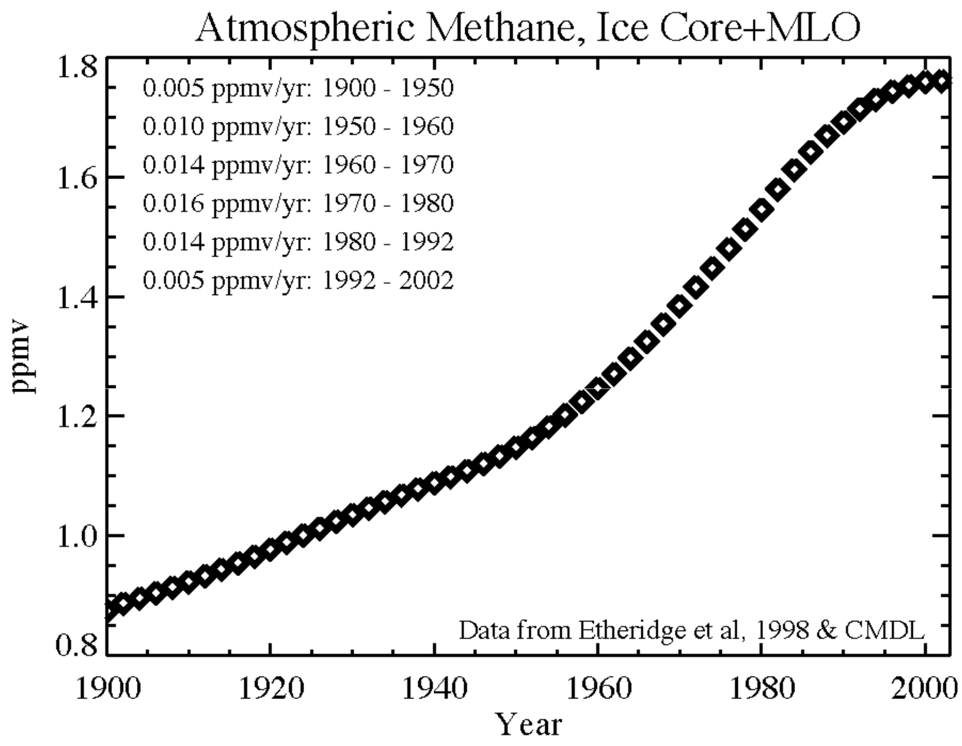
Over the 40 year record discussed in the SPARC 2000 report, this would correspond to an possible $H_2O$ increase of 1.2 ppmv.

# What happens to stratospheric water vapor will likely depend on:

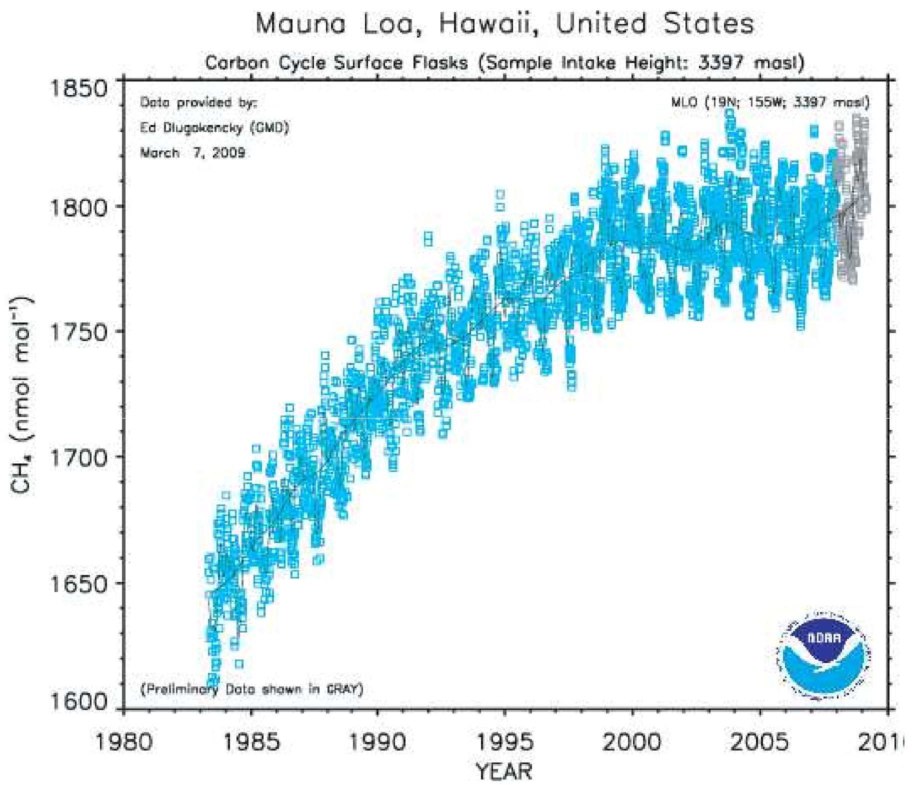
1) Surface methane changes (and transport into the stratosphere)
2) How conditions at the tropical cold point change
3) How transport (or age) within the stratosphere changes
4) Microphysics/aerosols at the tropical cold point

# Methane changes

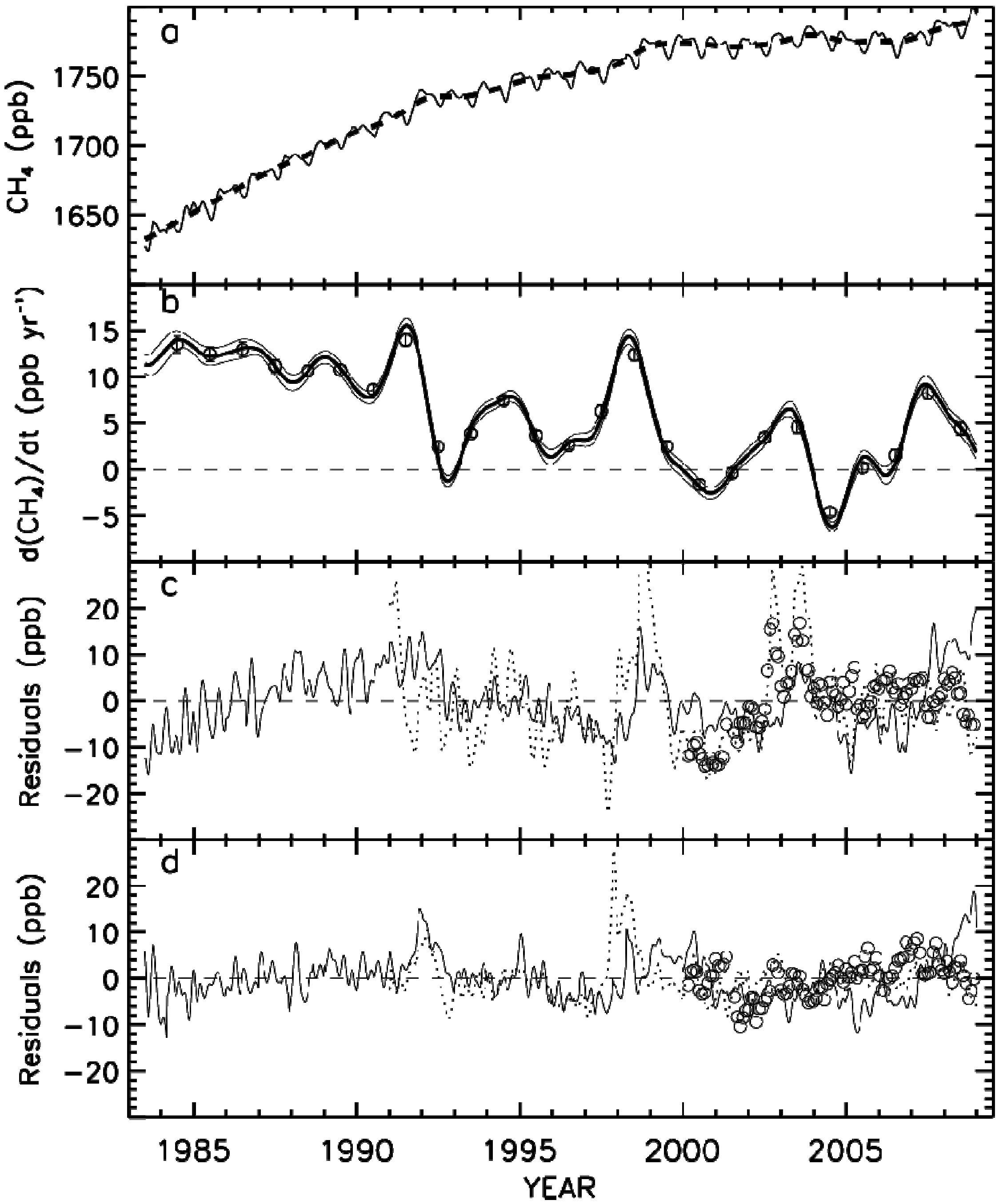
## Methane has increased over the industrial era.




From Etheridge et al. [1998]




Current measurements from MLO NOAA GMD surface data




Rate of methane increase slowed over past decade, but may be picking up again (Dlugokencky et al., GRL, in press "Observational constraints on recent increases in the atmospheric CH4 burden" (GRL on line version currently)

## How much of the historical increase is due to methane?

Over the period 1960-2000, and using the NOAA Boulder corrected trend, the estimated $H_2O$ increase is 1.2 ppmv.) Rohs et al. (2006) found that methane can account for a trend of .0132 ppmv/year, which amounts to about half of the corrected observed Boulder increase.
Trend in the corrected Boulder data set is is ~0.6% per year (~.03 ppmv/year).

So, what is left to explain is an increase of 0.6 ppmv over 40 years

For future evolution, an estimate of surface methane changes is needed.

# Future projections of methane

From IPCC 4th Assessment Report:

“Methane has increased as a result of human activities related to agriculture, natural gas distribution and landfills.  Methane is also released from natural processes that occur, for example, in wetlands.”

biogenic...wetlands, rice production, biomass burning and ruminant animals

note: climate change can impact wetlands/permafrost regions which then impacts emissions.

industrial sources include fossil fuel mining and distribution

Future scenarios:

Ref2, in CCMVal exercise (see Eyring et al, 2007, methane increases from 1.761 ppmv in 2000 to 2.399 ppmv in 2050

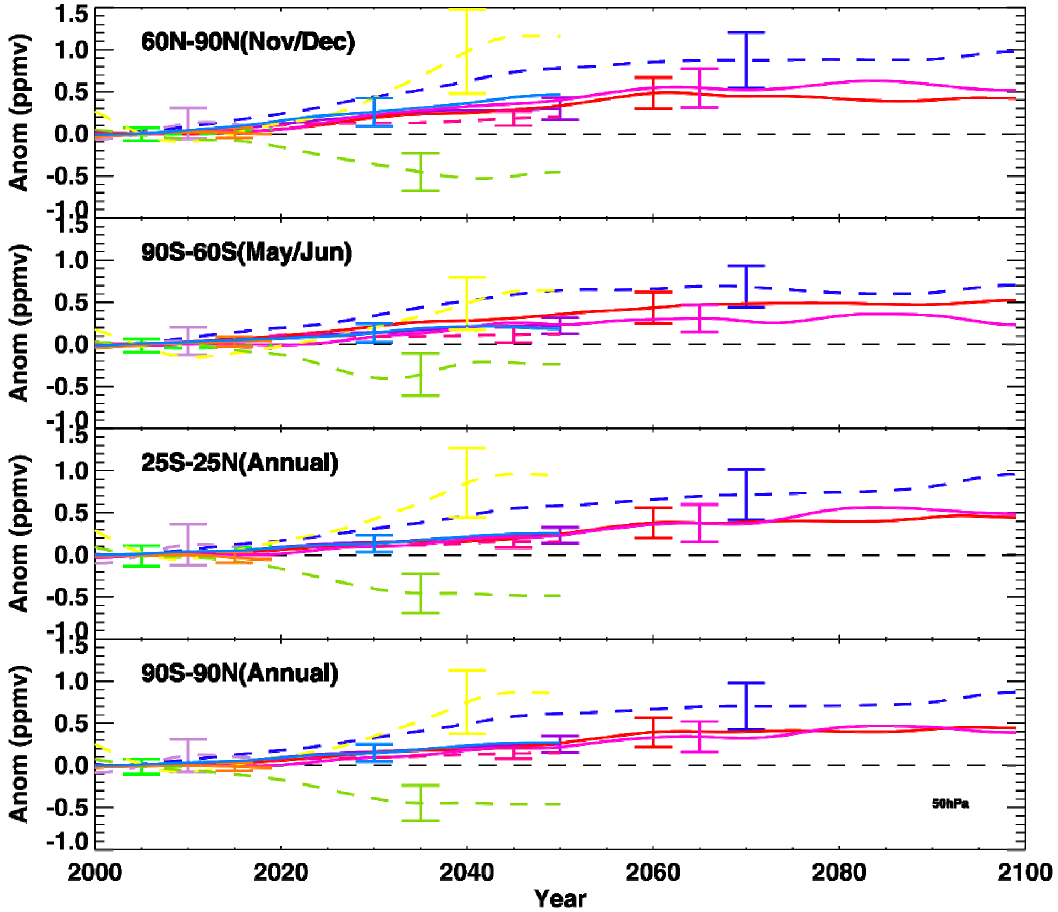


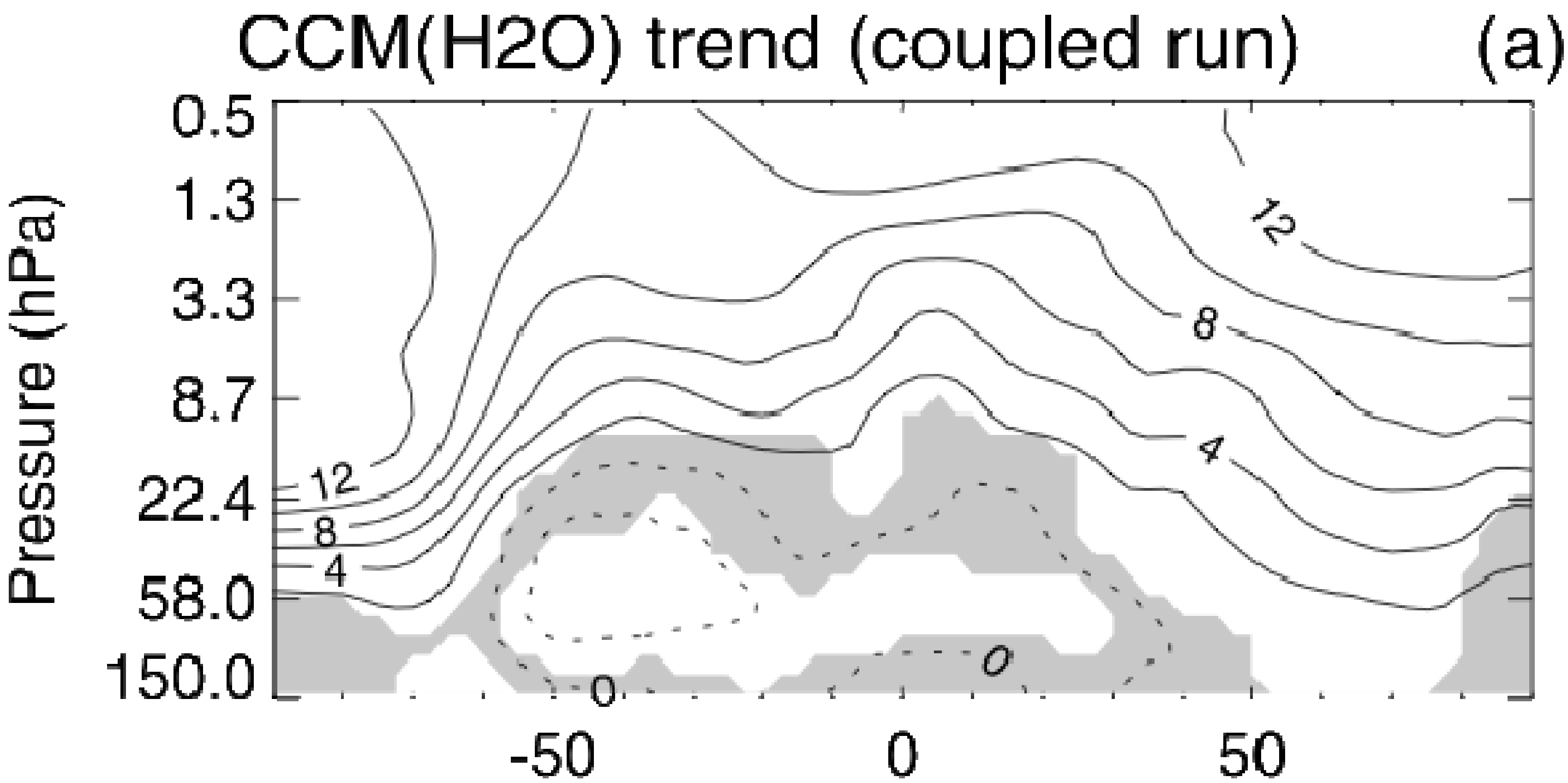

Figure 4. Modeled time series of monthly mean water vapor anomalies at 50 hPa from the CCMs. Water vapor anomalies are calculated with respect to a mean reference period between 2000 and 2010 using 2-month averages for November to December in the polar Northern Hemisphere (60 –90 N), May to June in the polar Southern Hemisphere (60 –90 S), and annual averages for the tropical and global anomalies.

del CH4=.638

del H2O=~.5

Not all increase in CCMVal runs due to methane

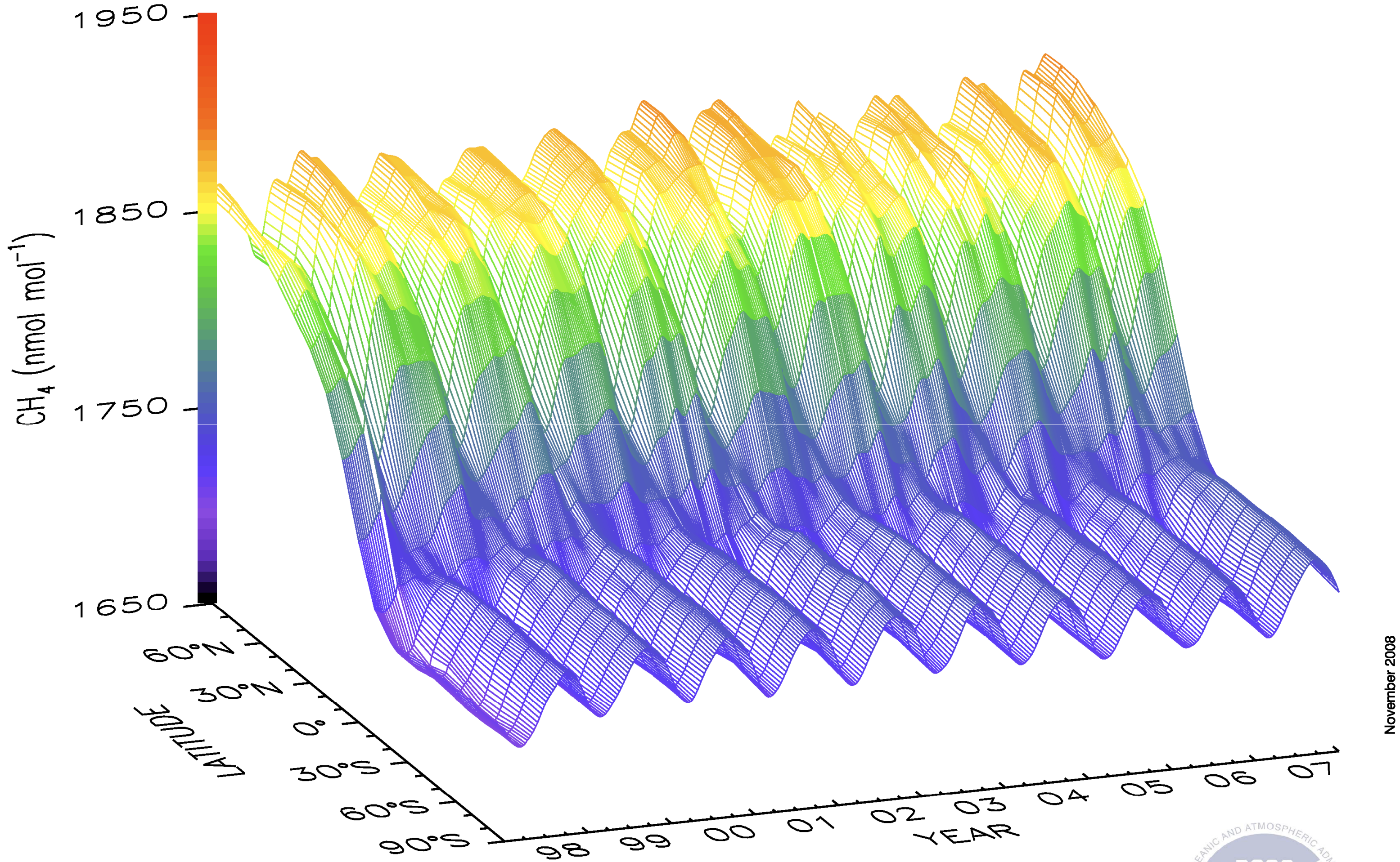
Tian and Chipperfield, 2005:
Incomplete CH4 oxidation leads to a maximum upward H2O trend in the upper stratosphere of about 1.4  the imposed tropospheric CH4 trend. Changes in the lower stratosphere may be caused mainly by changes in the injection of tropospheric water vapor and other processes.



Methane induced changes are going to be seen mainly in the upper stratosphere, and models would indicate that the entire methane increase does not translate into a water vapor increase in the stratosphere.

# Global Distribution of Atmospheric Methane

NOAA ESRL Carbon Cycle

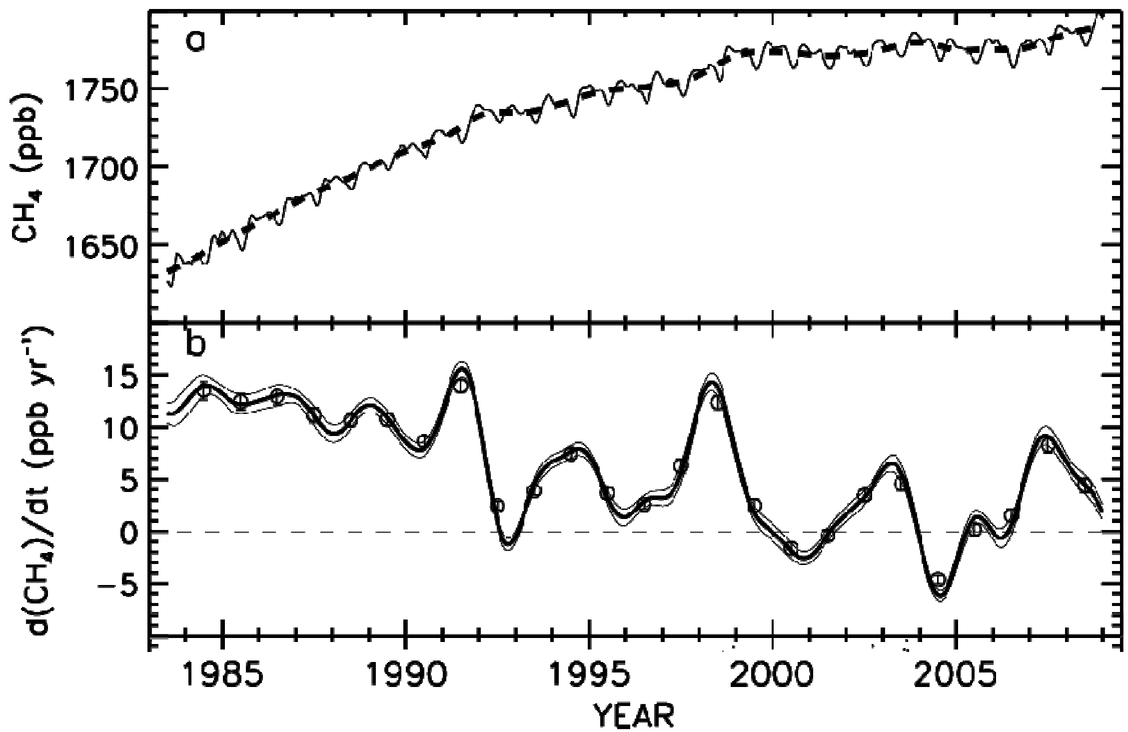



Three-dimensional representation of the latitudinal distribution of atmospheric methane in the marine boundary layer. Data from the Carbon Cycle cooperative air sampling network were used. The surface represents data smoothed in time and latitude. Contact: Dr. Ed Dlugokencky, NOAA ESRL Carbon Cycle, Boulder, Colorado, (303) 497-6228, ed.dlugokencky@noaa.gov, http://www.esrl.noaa.gov/gmd/ccgg/.

**How well can we estimate future methane?**

Really not very well. A significant problem is that the global methane budget is not well quantified. Long term changes likely from industrial changes, interannual variability due to natural sources (Dlugokenky, 2009 and other earlier papers) and changes in the $CH_4$ sink rate (OH)

And, natural sources may be impacted by climate change, so prediction of the future is difficult.




*But, if $CH_4$ increases, then stratospheric water will increase in the upper stratosphere, and in the middle/lower stratosphere at mid to high latitudes*

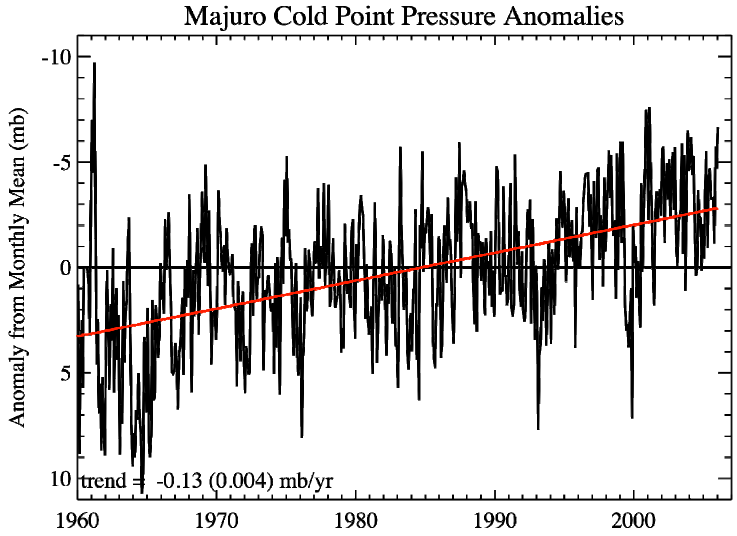
**How is the tropical cold point expected to change?**

Can have changes in temperatures or changes in altitude of the cold point.

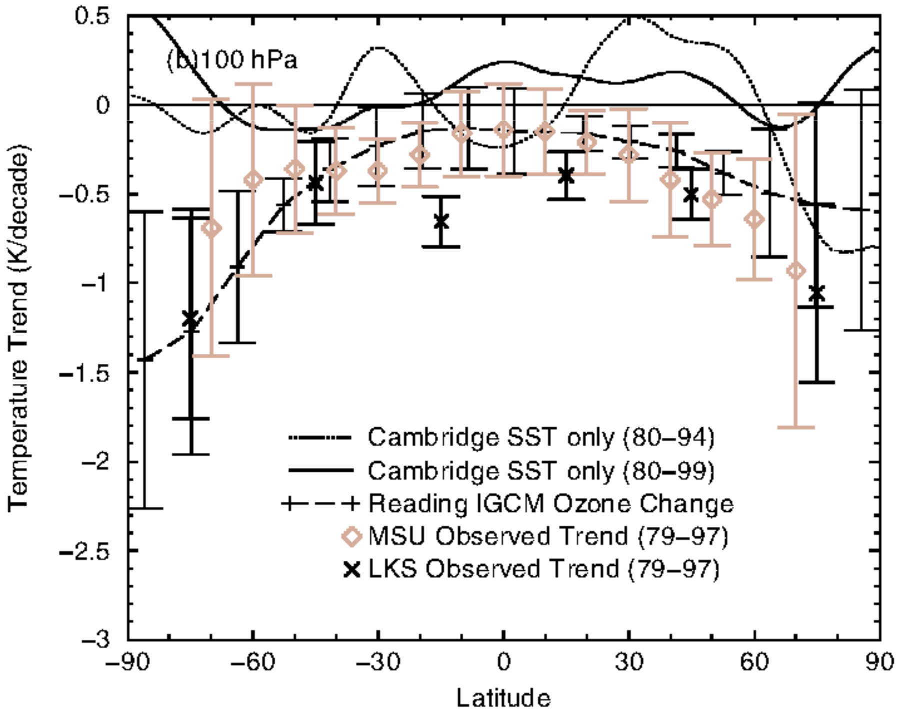
As a reference: over the historical record, the excess increase (Less the contribution due to methane increase) is ~ 0.6 ppmv.

Over the 1960-2000 period, starting with a T/P combo of 189.6/100 mb gives a Qsat ~ 3 ppmv
To get to 3.6 ppmv, a change to a T/P combo of 190.1/100mb, or a increase of 1.1 degrees over 40 years.

To get a similar increase by decrease in cold point pressure, the altitude would have to change from 100 mb to 83 mb.




CP pssrs at one station 1960-2000 period of .13 mb/year, or ~ 5mb (so nowhere near the amount needed.




*Temp trends since 1979*

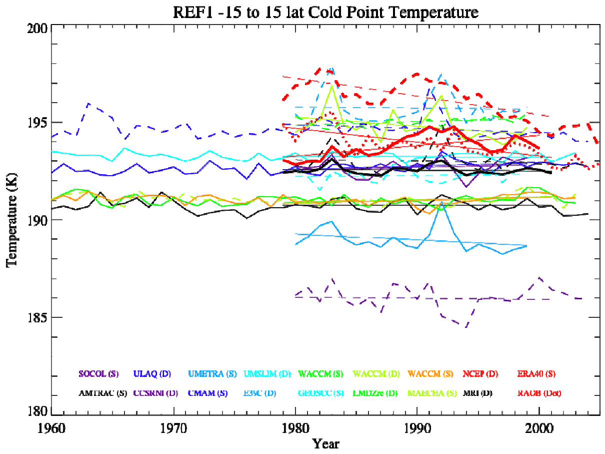
*from Shine et al (2003), shows temperature trends per decade at 100 mb)...changes modeled here are due to ozone and greenhouse gas changes*

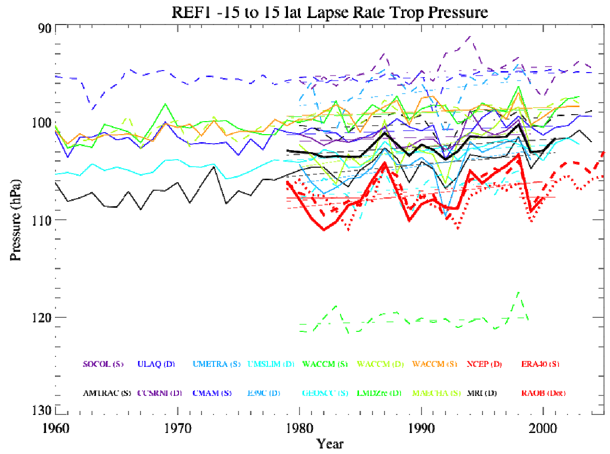
*LKS = Lanzante,Klein and Seidel, J. Climate, 2003*

# What do models show for the future?

**Table 3.** Trends (per decade "*d*") in Key TTL quantities from analysis systems (NCEP/NCAR and ERA40) and model simulations. Trends significantly different from zero (based on $2\sigma$ confidence intervals, or 95% level) indicated with an asterix. 13 models are included in statistics for REF1 and 10 for REF2.

| Diagnostic | Units | NCEP/NCAR 1979–2001 | ERA40 1979–2001 | RAOBS 1979–2001 | Sim REF1 1979–2001 | Sim REF1 1960–2004 | Sim REF2 1980–2100 | Sim REF2 1980–2050 |
|---|---|---|---|---|---|---|---|---|
| $T_{CPT}$ | K/d | −0.94* | 0.54* | −0.68* | −0.03 | −0.04 | 0.09* | 0.09* |
| $T_{ZLR}$ | K/d | −1.1* | 0.53* | | −0.03 | −0.03 | 0.10* | 0.10* |
| $P_{ZLR}$ | hPa/d | −0.28 | −0.86* | | −0.58* | −0.72* | −0.53* | −0.60* |
| $P_{LRT}$ | hPa/d | −1.0* | −1.3* | 0.0 | −0.75* | −0.66* | −0.60* | −0.64* |
| $P_{LRM}$ | hPa/d | −2.8* | −15* | −0.36 | −2.6* | −0.25 | −2.6* | −2.3* |




From Gettelman et al., 2009, ACP

Model change in water vapor amounts to a 20% increase from the present to 2100 due to tropopause temp/pressure changes. (Gettelman et al, 2009)

But, these may be subtle changes, we don't really know how well models represent past water vapor, so I have a hard time definitively stating how water vapor will change in the future. The Gettelman paper specifically concludes that "CCMs are not consistently able to reproduce historical trends in tropopause temperature (TCPT)." which is a problem for predicting changes in input of water into the stratosphere.

Keep in mind that the 100 mb change in the past 30 years appears to be negative in the tropics, while many of the CCMVal models show a much smaller decrease.

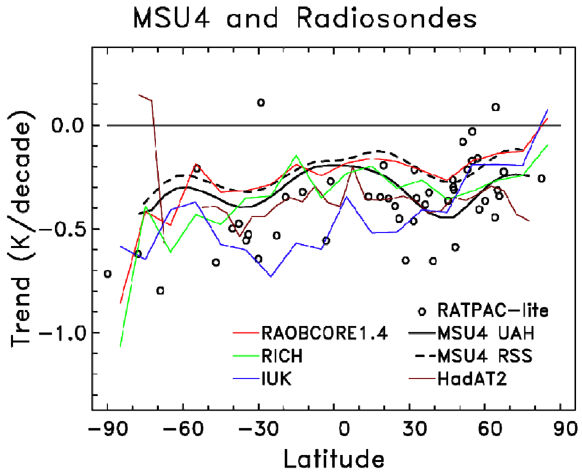



**Figure 6.** Latitudinal profile of temperature trends over 1979–2007 from zonal mean MSU4 and vertically integrated radiosonde data. The heavy solid and dashed lines show MSU4 trends derived from RSS and UAH data, and the colors show trends derived from the respective radiosonde data sets. Statistical uncertainties are not shown but are typically ~0.15 K (two-sigma) and substantially higher over polar regions. The circles show the corresponding trends from each RATPAC-lite radiosonde station.

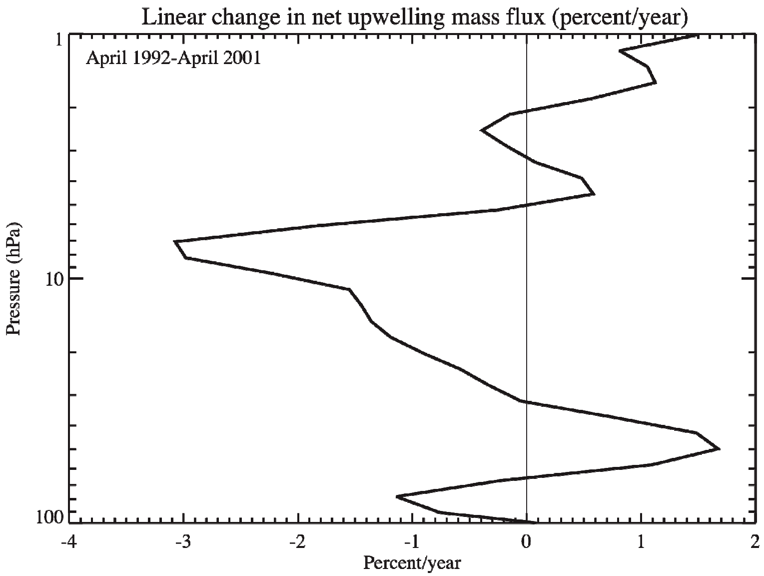
Weighted around 70 mb

How might water change due to transport changes?

1)If average age increases, could increase water vapor, if average age decreases, could decrease stratospheric water vapor.

2) Models would indicate that in an increased CO2 world, the BD circulation accelerate (Garcia and Randel, 2009)...could conceivable decrease age and water vapor in the stratosphere.

Example here, upwelling through the 10 mb surface decreases, age therefore increases, and we see a correlated decrease in CH4 and increase in water



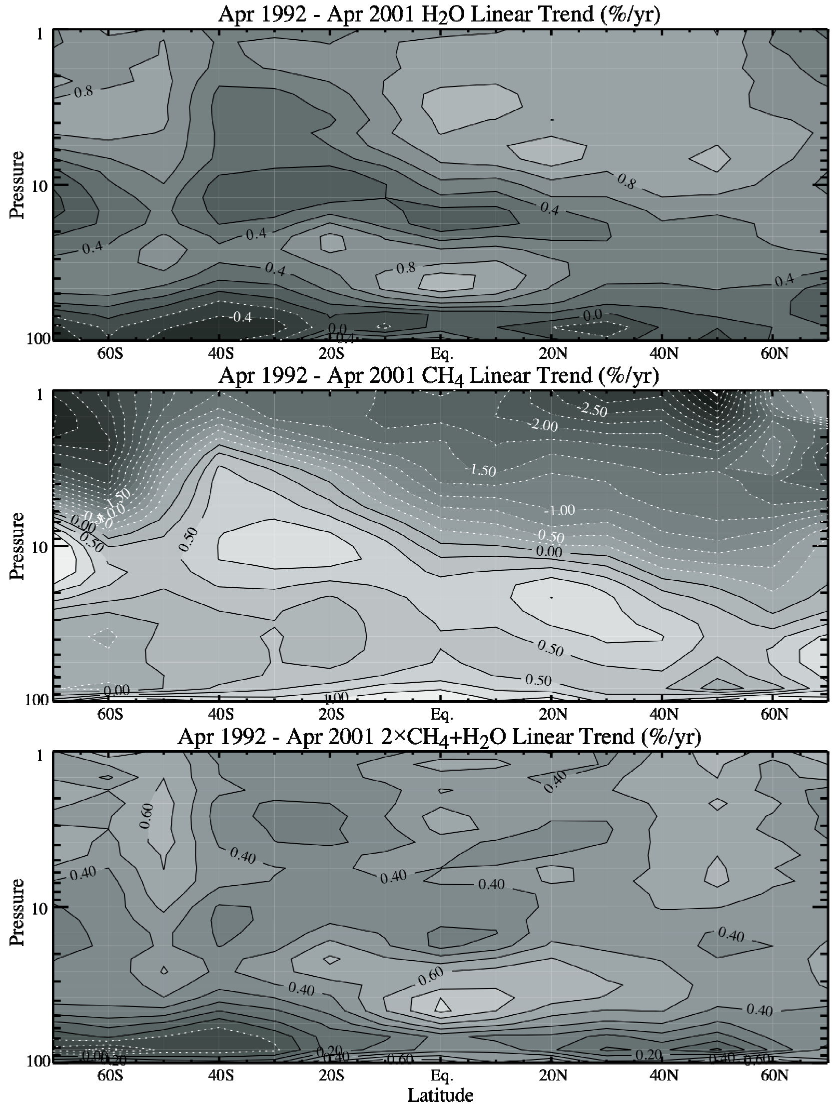




Figure 4

From Garcia and Randel, 2009, shows change in age of air in $CO_2$ increase scenarios...possible couple month change in age of air, will likely have little impact on the stratospheric water.



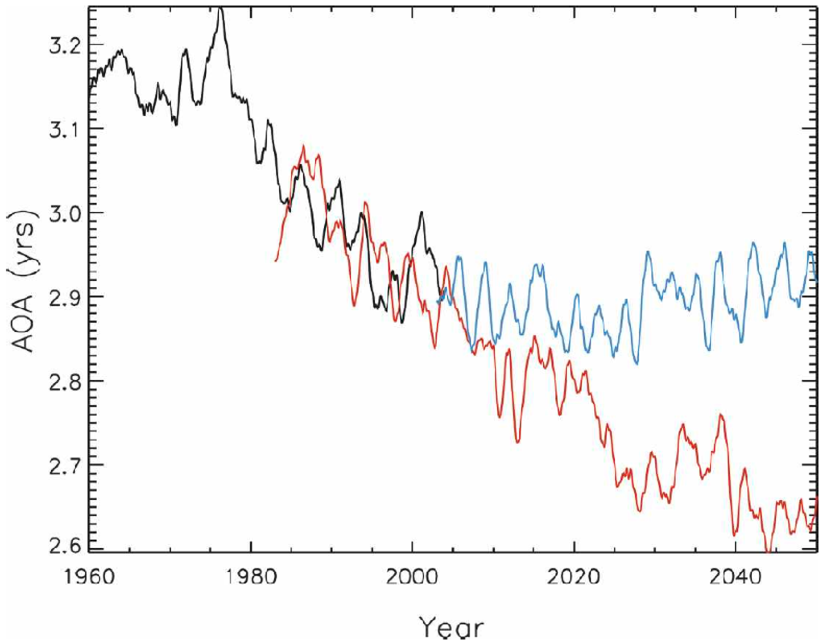
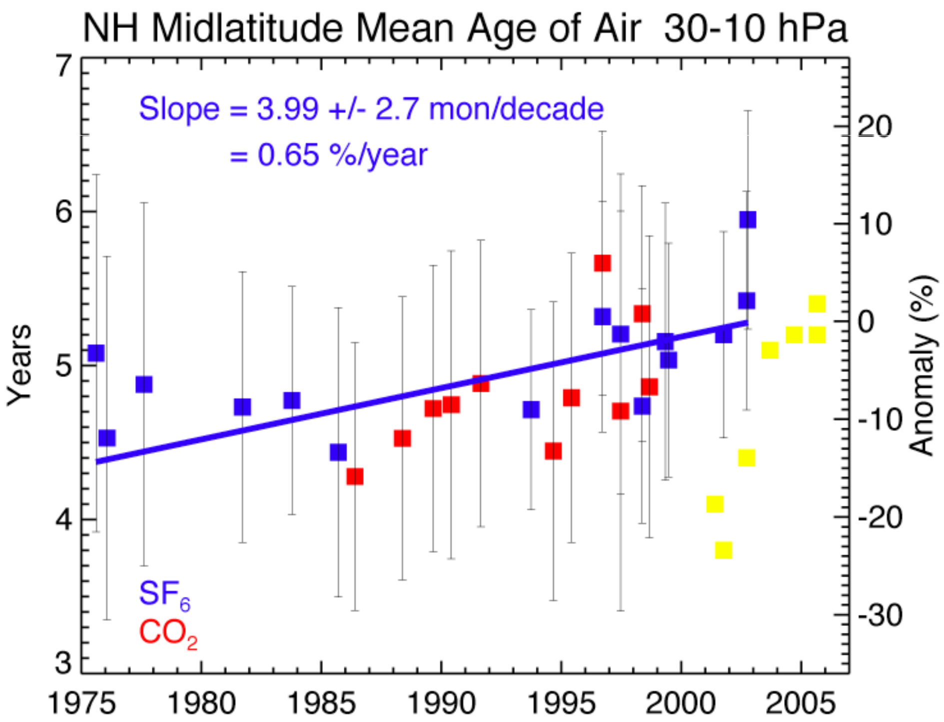



FIG. 1. Evolution of the age of air near 10 hPa averaged over ±22° [months (10 yr)$^{-1}$] for three-member ensemble simulations of the climate of the twentieth century (REF1; black curve); the climate of the twenty-first century under increasing loading of GHG (REF2; red); and the climate of the twenty-first century with GHG held constant at 1995 values (NCC; blue). See text for details.

Age of air estimates do not necessarily support an acceleration of the BD circulation over the historical record.

Hard to say what the future evolution of water vapor due to BD changes.



Microphysics/aerosols

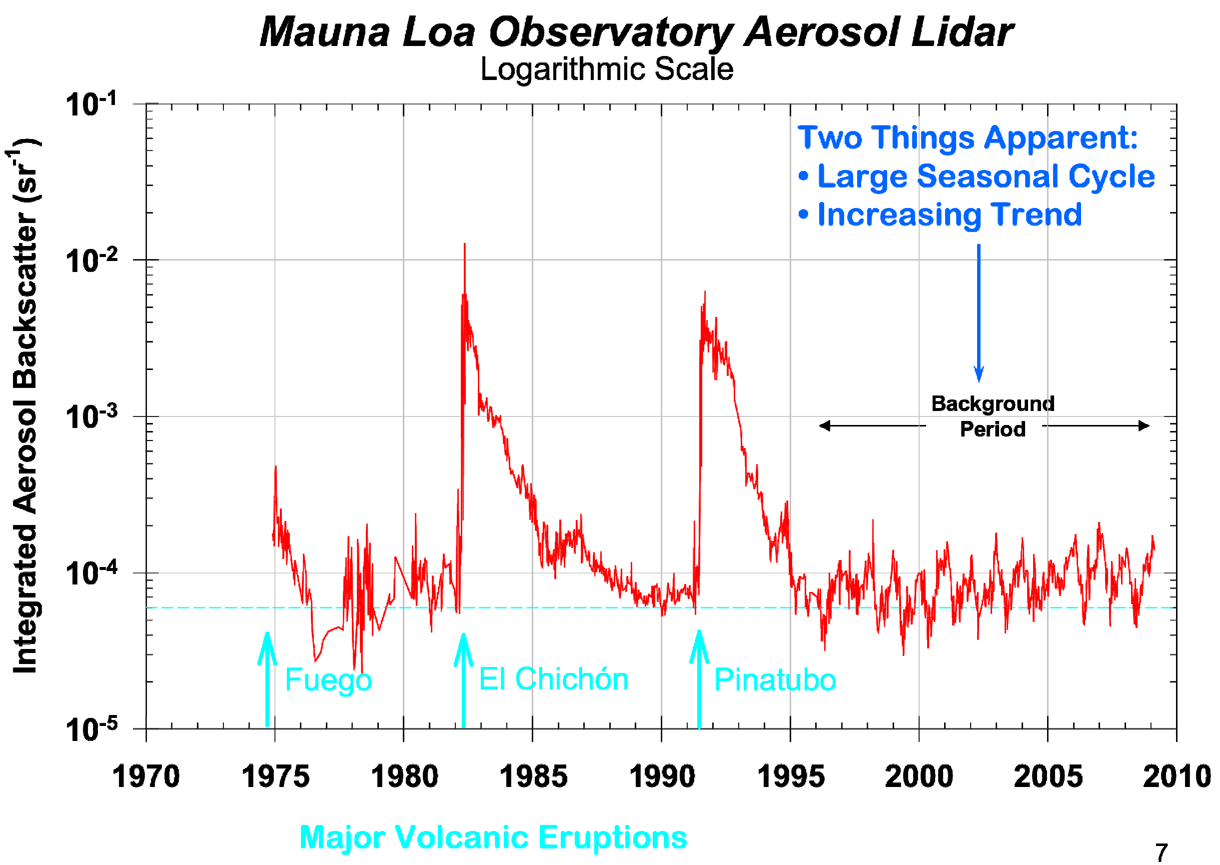
There some papers that suggest that anthropogenically induced changes in aerosols near the cold point could change the input of water into the stratosphere.

1) One possible explanation that has been discussed in the literature is that the increase could be due to changes in aerosol loading impacting microphysical processes near the tropical tropopause (Sherwood, 2002, Science).

> *More aerosols from biomass burning in the tropics could lead to smaller ice crystals in towering cumulus, and thereby more water vapor entering the stratosphere.*

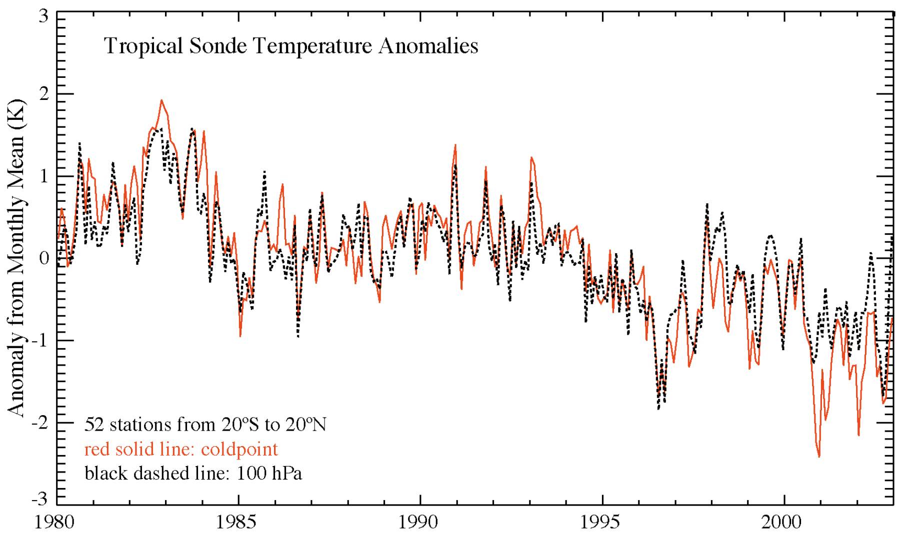
SO2 increases (in regions of slow ascent into the stratosphere) lead to increases in number of particles (and size decreases) which ultimately transports more water into the stratosphere (Notholt et al, 2005, GRL).

There is indication of increases of particles hypothesized due to Asian coal burning (Hofmann et al, GRL, 2009) during recent volcanic aerosol free period.



However, predicting volcanic aerosol free periods is not possible, but it appears that SO2 aerosols may be increasing, and could produce an increase in stratospheric water vapor. (Notholt study suggests an increase on the order of 0.5 ppmv over the historic period from 1950-2000.

Volcanic eruptions may also increase stratospheric water vapor (at least in model world) by increasing cold point temperatures (Joshi and Shine 2002), or by bringing up water on aerosols.




Possibly a factor for El Chichon, maybe not for Mt. Pinatubo

If stratospheric water vapor changes it can impact:

1) stratospheric temperatures
2) surface temperatures
3) stratospheric ozone chemistry

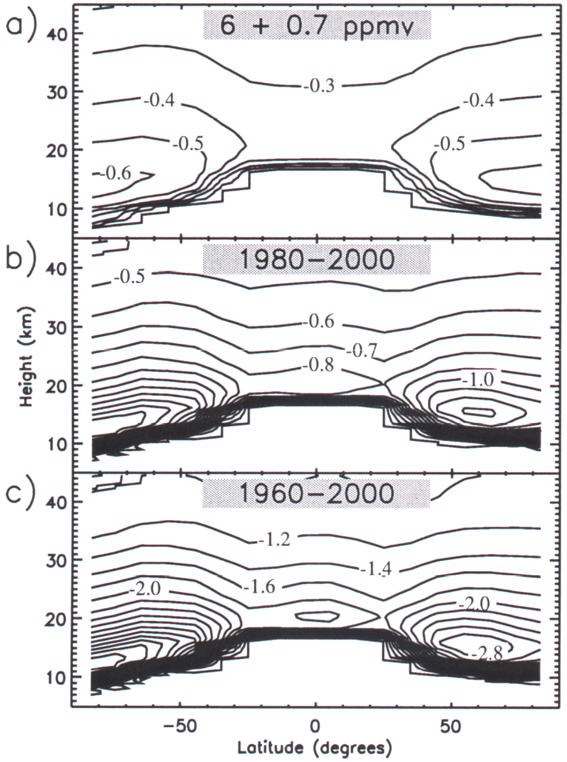
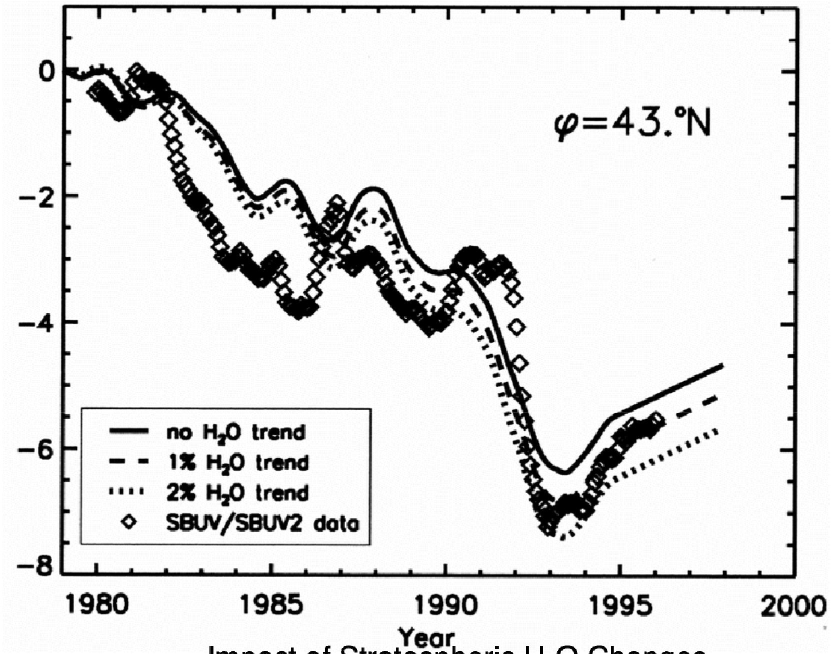
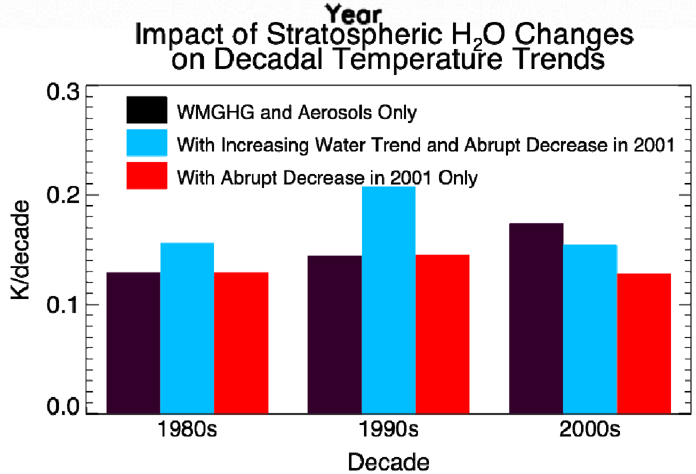



**Figure 2.** The annually averaged FDH stratospheric temperature change (in K) calculated by the NBM as a function of latitude for: (a) a 0.7 ppmv increase in SWV, from a 6 ppmv background value; (b) a 1 ppmv increase from a 1980 background, to simulate the 1980–2000 change in SWV and (c) a 2 ppmv increase from a 1960 background, to simulate the 1960–2000 change in SWV. (a) and (b) have a contour interval of 0.1 K and (c) a contour interval of 0.2 K.



From IPCC

To summarise, water vapour in the stratosphere has shown significant long-term variability and an apparent upward trend over the last half of the 20th century but with no further increases since 1996. It does not appear that this behaviour is a straightforward consequence of known climate changes. Although ideas have been put forward, there is no consensus as to what caused either the upward trend or its recent disappearance.

*At this point, determining how stratospheric water vapor will change in an increased CO2 climate is difficult, as is determing what sorts of feedbacks might occur...should be a good research topic for some time to come.*