

Stratospheric Ozone: How good are our measurements, how good were our model projections, and what do we need to attribute recovery to cause?

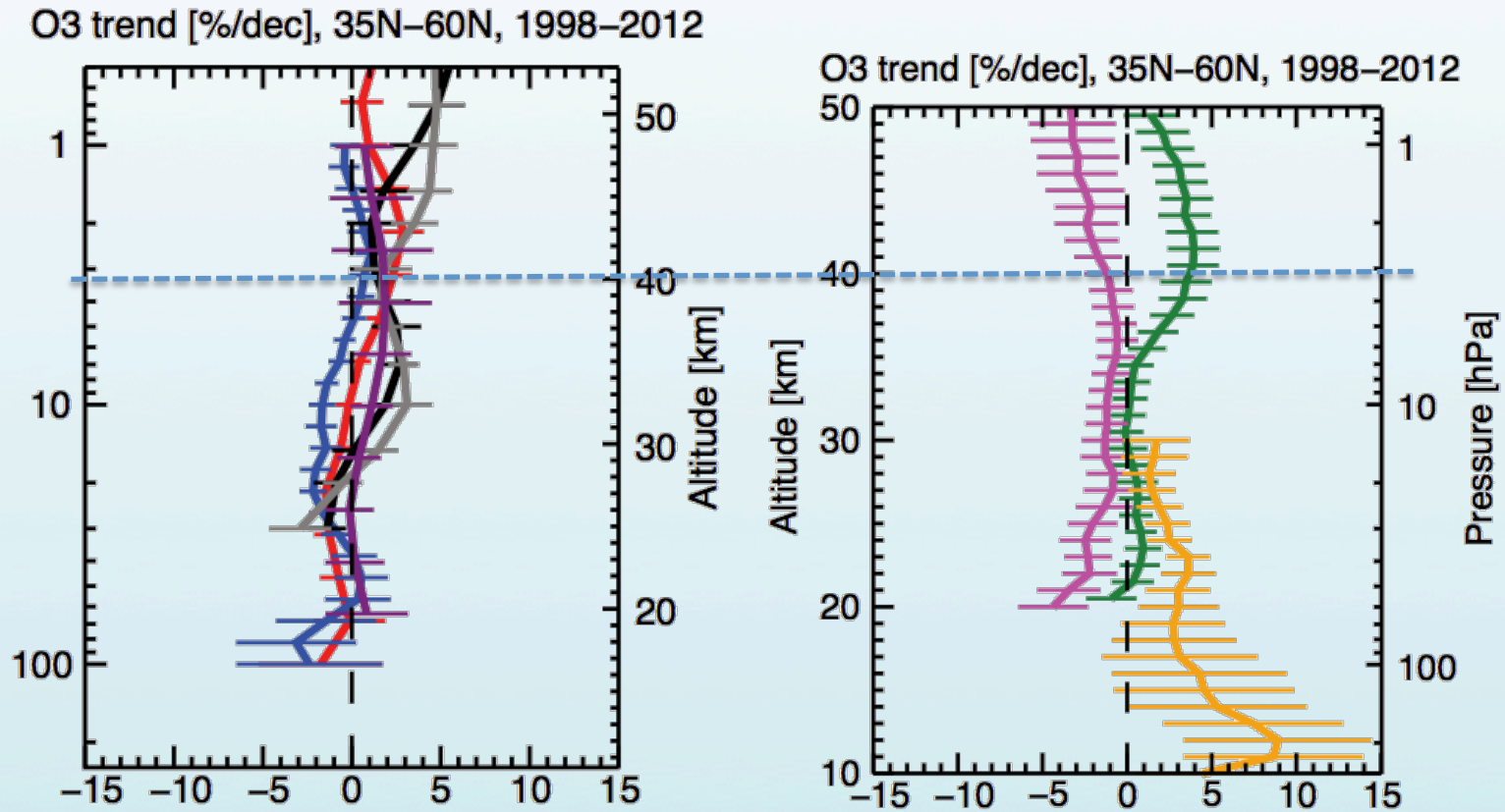
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Many have searched for signs of ozone recovery that can be attributed to the impact of the Montreal Protocol

I would like to briefly address 3 issues:

- Revisiting upper stratospheric ozone trends since 2000: evaluating uncertainties**
- How good were our model projections made about 10 years ago?**
- How do we make progress in the future: identifying causes of ozone change (recovery)?**

Revisiting upper stratospheric trends since 2000



From Harris et al. 2015

What is the uncertainty in this trend determination?

Individual values
and 2σ uncertainty

$+0.8 \pm 0.9$

$+2.2 \pm 1.1$

$+1.8 \pm 1.6$

$+1.9 \pm 2.8$

$+1.4 \pm 1.3$

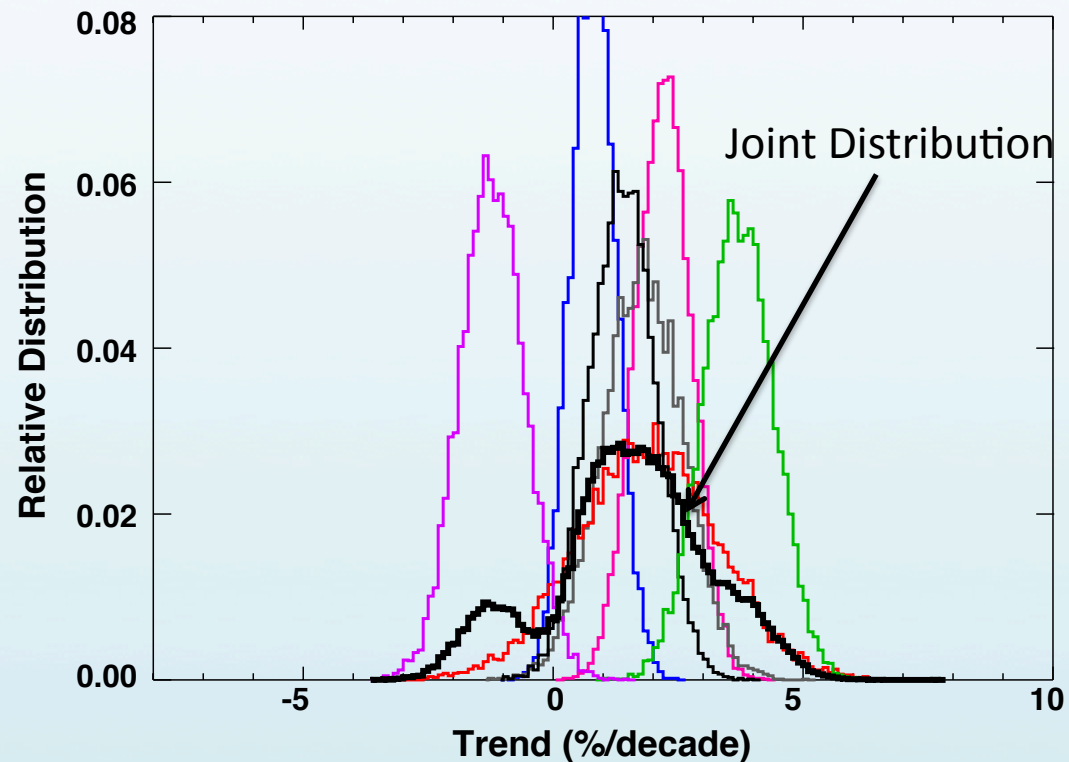
$+3.7 \pm 1.4$

-1.2 ± 1.3

Avg = $+1.5$

S.E.M. = $0.6 (2\sigma)$

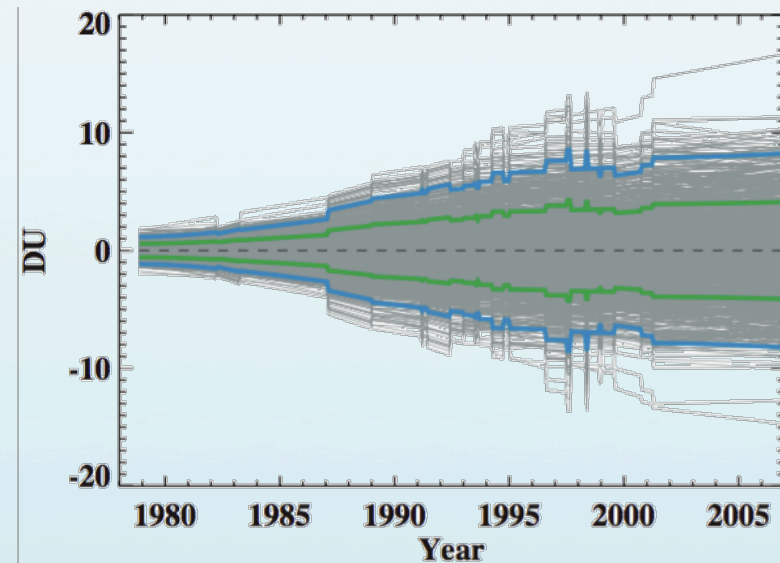
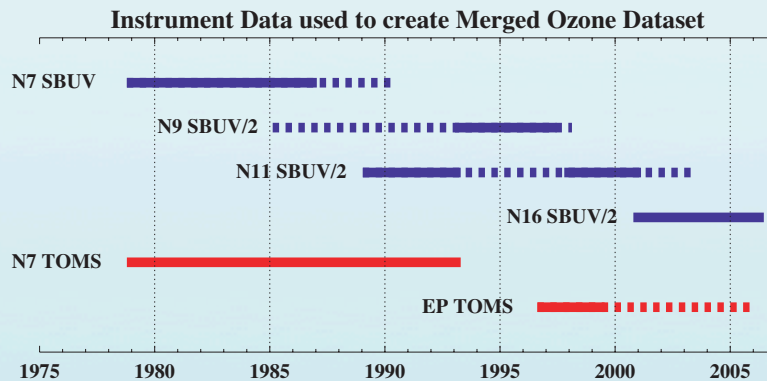
Width of joint
distribution = $3.2 (2\sigma)$



**So is the 2σ uncertainty
 $+1.5 \pm 0.6$ or $+1.5 \pm 3.2$???**

Crucial component of trend uncertainty: construction of continuous data set from multiple instruments

Stolarski and Frith, ACP 2006: Monte Carlo evaluation of instrument drift uncertainty plus offset (intercalibration) uncertainty



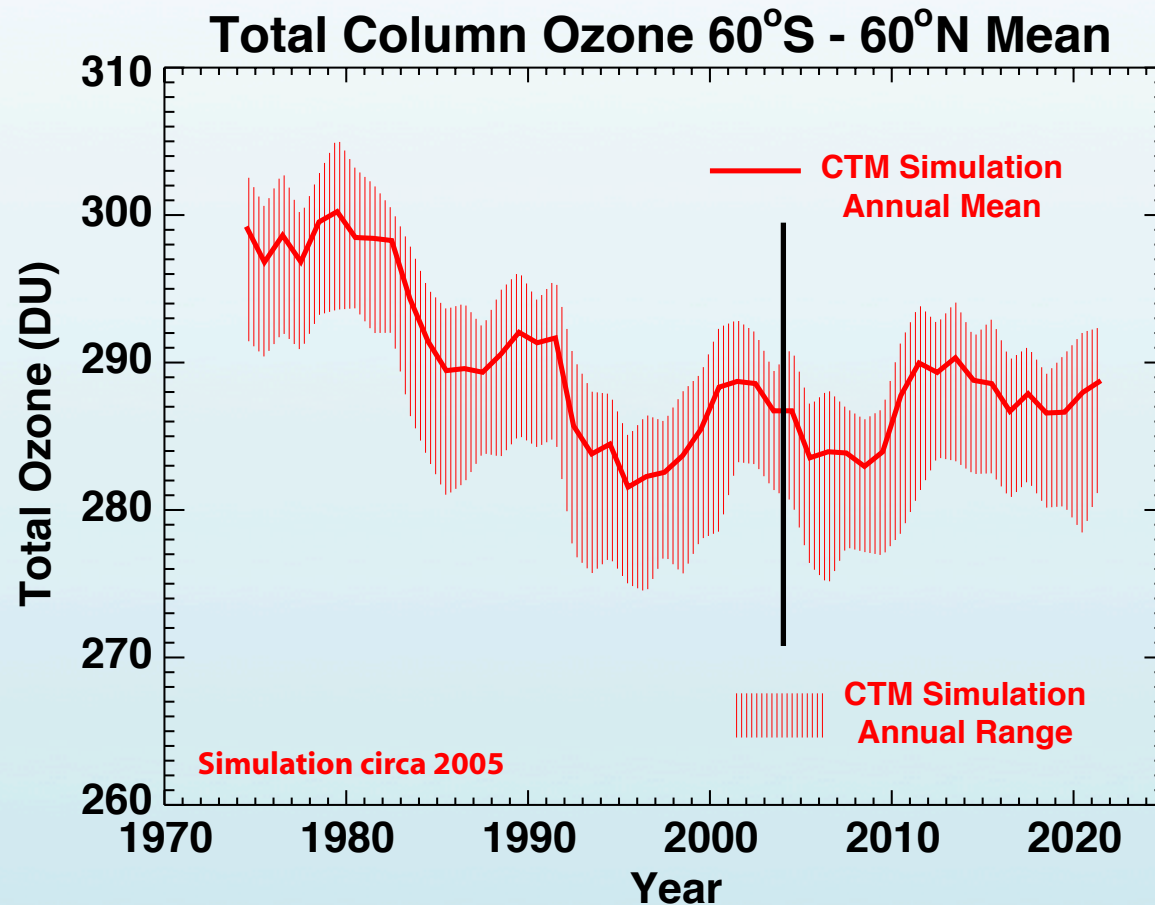
Conclusions

Determining uncertainties in ozone trends requires consideration of instrument uncertainty

- **Uncertainty in relative calibration of instruments**
- **Long overlap of instruments does not guarantee perfect relative calibration unless instruments show same seasonal cycle, response to atmospheric variability, etc.**
- **drift is also an issue with most instruments**

How Good are (were) Our Models?

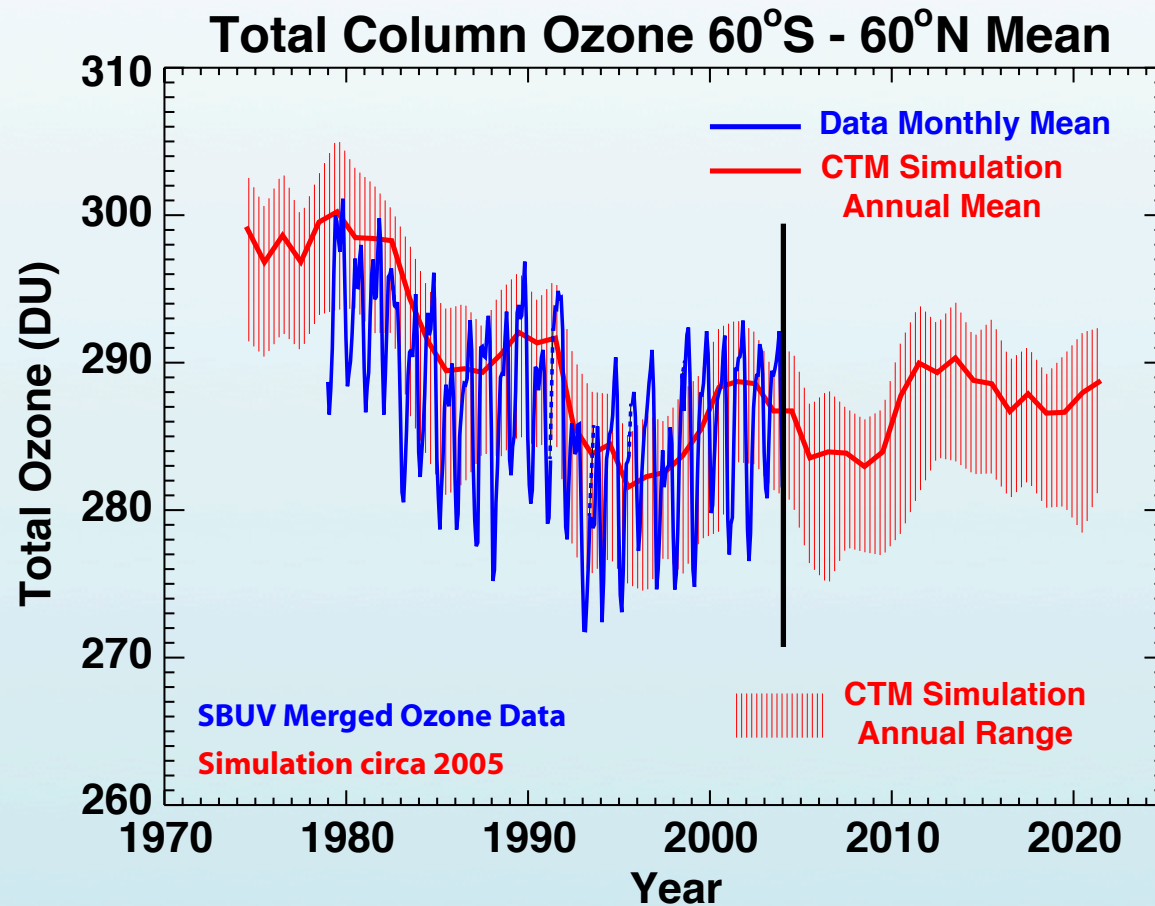
CTM Simulation (fvgcm winds) including ODS, N₂O, CH₄, CO₂, and solar UV changes



Stolarski et al. (2006) JAS 63, 1028-1041

Stahelin Symposium, 4 May 2016

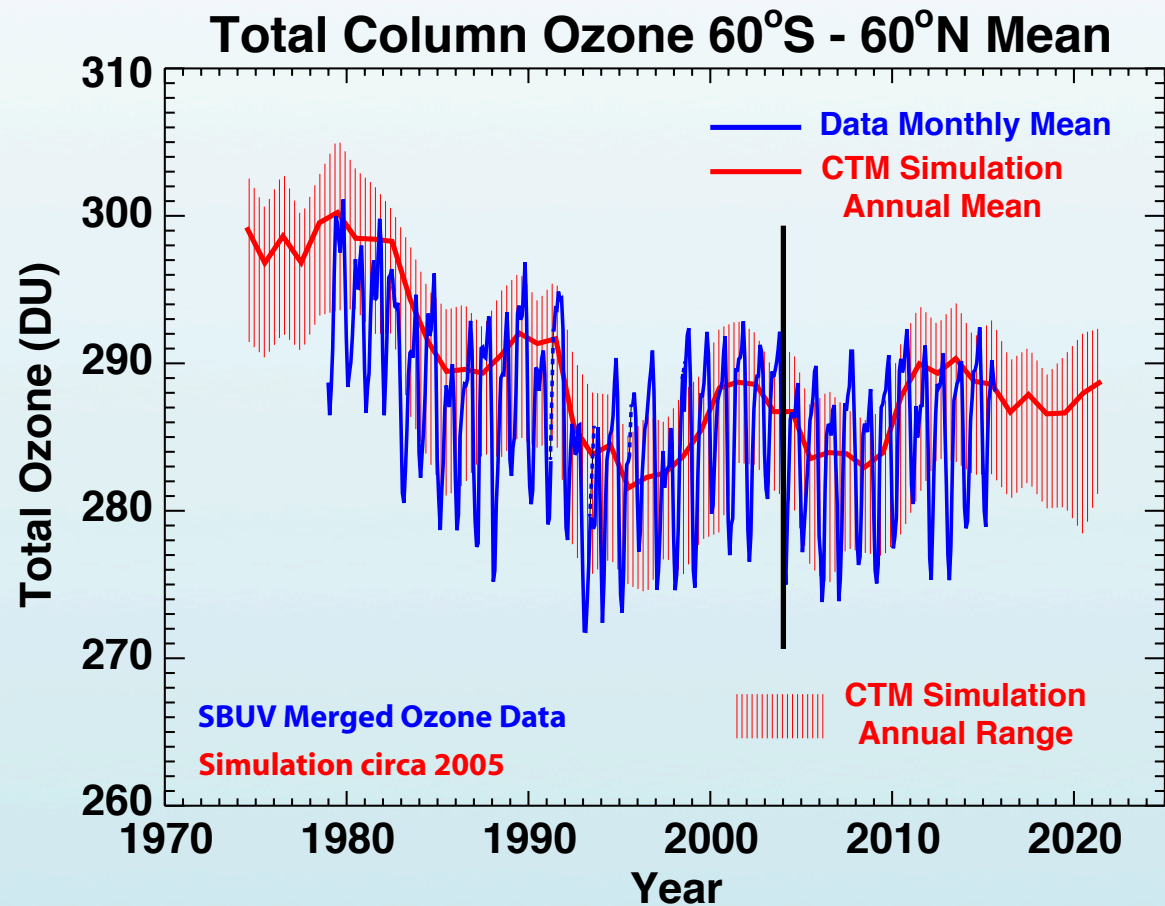
Comparison with merged SBUV ozone data available when Paper was written



Data: Frith et al. JGR (2014) 119, 9735-9751

Stahelin Symposium, 4 May 2016

Extension of SBUV data to mid-2015



Data: Frith et al. JGR (2014) 119, 9735-9751

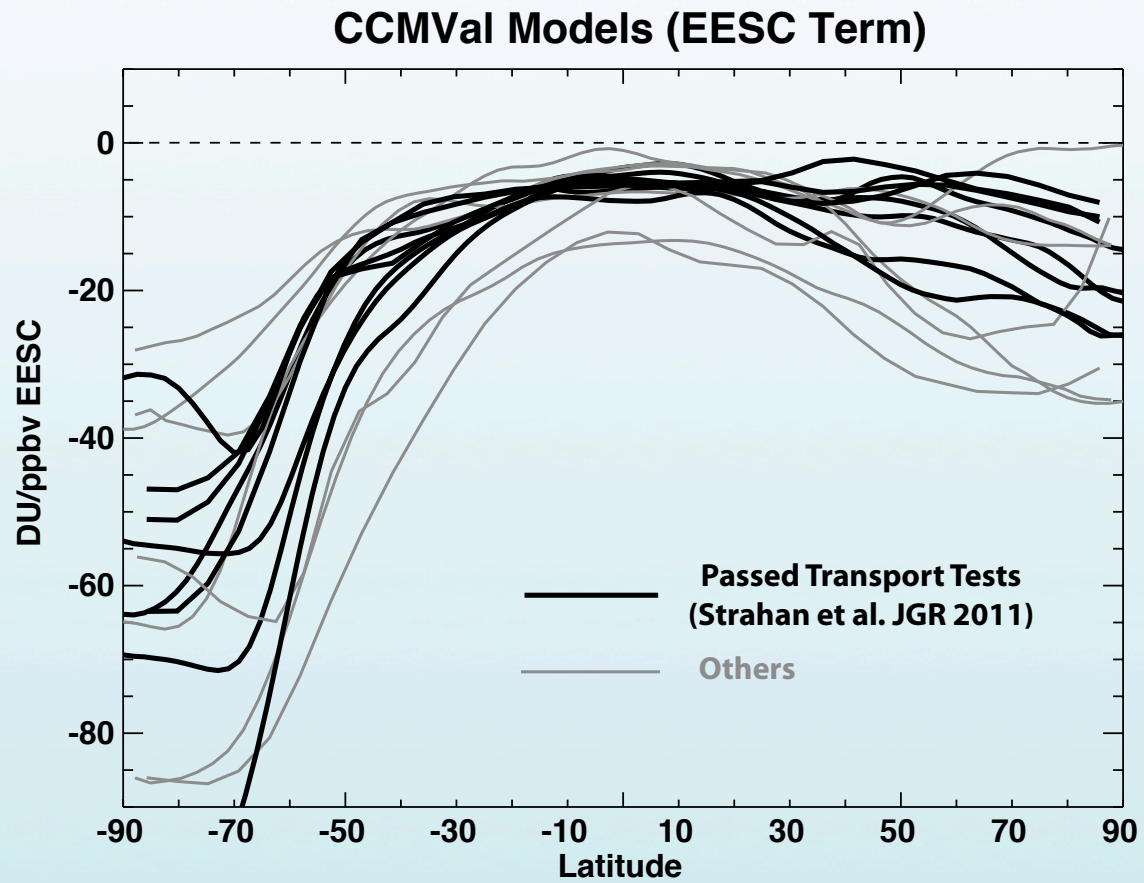
UV post-2005 projected from previous cycle

Some Qualitative Conclusions

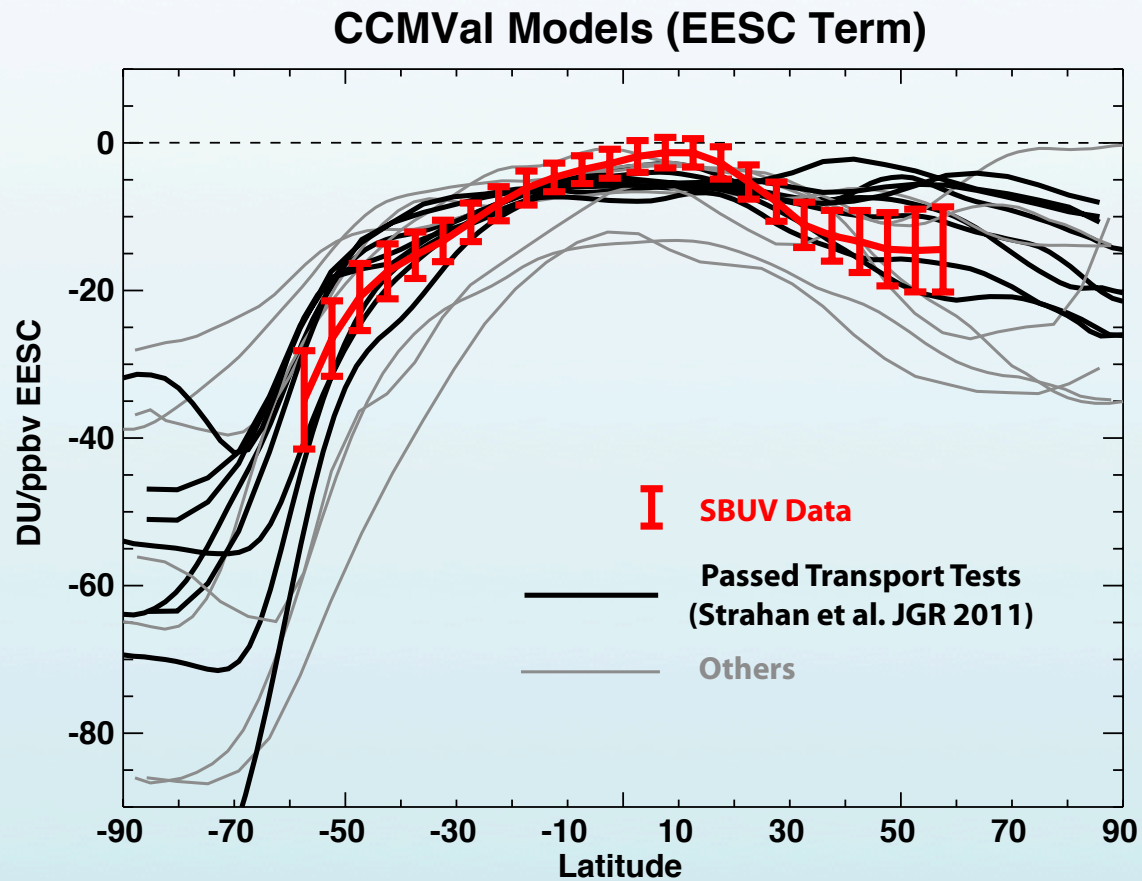
- **(2006) Model reproduces “look and feel” of quasi-global total ozone data time series**
 - Exhibits decrease from late 1970s into 1990s
 - Flattens out after 1990s
 - Responds to solar cycle in UV flux
 - Seasonal magnitude looks reasonable
- *However, model was above data in early years and close to data in later years*

What do model trends look like compared to data?

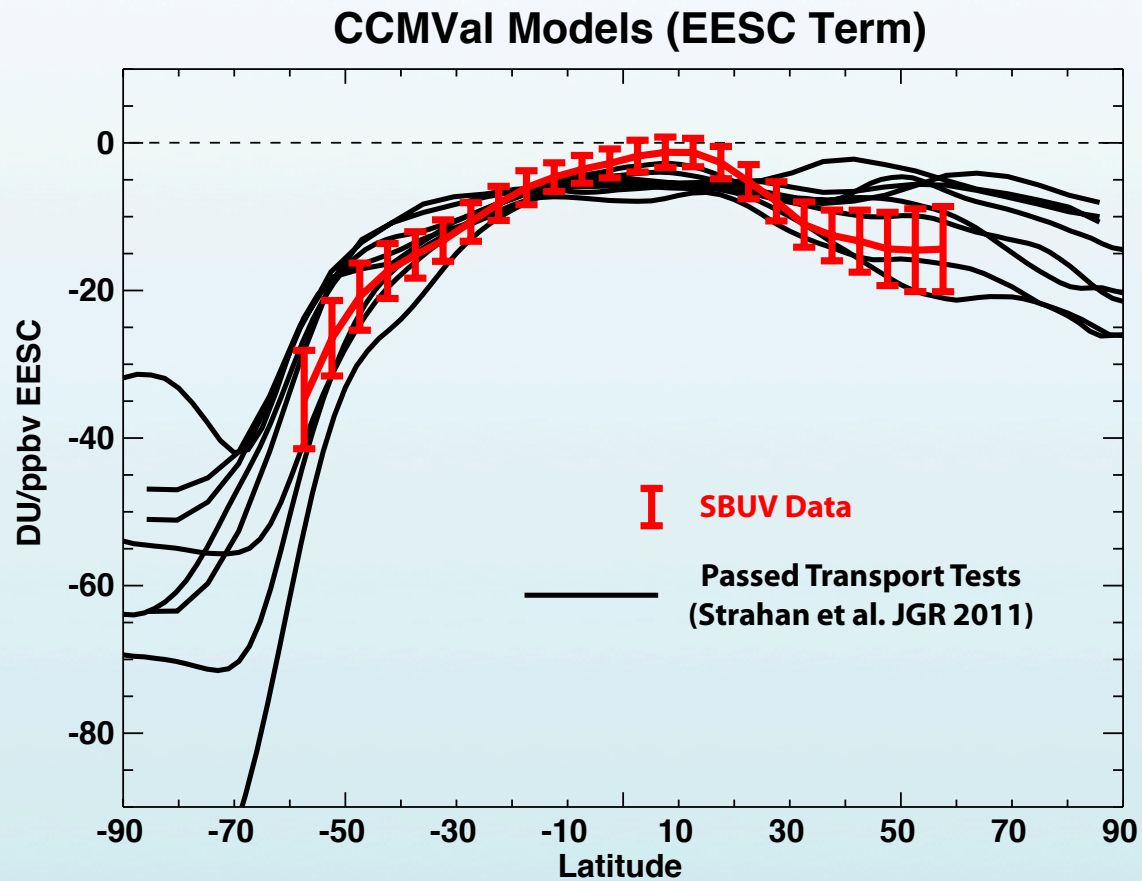
Latitude dependence of EESC term



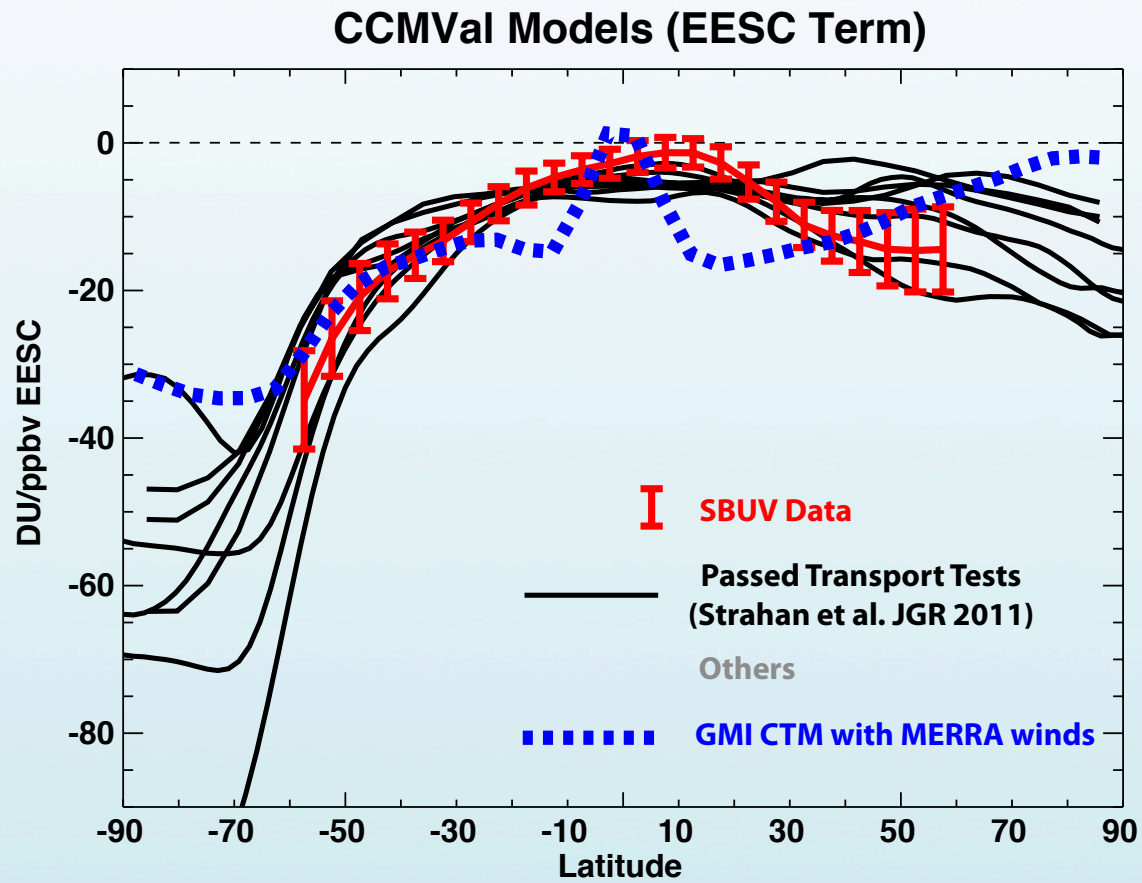
Latitude dependence of EESC term



Latitude dependence of EESC term



Latitude dependence of EESC term



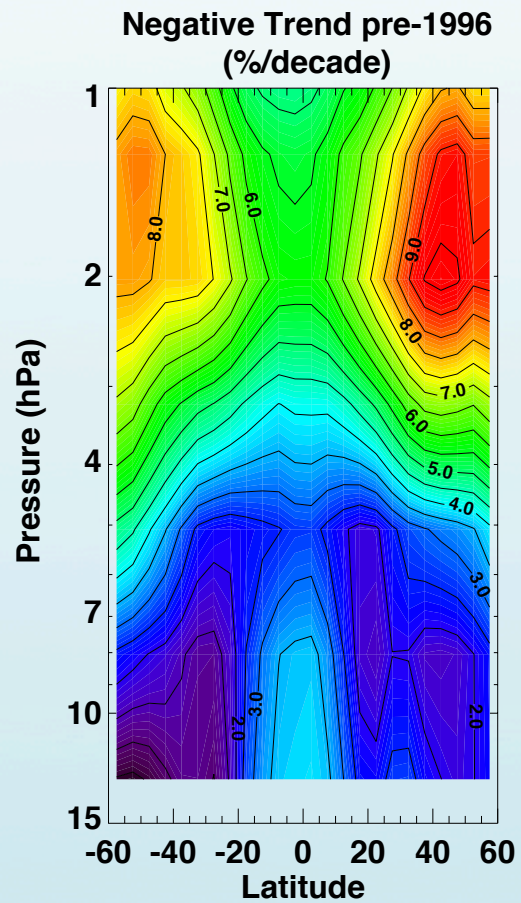
Some conclusions

- **Models capture many qualitative trend features seen in ozone data**
- **Still many quantitative issues**
- **Spread among models needs to be reduced**
 - **CCMVal was an important first step**
 - **Not clear what next step should be (quo vadis?)**
- **CTM on reanalysis winds gets some features that are probably dynamical issues pre-2000**

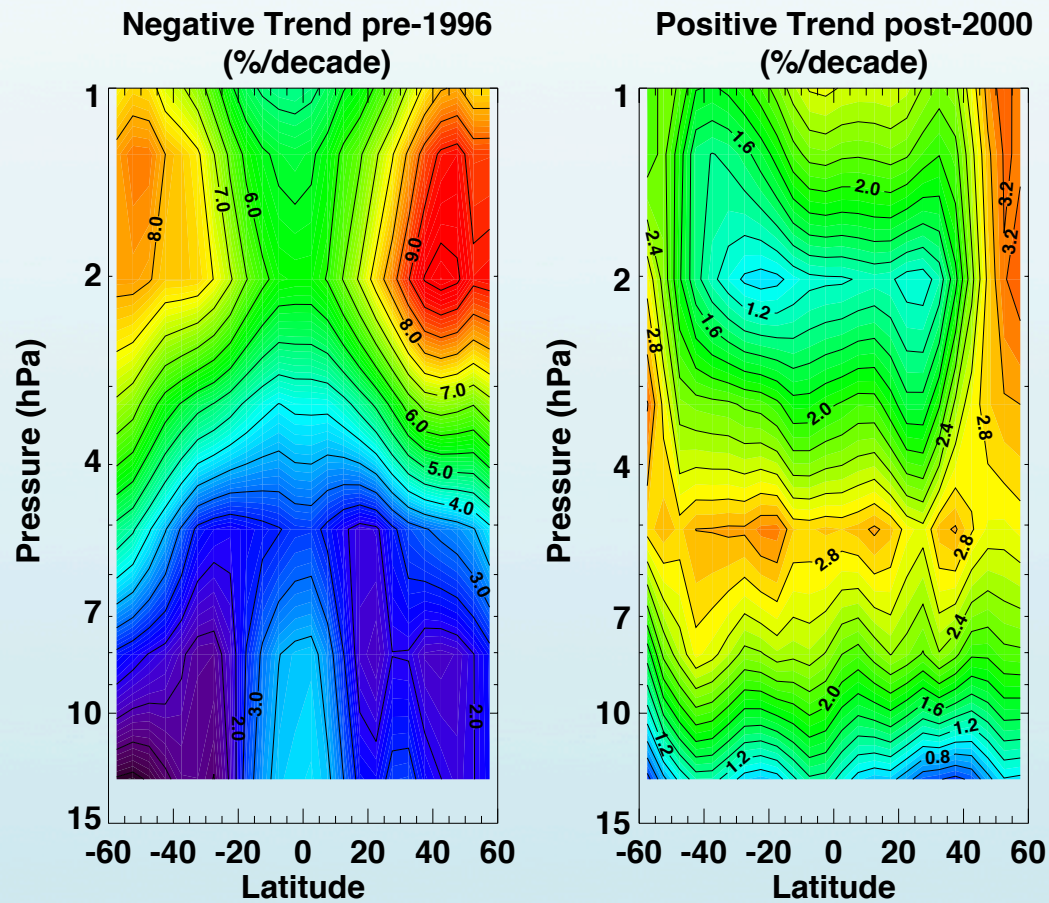
What about attribution to cause?

- **There can be many reasons for an apparent “recovery”**
- **How do we separate them?**
- **I will try pattern of ozone trends vs latitude and altitude using SBUV data**

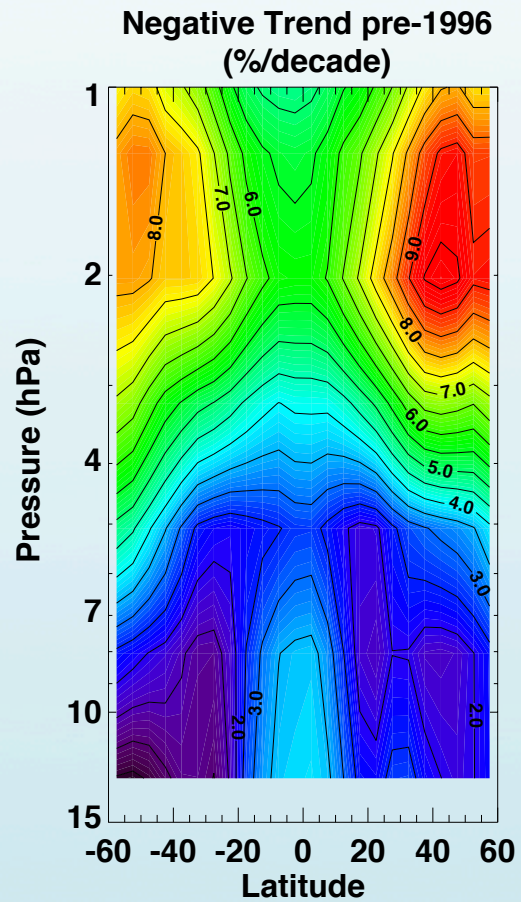
SBUV trends in upper stratosphere vs latitude and pressure altitude



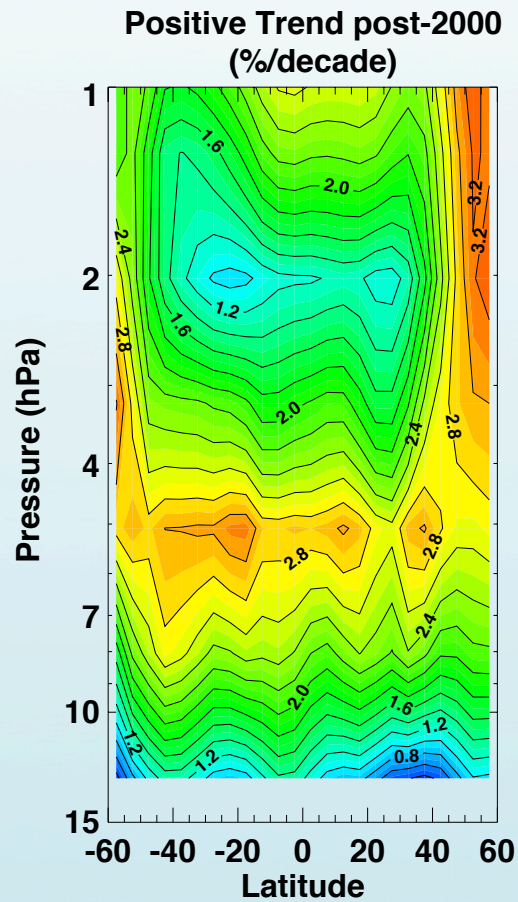
SBUV trends in upper stratosphere vs latitude and pressure altitude



SBUV trends in upper stratosphere vs latitude and pressure altitude



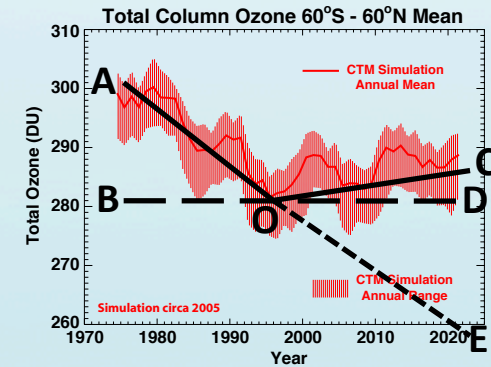
A-O/B-O



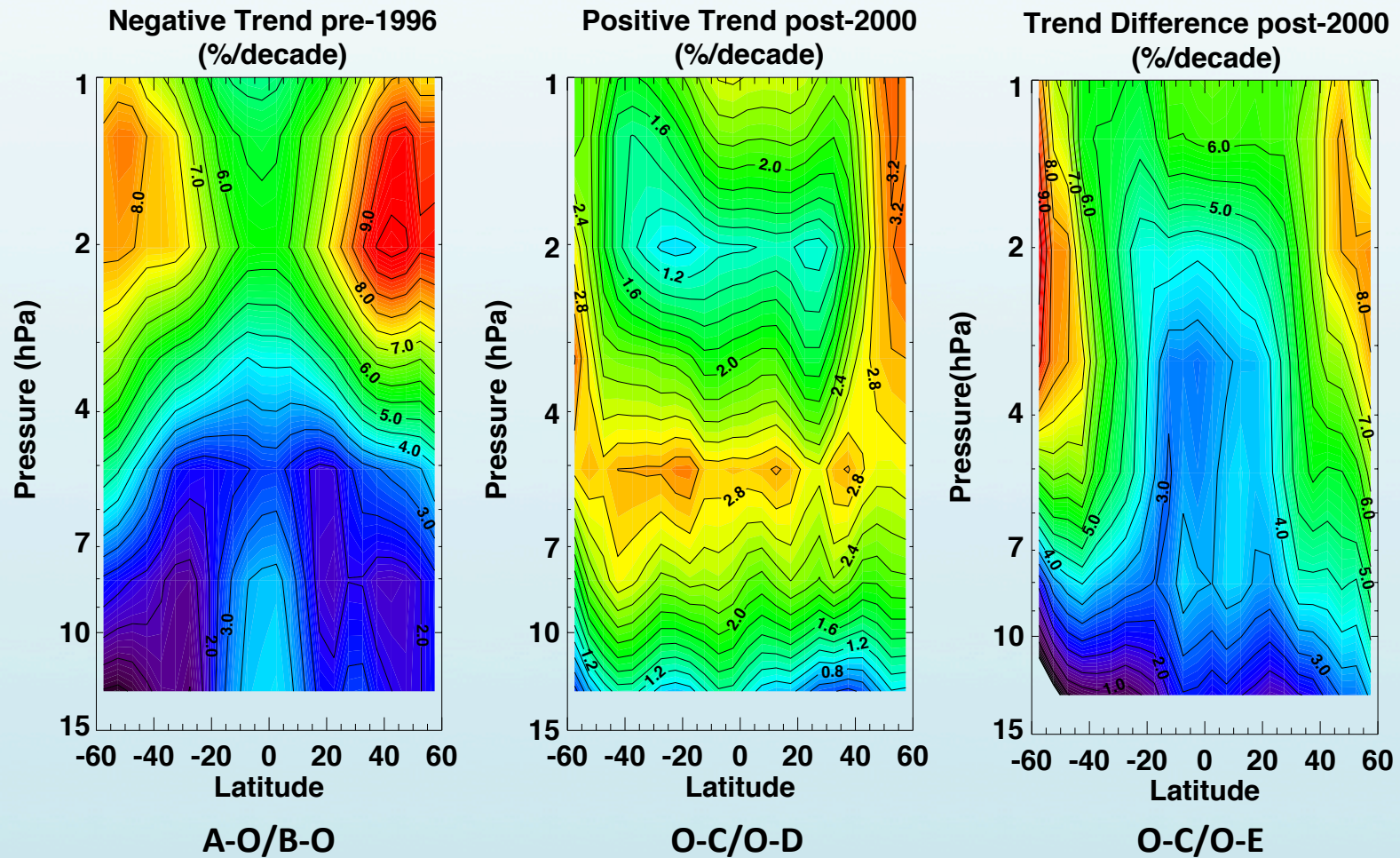
O-C/O-D

**Pattern is not the same!
Cannot attribute upward trend to recovery of ODS?**

What about leveling off from downward trend?



SBUV trends in upper stratosphere vs latitude and pressure altitude



Conclusions

- **Pattern of ozone loss in upper stratosphere as a function of latitude and altitude indicate that upward trend since 2000 is not consistent with ODS recovery**
- **Leveling off of the earlier trend shows a large contribution from ODSs.**

Overall Conclusions

- **Trend uncertainties for various data sets are underestimated if no account is taken for instrument calibration and drift uncertainties**
- **Models qualitatively (semi-quantitatively) predict ozone change, but still show a lot of inter-model variability. Beware of analyzed winds for trend analysis!**
- **Pattern of ozone loss in upper stratosphere as a function of latitude and altitude indicate that upward trend since 2000 is not consistent with ODS recovery, but the leveling off of the earlier trend shows a large contribution from ODSs.**