The impact of solar spectral irradiance (SSI) variations on stratospheric composition: Theory and observations

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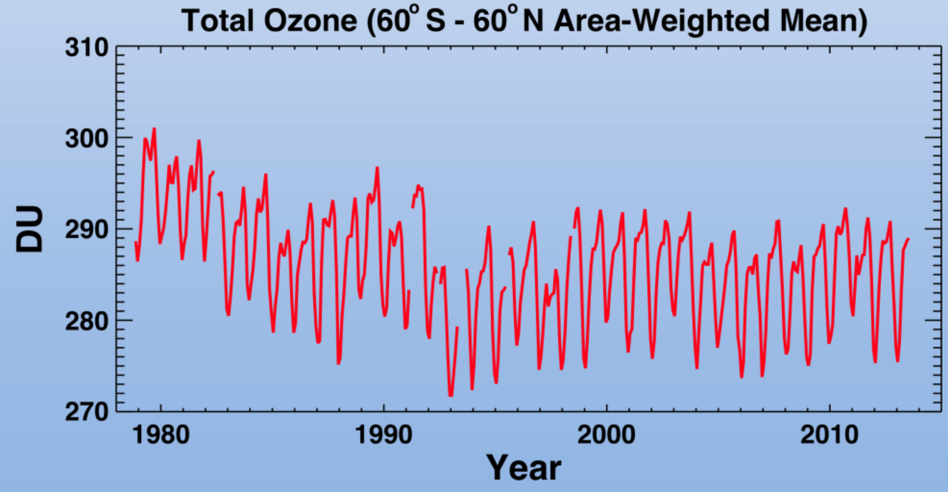
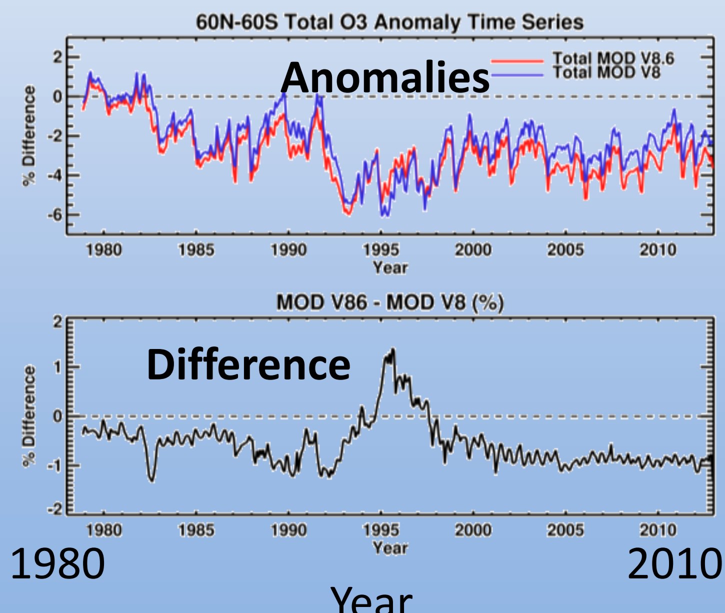


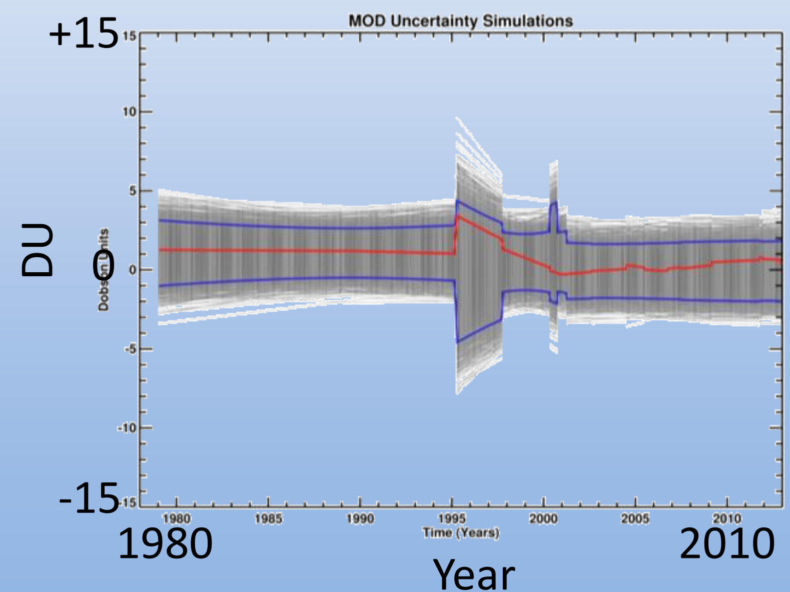
SBUV (Solar Backscatter UltraViolet) Instruments

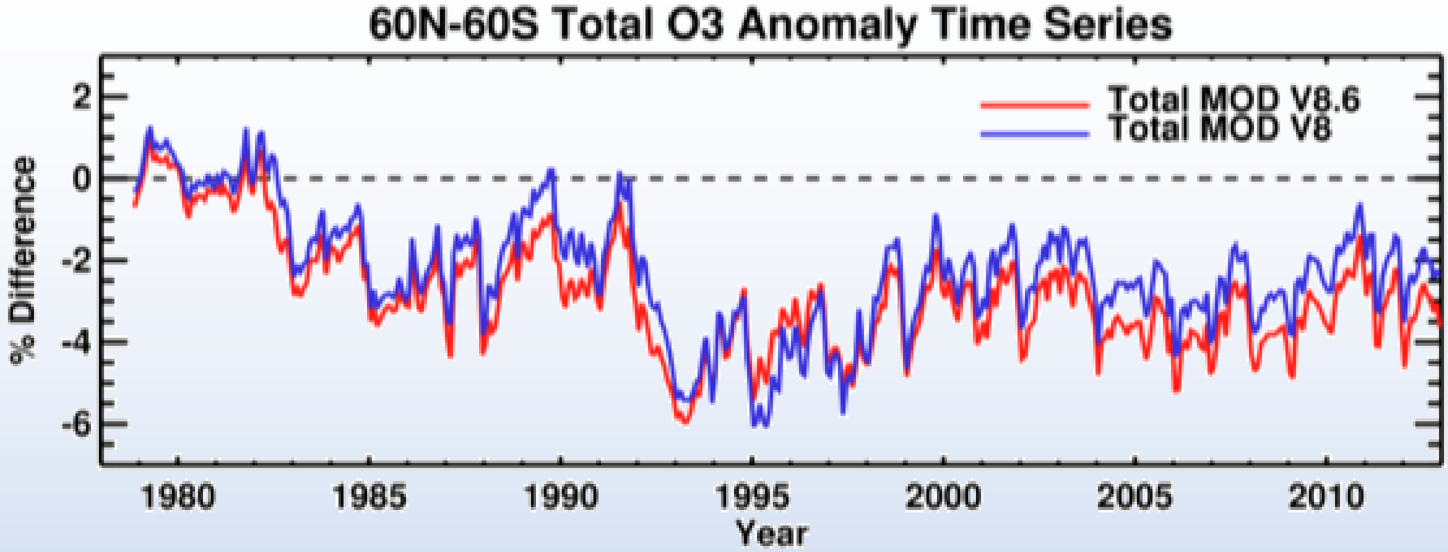
- Nadir-viewing; use solar UV radiation backscattered from the atmosphere to measure ozone
- New Version 8.6 (replacing version 8)
  - Total ozone is the sum of layer amounts
  - Early instrument calibration to SSBUV; late instrument calibration to NOAA 17
- Merged ozone data set (MOD) SBUV only: no TOMS data

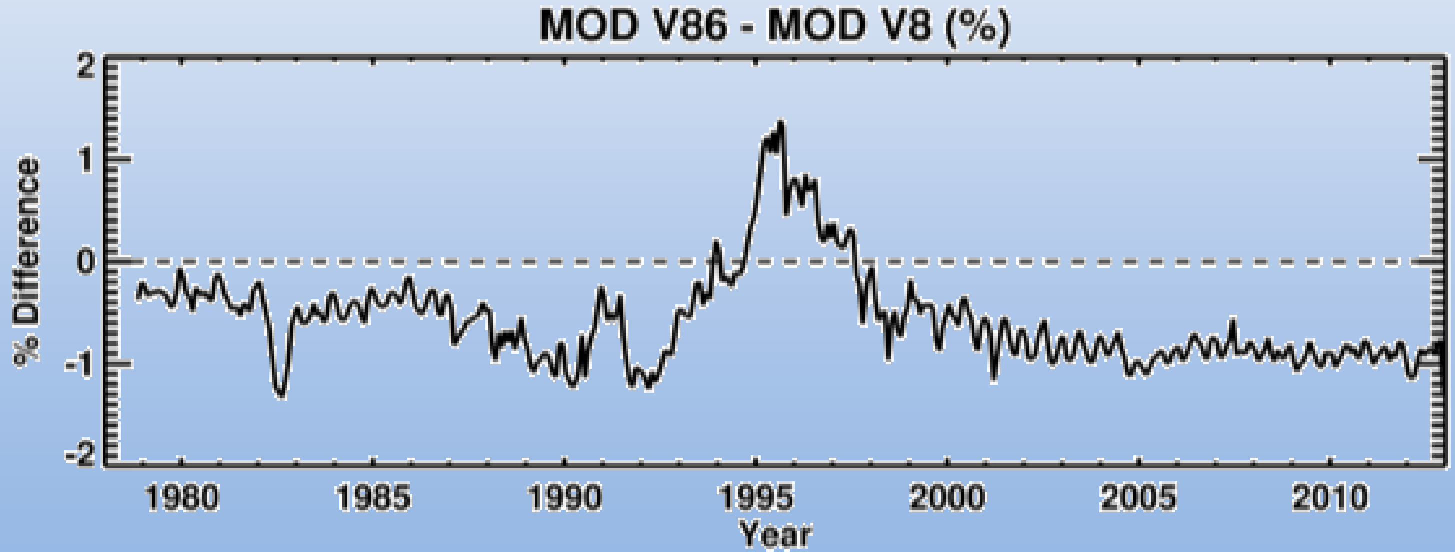
Version 8.6 to 8

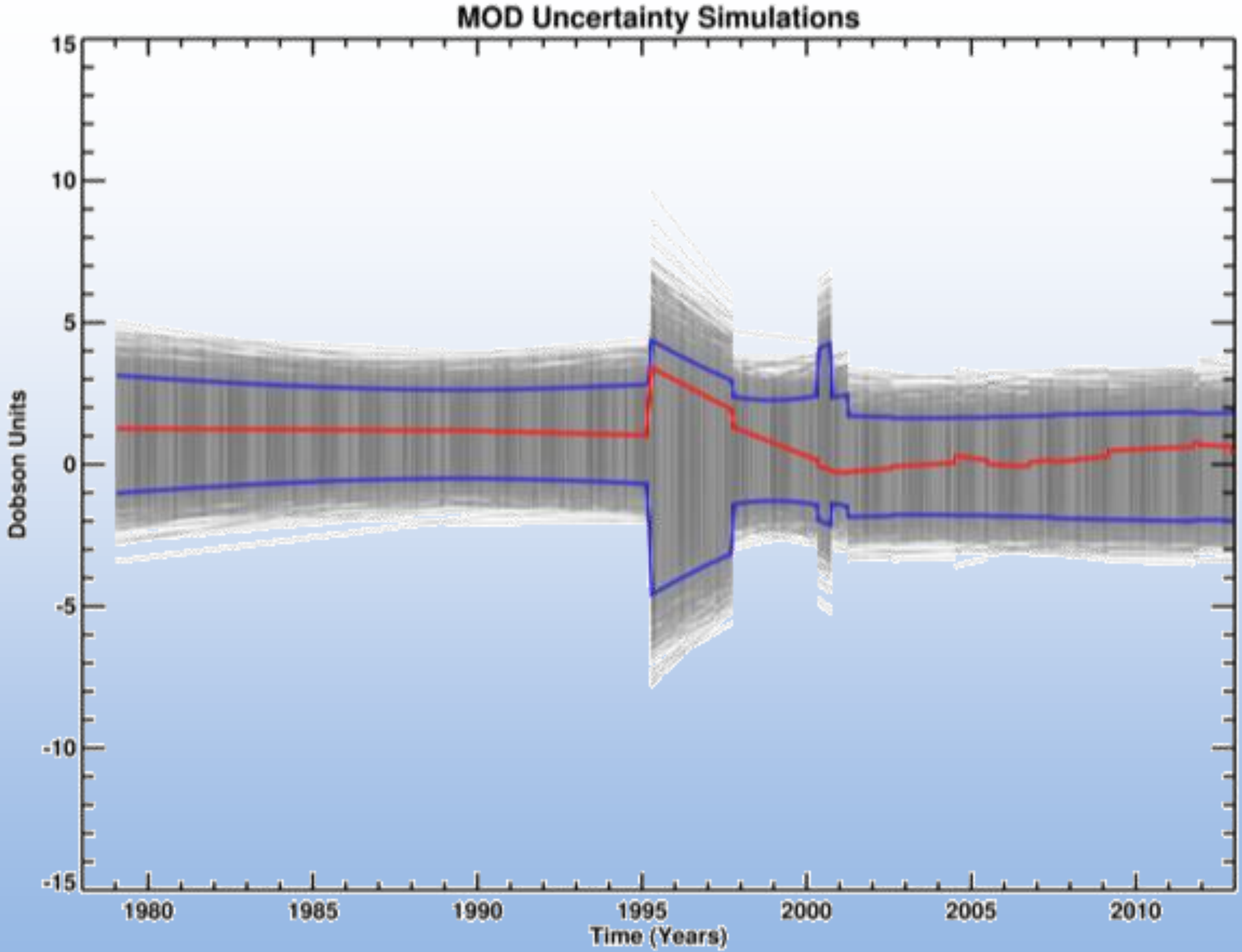


Merging Uncertainty



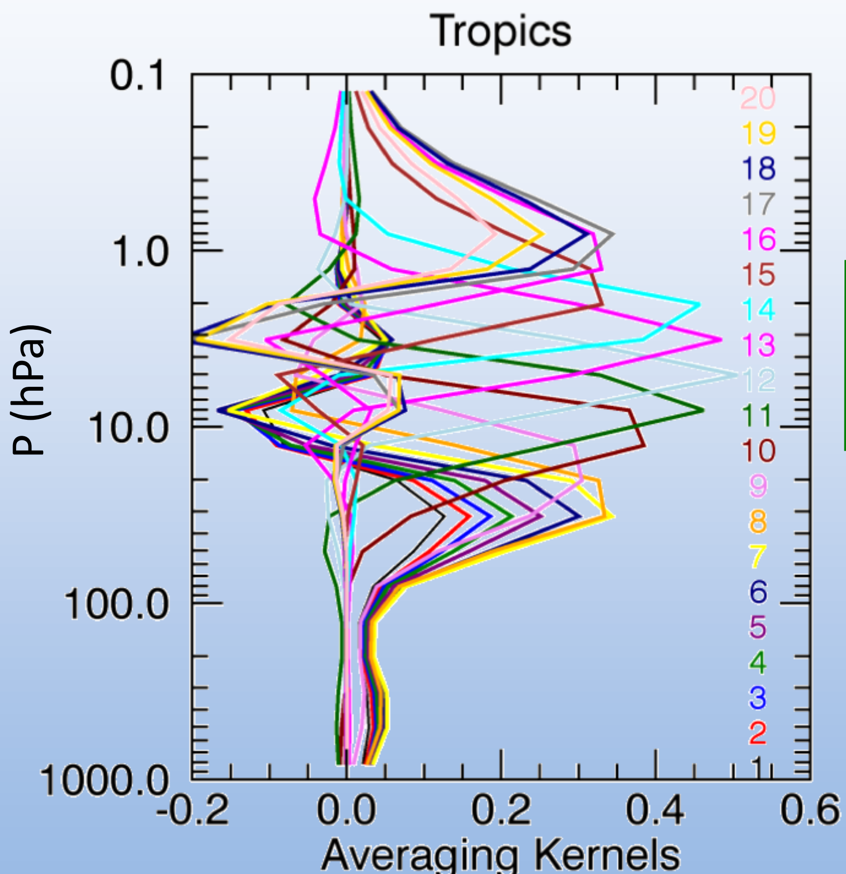

60N-60S Total O3 Anomaly Time Series
Total MOD V8.6
Total MOD V8
% Difference
2
0
-2
-4
-6
1980
1985
1990
1995
2000
2005
2010
Year


MOD V86 - MOD V8 (%)
% Difference
2
1
0
-1
-2
1980
1985
1990
1995
2000
2005
2010
Year


MOD Uncertainty Simulations
15
10
5
0
-5
-10
-15
Dobson Units
1980
1985
1990
1995
2000
2005
2010
Time (Years)

SBUV Altitude Profiles

Instrument uses wavelength to scan in altitude

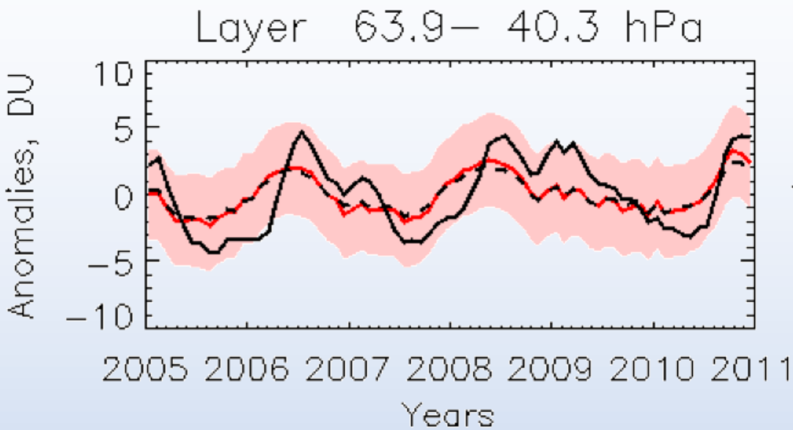


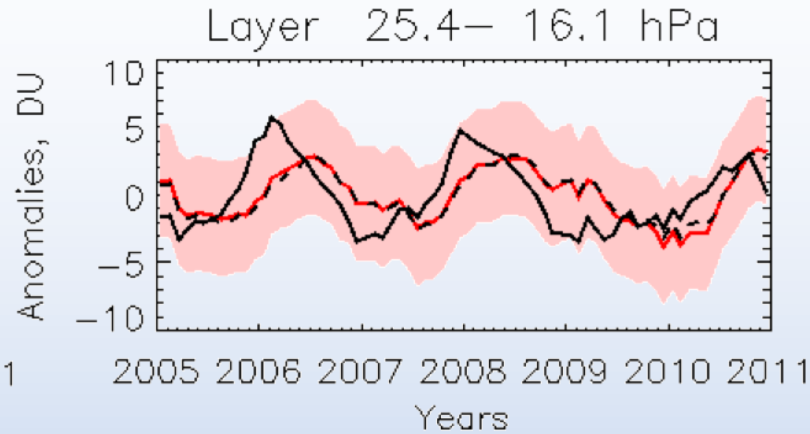
Good resolution in upper stratosphere

Poor resolution in lower stratosphere

SBUV Lower Stratospheric Measurements

Kramarova, N. et al. Atmos. Meas. Tech. 6, 2089-2099, 2013



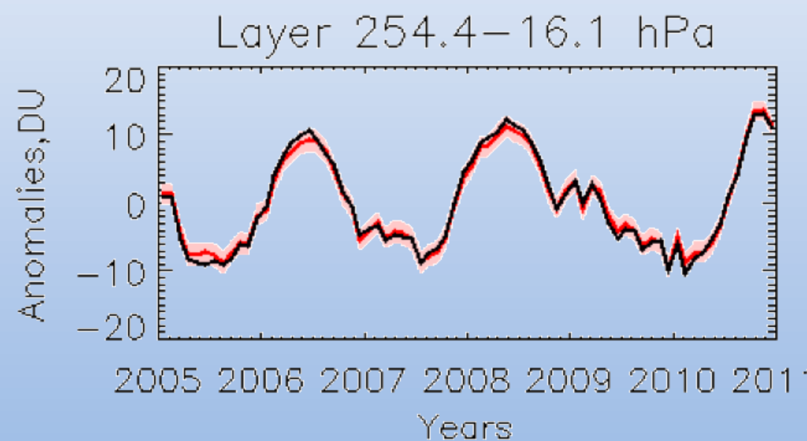


Black line: MLS anomalies

Red line: SBUV anomalies

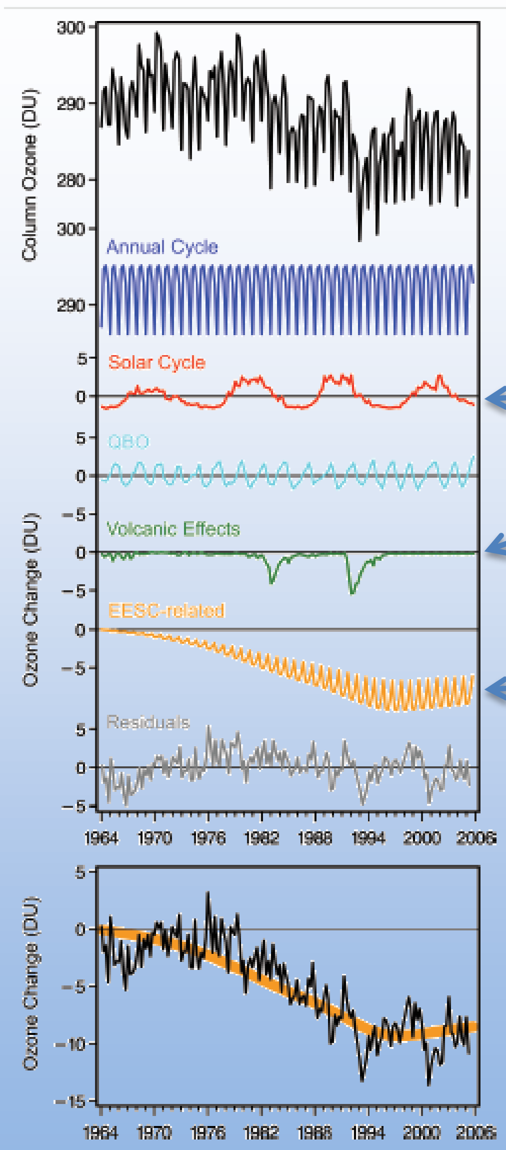
Red shaded: SBUV smoothing error

Black dashed line: MLS with SBUV Averaging Kernel applied



Conclusion: SBUV measurements, integrated over a broad vertical layer, provide an excellent data record for the lower stratosphere

The Regression Problem



Solar term and volcanic aerosol term are similar for two cycles

Third cycle is different at same time chlorine term changes direction

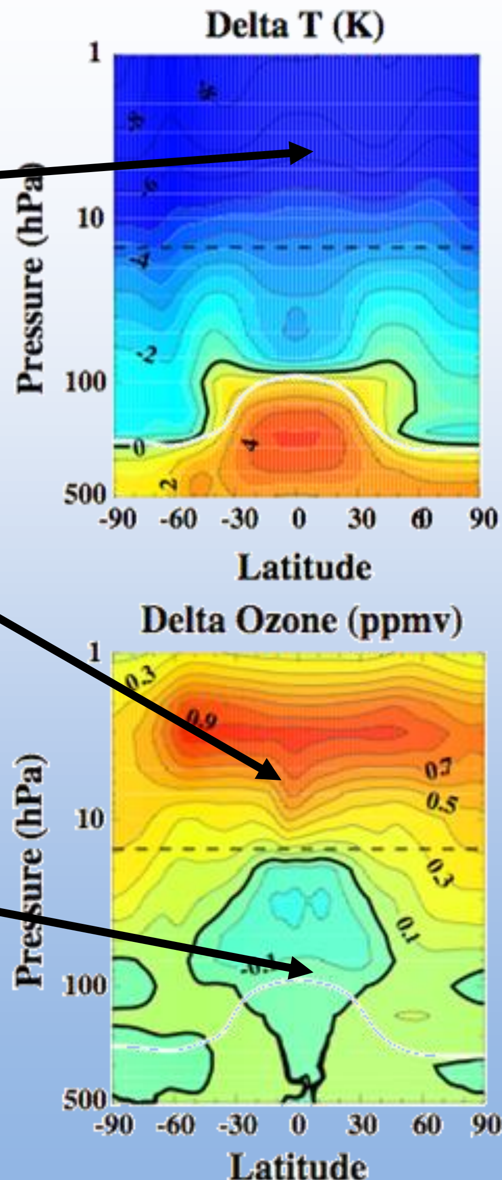
In addition, CO_2 affects ozone and has varied nearly linearly over time. We have the problem of separating this signal from the chlorine signal.

The Impact of GHGs on Stratospheric Ozone

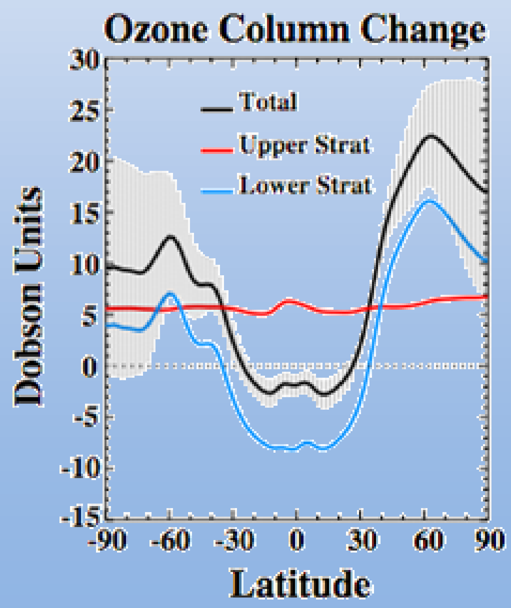
Results from the GEOS CCM 2065-1980

Li, F., et al. (2009), Stratospheric ozone in the post-CFC era, *Atmos. Chem. Phys., 9(6), 2207–2213.*

- **Greenhouse gases cool the stratosphere**
- **Cooling slows ozone loss in upper stratosphere leading to ozone increase**
- **Lower stratospheric circulation speeds up leading to tropical ozone decrease and mid-latitude ozone increase**



Net result is a column ozone increase at mid to high latitudes and almost no change near the equator



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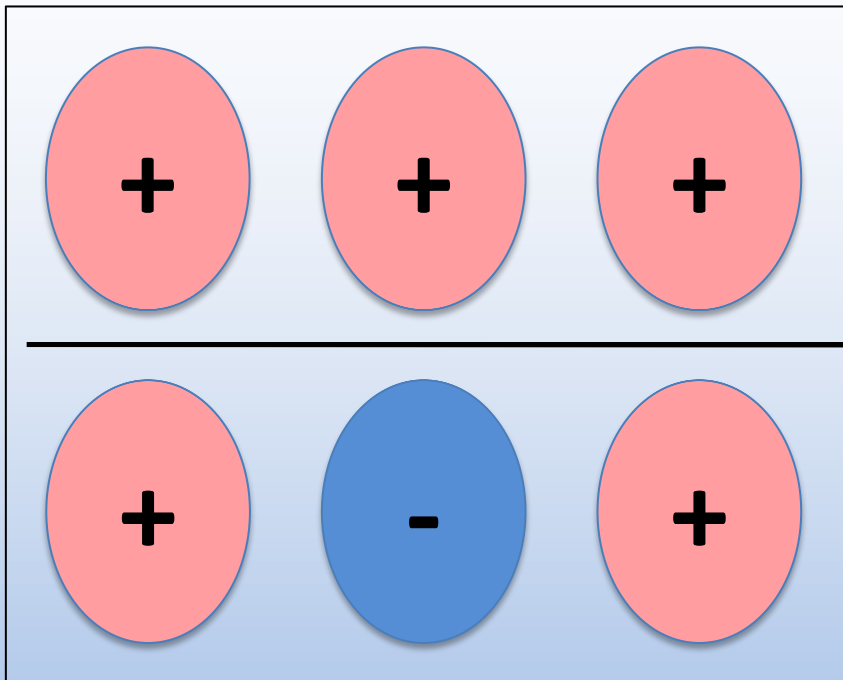
Expected Pattern for GHG Impact on Ozone



Upper Stratosphere:

Cooling → Ozone Increase

16 hPa

Lower Stratosphere:

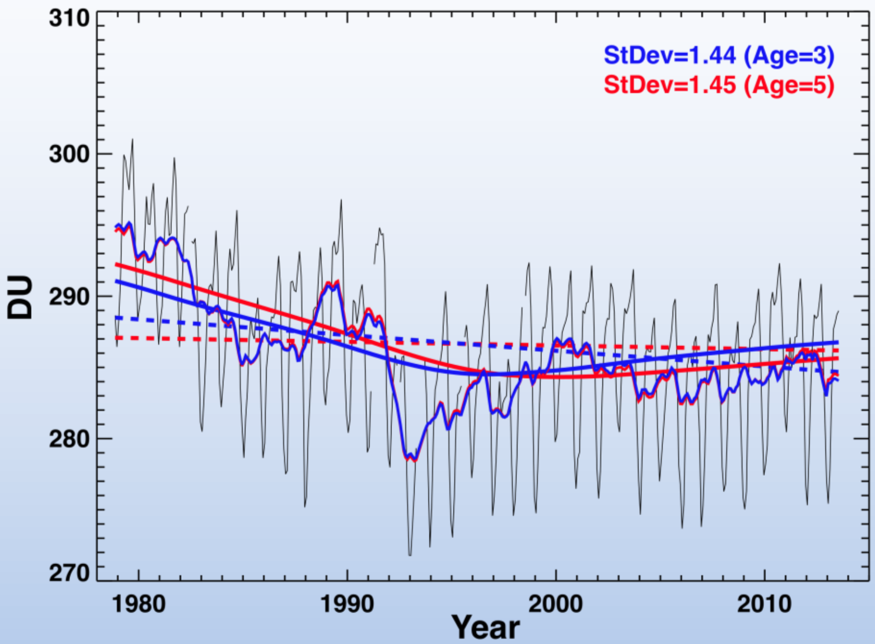
Circulation → Ozone Decrease in Tropics; Increase at Midlatitudes

Can we separate ozone change due to ODSs from that due to GHGs?

Example: 60S-60N Total Column Ozone: Fit to EESC + Linear Trend (plus Solar, volcanos, QBO, and ENSO)

Use Nash/Newman EESC (2 examples; Age=3 years and Age=5 years)

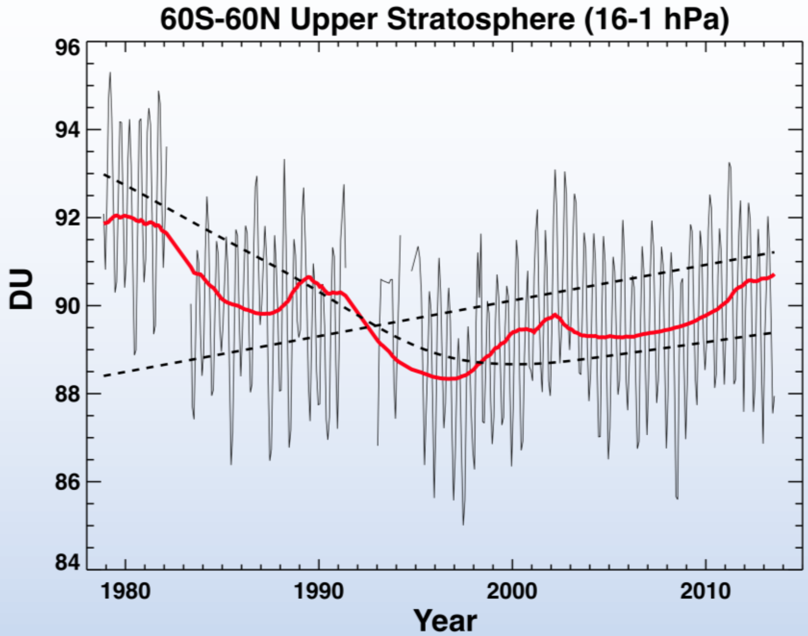
Linear trend represents GHGs and is expected to have a positive coefficient

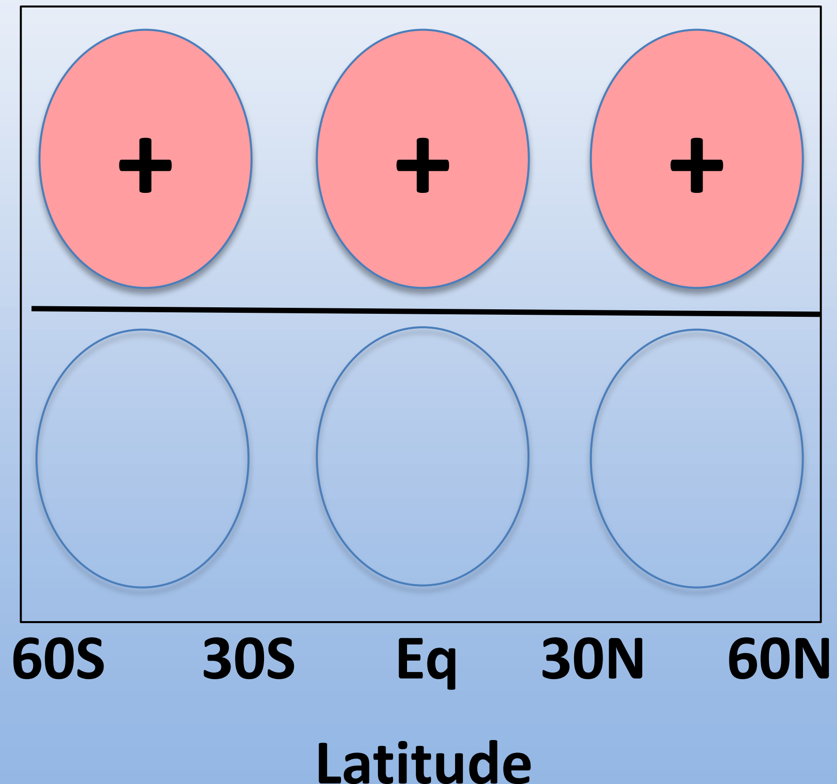


	EESC trend pre-1993	EESC trend post-2000	Linear trend
Age = 3 years	- 4.5 ± 1 DU/dec	+ 1.3 ± 0.3 DU/dec	- 1.1 ± 0.5 DU/dec
Age = 5 years	- 4.7 ± 1 DU/dec	+ 1.3 ± 0.3 DU/dec	- 0.2 ± 0.7 DU/dec

Upper Stratosphere (16-1 hPa)

Fit to EESC, Solar Cycle, and Linear Trend

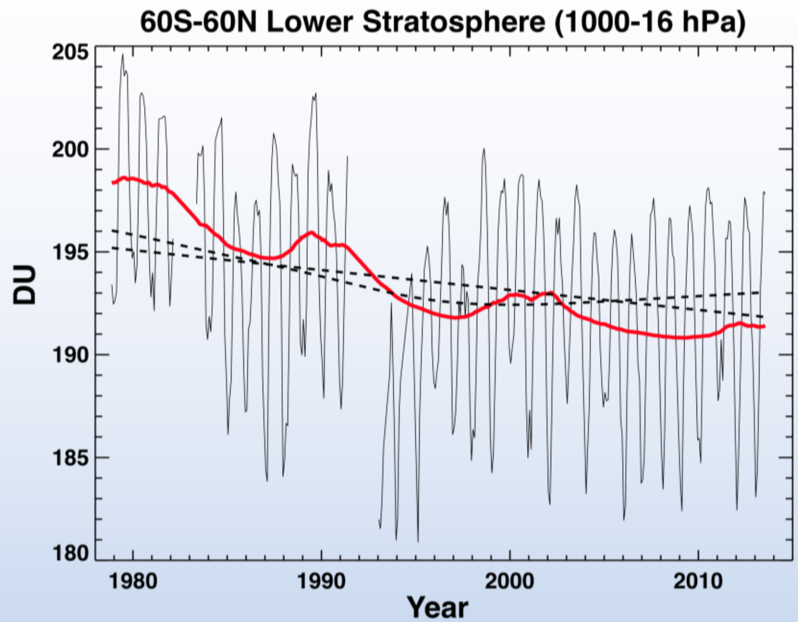


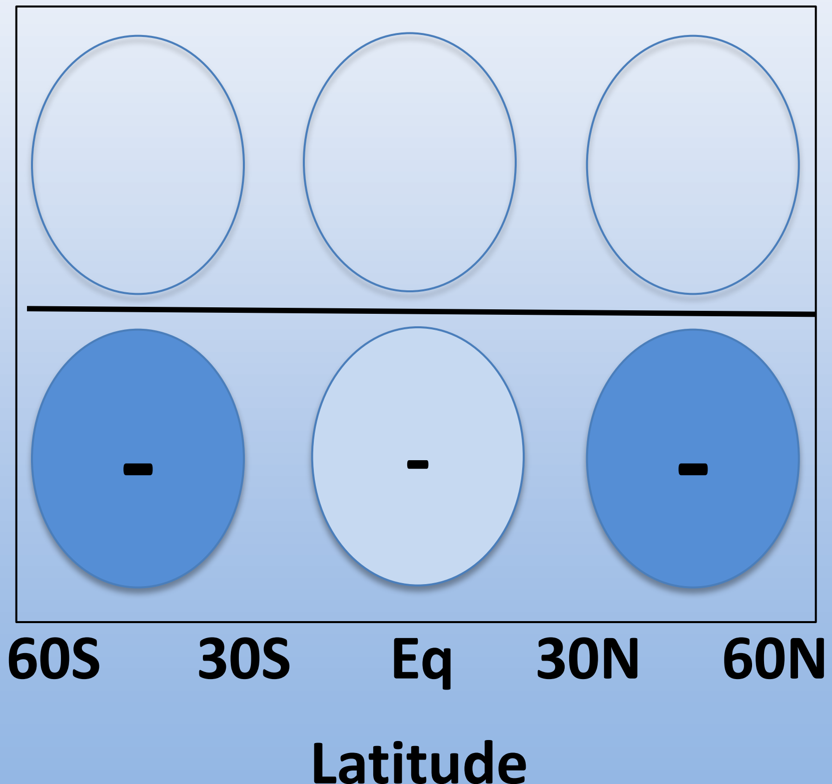


Upper Strat (16-1 hPa)	Trend (DU/decade)
60S-60N	+0.7 ± 0.4
60S-30S	+0.5 ± 0.3
30S-30N	+0.9 ± 0.6
30N-60N	+0.6 ± 0.4

Lower Stratosphere (1000-16 hPa)

Fit to EESC, Solar Cycle, and Linear Trend + QBO, Volcanos, ENSO

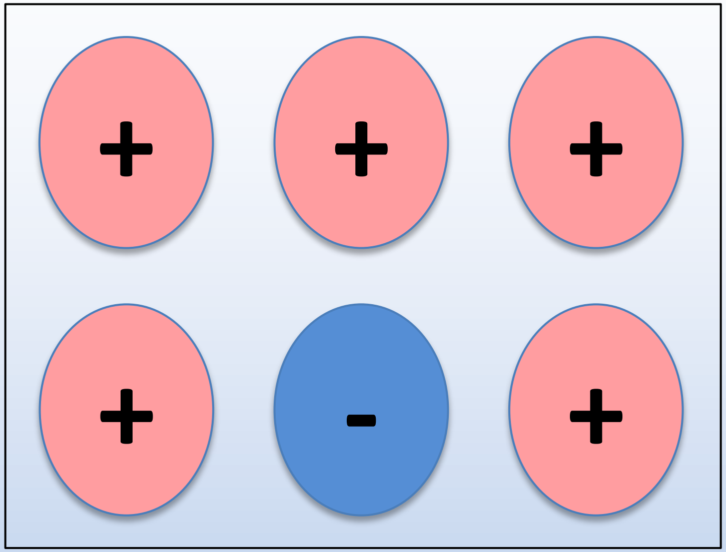




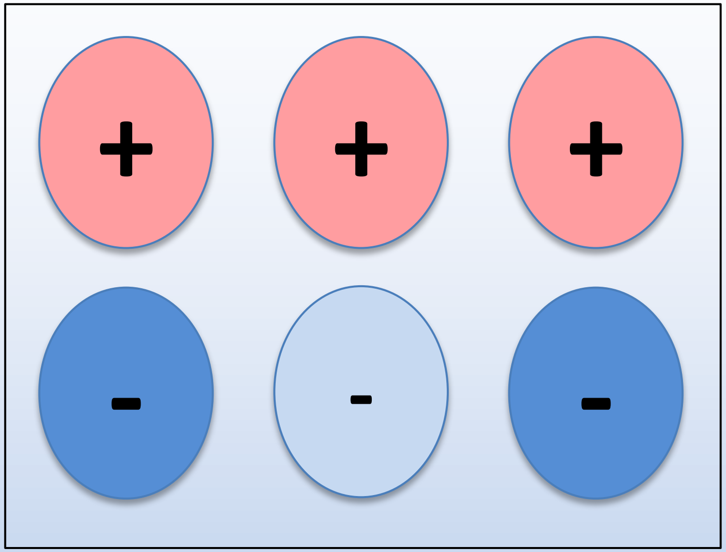
Lower Strat (1000-16 hPa)	Trend (DU/decade)
60S-60N	-1.4 ± 0.5
60S-30S	-2.3 ± 1.6
30S-30N	-0.8 ± 0.9
30N-60N	-2.0 ± 1.8

Summary

What we expect



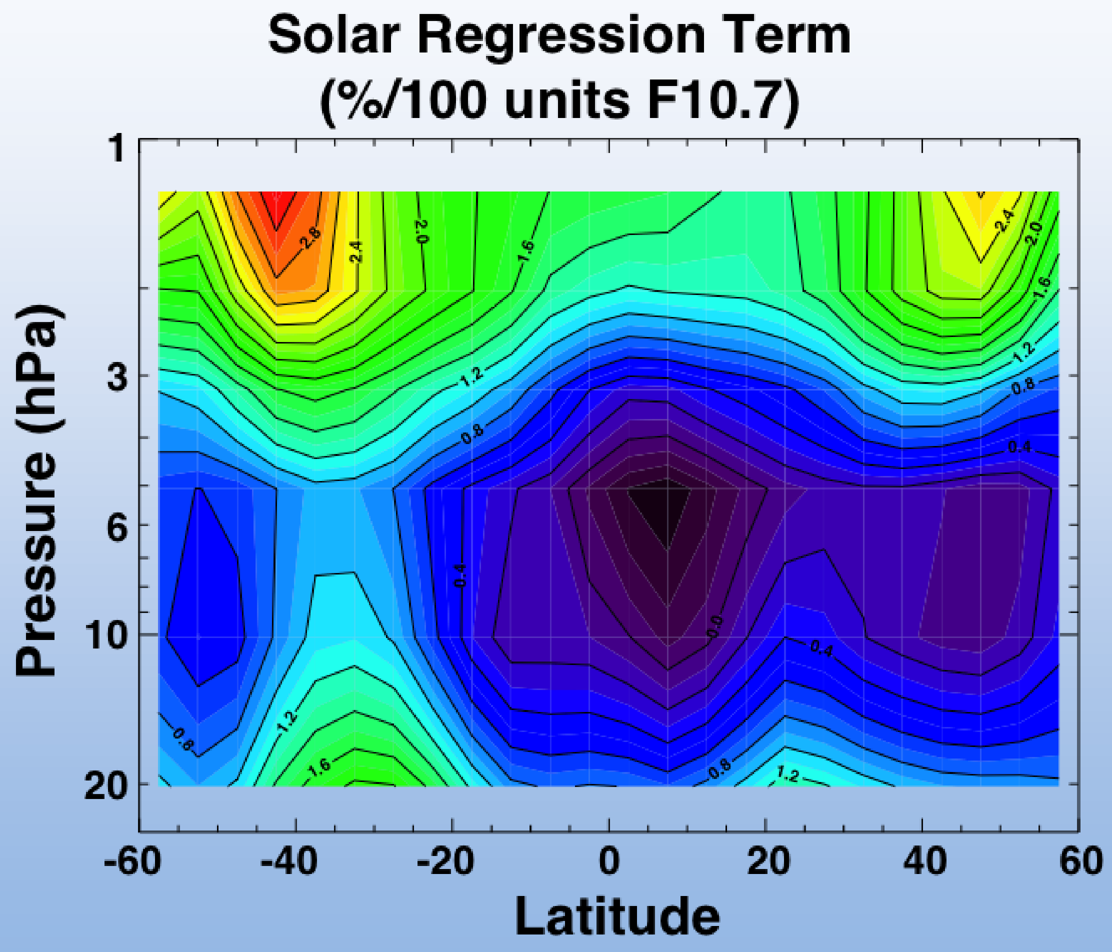
What we see



○ **Upper stratospheric cooling shows positive ozone response as expected**

○ **Lower stratospheric ozone does not show evidence of circulation speed-up**

SBUV Data 1979-2013



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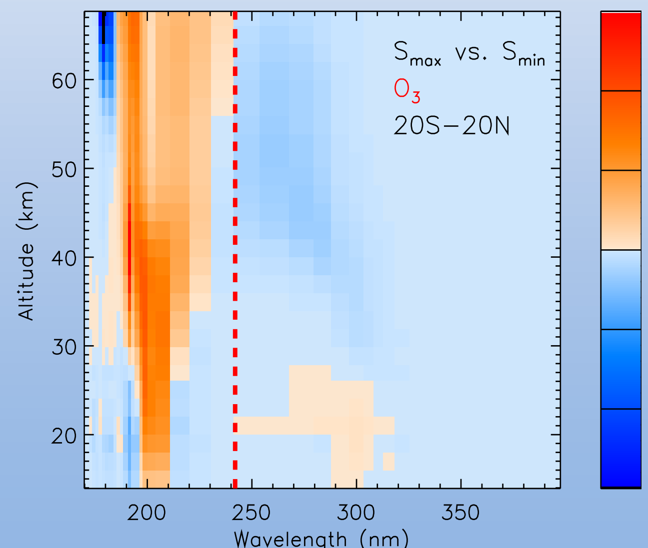
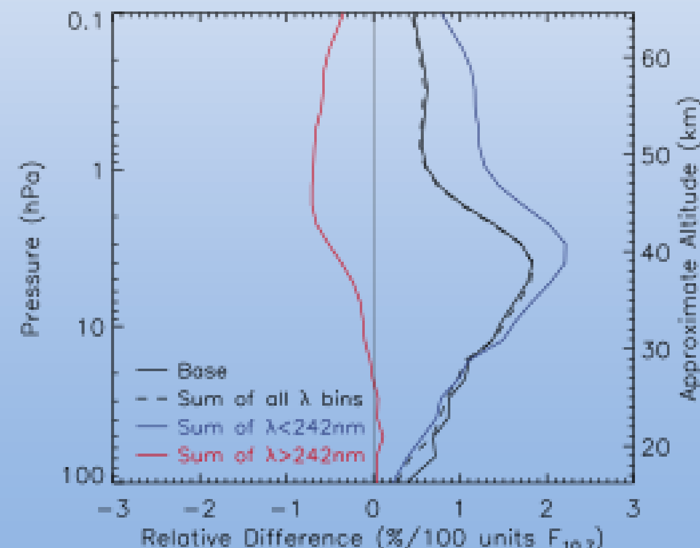
Solar Cycle Impact on Ozone: Theory (Top Down)

$$O_2 + h\nu\ (\lambda < 242\ \text{nm}) \rightarrow O + O + \text{k.e.}$$

$$O_3 + h\nu\ (\lambda < 308\ \text{nm}) \rightarrow O_2 + O + \text{k.e.}$$

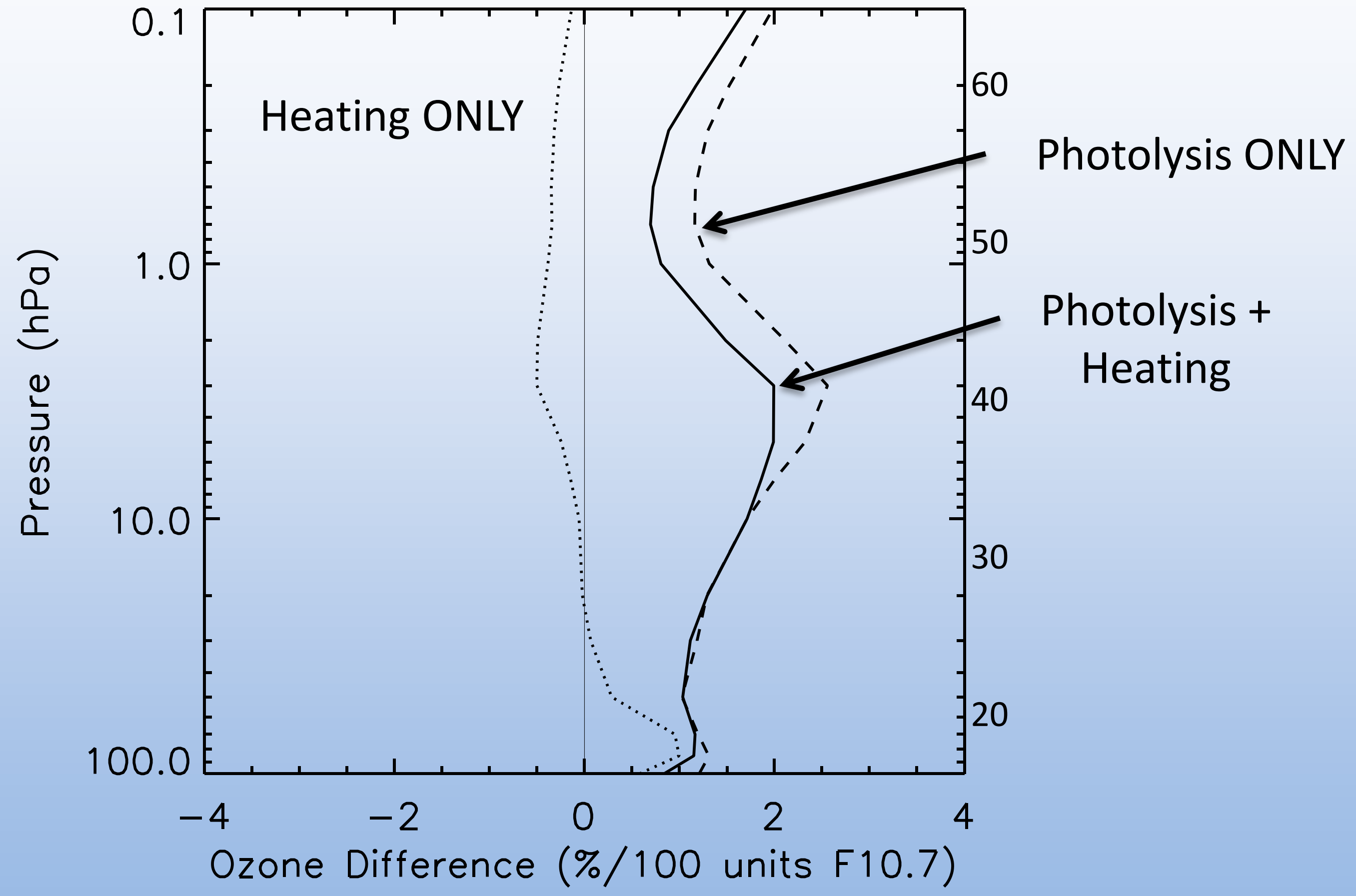
- **O_2 photolysis produces ozone (positive response)**
- **O_3 photolysis produces atomic oxygen that recombines ozone (negative response)**





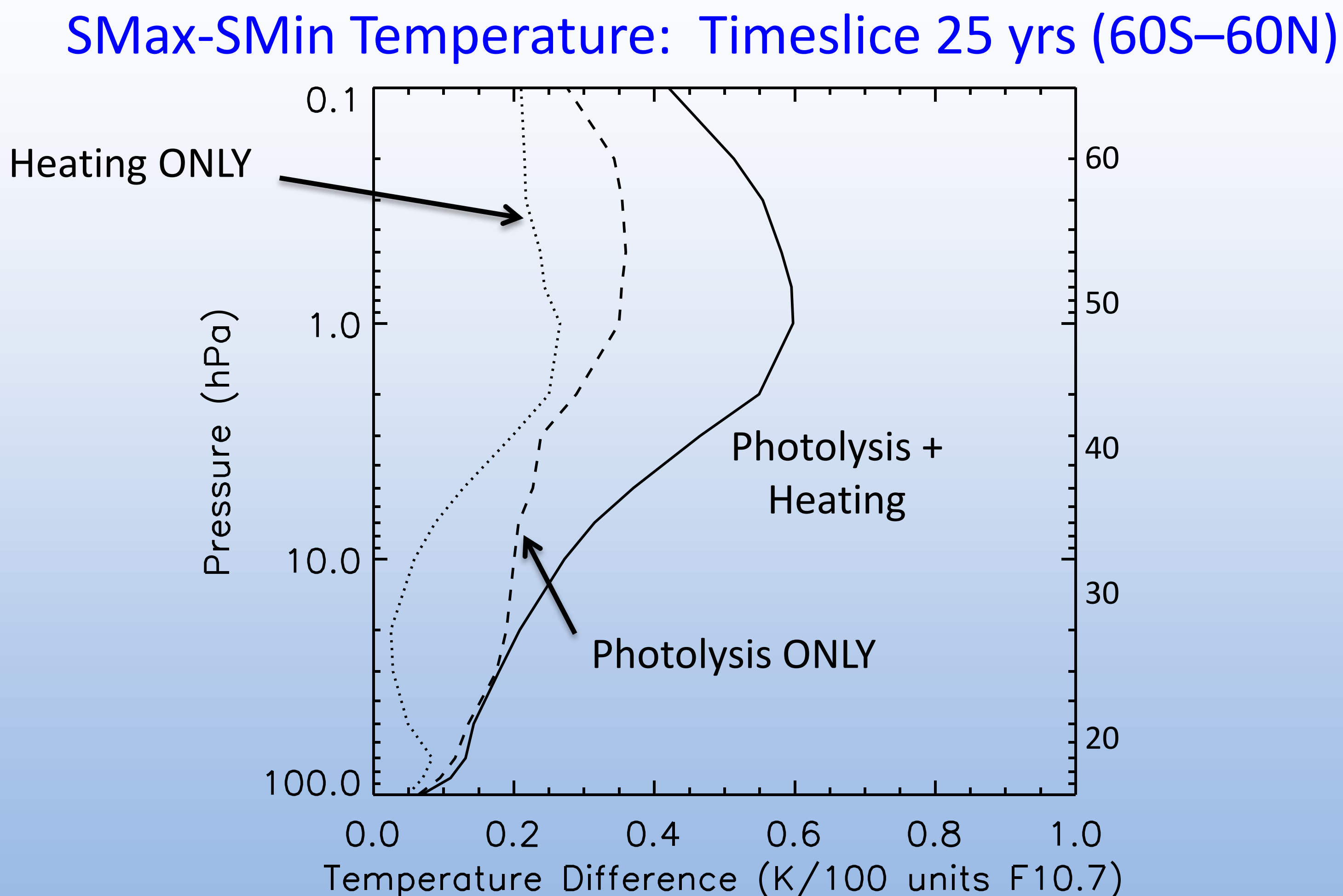
Photolysis accounts for virtually the entire ozone response

SMax-SMin Ozone: Timeslice 25 yrs (60S–60N)



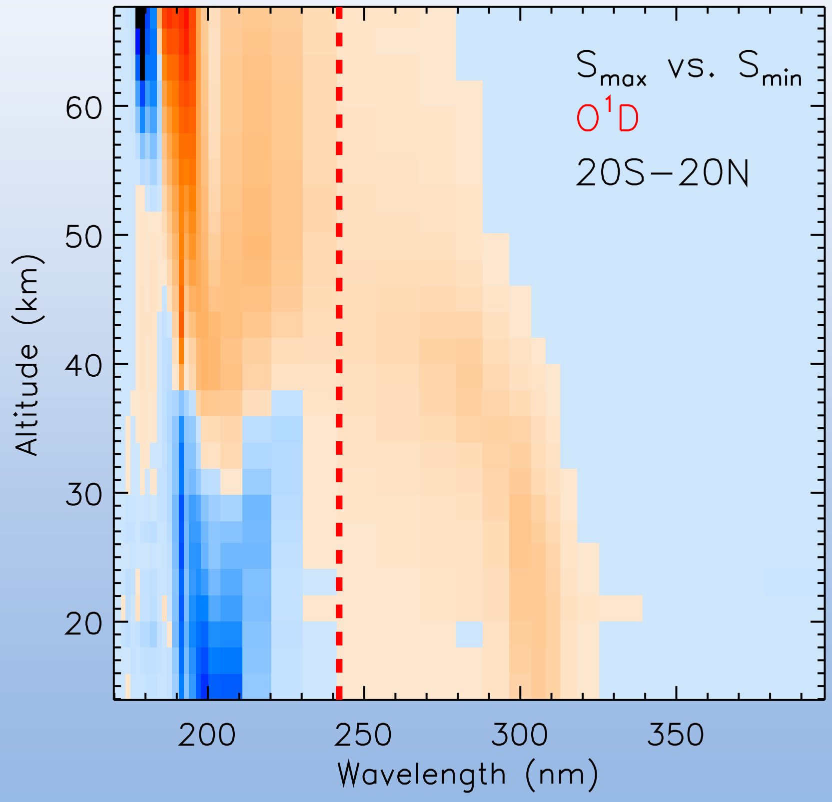
Chemistry–transport models (CTMs) should get the ozone response just about right.

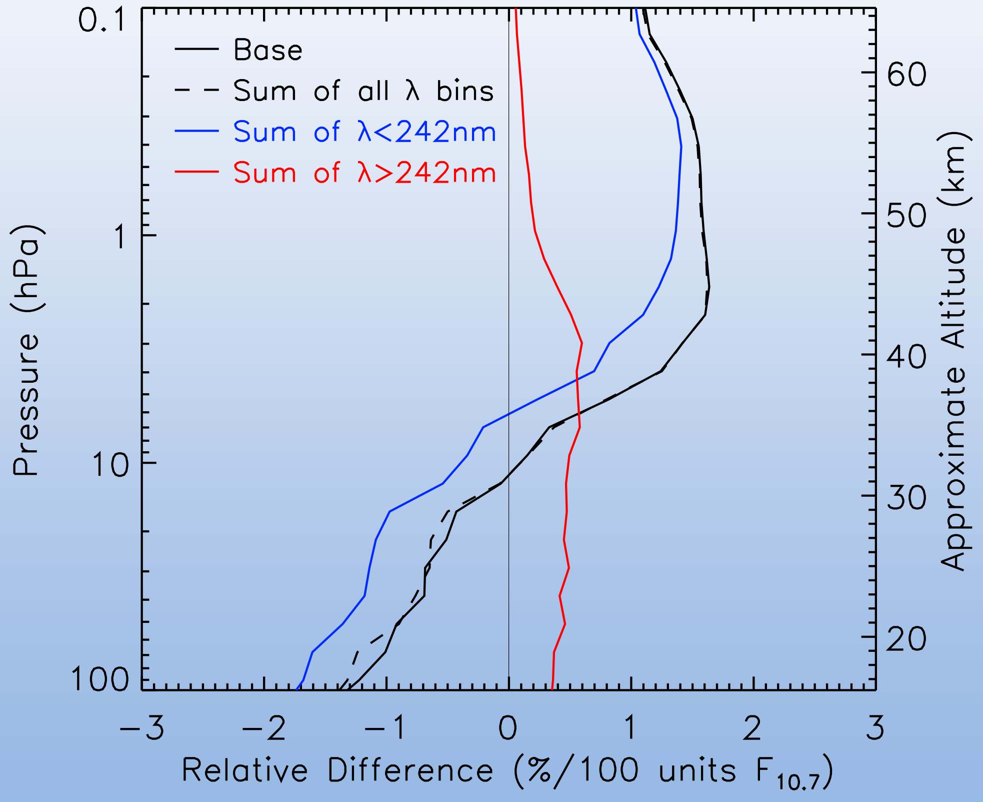
Photolysis accounts for more than half the temperature response



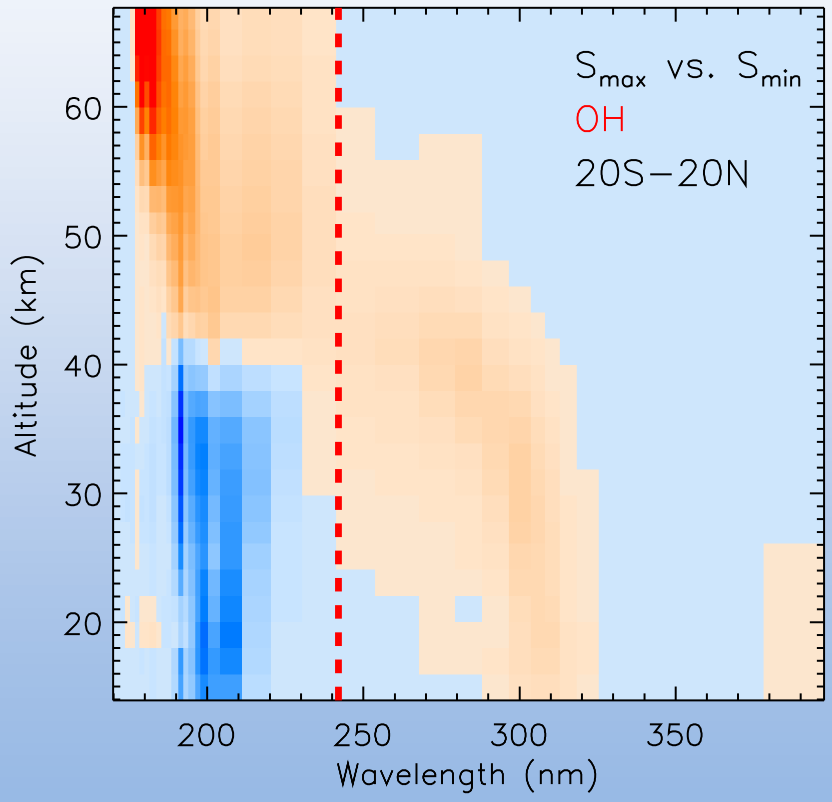
General circulation models (GCMs) without coupled chemistry may capture only half (or less) of the solar cycle impact on temperature.

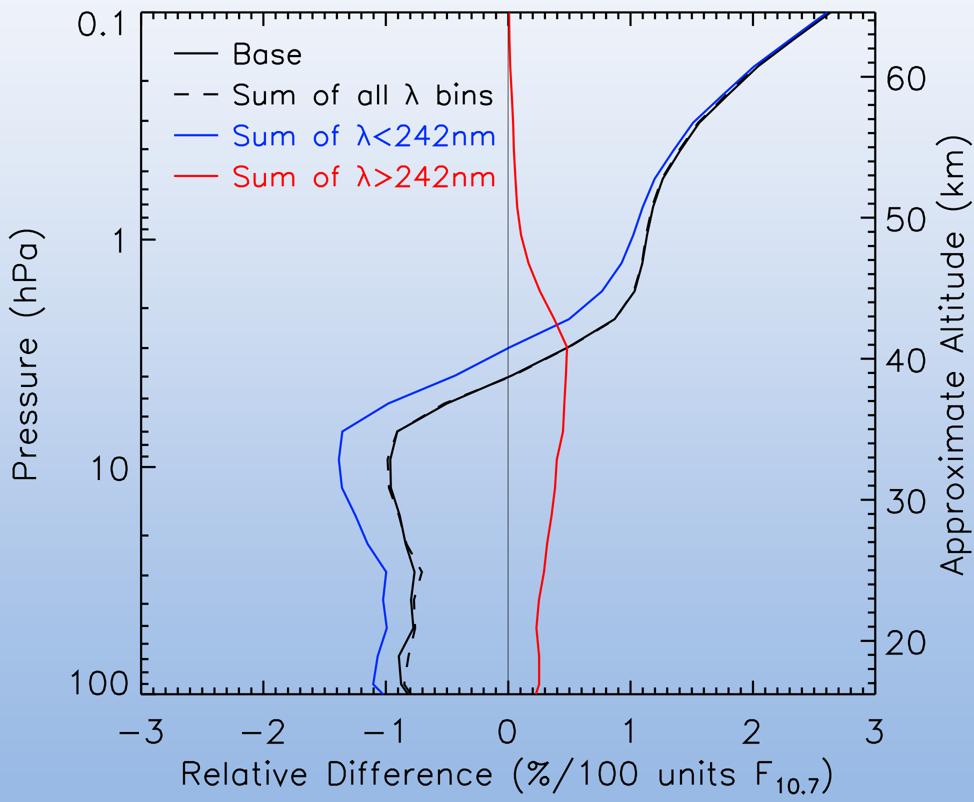
O^1D response = sum of the λ bins



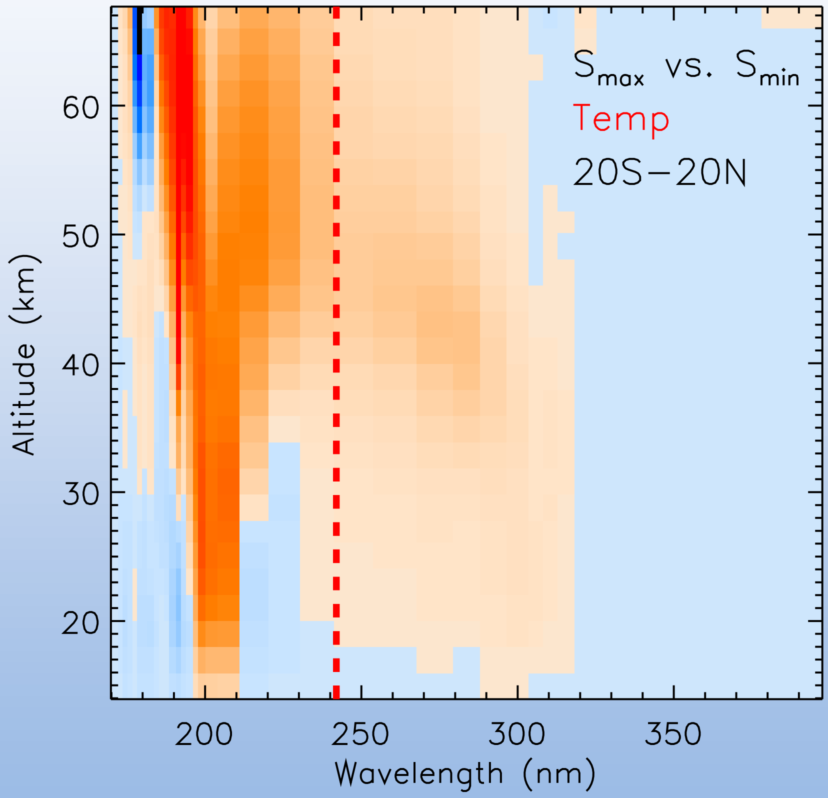


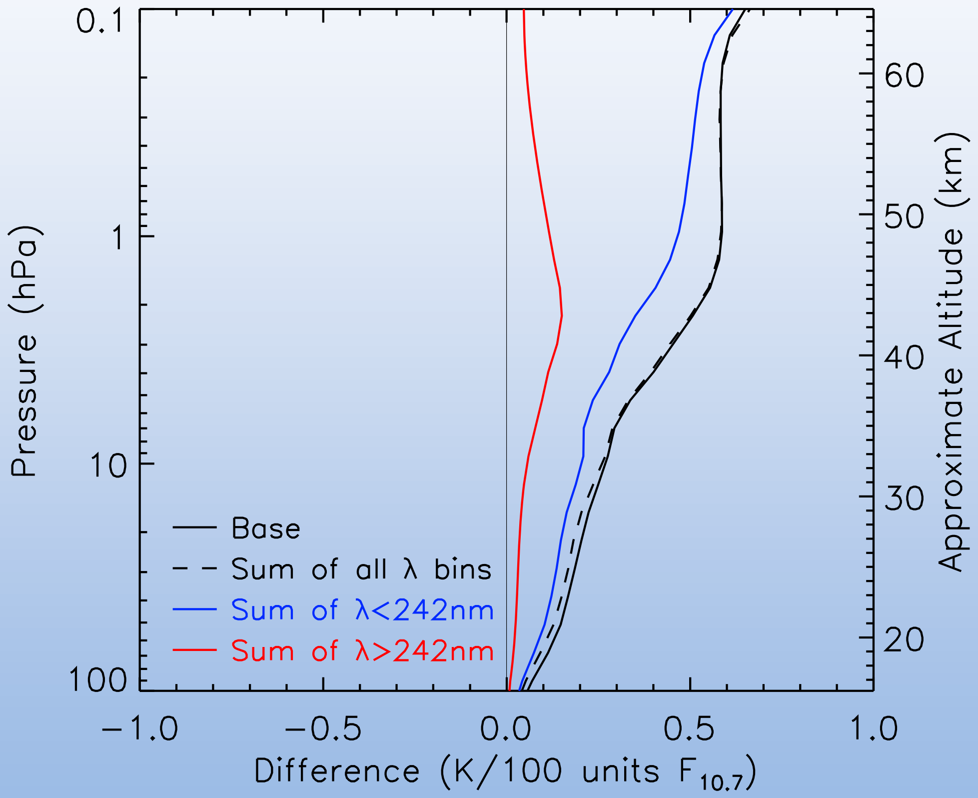
OH response = sum of the λ bins



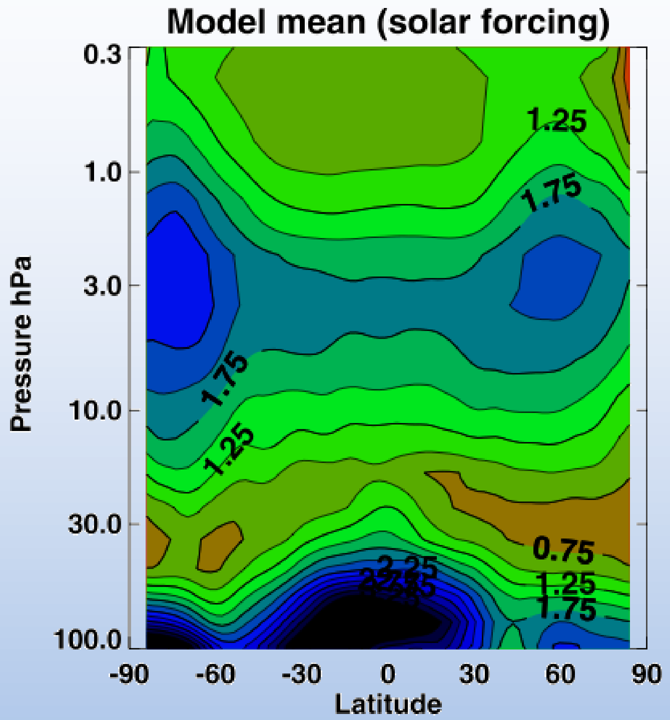


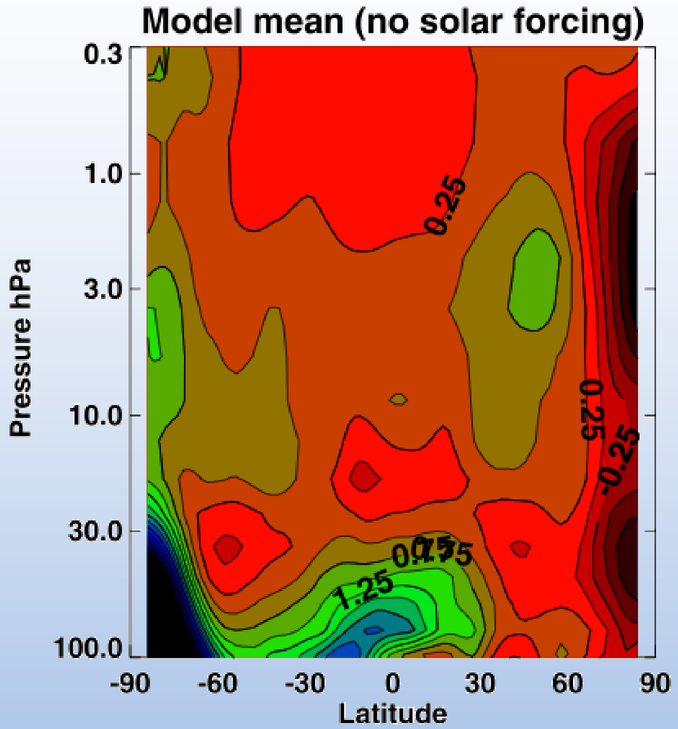
Temperature response = sum of the λ bins





Model (3D CCM) results for ozone response to solar UV forcing



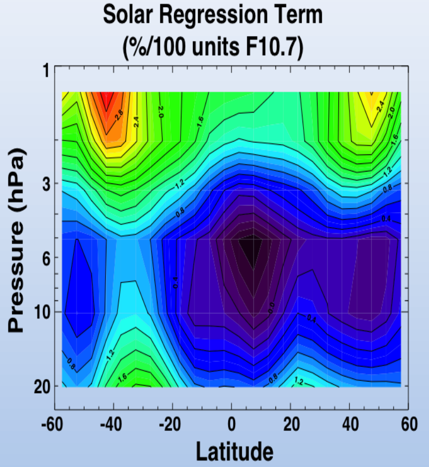


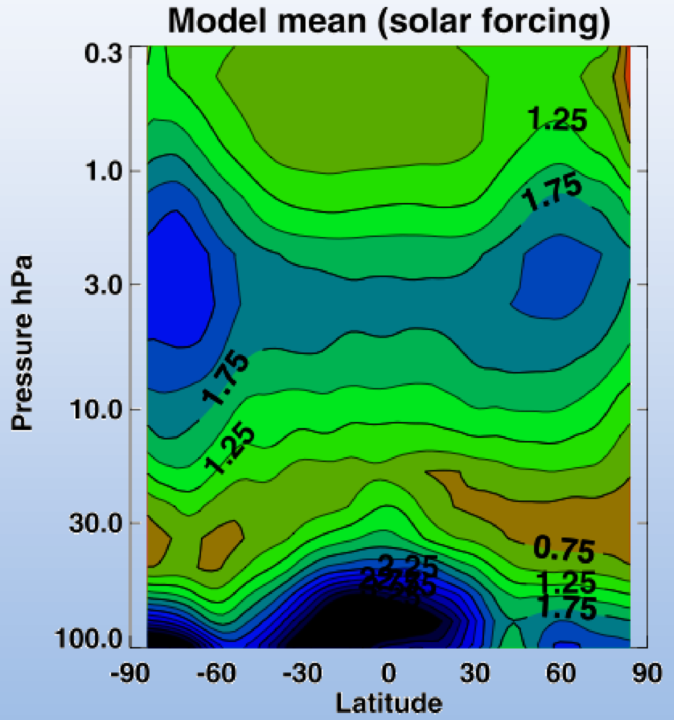
Models obtain maximum ozone response centered at about 3 hPa; larger at mid to high latitudes than at equator

Models without solar cycle forcing can appear to have a solar signal in polar regions and in lower stratosphere

Austin, J. et al. (2008), Coupled chemistry climate model simulations of the solar cycle in ozone and temperature, *J. Geophys. Res., 113(D11), doi:10.1029/2007JD009391.*

Observed solar signal in upper stratosphere has expected latitude signature, but occurs at higher altitude than expected (at least in SBUV data)





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Conclusions

- **Separation of chlorine signal from greenhouse gas signal in ozone data presents a problem**
  - **Upper stratosphere where GHG cool seems to work**
  - **Lower stratosphere where circulation speed-up is expected doesn't work**
- **Separation of solar cycle signal from volcanic aerosol signal may get confused with chlorine/GHG separation**
  - **Works pretty well in upper stratosphere**
  - **Give result in lower stratosphere for solar signal, but extension of data set could easily modify answers**