Impact of the Montreal Protocol: Evidence from Stratospheric Ozone Data

Richard S. Stolarski

Johns Hopkins University

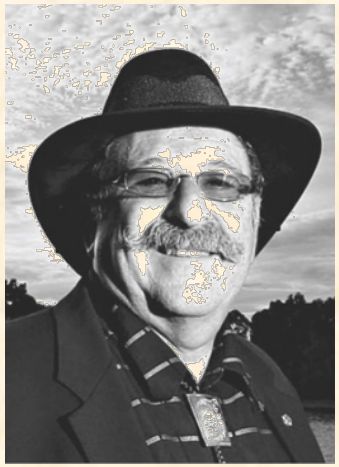
Earth and Planetary Sciences

Baltimore, MD 21218

Thanks to:
Luke Oman
Susan Strahan
Valentina Aquila
Stacey Frith
Anne Douglass

AMS Geller Symposium 14 Jan 2016

Geller Plots



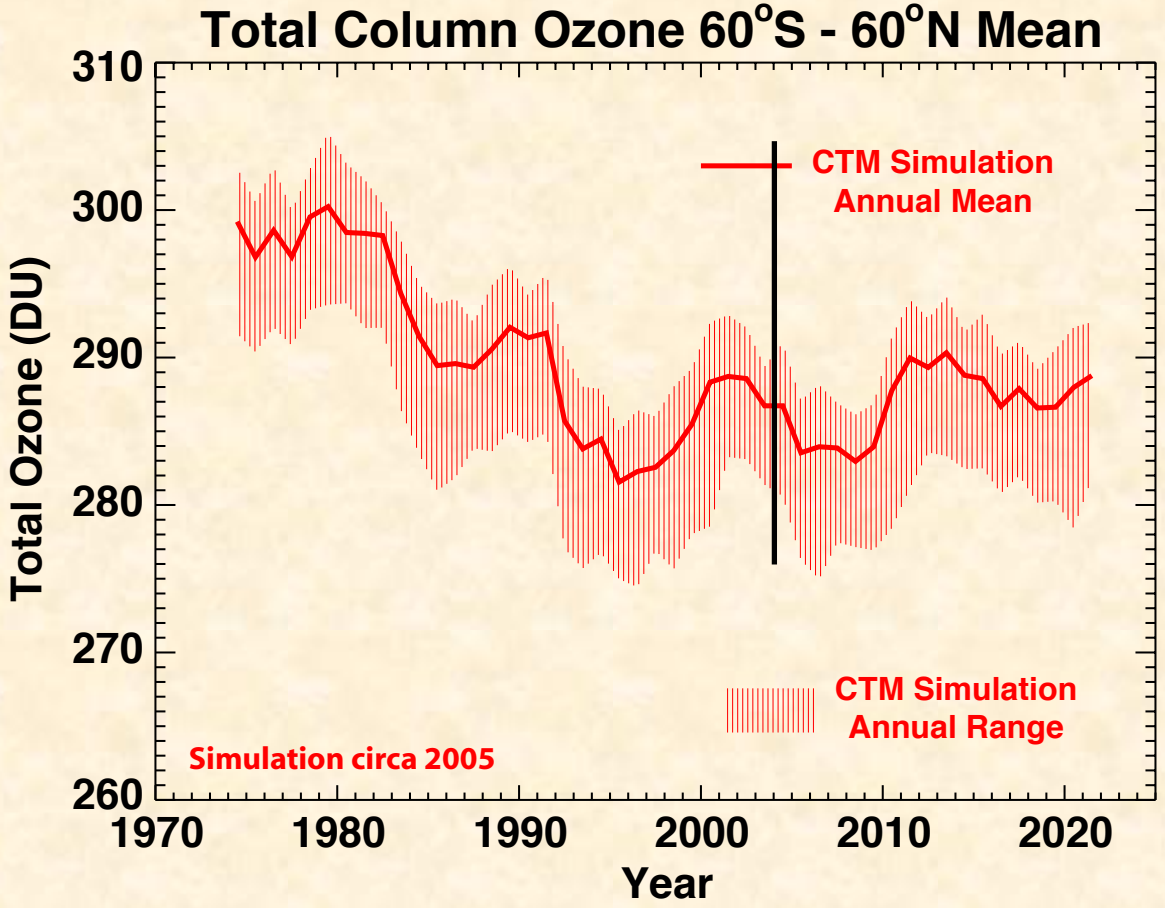
Many have searched for signs of ozone recovery that can be attributed to the impact of the Montreal Protocol

I would like to rephrase the question:

How good were our model projections made about 10 years ago?

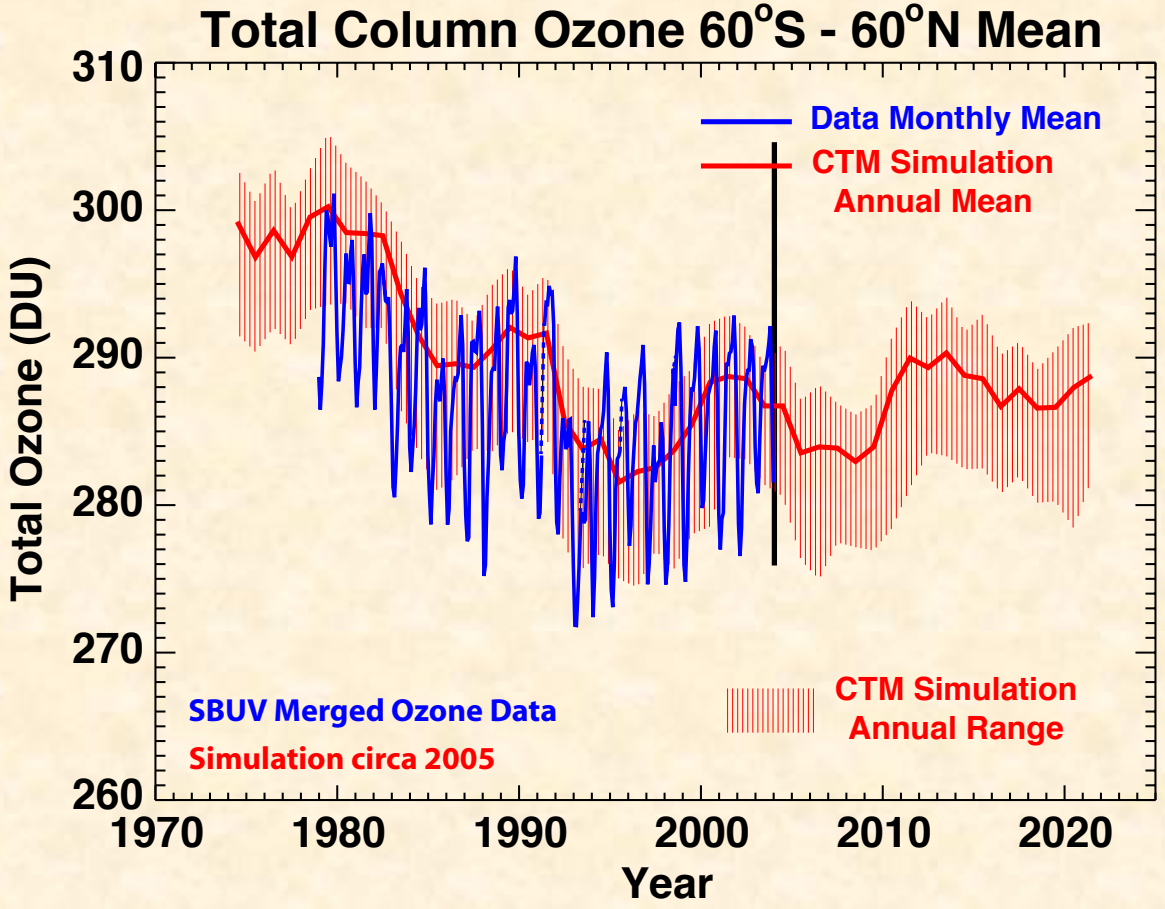
And how good are they today?

CTM Simulation (fvgcm winds) including ODS, N_2O, CH4, CO_2, and solar UV changes



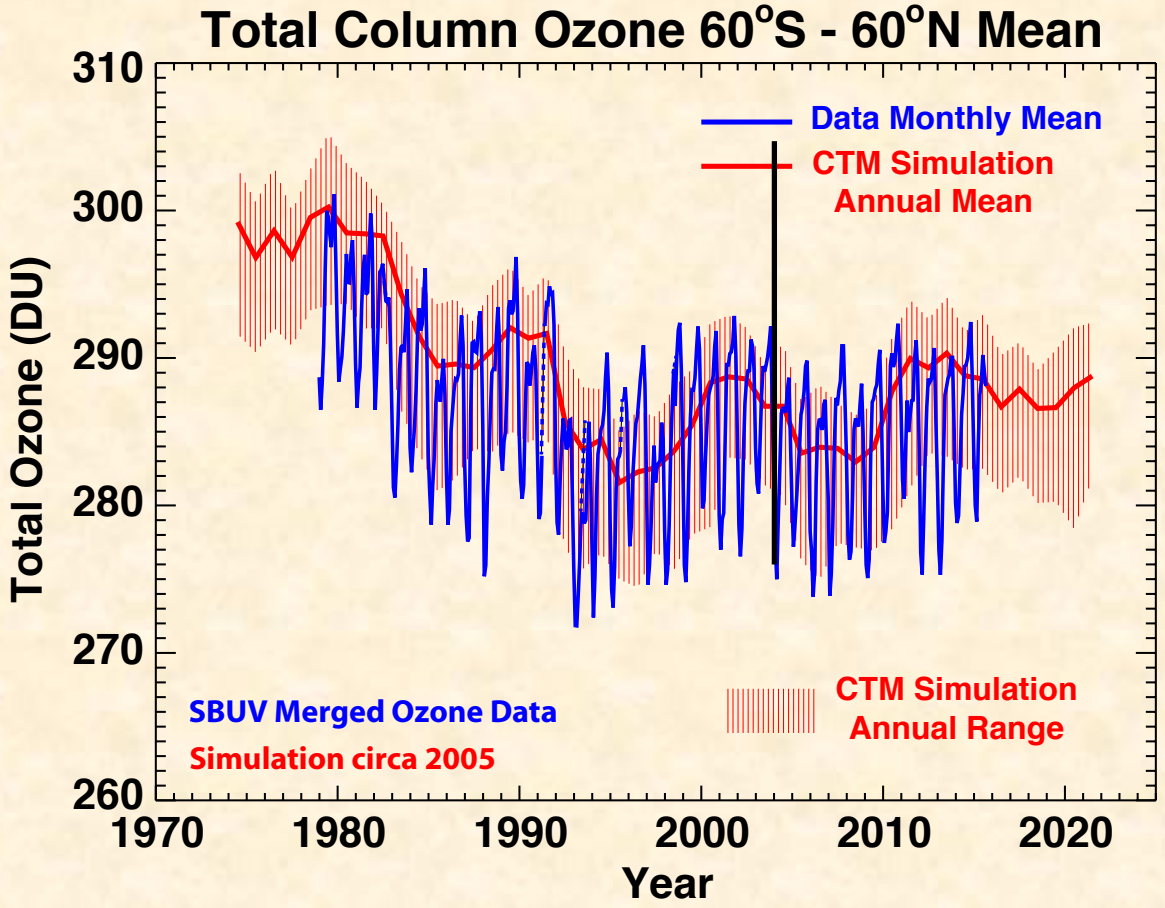
Stolarski et al. (2006) JAS 63, 1028-1041

Comparison with merged SBUV ozone data available when Paper was written



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

Extension of SBUV data to mid-2015



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

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***

Fit model and data (SBUV merged total ozone) to same multiple linear regression to evaluate comparison quantitatively

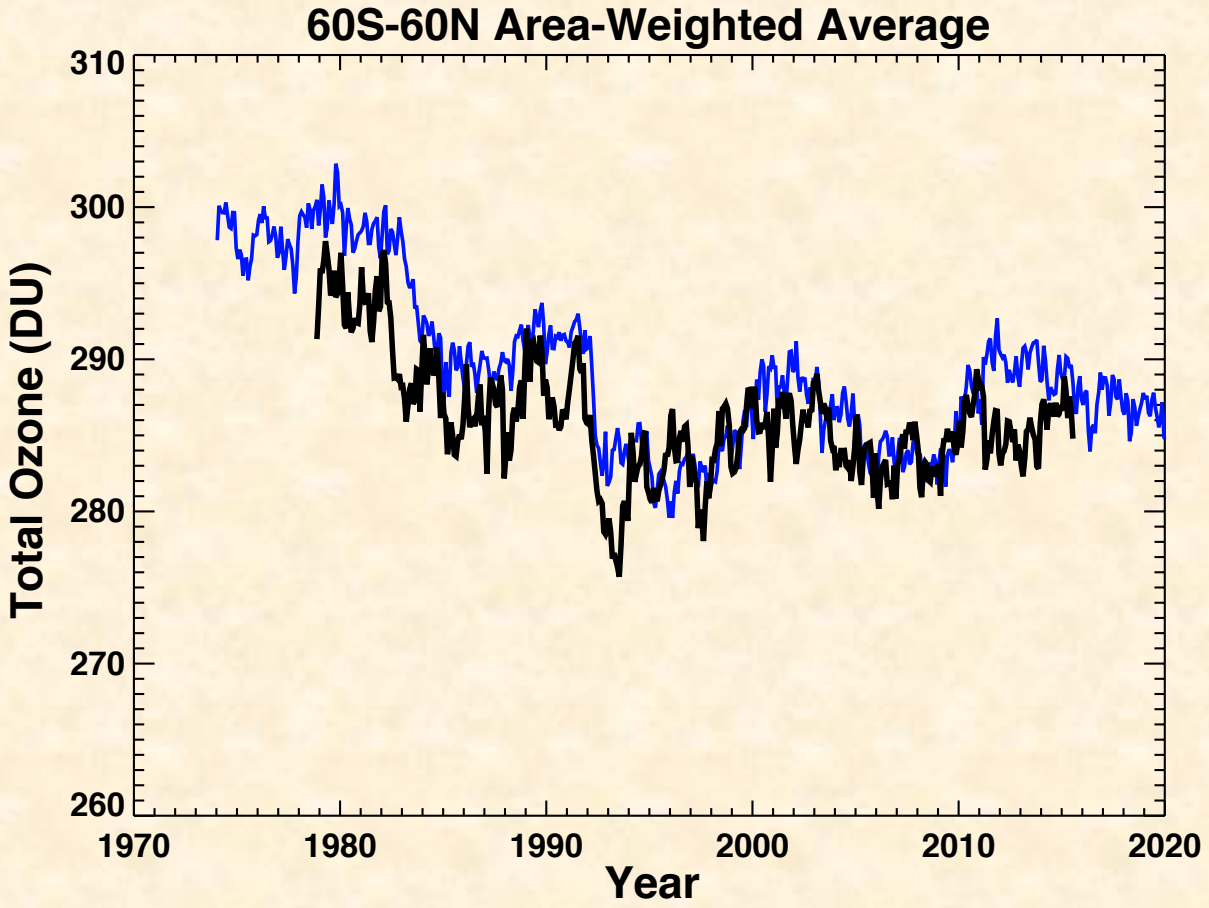
Results from 2006 Paper			
	EESC DU/decade	EESC %/decade	Solar DU/100 F10.7
Observed	-3.7 ± 0.5	-1.3 ± 0.2	5.2 ± 0.6
Model	-6.9 ± 0.2	-2.4 ± 0.1	4.5 ± 0.3

- **Solar cycle agrees with data within uncertainty estimates (barely)**
- **Slope of EESC curve (1979-1995) in model is significantly larger than that from data**

How are we doing now, 10 years later?

Compare updated SBUV Merged Ozone Data to a variety of versions of Goddard models

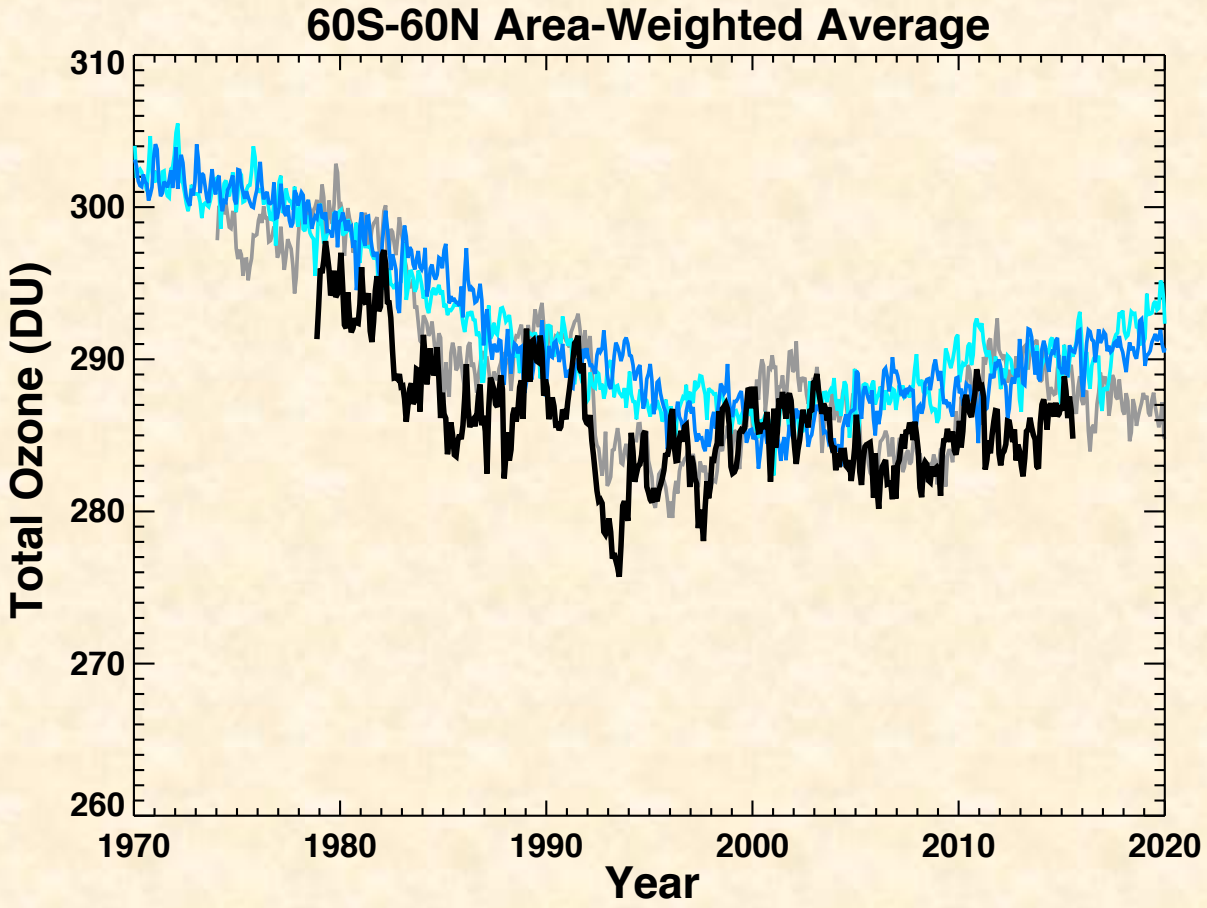
Goddard CTM using FVGCM winds



Black line: SBUV Merged Ozone Data Deseasonalized

CTM with solar UV variation no volcanoes

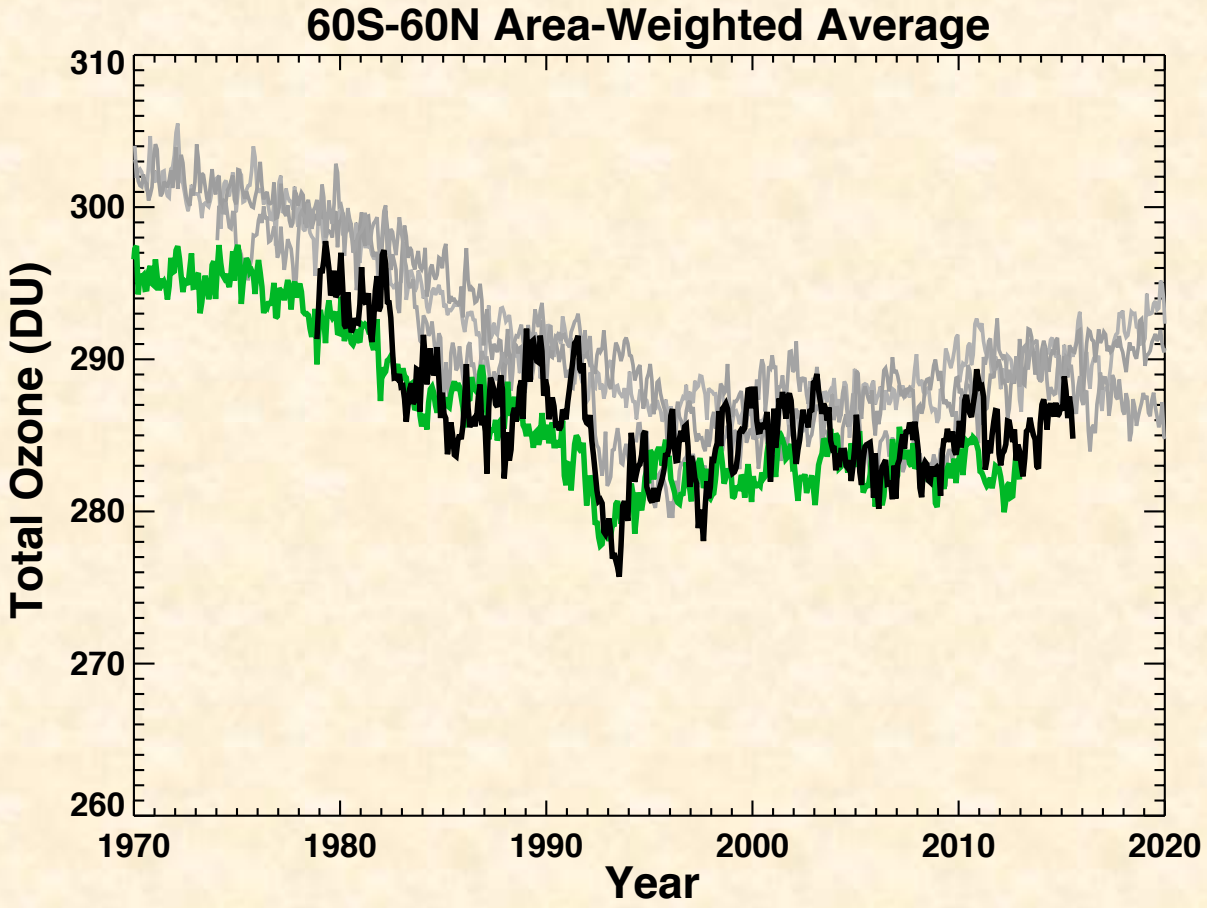
GEOSCCM (GEOS 4: CCMVal2)



Black line: SBUV Merged Ozone Data Deseasonalized

2 ensemble members: ODS, GHG no solar, no volcanoes

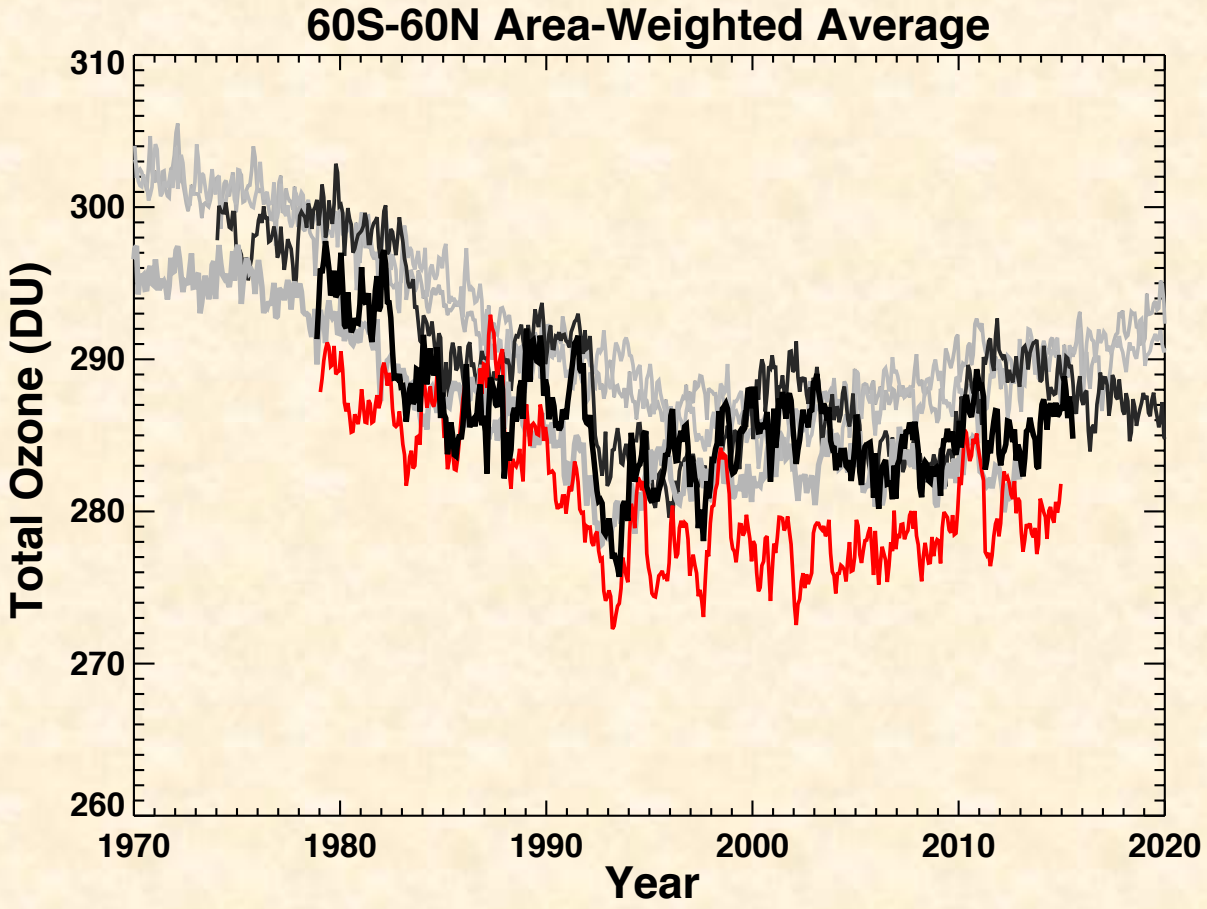
GEOSCCM (GEOS 5: CCMI)



Black line: SBUV Merged Ozone Data
Deseasonalized

no solar, no volcanoes
STRATCHEM version

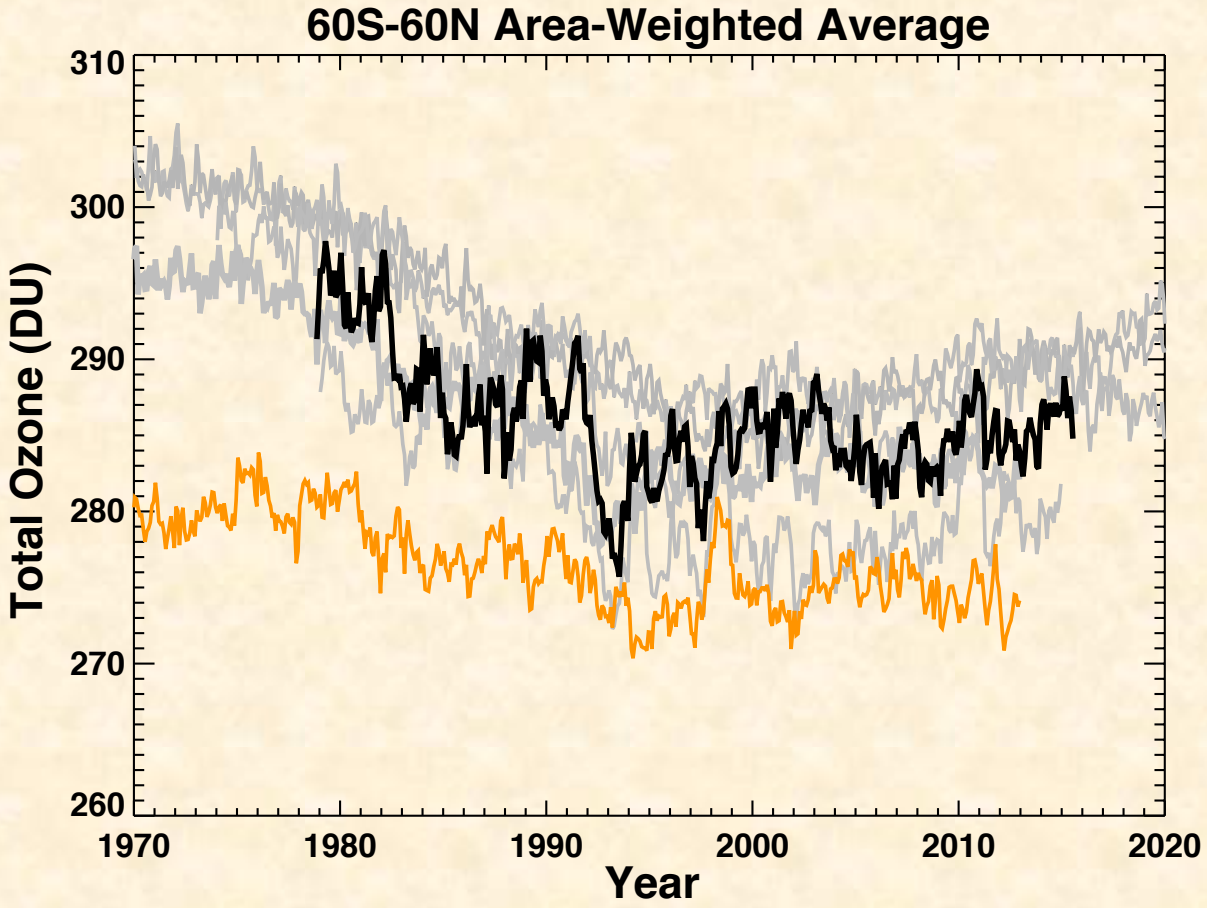
GMI CTM (MERRA Winds)



Black line: SBUV Merged Ozone Data Deseasonalized

COMBO Stratospheric + Tropospheric Chemistry

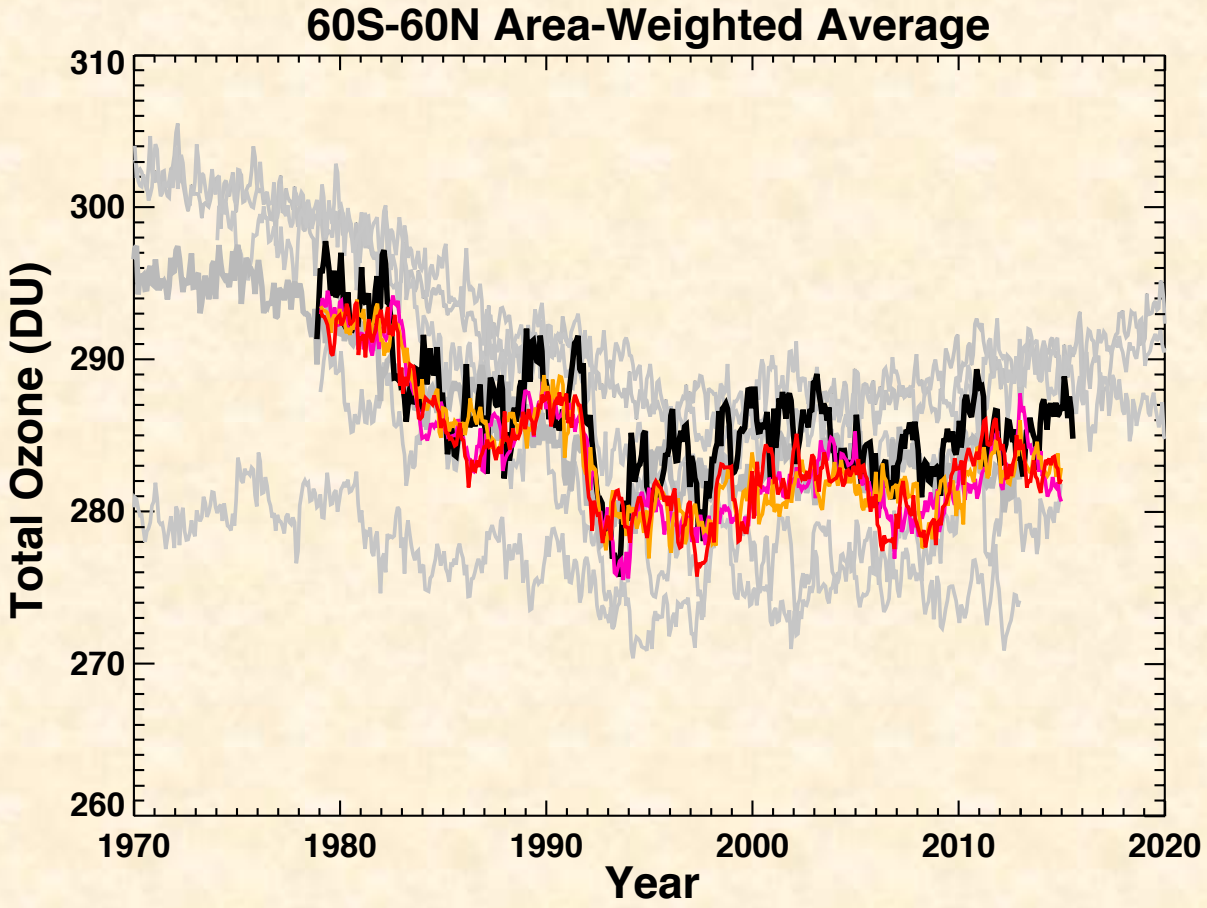
GEOSCCM (GEOS5: CCMI)



Black line: SBUV Merged Ozone Data Deseasonalized

Stratosphere + Troposphere Chemistry; no solar, no volcanoes

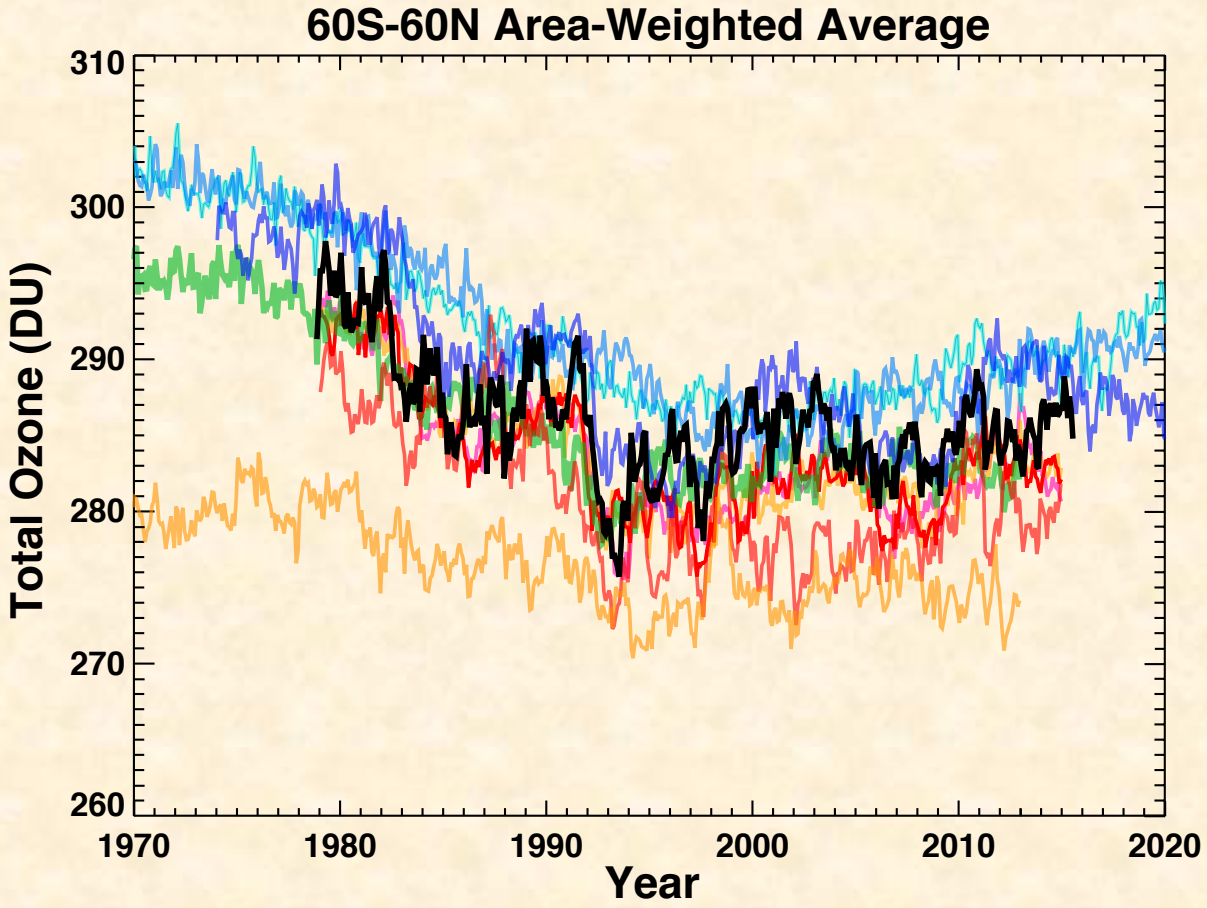
GEOSCCM (Aquila et al. 2014)



Black line: SBUV Merged Ozone Data Deseasonalized

3 ensemble members: ODS, GHG solar + volcanoes

All Model Results



Black line: SBUV Merged Ozone Data Deseasonalized

Summary Table of Model and Data Results

Old ← → New → Data

	GEOS4 CTM	GEOS4 CCM	GMI CTM	STRAT CHEM	STRATCHEM with Solar	STRAT TROP	SBUV
EESC (DU/PPB)	-15.1	-14.9 -16.8	-12.9	-11.5	-13.4 -13.7 -12.5	-6.3	-9.6
Solar (DU/100)	5.0	0.2 0,3	0.7	0.7	3.1 2.8 3.4	0.7	3.3
Season (DU)	2.9	4.6 4.6	3.0	3.6	4.6 4.6 4.7	4.6	3.0

Summary Table of Model and Data Results

Old ← → New → Data

	GEOS4 CTM	GEOS4 CCM	GMI CTM	STRAT CHEM	STRATCHEM with Solar	STRAT TROP	SBUV
EESC (DU/PPB)	-15.1	-14.9 -16.8	-12.9	-11.5	-13.4 -13.7 -12.5	-6.3	-9.6
Solar (DU/100)	5.0	0.2 0,3	0.7	0.7	3.1 2.8 3.4	0.7	3.3
Season (DU)	2.9	4.6 4.6	3.0	3.6	4.6 4.6 4.7	4.6	3.0

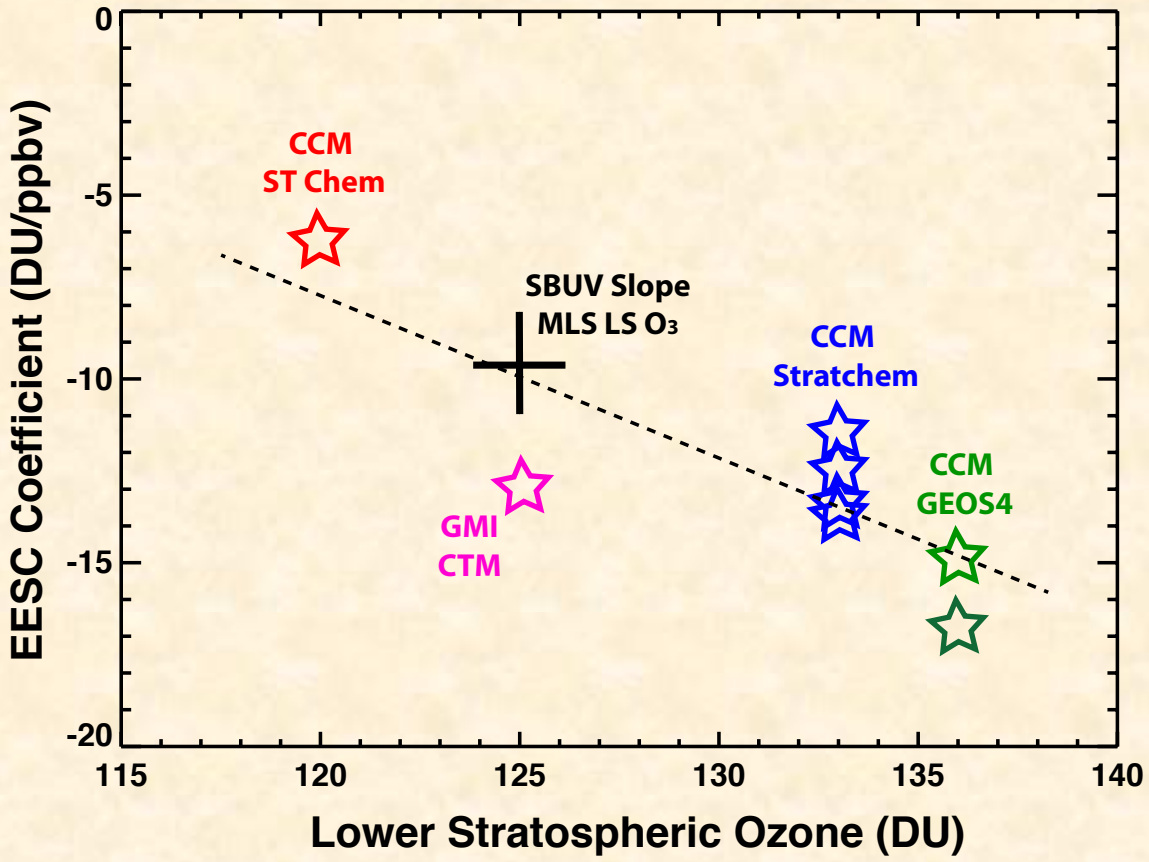
Luke Oman suggested that I look at model bias in lower stratospheric ozone

Summary Table of Model and Data Results

Old ← → New → Data

	GEOS4 CTM	GEOS4 CCM	GMI CTM	STRAT CHEM	STRATCHEM with Solar	STRAT TROP	SBUV
EESC (DU/PPB)	-15.1	-14.9 -16.8	-12.9	-11.5	-13.4 -13.7 -12.5	-6.3	-9.6
Solar (DU/100)	5.0	0.2 0,3	0.7	0.7	3.1 2.8 3.4	0.7	3.3
Season (DU)	2.9	4.6 4.6	3.0	3.6	4.6 4.6 4.7	4.6	3.0
O3 LS (DU)		136 136	125	133	133 133 133	120	125 (MLS)

Are ozone loss differences correlated with baseline lower stratospheric ozone?



Conclusions

- **Ozone decreased through the 1980s into the 1990s and then ceased to decrease; as predicted by the models in response to the Montreal Protocol**
- **There are still quantitative issues about the sensitivity of this quasi-global ozone to added chlorine/bromine**
- **There are thus issues about how large the upward slope in the 2000s should be due to decrease of ODSs due to the Montreal Protocol**