Explaining Differences in the Long-Term Changes in Tropical Upwelling and Stratospheric Mean Age among Chemistry-Climate Models

Luke Oman[1], Darryn W. Waugh[1], Richard S. Stolarski[2], Steven Pawson[2], and Paul A. Newman[2]
[1]Johns Hopkins University, Baltimore, Maryland, [2]NASA GSFC, Greenbelt, Maryland

Introduction

Climate simulations using the GEOS coupled chemistry/climate model (CCM) were conducted using various sea surface temperature (SST), greenhouse gas (GHG) and halogen concentrations. These simulation were analyzed to understand stratospheric circulation changes. Most models simulate an increasing stratospheric circulation (e.g. younger mean age). We use the GEOSCCM simulations to show the cause of changes in the model and use this new understanding to help explain the large differences seen in upwelling mass flux among CCMs (Butchart et al. 2006).

Table 1. Model simulations used in this study.

Runs	Time Period	SST	GHG	Halogen
Reference Past 1 & 2	1951-2004	Observations	Observations	Observations
Reference Future	2000-2099	CCSM3	A1b	Ab
Low Cl Past	1960-2004	Observations	Observations	Fixed 1960
Low Cl Future	2000-2099	CCSM3	A1b	Fixed 1960
Cold Biased SST	1971-2099	HADGEM1	Obs. and A1b	Obs. and Ab
TS 1980	26x 1980	Obs. (1979-2004)	Fixed 1975	Fixed 1975
TS 2000	26x 2000	Obs. (1979-2004)	Fixed 1995	Fixed 1995
TS 2020	26x 2020	Obs. (1979-2004)	Fixed 2015	Fixed 2015
TS 2050	26x 2050	Obs. (1979-2004)	Fixed 2045	Fixed 2045

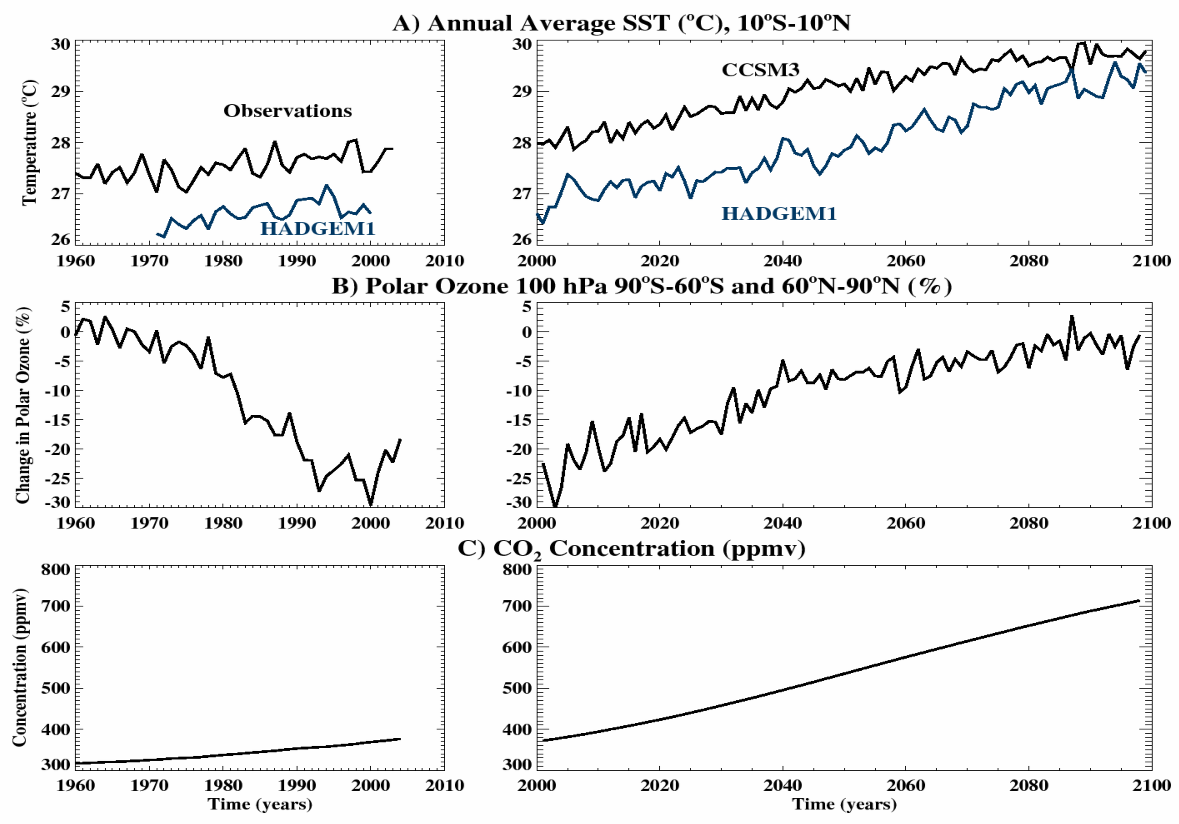

Figure 1. A) Annual tropical SSTs with our reference simulations in black and cold biased SSTs in blue (HADGEM1 biased 1K colder than observations & CCSM3), B) Polar ozone depletion at 100 hPa (averaged over both polar regions) and C) surface CO_2 concentration.

Table 2. Cases used to separate influences on mean age and other variables.

Case	Time Period	Model Runs
∂Γ/∂SST_1	1995-2004	Ref. Past - Cold Biased SST
∂Γ/∂SST_2	2015-2024	Ref. Future - Cold Biased SST
∂Γ/∂SST_3	2035-2044	Ref. Future - Cold Biased SST
∂Γ/∂SST_4	2055-2064	Ref. Future - Cold Biased SST
∂Γ/∂SST_5	2085-2094	Ref. Future - Cold Biased SST
∂Γ/∂O_3_1	1985-1994	Reference Past - Low Cl Past
∂Γ/∂O_3_2	1995-2004	Reference Past - Low Cl Past
∂Γ/∂O_3_3	2005-2014	Reference Future - Low Cl Future
∂Γ/∂O_3_4	2015-2024	Reference Future - Low Cl Future
∂Γ/∂O_3_5	2025-2034	Reference Future - Low Cl Future
∂Γ/∂CO_2	Last 10 years	TS2050 - TS1980

Stratospheric Circulation

The Brewer-Dobson circulation is a global scale cell with rising motion in the tropics and downward motion in the extratropics. An alternative measure of the strength of this circulation is the stratospheric mean age. Figs. 2A,B shows our models annual mean age and change over 120 years (Figure 2C shows the percentage change). Outside of the tropical low-mid stratosphere the mean age decrease approaches 1 year.

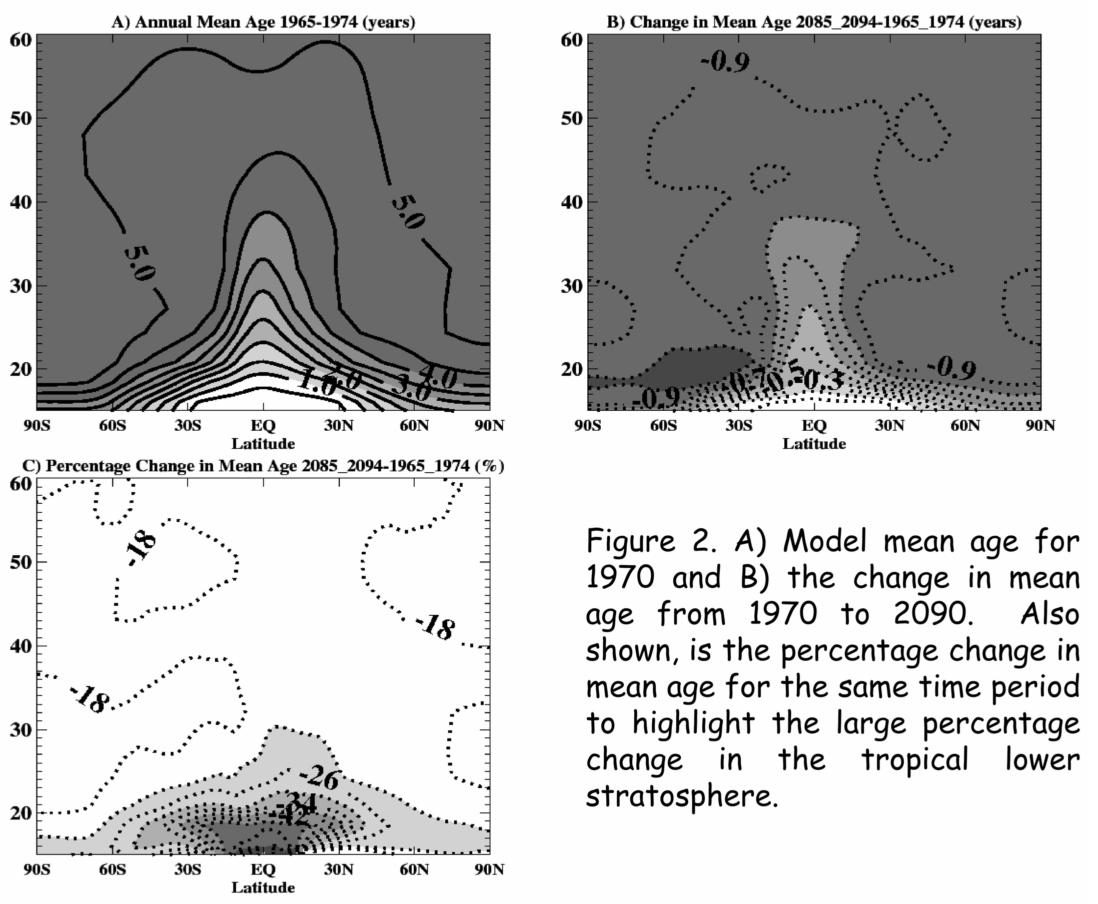

Figure 2. A) Model mean age for 1970 and B) the change in mean age from 1970 to 2090. Also shown, is the percentage change in mean age for the same time period to highlight the large percentage change in the tropical lower stratosphere.

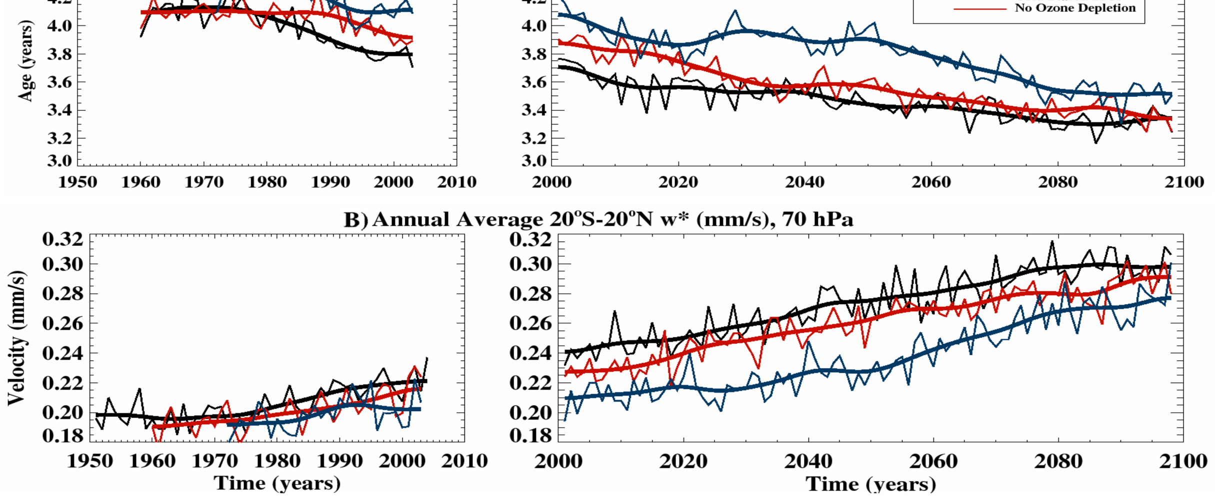

Figure 3. A) Evolution of annual mean age (years) over equator at 3 hPa with various forcings and B) tropical lower stratospheric upwelling (mm/s).

Reconstruction of Changes in Mean Age

Changes in SSTs, CO_2, and O_3 induce changes in the stratospheric mean age. The impact of each of these factors can be isolated by comparing different pairs of simulations that differ by only one of these factors.

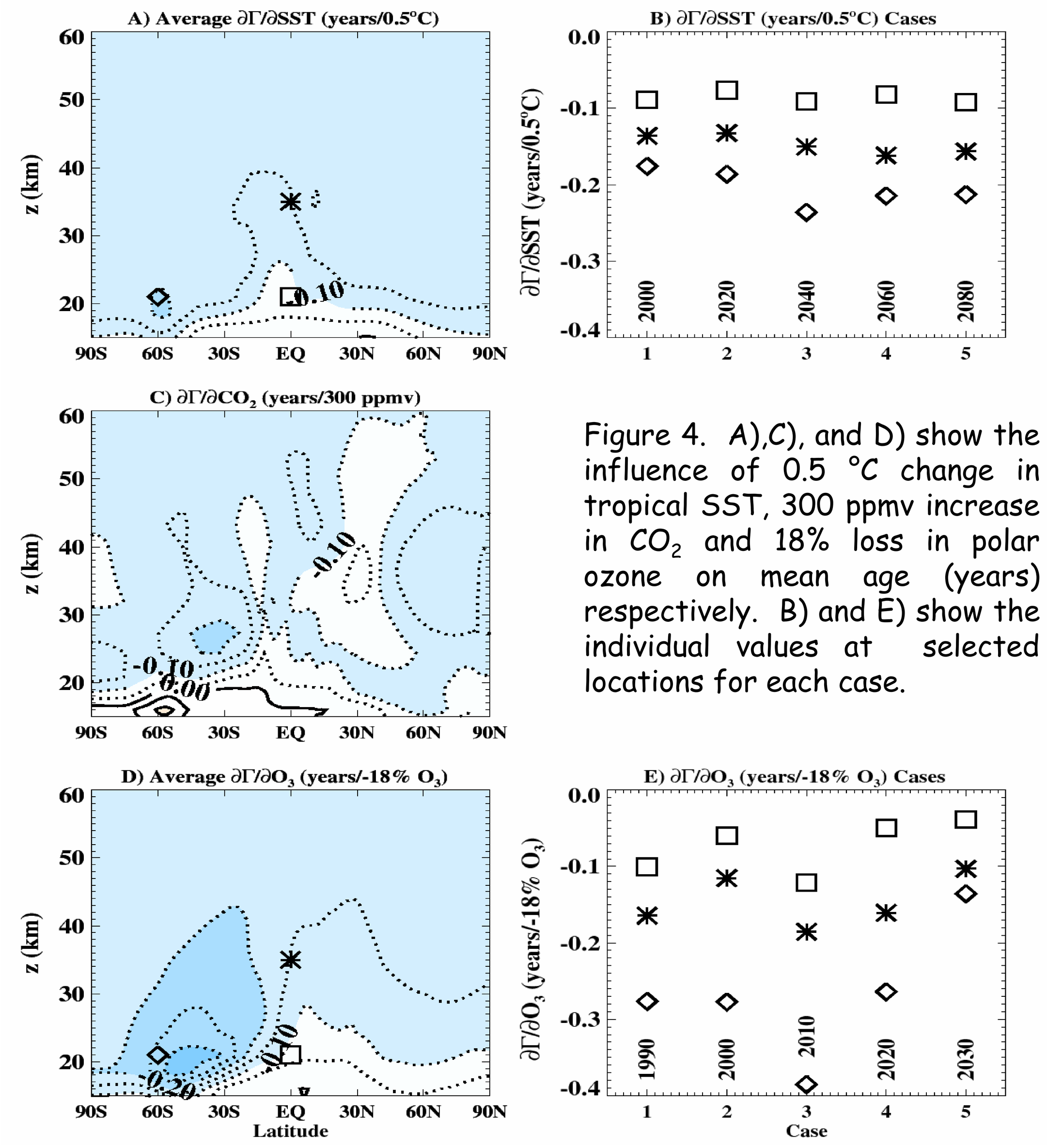

Figure 4. A),C), and D) show the influence of 0.5 °C change in tropical SST, 300 ppmv increase in CO_2 and 18% loss in polar ozone on mean age (years) respectively. B) and E) show the individual values at selected locations for each case.

If changes in SSTs, polar ozone, and CO_2 are the main causes of changes in the mean age, we should be able to reconstruct these changes using the equation below.

$$\Delta\Gamma = \Delta SST\,(\partial\Gamma/\partial SST) + \Delta O_3\,(\partial\Gamma/\partial O_3) + \Delta CO_2\,(\partial\Gamma/\partial CO_2)$$

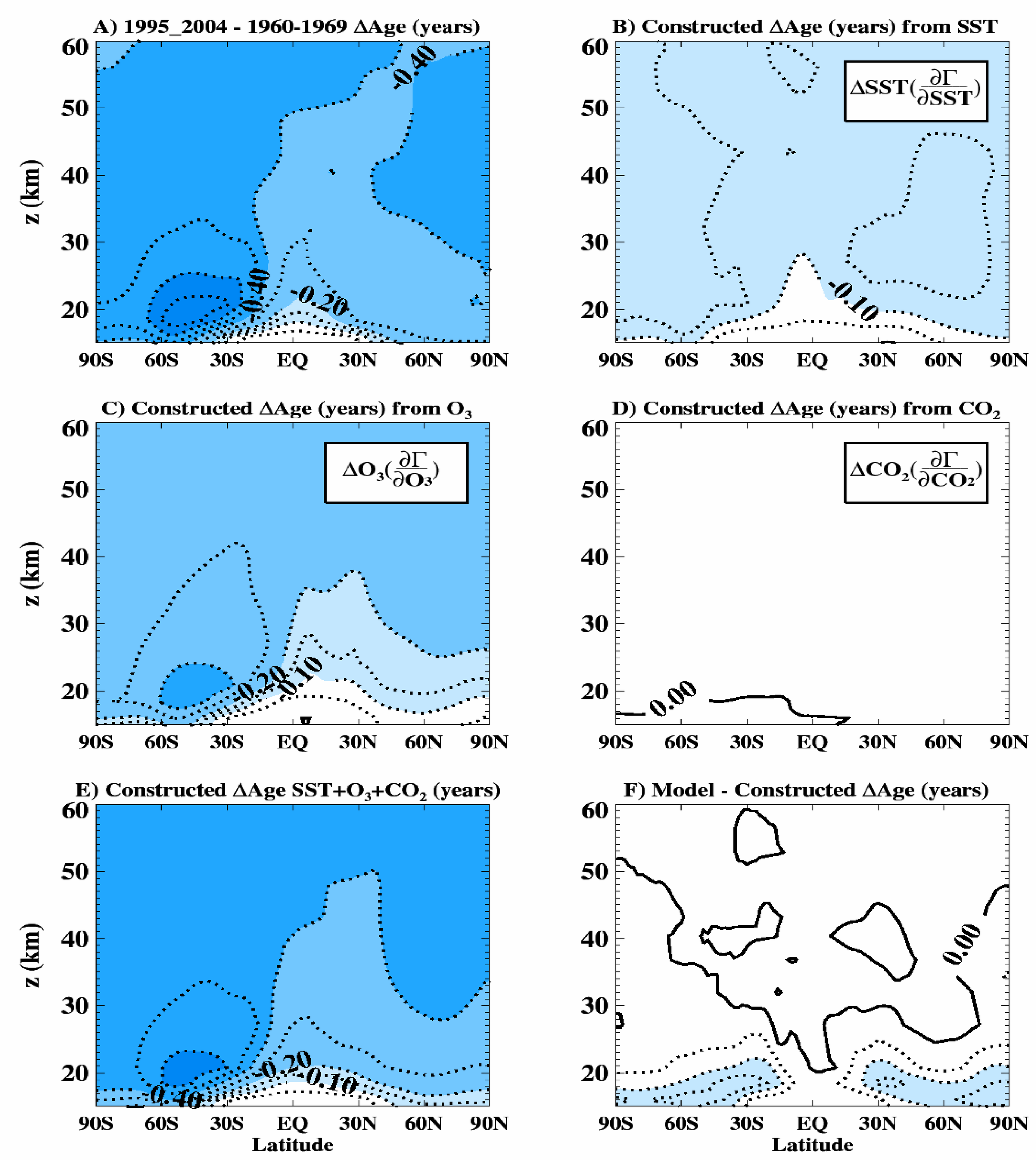

Figure 5. A) Change in model mean age (years) from 1965-2000. B),C), and D) show the individual influences of SSTs, O_3, and CO_2 respectively. E) shows the sum of the components and F) is the difference with respect to the model.

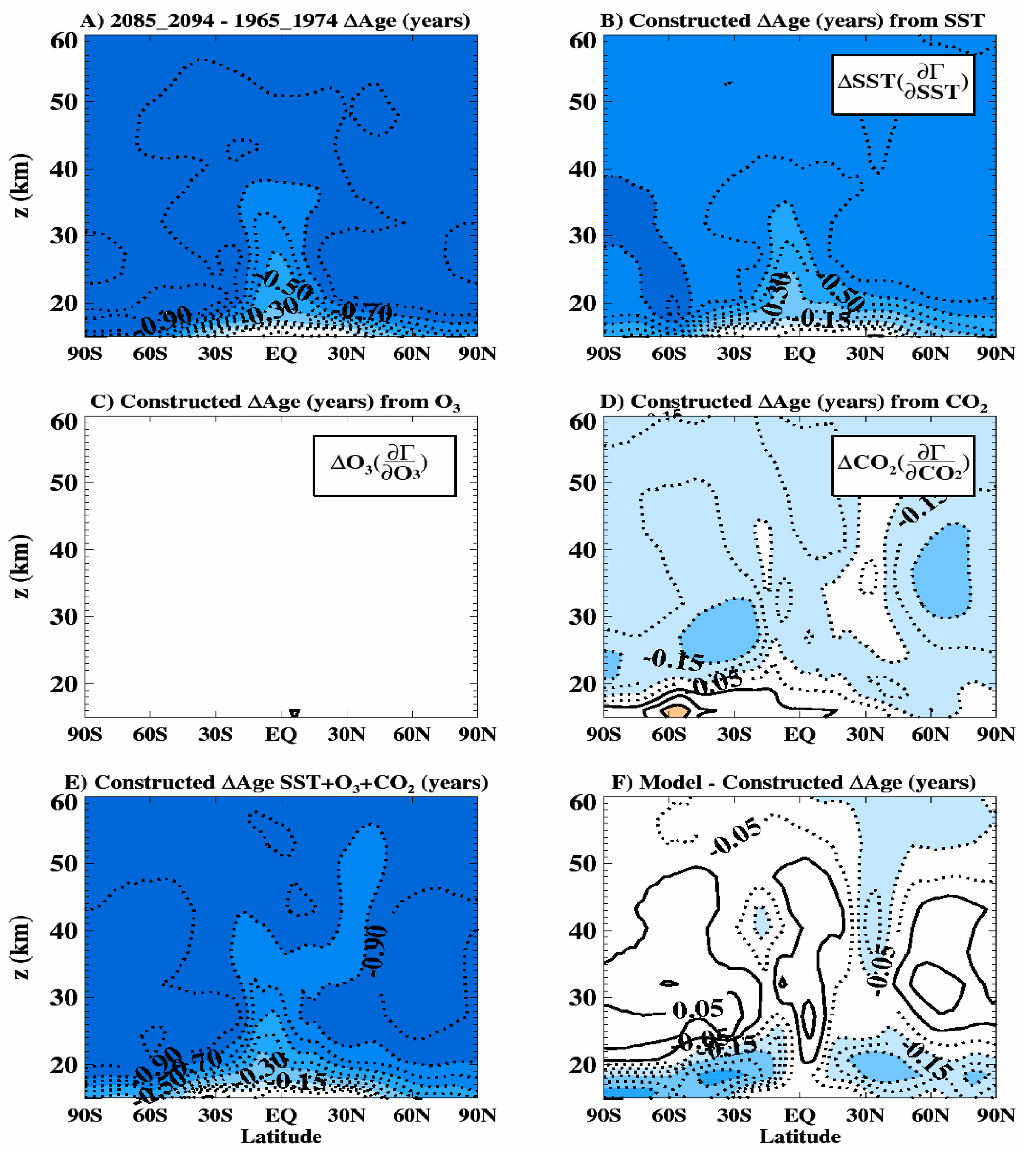

Figure 6. A) Change in model mean age (years) from 1970-2090. B),C), and D) show the individual influences of SSTs, O_3, and CO_2 respectively. E) shows the sum of the components and F) is the difference with respect to the model.

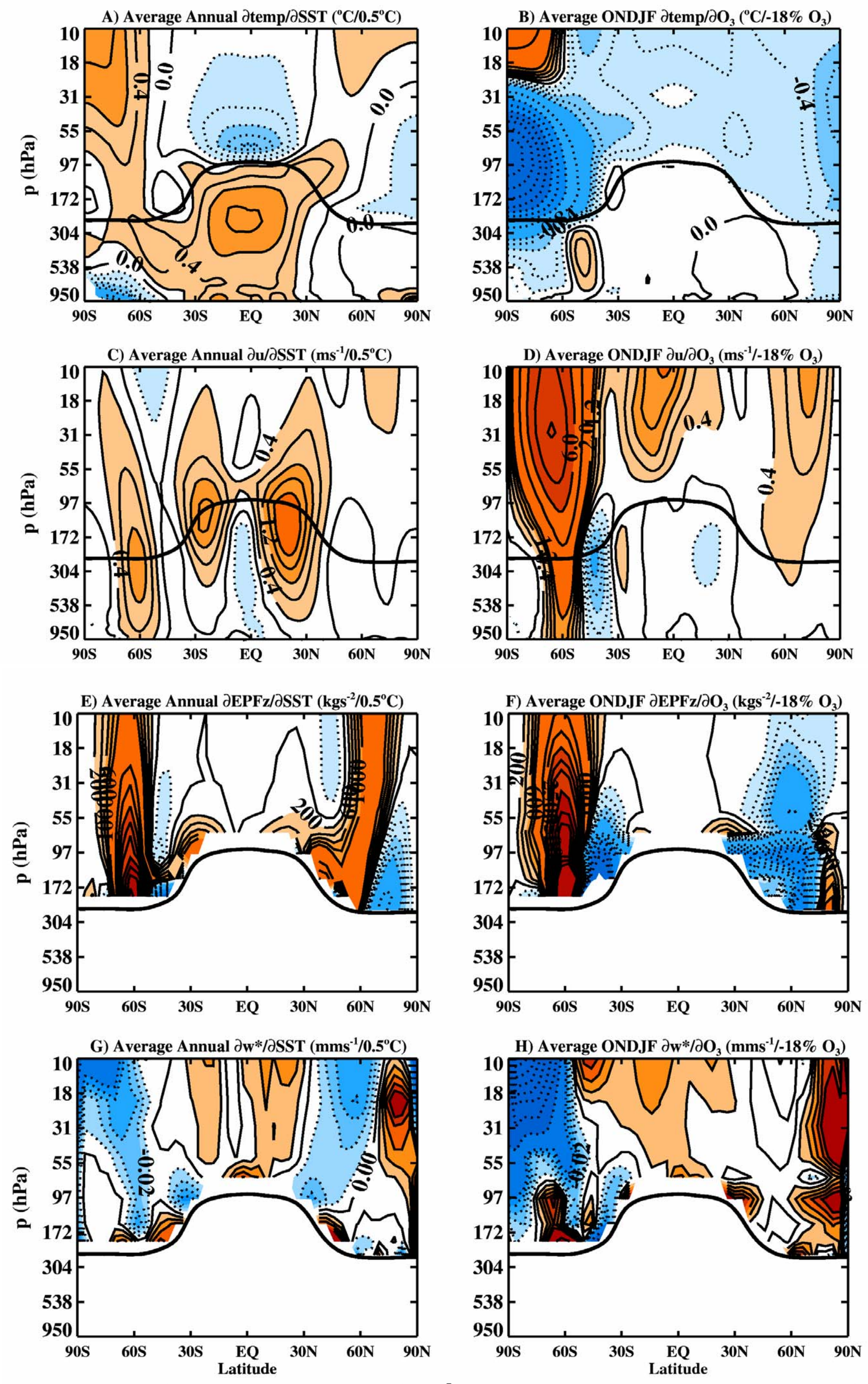

Figure 7. Annual Changes caused by 0.5 °C increase in tropical SSTs (left) and ONDJF changes caused by 18% decrease in polar ozone (right) from the same cases used in Table 2 for mean age for A) and B) Temperature, C) and D) zonal mean zonal wind, E) and F) vertical component of E-P Flux, and G) and H) residual vertical velocity.

Helping to Explain Differences Among CCMs

This new understanding of factors impacting the circulation of the stratosphere can help explain the large differences seen in Butchart et al. (2006) survey of chemistry climate models.

Models with fixed SSTs had the lowest rate of mass flux increase, whereas models that simulated 2x CO_2 conditions

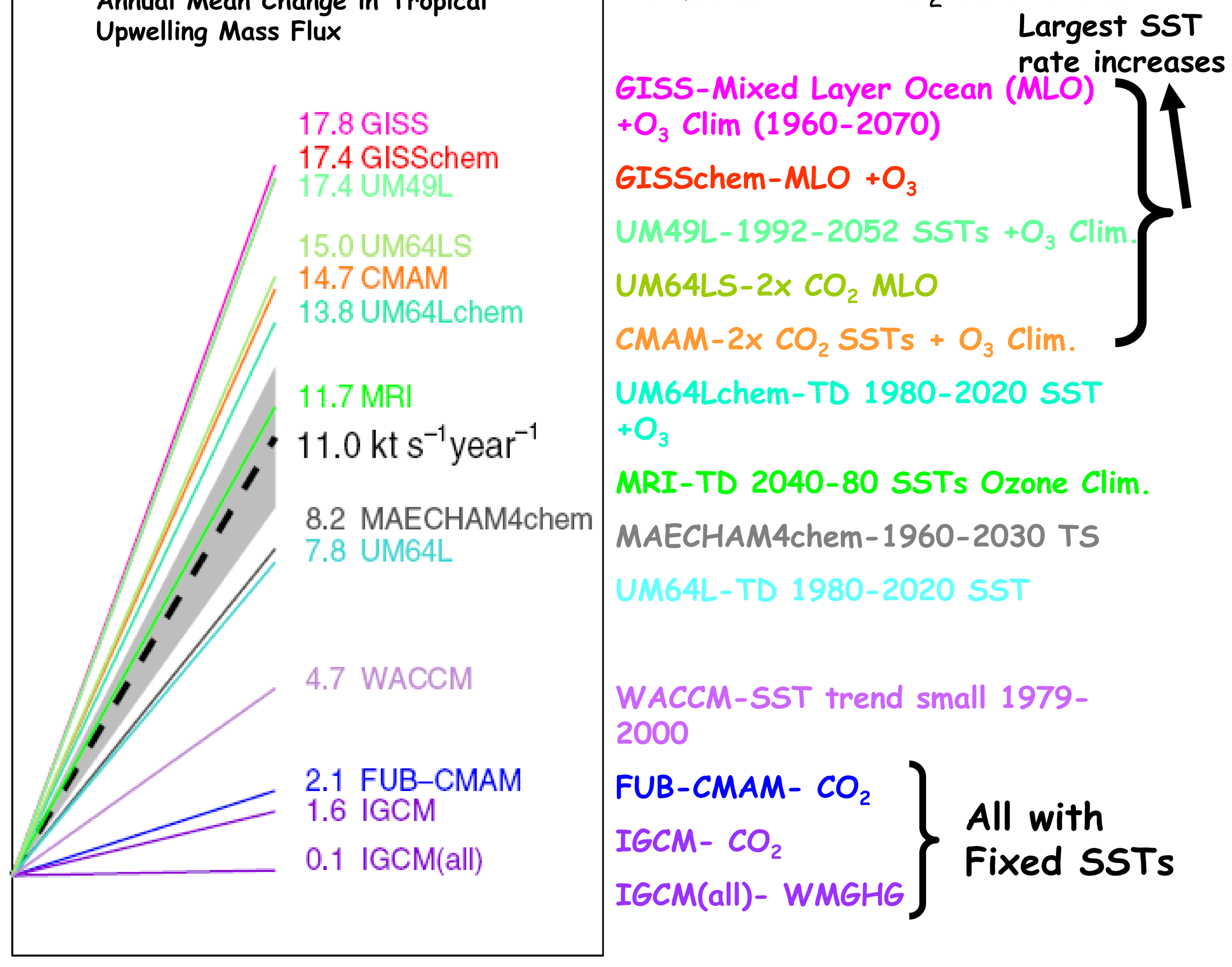

Figure 8. Annual mean change in upwelling mass flux from Butchart et al. (2006) with forcings for each simulation.

or simulations that extend to mid-late 21st century, which has higher than average SST increases had the highest increase in mass flux rates.

Conclusions

- Model simulations show a significant increase in stratospheric circulation (e.g. younger mean age) over time.
- Changes in tropical SSTs appear to be driving the largest change especially during the 21st century.
- Polar lower stratospheric ozone changes also significantly impact mean age.
- Model changes in stratospheric mean age can be reconstructed quite well by changes in SSTs, polar O_3, and CO_2.
- The effect of increasing SSTs from increasing WMGHGs is very important to include in simulations of stratospheric climate change causing large changes to the dynamics, chemistry, and radiation.
- This new understanding can help explain the large differences seen in upwelling mass flux among CCMs simulations shown in Butchart et al. (2006).

Acknowledgements

We would like to thank the NASA MAP program for supporting this research.
For more information e-mail Luke Oman: oman@jhu.edu

References

Butchart, N., et al. (2006), Simulations of anthropogenic change in the strength of the Brewer-Dobson circulation, *Clim. Dyn.*, doi:10.1007/s00382-006-0162-4.