Evidence for Changes in Stratospheric Transport and Mixing Over the Past Three and a Half Decades

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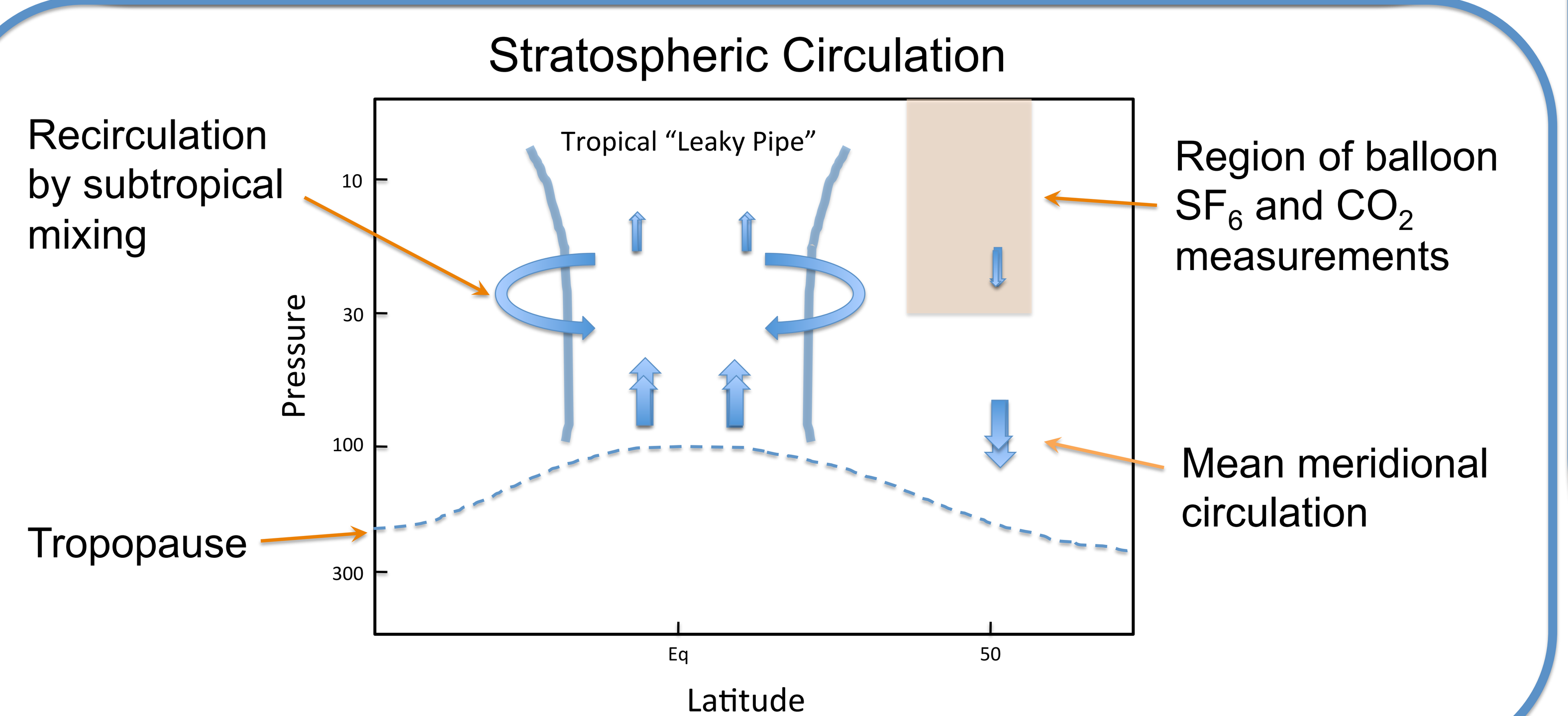
Why do we care about stratospheric circulation changes?

The stratospheric mean meridional, or Brewer-Dobson, circulation and horizontal mixing between the tropics and extratropics impact polar ozone depletion and determine the distribution of radiatively important trace gases within the stratosphere. Both the mean stratospheric circulation and horizontal mixing are driven by wave activity generated in the troposphere primarily by extratropical weather patterns, the strength and position of the subtropical jets and tropical convective activity. Thus, changes in the stratospheric circulation not only affect important processes in the stratosphere but are also an important indicator of changes in a variety of tropospheric processes.

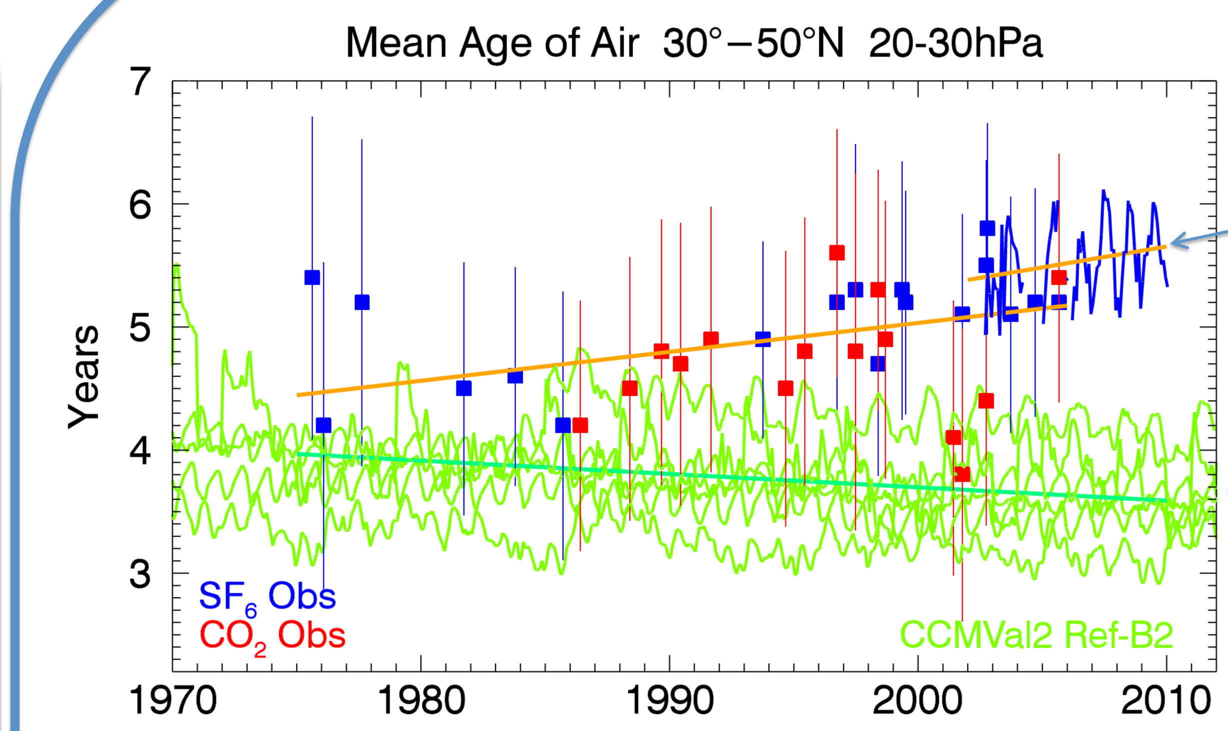
How is the stratospheric circulation measured?

It cannot be measured directly but can be inferred, for example, from measurements of certain trace gases such as SF_6 and CO_2 that have increasing concentrations in the atmosphere. From these trace gases the stratospheric age of air can be calculated. The age of air reveals characteristics of both the mean circulation and mixing as shown in the schematic below.



Observations and Reanalysis

Mean Age of Air

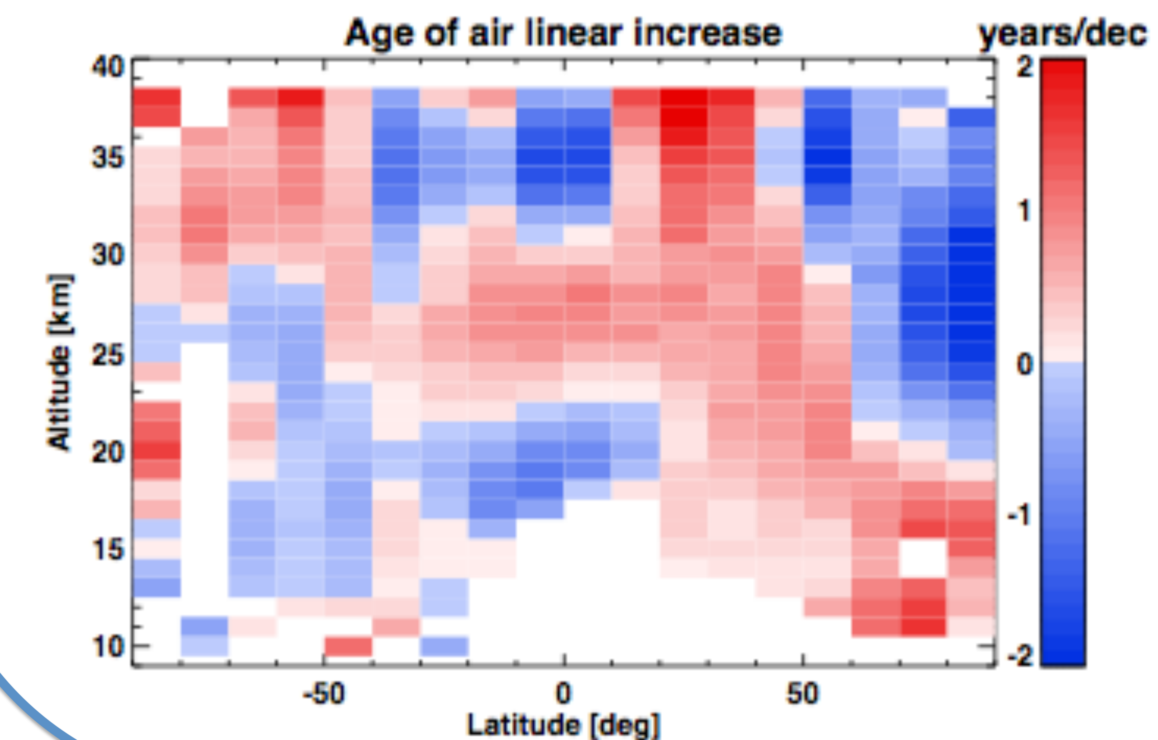


Squares are mean ages calculated from SF_6 and CO_2 balloon measurements (Engel et al., 2009) and the blue line is mean age from MIPAS satellite SF_6 measurements (Stiller et al., 2011). The green lines are six different model mean ages from CCMVal2 Ref-B2 output.

Observations
Linear increase of 0.24±0.22 years/decade (1975-2006) from balloons
0.6±0.1 years/decade (2002-2010) from MIPAS

Models
Linear decrease of -0.1 (range of -0.06 to -0.16) years/decade (1975-2010)

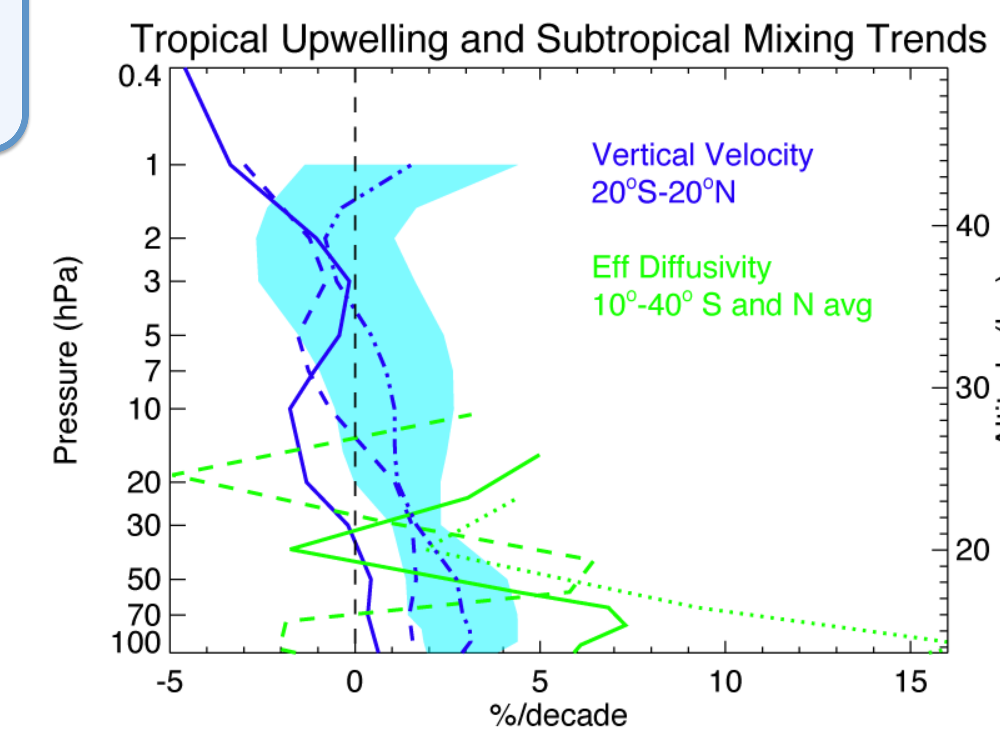
Large discrepancy!
Small part may be explained by use of linearly increasing tracer to calculate age in CCMs (Garcia et al., 2011).



MIPAS mean age linear changes throughout the stratosphere shown at left reveal a complicated pattern of increases in certain regions and decreases in others.

Comparison of these patterns to model results will provide an important new constraint on modeled stratospheric circulation changes.

Trend Profiles From Reanalyses and CCMs



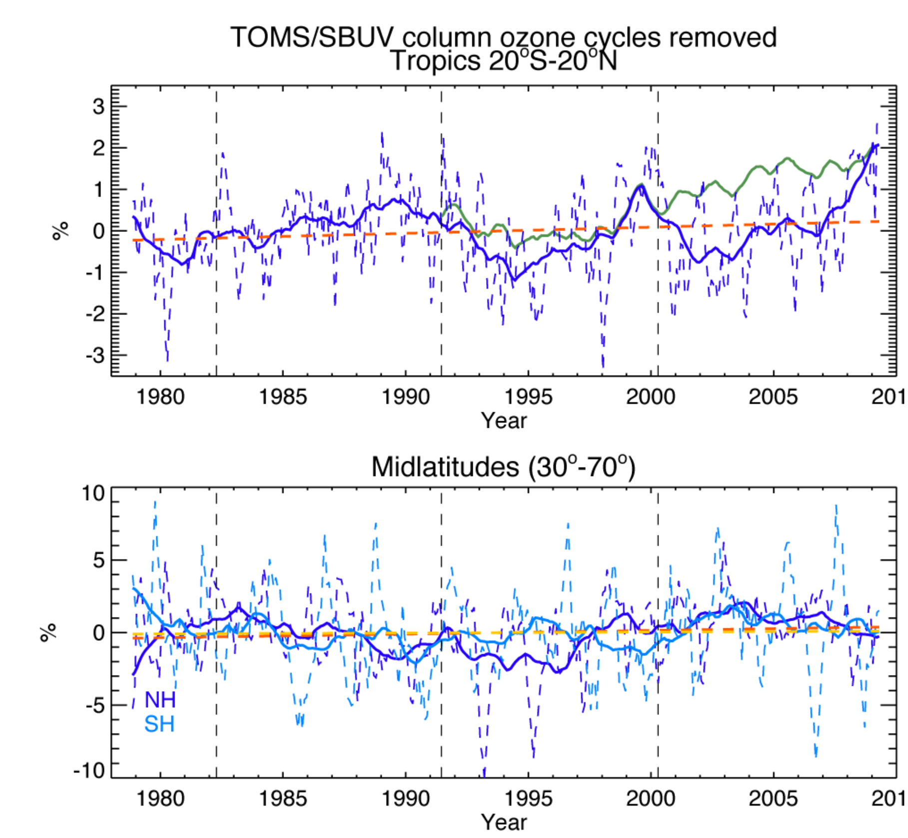
Solid lines = JRA-25, Dashed lines = ERA-40, Dotted line = NCEP Reanalysis
Dash-dot-dot line = CCMVal-2 nine model average, shading is model spread

Tropical upwelling trends: Positive in lower strat, Negative in upper strat for the reanalyses and most models.

Effective diffusivity in the subtropics is used as a diagnostic of mixing across the tropical pipe edge.

Subtropical mixing trends: Positive in most of the lower stratosphere in the reanalyses.

Total Ozone



Total ozone variability is driven by a variety of transport processes on a range of time scales.

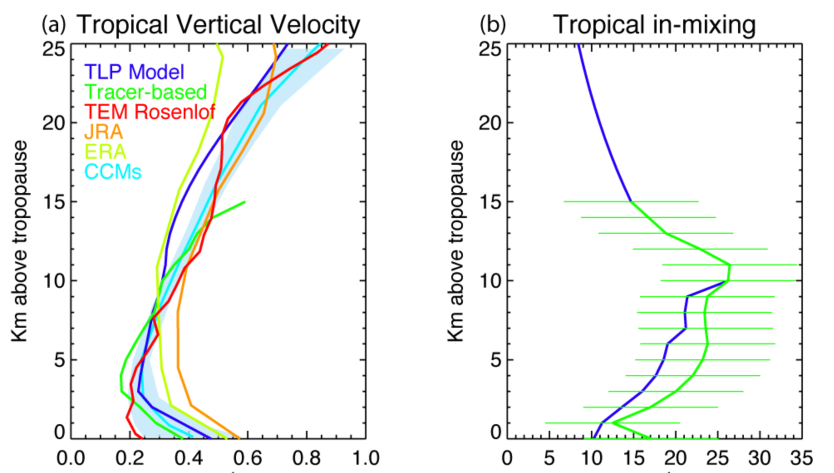
We identify the "residual" total ozone trends due to circulation and mixing changes by using multiple linear regression to remove QBO, ENSO, EESC, solar cycle and volcanic aerosol variability.

The residual trends are slightly positive in both regiions.

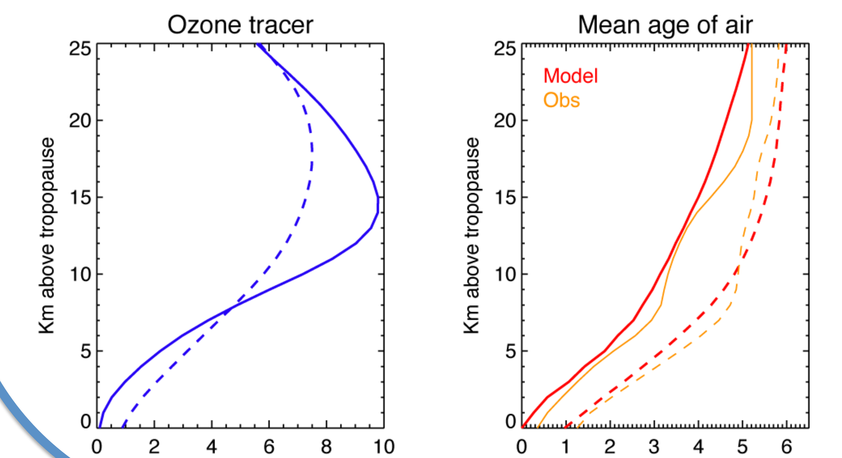
TLP Model Basics

Three coupled 1-D regions including advection, mixing, diffusion and photochemistry [Neu and Plumb, 1999].

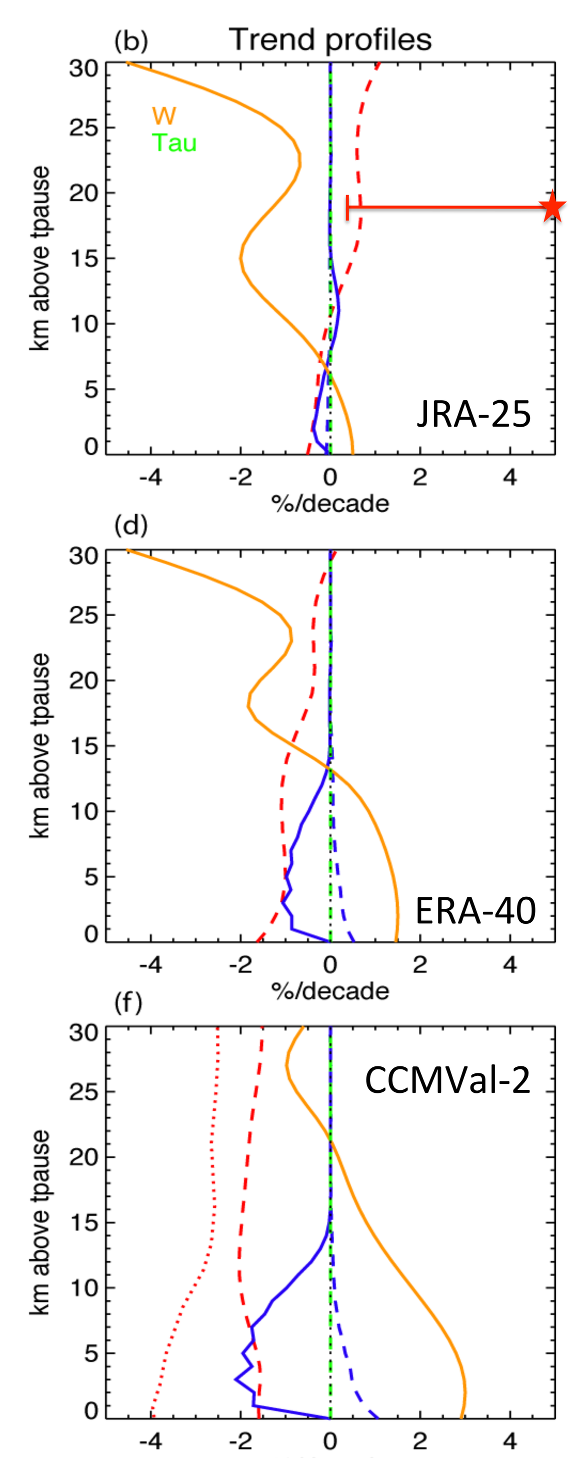
For inputs we use observationally based profiles for vertical velocity and in-mixing rate and an ozone tracer is initialized with SAGE average tropical and mid latitude profiles.



Outputs are time series of tropical and mid latitude mean age and ozone profiles, from which linear trends are calculated.



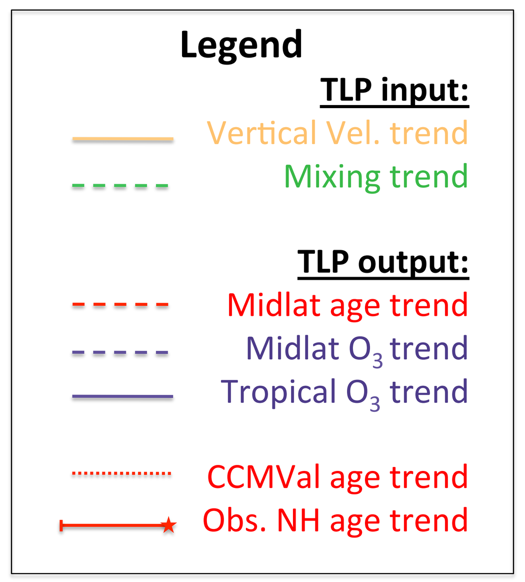
Tropical Leaky Pipe Model Results



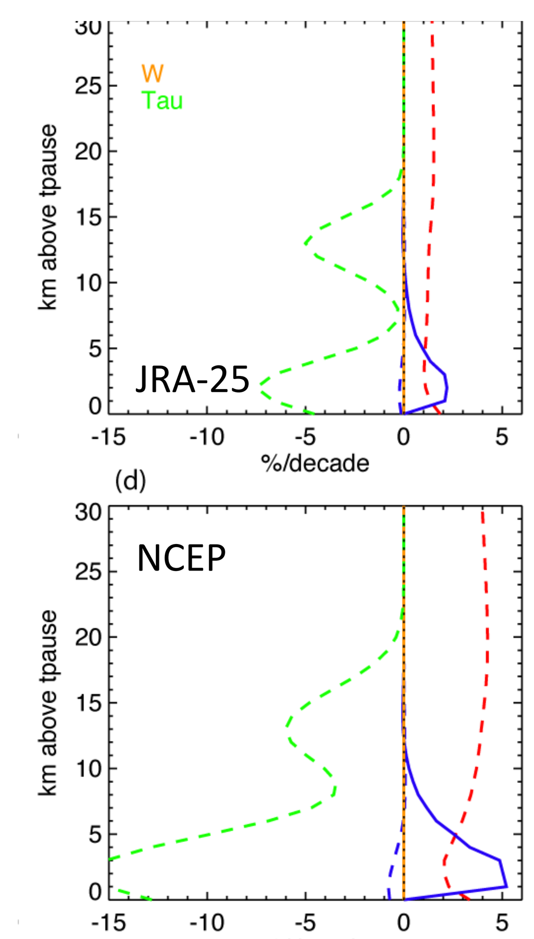
Output with Reanalysis and CCMVal vertical velocity (w) trends – mixing (τ) constant

Larger positive w trends seen from top to bottom result in larger negative mean age and tropical lower stratospheric ozone trends.

Note that mean age trends from CCMVal models (dotted red line on bottom plot) are more negative than TLP model trends.



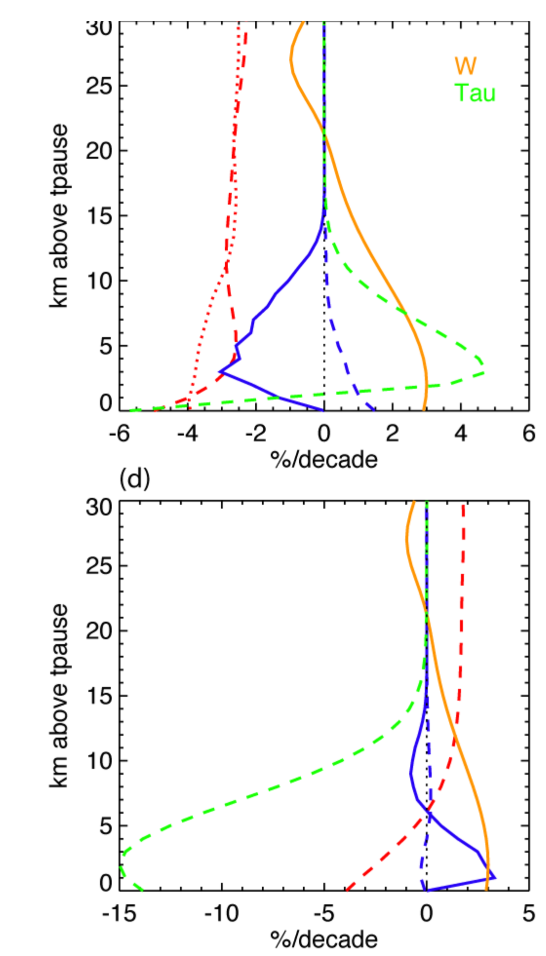
Output with Reanalysis mixing trends – w constant



Larger positive mixing (negative τ) trends seen from top to bottom cause larger positive mean age and tropical ozone trends.

4.2%/dec mean age trend roughly as large as observed, but tropical total ozone trend is much larger than observed.

Output with CCMVal w trends - theoretical mixing trends



Top plot shows inferred mixing trend profile such that the TLP model and CCMVal age trends match.

Bottom plot shows NCEP-like mixing trend reverses the sign of the CCMVal mean age and tropical ozone trends from negative to positive.

Conclusions

- Observed indicators of stratospheric circulation changes disagree with simulated changes from CCMs.
- Recent MIPAS measurements greatly enhance our ability to "observe" the variability of the stratospheric circulation.
- Simulations with the TLP model show that it is possible to have mean circulation and mixing trends in the stratosphere that are consistent with the observed NH mean age and total ozone "residual" trends.
- The discrepancy between CCM and observed mean age trends may be largely due to inadequately modeled mixing trends.

References

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Garcia, R. R., Randel, W. J., and Kinnison, D. E.: On the determination of age of air trends from atmospheric trace species, J. Atmos. Sci., 68, 139–154, 2011.
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