Why does the stratosphere get moister during the 21st century?

A. E. Dessler[1], M. R. Schoberl[2], H. Ye[1], T. Wang[3], L. Oman[4], A. R. Douglass[4]

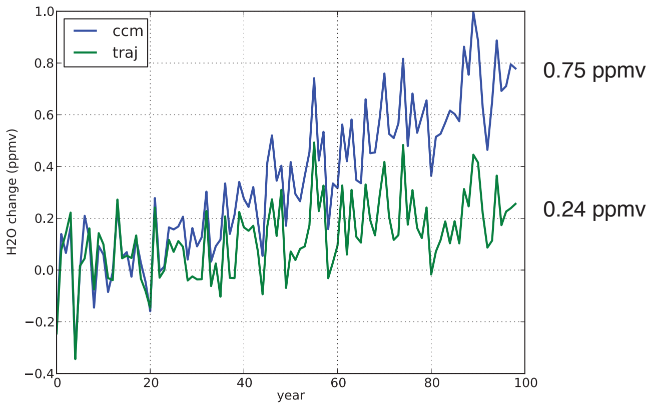
[1] Department of Atmospheric Sciences, Texas A&M University, [2] Science and Technology Corporation, [3] NASA Jet Propulsion Laboratory, [4] NASA Goddard Space Flight Center

Summary:

- **Models uniformly predict that air entering the stratosphere will become moister over the 21st century**
- **It's generally assumed this is due to a warming tropopause**
- **We show here that it's not — in one model at least. Rather, it's due to increased evaporation of lofted ice.**

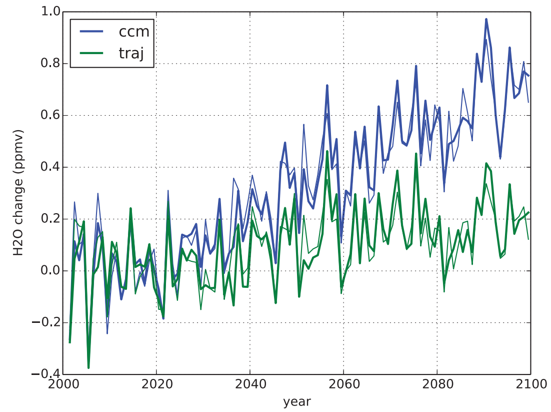
Data and Methods:

- Run RCP6 simulation of the 21st century in Goddard CCM; analyze water vapor in the tropical lower stratosphere
- Winds from the GEOSCCM are also used to drive a trajectory model, which produces another estimate of tropical lower stratospheric water vapor
  - The trajectory model regulates stratospheric water vapor through large-scale TTL temperatures only
- Thus, differences between GEOSCCM and trajectory model indicate processes other than tropopause temperature regulating stratospheric water vapor in the model

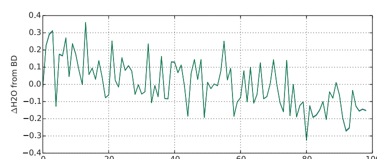


- This plot shows 85-hPa, 30°N-30°S, annual average H2O (relative to 2000-2010 avg.) over the 21st century
- The increase in the trajectory model is only 1/3rd that of the GEOSCCM
- We conclude that the trajectory model is missing physics
- In other words, processes other than tropopause temperatures are responsible for most of the increase

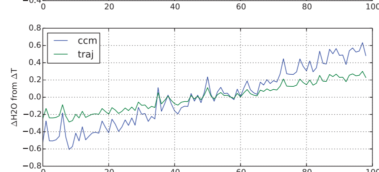
- So what are these other processes? To determine them, we first fit both time series to the following linear regression model:
- H2O = a BD + b ΔT
- BD = Brewer-Dobson index (85-hPa tropical heating rate)
- ΔT = temperature of the troposphere (500-hPa tropical avg. temperatures)
- Previous work (Dessler et al., PNAS, 2013) showed that this regression model accurately reconstructs the CCM's water vapor



- The thicker lines are the water vapor predictions from the GEOSCCM and trajectory models
- The thinner lines are the reconstructions from the regression model
- As is apparent, the regression model does an excellent job reconstructing the two time series; R^2 of the regression models are 0.95 and 0.81 for the CCM and trajectory regressions, respectively



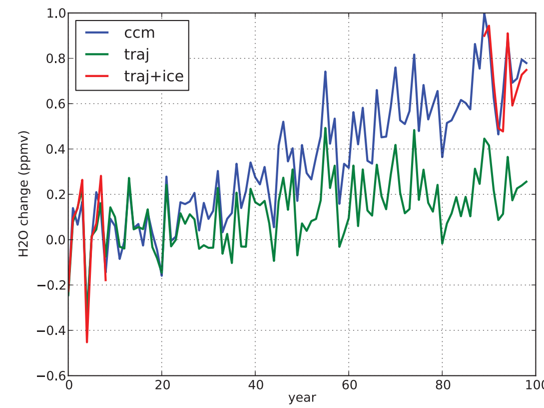
- Brewer-Dobson components of the fit are essentially identical, as expected



- The difference between the CCM and trajectory runs are in the ΔT components

We conclude from this:
- Trajectory model is missing physics
- The missing physics is responsible for 2/3rds of the increase in strat. H_2O over the 21st century
- Missing physics correlates w/ troposphere temperatures

- But this still does not tell us what the missing physics is
- One possibility is a trend in moistening from lofted ice; such a trend could be decoupled from a trend in tropopause temperatures
- The GEOSCCM tracks convective ice separately
- We modify the trajectory model to account for this
  - on each time step of each trajectory, we add any convective ice at the parcel's location and time to the parcel
  - we do not allow the parcel's relative humidity to exceed 100%
- We have 6-hourly convective ice for two decades: 2000-2010 and 2090-2100



Conclusions

- About 1/3rd of the trend in stratospheric water vapor over the 21st century in the GEOSCCM is due to a warming tropopause
- The other 2/3rds is due to missing physics that correlates with tropospheric temperatures
- There is strong evidence that ice lofting is the missing physics