CCMI WACCM:
Model Development and Evaluation

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WACCM Working Group, Boulder,
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WACCM Whole Atmosphere Community Climate Model

Major WACCM Updates Since CCMVal2

- Interactive ocean for all REFC2 and SENC2 simulations.
  [Marsh et al., *J of Climate*, 2012.]

- Updated polar heterogeneous chemistry (NAT, STS, Water-Ice).
  [Wegner et al., *JGR*, 2013, Solomon et al., *JGR*., 2015.]

- Improved representation of polar stratosphere temperatures and winds.
  [Garcia et al., *in prep*, 2016.]

- Improved representation of volcanic heating.
  [Randel et al., *in prep*, 2016]

- Enhanced tropospheric chemistry (total of 164 species and 450 reactions).
  [Tilmes et al., *in review*, 2016; Kinnison et al., *in prep*., 2016]

- Improved representation of polar SMLT NOY.
  [Marsh et al. *in prep*, 2016]

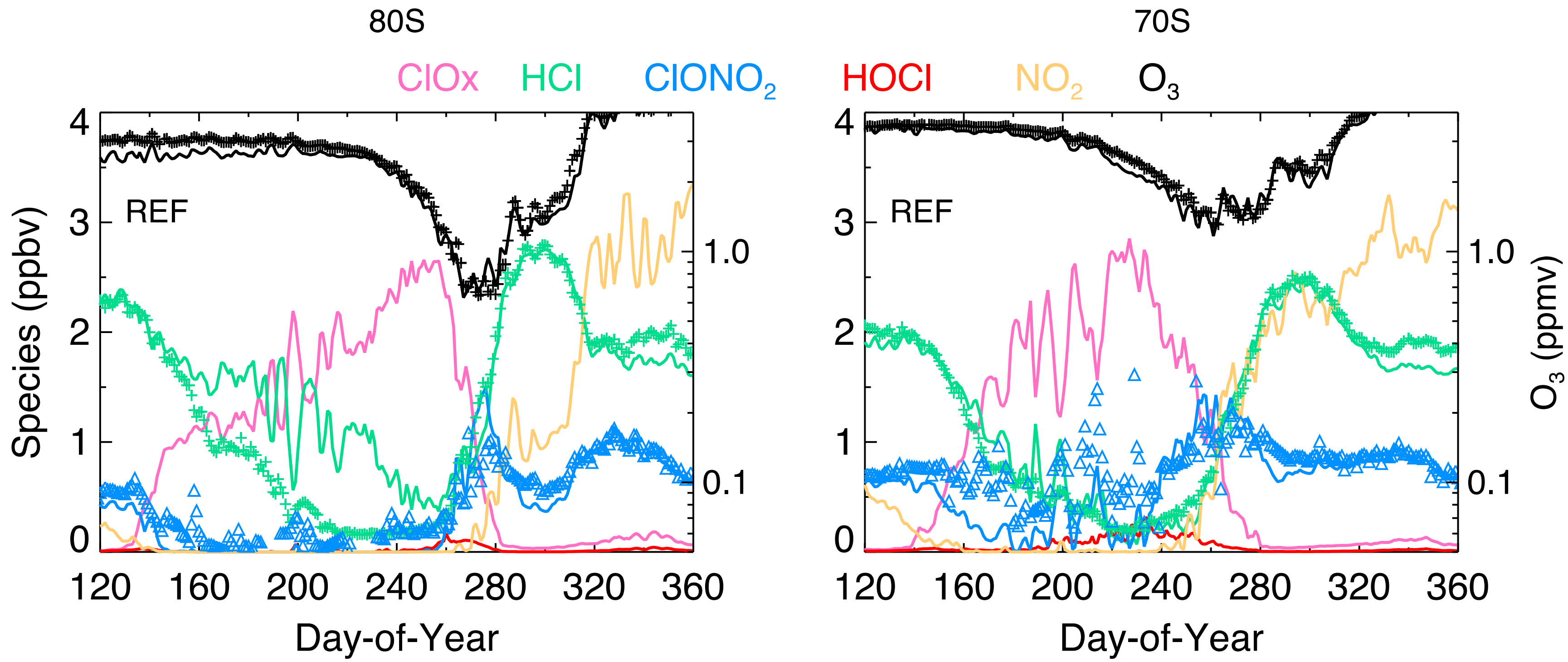
CESM1-WACCM4 CCMI Simulations: Status

Scenario	Period	Ocean	RCP	Members	CMOR#
REFC1	1955-2014	Data	-	5	Done
REFC1-PI	1850-1960	Data	-	1	-
REFC1SD	1979-2014	Data	-	1	Done
REFC2	1960-2100	Interactive	RCP6.0	3	Almost…
SENC2	2001-2100	Interactive	RCP4.5	1	-
SENC2	2001-2100	Interactive	RCP8.5	3	-
SENC2-fGHG1960	1960-2100	Interactive	RCP6.0	1	-
SENC2-fODS1960	1960-2100	Interactive	RCP6.0	1	-
SENC2-fODS2000	2000-2100	Interactive	RCP6.0	1	-
SENC2-nVSL	1955-2100	Interactive	RCP6.0	1	-

#CMOR'izing addressed by Simone Tilmes and Gary Strand.

All simulations are run with the TSMLT (chemistry). Horizontal resolution is 1.9ºx2.5º.
~1800 model years complete (6.3 million pe-hrs).

Evaluation of Stratospheric Chemistry (SD-WACCM / MERRA)

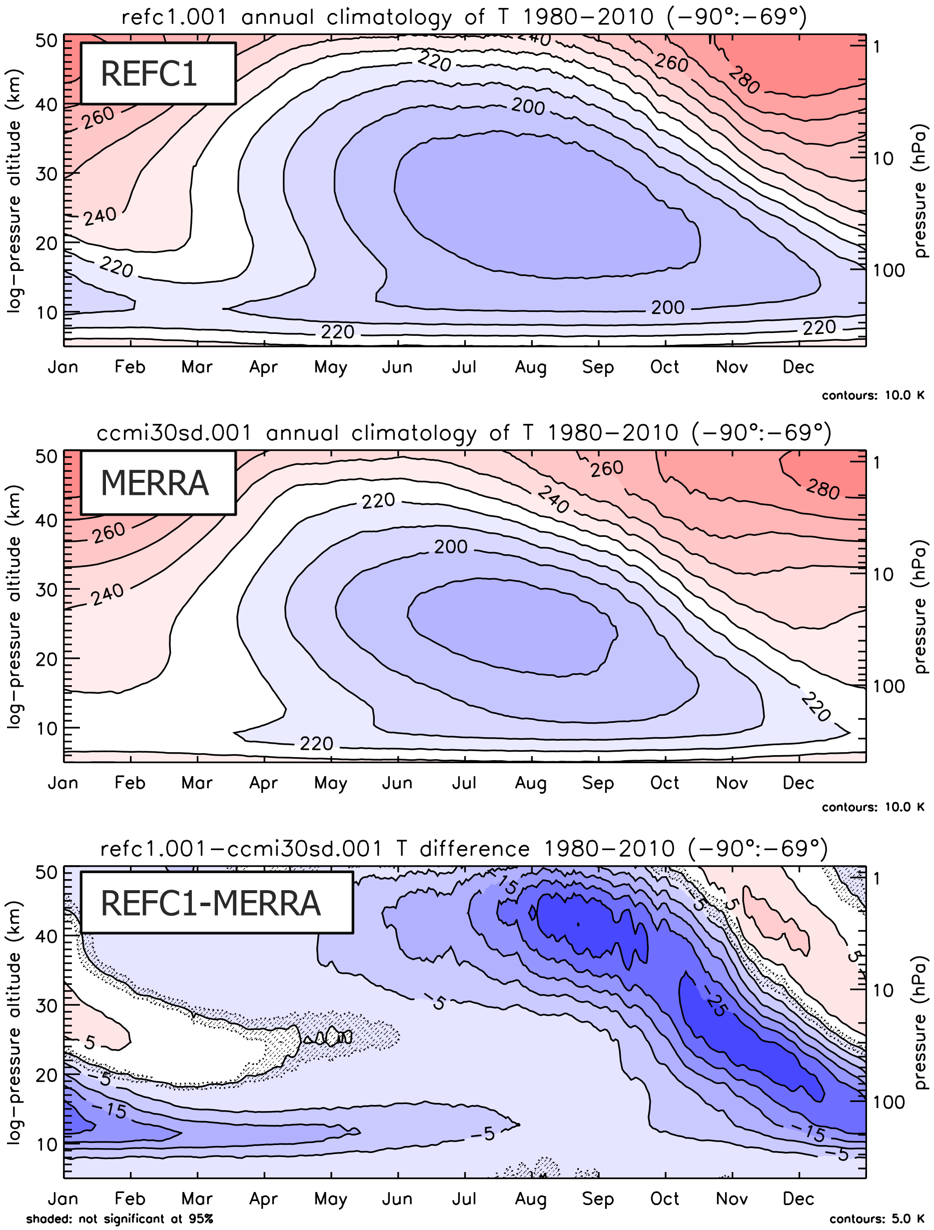


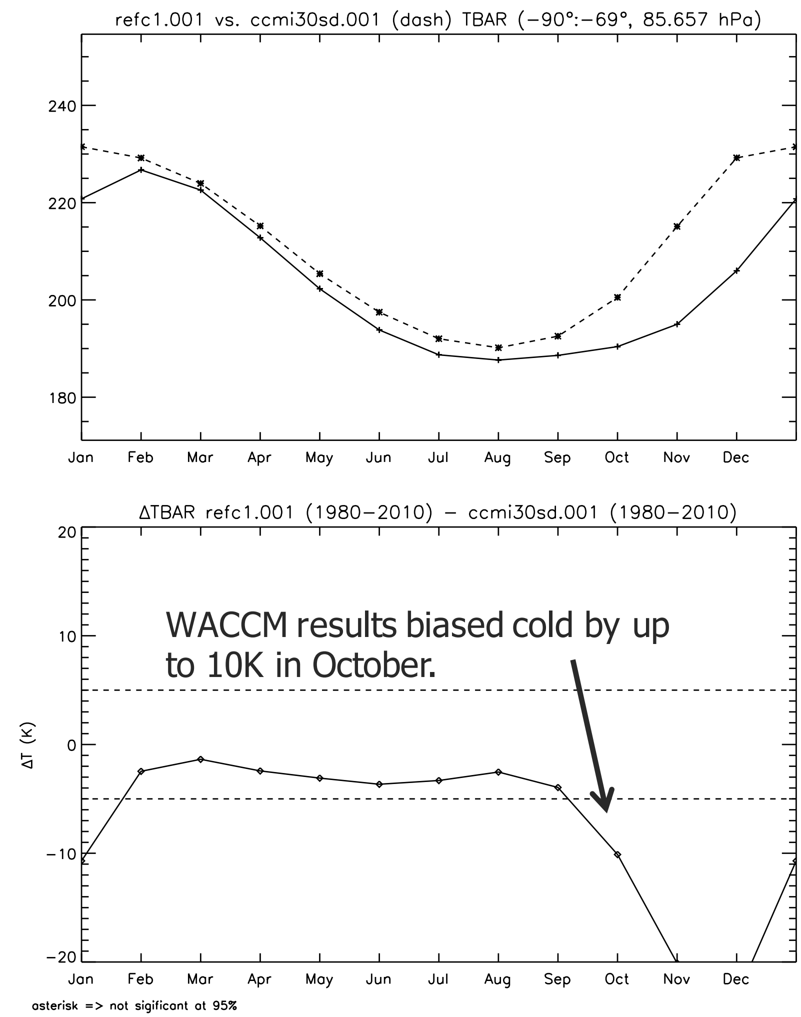
Amazing representation of stratospheric chemistry. Comparisons above are made with: Aura MLS (HCl, O_3); MIPAS ($ClONO_2$).

Wegner, T, D. E. Kinnison, R. R. Garcia, S. Madronich, and S. Solomon, Polar Stratospheric Clouds in SD-WACCM4, *J. Geophys. Res.*, VOL. 118, 1-12, doi:10.1002/jgrd.50415, 2013.

Solomon, S., D. E. Kinnison, J. Bandoro, R.Garcia, Simulations of Polar Ozone Depletion: An Update, *J. Geophys. Res.,* 120, 7958-7974, doi:10.1002/2015JD0233652015.

Temperature Bias in the SH Polar Region (90S-60S)





Figures Courtesy of R. Garcia, NCAR

CCMI: Changes to GW parameterization

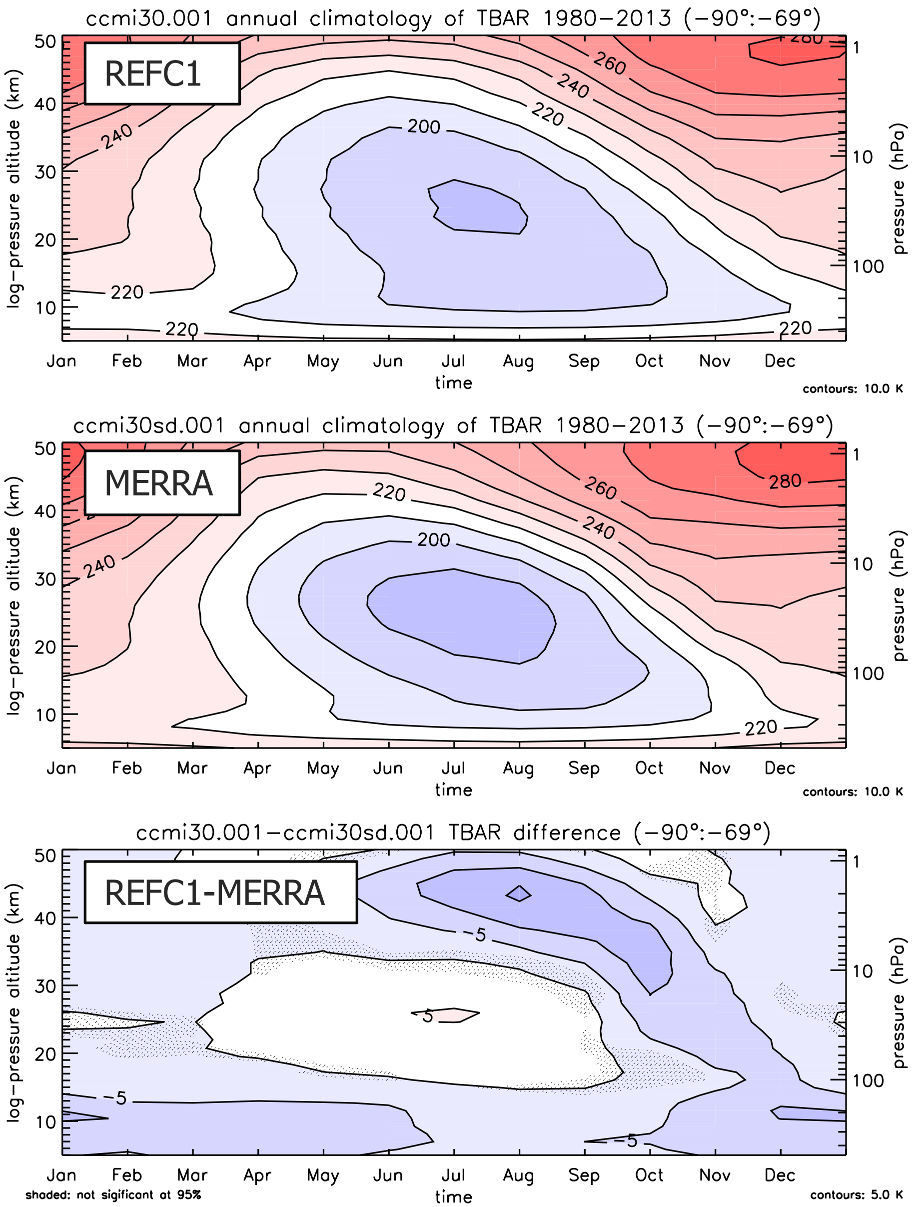
Orographic gravity wave modification (final approach)

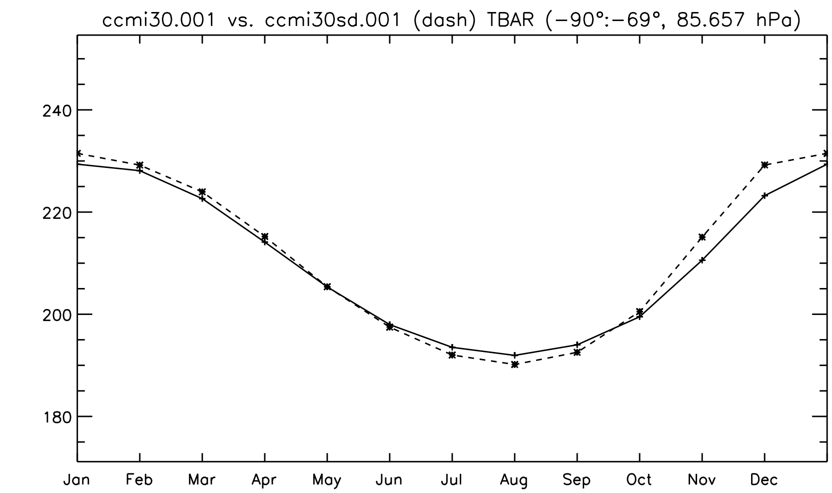
- two settings that adversely affected wave generation in the SH compared to the NH.
  - removed a parameter that de-emphasized the impact of islands relative to continental mountains.
  - added a parameter to account for the relative angle between the prevailing wind and the orientation of the dominant ridge line.

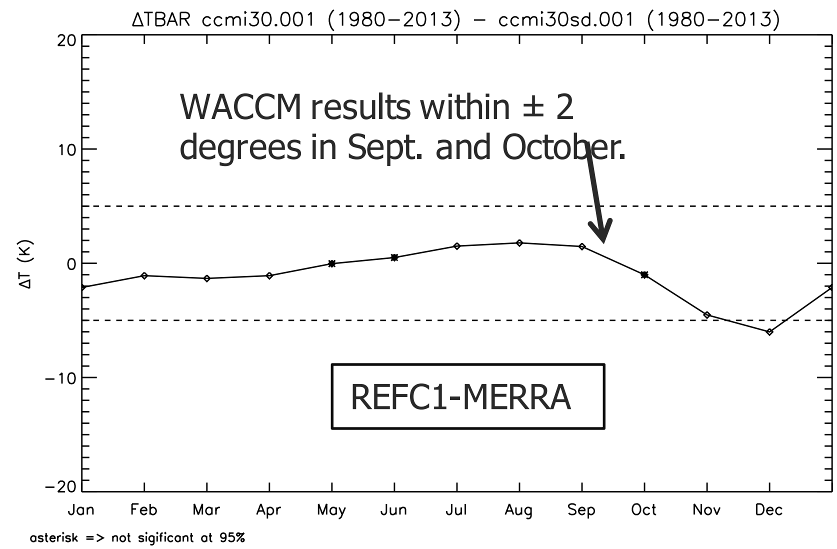
- the net impact of these changes is stronger orographic GW forcing in the winter SH stratosphere and lower mesosphere.

*** Implemented by A. Smith, currently used in all CCMI simulations ***

CCMI: Temperature Bias Reduced in the SH Polar Region (90S-60S)



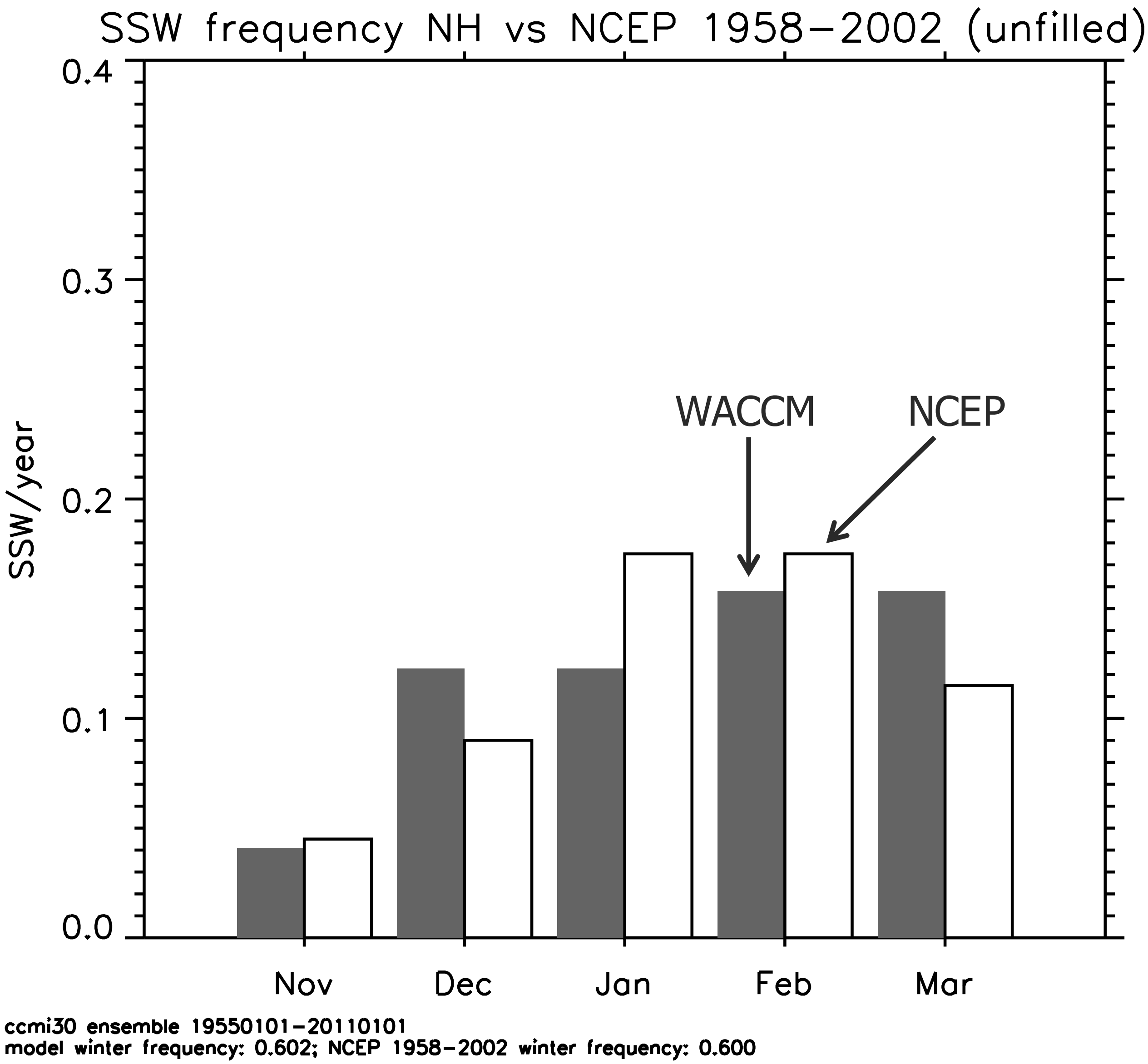




AKS, RG added Orographic GW modification.

Figures Courtesy of R. Garcia, NCAR

Northern Hemisphere Sudden Stratospheric Warming (SSWs)

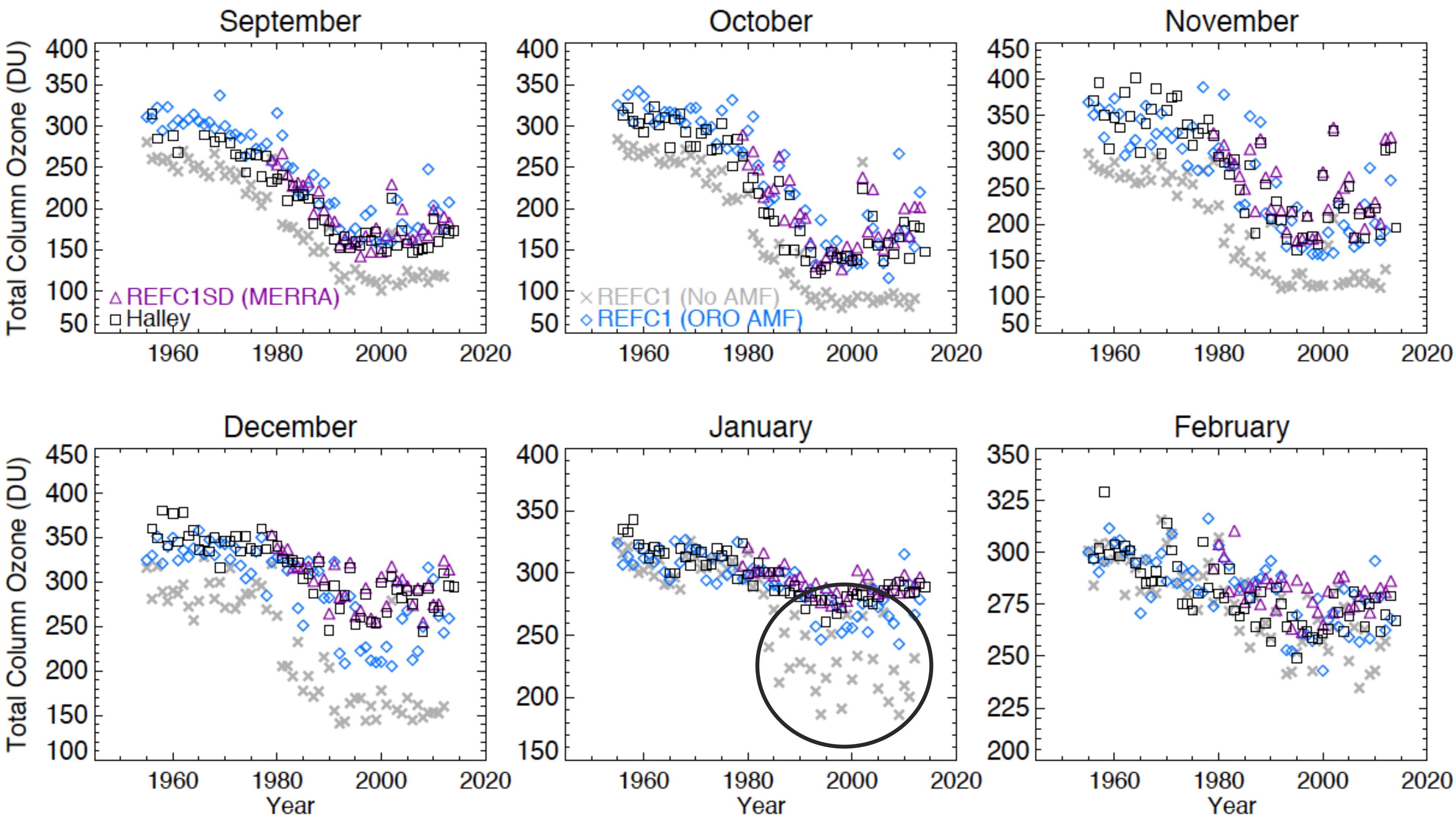


SSW definition:
zonal wind reversal at 10hPa, 60°N.

Excellent agreement between NCEP and REFC1 ensemble.

Garcia, et al., in prep., 2016.

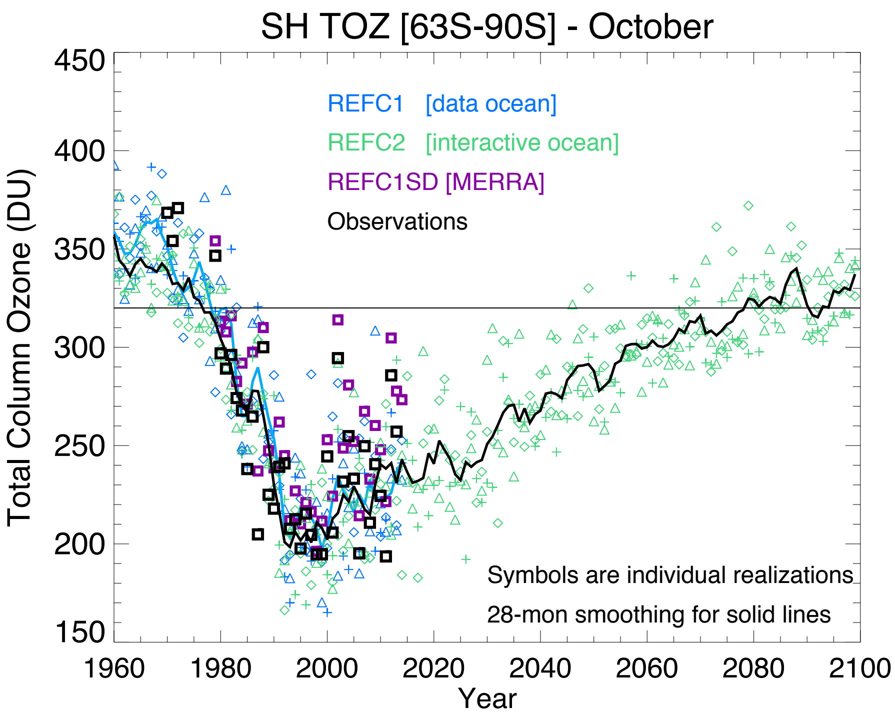
TOZ time series (1955-2014) *** Halley (75S)

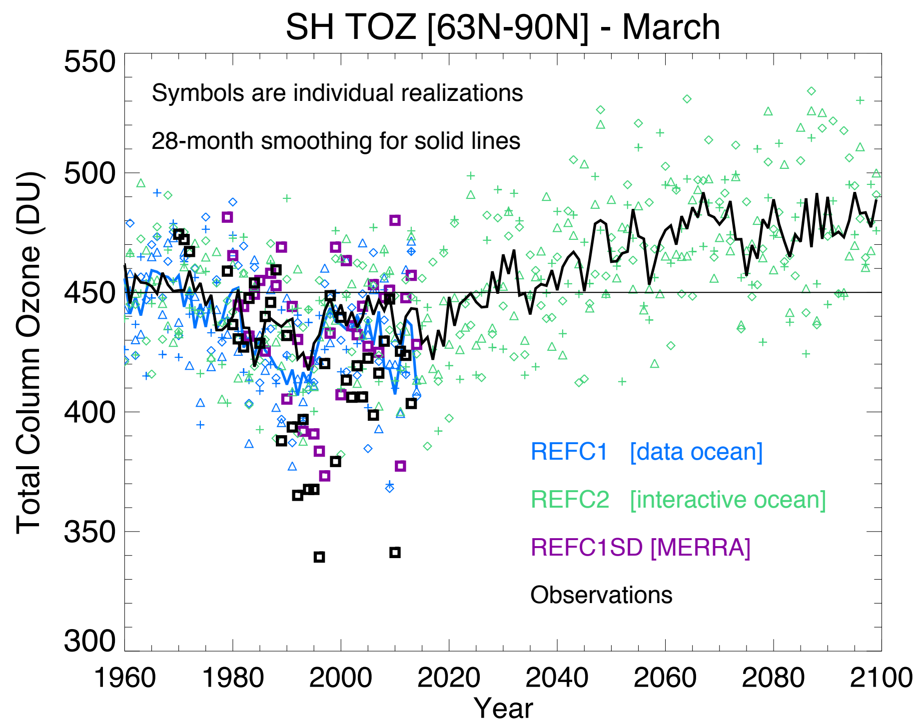


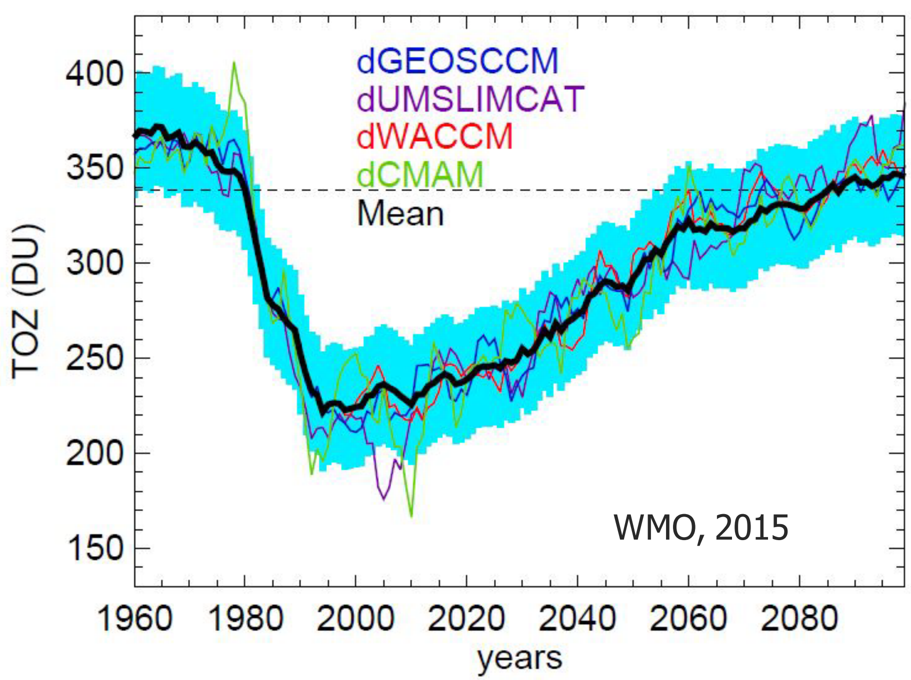
Conclusion:

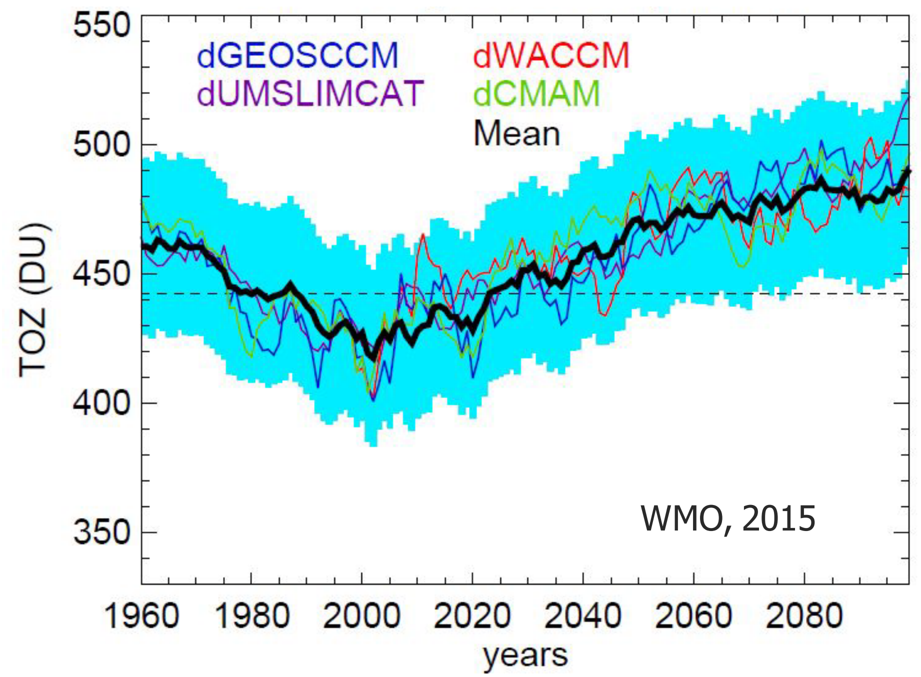
- With additional momentum forcing (AMF), SH polar vortex breaks up earlier.
- Ozone depletion in Sept and October are better represented.

TOZ time series (1960-2100)

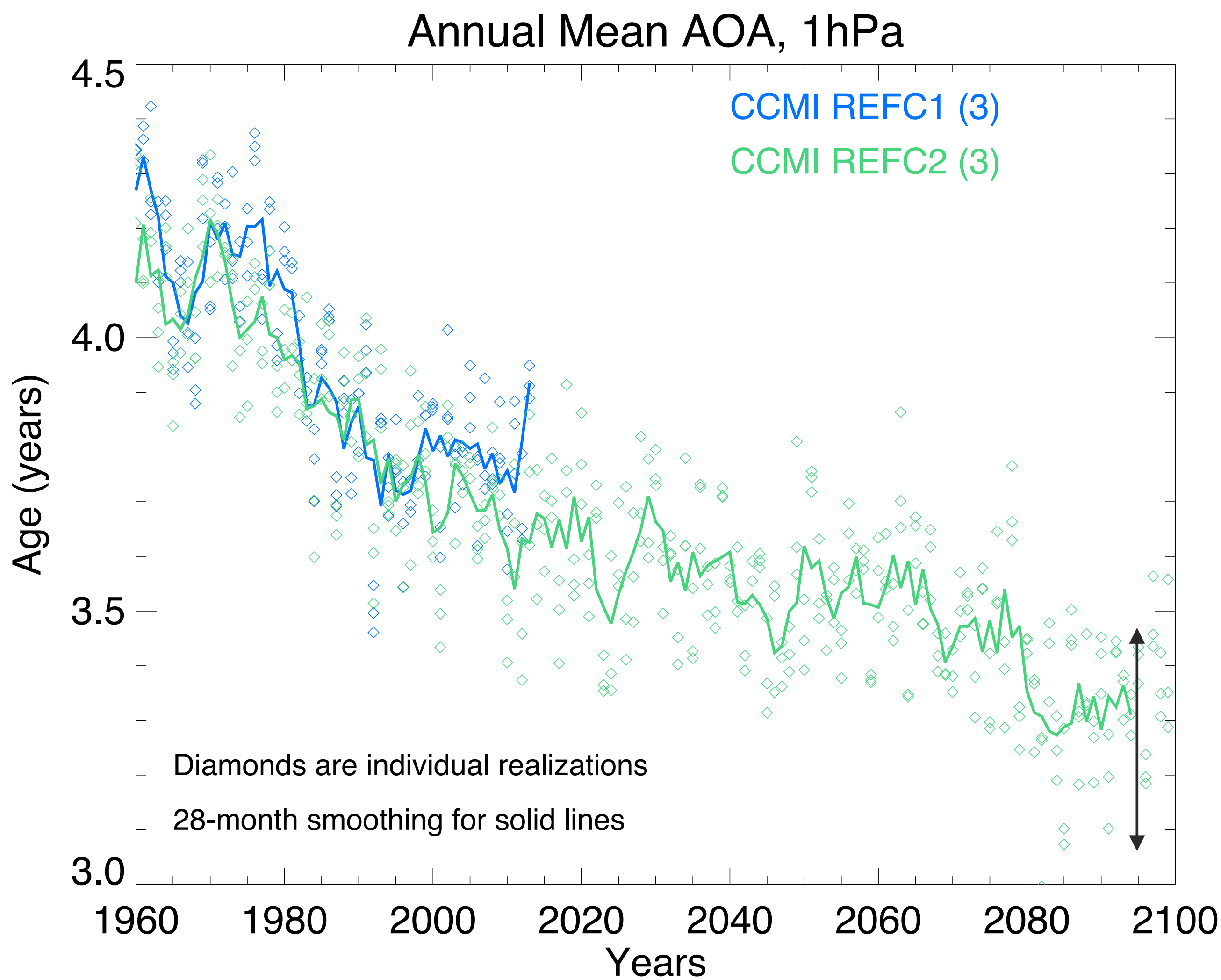








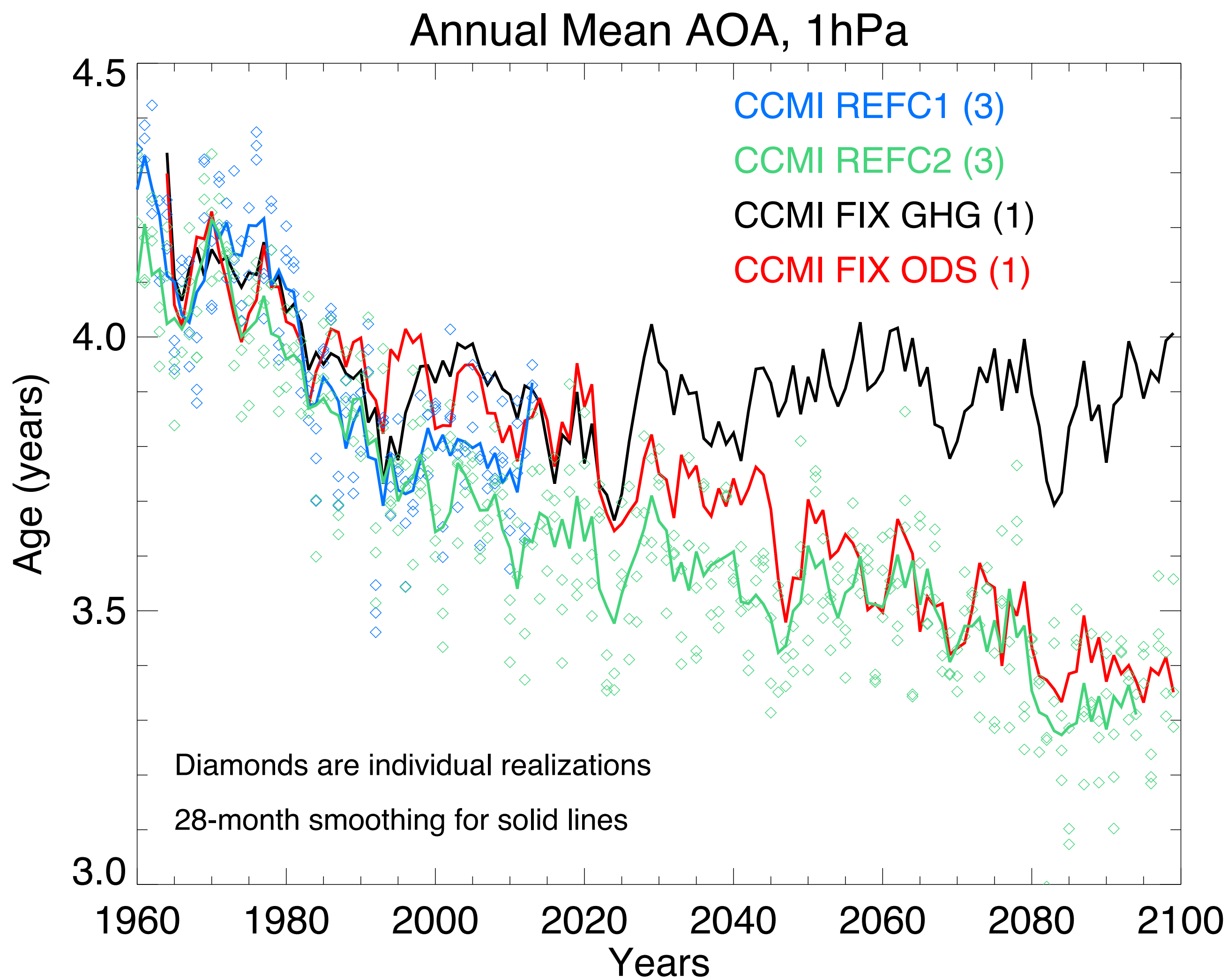
Mean Age Derived from a Linearly Increasing Tracer



Conclusion:

- The mean age <u>decreases</u> by ~1 year in the tropical upper stratosphere (1960-2100) consistent with a "speed up" of the Brewer-Dobson circulation.
- REFC1 (data ocean) and REFC2 (interactive ocean) results are consistent.
- Mean age variability across realizations is ~0.4 years (see arrow above).

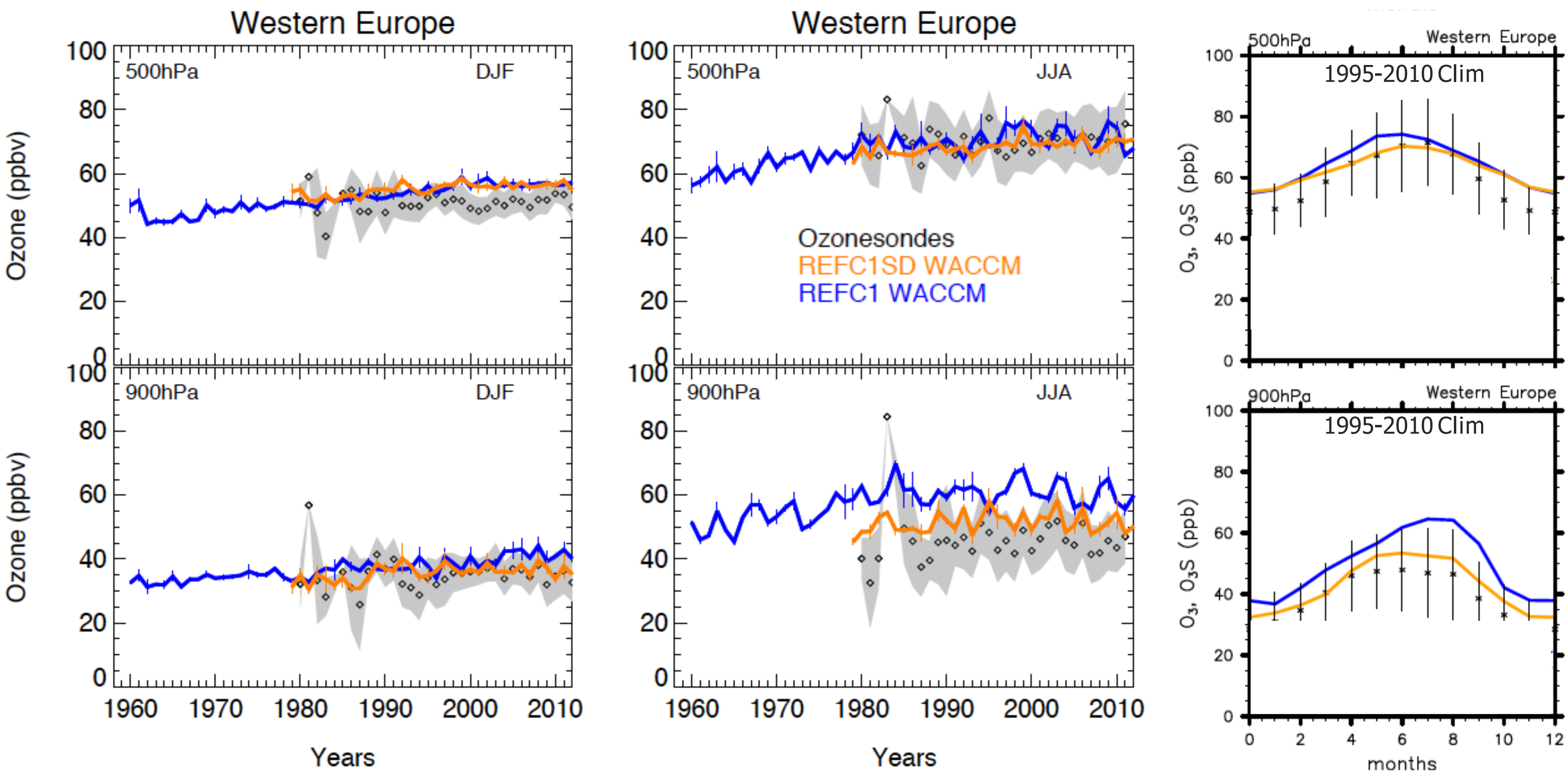
Mean Age *** with SENC2 Simulations



Conclusion:

- The "Fixed 1960 ODS" simulation (1-realization) is "older" than REFC2 between 1985-2045. [Less ozone depletion, "slower" Brewer-Dobson circulation.]
- The "Fixed 1960 GHG" simulation is essentially "constant" from 1980 forward.

Tropospheric Ozone Trends (Western Europe)

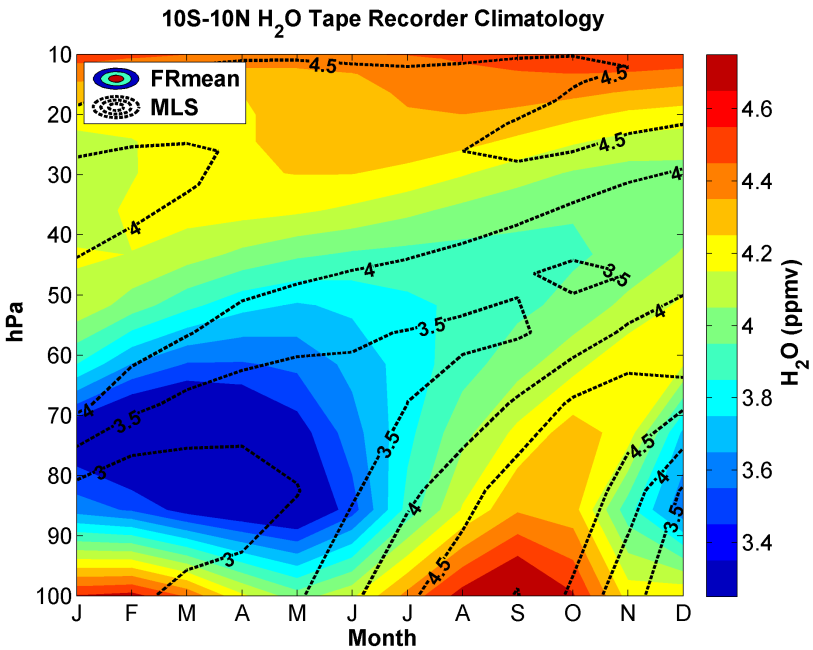


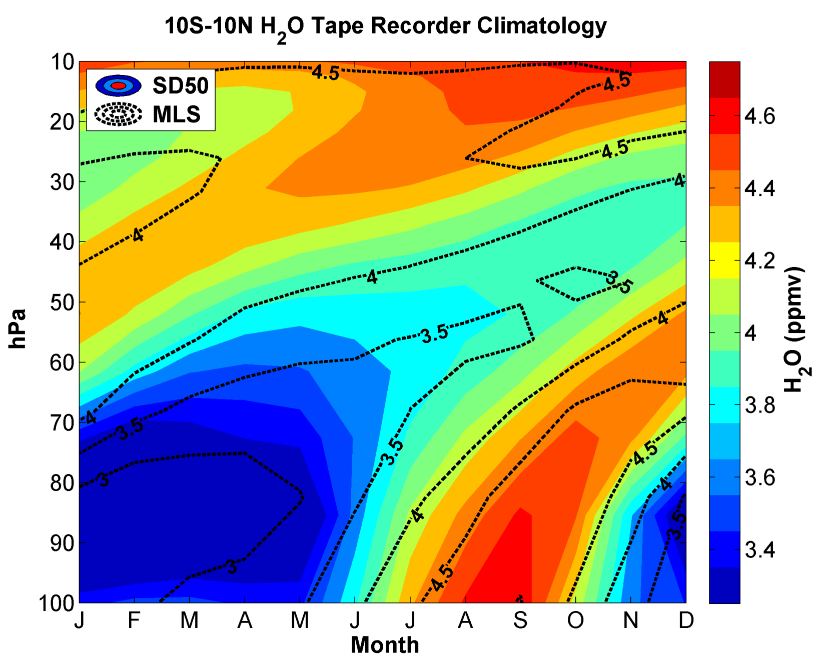
Conclusion:

- Previous attempts showed higher ozone bias of model to obs. Update wet deposition scheme (Val Martin, GRL, 2014) reduced bias.
- Seasonal cycle also better in SD than FR REFC1.
- Surface trend (in summer) is higher in REFC1 (vs REFC1SD). The reason for this difference is currently being examined.

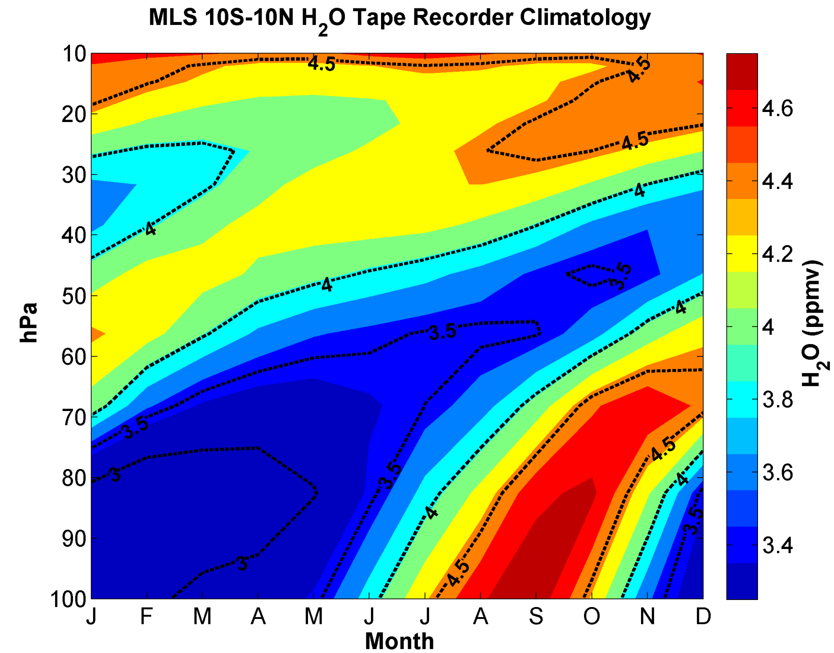
Figure Courtesy of S. Tilmes, NCAR

Tropical H_2O vapor





MLS V4

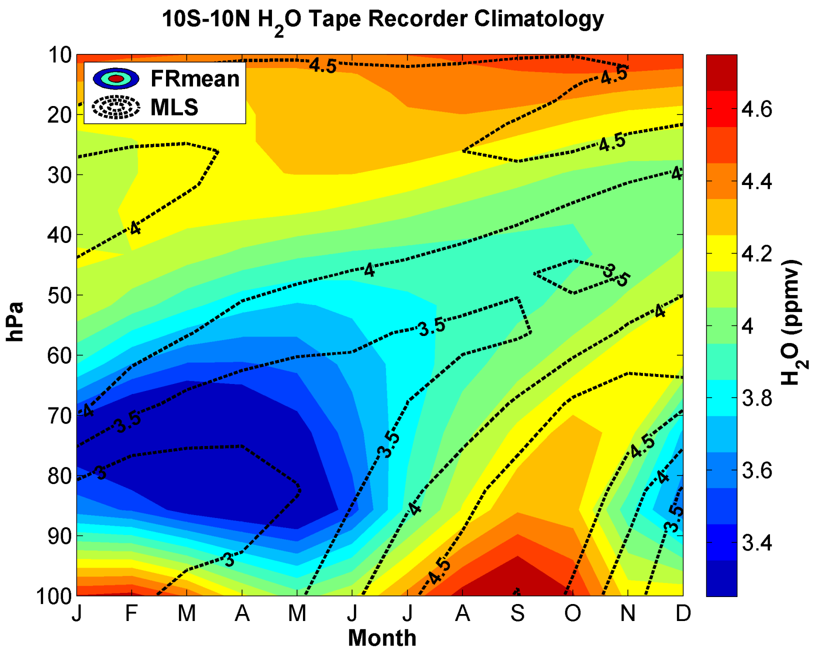


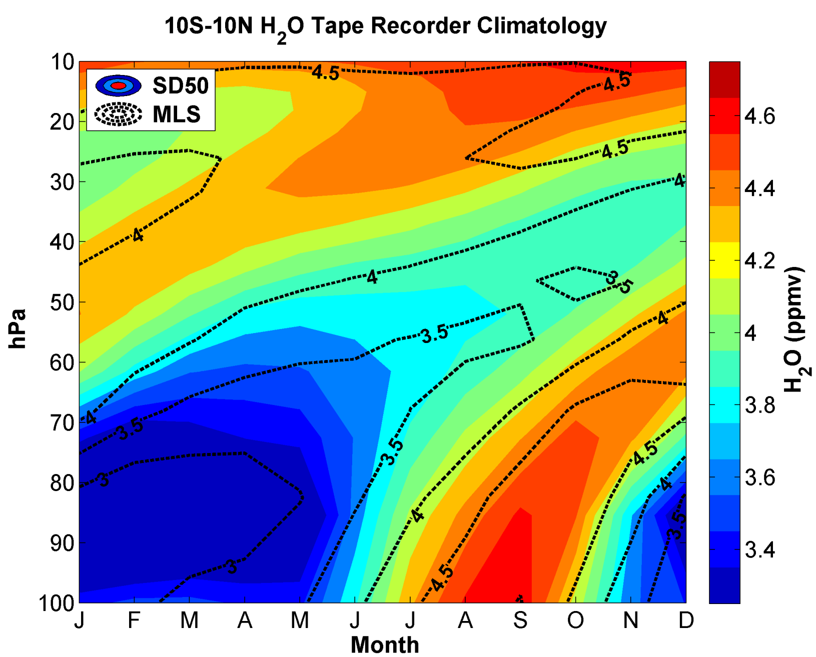
Conclusion:

- Overall SD represents MLS obs better than FR.
- FR has a high bias in H_2O between 100-90hPa.

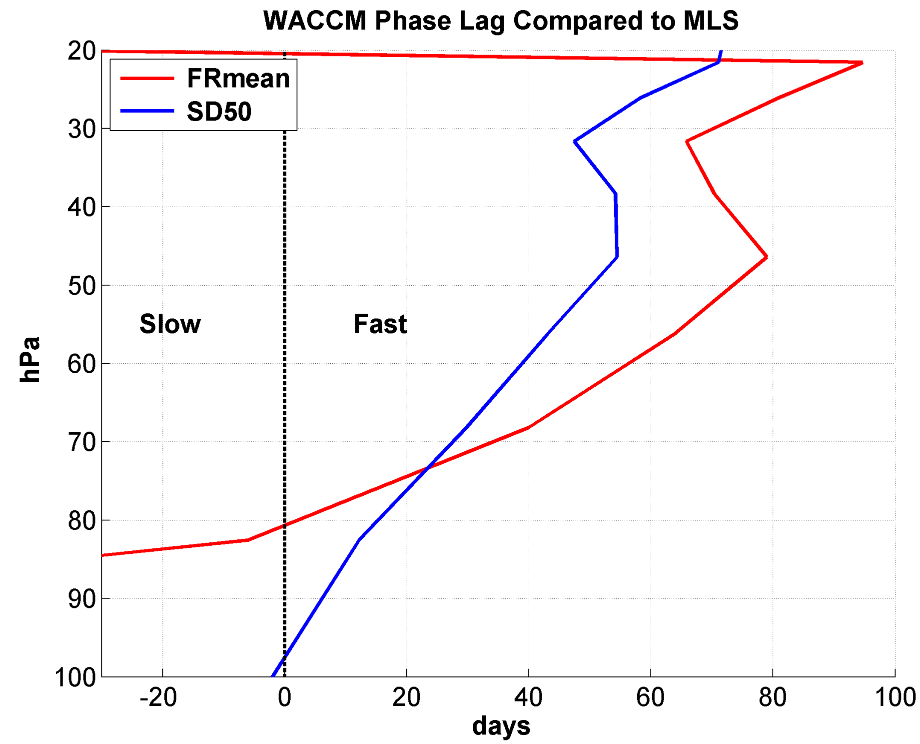
Figures courtesy of Sasha Glanville, NCAR

Tropical H_2O vapor





Phase Lag

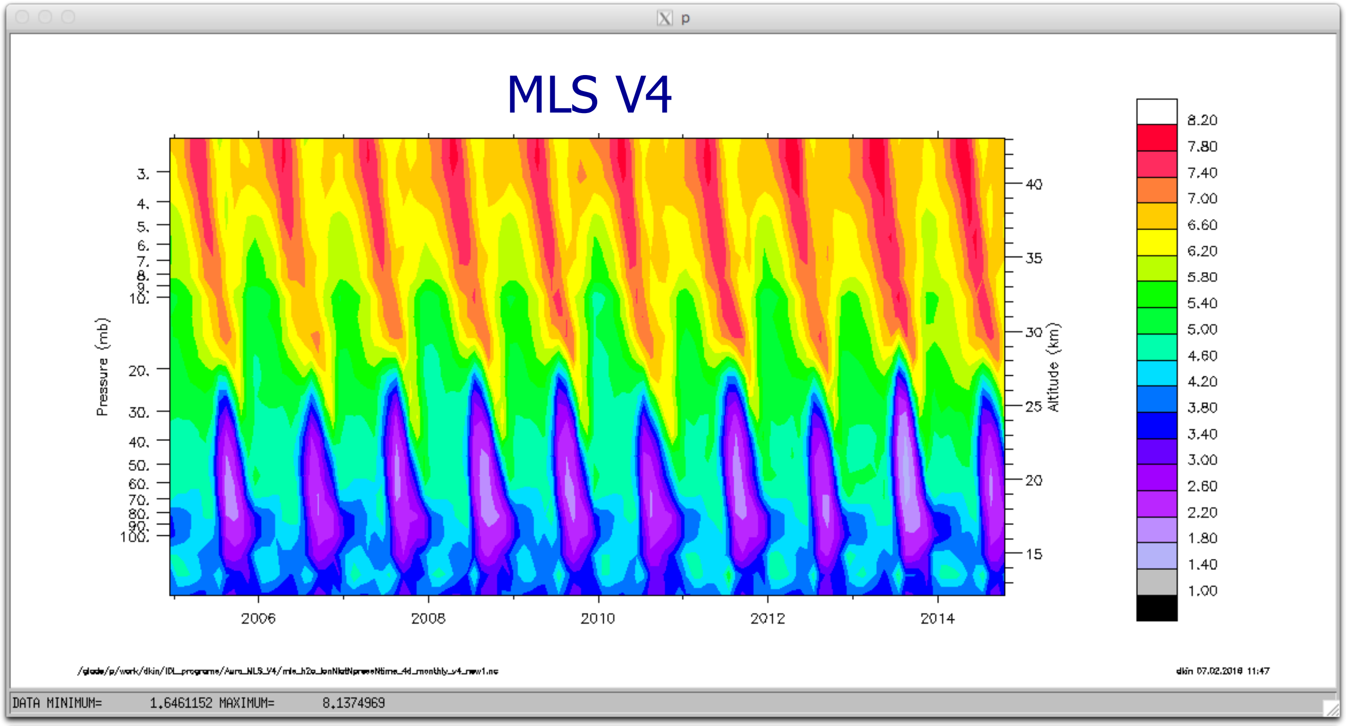


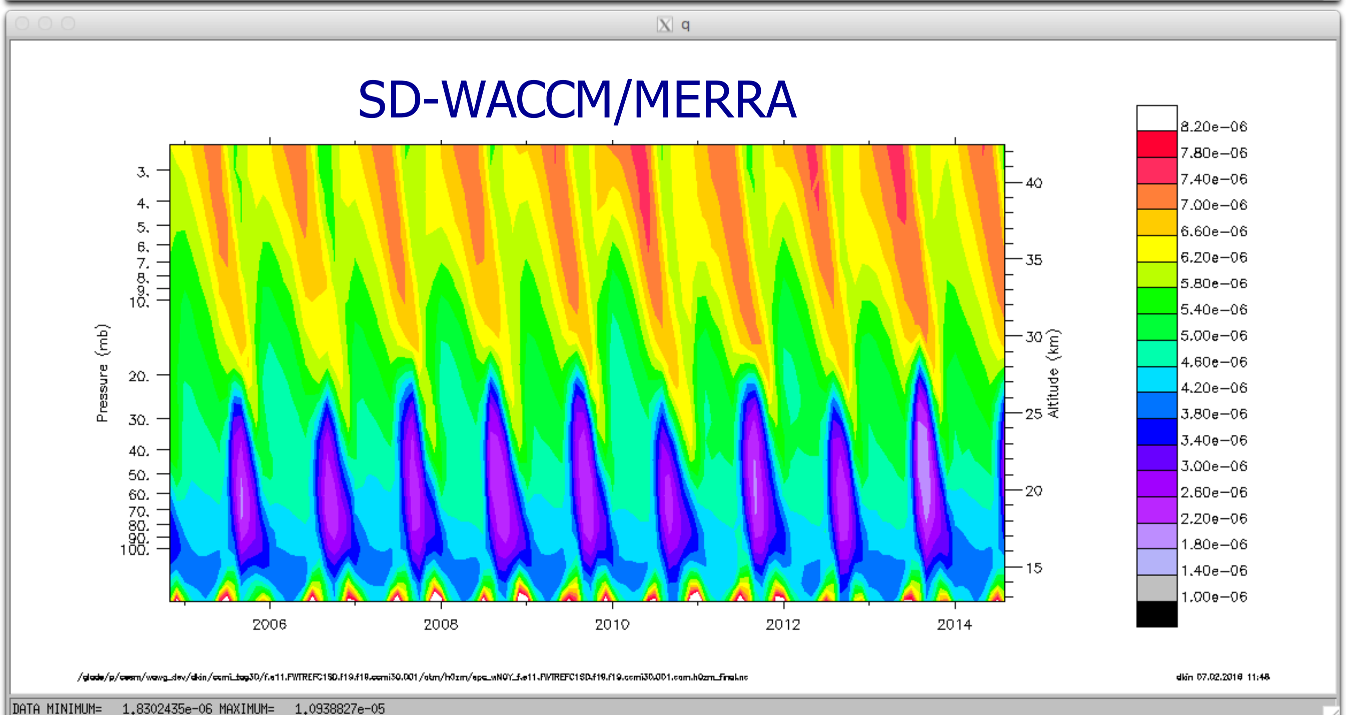
Conclusion:

- Both model versions have a phase lag that leads obs by ~50 (SD) and ~70 (FR) days at 50hPa.
- The tape recorder velocity will be discussed more in the CCWG on Wednesday (Glanville and Neu).

Figures courtesy of Sasha Glanville, NCAR

Polar H_2O vapor *** 78S

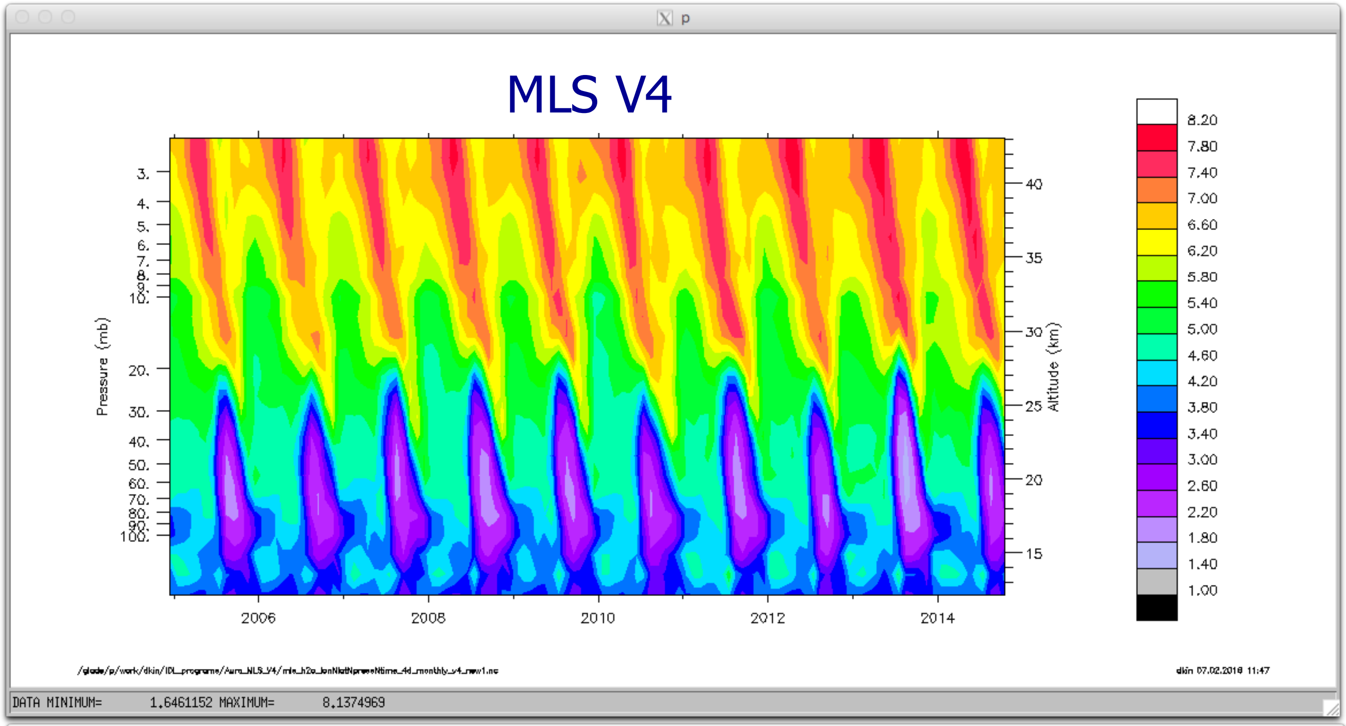


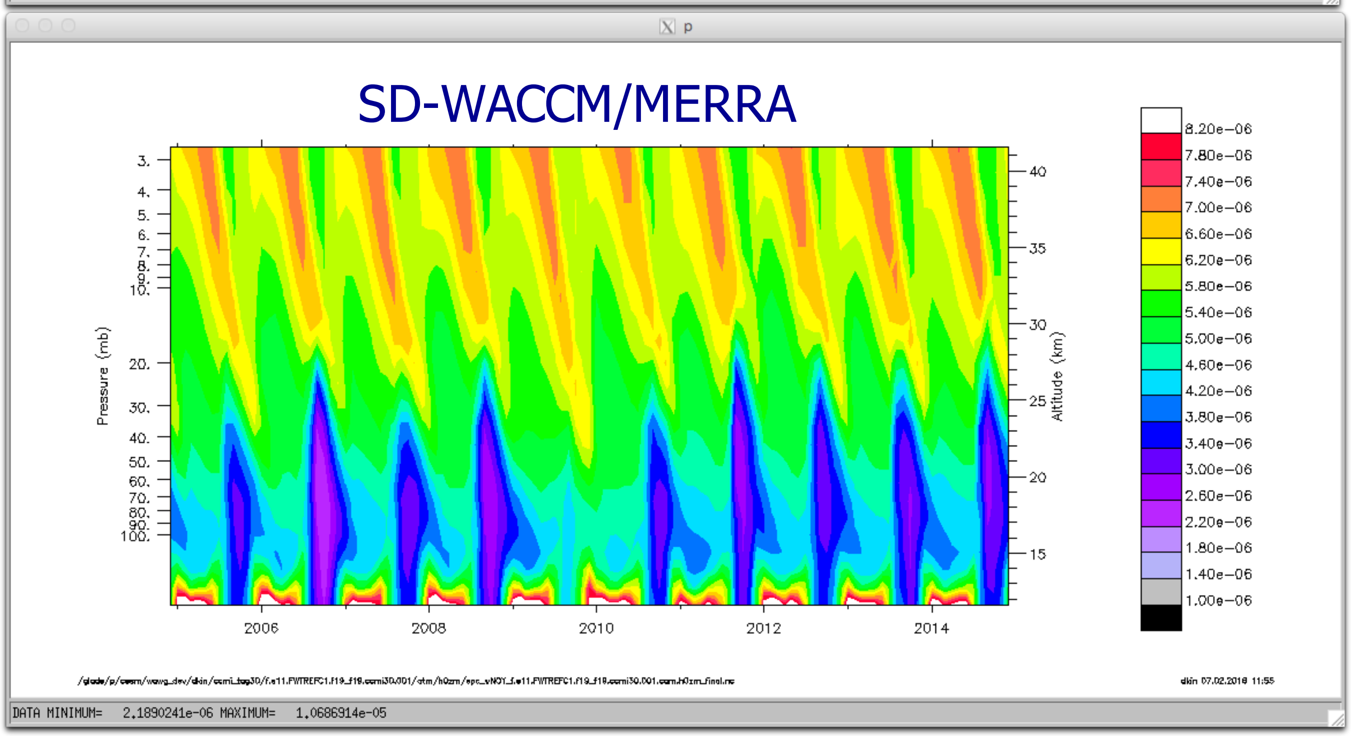


Conclusion:

- Overall SD represents the overall structure of H_2O in the polar stratosphere relative to MLS.
- SD is ~0.3 ppmv drier than MLS in the upper stratosphere.

Polar H_2O vapor *** 78S





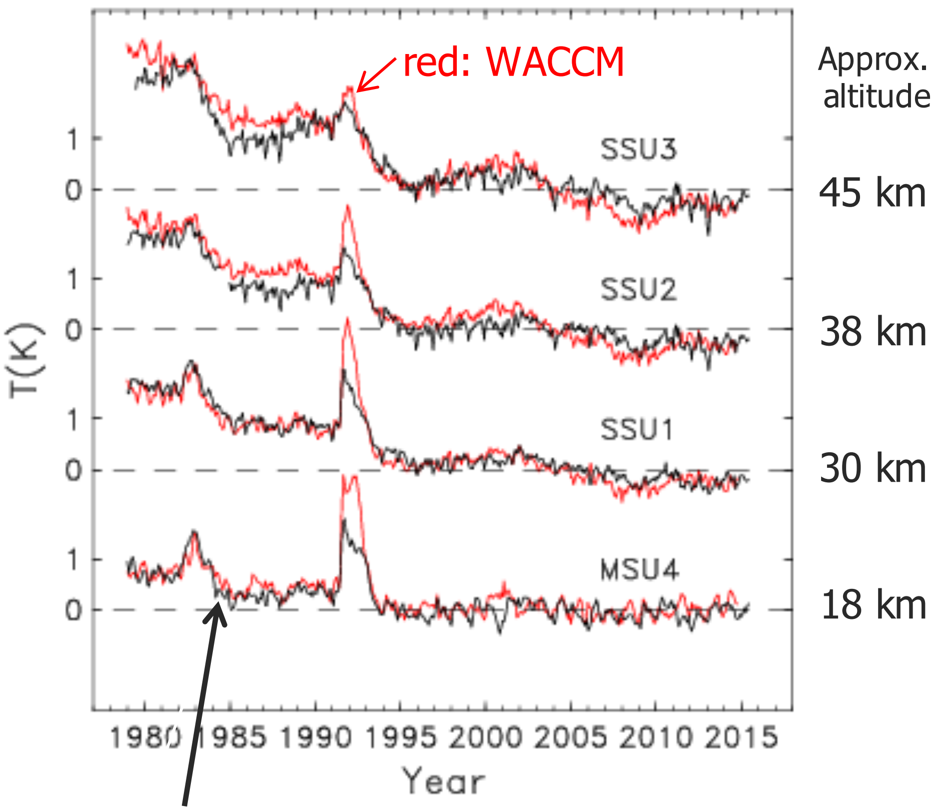
Conclusion:

- FR WACCM does show dehydration in the polar stratosphere. However it is more variable than MLS and the vertical and temporal structure is not as well represented as SD.
- SD is ~0.5 ppmv drier than MLS in the upper stratosphere.

Evaluating Stratospheric Temperature Changes in WACCM

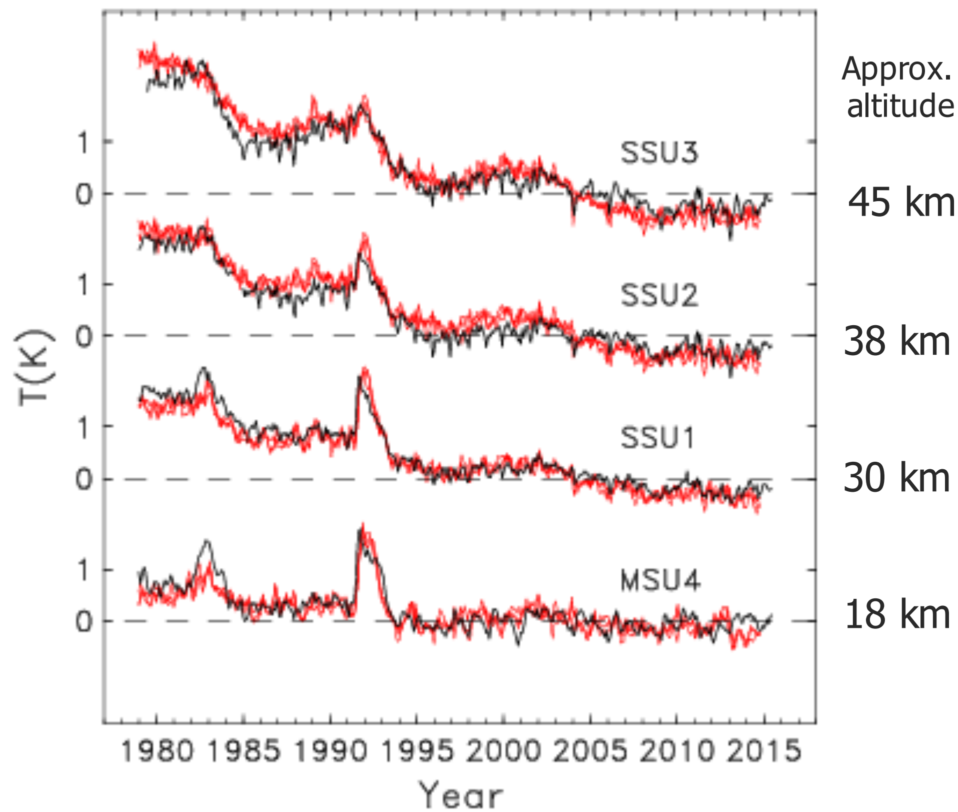
Global temperature anomalies after removal of solar cycle, QBO, and ENSO.

CMIP5 + RCP6.0 simulations



black: satellite observations
merged SSU+MLS data
Randel et al, 2016.

CCMI simulations (three runs)



Conclusion: Improvements in both radiative transfer modeling and sulfate mass distributions improved the CCMI WACCM temperature trend.

Figure Courtesy of W. Randel, NCAR

Next Steps

- NCAR team and colleagues are currently writing model description, evaluation, science papers.

- Will continue putting results on NCAR ESG ASAP for community use.

Thank you for your attention.