Polar Stratosphere:

Comparison of CESM1 (WACCM4-CCMI) and CESM2 (WACCM6) to Observations

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WACCM Working Group, Boulder,

28 February 2017

Outline

- Status of CCMI simulations. Are we done?
- Comparison of Total Ozone Column (TOZ) model results to Aura OMI observations.
- Comparison of model species (T, O_3, HCl, HNO_3, H_2O, ClO, N_2O) to Aura MLS observations.

Both FR and SD versions of the CESM2 model will be examined.

CESM1-WACCM4 CCMI Simulations: Status

Scenario	Period	Ocean	RCP	Members	CMOR#
REFC1	1955-2014	Data	-	5	Done
REFC1-fODS1960	1955-2014	Data	-	5	Done
REFC1-PI	1850-1960	Data	-	1	-
REFC1SD	1979-2014	Data	-	1	Done
REFC2	1960-2100	Interactive	RCP6.0	3	Done
SENC2	2001-2100	Interactive	RCP4.5	1	Done
SENC2	2001-2100	Interactive	RCP8.5	3	Done
SENC2-fGHG1960	1960-2100	Interactive	RCP6.0	3	-
SENC2-fODS1960	1960-2100	Interactive	RCP6.0	3	-
SENC2-fODS2000	2000-2100	Interactive	RCP6.0	3	-
SENC2-nVSL	1955-2100	Interactive	RCP6.0	1	-
SENC2-fEmis	1960-2100	Interactive	RCP6.0	1	-
SENC2-fN2O1960	1960-2100	Interactive	RCP6.0	1	-
SENC2-fCH41960	1960-2100	Interactive	RCP6.0	1	-
SENC2-CH4RCP85	2000-2100	Interactive	Mixed	1	-

All simulations are run with the TSMLT (chemistry). Horizontal resolution is 1.9ºx2.5º. 3371 model years, 10M pe-hrs.
Currently >35 ongoing or published studies.

Most Recent CCMI Publications.

Morgenstern, et al. (>30 coauthors), Review of the global models used within the Chemistry-Climate Model Initiative (CCMI), in press, *Geos. Mod. Dev.*, 2017.

Ivy, D., J., S. Solomon, D. Kinnison, M. J. Mills, A. Schmidt, and R. R. Neely III, The influence of the Calbuco eruption on the 2015 Antarctic ozone hole in a fully coupled chemistry-model, in press, *Geophys. Res. Lett.*, 2017.

Garcia, R. R. Anne K. Smith, D. Kinnison, Á. de la Cámara, and D. Murphy, Modification of the gravity wave parameterization in the Whole Atmosphere Community Climate Model: Motivation and results, *Atmos. Sci.*, , doi:10.1175/JAS-D-16-0104.1, 2017.

Orbe, C., D. W. Waugh, H. Wang, D. E. Kinnison, J-F Lamarque, Simone Times, Tropospheric Transport Differences Between Models Using the Same Large-Scale Meteorological Fields *Geophys. Res. Lett.,* doi:10.1002/2016GL071339, 2016.

Solomon, S., D. E. Kinnison, R. R. Garcia, J. Bandoro1, M. Mills, C. Wilka, R. R. Neely III, A. Schmidt, J. Barnes, J-P Vernier, M. Höpfner, Monsoon circulations and tropical heterogeneous chlorine chemistry in the stratosphere, *Geophys. Res. Lett.,* doi:10.1002/2016GL071778, 2016.

Solomon, S., D. J. Ivy, D. Kinnison, M. J. Mills, R. R. Neely III, A. Schmidt, Emergence of Healing in the Antarctic Ozone Layer, *Science,* 353, 269-274, 2016.

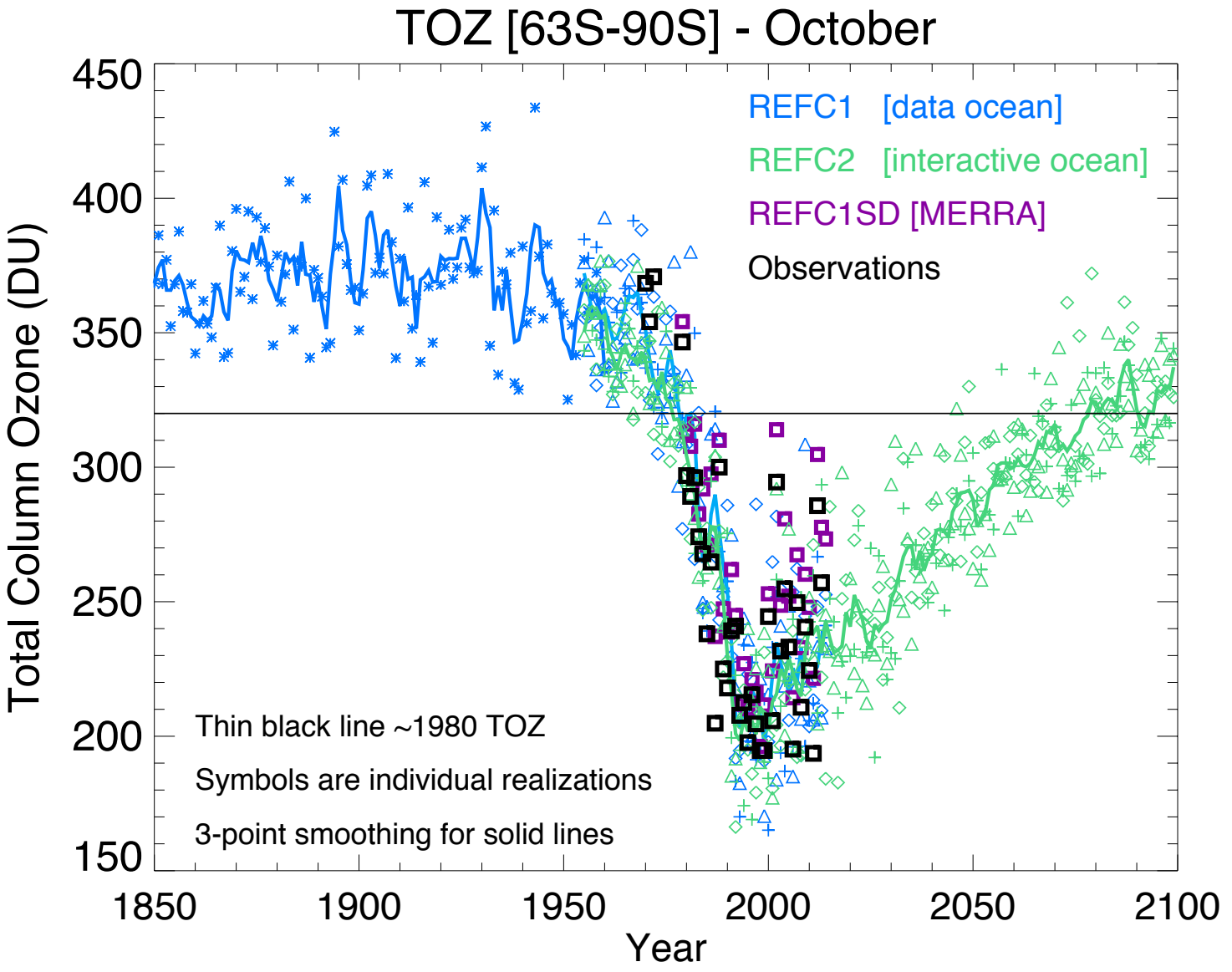
Tilmes, S., J.-F. Lamarque, L. K. Emmons, D. Kinnison, D. Marsh, R. R. Garcia, A. K. Smith, R. R. Neeley, A. Conley, F. Vitt, Maria Val Martin, H. Tanimoto, I. Simpson, D. R. Blake, and N. Blake, Representation of the Community Earth System Model (CESM1) CAM4-Chem within the Chemistry-Climate Model Initiative, *Geosci. Model Dev.,* 9, 1853–1890, doi:10.5194/gmd-9-1853-2016.

Jackman, C. H., D. R. Marsh, D. E. Kinnison, C. J. Mertens, and E. L. Fleming, Atmopspheric changes caused by galactic cosmic rays over the period 1960-2010, *Atmos. Chem. Phys.* , doi:10.5194/acp-16-5853-2016.

Garcia, R. R., M. Lopez-Puertas, B. Funke, D. E. Kinnison, D. R. Marsh, L. Qian, On the secular trend of COx and CO_2 in the lower thermosphere, *J. Geophys. Res.,* 121, 3634-3644, doi:10.1002/2015JD024553.

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.

Currently have >35 Science publication in progress.



Daily and Monthly Ozone will be used for input for non-interactive CMIP6 models.

Comparison of

CESM1 (WACCM4 - CCMI)

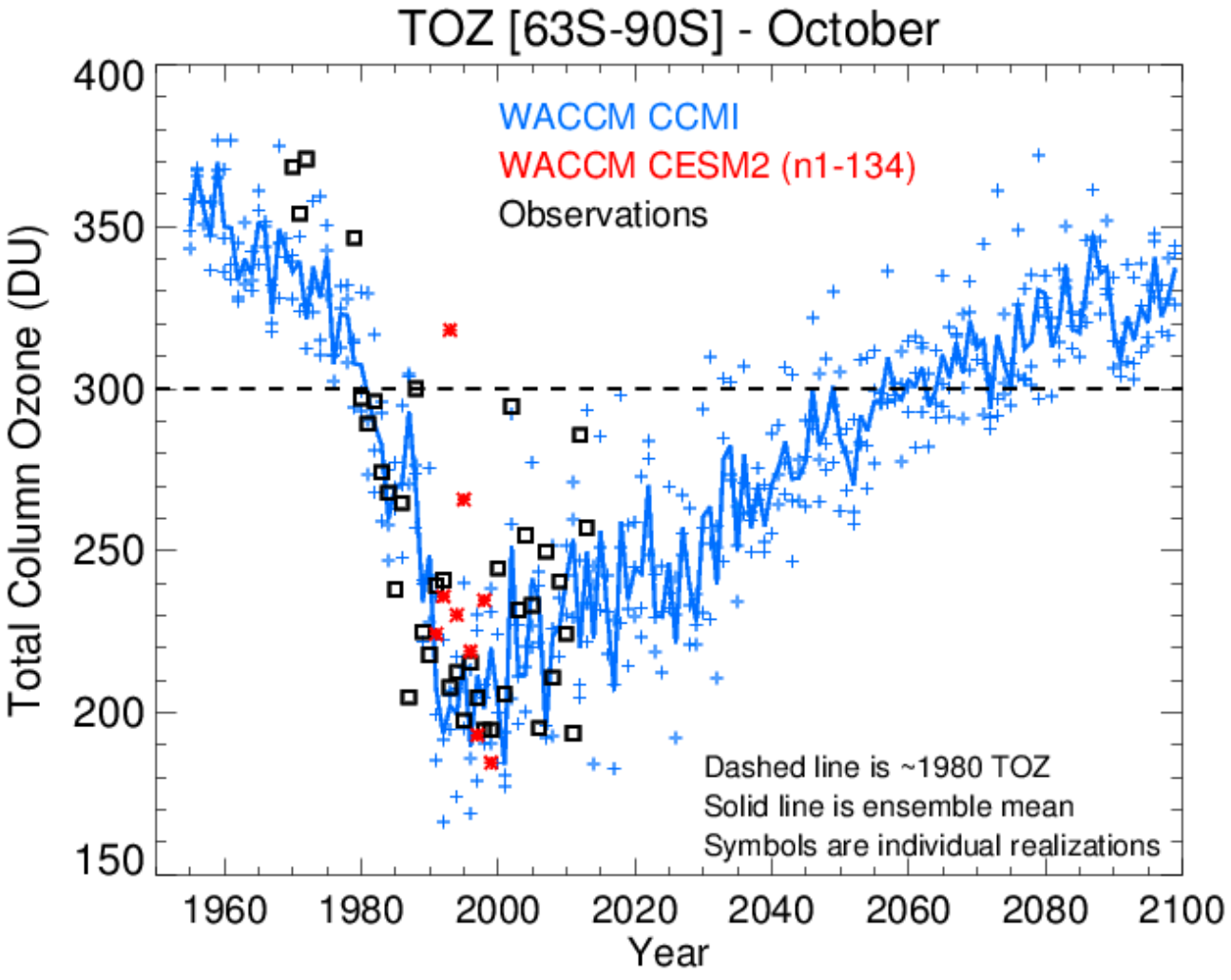
with

CESM2 (WACCM6)

Column Physics and Chemistry

		CESM1 (WACCM4) CCMI	CESM2 (WACCM6)
Column Physics	Horizontal Resolution	1.9°x2.5°	0.95°x1.25°
	Vertical Layers	26/66/88	32/70/88
	Boundary Layer	HB	CLUBB
	Shallow Convection	Hack	CLUBB
	Deep Convection	ZM	ZM
	Macrophysics	R&K	CLUBB
	Microphysics	R&K	MG 2.0
	Radiation	CAMRT	RRTMG
	Aerosols	Bulk	MAM4
	QBO	Nudged to Observations	Interactive
Chemistry	Chemical Mechanism	180 species	228 Species
	Chemical rates	JPL-11	JPL-15
	Sulfate SAD	Prescribed (CCMI)	Interactive (MAM)
	ICE SAD	Bulk Scheme	MG 2.0 / CCMI
	Solar Variability / ETF	Lean	Lean (updated)
	GHG abundances	Meinshausen, 2011	Meinshausen, 2016
	Halogens	WMO, 2010	Meinhassen, 2016

Free-Running (data ocean) CESM2 (n1-134) vs CCMI REFC2



CESM2 [f.e20.FWAMIP.f09_f09.134.Pinatubo.001]

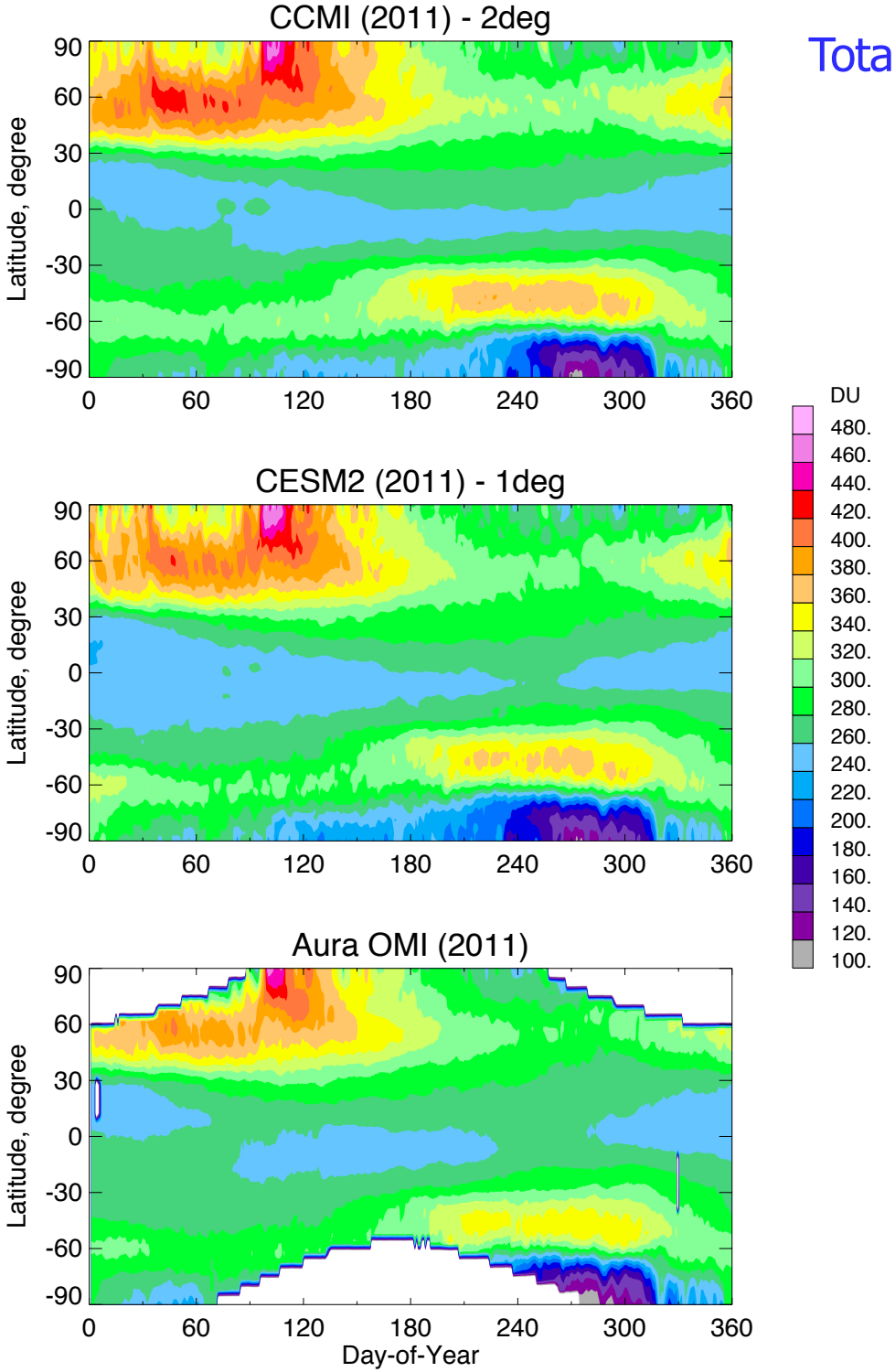
Comments:

Overall the TOZ from the frozen CESM2 model is within the range of both observations and CCMI REFC2 (3-members).

- Multiple realizations of this CESM2 hindcast are needed to fully assess the representation of polar ozone depletion.
- This hindcast should start in ~1975 and finish in 2014.

CESM2 simulation completed by M. Mills, NCAR.

Total Column Ozone (TOZ), SD configuration



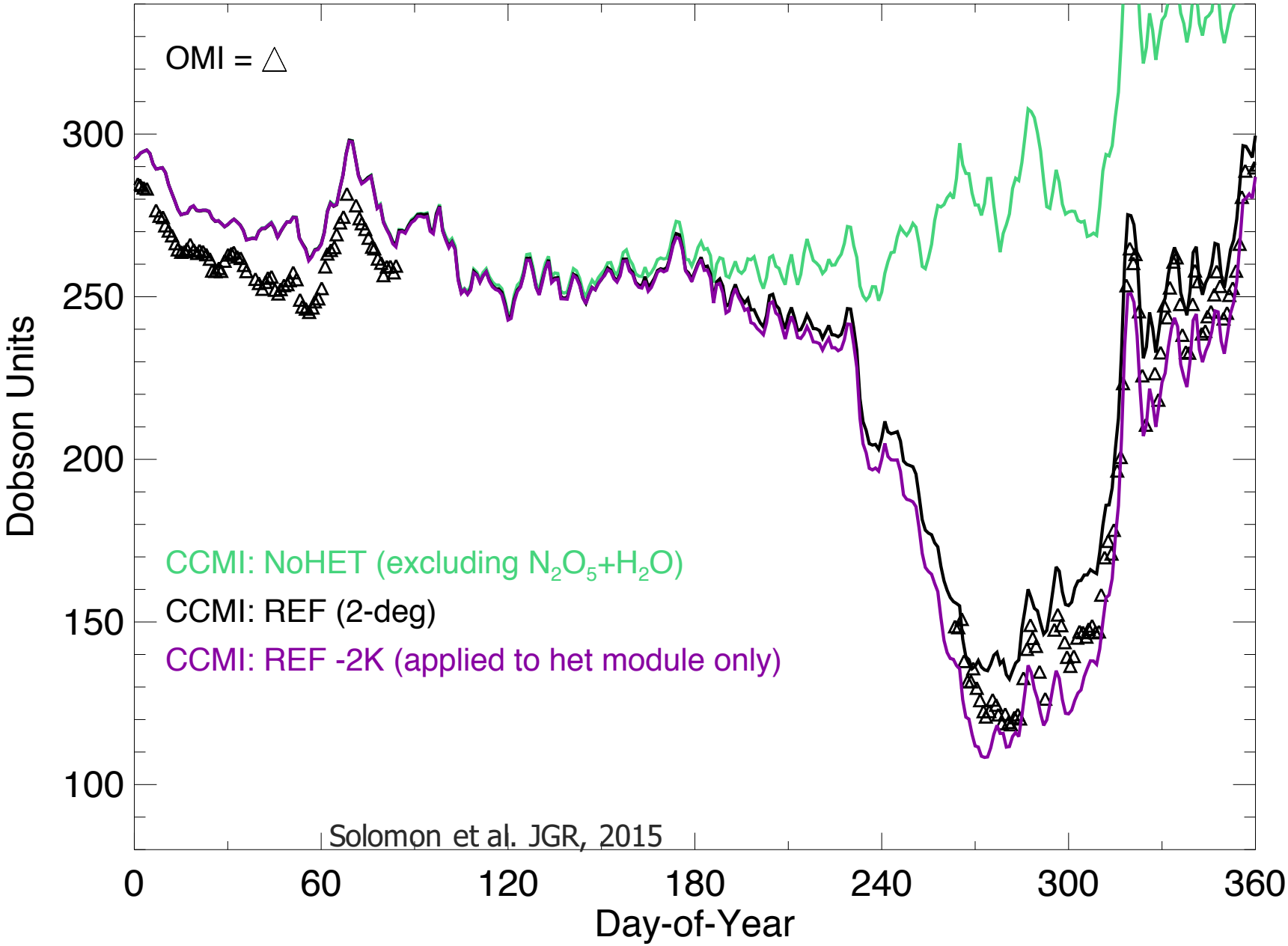
Comments:

Overall, both model versions compare well to TOZ observations for year 2011.

- Tropics, ExtraTropics: CCMI is more consistent with OMI. There is larger regions of low (260DU) TOZ.
- Polar NH (60N) Spring maximum: CESM2 is more consistent with OMI.
- Polar SH (60S) Spring maximum: CESM2 is more consistent with OMI.
- Polar, SH Spring: There is more depletion near 1 Oct (day 270) in CCMI.
- Polar, SH, Winter: CESM2 has lower TOZ in May and throughout the winter. See next slide.

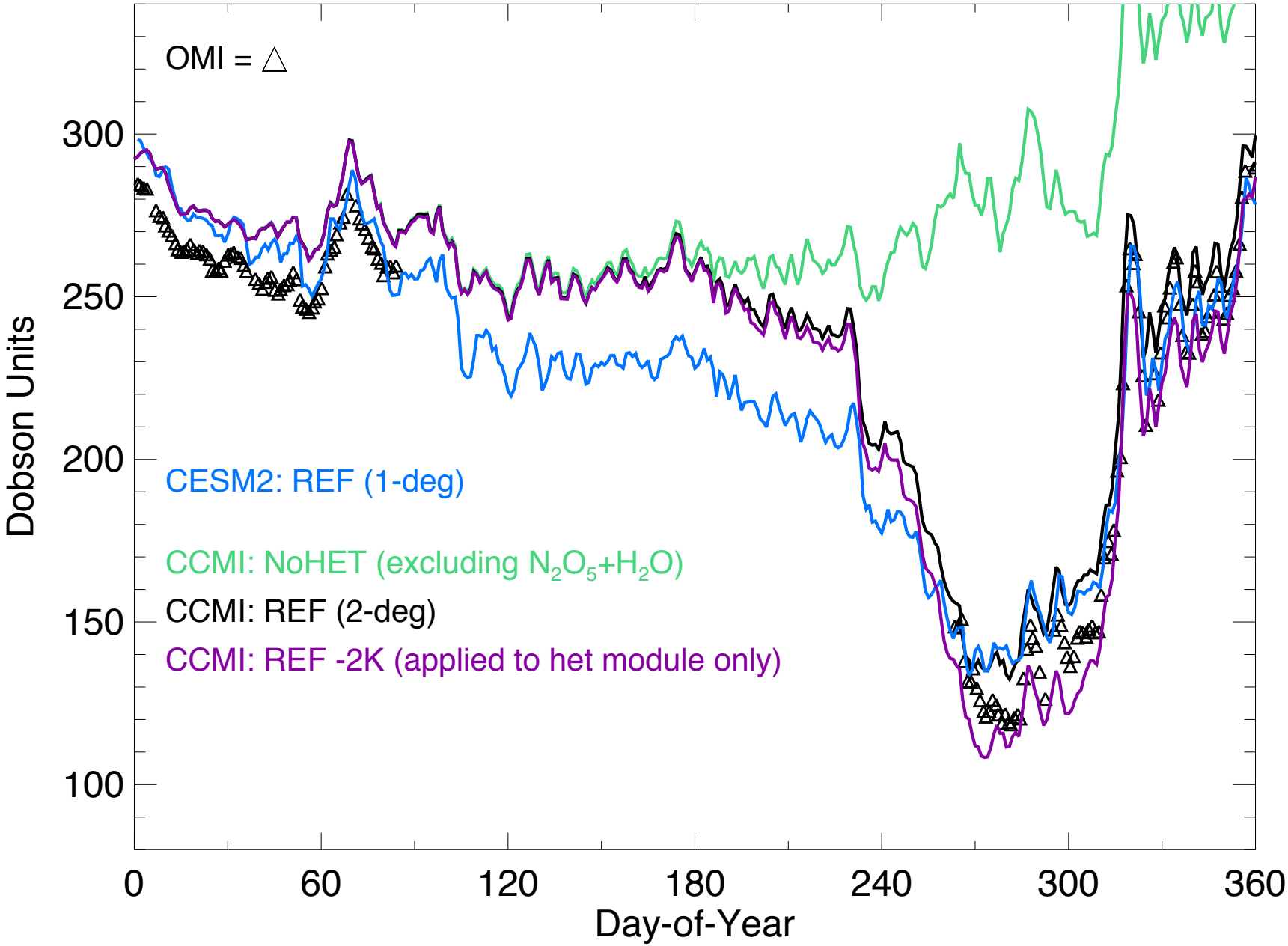
CESM2 simulation completed by M. Mills, NCAR.

Total Column Ozone *** 82.4S, ZM *** 2011



Solomon, S., D. E. Kinnison, J. Bandoro, R. Garcia, Simulations of Polar Ozone Depletion: An Update, *J. Geophys. Res. 2015*.

Total Column Ozone *** 82.4S, ZM *** 2011

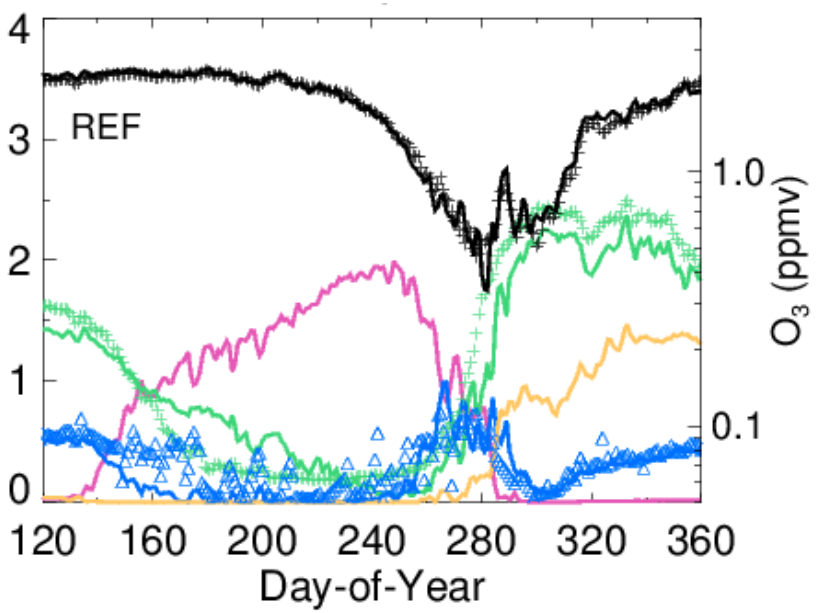


Solomon, S., D. E. Kinnison, J. Bandoro, R. Garcia, Simulations of Polar Ozone Depletion: An Update, *J. Geophys. Res. 2015*.

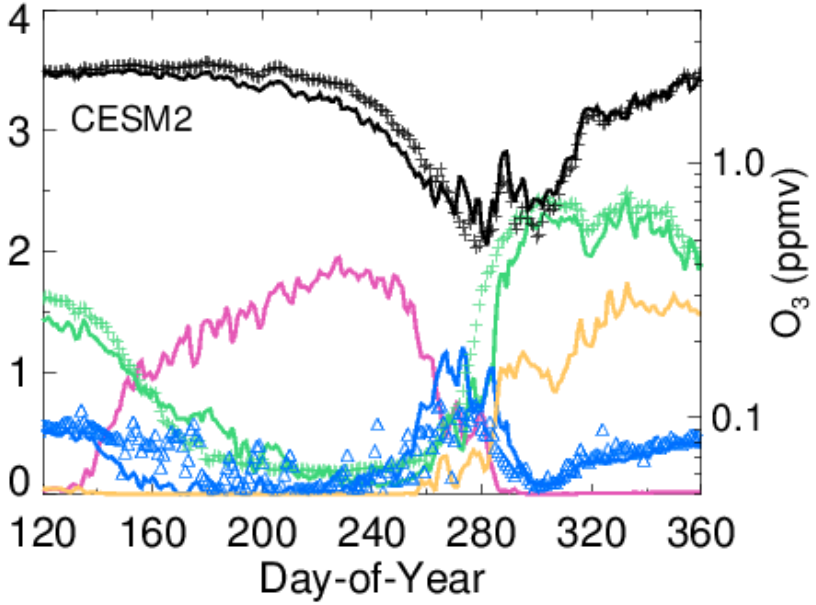
Comparison to Aura MLS (one example)

2011, 74S, 61hPa

CCMI =>



CESM2 =>



Comments:

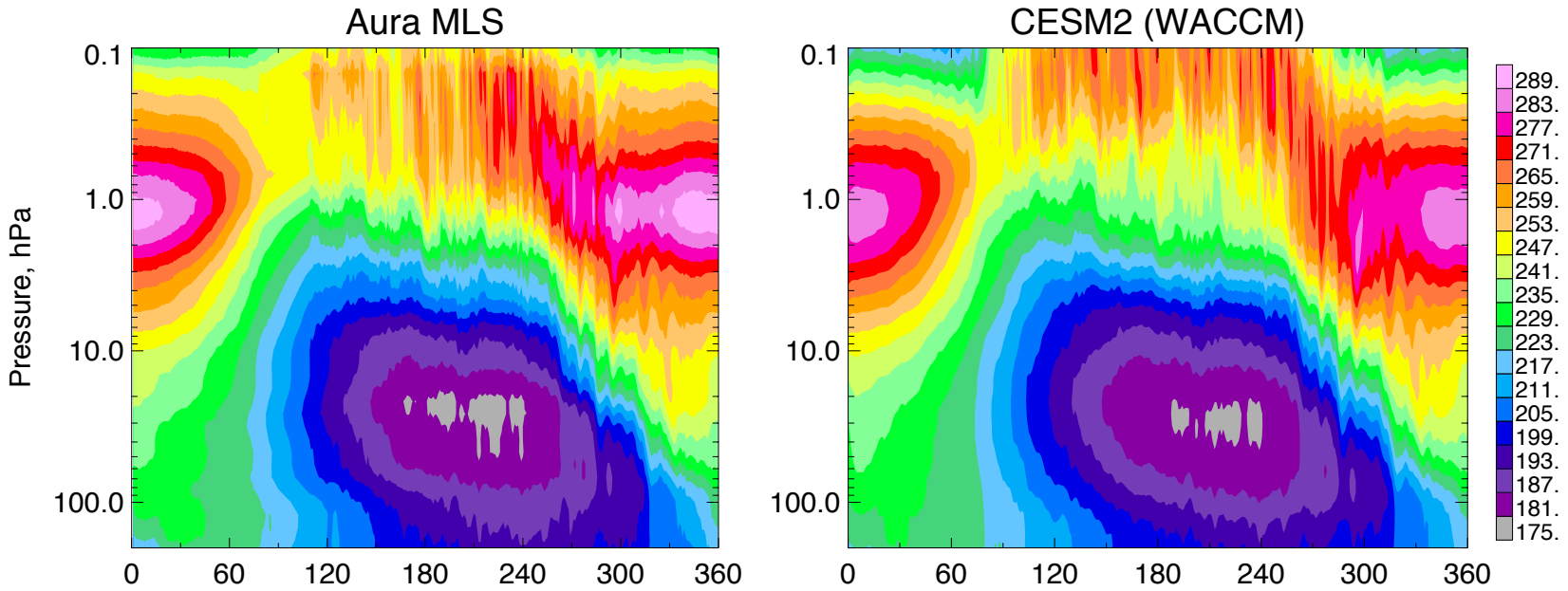
Overall, CESM2 does an adequate job of representing observations for a given pressure and latitude.

- **Ozone:** CCMI is more consistent with MLS. CESM2 is too low for days <270.
- **ClOx:** CESM2 and CCMI are similar, with CCMI peaking a little higher in August.
- **HCL (g):** CESM2 and CCMI are similar and both delay the recovery of chlorine back into HCl.
- **$ClONO_2$:** Both CESM2 (and CCMI) accurately represent the magnitude and recovery of chlorine back into $ClONO_2$.

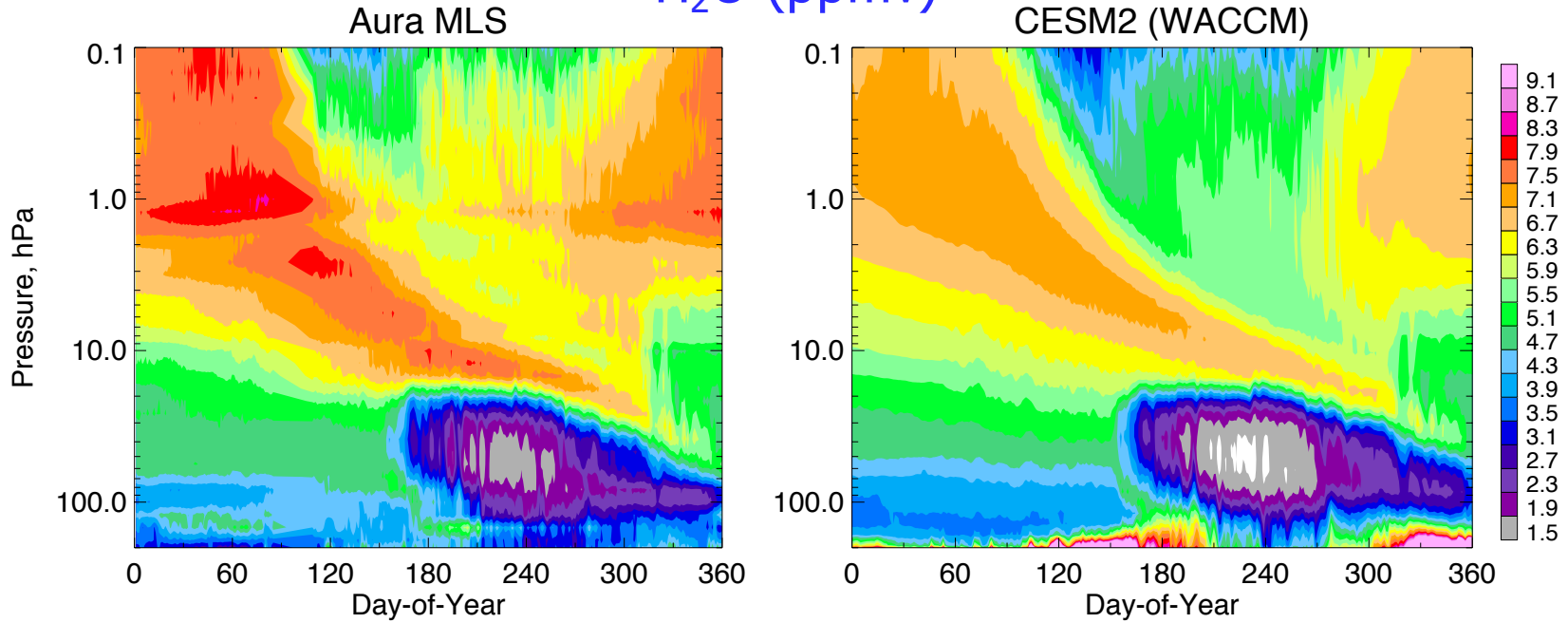
More comparisons to Aura MLS species in the next slides.

81S, 2011

Temperature (K)



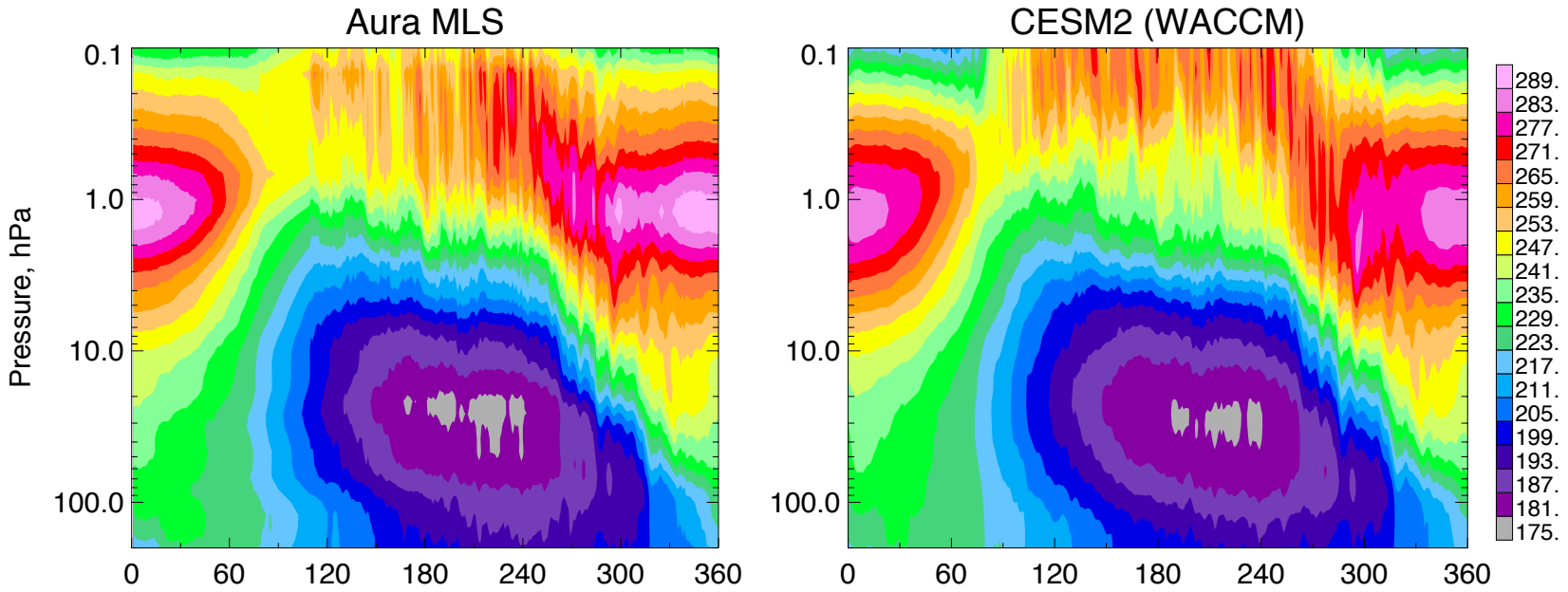
H_2O (ppmv)



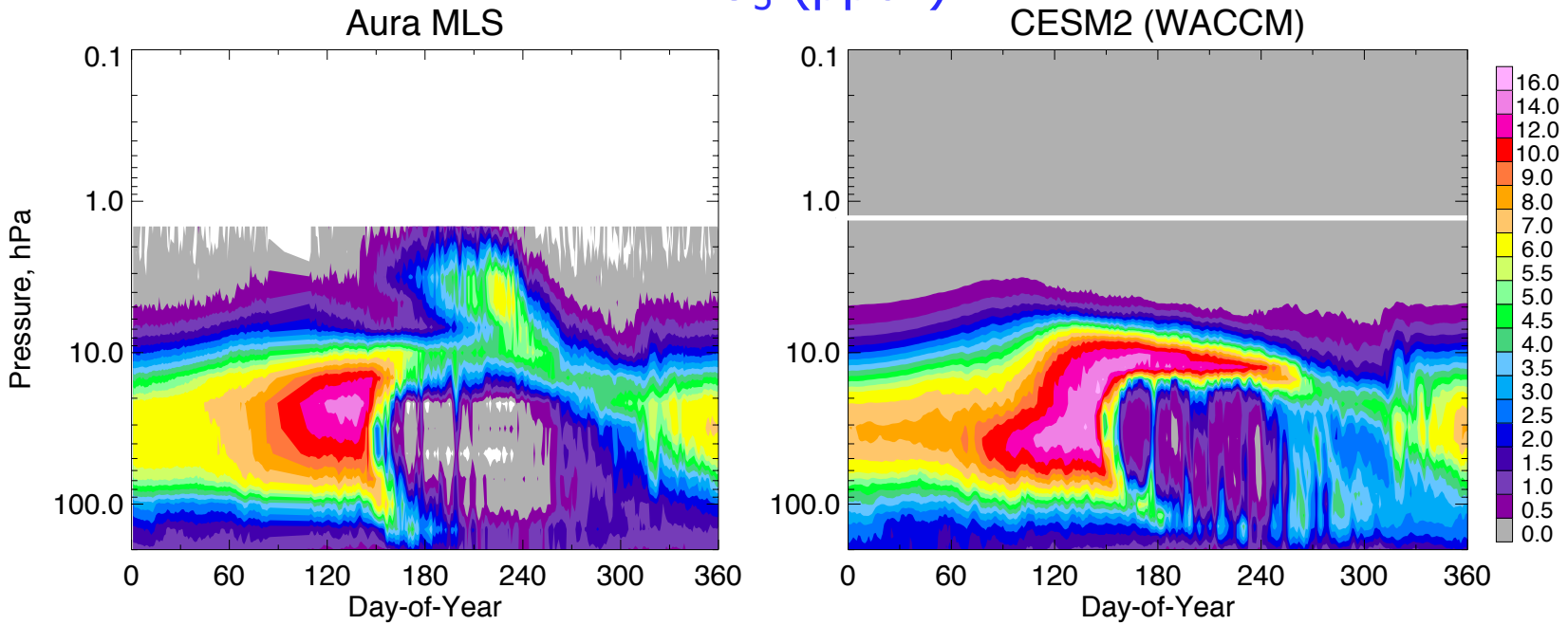
Aura MLS binned up by Chuck Bardeen, NCAR

81S, 2011

Temperature (K)



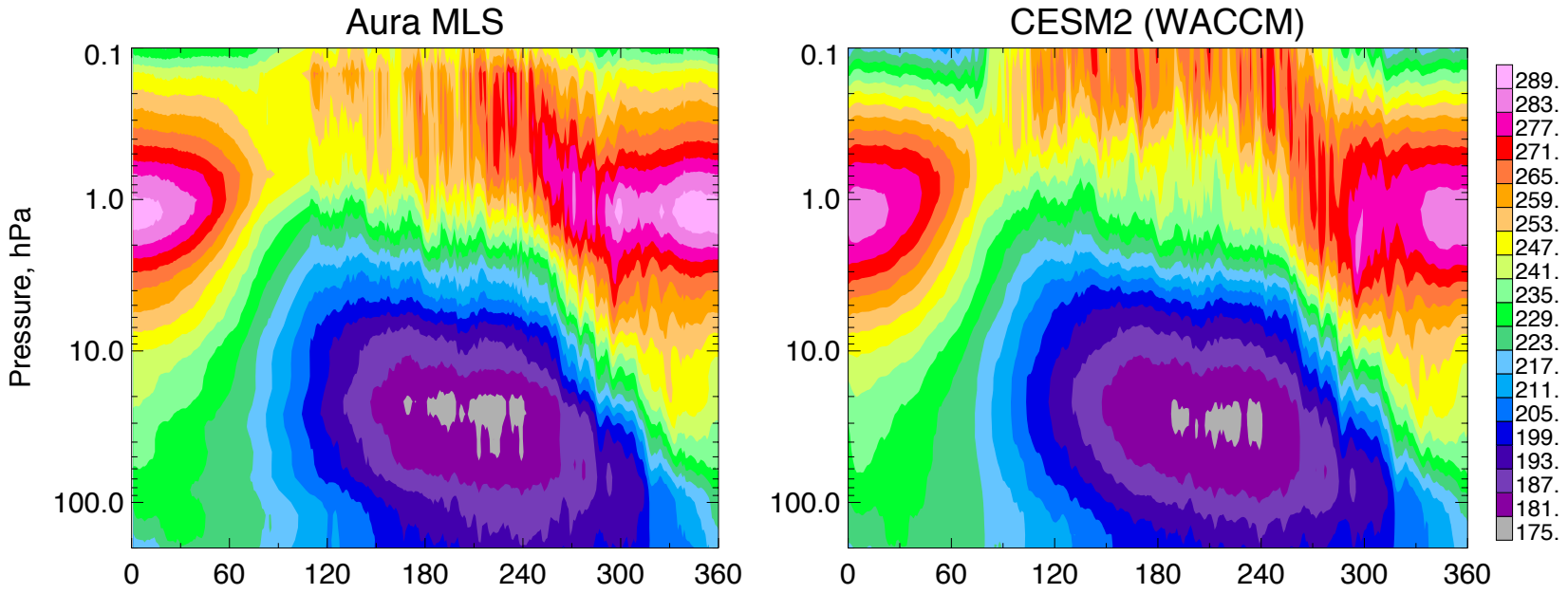
HNO_3 (ppbv)



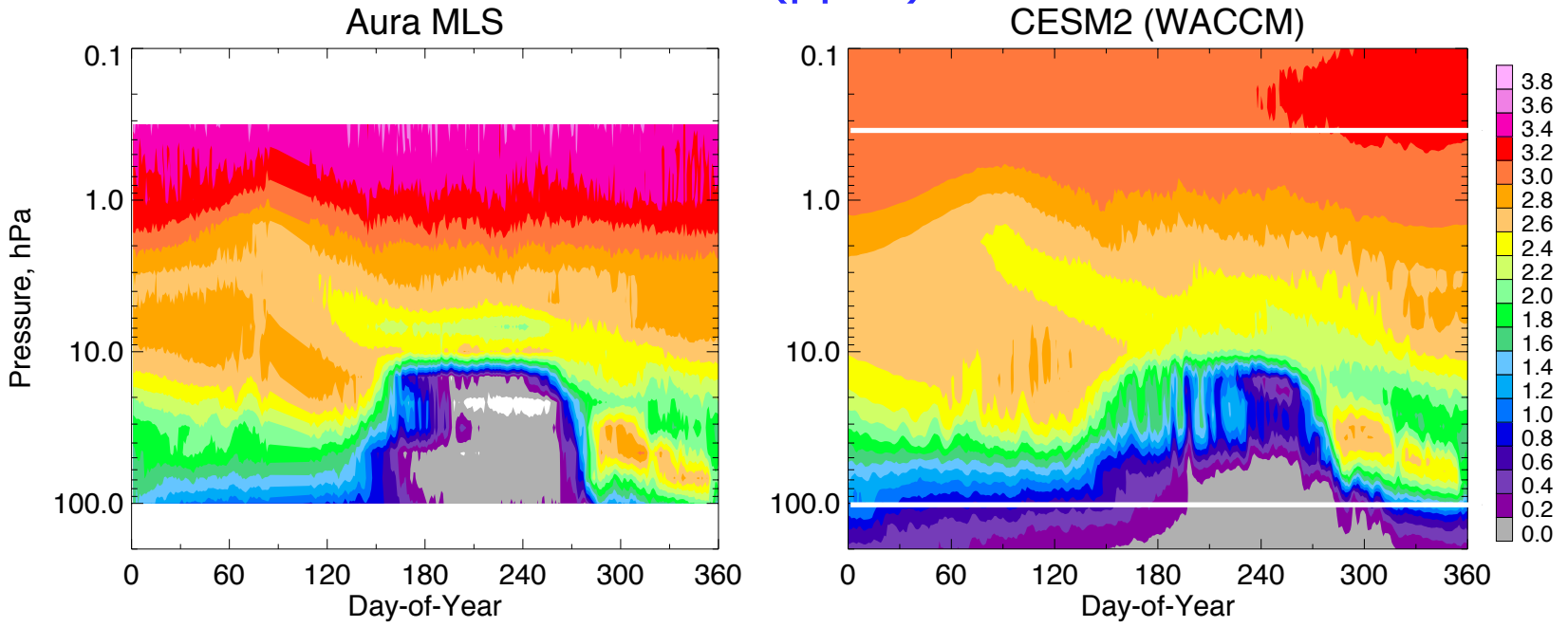
Aura MLS binned up by Chuck Bardeen, NCAR

81S, 2011

Temperature (K)



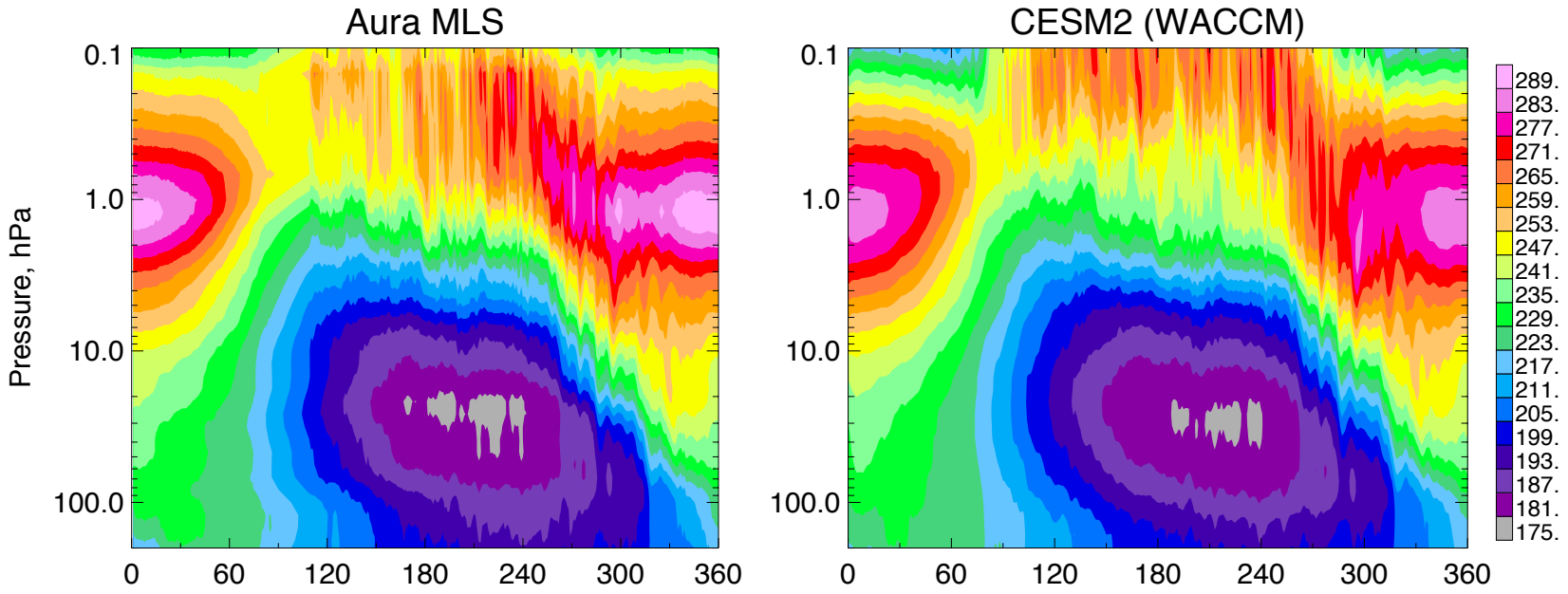
HCl (ppbv)



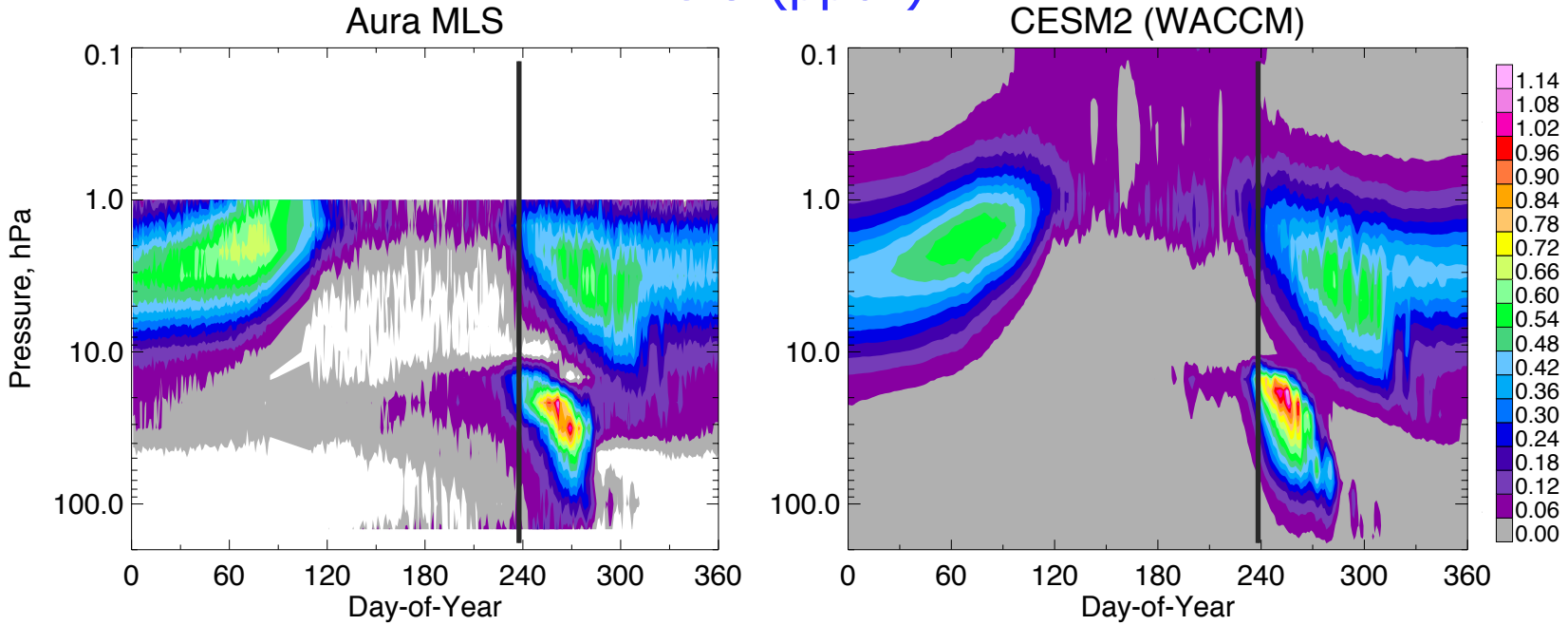
Aura MLS binned up by Chuck Bardeen, NCAR

81S, 2011

Temperature (K)



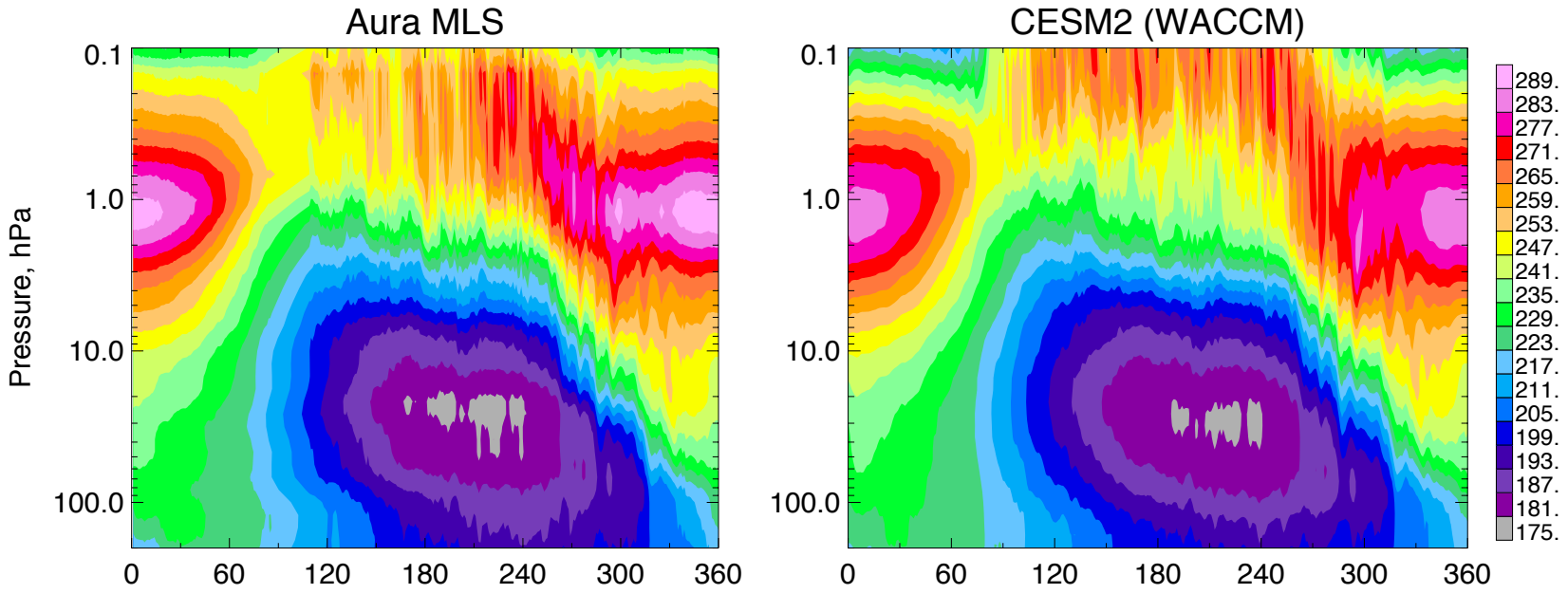
ClO (ppbv)



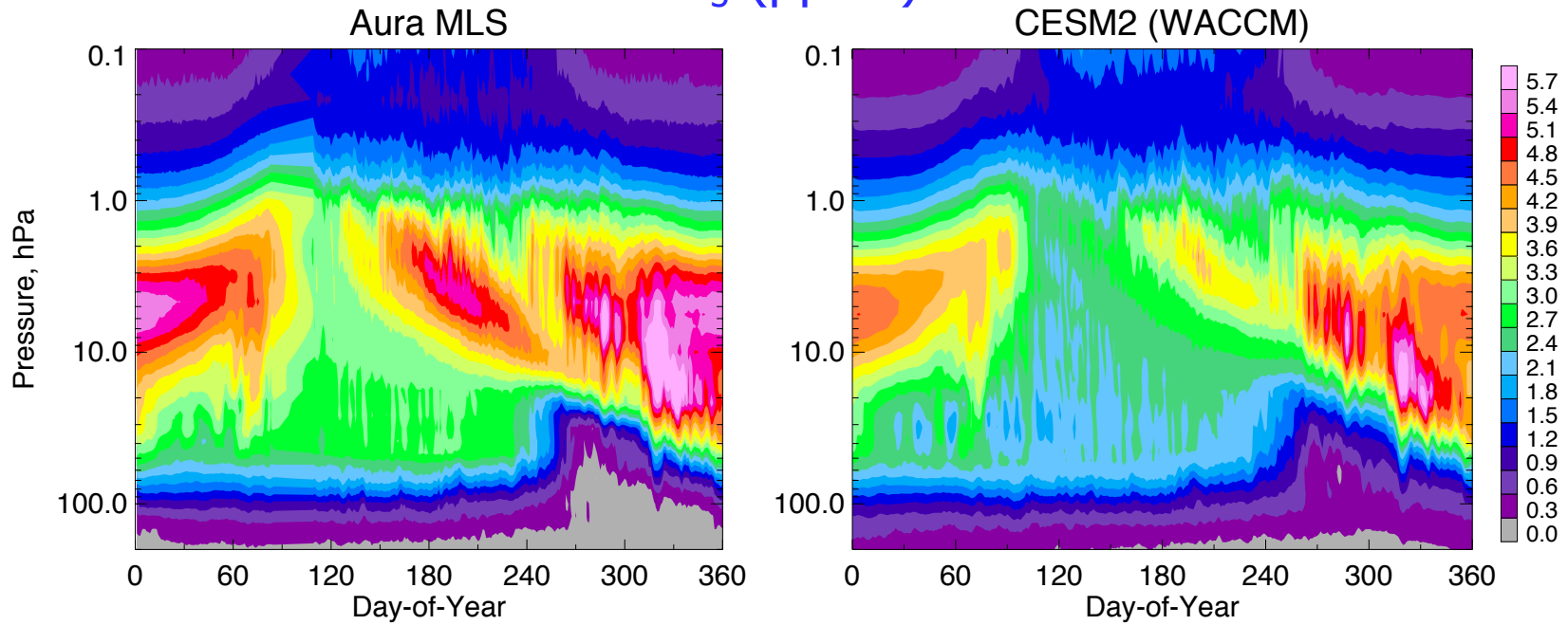
Aura MLS binned up by Chuck Bardeen, NCAR

81S, 2011

Temperature (K)



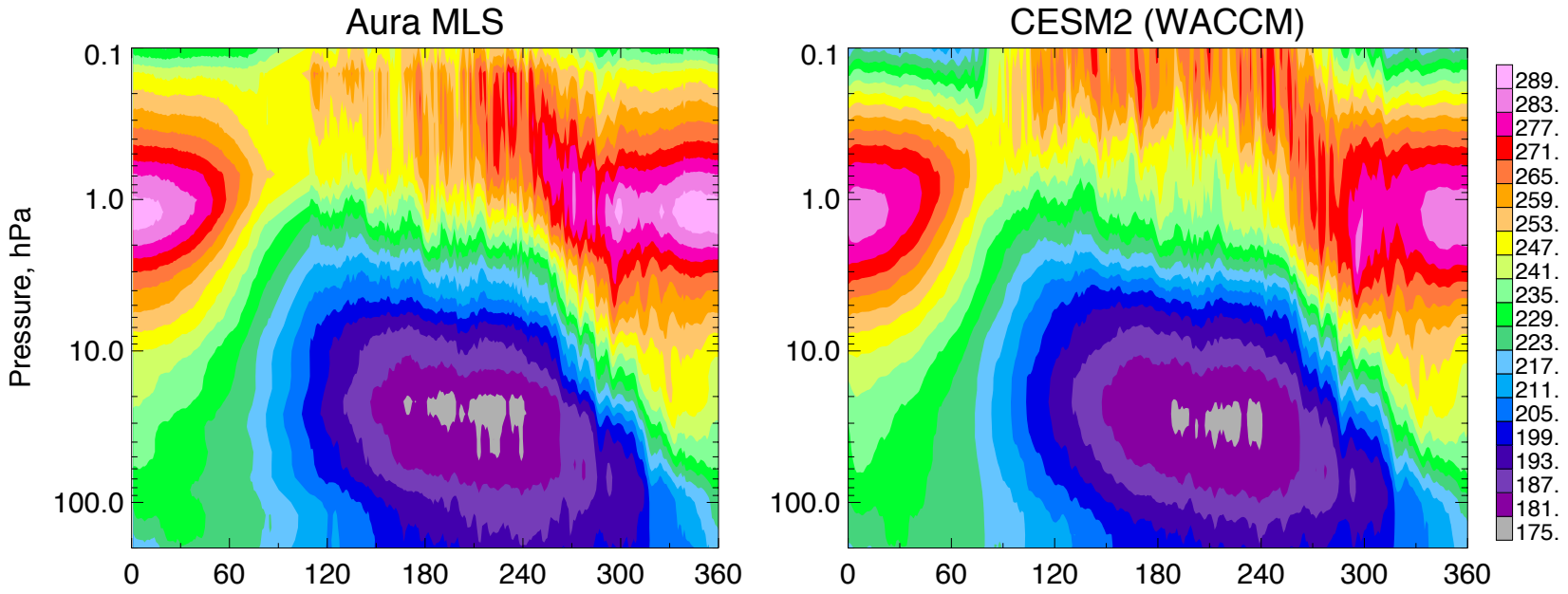
O_3 (ppmv)



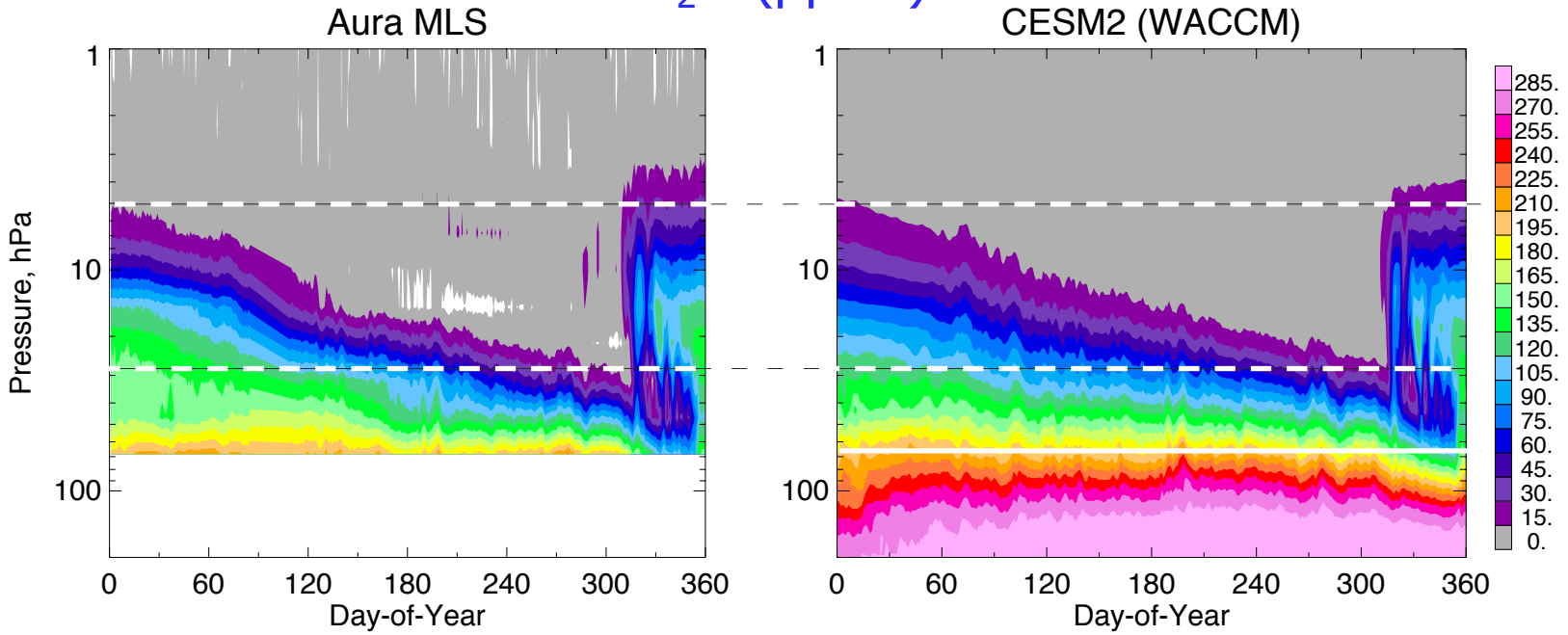
Aura MLS binned up by Chuck Bardeen, NCAR

81S, 2011

Temperature (K)



N_2O (ppmv)



Aura MLS binned up by Chuck Bardeen, NCAR

Conclusions - TOZ

Free-Running:

- CESM2 Total Column Ozone (TOZ) is within the range of previous CCMI results and observations (1991-1999). Longer period simulations are needed.

Specified-Dynamics (year 2011)

- CESM2 TOZ is consistent with Aura OMI observations. There are differences in the tropics (CESM2<OMI) that will need to be investigated.

- CESM2 has less TOZ (relative to CCMI) from May to August at high SH latitudes. The cause of this difference is unknown (or which model is correct). Integration of stratospheric Aura MLS O_3 may give insight.

Conclusions - Species

Specified-Dynamics (year 2011)

- CESM2 H_2O (g) is in good agreement with Aura MLS in the 200-20hPa region. There is more H_2O descending from 0.1 to 20hPa in Aura MLS compared to CESM2 (up to 1ppmv). This could be a IC file issue. This is an improvement over CCMI.

- CESM2 HNO_3 (g) spatial and temporal distribution follows Aura MLS. The model has ~0.4 ppbv more HNO_3 (g) during the depletion period. This could be tuned by changing the assumption on NAT number density (0.01 => 0.005 cm^{-3}).

- CESM2 HCl (g) is consistent with Aura MLS in September and October. There is a known issue with too much HCl in July and August. This is a research topic.

- CESM2 ClO is in good agreement with Aura MLS during the ozone depletion period.

- CESM2 O_3 is also in good agreement with Aura MLS in the 200-20hPa region. With the possible exception that ozone depletion is starting late in early September. This has also been seen in CCMI simulations.

- CESM2 N_2O is also consistent with Aura MLS. No major issues are apparent.

Thank you for your attention.