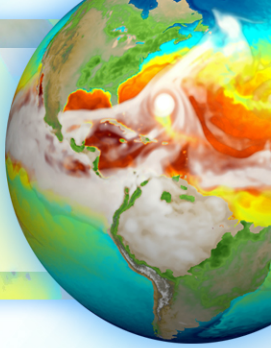
# Evaluation of the interactive stratospheric ozone (O3v2 module) for the E3SMv2



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# Motivations

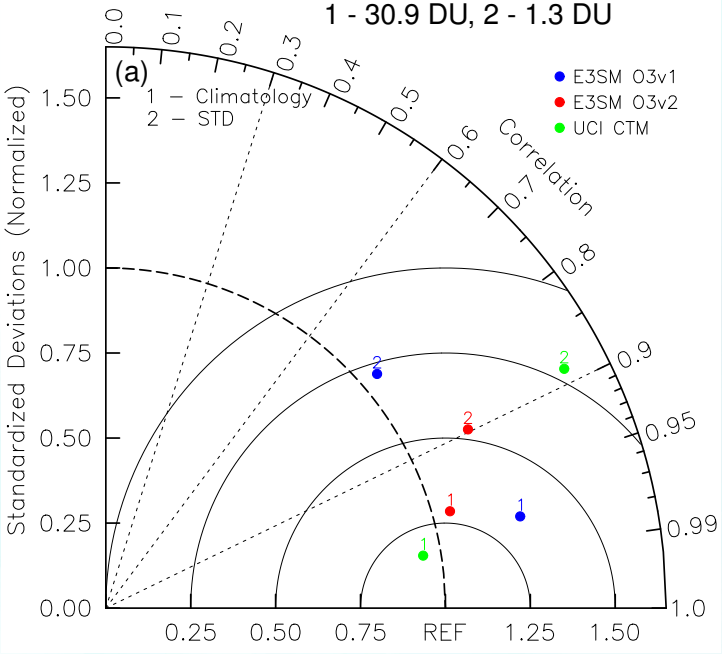
- Implement O3v2 for better cross-tropopause O3 treatment
  - O3v2 O3 is now a passive tracer in troposphere with lower boundary sink.
- Diagnose stratosphere-troposphere exchange (STE) flux of O3
- Overcome E3SMv1 chemistry (O3v1) weaknesses
  - Decadal monthly mean climatology prescribed in trop + Linoz in strat
  - Misses tropopause (TPP) variability, esp. at the jet; assigns high (stratospheric) O3 to trop air when TPP rises above monthly climatology
  - May affect climate (did not examine O3 climatology in release of E3SMv1)
  - Incompatible with chemUCI or any interactive chemistry
  - Cannot diagnose STE flux (major trop O3 budget term)
  - Unrealistic Upper Troposphere / Lower Stratosphere (UT/LS) region

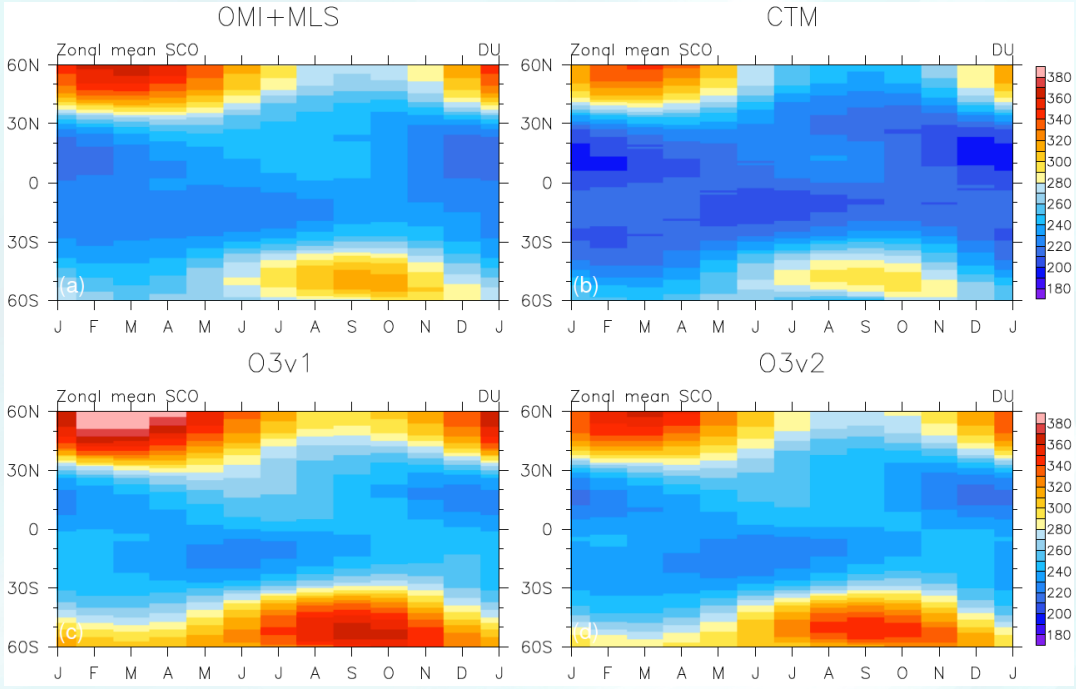
# Simulations and measurements

| Setting | Years | Purpose |
|---|---|---|
| O3v1 AMIP | 1870-2014 | Control run from E3SMv1 DECK |
| O3v2 AMIP | 1990-2014 | O3v2 test run |
| UCI CTM | 1990-2017 | Same O3v2 but using ECMWF circulation and a 199 K PSC T threshold |
| O3v2 F2010 | 0001-0005 | Cess control experiment |
| O3v2 F2010+4K SST | 0001-0005 | Cess experiment with +4K SST |

| Instrument | Years | Specifications |
|---|---|---|
| Aura OMI & MLS | 2005-2017 | 1°, 60S-60N, monthly zonal stratospheric column ozone (SCO) |
| Aura MLS | 2005-2019 | 4°, 82S-82N, <216 hPa, monthly zonal O3 profile |
| Nimbus-7 TOMS, Aura OMI, Suomi NPP OMPS | 1979-2019 | Daily O3 hole area, SH minimum total column ozone (TCO) |

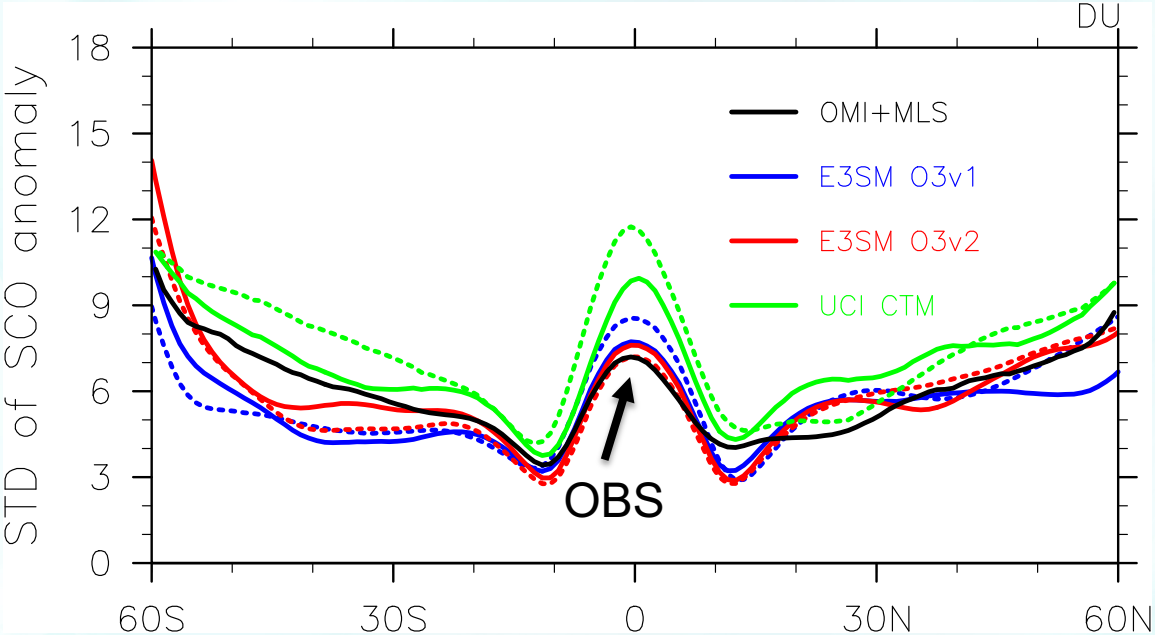
# Zonal stratospheric column $O_3$ (SCO) climatology



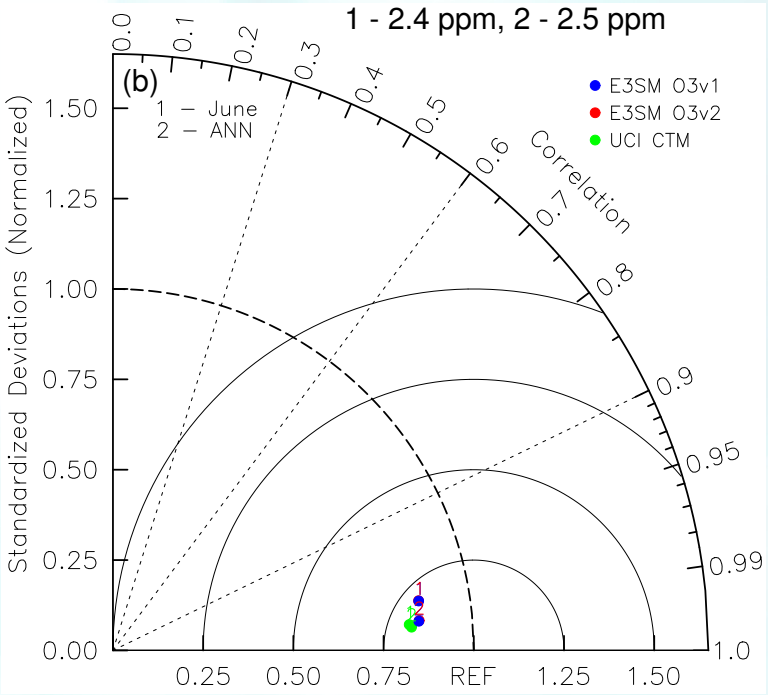

- O3v2 SCO has smaller mean bias (+4% vs. +7%) with similar RMSE.

# SCO residual variability (interannual)



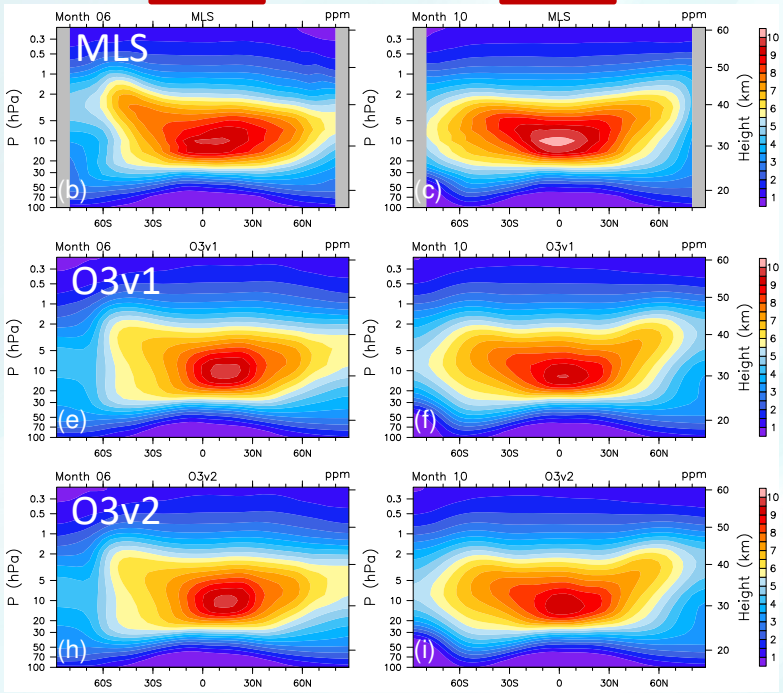

- Tropics: all models overestimate; small O3v1-O3v2 diff due to small TPP var.
- Extra-tropics: O3v2 shows greater var due to more O3 interaction with TPP.
- In SH, O3v2 looks better; in NH, O3v2 and O3v1 are about the same.
- EC winds appear to overestimate interannual (QBO) var.

# Stratospheric (<100 hPa) profile climatology



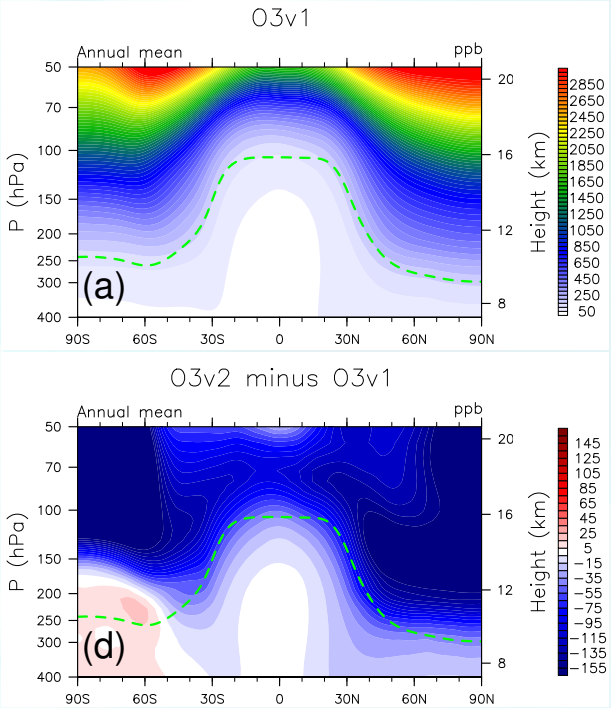

Jun

Oct

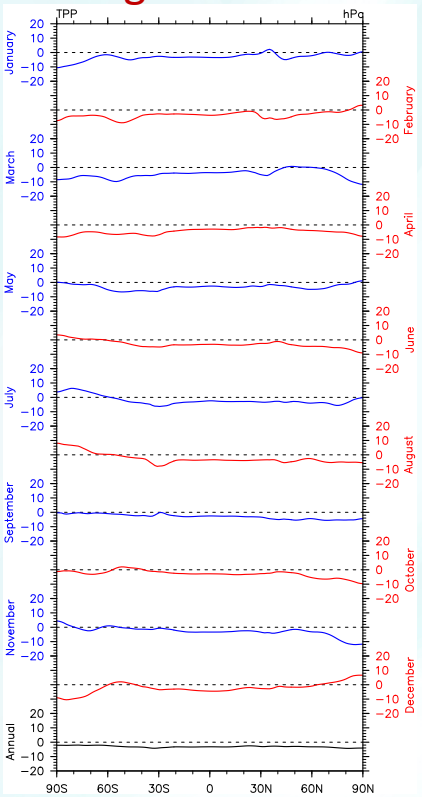



- O3v2 and O3v1 are very similar: makes sense as this region is mostly chemistry driven and they have the same chemistry here.

# O3v2 changes focus in UT/LS

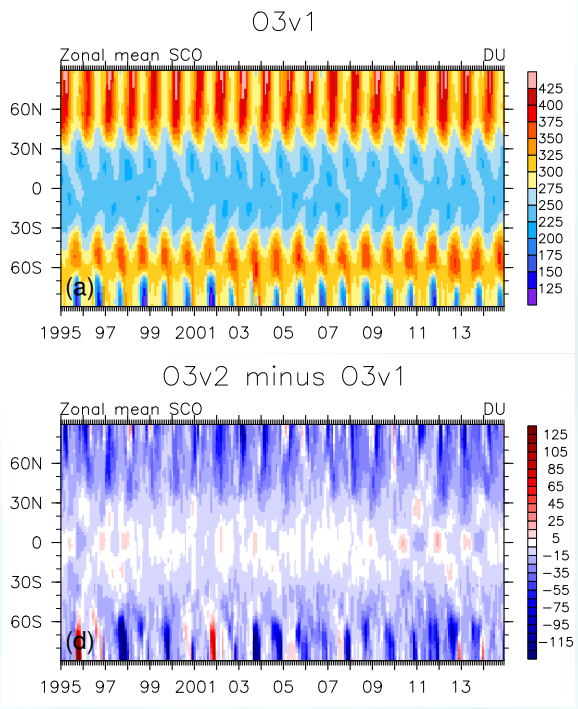


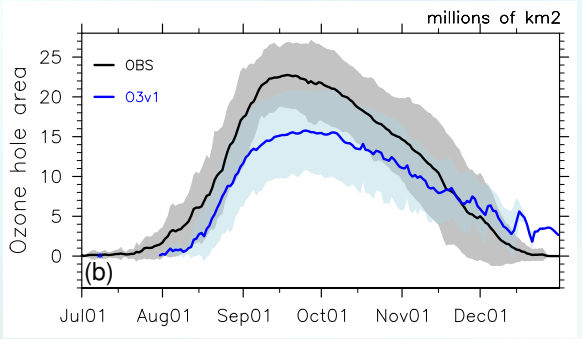

TPP changes: O3v2 – O3v1

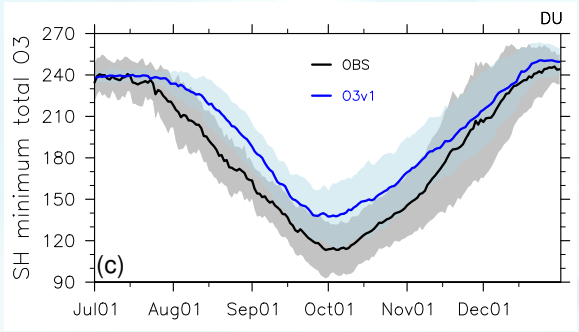


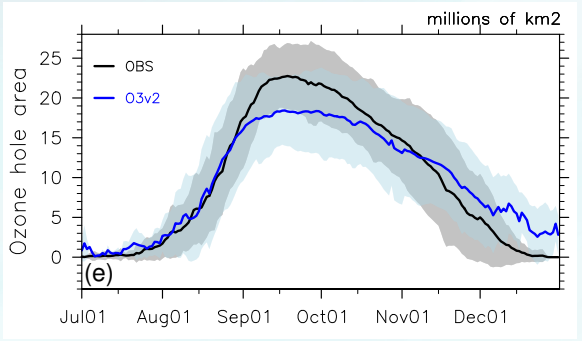

- (Expected) O3 decrease above TPP (>30N), TPP moves up.
- (Unexpected) O3 increases above TPP (<60S), TPP moves down.
- (Unexpected) Antarctic O3 hole is much weaker in many (not all) years.

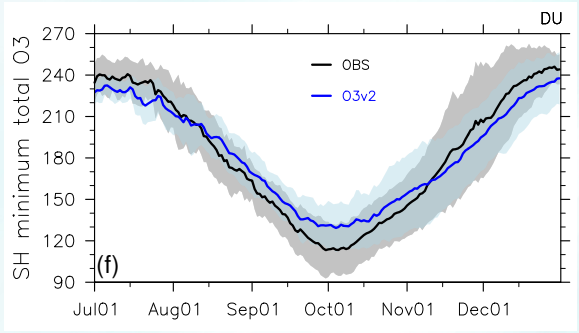
# How is the ozone hole represented?



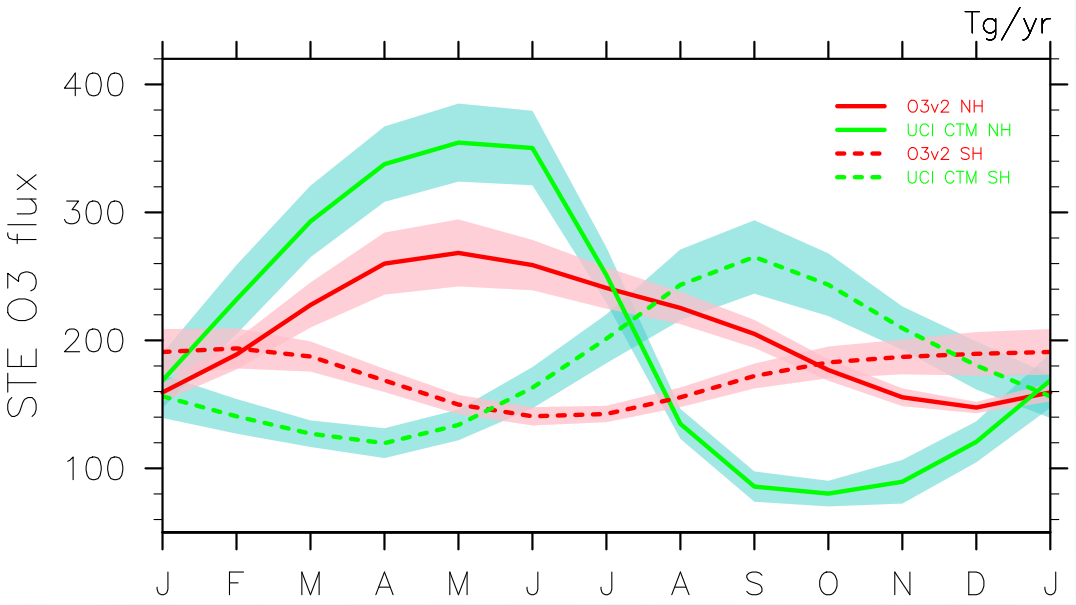



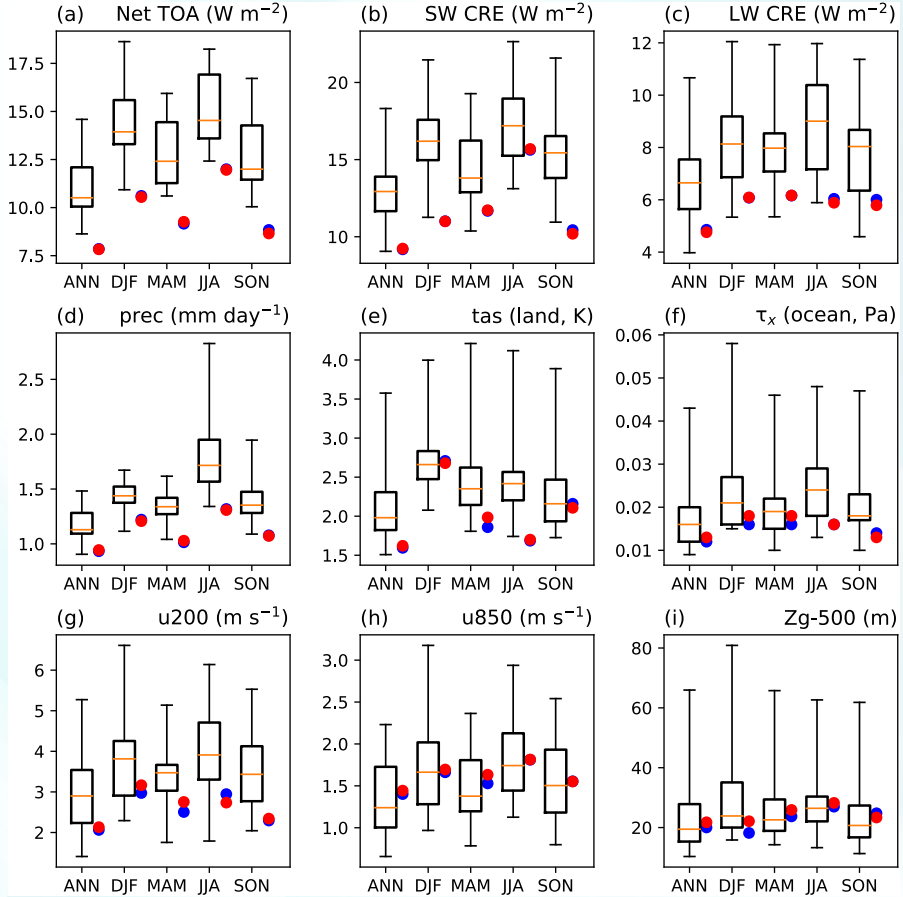

- O3v2 improves both the ozone hole area and minimum TCO with a more realistic polar stratospheric cloud (PSC) T threshold for ozone depletion.

# New STE ozone flux diagnostics




- Similar annual means and similar year-to-year variability for both models
- The seasonal amplitude is 2x larger for the UCI CTM than the O3v2.
- Differences in phases, e.g., 4-month lag in SH.
- ~400 Tg $O_3$/yr falls at the lower end of the constrained global means.

# Do global mean climate & sensitivity change?




## O3v1 vs O3v2

$\lambda = -\Delta F_{TOA}/\Delta T_{glb\_avg}$

| | $\lambda$ (W/m2/K) |
|---|---|
| O3v1 (LR) | -1.36 |
| O3v2 | -1.38 |
| O3v1 (HR) | -1.29 |

(Caldwell et al., 2019)

**not a lot of differences**

# Conclusions

- O3v2 corrects the unphysically high ozone biases in the lowermost stratosphere found in O3v1 and retains the shape cross-tropopause ozone gradient.
- O3v2 enables the new diagnostic of the stratosphere troposphere exchange of ozone flux, an important tropospheric ozone budget term.
- The temperatures (T) in the Antarctic winter stratosphere increase with O3v2, and thus allow us to simulate a better ozone hole with a more realistic polar stratospheric cloud T threshold.
- Applying the same climate diagnostics as the E3SMv1 overview papers, we quantify almost identical global climate and climate sensitivity for O3v1 and O3v2, confirming the fidelity of the E3SMv1 climate simulations.