Evaluation of WACCM simulations of winter 2004-2005 Arctic ozone

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SUMMARY

The work presented here evaluates polar stratospheric ozone (O_3) simulations of the Community Earth System Model (CESM) Whole Atmosphere Community Climate Model (WACCM) component set for the Arctic winter of 2004-2005 by comparing to the Earth Observing System Microwave Limb Sounder (MLS). We use the Specified Dynamics version of WACCM (SD-WACCM), in which temperatures and winds are nudged to meteorological assimilation analysis results.

Results:

- Modeled vortex-averaged O_3 and related constituents for December 2004 through March 2005 generally compare well to observations **[Fig. 2]**
- We attribute the SD-WACCM O_3 overestimate to too much simulated descent early in the winter, too much mixing across the vortex edge later in the winter, and too little heterogeneous processing of halogens **[Fig. 2]**
- Errors in transport and mixing result in excess transport of O_3-rich air into the lower stratospheric polar vortex **[Fig. 3]**
- Errors in heterogeneous processing result in underestimate of activated chlorine, thus too little chemical ozone loss **[Fig. 2]**
- Too much depletion of nitric acid, suggesting overestimate in production of PSCs **[Fig. 4]**
- Even though the previous result would lead to excess availability of aerosol surface area for heterogeneous reactions, underprediction of $ClONO_2$ limit such reactions **[not shown]**
- 1.1 ppmv of inferred ozone loss on average and up to 1.6 ppmv locally **[Fig. 5 & 6]**
- O_3 loss based on the pseudo-passive ozone subtraction method similar to that based on tracer-tracer correlations **[Fig. 7]**
- O_3 loss in good agreement with previous independent results for the Arctic winter of 2004-2005 **[Fig. 8]**

1. METHOD

- Initialization on 1 Dec (O_3, N_2O, HNO_3, HCl, and H_2O)
- Three model simulations (nudged with u, v, T, p_{sfc}):
  - full-ozone chemistry
  - gas-phase-ozone chemistry only (pseudo-passive O_3)
  - -1.5K T bias for Cl activation due to heterogen. chemistry
- Polar vortex averaging (sPV > $1.4\cdot10^{-4}s^{-1}$)

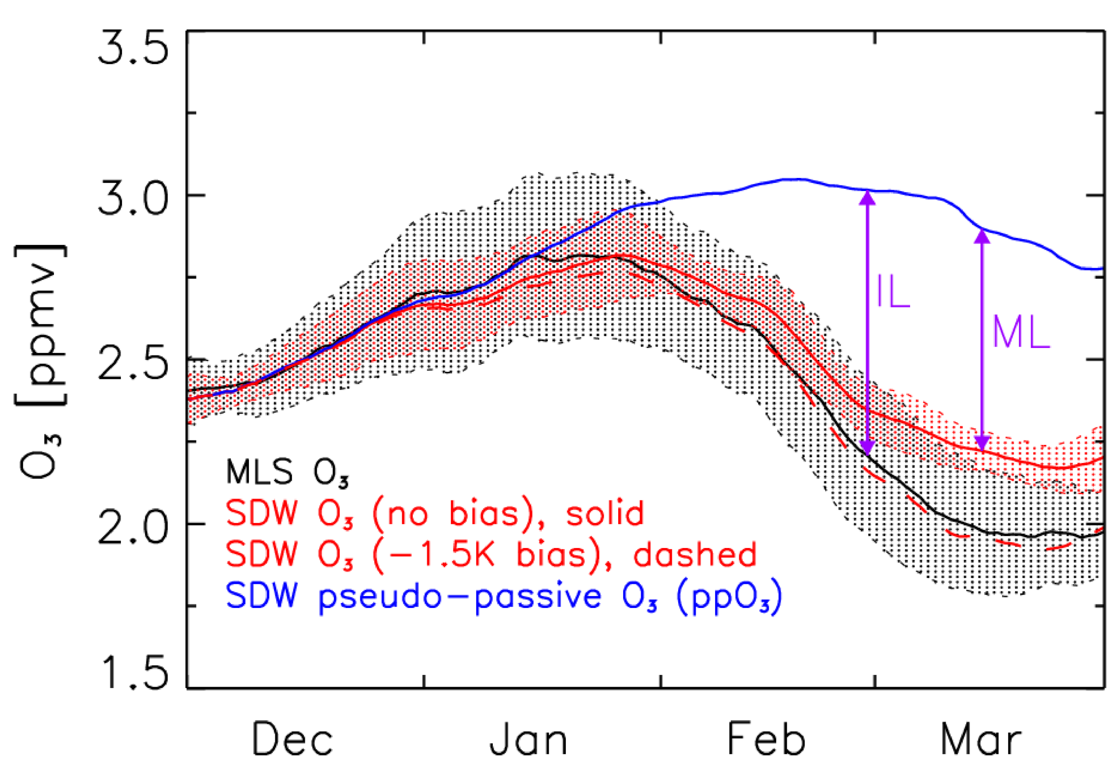

Fig. 1: Evolution of vortex averaged MLS O_3, SD-WACCM O_3, and SD-WACCM pseudo-passive O_3 (ppO_3) at 450 K.

Inferred O_3 loss (IL) = MLS O_3 - SD-WACCM ppO_3

Modeled O_3 loss (ML) = SD-WACCM O_3 - SD-WACCM ppO_3

The shaded areas are O_3 vortex averages ± one standard deviation of the data used for the vortex average (natural variability).

Also shown is the evolution of vortex averaged SD-WACCM O_3 with a -1.5 K bias for heterogeneous chemistry (dashed red).

Natural variabilities inside vortex overlap before March. Imposing -1.5 K bias improves het. chem. and brings modeled O3 closer to observations.

2. EVALUATION OF SD-WACCM

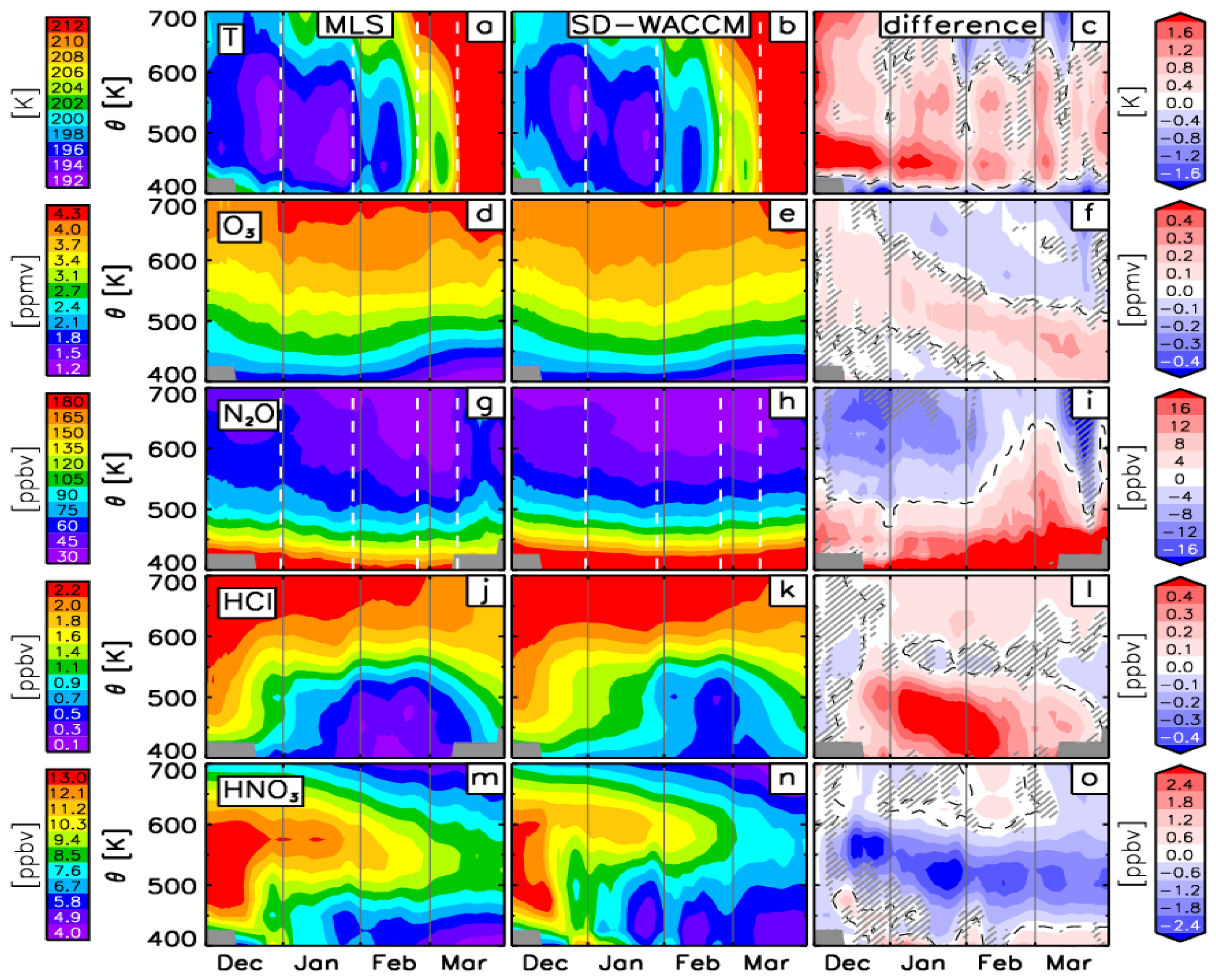

Fig. 2: Evolution of vortex averaged MLS (left), SD-WACCM (center) and their difference (right).

Difference = SD-WACCM - MLS, gray areas indicate no data inside the polar vortex or missing data, white lines are warming events, hatched areas are not statistically significant

Good agreement in T (±2K) and O_3 (±15%), correct N_2O (±20%) morphology. HCl (±50%) and HNO_3 (±20%) show small discrepancies.

3. COMPARISON OF MEASURED AND MODELED N_2O

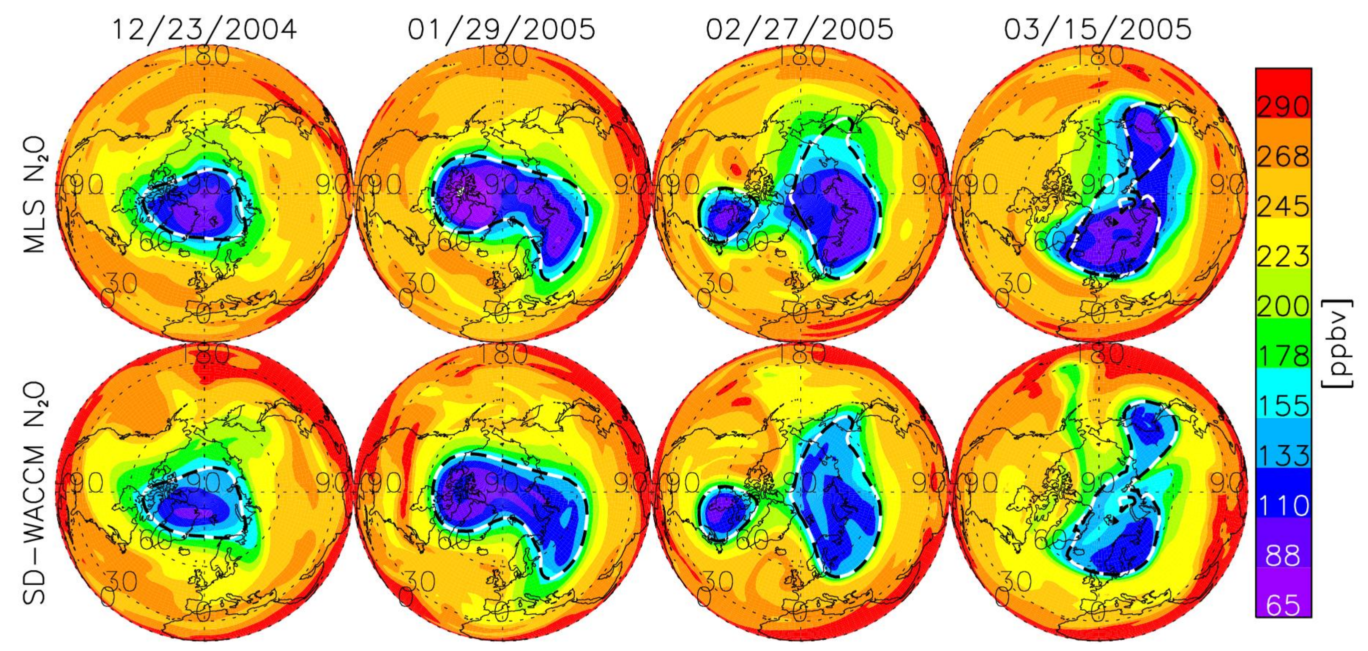

Fig. 3: Spatial distribution of N_2O at 450 K for one day each month throughout the season with polar vortex edge line contour. The final warming began Mar ~10 [*Manney et al.*, 2006].

Model overestimates mixing processes across vortex edge late in the winter.

4. COMPARISON OF MEASURED AND MODELED HNO_3

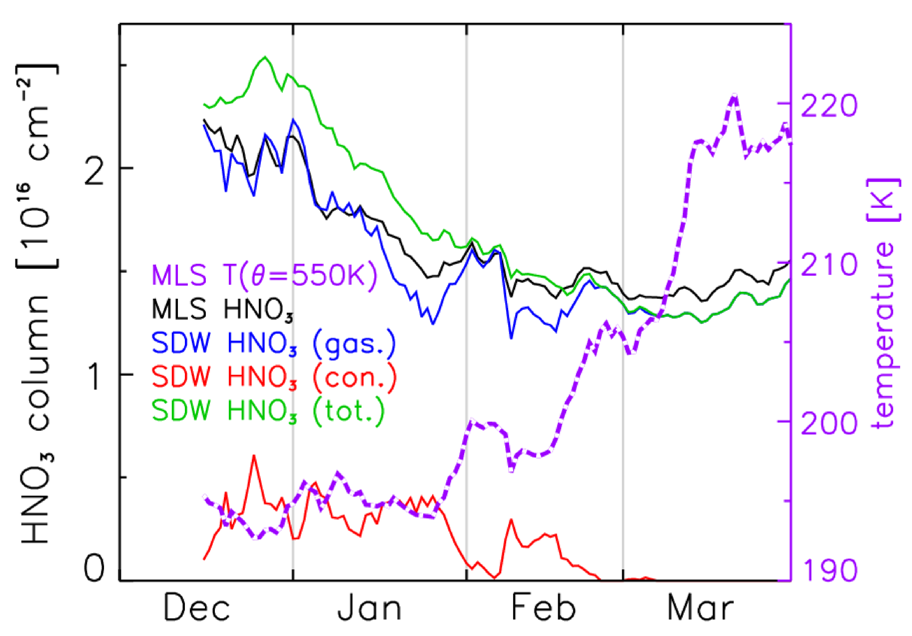

Fig. 4: Partial columns (400 K – 700 K) of polar vortex averaged modeled and observed gas-phase HNO_3.

Modeled condensed-phase HNO_3 (~PSCs) and modeled total HNO_3

MLS temperature at 550 K is superimposed.

Modeled uptake of HNO_3 is overestimated at local minima of T. Difference in March hints at permanent HNO_3 removal.

5. CHEMICAL O_3 LOSS DUE TO HET. ACTIVATED HALOGENS

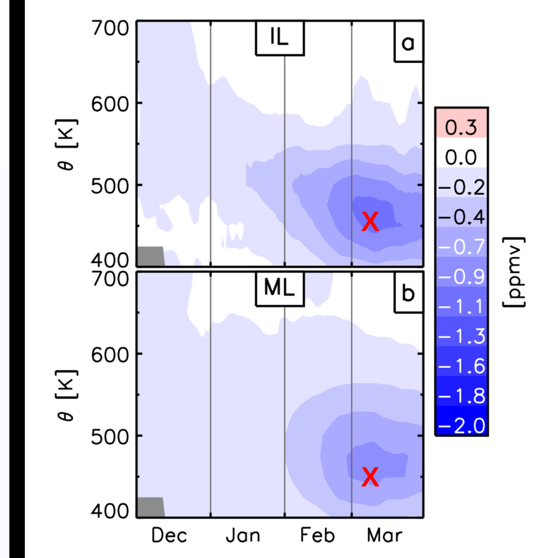

Fig. 5: Evolution of O_3 loss profile using the pseudo-passive subtraction technique. Model underestimates O_3 loss by ~18%.

O_3 loss due to halogens peaks in lower stratosphere. Model underestimates O_3 loss.

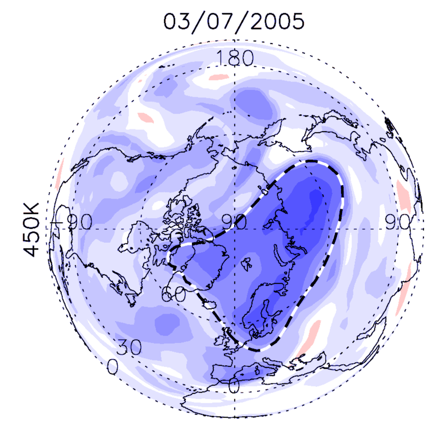

Fig. 6: Spatial distribution of IL at 450 K on 7 March 2005.

Polar vortex edge white/black dashed.

Largest local O_3 loss up to 1.6 ppmv.

Locally large O_3 loss due to spatially inhomogeneous T distribution.

6. EVALUATION OF O_3 LOSS RESULTS

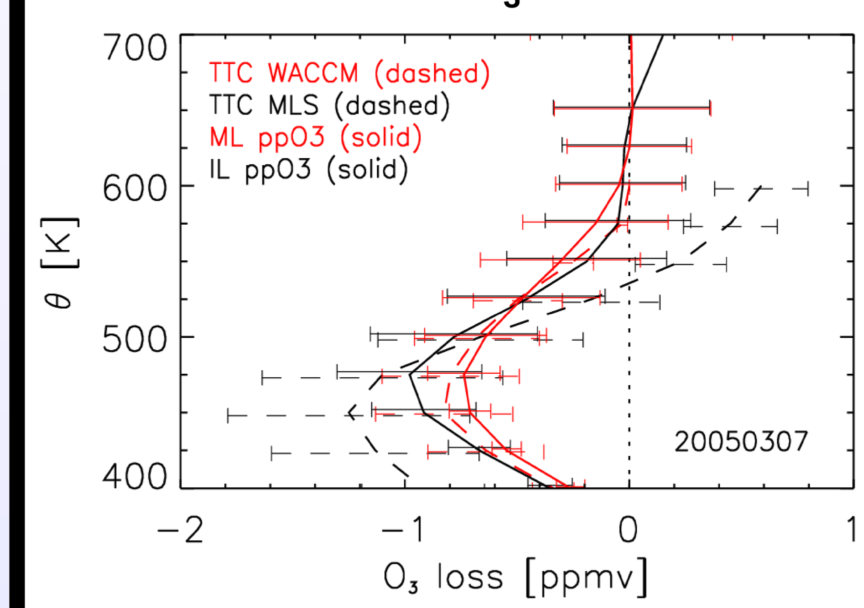

Fig. 7: Polar vortex averaged O_3 loss on Mar 7.

Inferred and modeled O_3 loss. Tracer-tracer correlation technique (dashed) and pseudo-passive subtraction technique (solid). Horizontal bars show ±1σ.

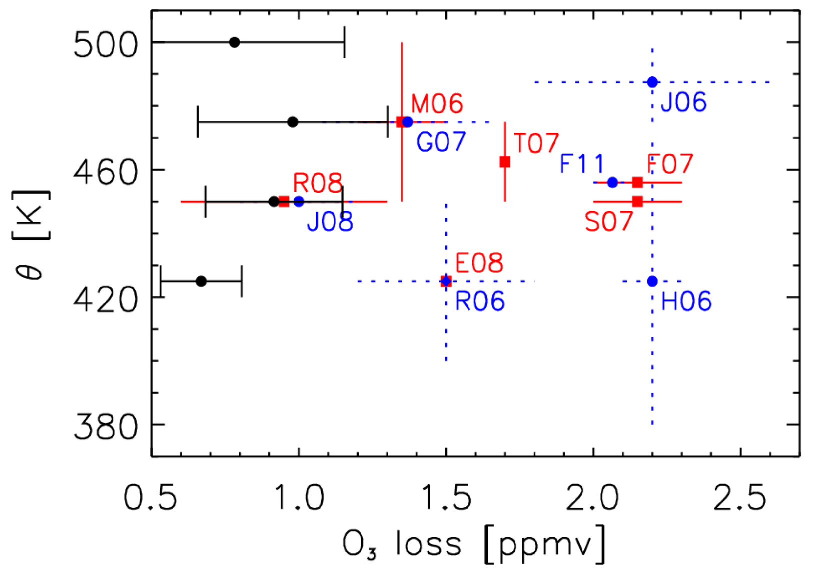

Fig. 8: Comparison of this study's O_3 loss results (black) with previous research.

Blue and red colors as well as linestyles were chosen for better legibility only.

O_3 loss results are independent of method and are in the range of previous research.

M06	*Manney et al.*, 2006	R08	*Rösevall et al.*, 2008	J06	*Jin et al.*, 2006b
S07	*Singleton et al.*, 2007	T07	*Tsvetkova et al.*, 2007	F07	*Feng et al.*, 2007
H06	*von Hobe et al.*, 2006	J08	*Jackson & Orsolini*, 2008	F11	*Feng et al.*, 2011
E08	*El Amraoui et al.*, 2008	G07	*Grooß and Müller*, 2007	R06	*Rex et al.*, 2006

CONCLUSIONS

- SD-WACCM is valid for inferring O_3 loss from observations.
- More accurate simulation of O_3 loss in WACCM requires further investigation of chlorine partitioning and PSC particle sizes.
- Equivalent analysis for Antarctic winter needed to better investigate mixing and descent.
- Future plans include O_3 loss calculations for all Arctic and Antarctic winters since 2004.

References:

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