Stratospheric Denitrification in WACCM and Impacts on Polar Chemistry

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+

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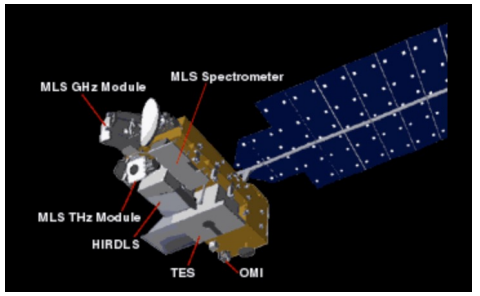
WACCM / Cheyenne

Chemistry

MIPAS ENVISAT



OMI/MLS Aura

WACCM Working Group Meeting
NCAR/ACOM,
13 June 2023

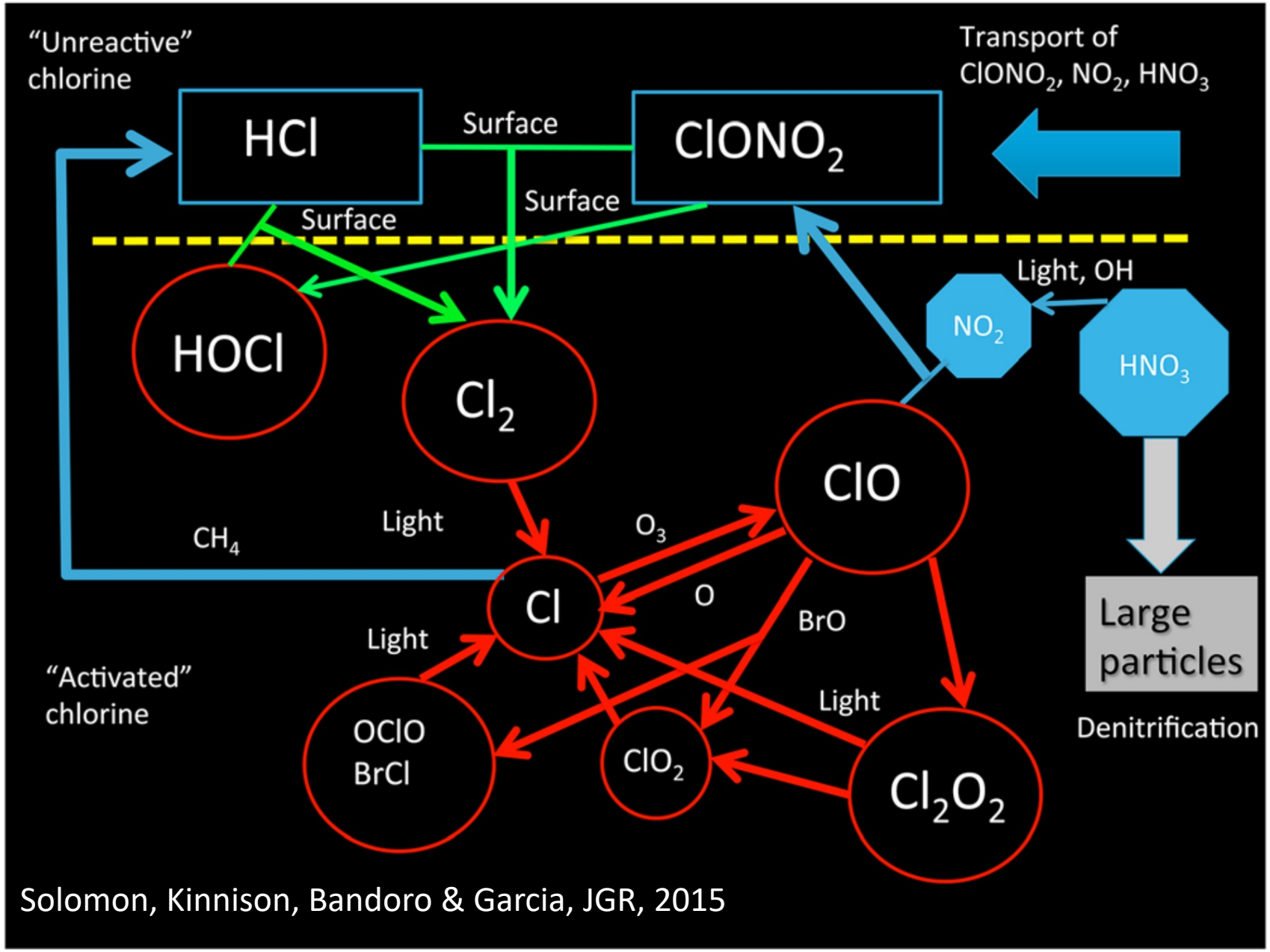
Ozonesondes

(Funded by NASA ACMAP grant 80NSSC19K0952)

NCAR

WACCM

Whole Atmosphere Community Climate Model



Why do we care about Denitrification?

>195K HNO_3 (g), Liquid binary sulfate (LBS)

~195K NAT forms

deNOy occurs; larger particles, faster settling rate, more deNOy

~192K Supercooled Ternary Solution forms (STS) – Liquid aerosols that swell and uptake HNO_3 and HCl. Main SAD that activates (inorganic chlorine)

Competition between activation and deactivation in the polar spring.

Observations and Model version

Satellite Data:

- **HNO_3 (g)** *** Microwave Limb Sounder (MLS) (Aura), ~4km vertical resolution
  - ~4km vertical res., >0.6ppbv precision
  - Examined only year 2020 (cold NH winter)

- **HNO_3 (g)** *** Michelson Interferometer for Passive Atmospheric Sounding (MIPAS), V8
  - **~3km** vertical res., **0.2 ppbv** precision
  - Examined years 2002-2012

- **Total Column Ozone** *** Ozone Monitoring Instrument (Aura)

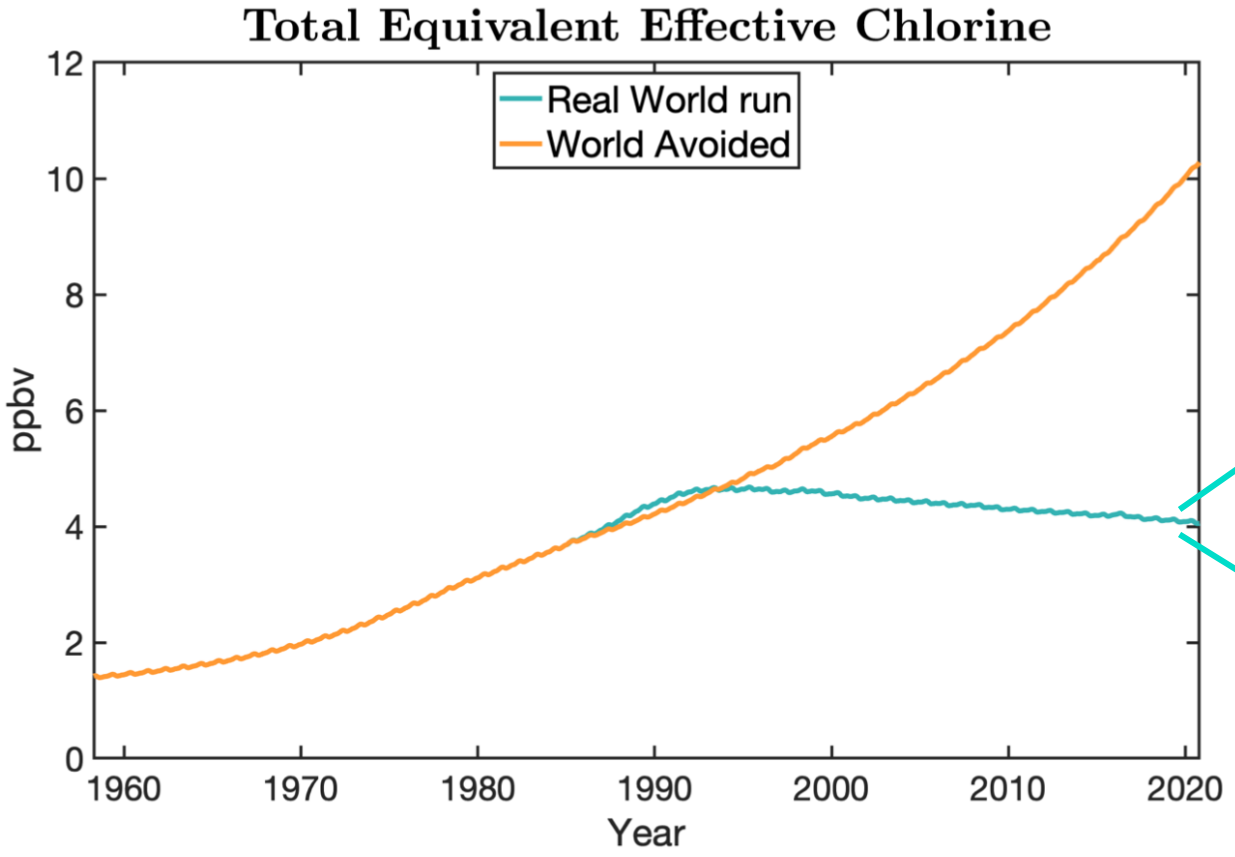
Ozonesonde

- @Eureka Station (80ºN, 86ºE)
- Electrochemical conc. cell, precision 3-5%, uncertainty +-10%

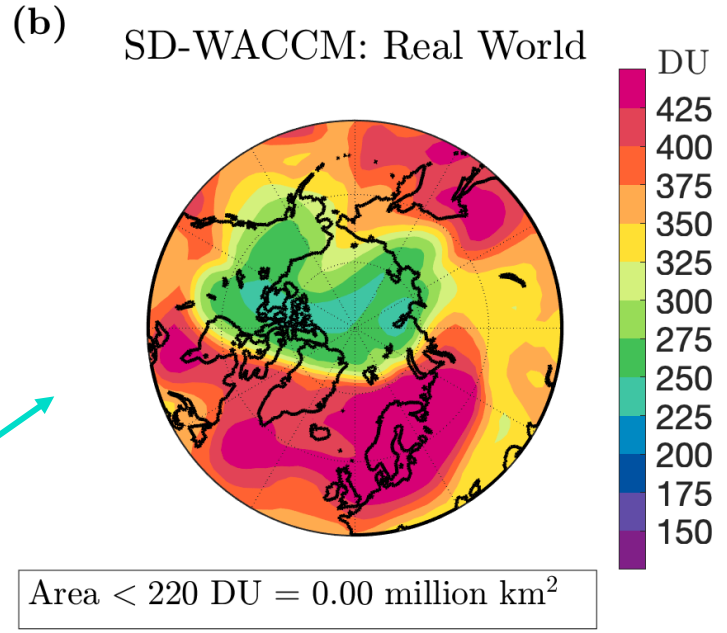
Model: CESM2 (WACCM6):

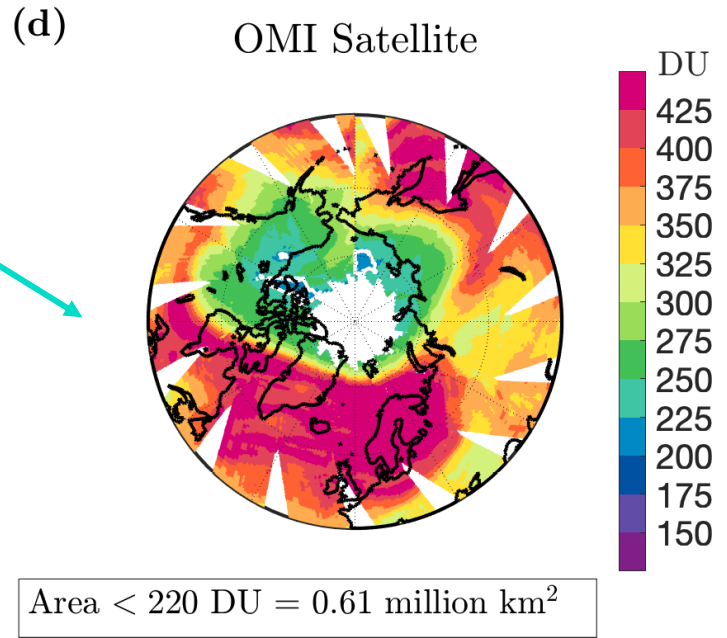
- 2-Deg horizontal, 0-140km
- Meteorological field constraints from MERRA-2– representative temperatures!

Wilka, Solomon, Kinnison, Tarasick, An Arctic ozone hole in 2020 if not for the Montreal Protocol, Atmos. Chem. Phys., 21, 15771–15781, 2021



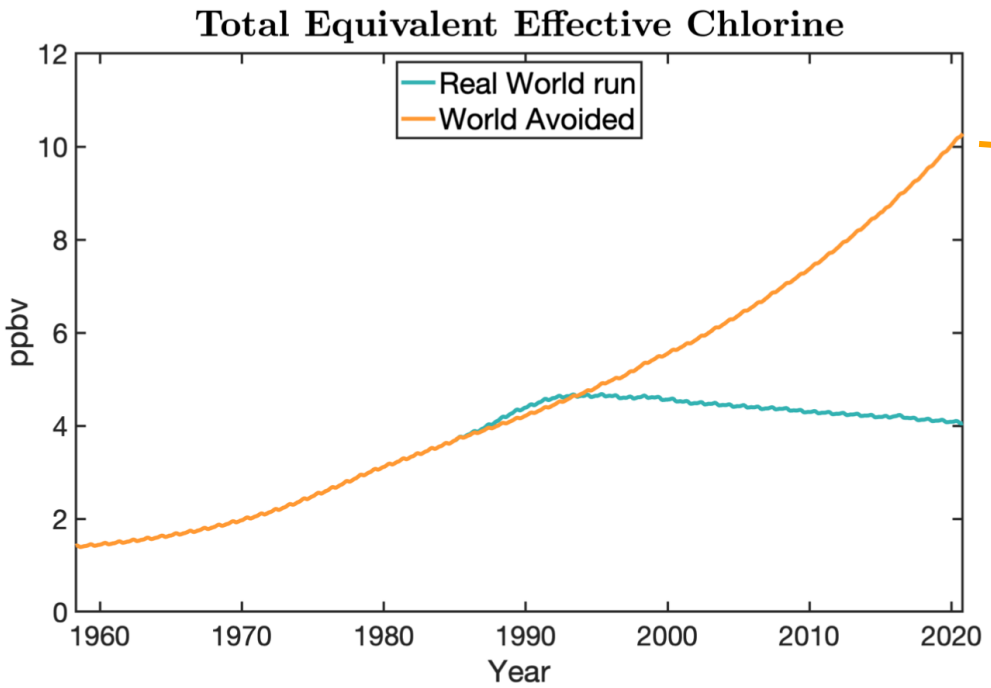
Total Colum Ozone on 13 March 2020



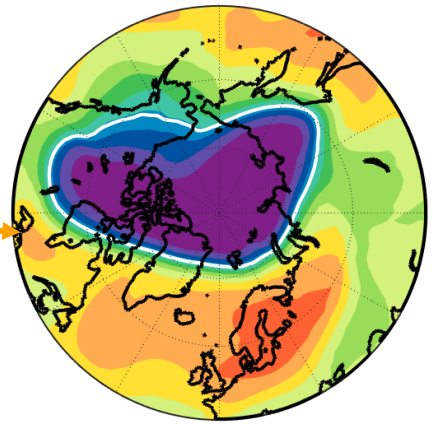


Excellent agreement with OMI.

Total Column O_3 on 13 Mar 2020

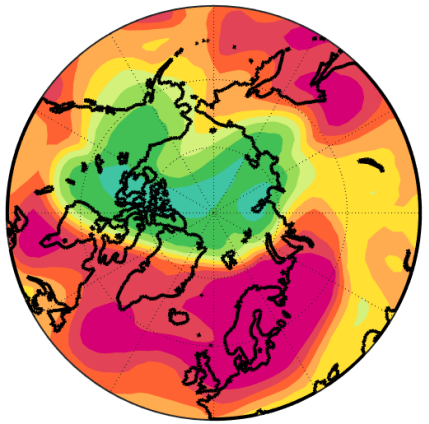


(a) SD-WACCM: World Avoided



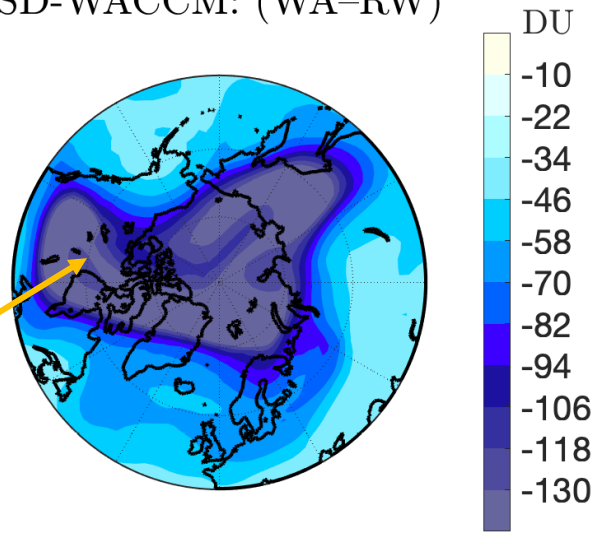
Area < 220 DU = 19.71 million km^2

(b) SD-WACCM: Real World

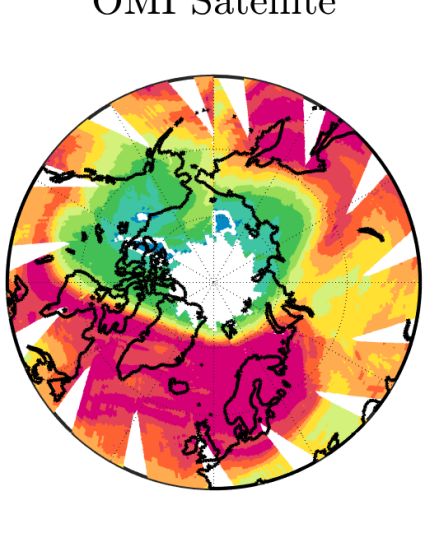


Area < 220 DU = 0.00 million km^2

(c) SD-WACCM: (WA–RW)



(d) OMI Satellite



Area < 220 DU = 0.61 million km^2

Difference [World Avoided – Real World]
>130DU depletion and a Northern Hemisphere Ozone hole area **(~20 million km²)** similar to Southern Hemisphere.

NAT Settling and Denitrification in WACCM

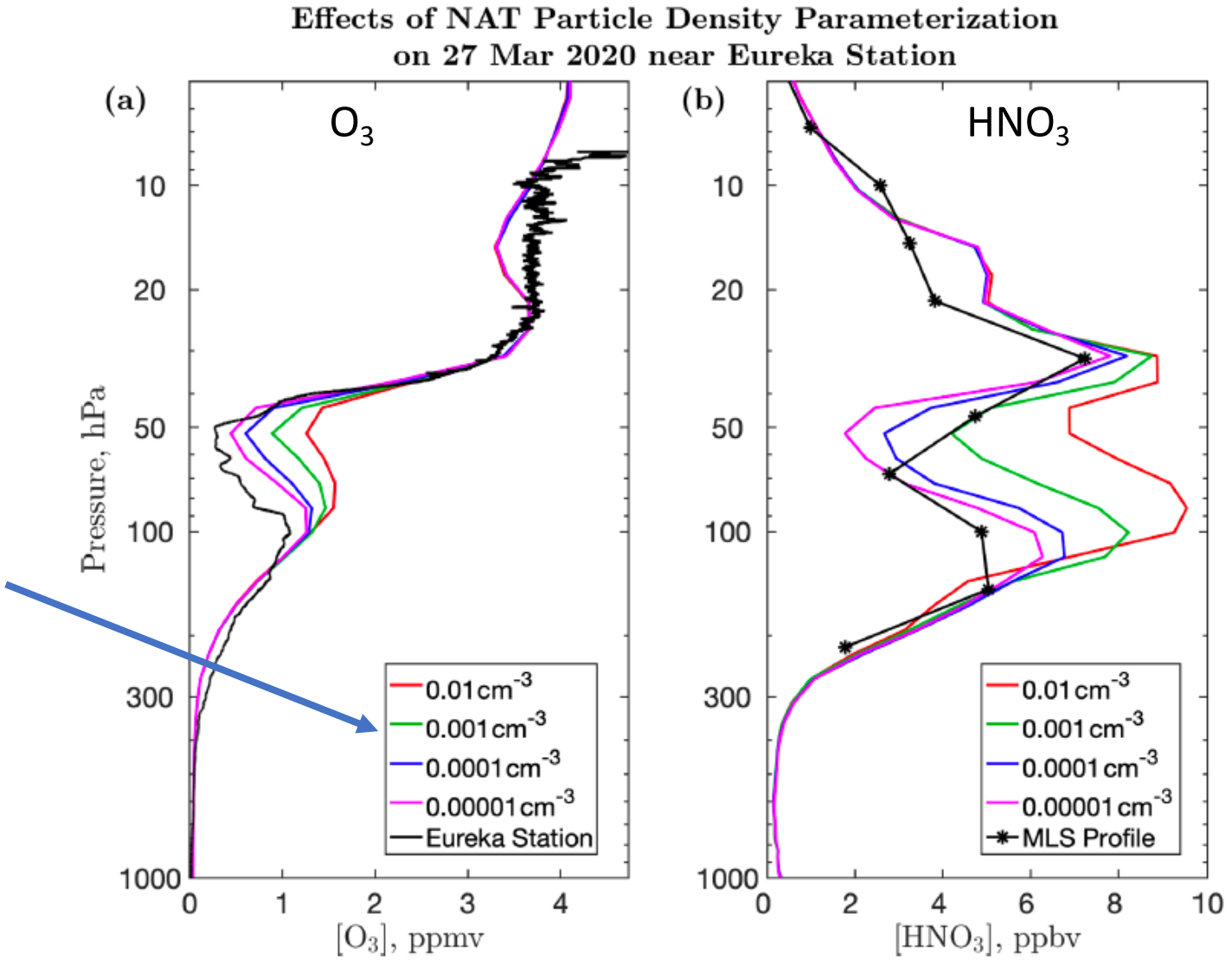
- Derive the amount of condensed phase HNO_3 (assume supersaturation of 10)
- Assume a lognormal size distribution, specify the width and #particles cm^{-3}.
- Derive a Mean Radius (deNOy) and Surface Area Density (het. Chemistry)

NH observations suggest NAT rocks form (Fahey et al., 2001).

NAT radius is proportional to the amount of condensed phase HNO_3 and #particles cm^{-3}.

The NAT radius is used to derive the settling velocity for NAT.

Use one # global value for #particles per cm^{-3}.



Next Step: We wanted to use a more quantitative approach at deriving the **# NAT particles per cm^{-3}** to:

- Better represent HNO_3(g) and
- the amount of HNO_3 available for STS (ozone depletion).

Approach:

- Comparison to MIPAS HNO_3(g)
- Also examined MIPAS O_3 and $ClONO_2$ (not discussed today).

Analysis Approach Using MIPAS data and Model Output

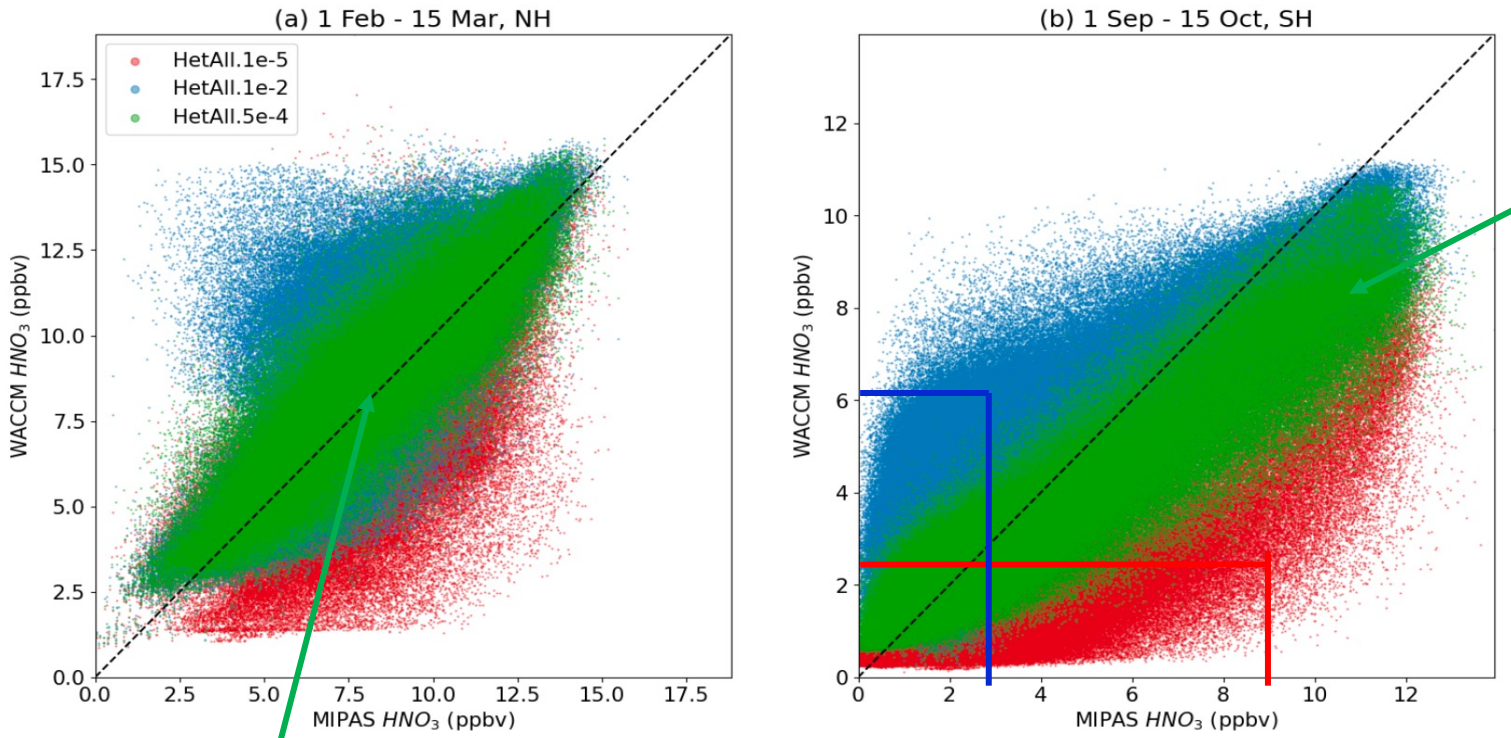
- SD-WACCM6 simulations for the 2002-2012 MIPAS period using multiple NAT particle densities (1e-5, 5e-4, 1e-2).
- Used coordinate analysis output approach where we output HNO_3 profiles from the model at measurement locations (lat/lon/time)
- Sampled only model and observations within the NH and SH polar vortex (using the Nash Criteria; i.e., Ertel PV max gradient) during Spring.
- Created Scatter plots (Obs vs Model sims) – show today.
- Created vortex average time series for given years and 2002-2012 Average – show today.
- Created PDFs (Obs vs Model sims) – show today
- Created Cumulative density functions and derived the maximum difference between obs and model simulation. (Zambri, Kinnison, Solomon, GRL, 2020) – not shown today.

Weimer, Kinnison, Wilka, and Solomon, Effects of denitrification on the distribution of trace gas abundances in the polar regions: a model-data comparison, ACP, in press, 2023.

Vortex average 2002-2012: Model uses MIPAS profile coordinates (lat, lon, time)

NAT particle densities: **1e-5**, **5e-4**, **1e-2**.

NH **Spring, 30-150hPa** SH



The SH **5e-4** value does tend to overestimate the denitrification.

NH fits the **5e-4** NAT density really well – consistent with the Wilke et al. study.

Best: NAT particle Density of 5×10^{-4} cm^{-3}

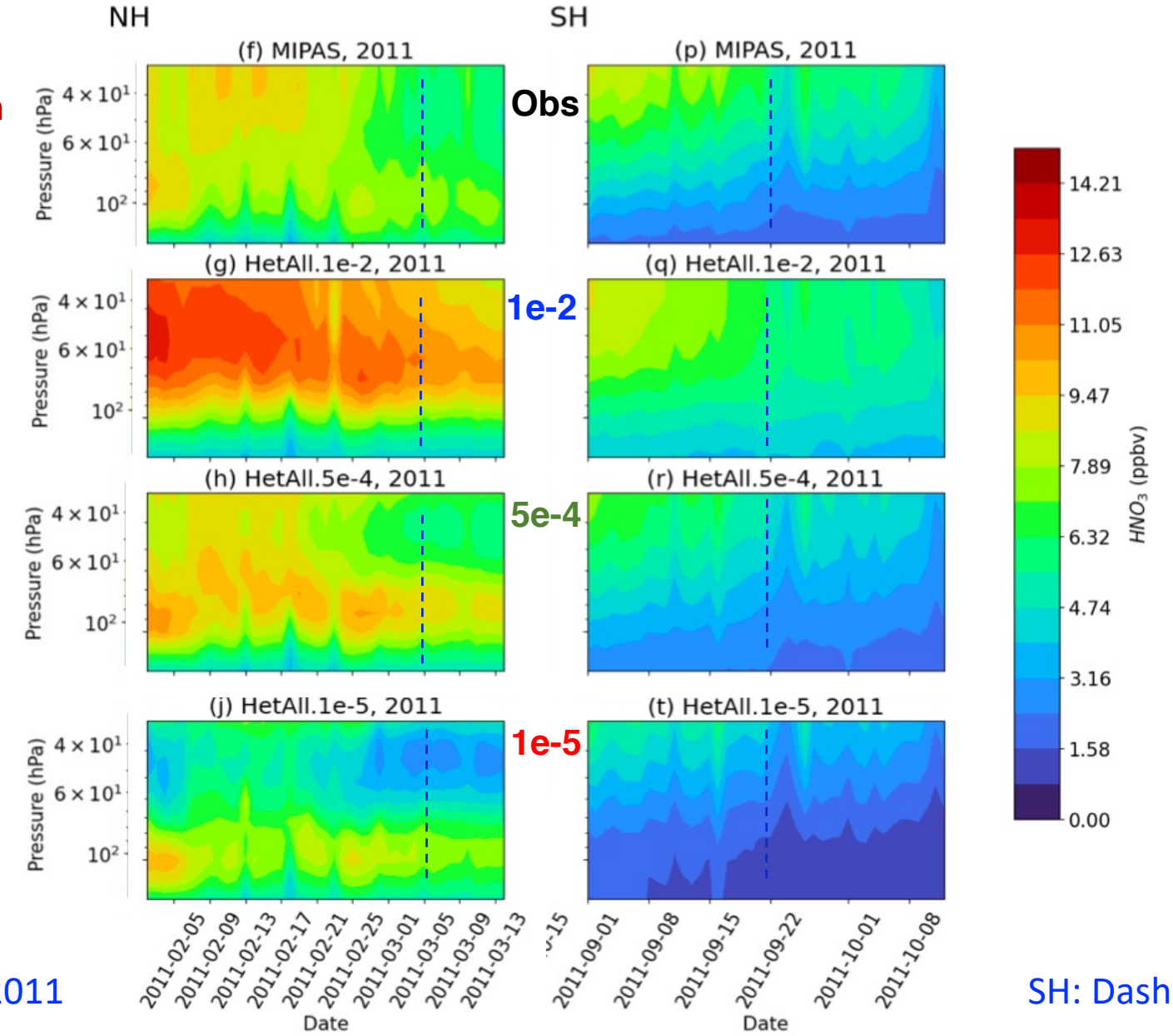
Vortex average time series for year 2011(150-30hPa)

2011 cold NH year, with noticeable deNOY

Very little deNOY with this NAT density

Consistent with Obs.

Too much DeNOy



As the tracer/tracer comparison showed, **5e-4** NAT density does a good job of representing the deNOY

NH: Dashed line is 3/1/2011

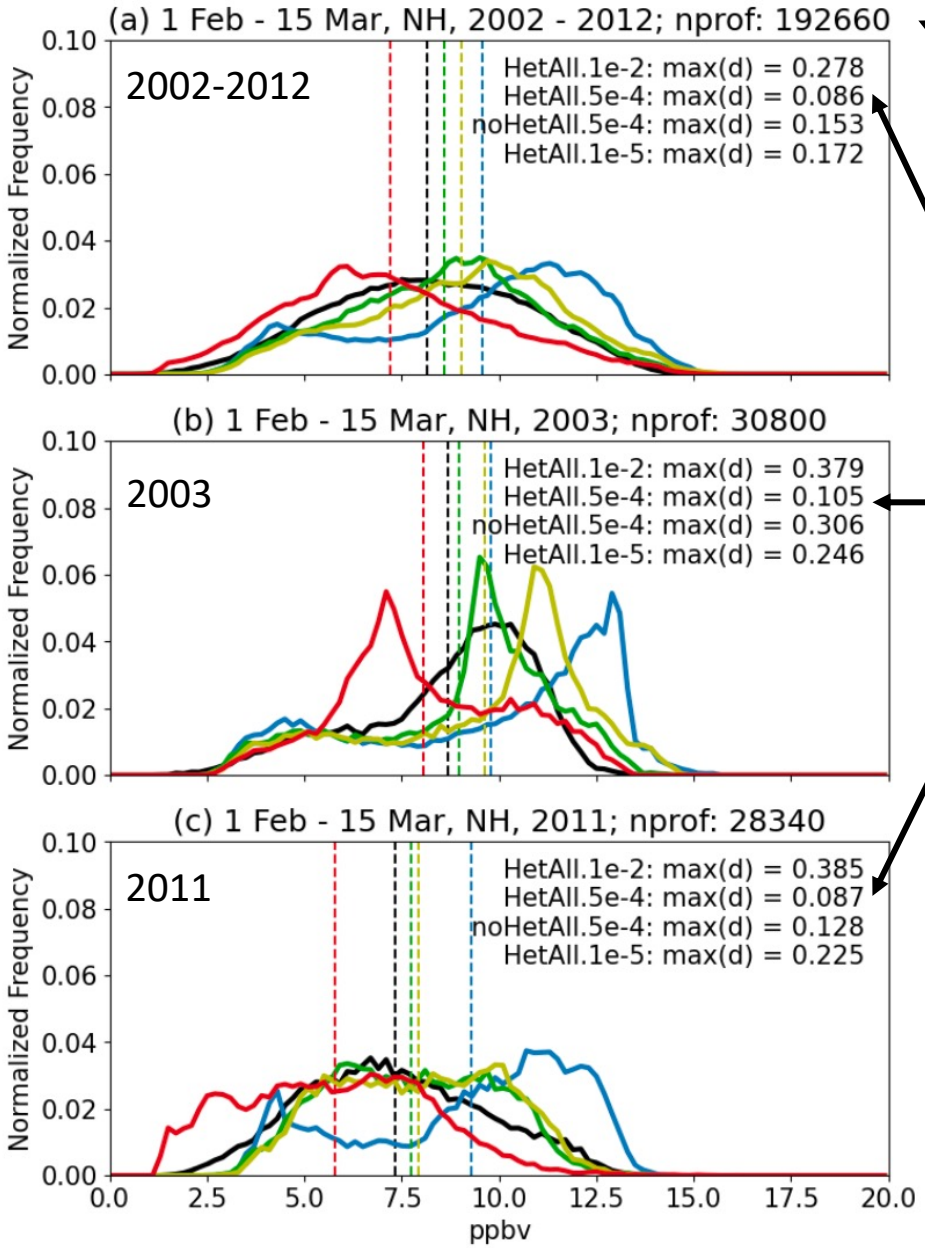
SH: Dashed line is 9/22/2011

Northern Hemisphere

Particle density:
1e-5, 5e-4, 1e-2.

Black line = MIPAS

Note: ~200,000 profiles



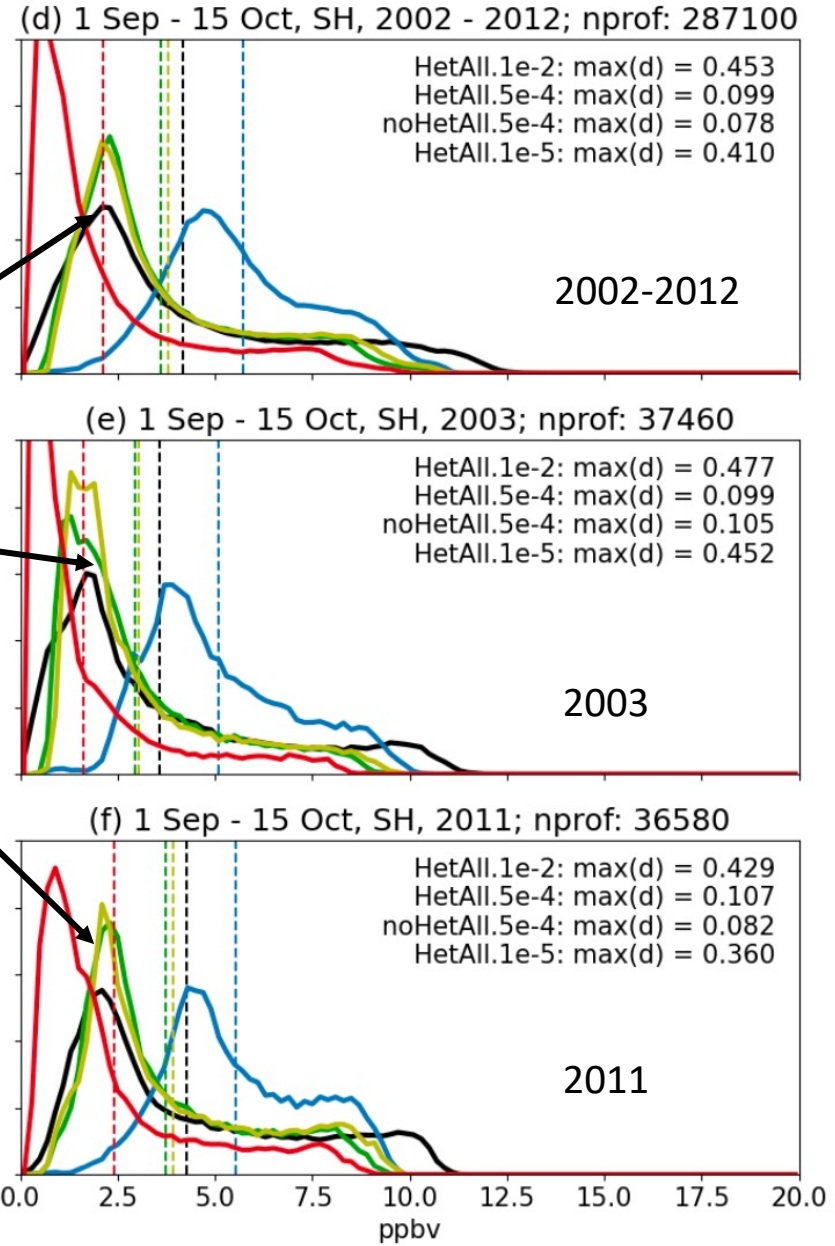
The **Max(d)** is the difference in the Cumulative density function. Smaller the number the more consistent with Obs. The **5e-4** NAT particle density is the most representative of the observations. See Weimer et al., ACP, for more details.

One can visually see that the **5e-4** NAT particle density agrees better with MIPAS.

Southern Hemisphere

Particle density:
1e-5, 5e-4, 1e-2.

Black line = MIPAS



One can visually see that the **5e-4** NAT particle density agrees better with MIPAS.

Shape and means of the PDF is best represented by NAT particle Density of 5×10^{-4} cm^{-3}

A NAT particle density of **$5x10^{-4}$ cm^{-3}** will be used in all versions of CESM2 “chemistry versions” going forward.

See the Weimer et al. ACP, 2023 paper for more details.

Thank you for your attention!