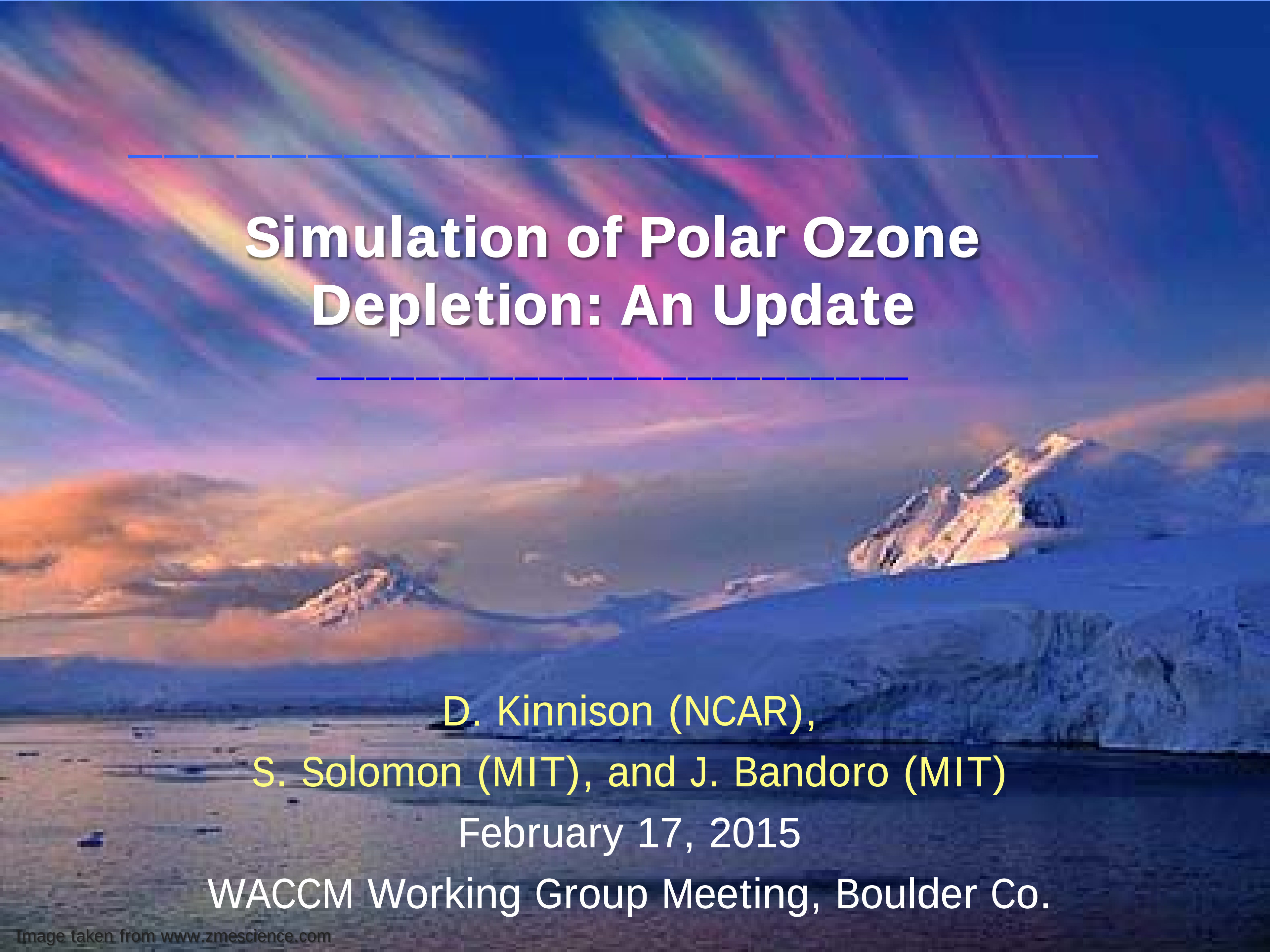

Simulation of Polar Ozone Depletion: An Update

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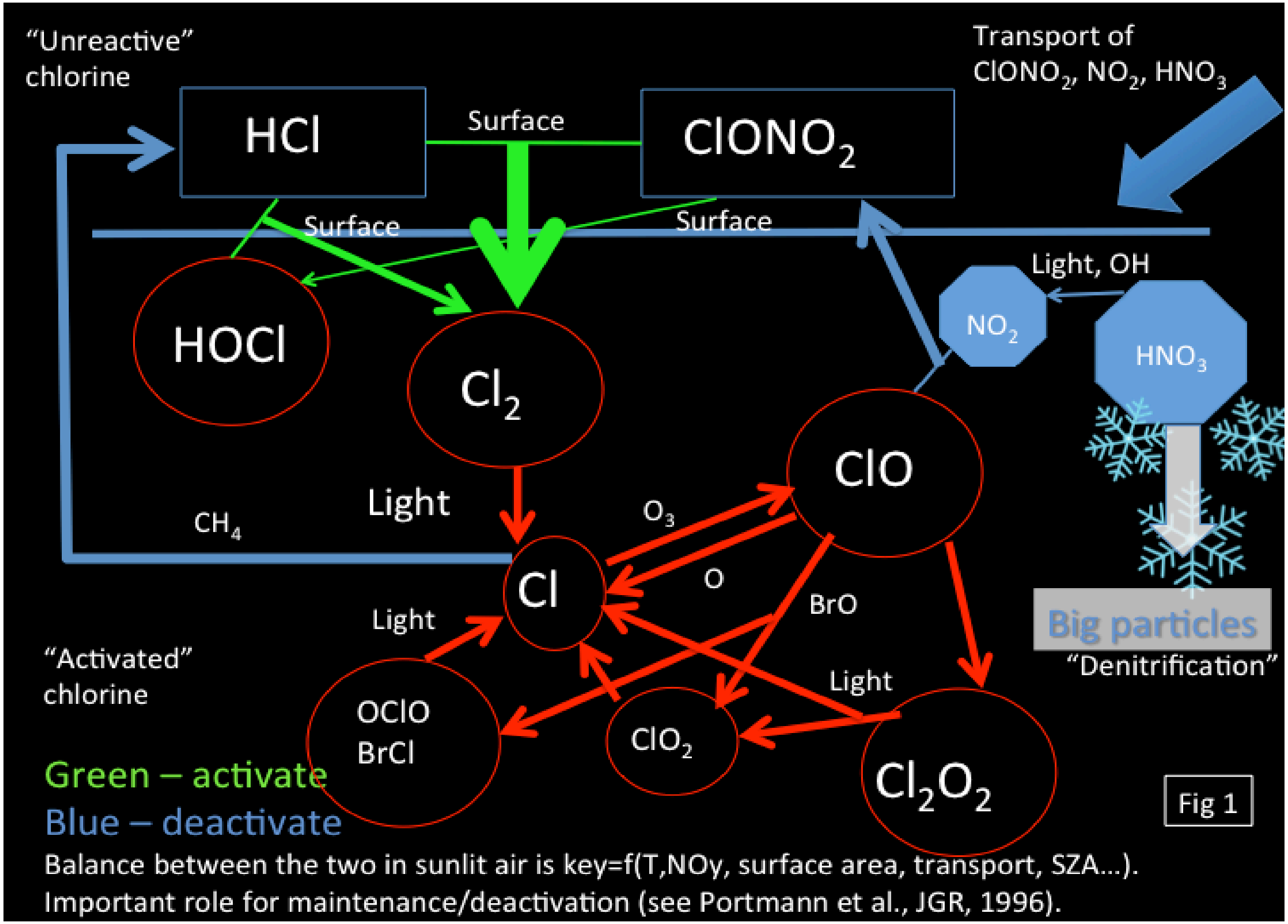
S. Solomon (MIT), and J. Bandoro (MIT)

February 17, 2015

WACCM Working Group Meeting, Boulder Co.

Image taken from www.zmescience.com

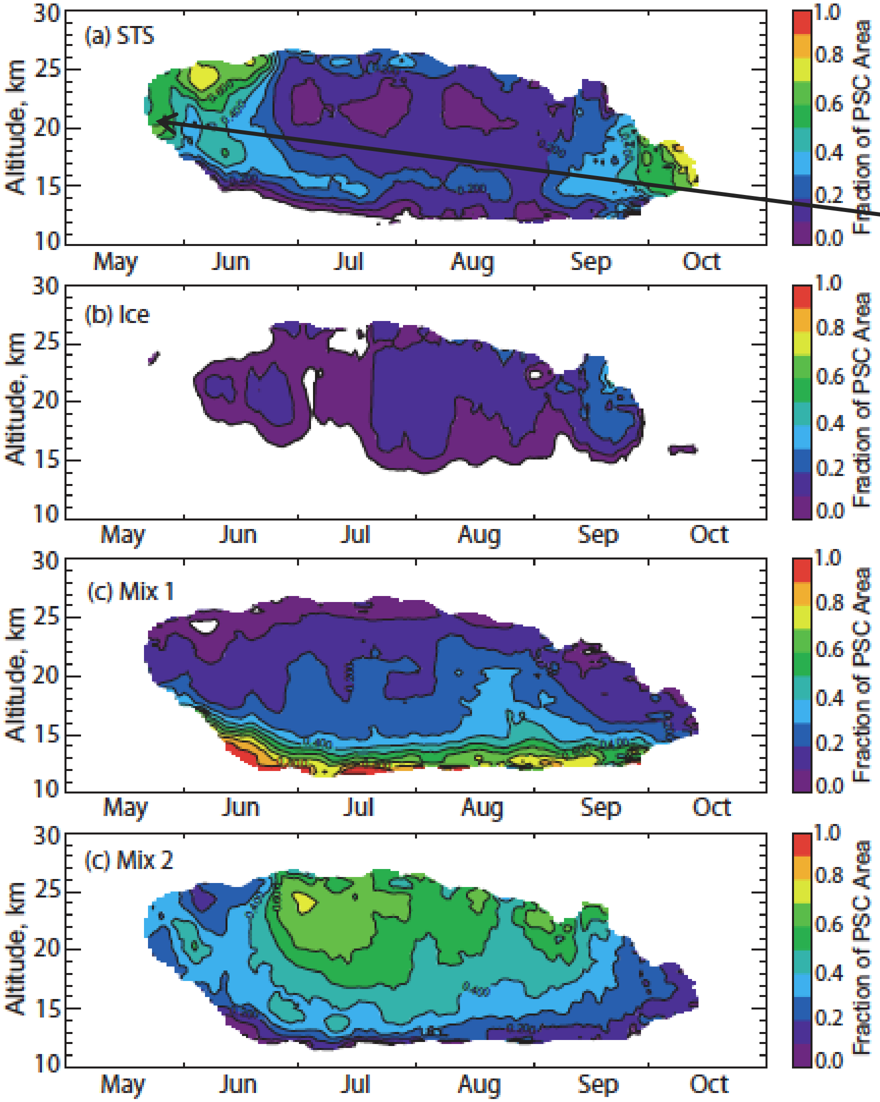
Polar Chemical Processes in the Lower Stratosphere



While activation may take place during dark polar winter, substantial ozone losses require that sunlight as well as activated chlorine (and bromine) be present to catalytically destroy ozone.

CALIOP Observations (liquid => solid), Pitts *et al.*, 2009

Antarctic Vortex, 3-year Mean area coverage.



<= Supercooled Ternary Solution (STS), with some solid mixtures

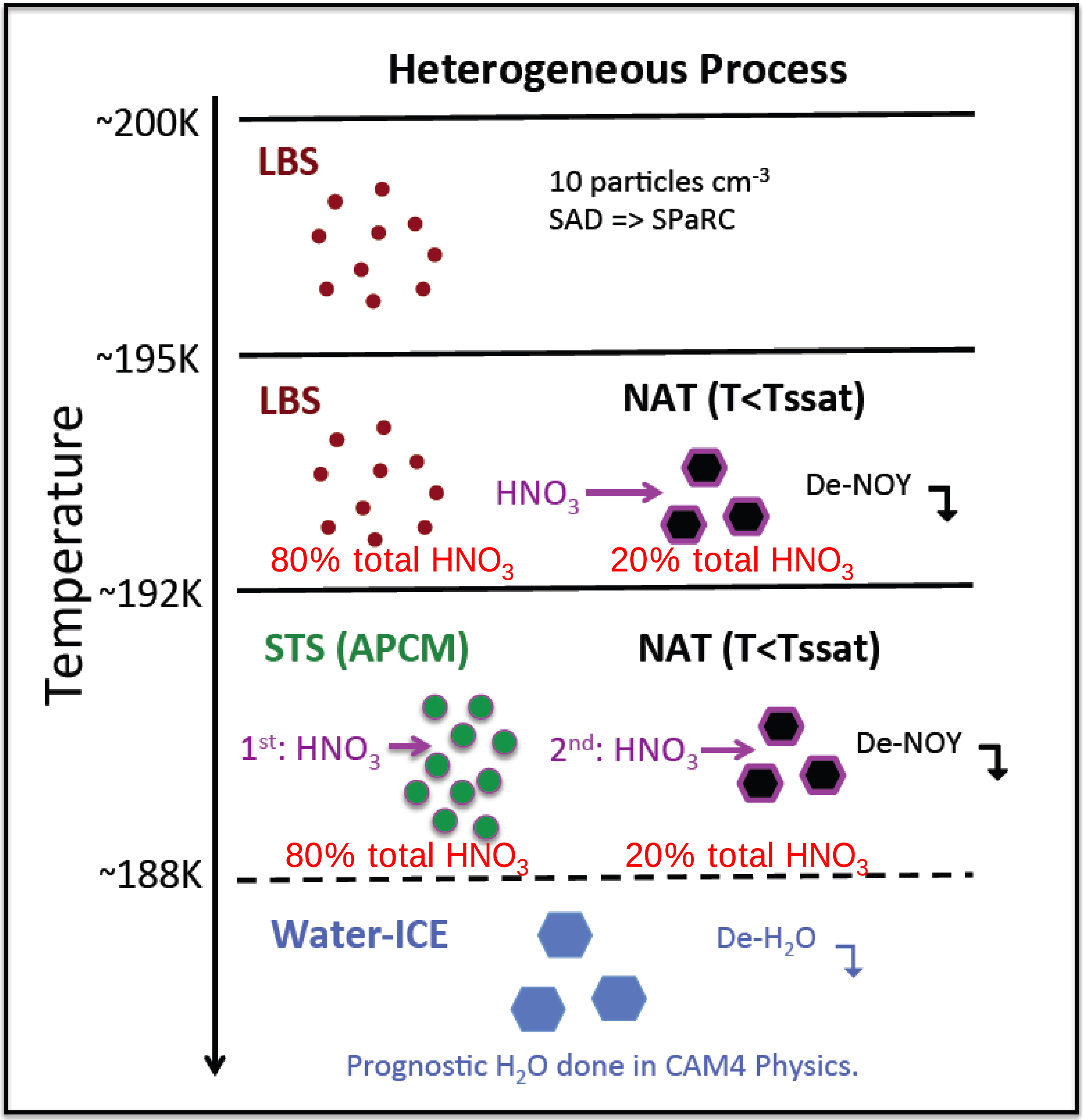
STS is forming in early winter (~60%) at 20km.

<= Water-Ice (and STS)

<= STS-NAT clouds (low NAT #density)

<= STS-NAT clouds (high NAT #density)

Modifications to PSC Parameterization: 80/20 partitioning

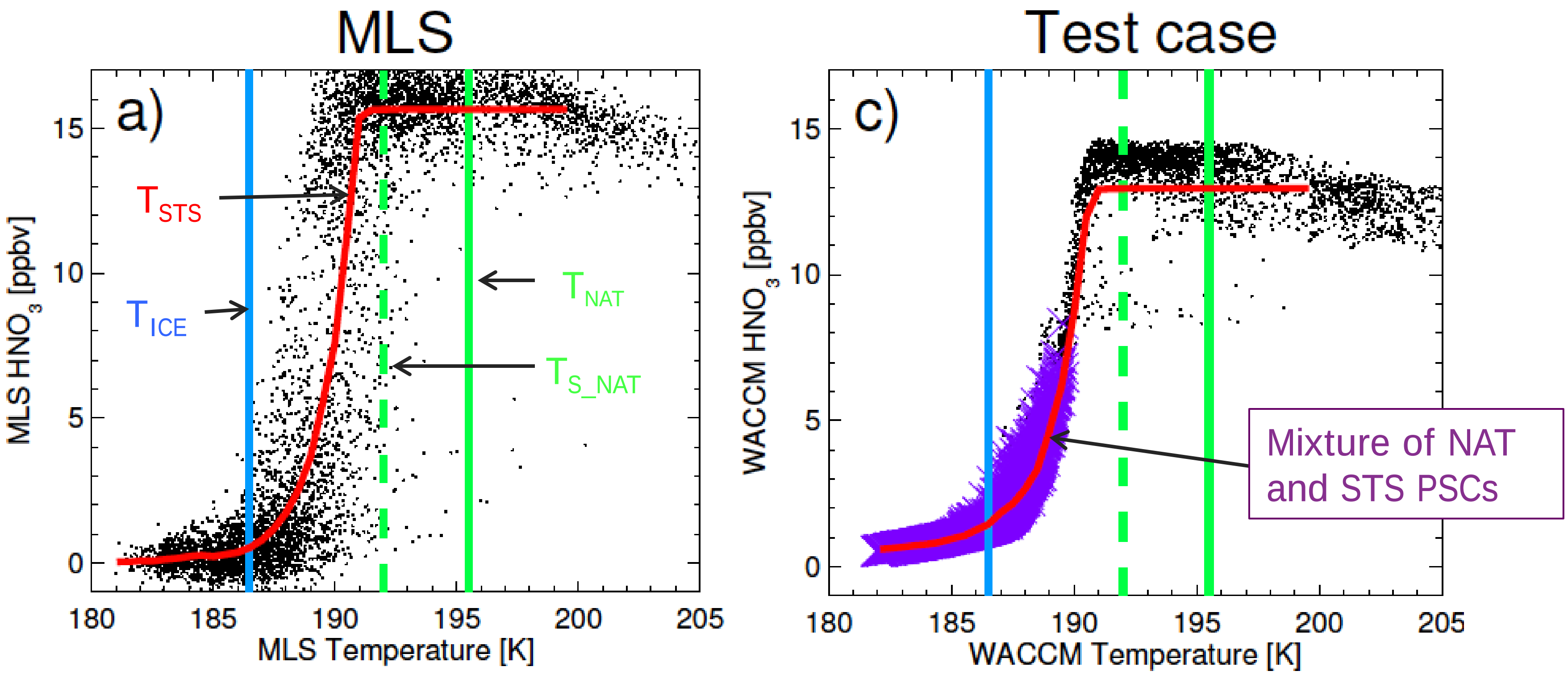


Equilibrium Approach for WACCM….

- Considine *et al.*, JGR, 2000.
  - Settling Velocity
- Kinnison *et al.*, JGR, 2007.
- Empirically, the partitioning of 80% total HNO_3 into STS and 20% into NAT best represents the evolution of HNO_3(g) in WACCM.
- CALIOP measurements show PSCs Fractional area is >60% in early winter (Pitts et al., 2009).
- Wegner et al., JGR, 2013.

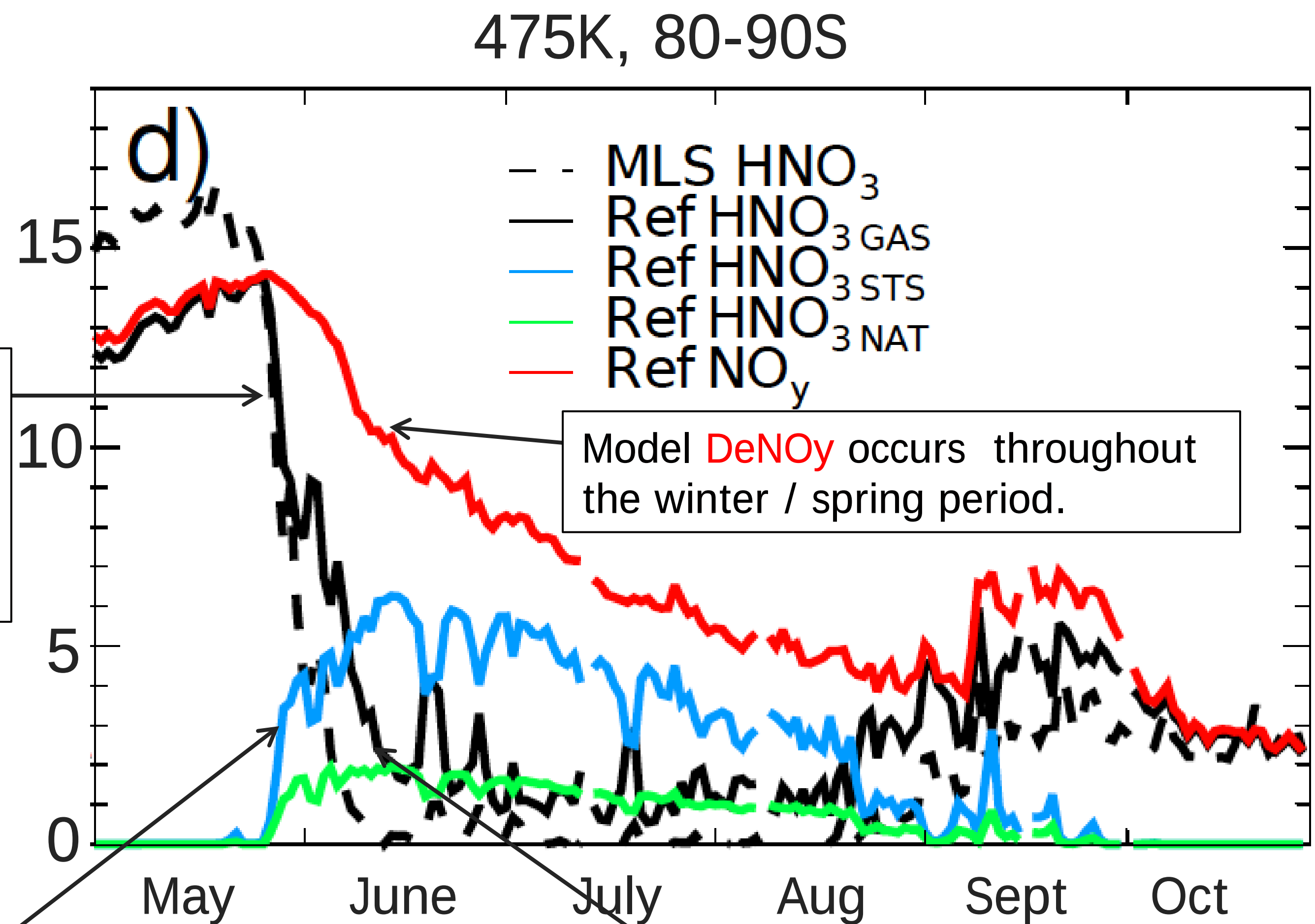
Comparison to Aura-MLS Observations

475K, between 1 May and 1 July 2005, >80°S EqL.



The model shows significantly less scatter than the satellite observation due to the simplification that all PSCs form instantaneously with a prescribed size distribution.

HNO_3 Comparison to Aura MLS observations



There is no temporal offset in gas-phase HNO_3 between model and Obs.

Model DeNOy occurs throughout the winter / spring period.

Mixture of NAT and STS forms in late May / early June.

Model overestimates HNO_3 (g) – larger NAT radius needed?

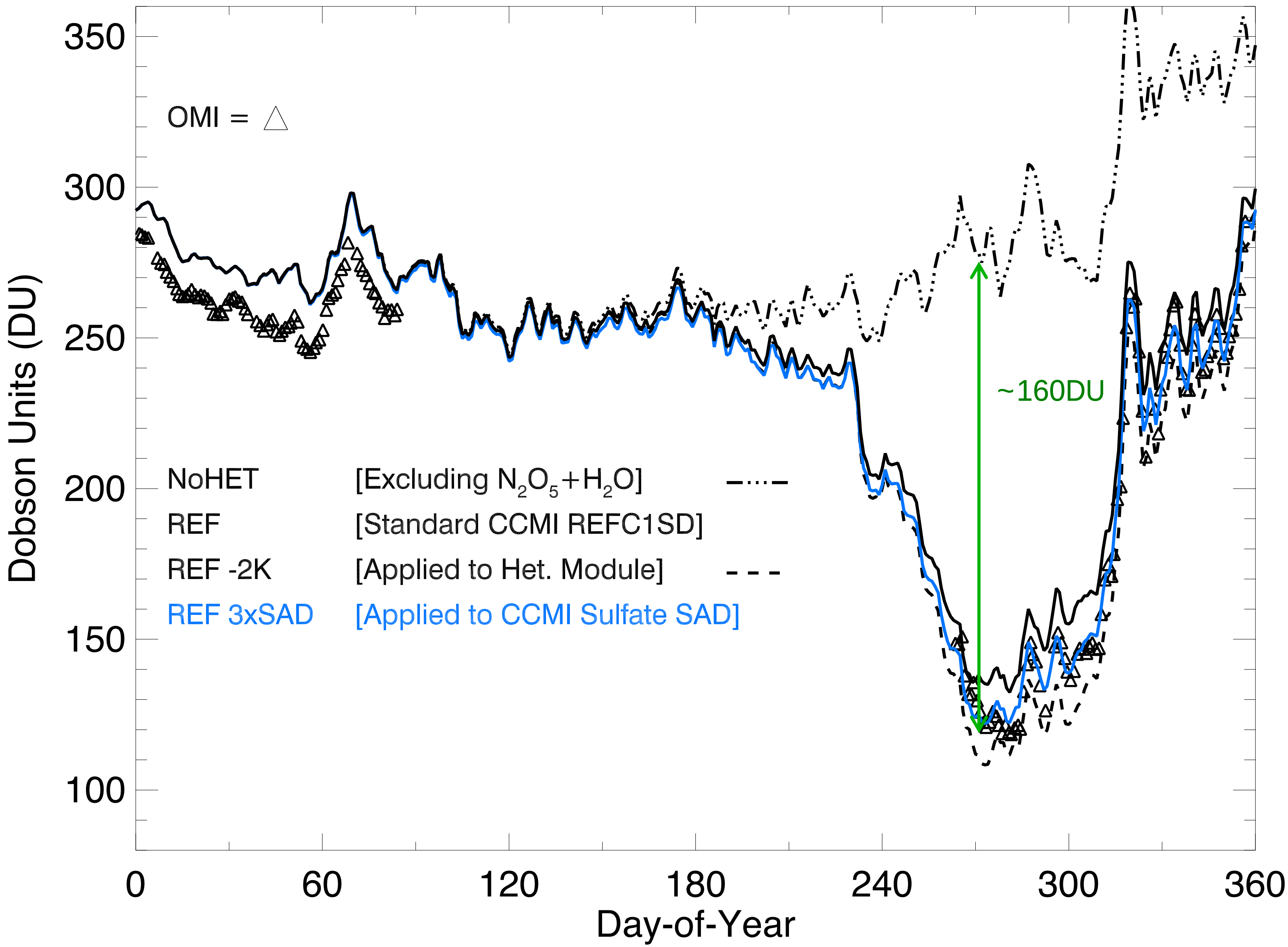
PSC Model Development Summary

- We have updated the PSC representation in WACCM using Aura MLS and CALIOP data as constraints (Wegner et al., JGR 2013).
- The model now has a mixed phase of STS and NAT in early winter that is more consistent with CALIOP data.
- The evolution of gas-phase HNO_3 also is in better agreement with Aura MLS.
- We also updated (not shown) the dehydration threshold for polar stratospheric H_2O. We were dehydrating at 80% saturation of water over ICE. We are now dehydrating at 100%.

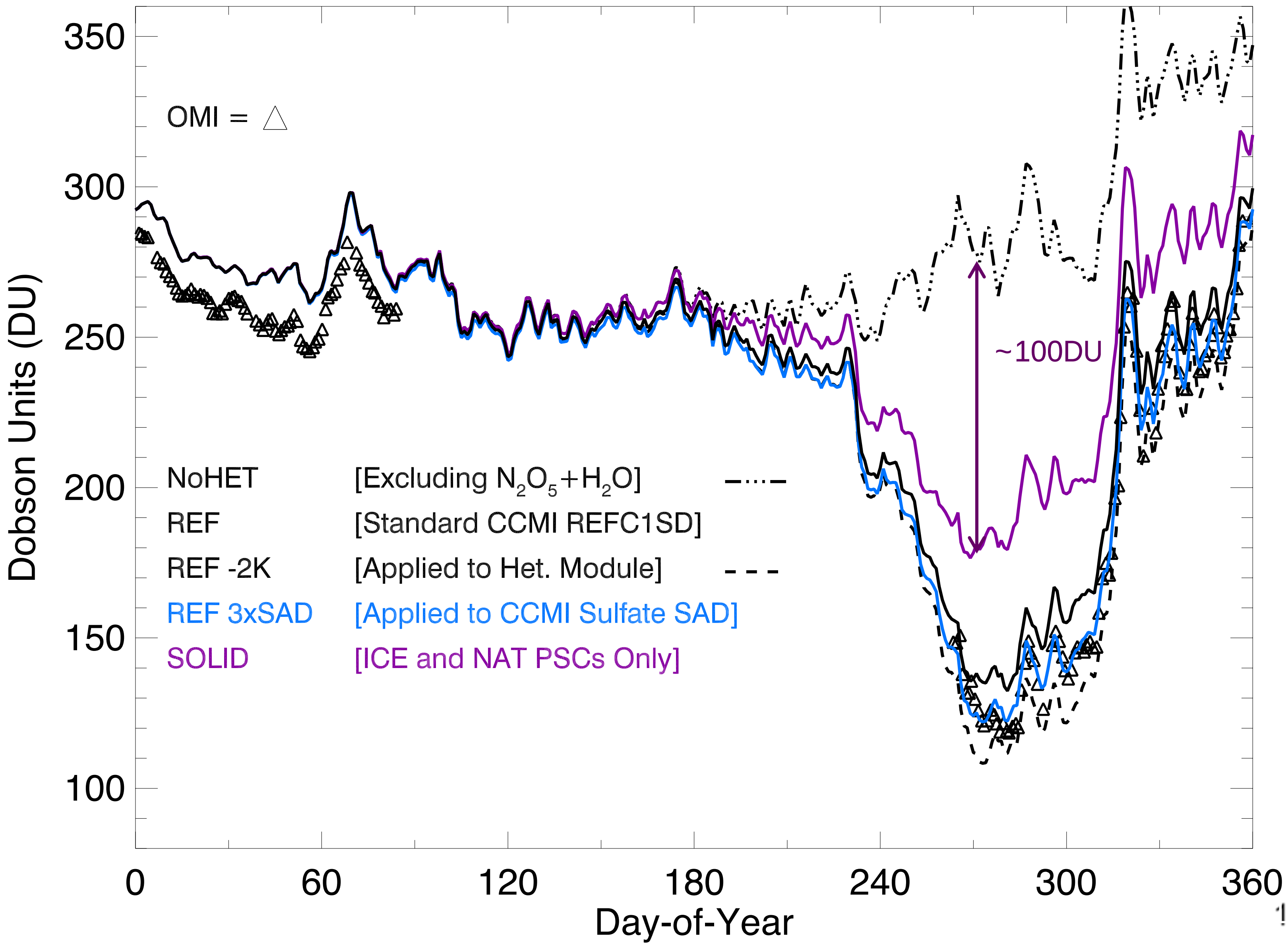
Examine PSC Assumptions on Ozone Depletion

Scenario	Temperature	PSCS	Comments
No Het	-	NONE	Zeroed halogen het. rates.
Reference	-	ALL TYPES	CCMI Version
2Kbias	-2K applied	ALL TYPES	Only to the Het Module.
3xSAD	-	ALL TYPES	Show the sensitivity to sulfate SAD in polar region only.
REFnat	-	ALL TYPES	2-NAT MODES (0.0001, 5 particles cm^{-3})
SOLID	-	NAT, ICE	Liquid PSCs reactivity zeroed.
LIQUID#1	T≥195K	LBS	Test Drdla+Muller 2012 result.
LIQUID#2	T≥192K	LBS, ~STS	STS starts to form.
LIQUID#3	-	LBS, STS	

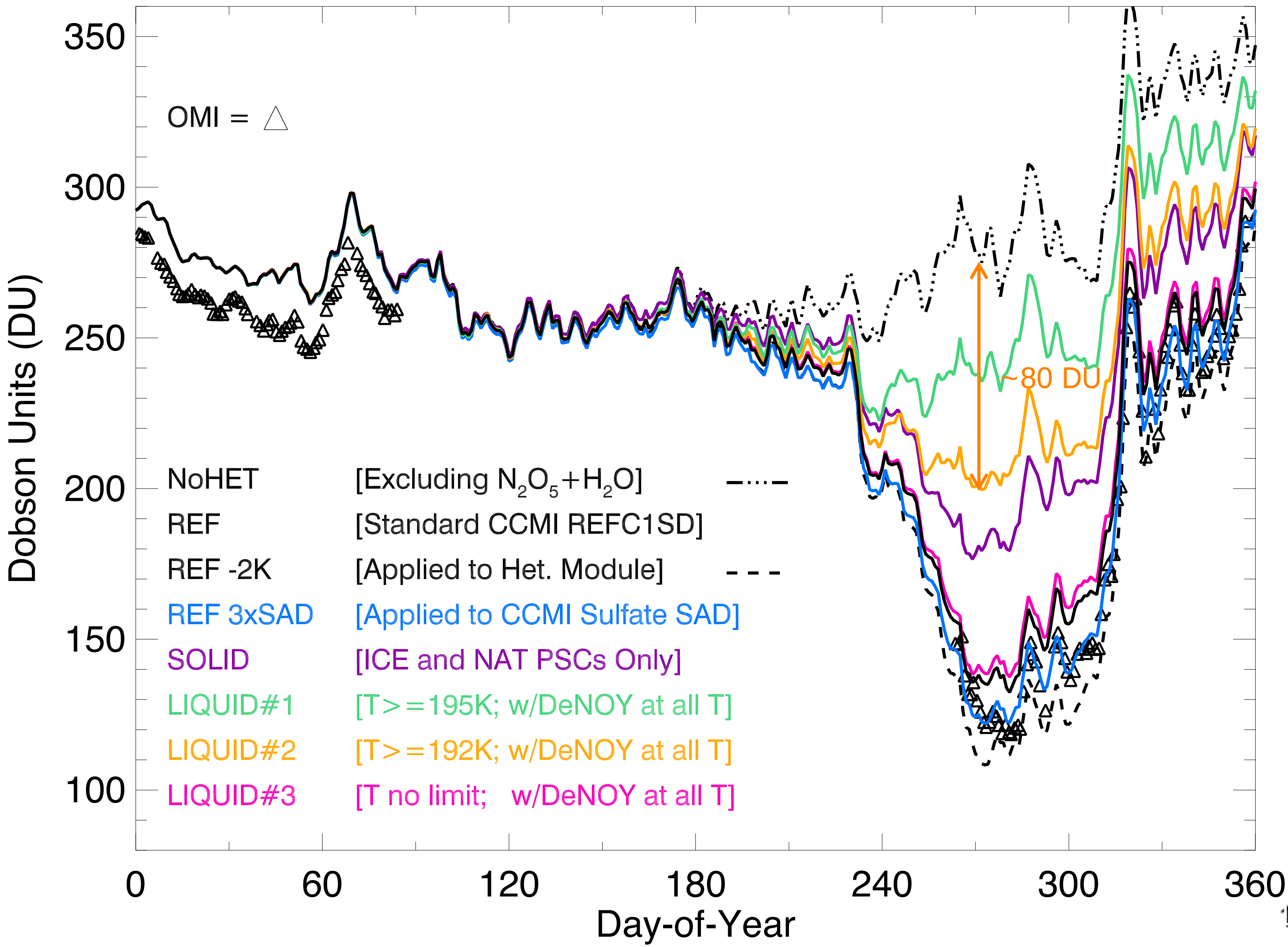
TOZ (DU) *** 82° S *** Zonal Mean *** 2011



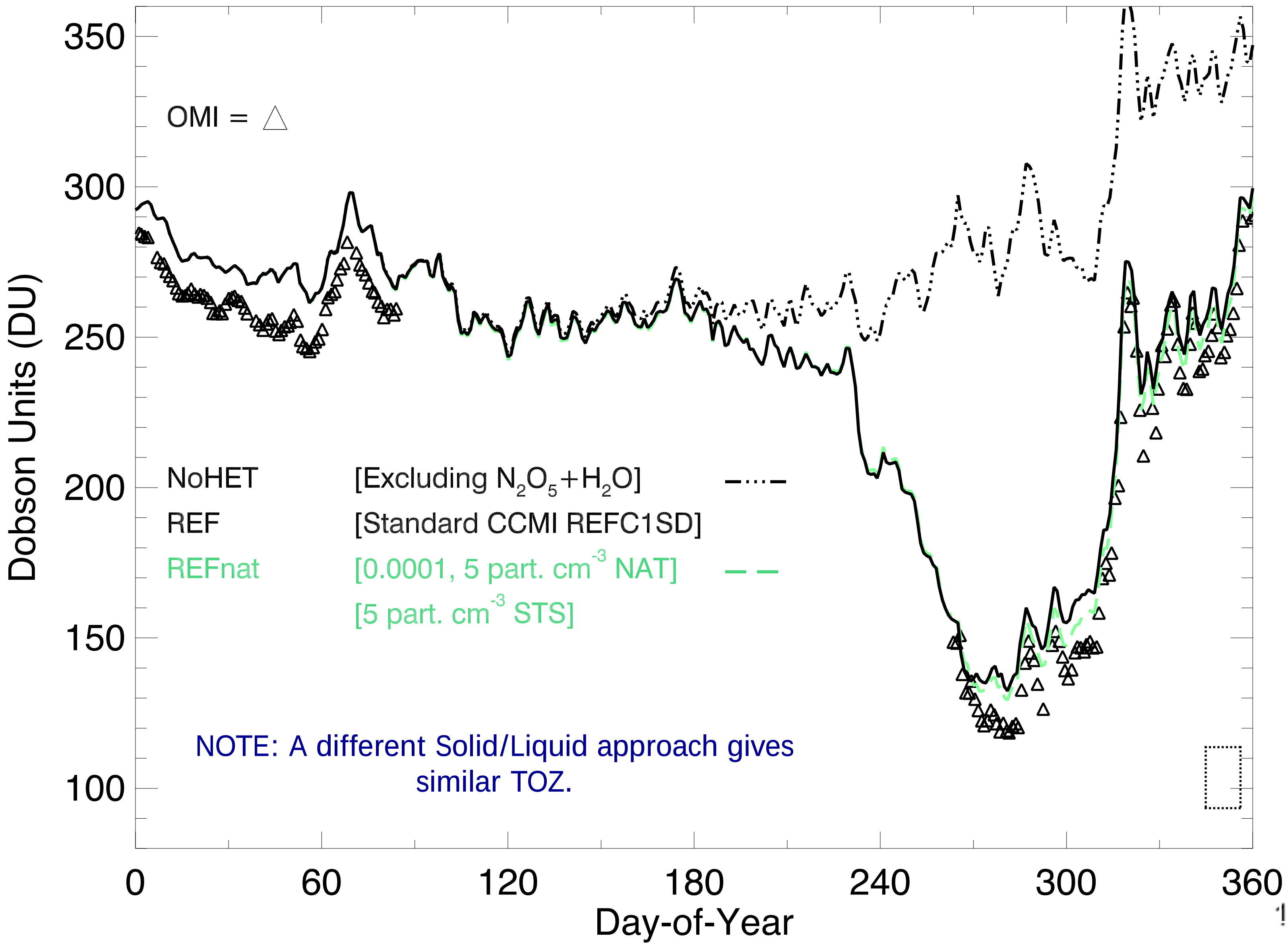
TOZ (DU) *** 82° S *** Zonal Mean *** 2011



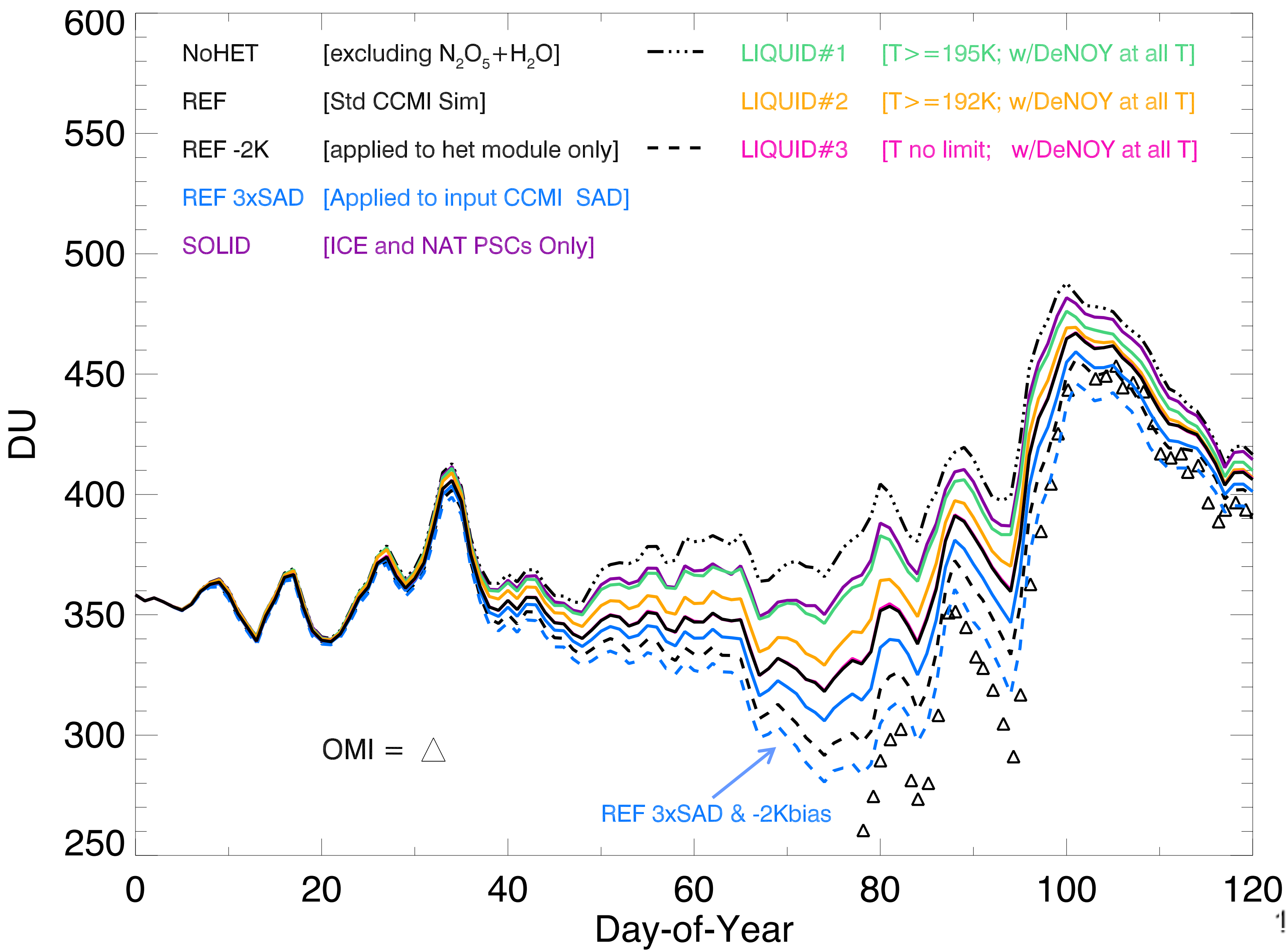
TOZ (DU) *** 82° S *** Zonal Mean *** 2011

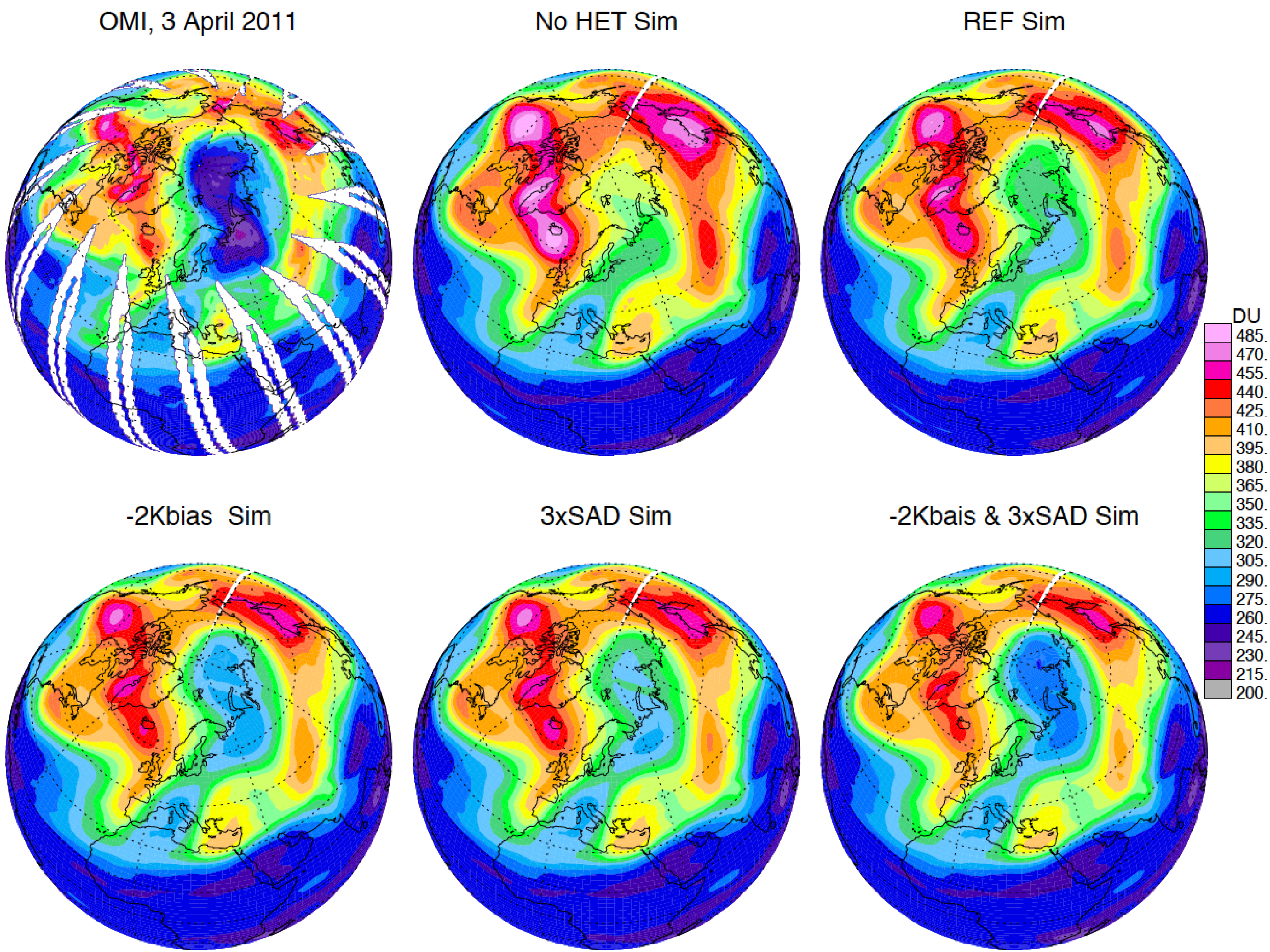


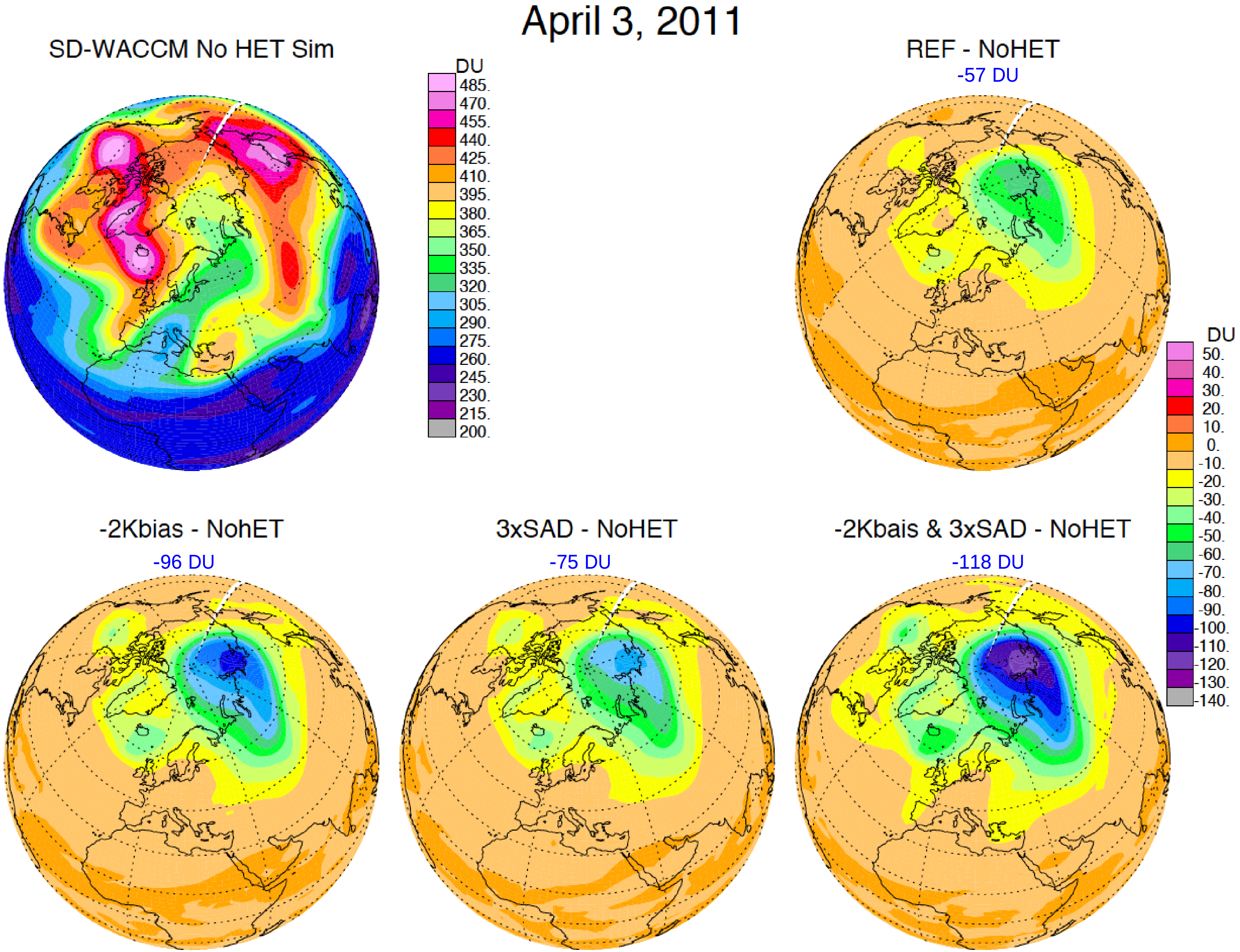
TOZ (DU) *** 82° S *** Zonal Mean *** 2011



TOZ (DU) *** 82° N *** Zonal Mean *** 2011




OMI, 3 April 2011
No HET Sim
REF Sim
-2Kbias Sim
3xSAD Sim
-2Kbais & 3xSAD Sim
DU
485.
470.
455.
440.
425.
410.
395.
380.
365.
350.
335.
320.
305.
290.
275.
260.
245.
230.
215.
200.



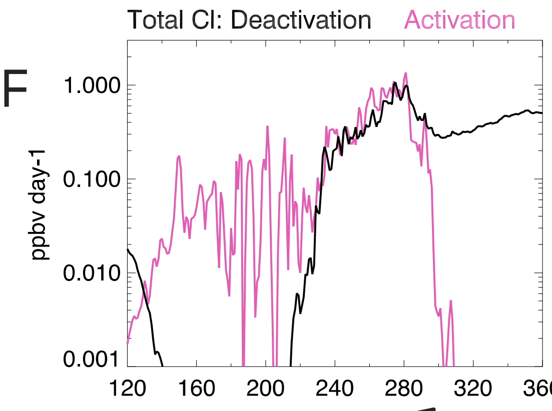
April 3, 2011
SD-WACCM No HET Sim
DU
485.
470.
455.
440.
425.
410.
395.
380.
365.
350.
335.
320.
305.
290.
275.
260.
245.
230.
215.
200.
REF - NoHET
-57 DU
DU
50.
40.
30.
20.
10.
0.
-10.
-20.
-30.
-40.
-50.
-60.
-70.
-80.
-90.
-100.
-110.
-120.
-130.
-140.
-2Kbias - NohET
-96 DU
3xSAD - NoHET
-75 DU
-2Kbais & 3xSAD - NoHET
-118 DU

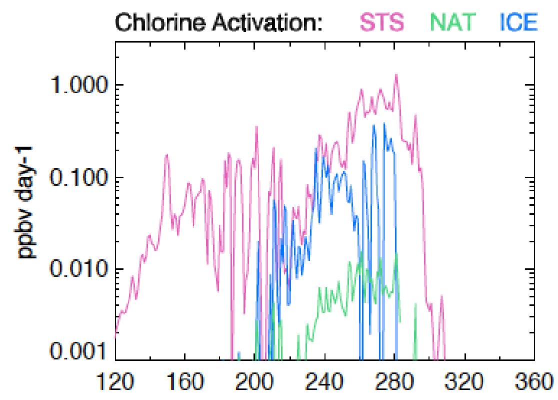
TOZ Summary

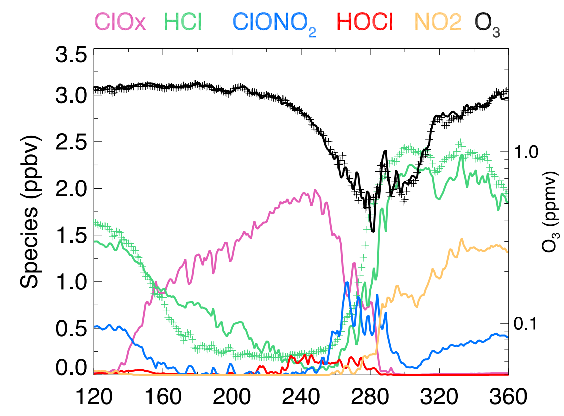
- In the SH, the REF case underestimates the observed TOZ (OMI) by approximately 25DU.
- In the SH, adding a -2K bias to the heterogeneous module overestimates the depletion.
- In the SH, adding a 3xSAD to the input CCM sulfate SAD (which is consistent with small volcanic eruptions) shows very good agreement with OMI TOZ.
- The model has difficulty representing the observed TOZ in the NH. Only when the -2K bias and 3xSAD is applied does the model come close to the observed decrease. More work is needed to understand this model/observed difference.
- The depletion due to LIQUIDS and SOLIDS is not additive.
    - REF ≠ SOLID only + LIQUID#3

Activation vs Deactivation: 74° S, 61hPa

REF







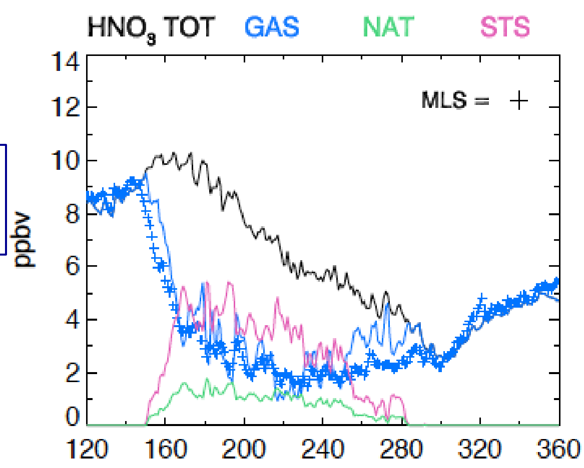
Chlorine Activation: Sum of all het. Rates that produce chlorine.

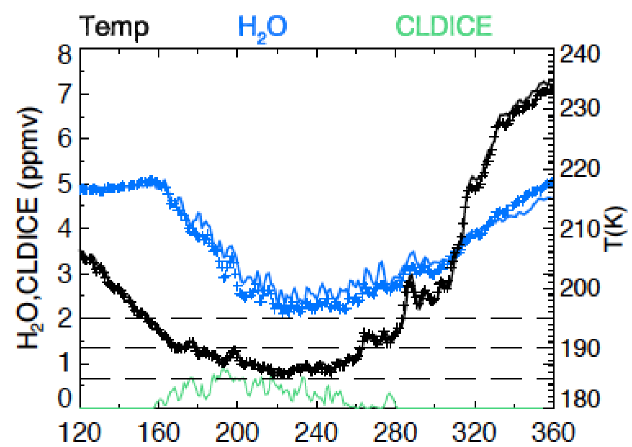
Chlorine Deactivation: Sum of the rate that produce NO_2 ($JHNO_3$, HNO_3+OH) and $Cl+CH_4$ => HCl

Both liquid PSCs and water-ICE are important for chlorine activation at this location in the reference cases.

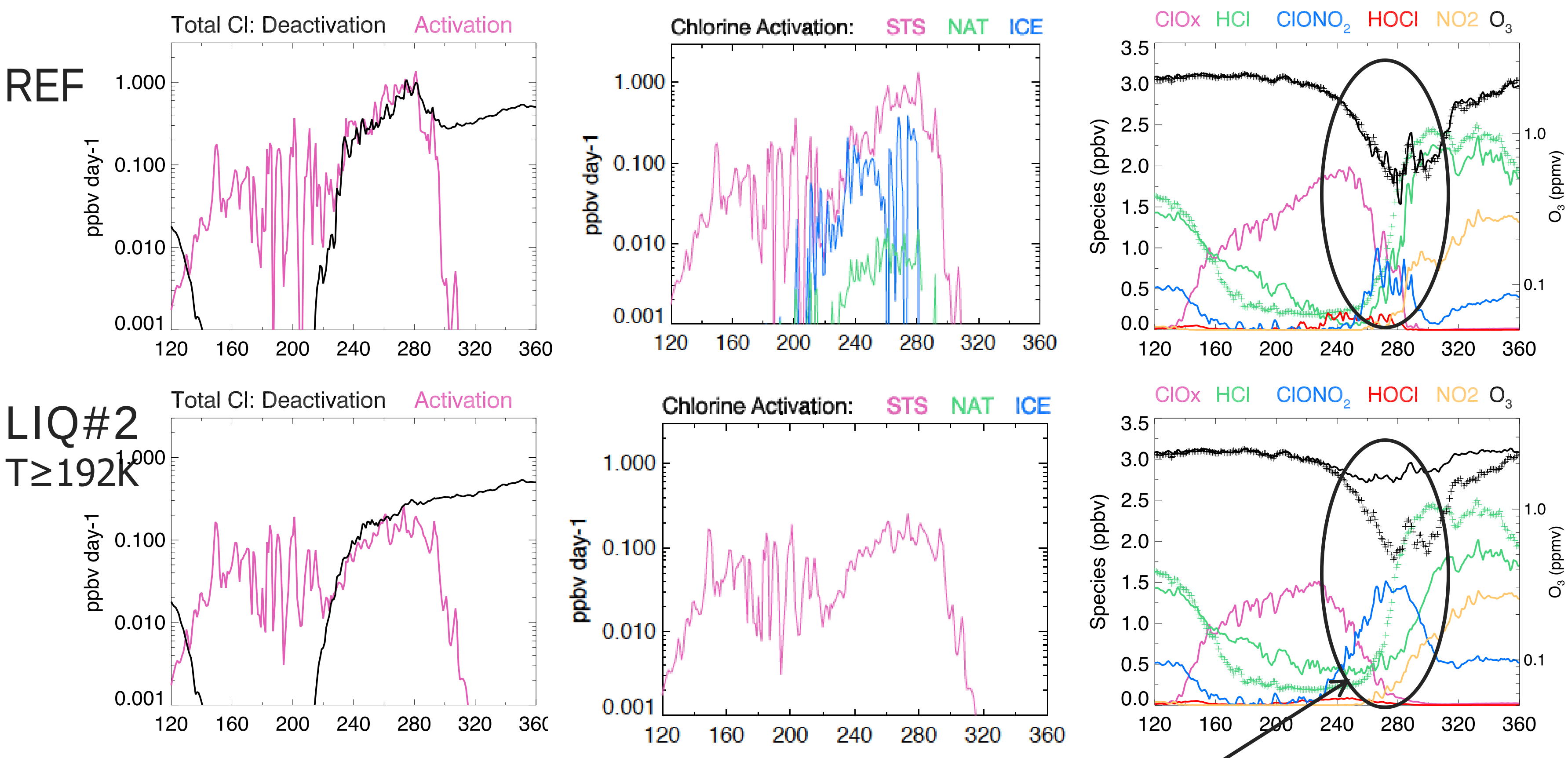
Overall – a very good representation of O3 depletion.

HNO_3(g), H_2O(g) and T in good agreement with MLS =>



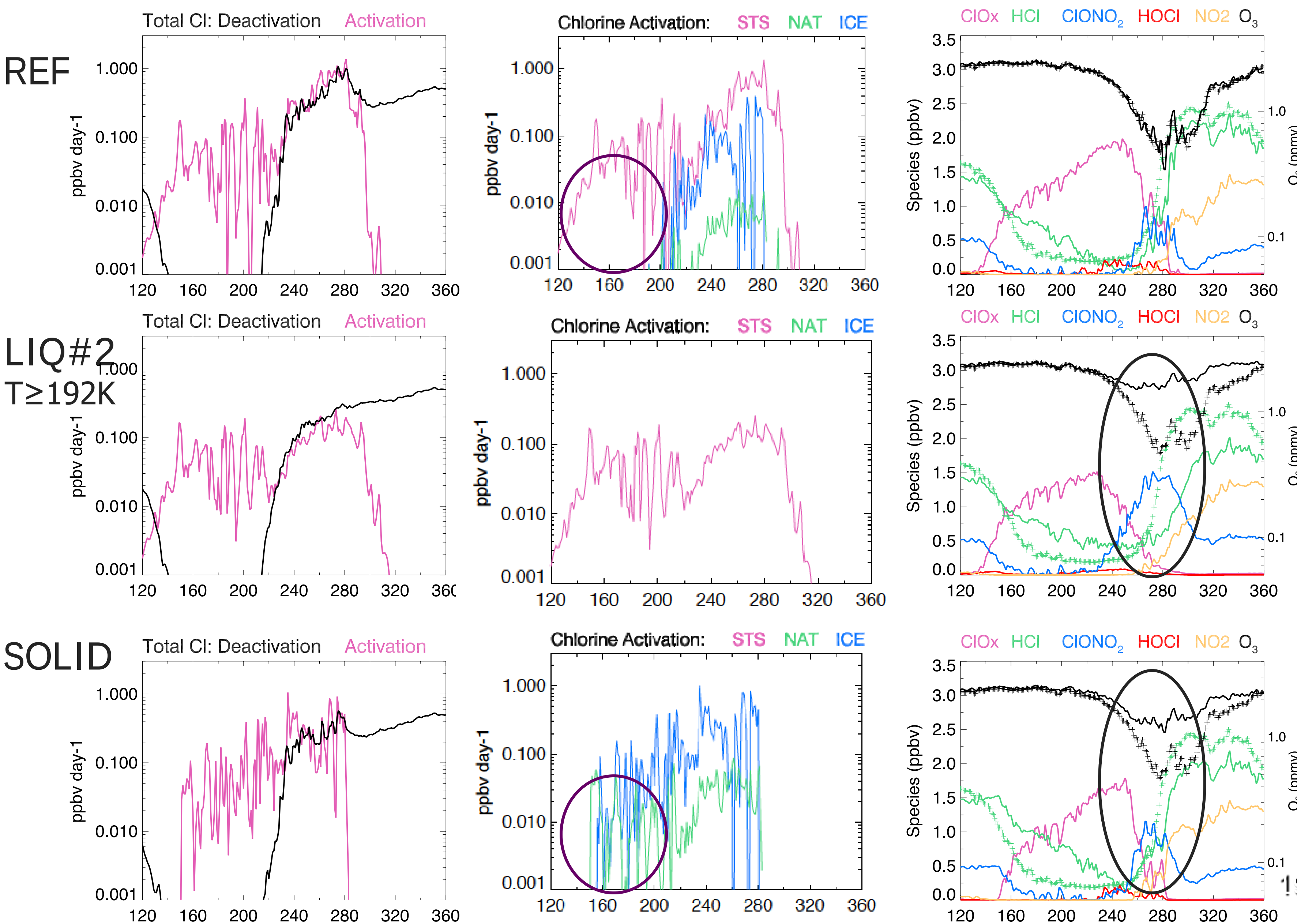


Activation vs Deactivation: 74° S, 61hPa



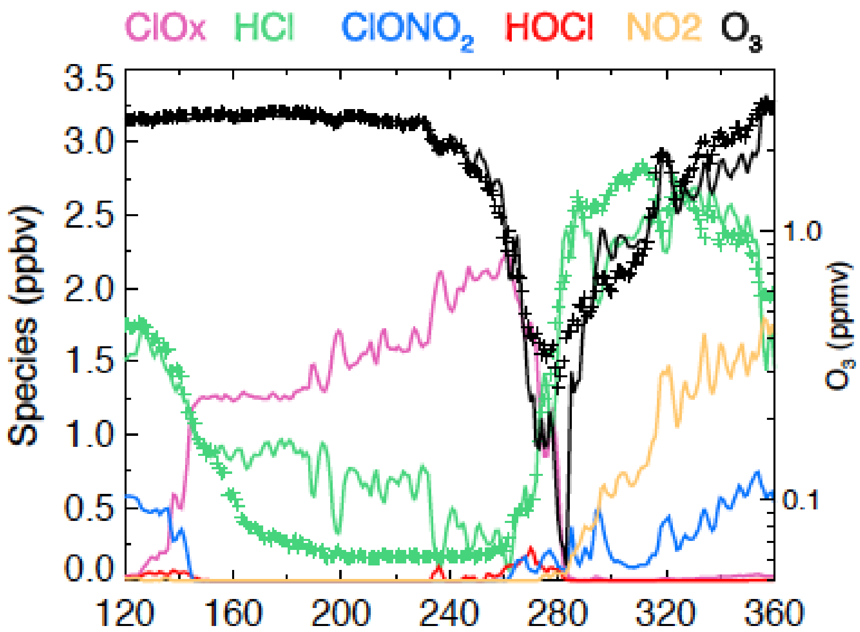
- LIQUID#2 shuts off ozone loss process by converting a great deal of active chlorine back into the reservoir species ($ClONO_2$).
- If deactivation into $ClONO_2$ occurs too early, related chemical indicator is a reduced rate of formation of HCl at later times.

Activation vs Deactivation: 74° S, 61hPa

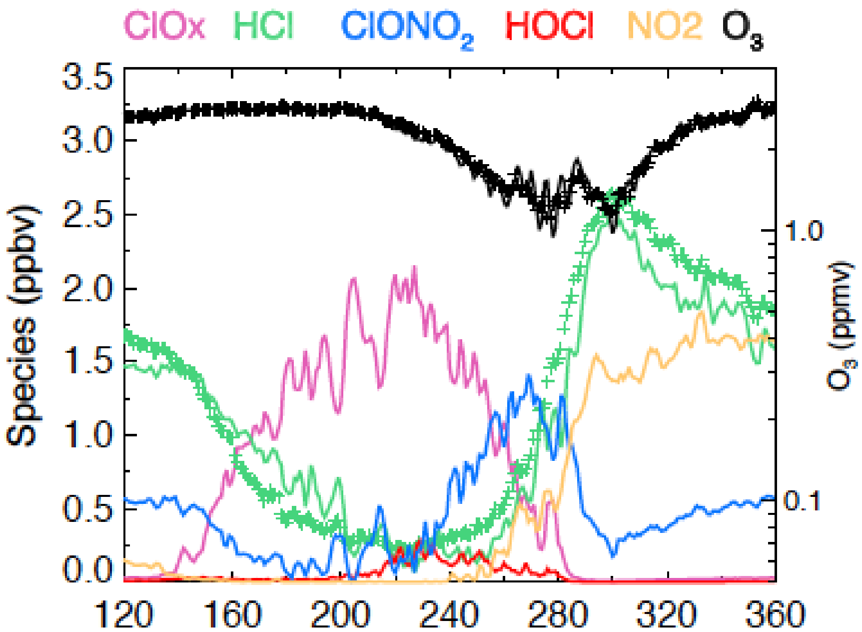


HCl Rate Change as an Indicator Het. Processing.

Vortex Core, 52hPa



Vortex Edge, 52hPa



D[HCl]/dt

Cl + O_3 => ClO + O_2

Cl + CH_4=> HCl + CH_3.

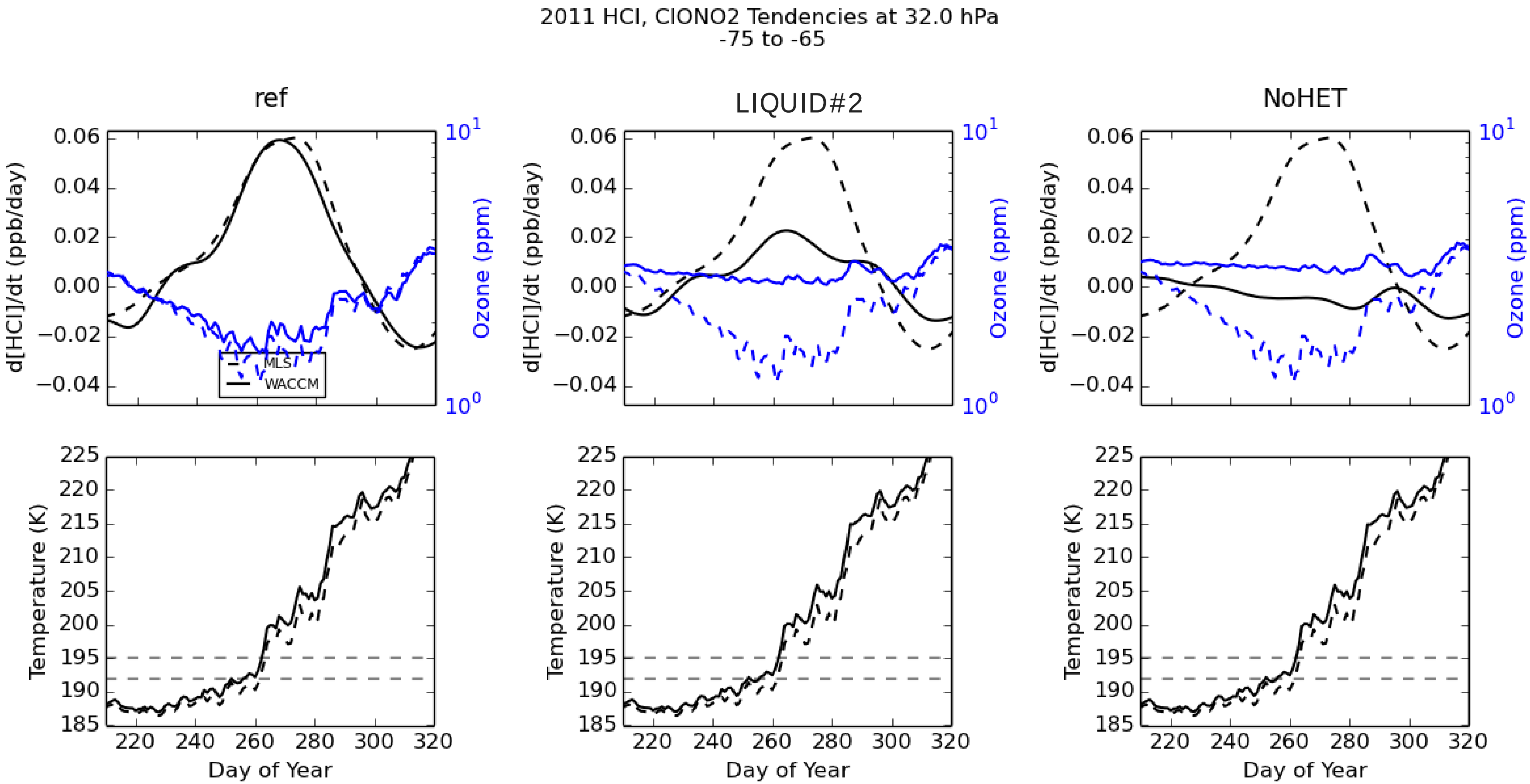
Douglass et al., 1995

D[HCl]/dt

Production and loss chemistry of ClONO2 is key.

Cl + CH_4 => HCl + CH_3.

HCl Rate Change as an Indicator Het. Processing.



Summary

- We find that the occurrence of cold temperatures and PSC chemistry at T<192K is <u>essential</u> to produce substantial ozone loss (O3L).

- This conclusion is bolstered by broad agreement of the temporal behavior of computed ozone and related species (HNO_3, H_2O, HCl) compared to Aura MLS.

- The magnitude of the calculated TOZ in both polar regions is sensitive to small differences in temperature and sulfate surface area density (~10-40DU).
  - These sensitivities are important in quantifying ozone recover due to halogens.

- These results confirm earlier studies suggesting that liquid PSCs particles are sufficient to simulation nearly all of the O3L using current model chemistry.
  - However, solid PSCs do play an important role in de-NOY and de-H2O. They also add to the O3L for altitudes >18km.
  - We have shown that the results for O3L from each particle type are not additive.

- We've shown that the rate of change of HCl can be used as a key indicator of ozone depletion chemistry, primarily outside of the vortex core.