Understanding the Relation between V_{PSC} and Arctic Ozone Loss

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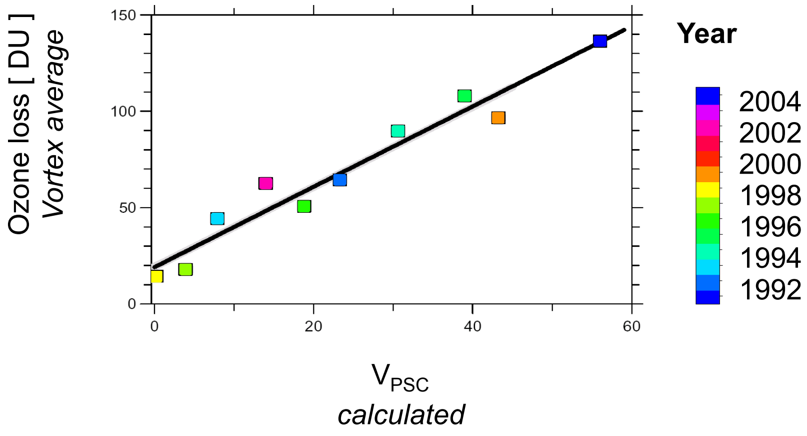
SCOUT-O3

Outline

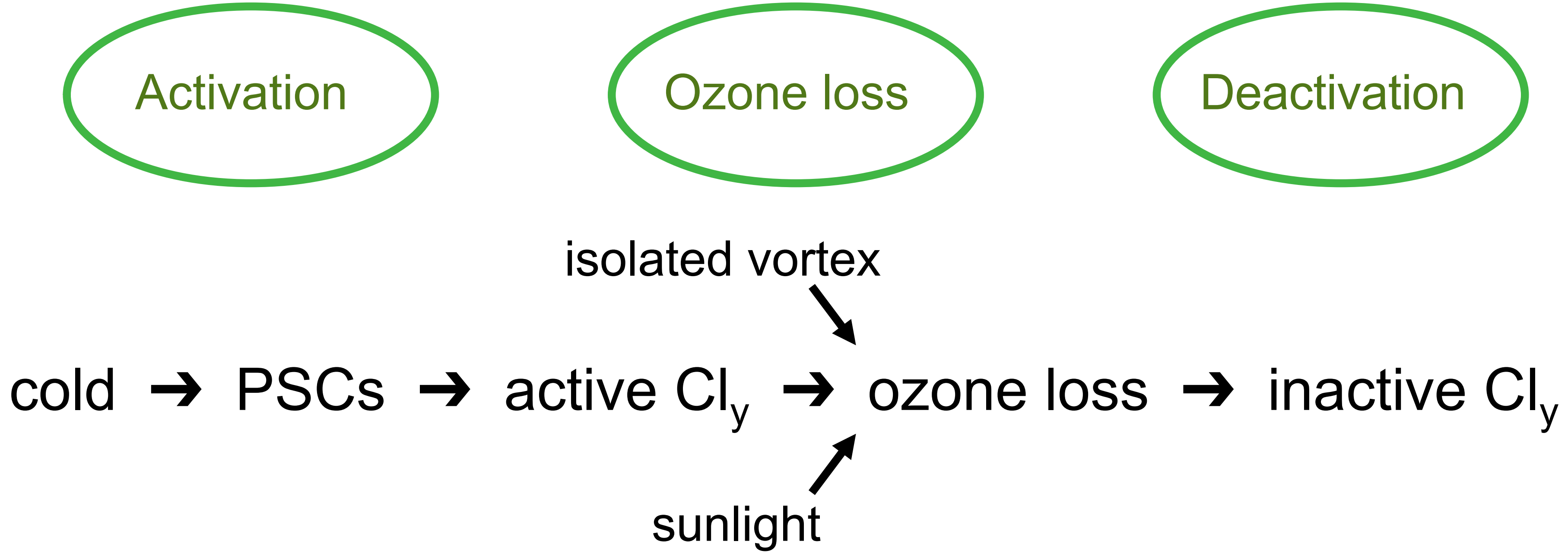
1. Introduction
2. Approach and previous results
3. Updated results
4. Idealised photochemical model study
    a) Ozone loss on a single layer
    b) Three dimensional aspects
5. Simple model of vortex average ozone loss
6. Summary



Acknowledgements:

- Many, many ozonesonde personnel; ECMWF; FU Berlin; Univ. Leeds
- European Commission, BMBF
- G. Bodeker & P. Huck (NIWA)

Polar ozone loss processes



Activation

Ozone loss

Deactivation

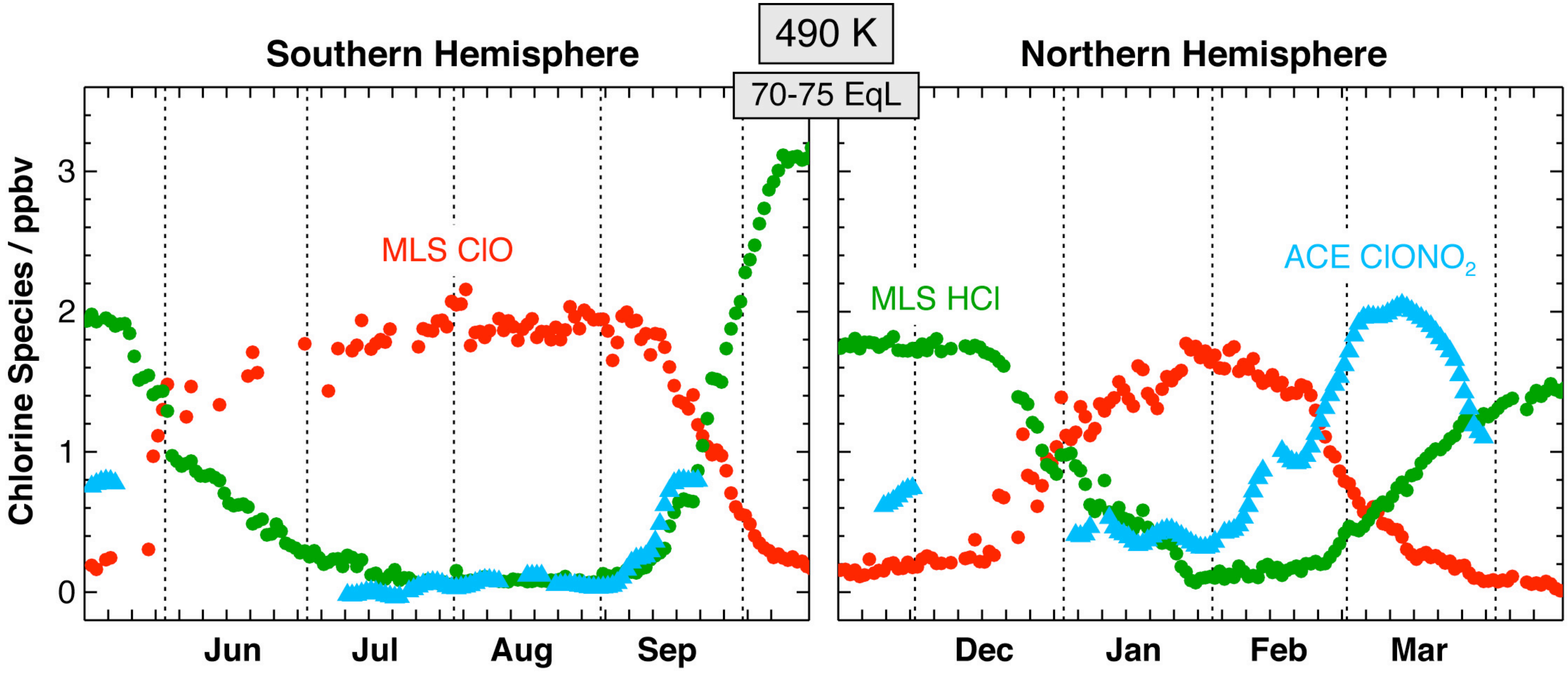
isolated vortex

cold → PSCs → active Cl_y → ozone loss → inactive Cl_y

sunlight

Complicating factors:

- meteorological variations
- denitrification
- solar exposure
- initial chemical fields
- descent rates
- in-mixing
- vortex inhomogeneities
- vertical extent



From Chapter 4 of *Scientific Assessment of Ozone Depletion: 2006* (WMO, 2007).

Left panel: Daily averages of ClO (red dots) and HCl (green dots) observed by Aura MLS, and ClONO$_2$ (cyan triangles) observed by ACE-FTS at 490 K (~20 km) during the 2005 Antarctic winter/spring, calculated for 70°-75°equivalent latitude using the Global Modeling and Assimilation Office GEOS-4 temperatures and potential vorticity. Only daytime measurements are included in the averages for ClO; ClO data appear sparser because measurements in sunlight are not always available at high equivalent latitudes, especially in early winter. The sampling of ACE-FTS does not provide coverage of this equivalent latitude band at all times throughout the winter.

Right panel: As in the left panel, for the 2004/2005 Arctic winter/spring.

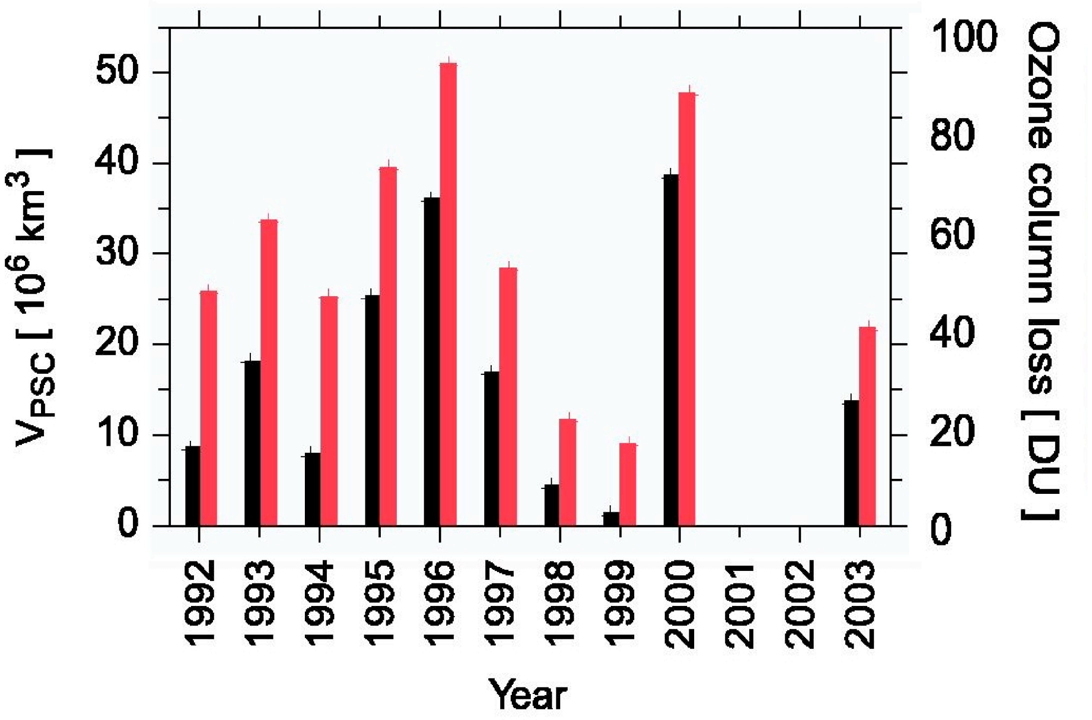
WMO, 2007

APPROACH

Ozone loss is calculated on descending potential temperature surfaces with heating rates from SLIMCAT and ozone measurements from the Arctic ozonesonde network ("vortex average")

V_{PSC} is calculated from ECMWF temperature fields and T_{NAT}

Both seasonal integrals/averages.



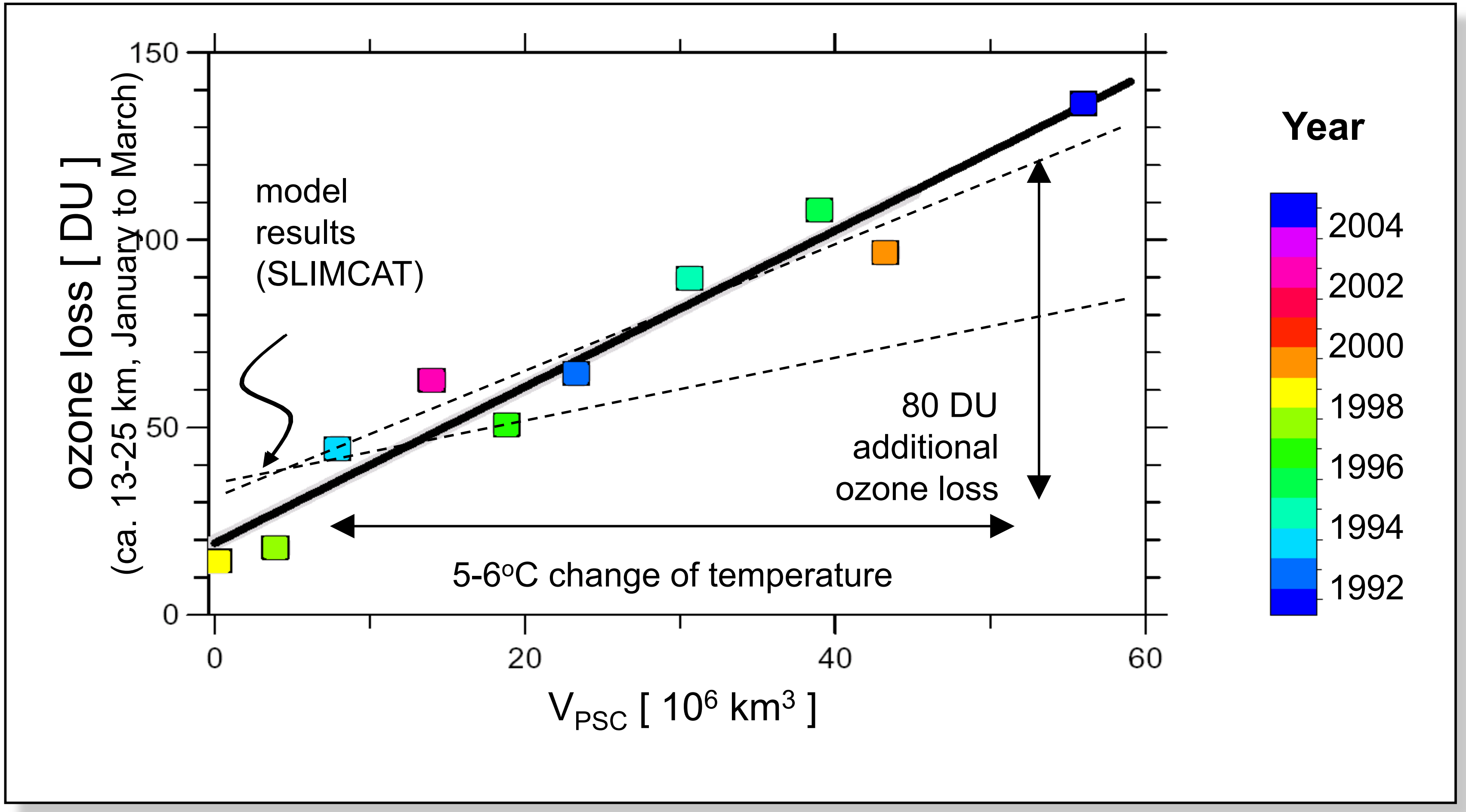
- Large variability
- Well correlated

(a) VPSC (black columns) and DO3 (red columns). DO3 was estimated from the data shown in Figure 1 between day 15 and day 85 of each year. Days 25 and 75 were chosen as start or end date of the integration for years when the well isolated vortex established late (1994, 1999) or broke up early (1992, 1998, 2003). In these cases ozone loss is not expected during the omitted ten days.

Rex et al., GRL, 2004

Ozone loss versus PSC formation potential (V_{PSC})

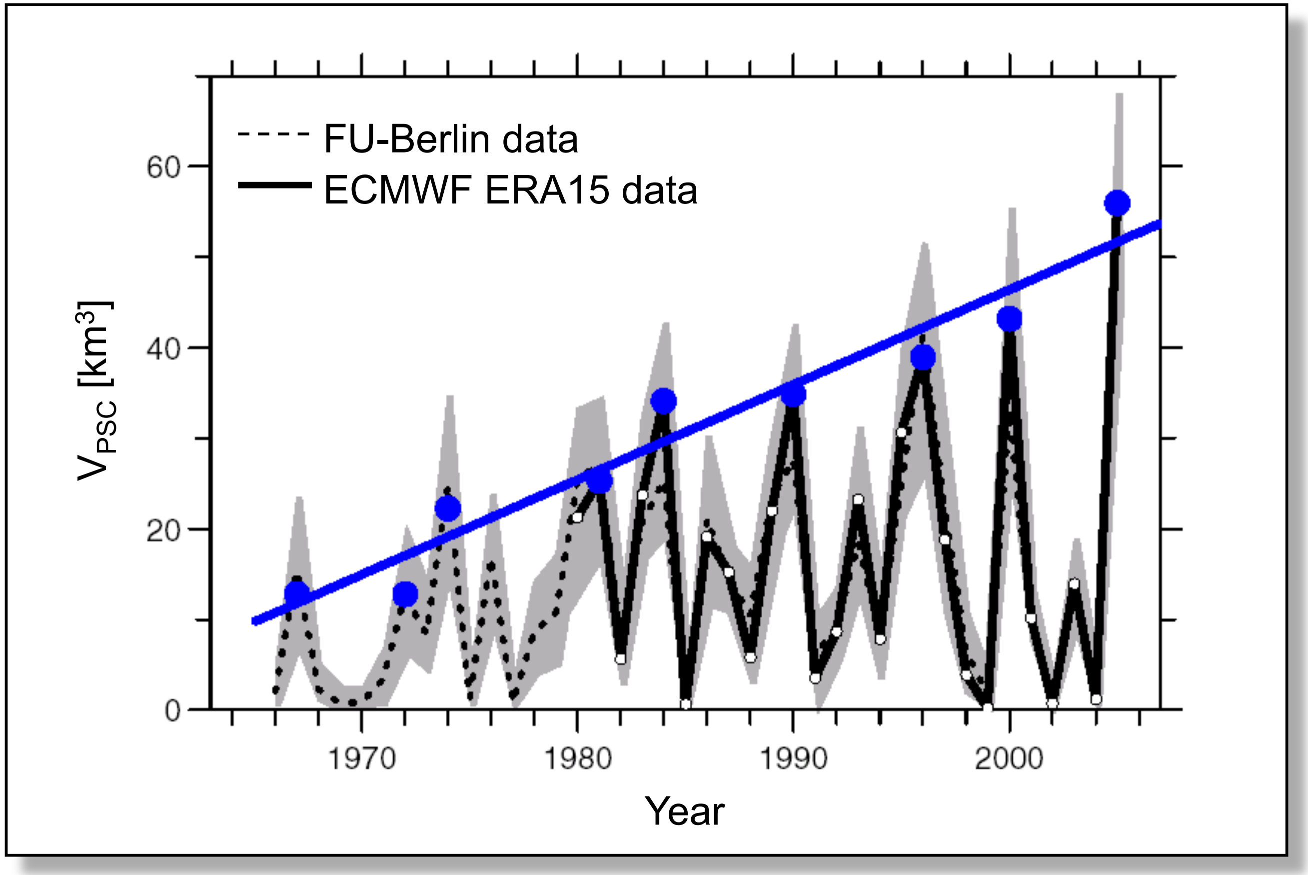
V_{PSC}: winter average volume of air cold enough for the formation of PSCs
(e.g. -78°C in 18 km Altitude)



- **climate sensitivity of ozone loss: 15 DU / 1°C cooling**
- **good test of model**

Rex et al., GRL 2006; WMO 2007

Long term evolution of V_{PSC}



- Long term increase in the maximum values reached during the cold winters
- This change in climate conditions in the Arctic stratosphere contributed to large ozone losses since the middle nineties.

Rex et al., GRL 2006; WMO 2007

Ozone loss versus PSC formation potential (V_{PSC})

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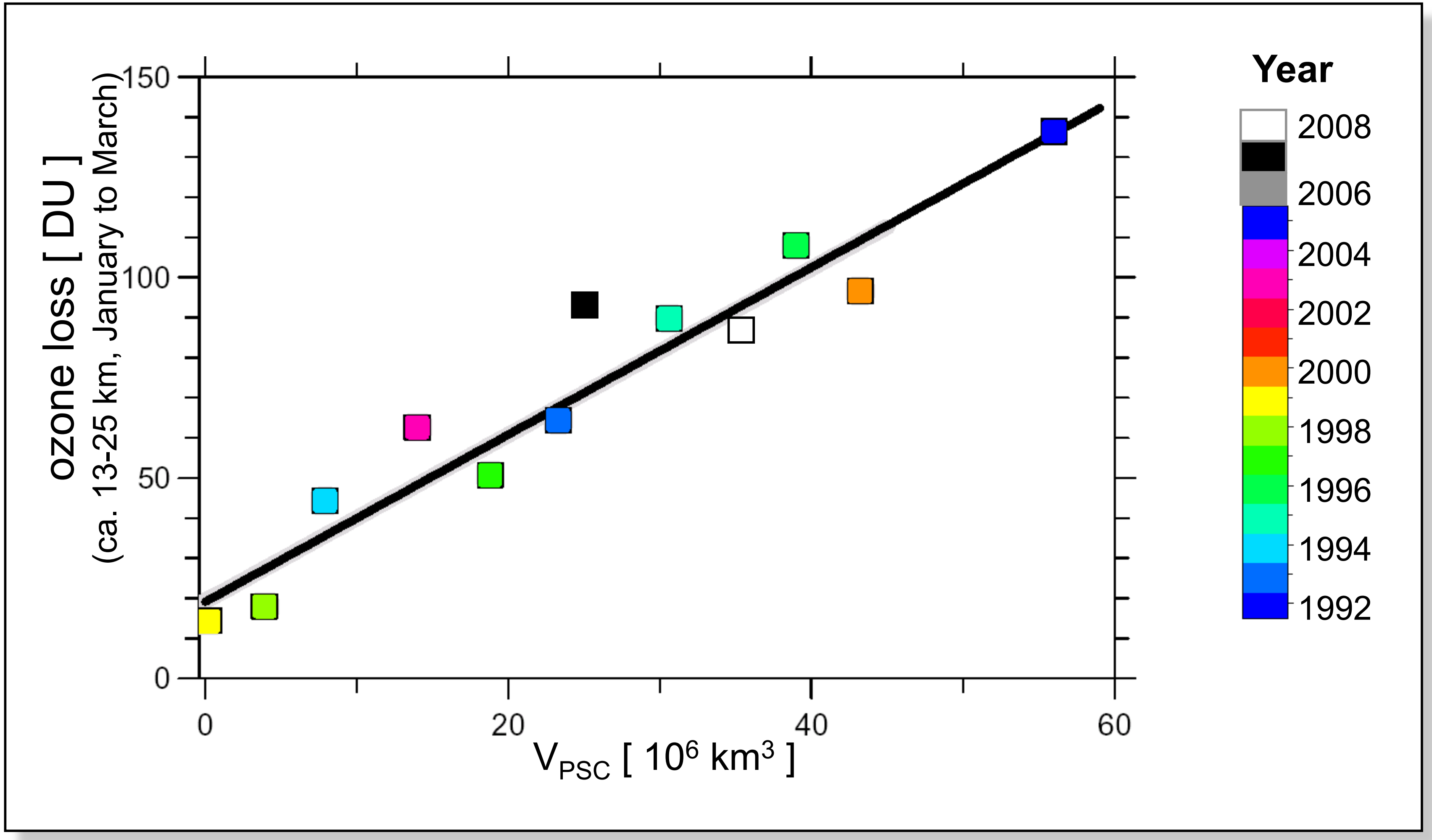
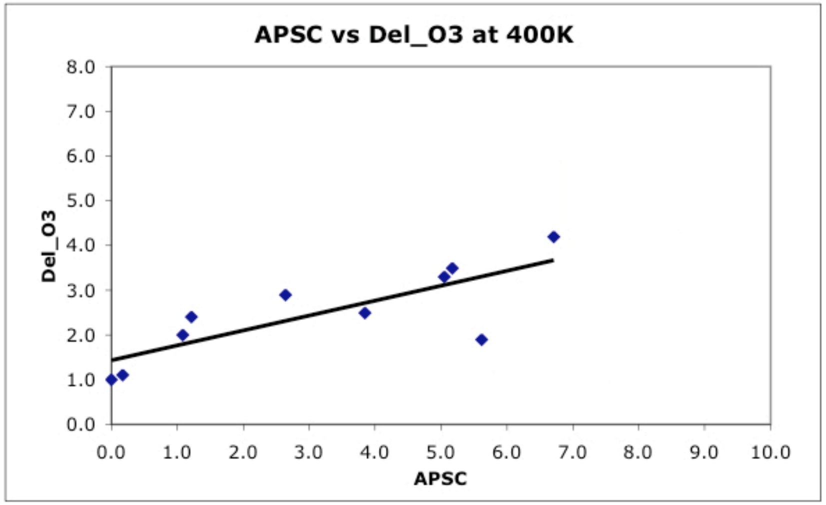


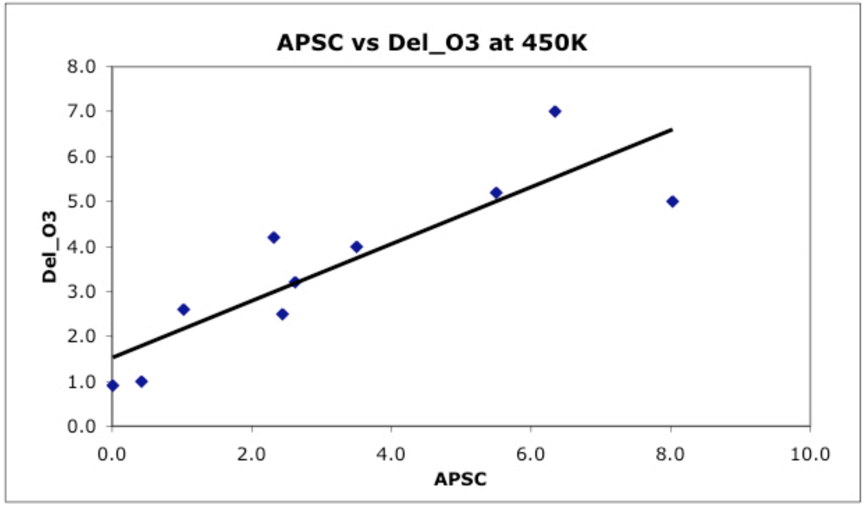
1991/92 - 2007/08

update of Rex et al., GRL 2006; WMO 2007

Moving to 3D



Intercept	1.429
slope	0.334
R2	0.795



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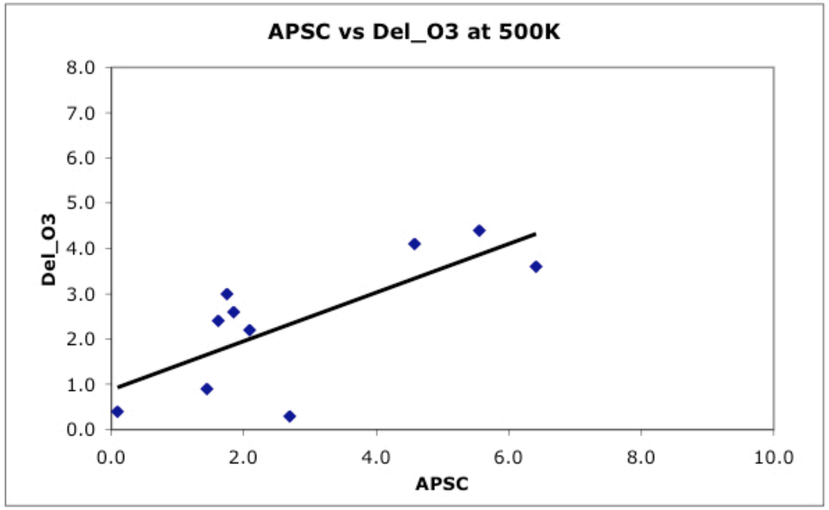

Intercept	0.879
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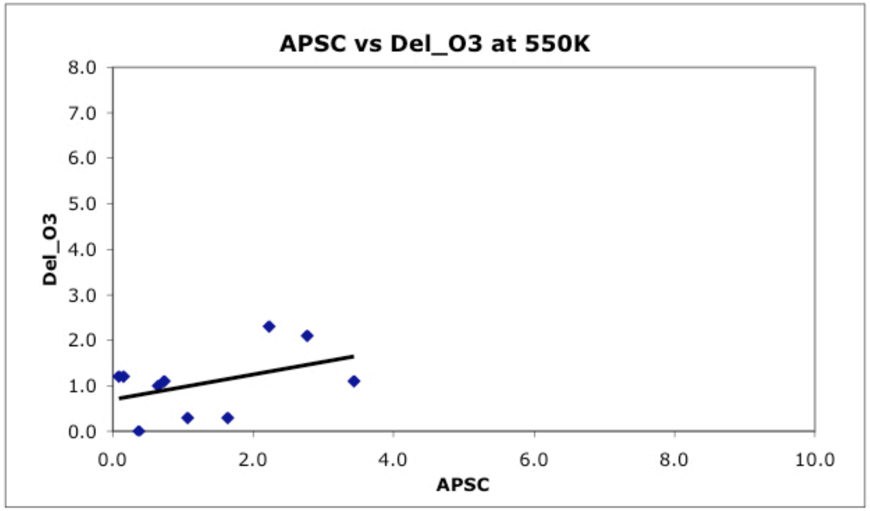
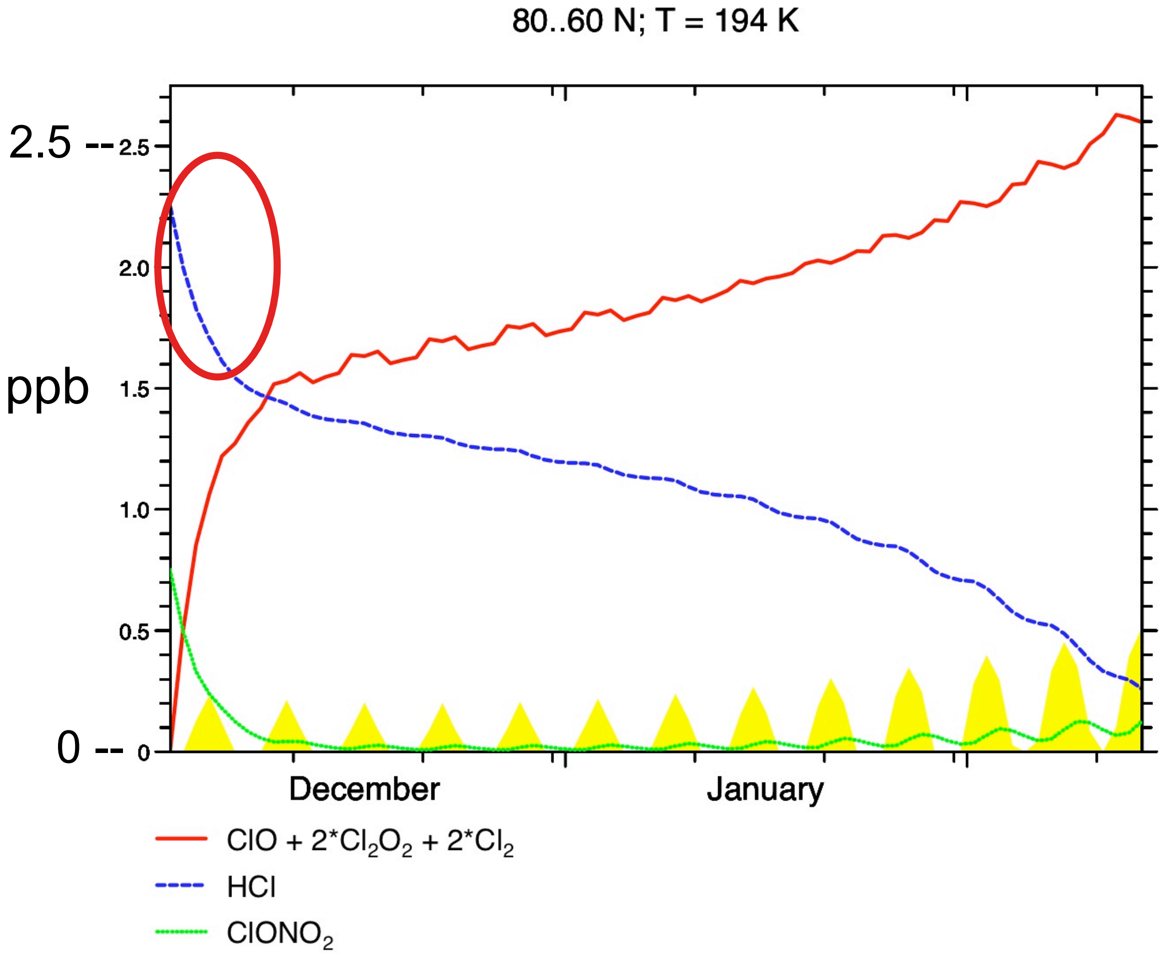


Intercept	0.698
slope	0.276
R2	0.432

Activation

AWI chemical box model, Cl_y = 3ppb
sinusoidal 6 day cycle between 60 & 80˚ N at 50hPa (equiv to 20˚ offset vortex)
Persistent PSCs



$ClONO_2 + HCl \rightarrow Cl_2 + HNO_3$

FAST, if cold

T-dependent (over vortex)

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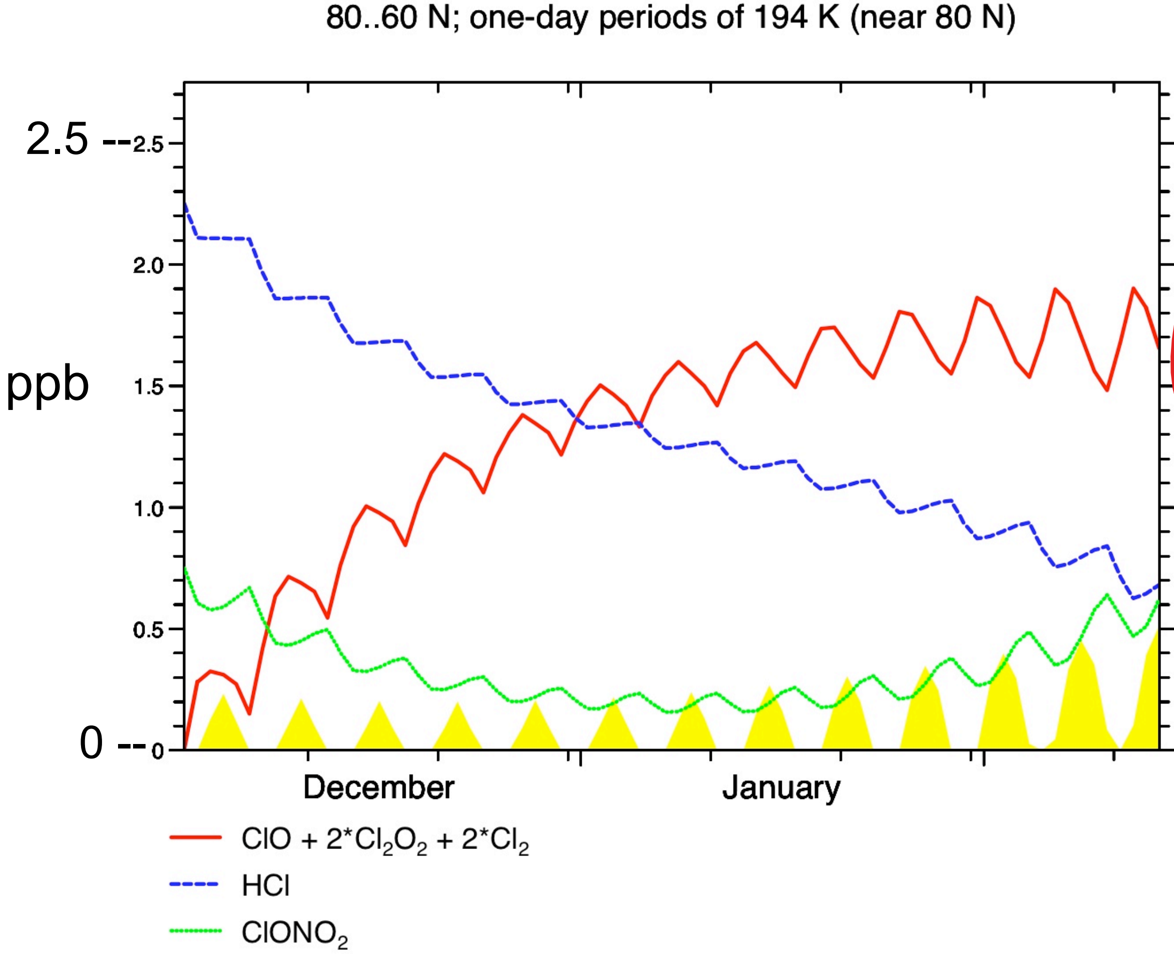
Activation

AWI chemical box model, Cl_y = 3ppb

sinusoidal 6 day cycle between 60 & 80˚ N at 50hPa (equiv to 20˚ offset vortex)

Intermittent PSCs



$ClONO_2 + HCl \rightarrow Cl_2 + HNO_3$

$HNO_3 + h\nu \rightarrow NO_2 + OH$

$NO_2 + ClO \rightarrow ClONO_2$

SLOW

Ozone loss vs de-activation

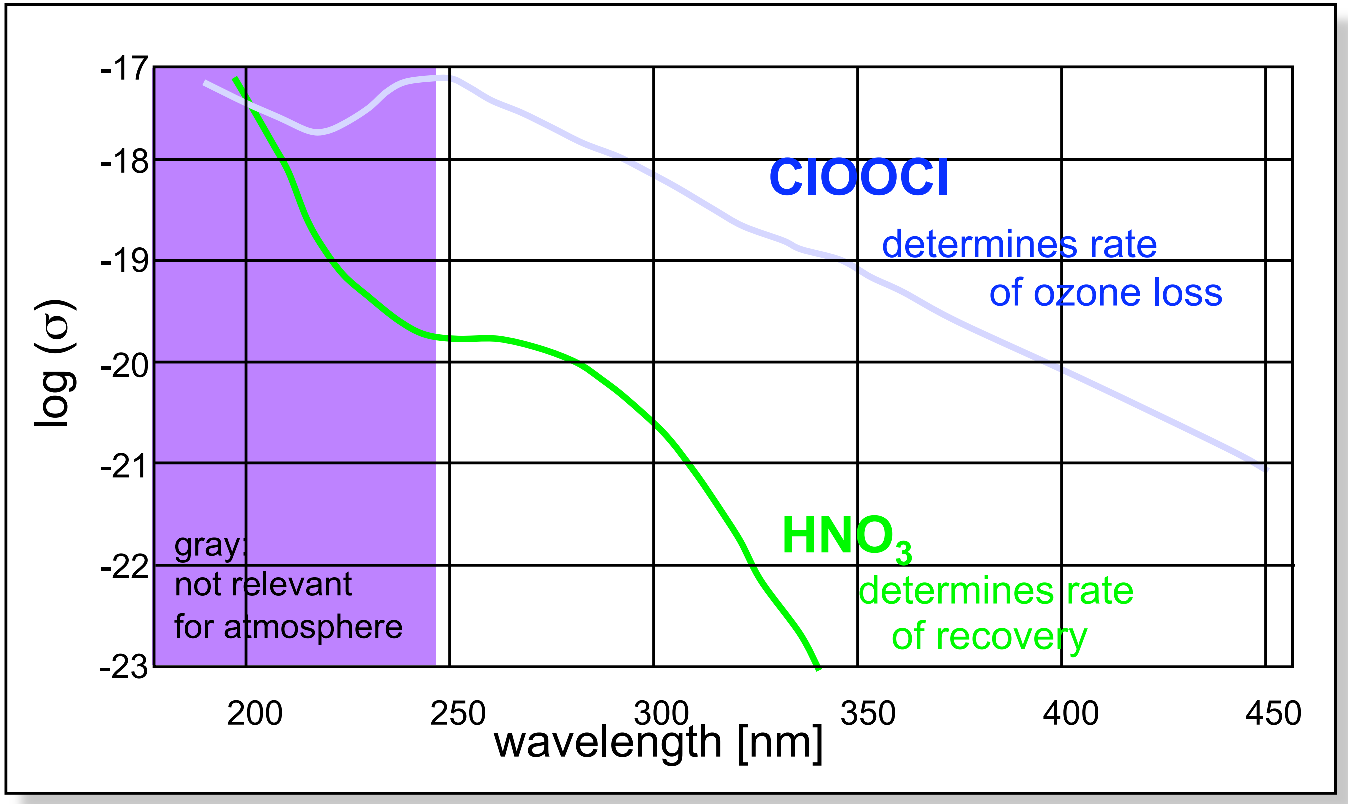
Both, ozone loss and chlorine deactivation are driven by sunlight:

Ozone loss:

$ClOOCl + h\nu \rightarrow ClOO + Cl$

Chlorine deactivation:

$HNO_3 + h\nu \rightarrow NO_2 + OH$ followed by $NO_2 + ClO \rightarrow ClONO_2$



- Both cross sections fall off steeply between UV and vis
- HNO_3 fall off somewhat steeper

Ozone loss vs de-activation

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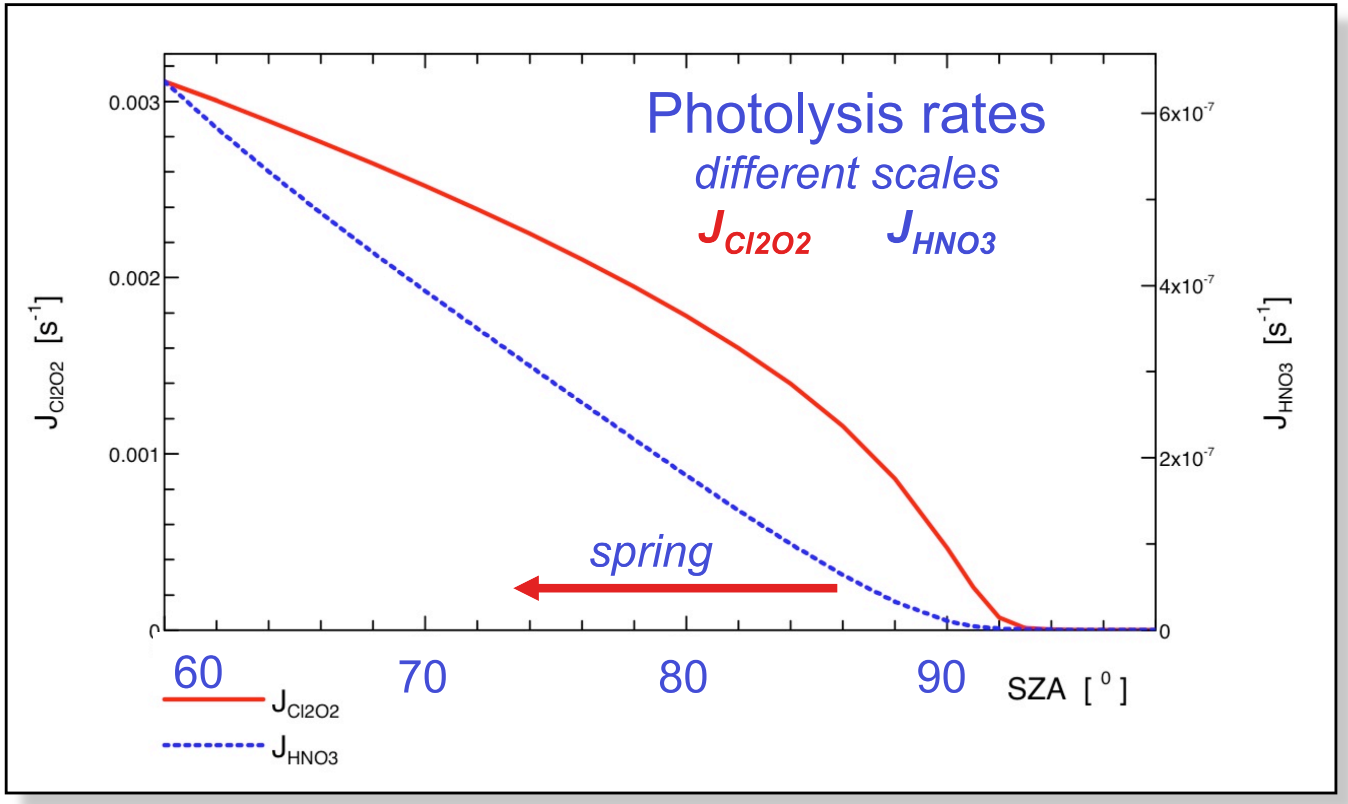
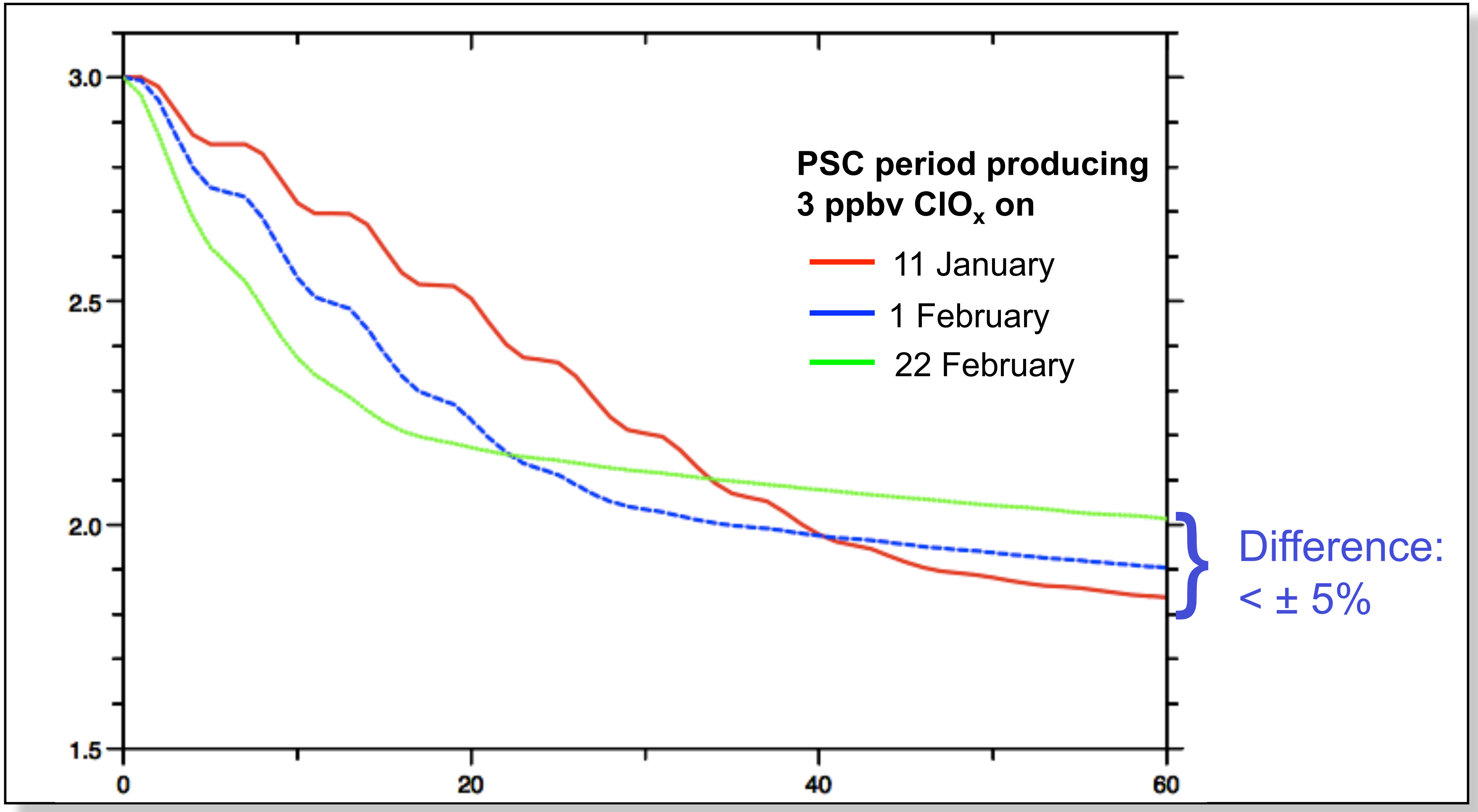


As SZA increases:

- both Js increase
  - ⇨ ozone loss rate ↑
  - ⇨ ozone loss rate period ↓
- J_{HNO3} increases more
- Deactivation > loss

Ozone loss vs de-activation



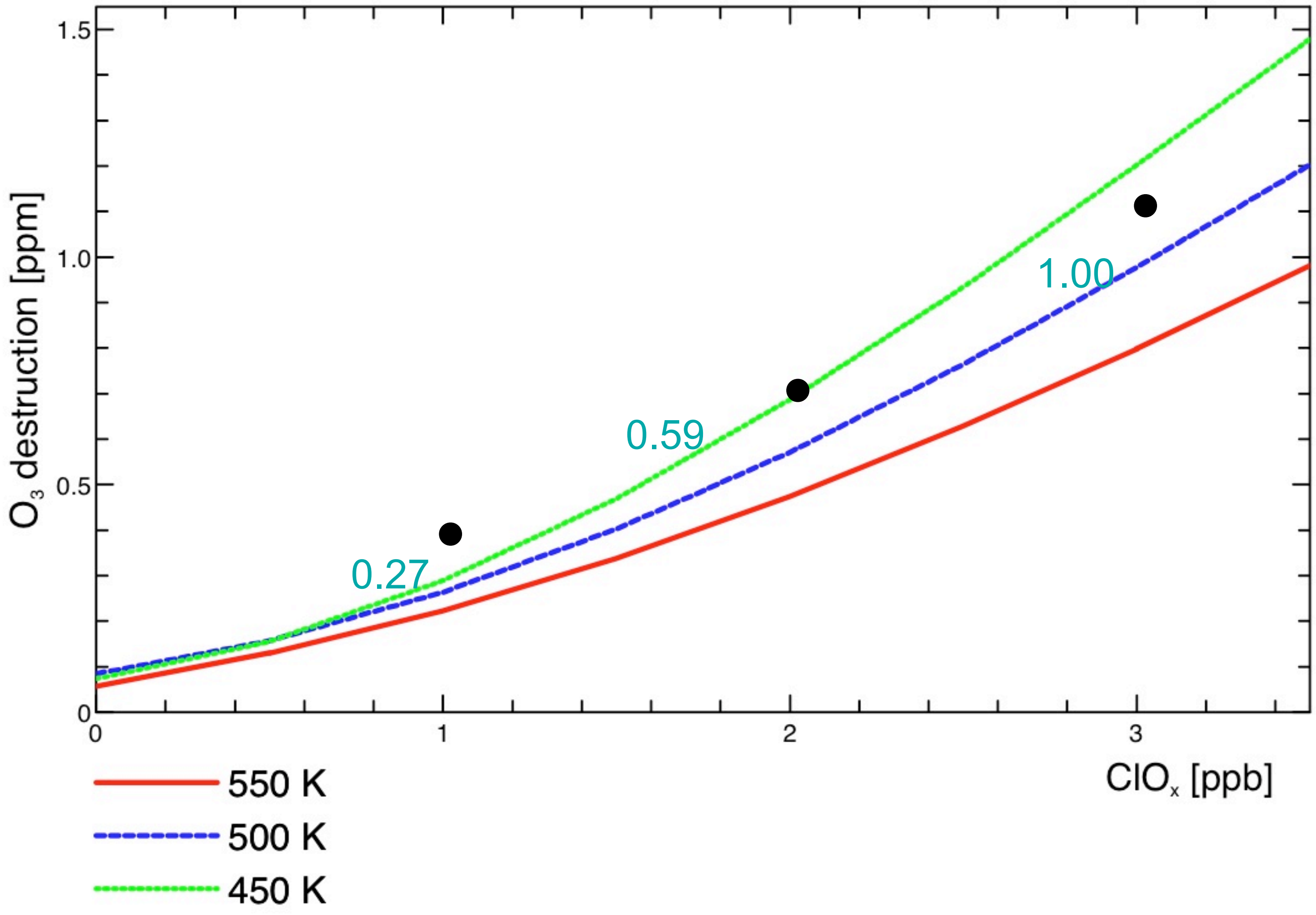
Difference:
< ± 5%

- A PSC event that activates 3 ppbv ClO$_x$ will result in ~1.1 ppmv loss of ozone, no matter when the PSCs occur (assuming stable vortex)
- Later activation: initially faster, but slightly less overall

Moving to 3D - offsetting ClO_x factors

O_3 loss close to linear with ClO_x (not close to quadratic)

- though (+)ve non-linearity partly offsets (-)ve non-linearity in activation



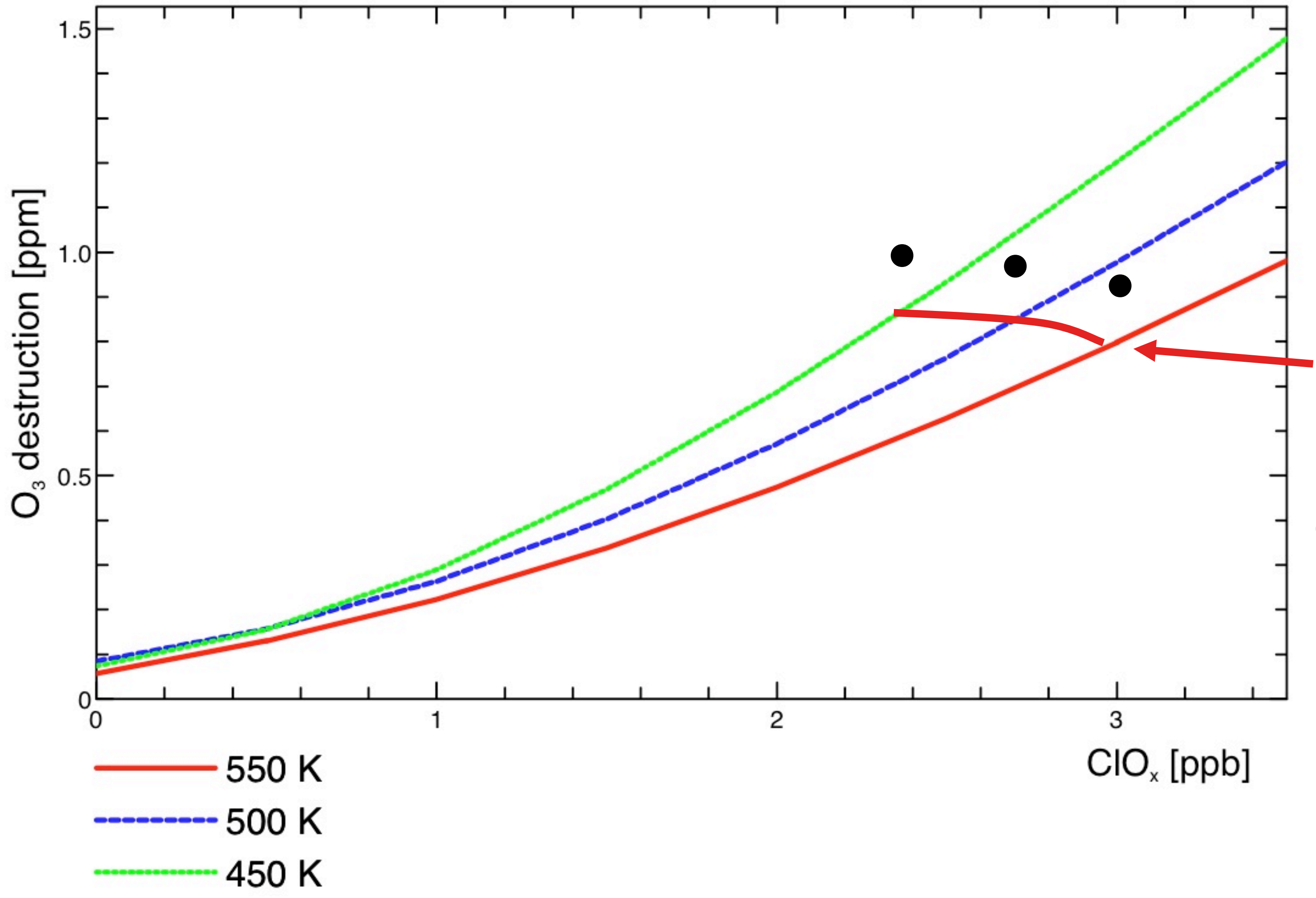
Moving to 3D - offsetting ClO_x factors

O_3 loss depends on initial ClO_x at different altitudes

more loss at lower altitudes for given ClO_x

Cl_y vertical profile provides upper limit to O_3 loss and vertical variation

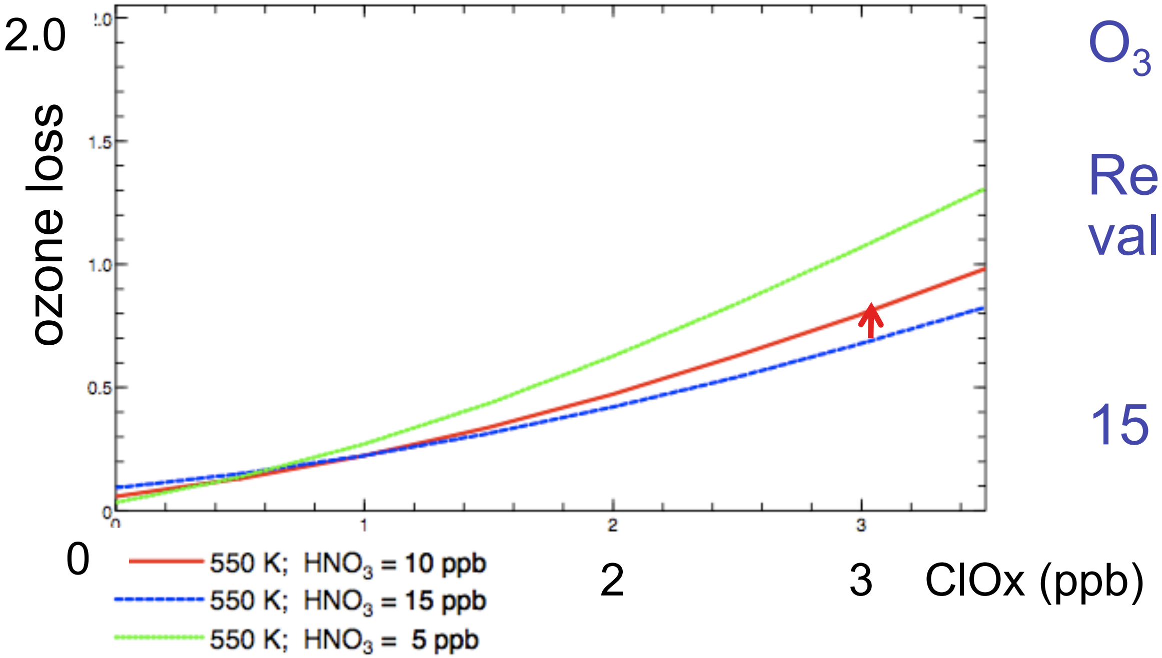
Limit to effect of PSC altitude variations on O_3 loss



Observed Cl_y in March

(Schmidt el at, 1994)

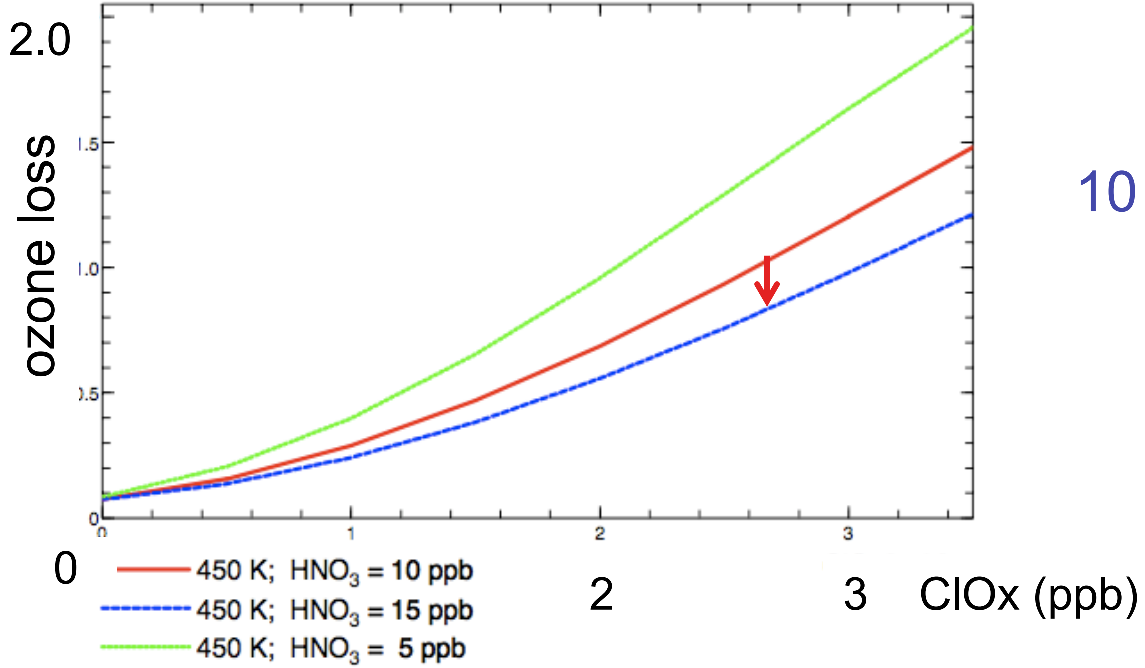
Moving to 3D - denitrification



O_3 loss vs ClO_x for different HNO_3

Reasonable offset when proper values for available ClO_x used

15 ➔ 10 ppb HNO_3 at 550K:
ΔO_3 loss= ~ + 0.15 ppb



10 ➔ 15 ppb HNO_3 at 450K:
ΔO_3 loss= ~ - 0.25 ppb

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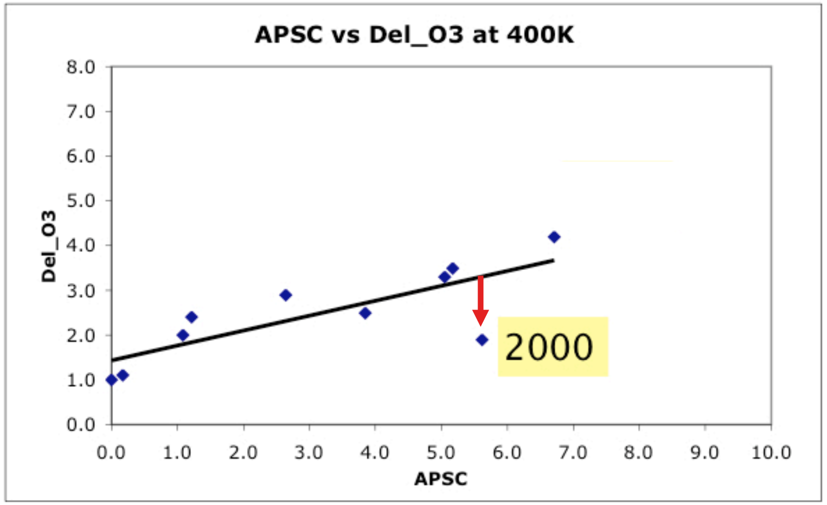
Moving to 3D - denitrification

Seen in 2000??



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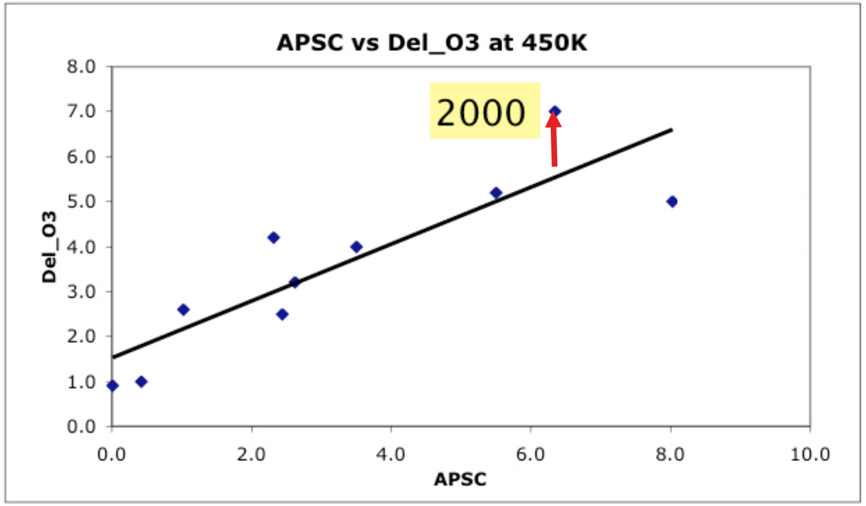

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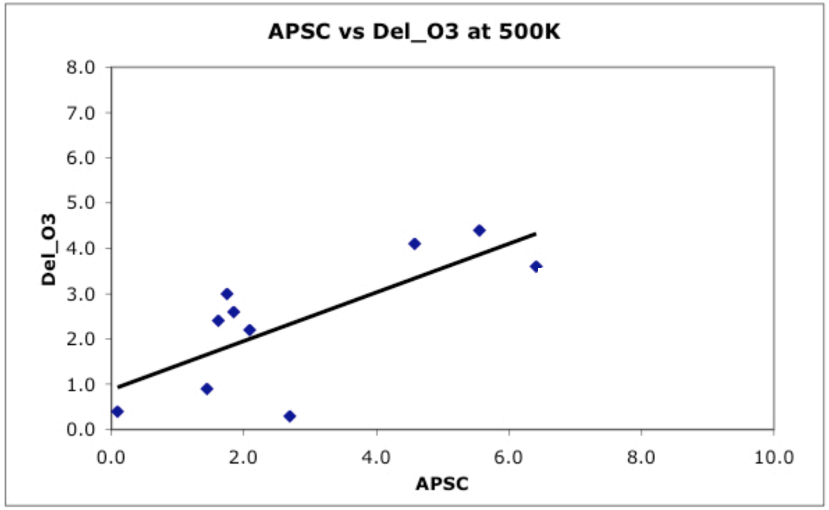

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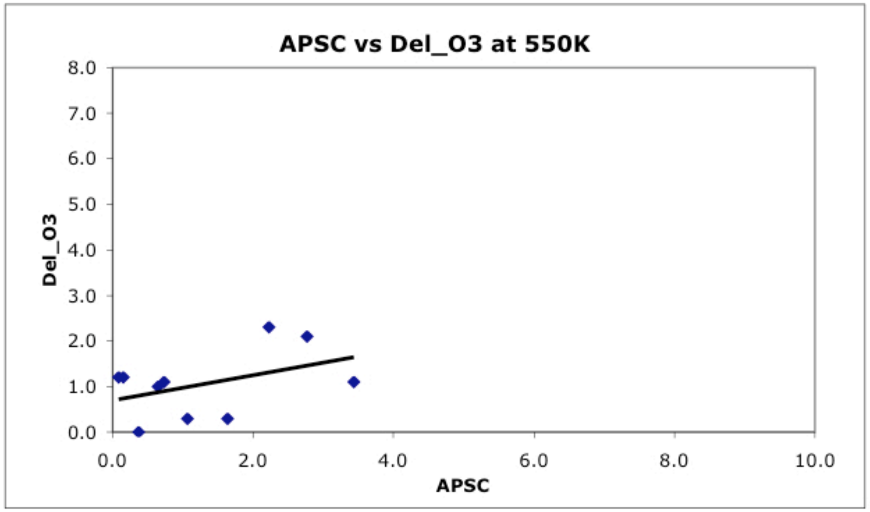

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Simple model of Arctic vortex average ozone loss - I

Activation:

initial: FAP × $ClONO_2$
further supply through $J(HNO_3)$, i.e. FAS-dependent
calculate instantaneous activation rate
i.e. $ClONO_2$, HCl and ClO_x evolution through winter

Ozone loss:

O_3 loss $\propto$ ClO_x × FAS

Deactivation:

depends mainly on HNO_3, ClO_x & FAS (Arctic)

Method:

- Solve 4 coupled differential equations
- Initial Cl_y and $ClONO_2$/HCl
- Meteorological fields (vortex fraction (a) with PSCs (FAP) & (b) sunlit (FAS))
- Chemical rates by training on $ClONO_2$ (ACE) and ClO & HNO_3 (MLS)

Poster by Petra Huck on similar model for Antarctic
[Session C ; P37; Thurs 1730]

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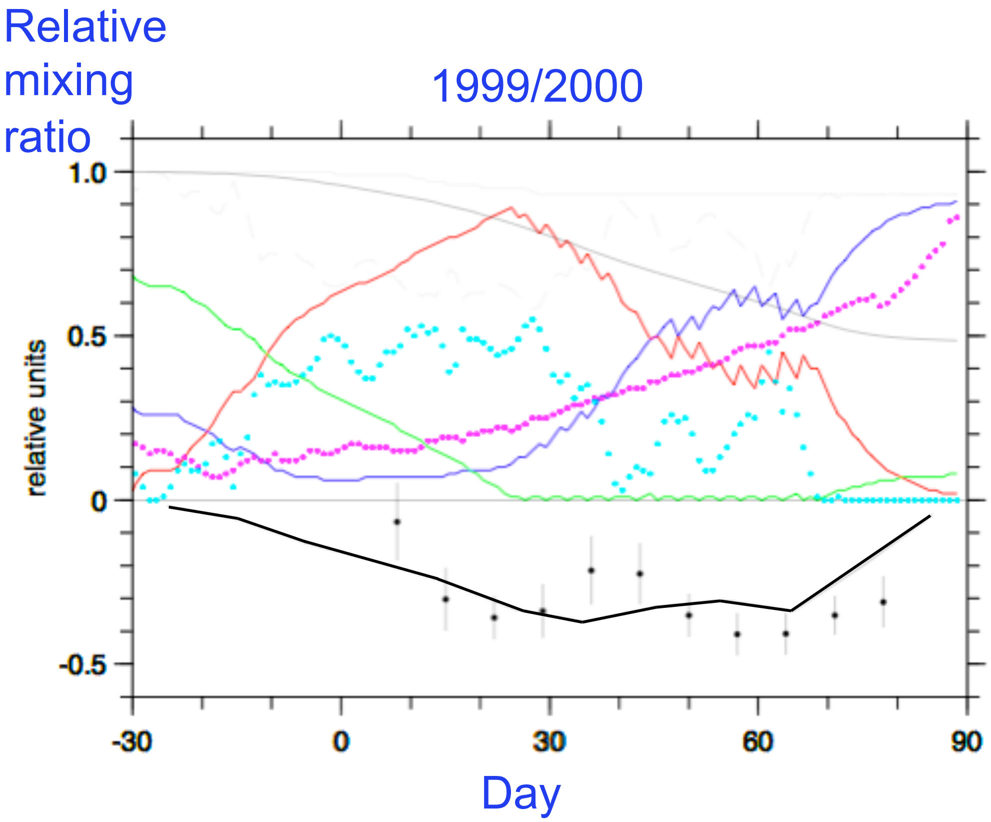
Simple model of Arctic vortex average ozone loss - II



Large interannual variability in HCl, $ClONO_2$ and ClO_x evolution

(c.f. Santee et al., JGR, 2008)

Effect of interplay between PSC and sunlit exposure

Currently realistic, but preliminary

<u>Upper panel (calc.)</u>	<u>Upper panel (input)</u>	<u>Lower panel</u>
O_3	FAP (dots)	O_3 loss
HCl	FAS (dots)	Match (dots)
$ClONO_2$		
ClO_x		
HNO_3 (not shown)		

Rex et al., in preparation

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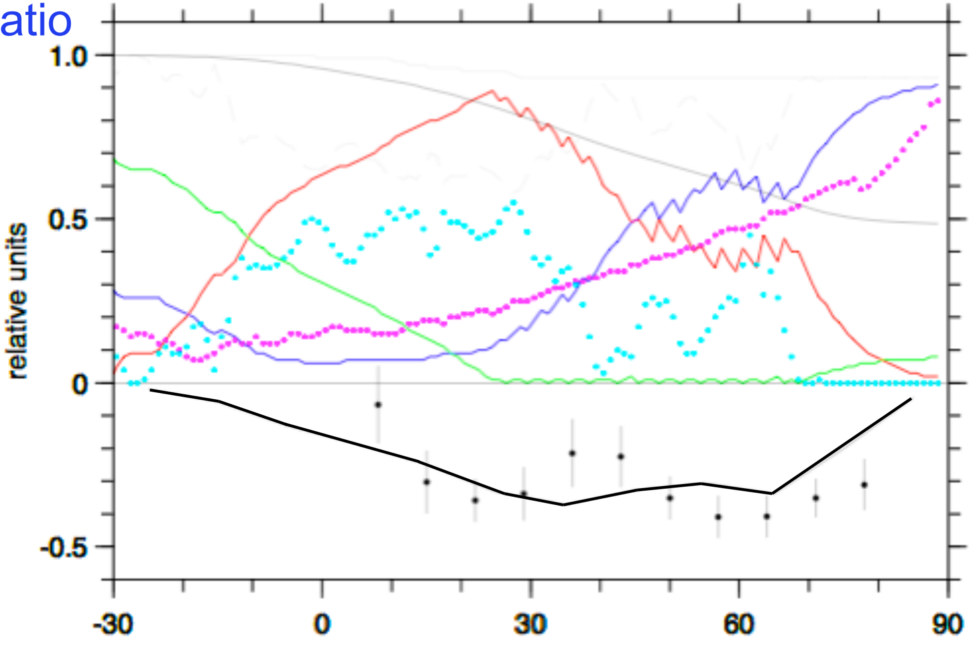
Simple model of Arctic vortex average ozone loss - II

Relative mixing ratio

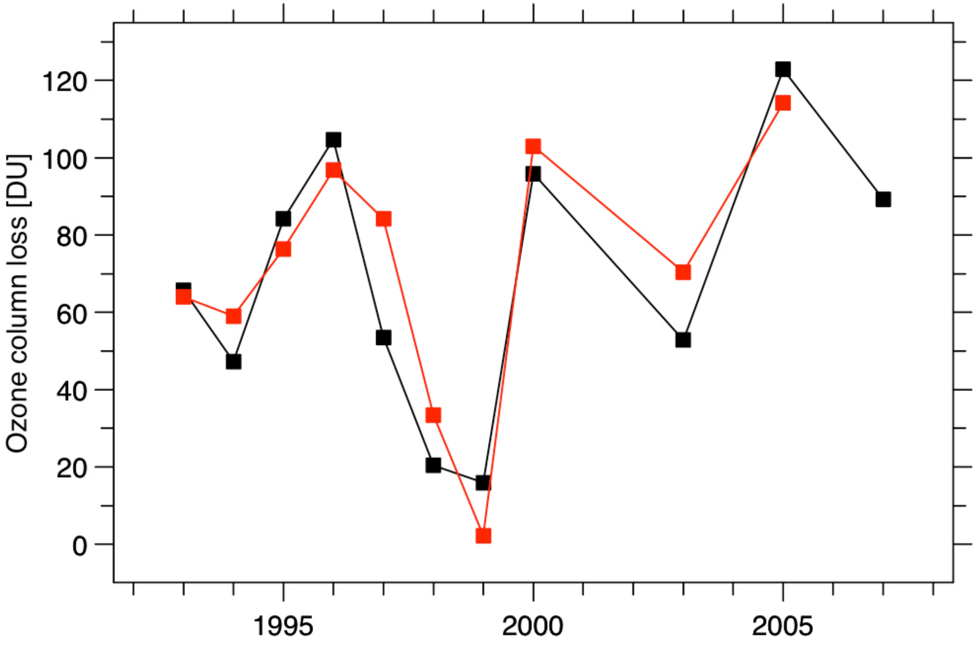
1999/2000



Day

Column O_3 loss

1992 - 200x



Year

Upper panel (calc.)
O_3
HCl
$ClONO_2$
ClO_x
HNO_3 (not shown)

Upper panel (input)
FAP (dots)
FAS (dots)

Lower panel
O_3 loss
Match (dots)

Observations
Simple model

Rex et al., in preparation

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Implications for CCMs

Critical parameters for calculating Arctic vortex ozone loss

- Cl_y, NO_y, meteorological fields as input
- T -> activation (FAP)   (PSC scheme?)
- Photolysis rates (ClOOCl, HNO_3) in 300-380nm -> deactivation
- Vortex position & extent -> solar exposure (FAS)

➔ *Development of simple algorithm for use in climate models?*

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Summary

Relation updated - it still holds

Activation:

- linearity: $J(HNO_3)$ limits $ClONO_2$ & ClO_x formation *(if PSCs present)*
- spatial/temporal averaging smooths idealised relation

Competition between O_3 loss and deactivation

- ~0.4 ppm of O_3 loss / 1ppb ClO_x
  - *$J(Cl_2O_2)$ vs $J(HNO_3)$ cancels out effects on O_3 loss*

Vertical offsets

- vertical profile of Cly
- denitrification / renitrification

Simple model

- surprisingly good description - *needs comparison with chemical fields*

All these processes in CTMs and CCMs show linear, compact behaviour

No new processes involved

Thank You!

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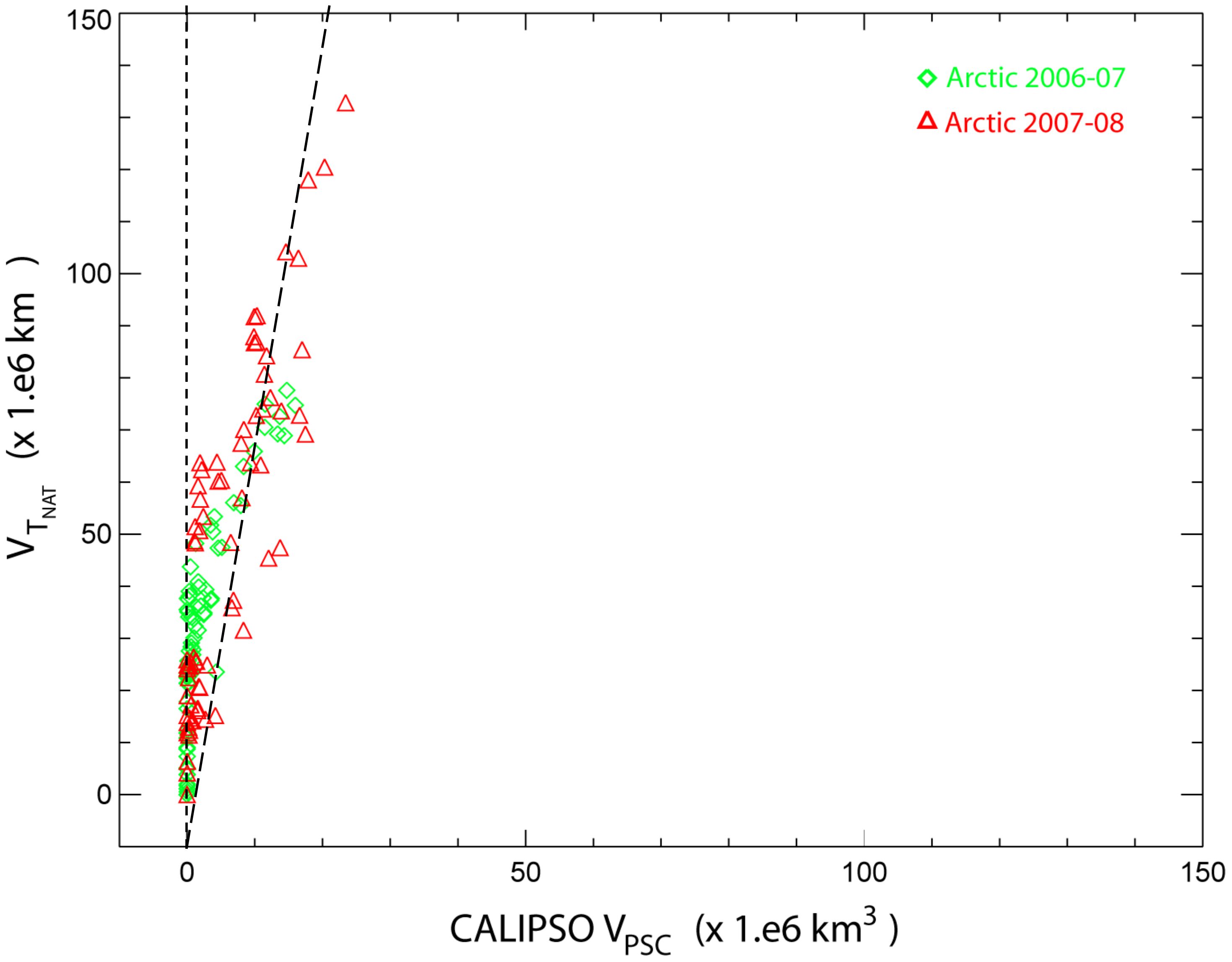
CALIPSO PSC Volume versus $T<T_{NAT}$ Volume

Arctic Only



Compactness of ozone loss vs. V_{PSC} relation

Quantitative work in progress about:

- **Cancelling effect of denitrification on column loss:**

denitrification at one level <=> renitrification at level below
larger loss less loss

- **Cancelling effect of baroclinicity on chlorine activation/denitrification:**

PSCs in vortex core cold region displaced
less air processed<=> more air processed
more denitrification less denitrification

- **Cancelling effect of solar illumination on ozone loss rates and chlorine deactivation:**

early PSCs late PSCs
slow ozone loss<=> rapid ozone loss
slow recovery / long loss period rapid recovery / short loss period

work in progress
Harris, Rex, Lehmann

UNIVERSITY OF CAMBRIDGE AWI

Activation

SLIMCAT overestimates activation

SANTEE ET AL.: *Stratospheric Chlorine Partitioning* 6

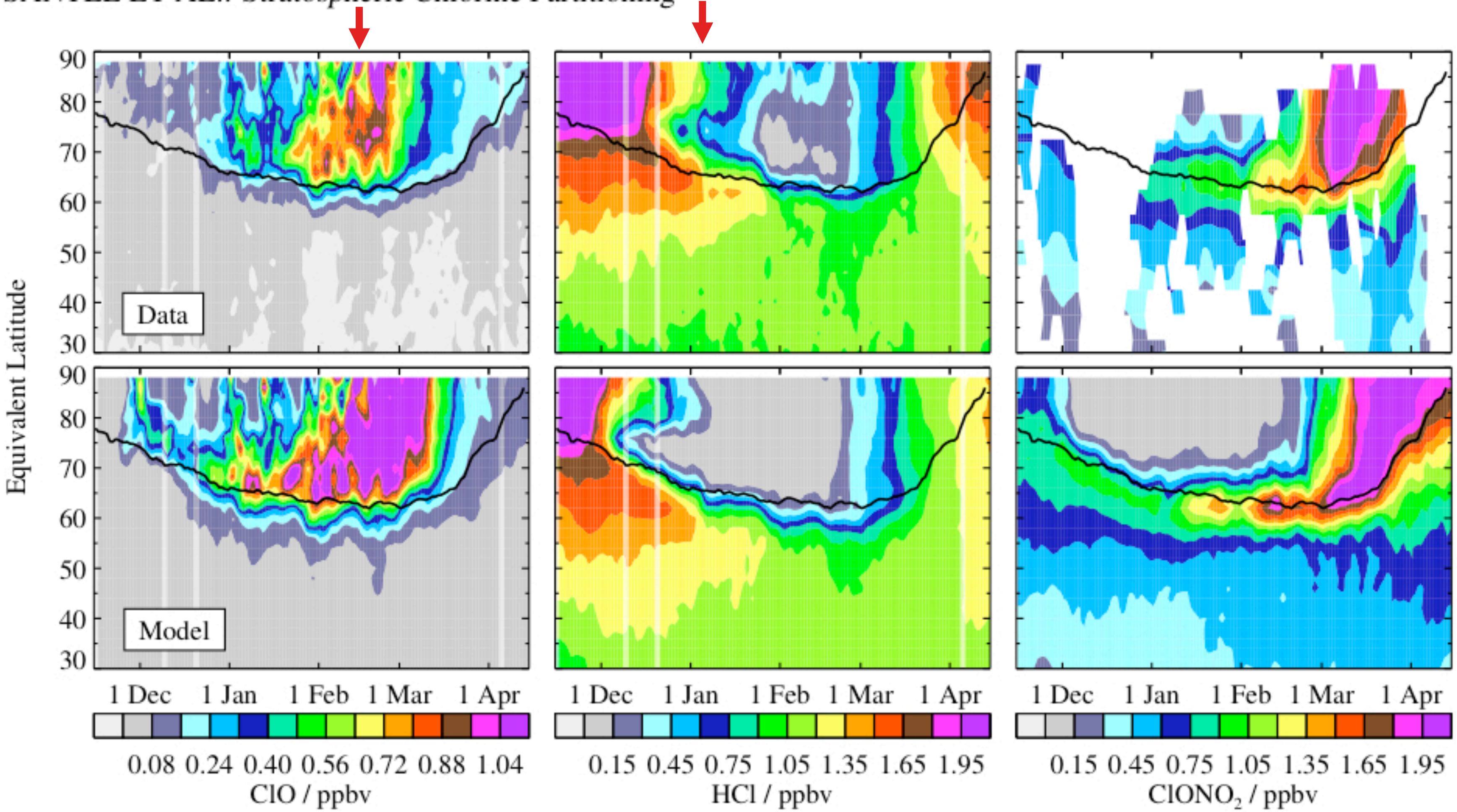


Figure 2. Time series over the 2004/2005 Arctic winter as a function of equivalent latitude (EqL) at 490 K. (Top row) ClO and HCl data from MLS and $ClONO_2$ data from ACE-FTS. Only daytime (ascending) data are shown for ClO; the individual measurements contributing to the daily averages have been adjusted to correct for a known negative bias in the MLS ClO data as discussed in section 2.1. Small gaps in the data have been filled using a Kalman smoother as in Figure 1. The $1.6\times10^{-4}\ s^{-1}$ contour of sPV is overlaid in black to demark the approximate edge of the polar vortex. (Bottom row) Corresponding SLIMCAT model results, sampled at the MLS measurement locations and times.

Basic requirements

Cold - PSCs - active chlorine - sunlight - isolation

Complicating factors:

- meteorological variations
- denitrification
- solar exposure
- initial chemical fields
- descent rates
- in-mixing
- vortex inhomogeneities
- vertical extent

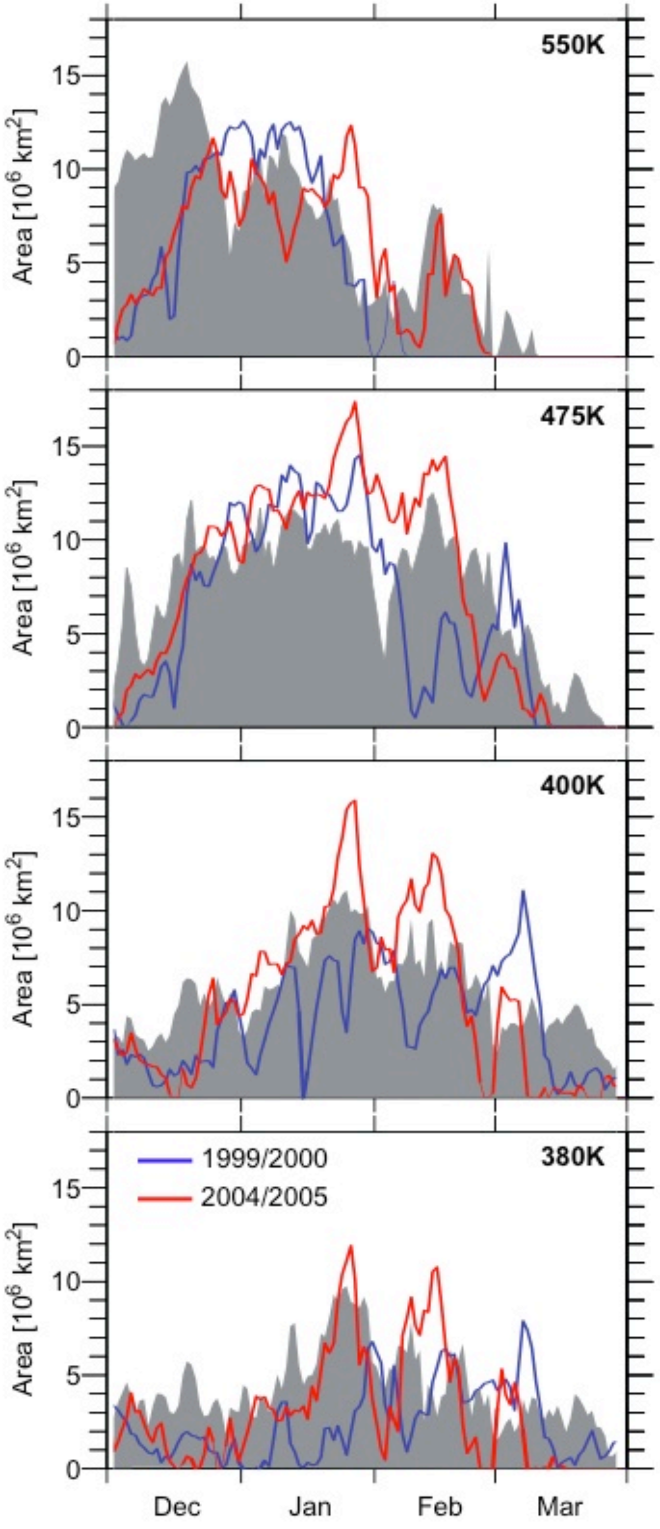
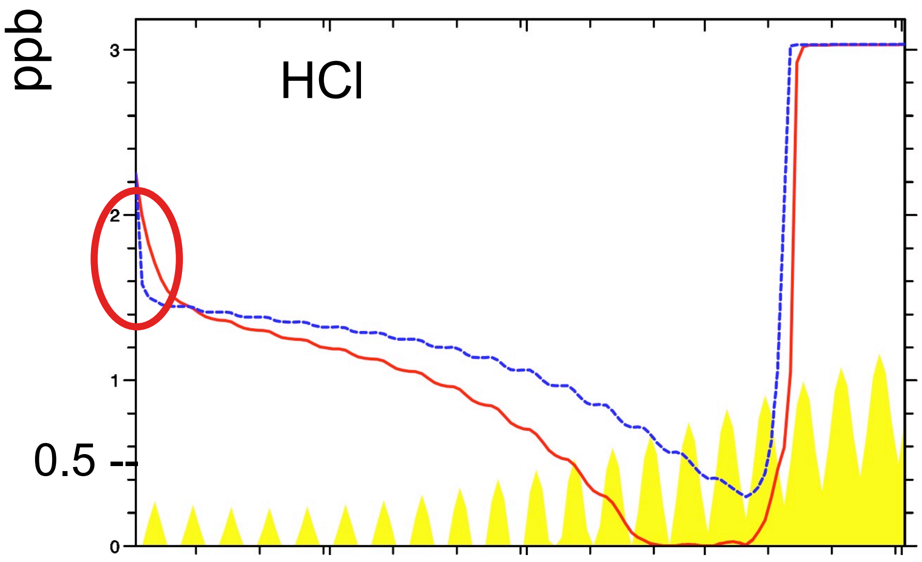
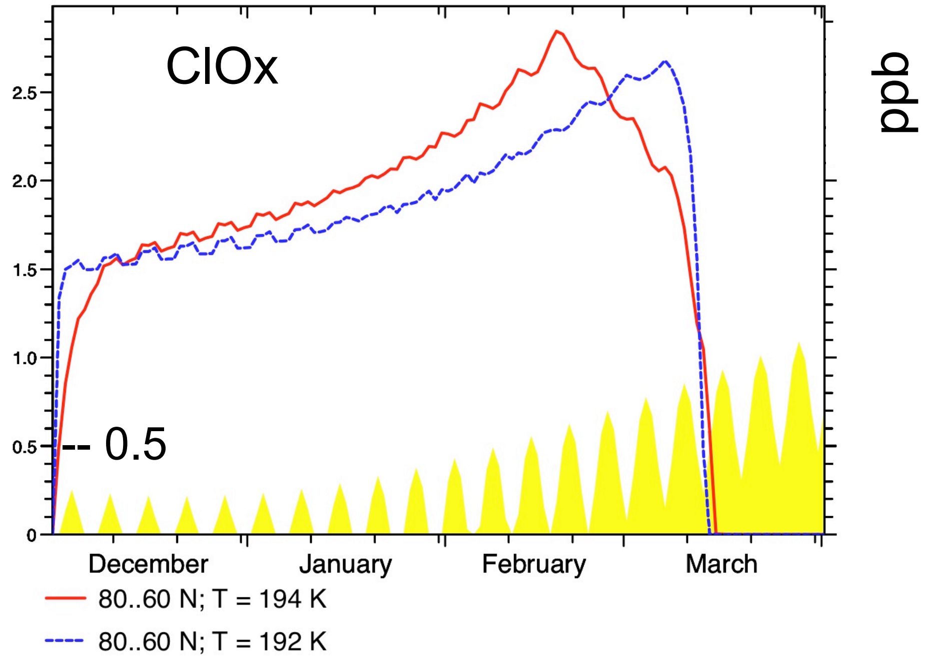


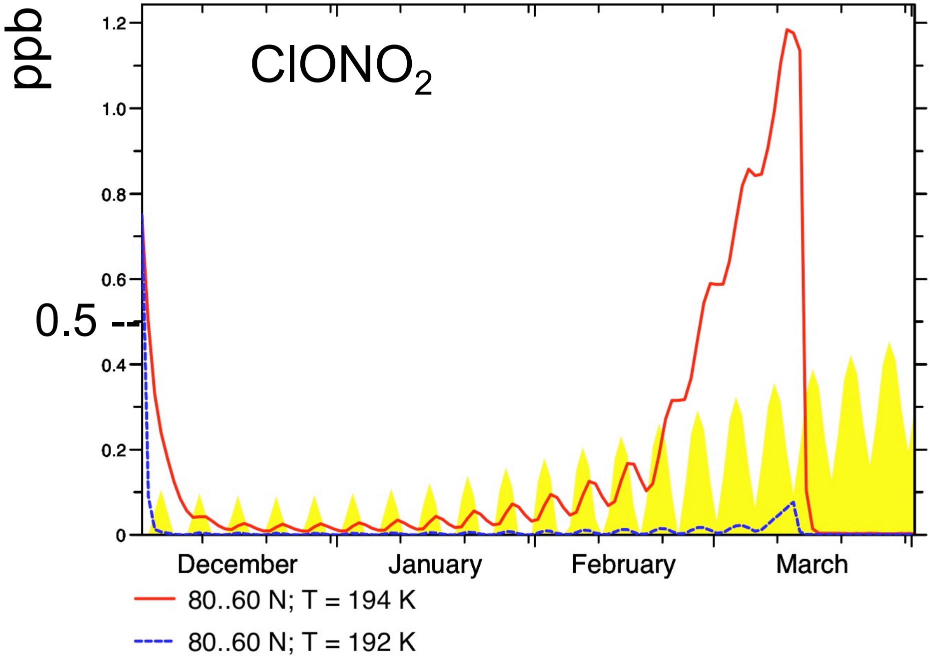
Figure 6. Time series of APSC for December to March of winter 2000 (blue) and 2005 (red) at the Θ = 380, 400, 475 and 550 K levels. Grey shading indicates the range of APSC between 1992 and 2004 (excluding the winter of 2000). Here, APSC denotes the daily horizontal extent of temperatures low enough for PSCs to exist

Activation

AWI chemical box model, Cl_y = 3ppb
sinusoidal 6 day cycle between 60 & 80° N at 50hPa (equiv to 10° offset vortex)







$ClONO_2 + HCl \rightarrow Cl_2 + HNO_3$

FAST, if cold

T-dependent (over vortex)

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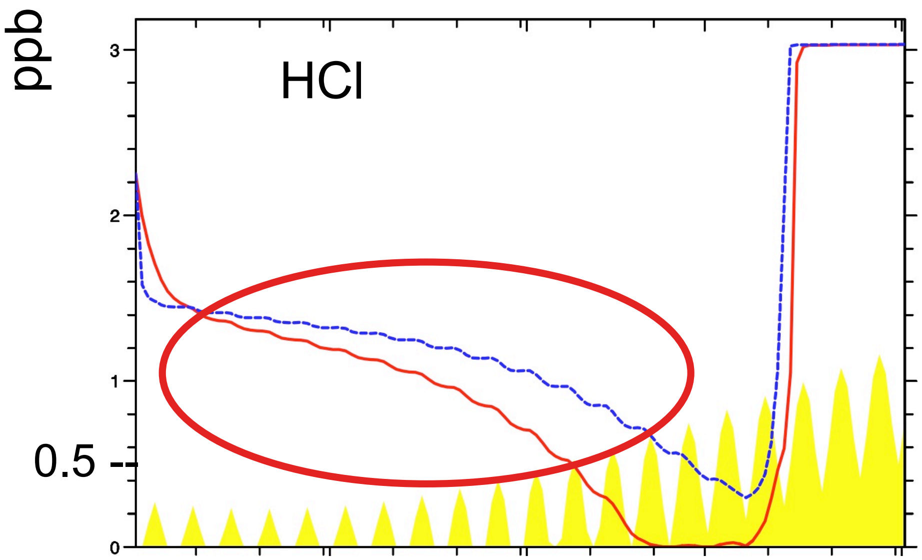

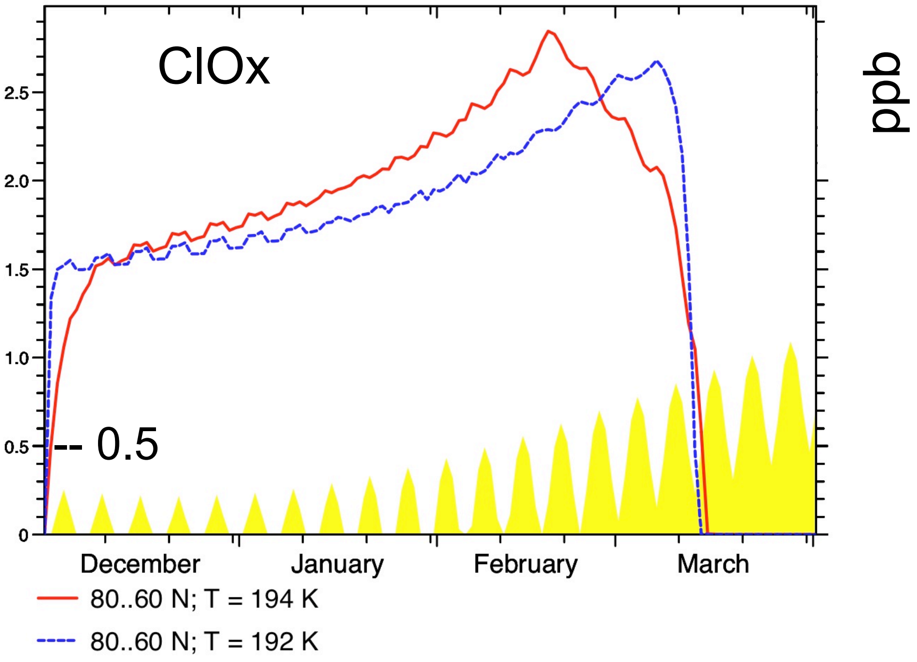

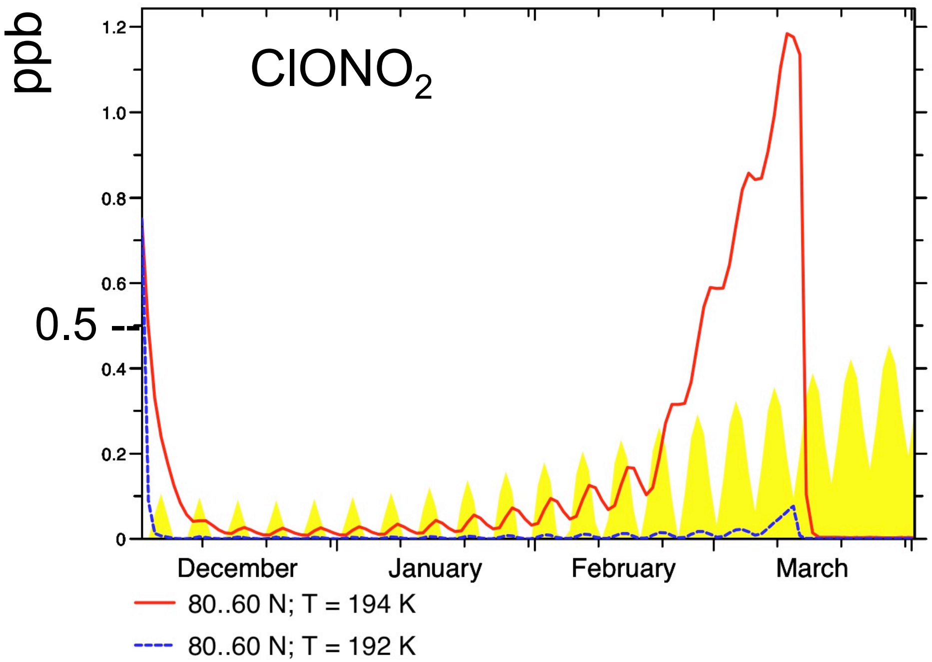

$ClONO_2 + HCl \rightarrow Cl_2 + HNO_3$

$HNO_3 + h\nu \rightarrow NO_2 + OH$

$NO_2 + ClO \rightarrow ClONO_2$

SLOW

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