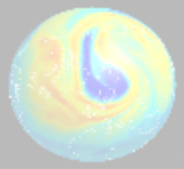

SPARC DA workshop, Brussels, 20-22 June 2011

Analyses and simulations of the Arctic “ozone hole” 2011

Karolien Lefever, Sebastien Viscardy

Contributors

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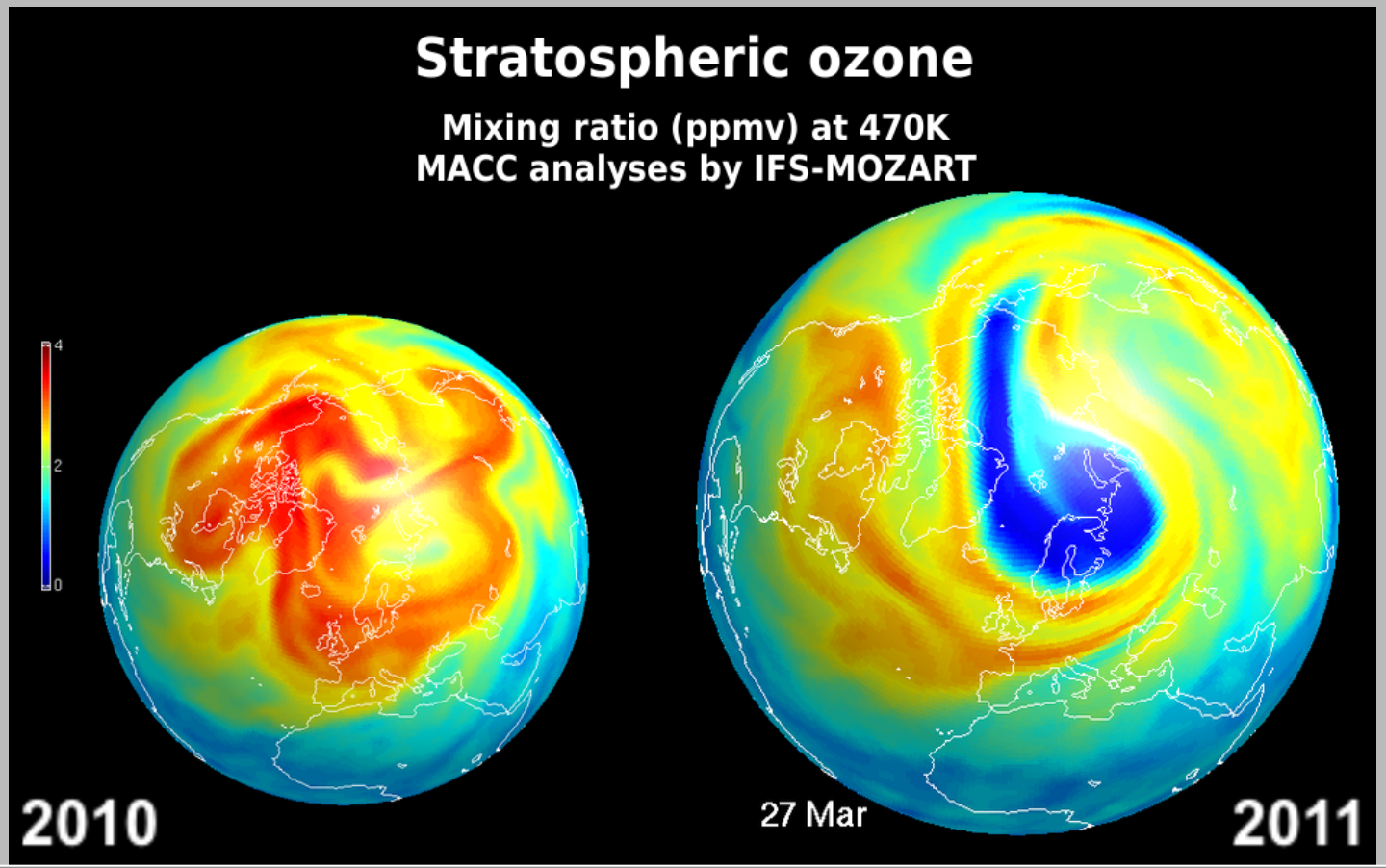
This research was done in the framework of the FP7 project MACC

Unprecedented loss of Arctic ozone



<u>GOAL:</u> to understand and evaluate the stratospheric processes that lead to this unusual event

Outline

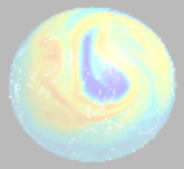
Part 1: Polar stratospheric clouds

- Formation
- Types of PSC
- Role of PSC
- Parametrization REPROBUS
- Parametrization MOZART3

Part 2: Ozone depletion event Winter/Spring 2011

- Meteorological circumstances
- Evaluation stratospheric processes
  - 3 models: IFS-MOZ, BASCOE FMR, BASCOE AN with different parametrizations
  - Dec 2010 – March 2011

Part 1: Polar Stratospheric Clouds



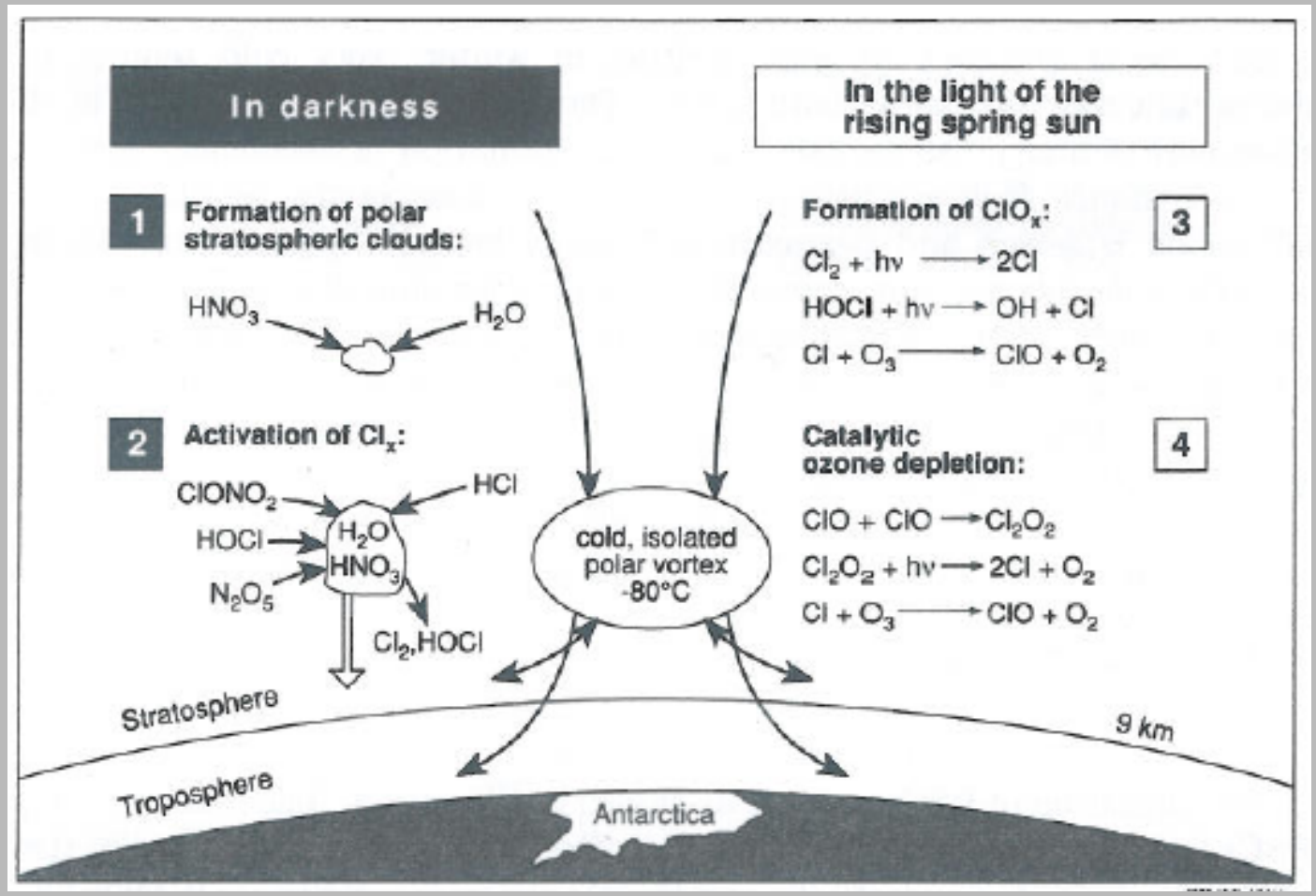
Polar Stratospheric Clouds

- Early winter: formation of a polar vortex
  → very cold temperatures in absence of solar heating
  → formation of polar stratospheric clouds

- Three main types of PSC particles:
  - NAT: solid Nitric Acid Trihydrate ($HNO_3.3H_2O$)
  - ICE: ice particles (frozen H_2O)
  - Liquid droplets of binary (H_2SO_4/H_2O) or ternary ($H_2SO_4/H_2O/HNO_3$) solutions

- Role of PSCs:
  - Heterogeneous reactions: conversion of chlorine reservoirs (HCl and $ClONO_2$) into active chlorine species (Cl_2, HOCl,…)
  - Denitrification (physical removal of HNO_3 from the gas phase)
  - Dehydration (physical removal of H_2O from the gas phase)

Physico-chemical processes

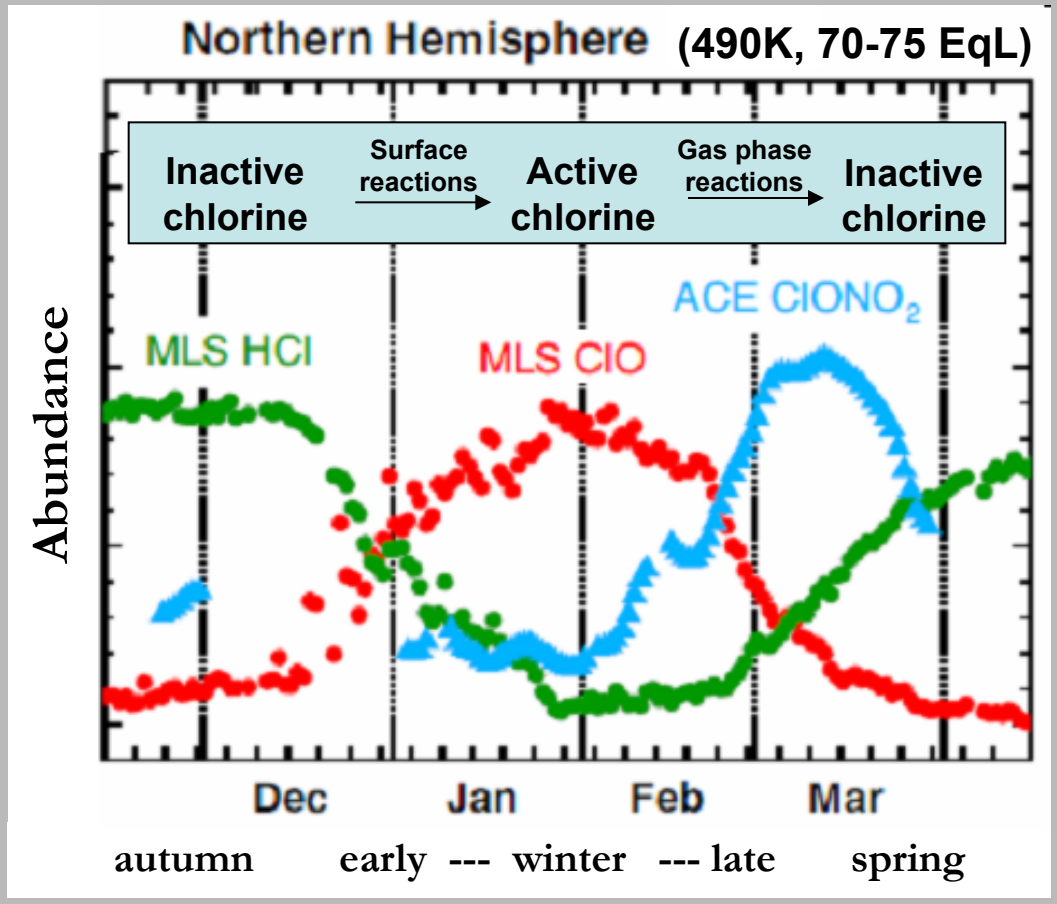


<u>Role of denitrification:</u>

Recovery of reservoir species: ClO + NO2 → ClONO2

But denitrification prevents such a reaction: HNO3 + hv → NO2 + OH

Evolution chlorine species during Arctic winter

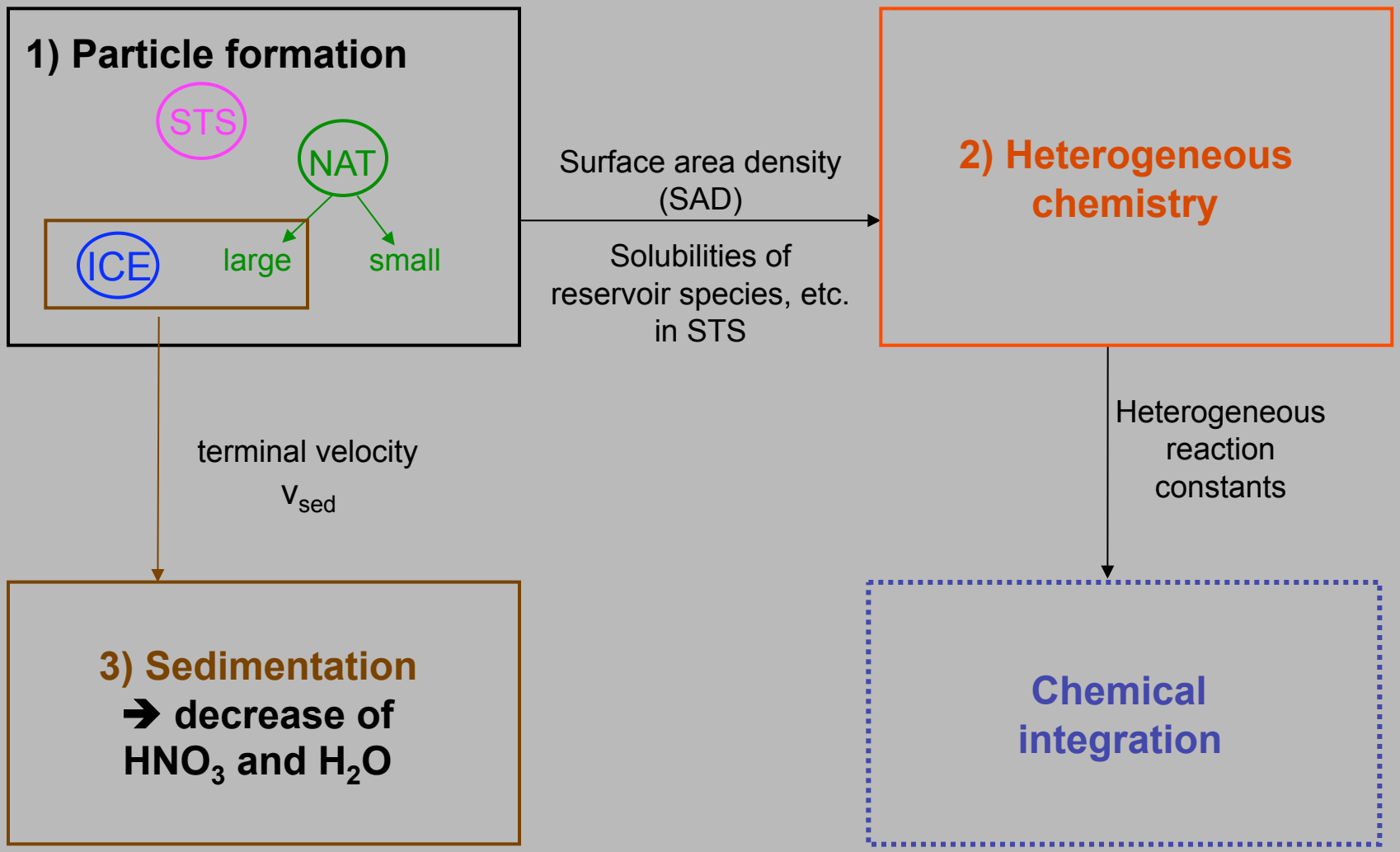


Denitrification and dehydration

Surface processing

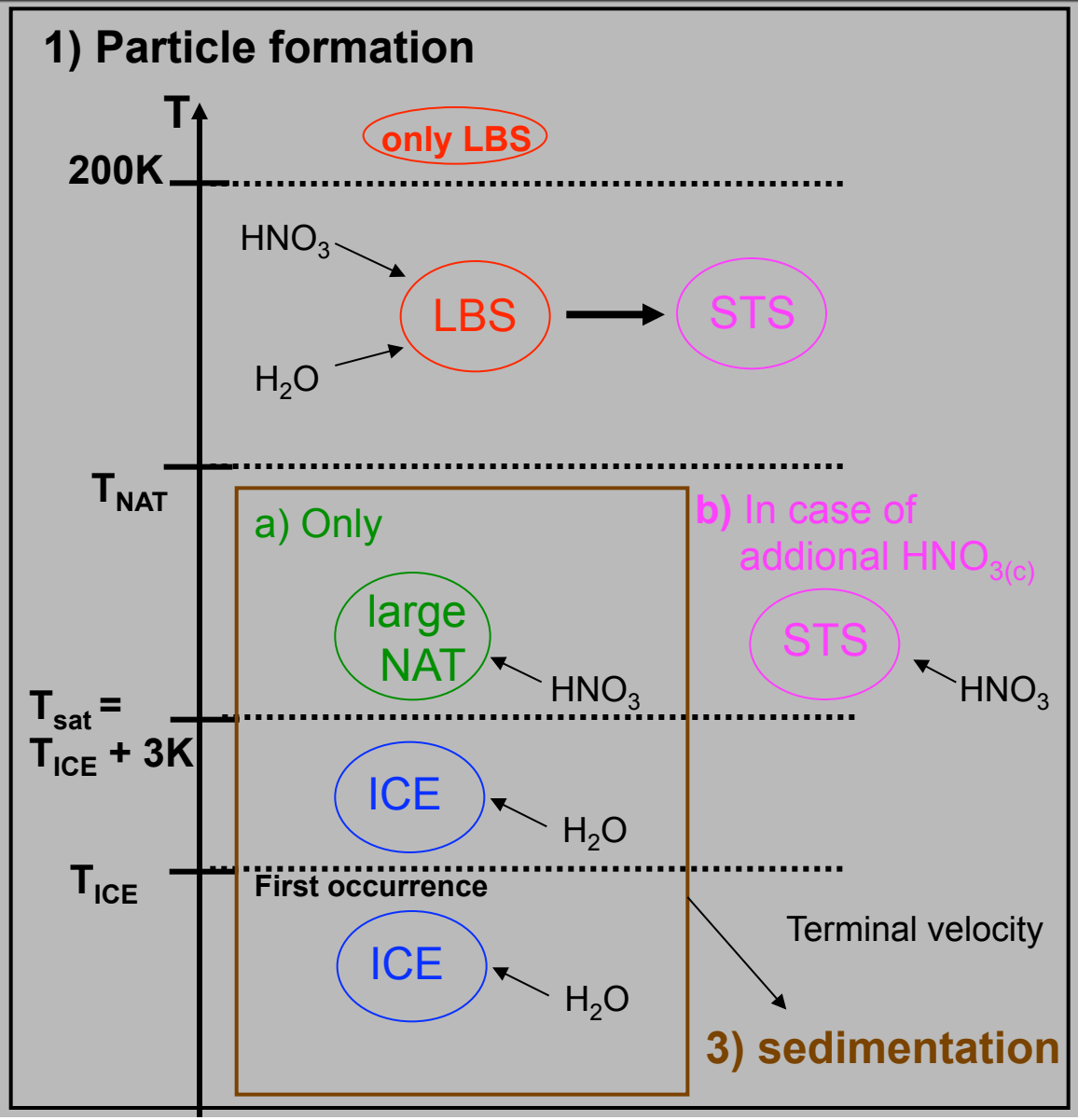
Cl-catalysed O_3 destruction

REPROBUS PSC parametrization

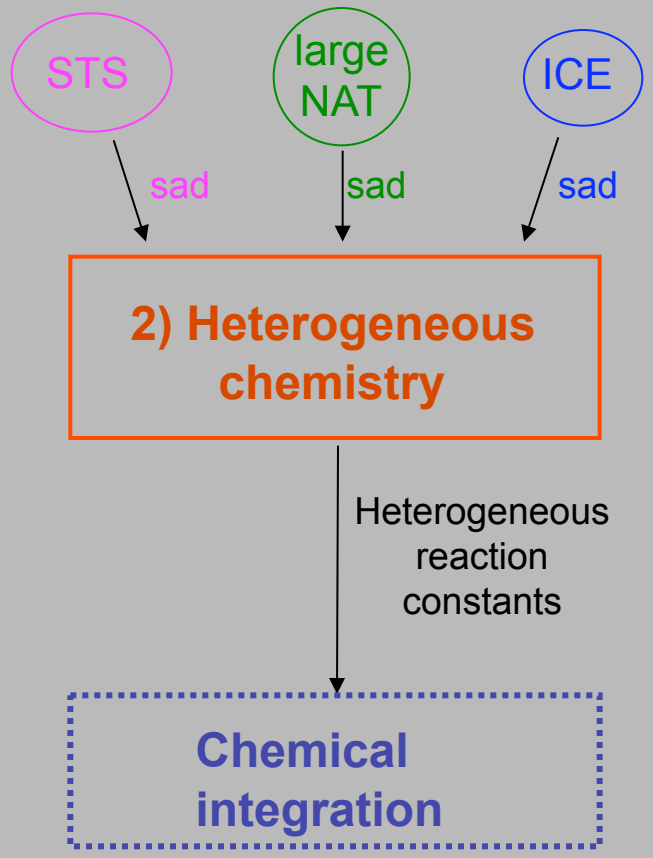


Assumption: thermodynamic equilibrium reached at each time step
i.e. no memory about the state of the PSC particles

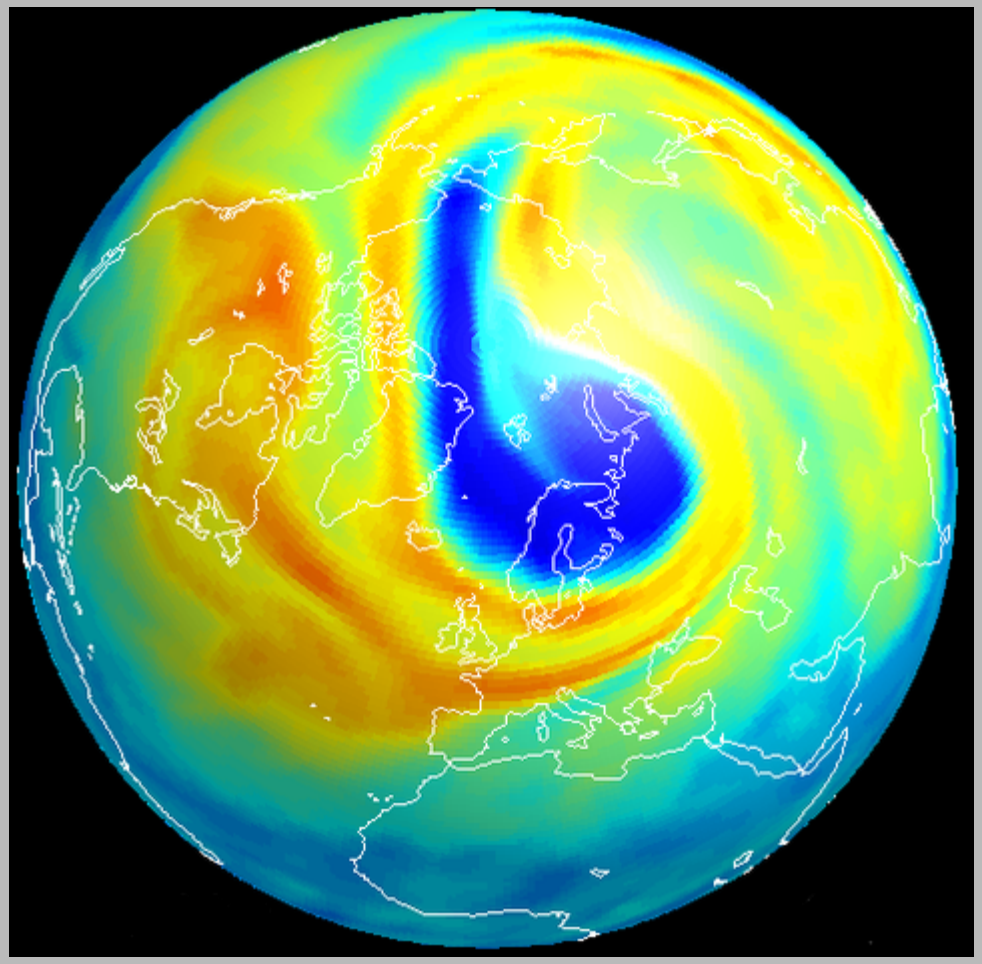
MOZART-3 PSC parametrization



LBS, STS, NAT and ICE: lognorm. size distr.
NAT: r_{median} = 6.5 μm; n_{NAT} = 2.3x10^{-4} cm^{-3}

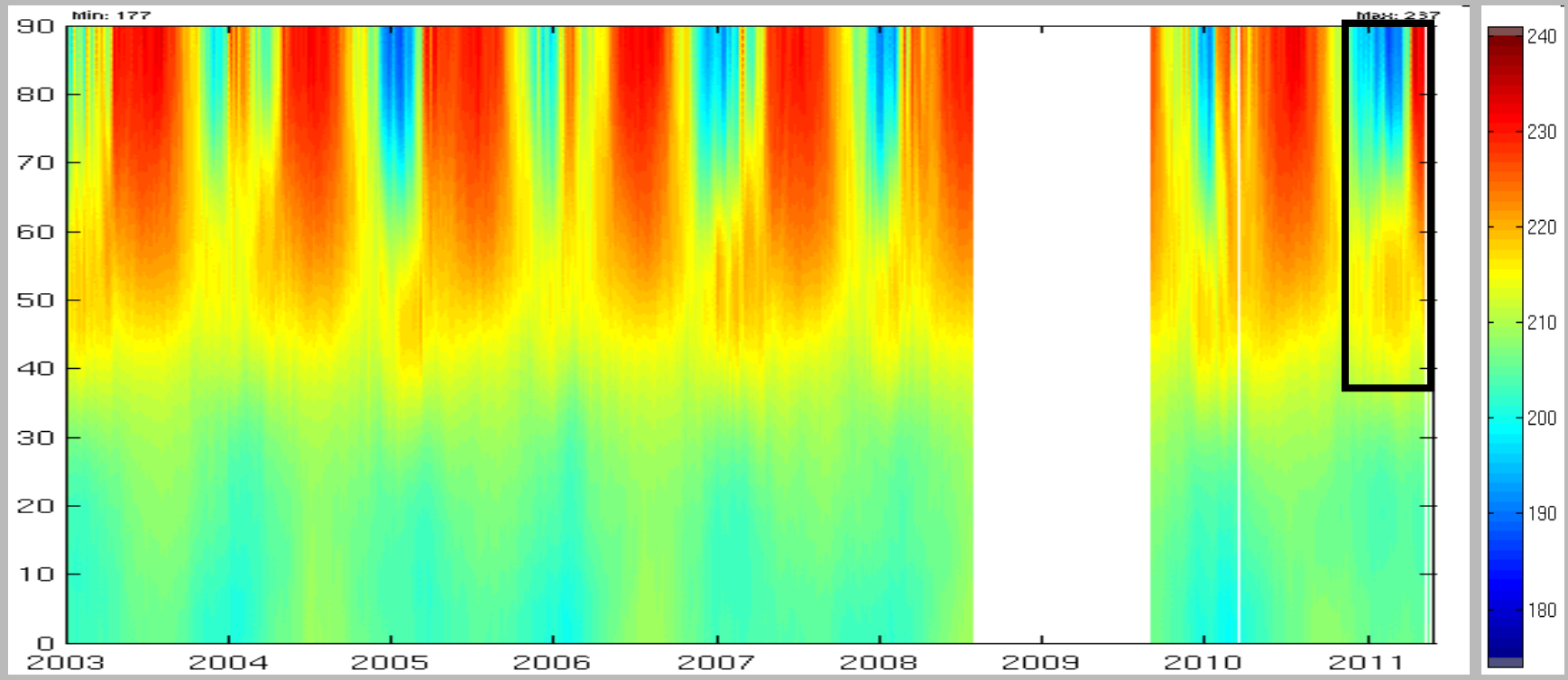


Part 2: Ozone depletion event Winter/Spring 2011



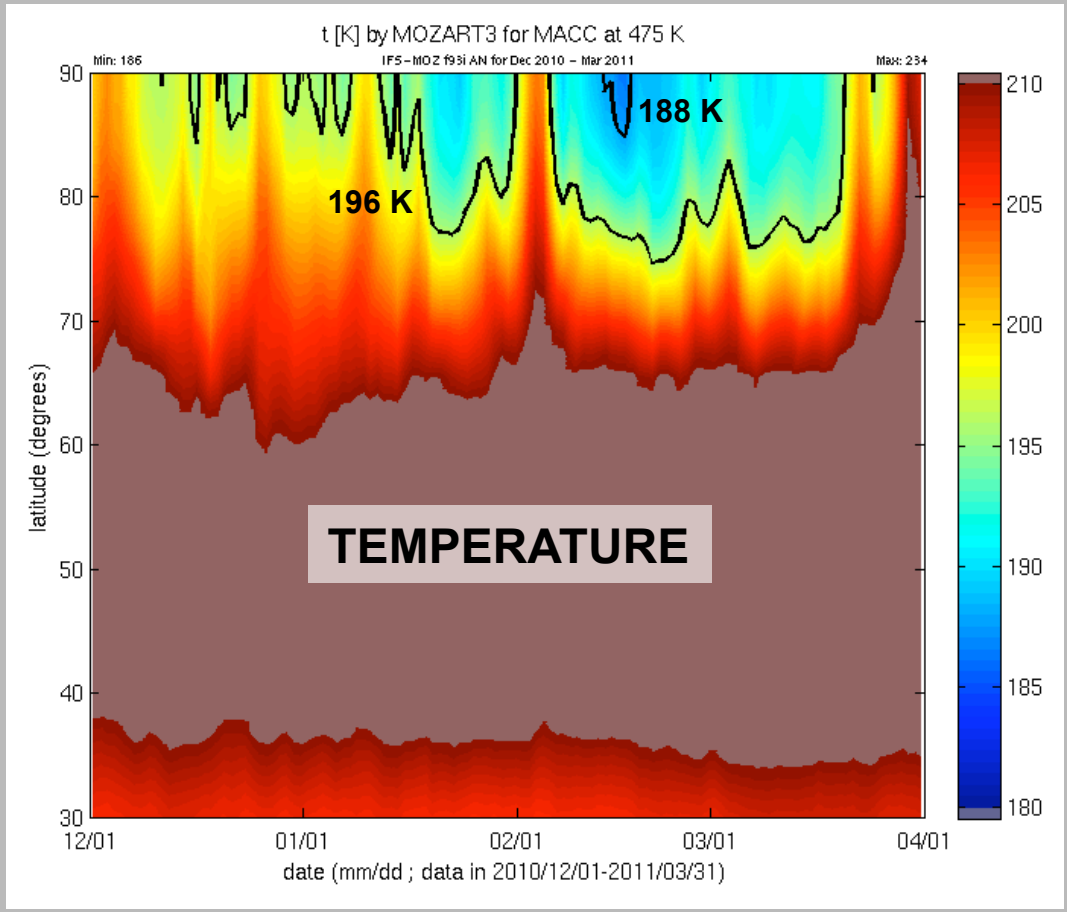
Meteorological circumstances

Temperature evolution at 475K from 2003-2011



Meteorological circumstances

Zonally averaged temperature time series at 475K for Dec-March



Evaluation stratospheric processes

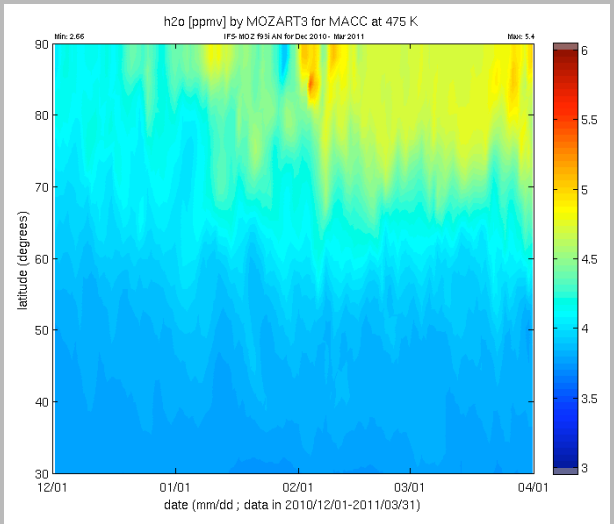
Evaluation based on 3 models

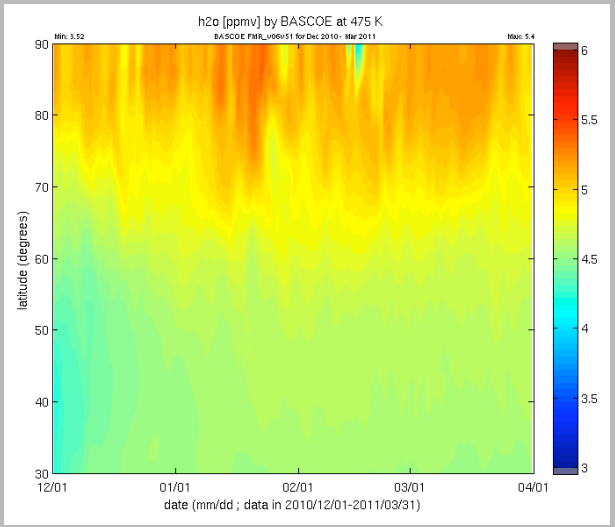
	IFS-MOZART ANALYSIS	BASCOE FREE MODEL RUN	BASCOE ANALYSIS
Type	Started on 1 Aug '09 Assim. of strato O3 only • Profiles: Aura/MLS • TC: SBUV, OMI, SCIAMACHY	Started on 1 Dec '10	Started on 1 Dec '09 Assim. of strato O3, N2O, HNO3, HCl, HOCl & H2O • Profiles from Aura/MLS (limb scanning instr.)
Hor. resol.	MOZ: 1.875° x 1.895° (191x95) IFS: 1° x 1° (360x181)	2.5° x 2° (144x91)	3.75° x 2.5° (96x73)
PSC param	based on NAT, STS and ice Described in Auxiliary Material of Kinnison et al. (2007)	based on NAT, STS and ice Parametrization from REPROBUS-CTM	Cold T limit: T < 194 K → NAT PSC T < 186 K→ ice PSC

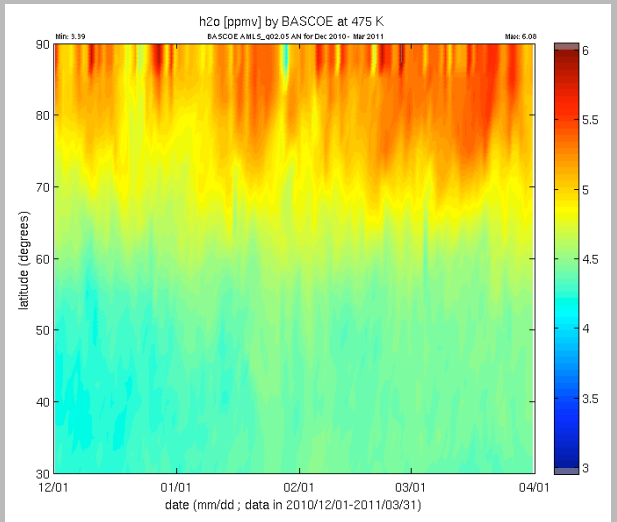
<u>Important note:</u> MLS ceased to send data from the 26th of March on

Water vapour H2O

IFS-MOZ | BASCOE FMR | BASCOE AN



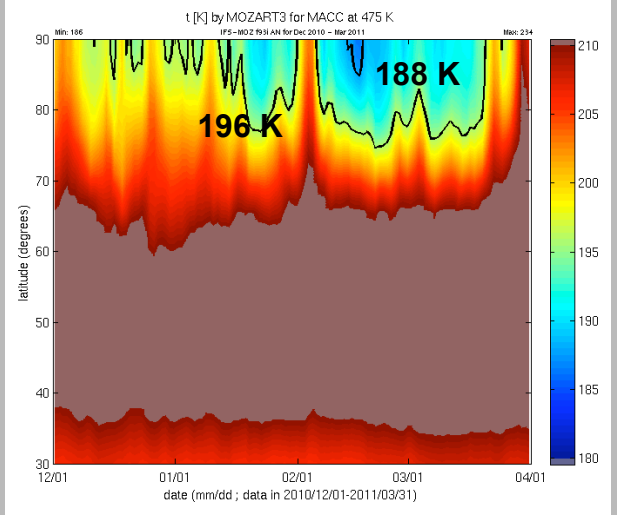




BASCOE H2O analysis suggests: little/no ice PSC

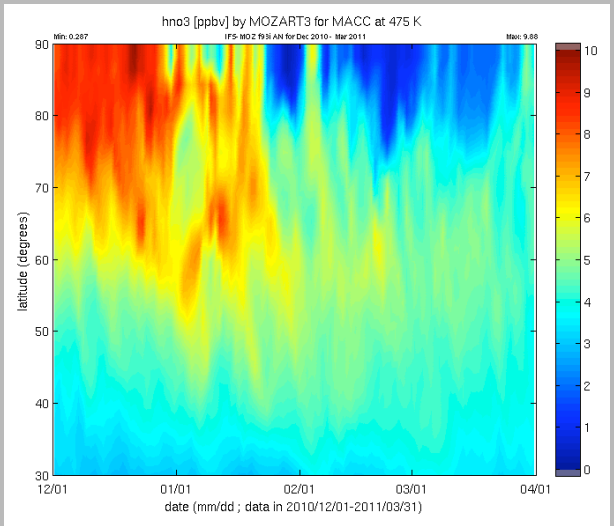
BASCOE FMR: simulates some dehydration

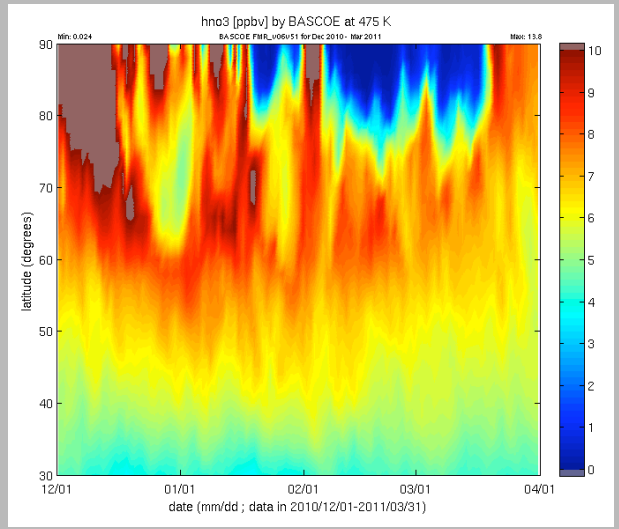
IFS-MOZ: global bias, but no dehydration

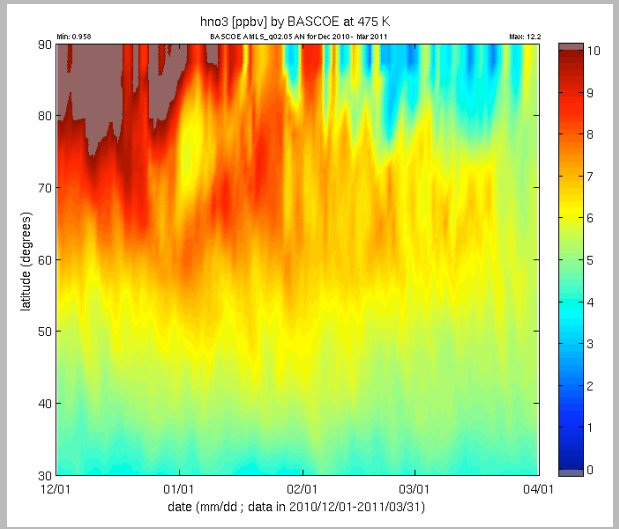


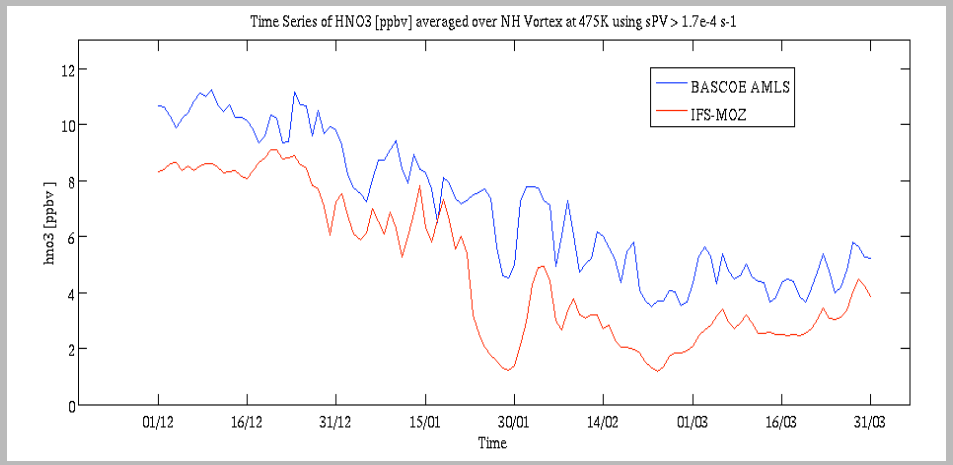
Nitric acid HNO3
(reservoir species)

IFS-MOZ | BASCOE FMR | BASCOE AN









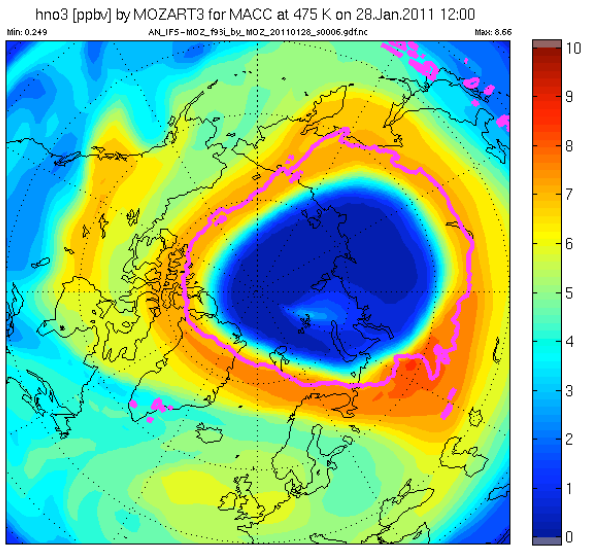
The BASCOE AN shows important denitrification due to formation of PSC type I

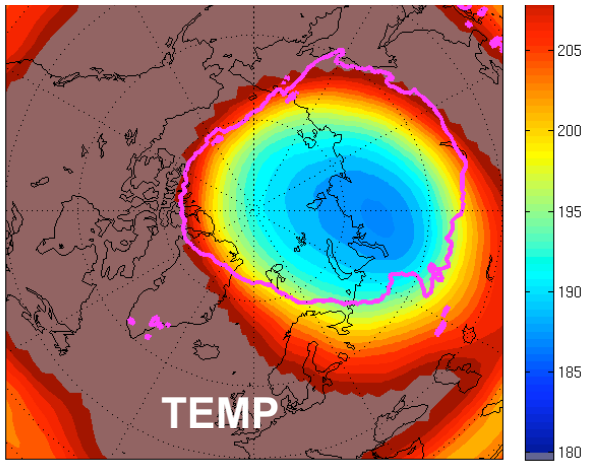
→ REPROBUS param overestimates this denitrification

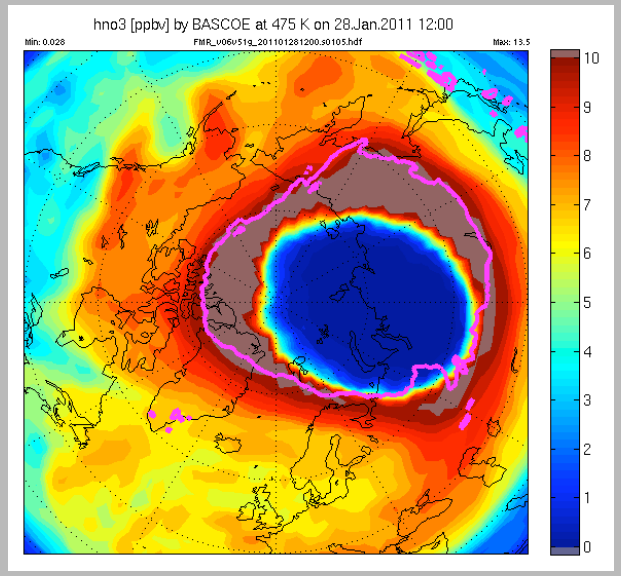
→ MOZART seems OK (taking into account the bias)

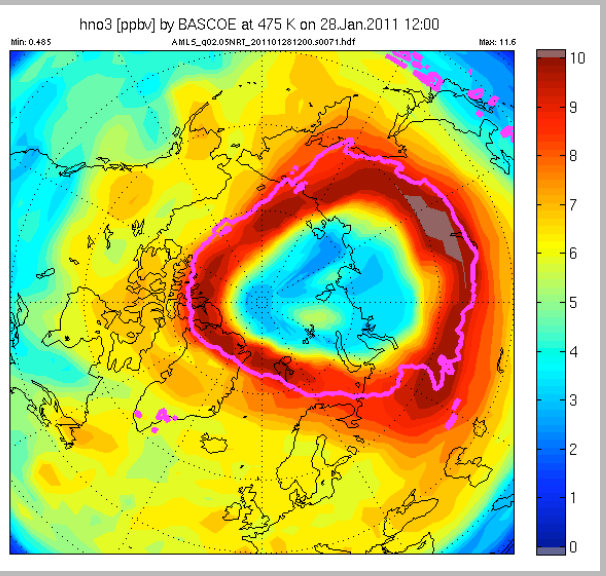
Nitric acid HNO3
(reservoir species)

IFS-MOZ	BASCOE FMR	BASCOE AN









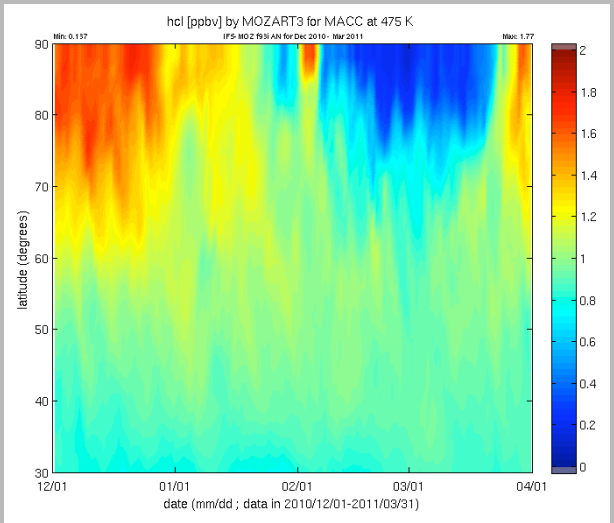
High values of HNO3 inside polar vortex, but outside low temperature region where PSC formation can take place

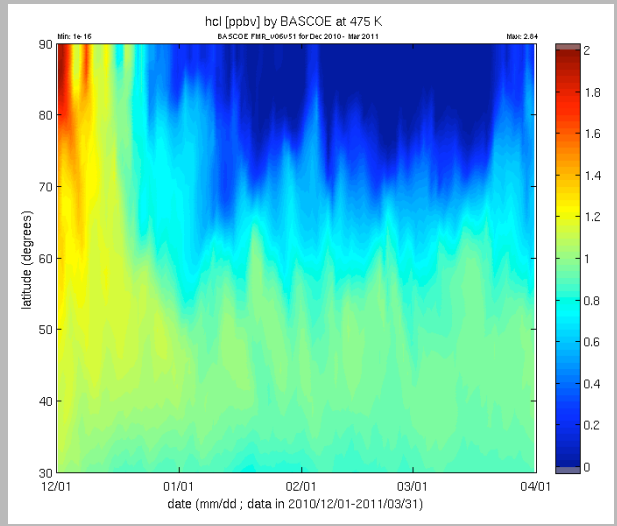
→ IFSMOZ: too few (can be related to bias)

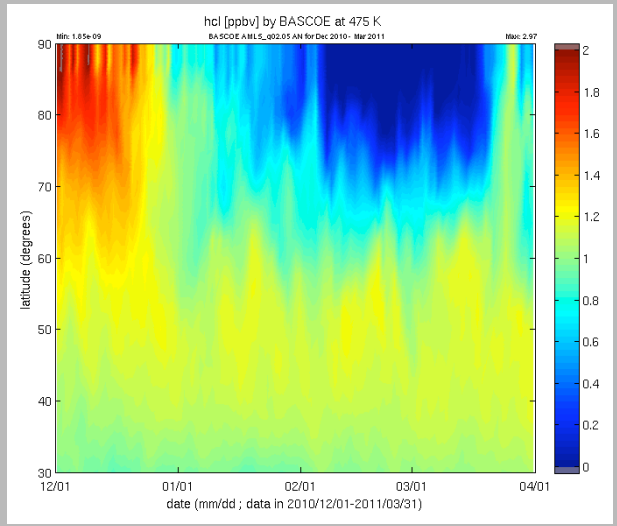
→ BASCOE FMR: too much (parametrization)

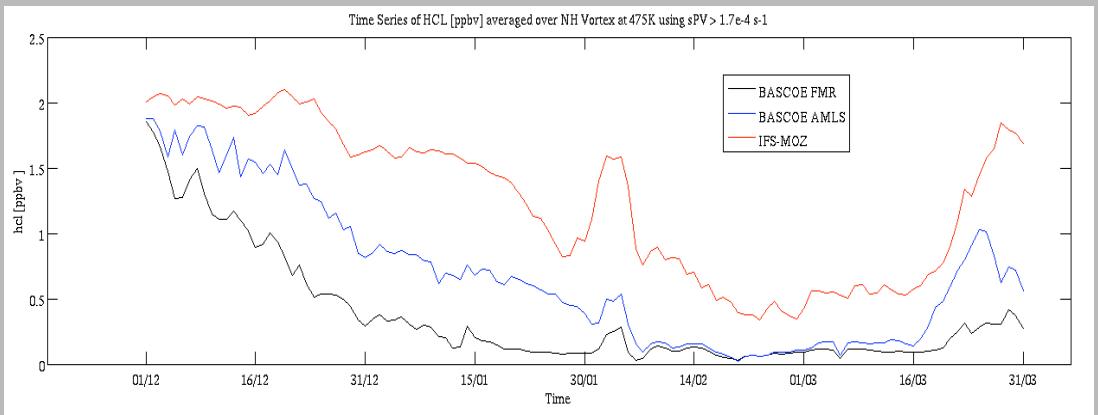
Hydrogen chloride HCl
(long-lived reservoir species)

IFS-MOZ | BASCOE FMR | BASCOE AN







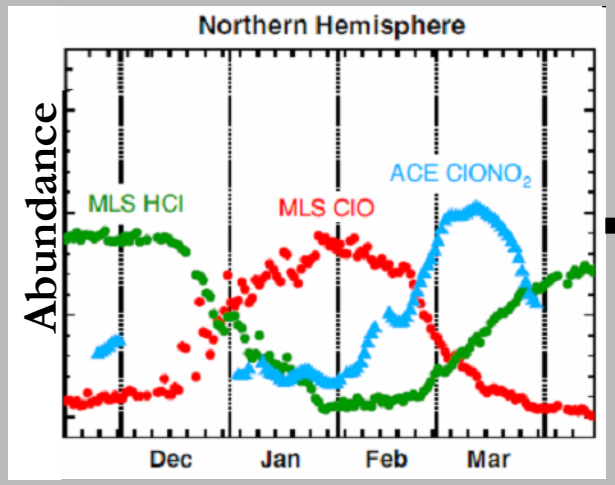


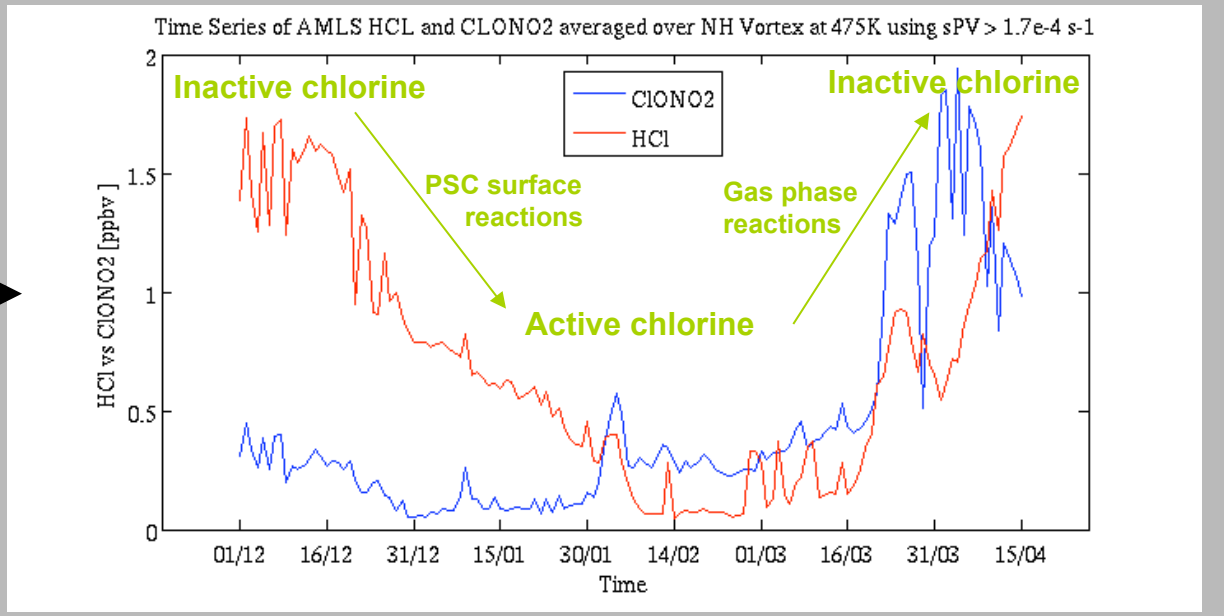
BASCOE HCL AN shows important losses due to heterogeneous chemistry

→ IFSMOZ: PSC param. too sensitive to temp during sudden stratospheric warming (2x)

→ BASCOE FMR: REPROBUS param overestimates this loss

Chlorine deactivation and reformation





Dominant chlorine reservoir before onset PSC processing: HCl

↓

Chlorine activation through heterogeneous reactions on PSC surface:

HCl + ClONO2 → HNO3 + Cl2

ClONO2 + H2O → HNO3 + HOCl

(HNO3 remains in the PSC particles and can sediment)

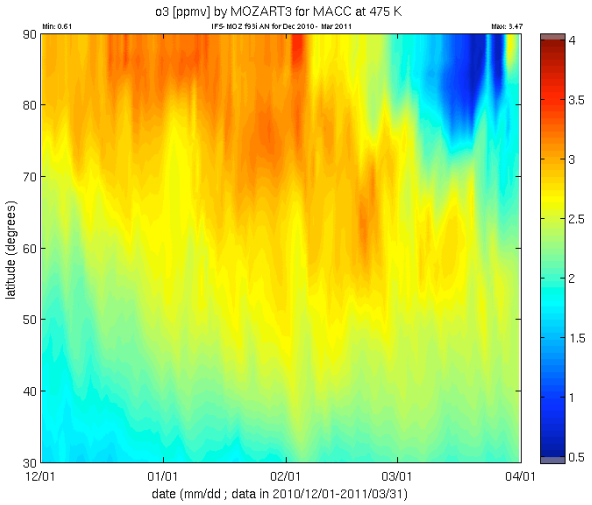
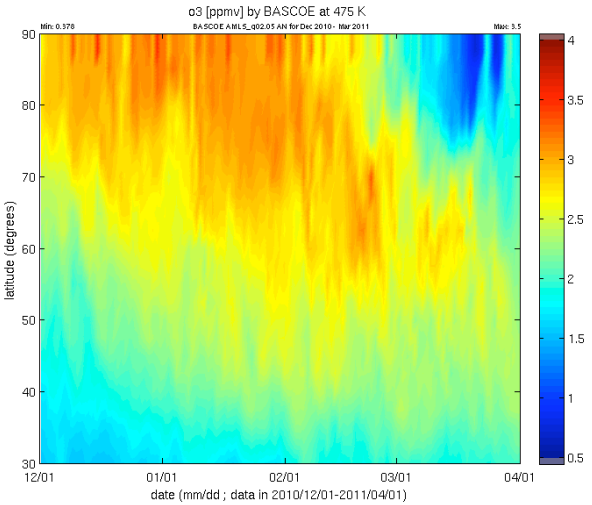
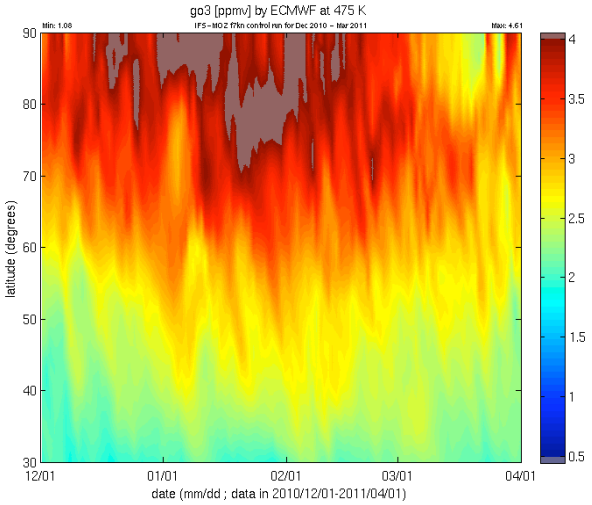
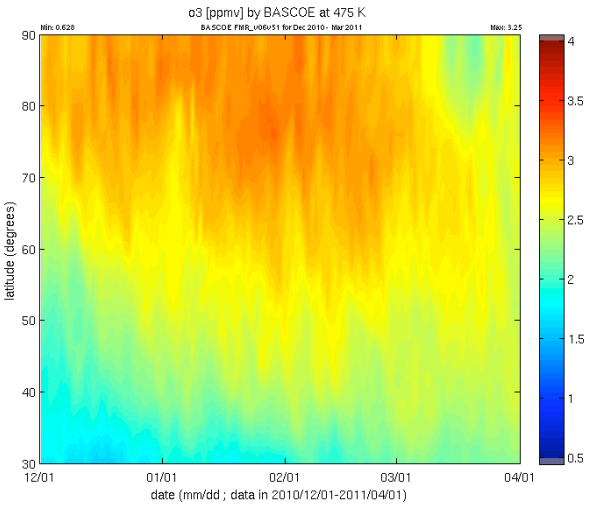
↓

Chlorine deactivation: primary pathway reformation is ClONO2

↓

Slow repartitioning between ClONO2 and HCl

Ozone O3

	IFS-MOZ	BASCOE
ANALYSES		
CONTROL RUNS		

Summary

- Arctic ozone depletion in winter/spring 2011 was unusually large and intense
- This exceptional event is well captured by the *analyses* realized in NRT by BASCOE and IFS-MOZART.
- The control runs do not simulate this ozone hole.
  - *Polar ozone depletion in models was validated mainly for Antarctic ozone hole and is not well adjusted for such unusual events at the North Pole*
  - *Control run hard to interpret if it starts more than a year earlier (new run under development)*
- BASCOE AN of O3-related species useful to understand processes and validate them in CTM:
  - *BASCOE H2O AN* *no/little ice PSC*
  - *BASCOE HNO3 AN* *important denitrification*
  - *BASCOE HCl AN* *important losses due to heterogeneous chemistry*.

  ⇒ Qualitatively, parametrization seems to perform quite well, quantitatively, however, improvements are required