WACCM studies at FMI

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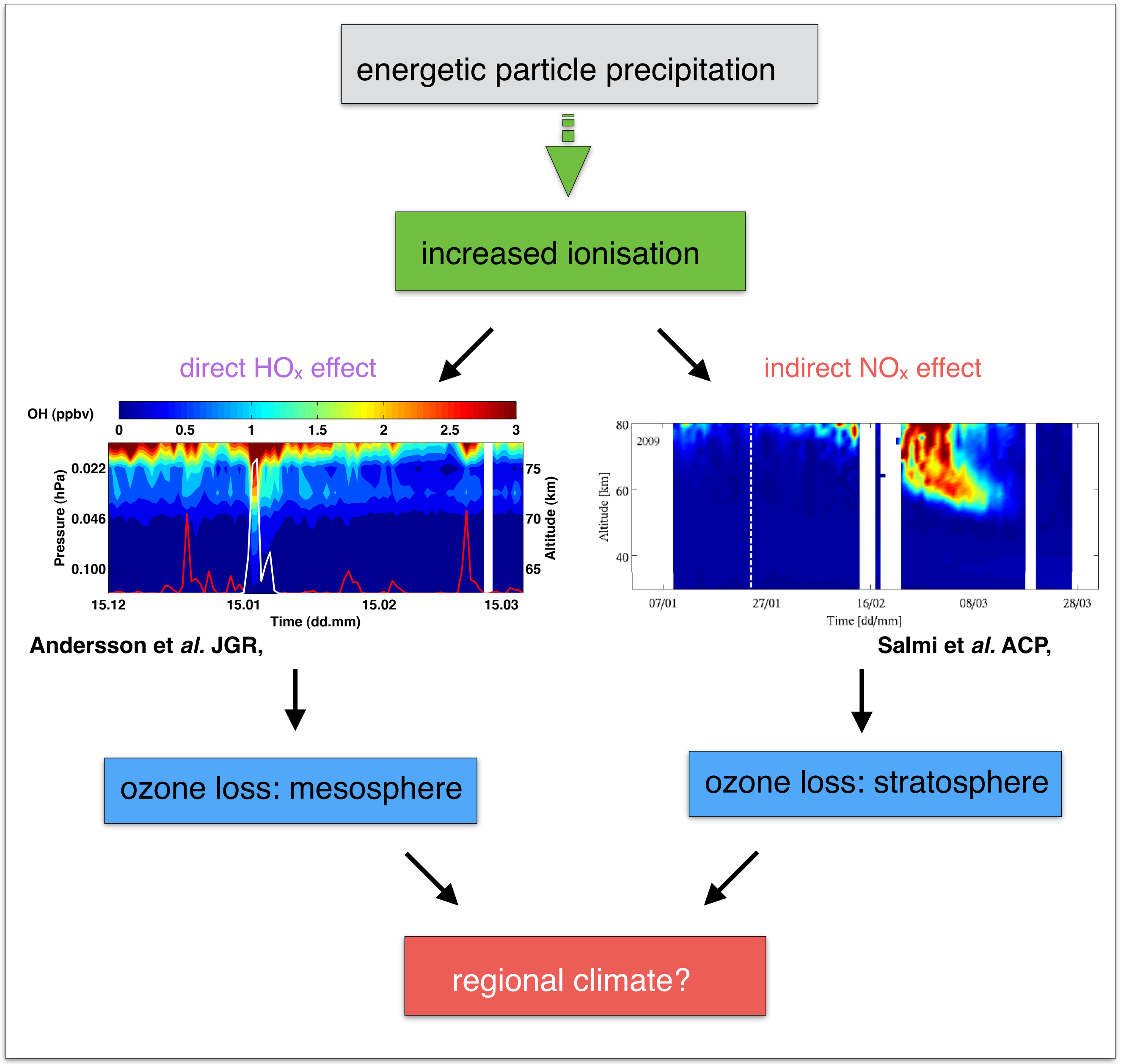
Energetic Particle Precipitation (EPP) mechanism



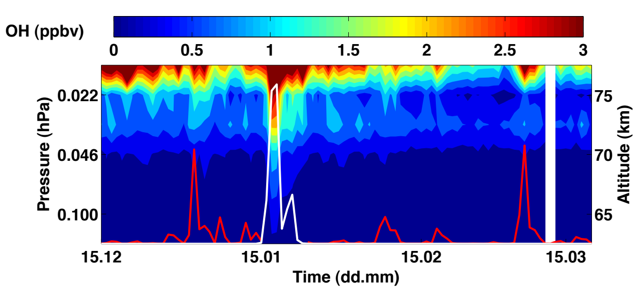
Energetic Particle Precipitation (EPP) mechanism

energetic particle precipitation

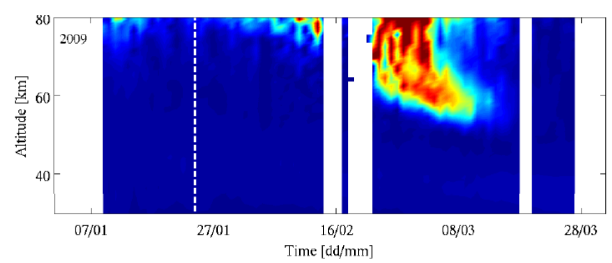
increased ionisation

direct HO_x effect

indirect NO_x effect



Andersson et *al.* JGR,



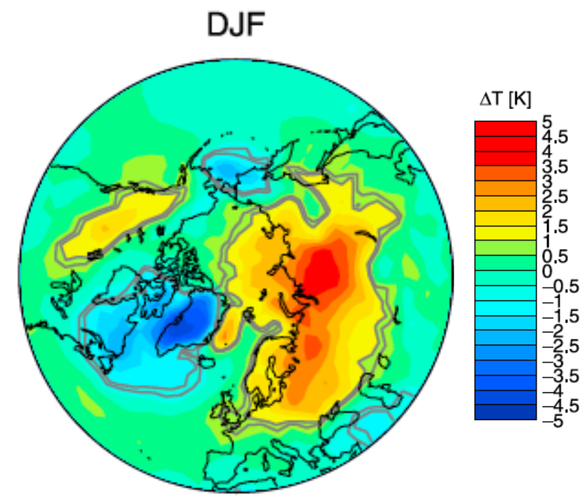
Salmi et *al.* ACP,

ozone loss: mesosphere

ozone loss: stratosphere

regional climate?

Energetic particle precipitation (EPP) signature in surface air temperatures

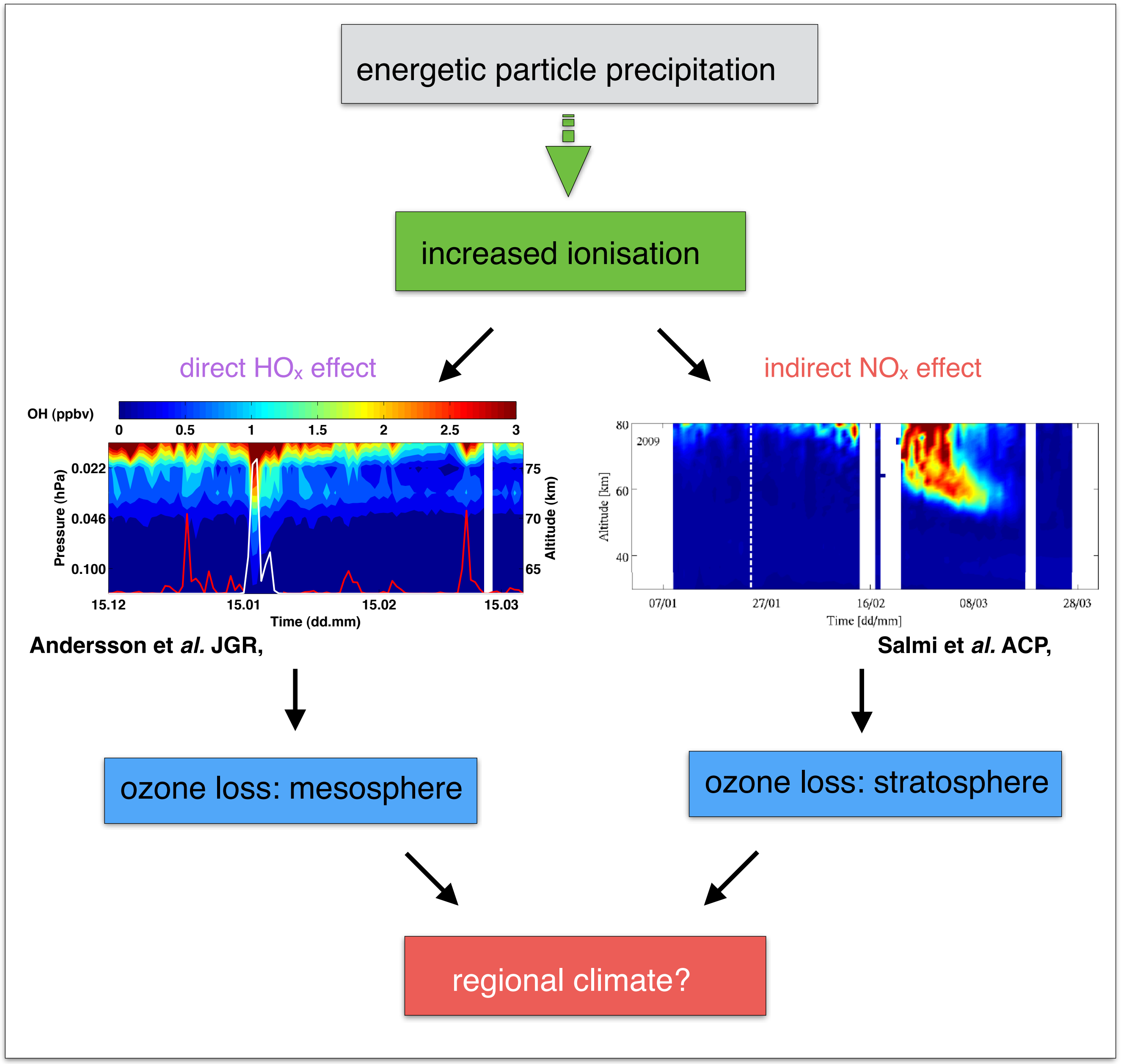


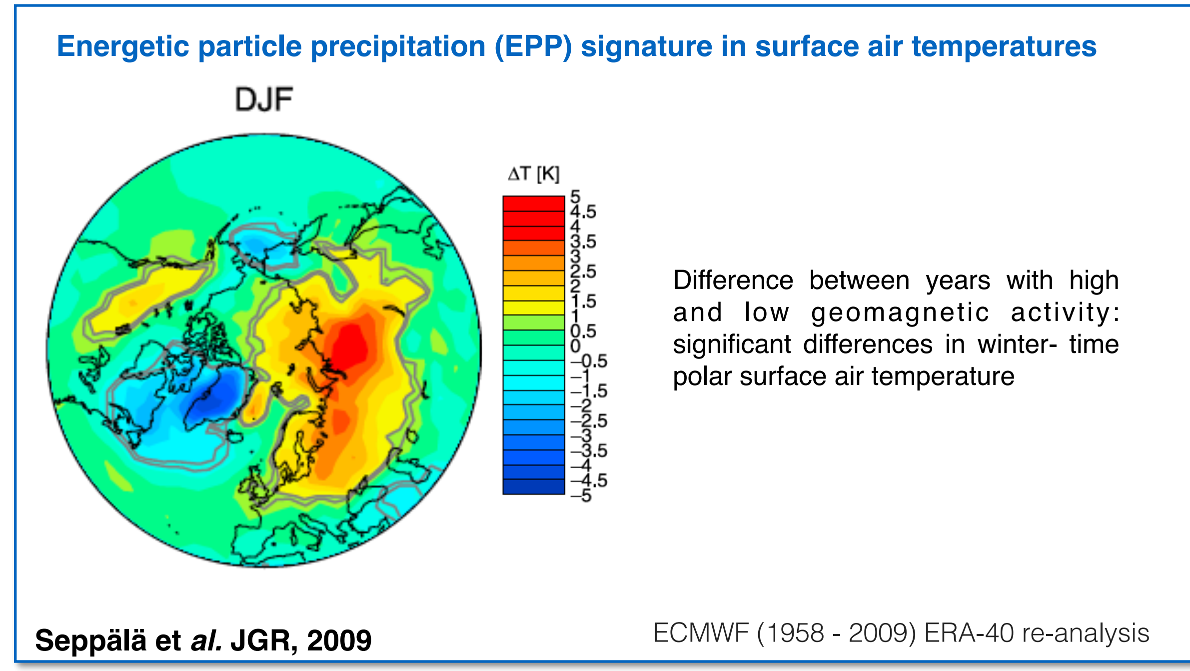
Difference between years with high and low geomagnetic activity: significant differences in winter- time polar surface air temperature

Seppälä et *al.* JGR, 2009

ECMWF (1958 - 2009) ERA-40 re-analysis

Energetic Particle Precipitation (EPP) mechanism





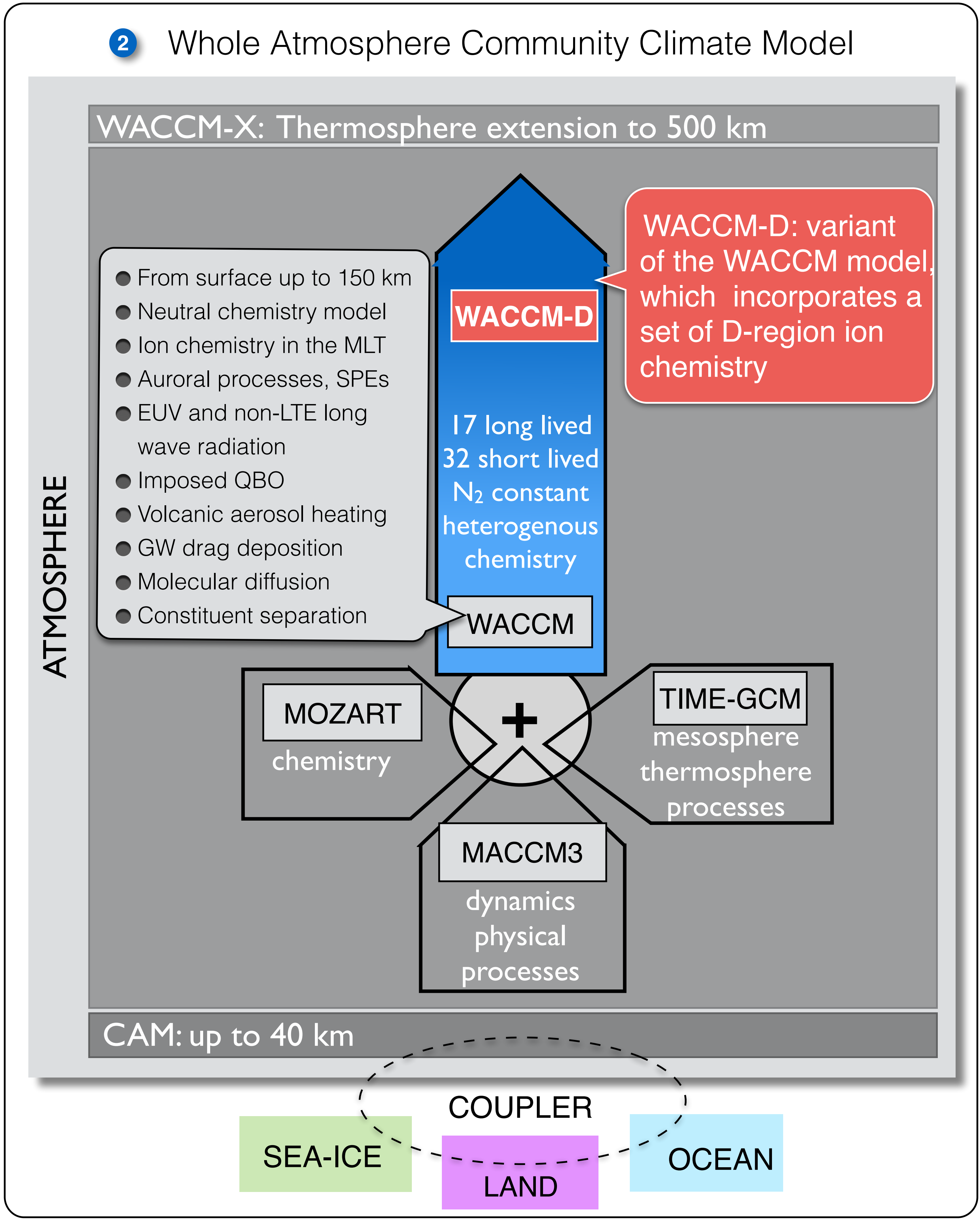
However:

1. The ion-neutral connection in the middle atmosphere is missing from the climate models today and the observed EPP effects in some important species such as HNO_3 cannot be reproduced using the commonly used parameterisation of HO_x and NO_x production

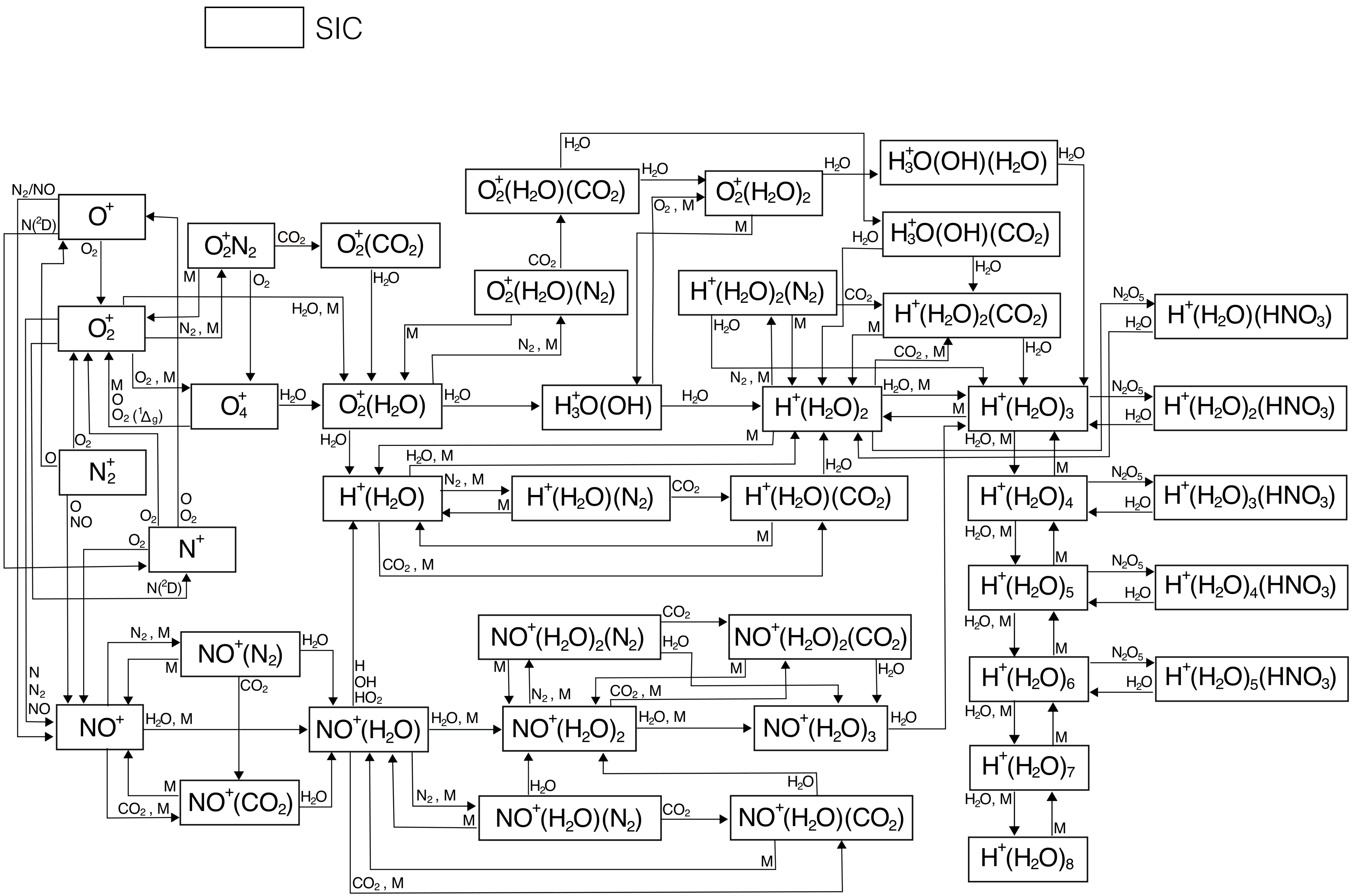
2. EEP ionisation is not included in the models

WACCM-D

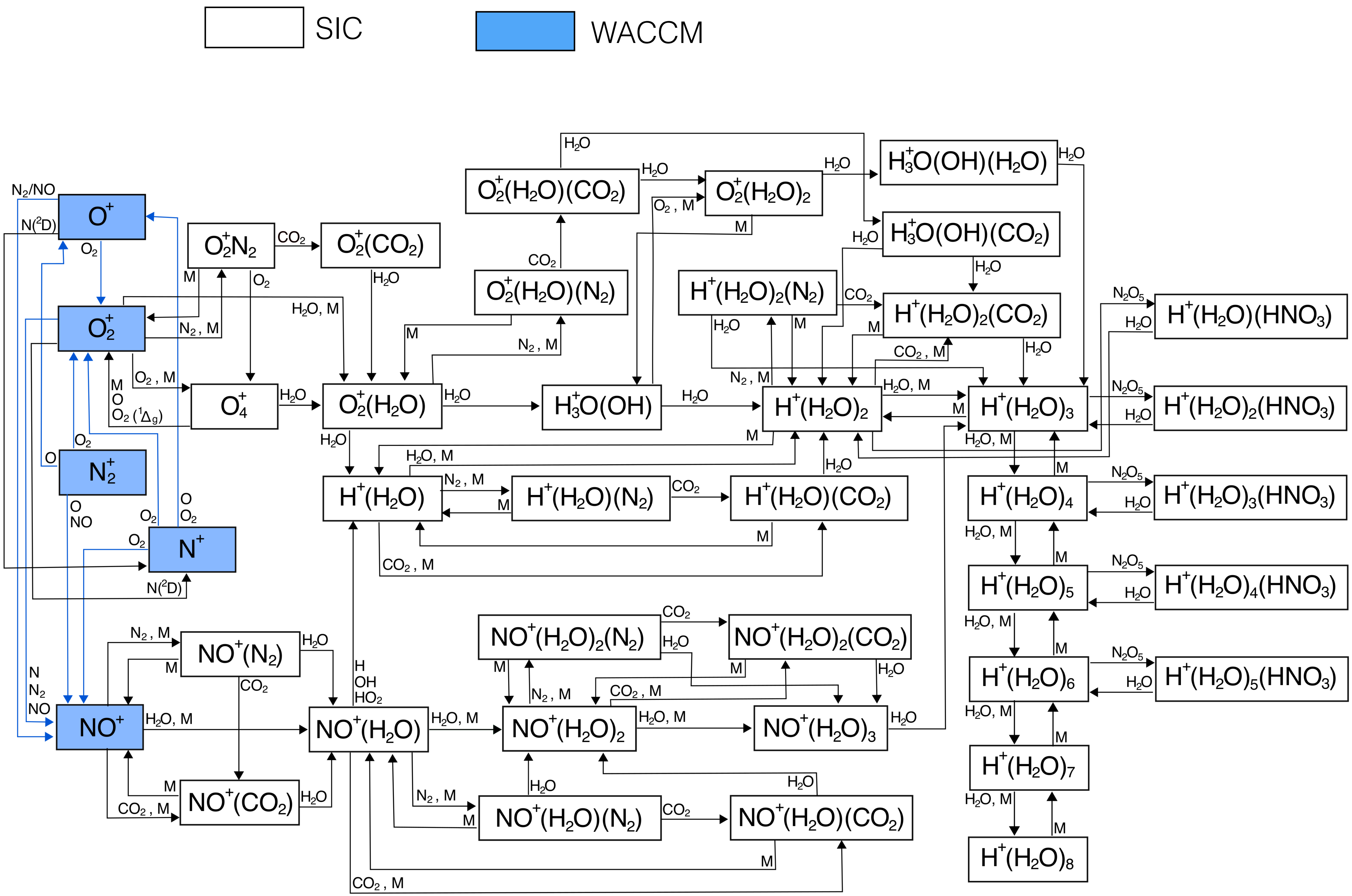
- incorporates D-region ion chemistry with the aim to produce the observed EPP effects
- parameterised HO_X and NO_X production replaced by initial production rates of ions and neutrals due to particle impact
- reaction rate coefficients for the WACCM-D ion chemistry from SIC model, original WACCM 6-constituent ion chemistry model for the E-region retained
- ion reaction schemes based on SIC model, significant number of ions and reactions have been excluded



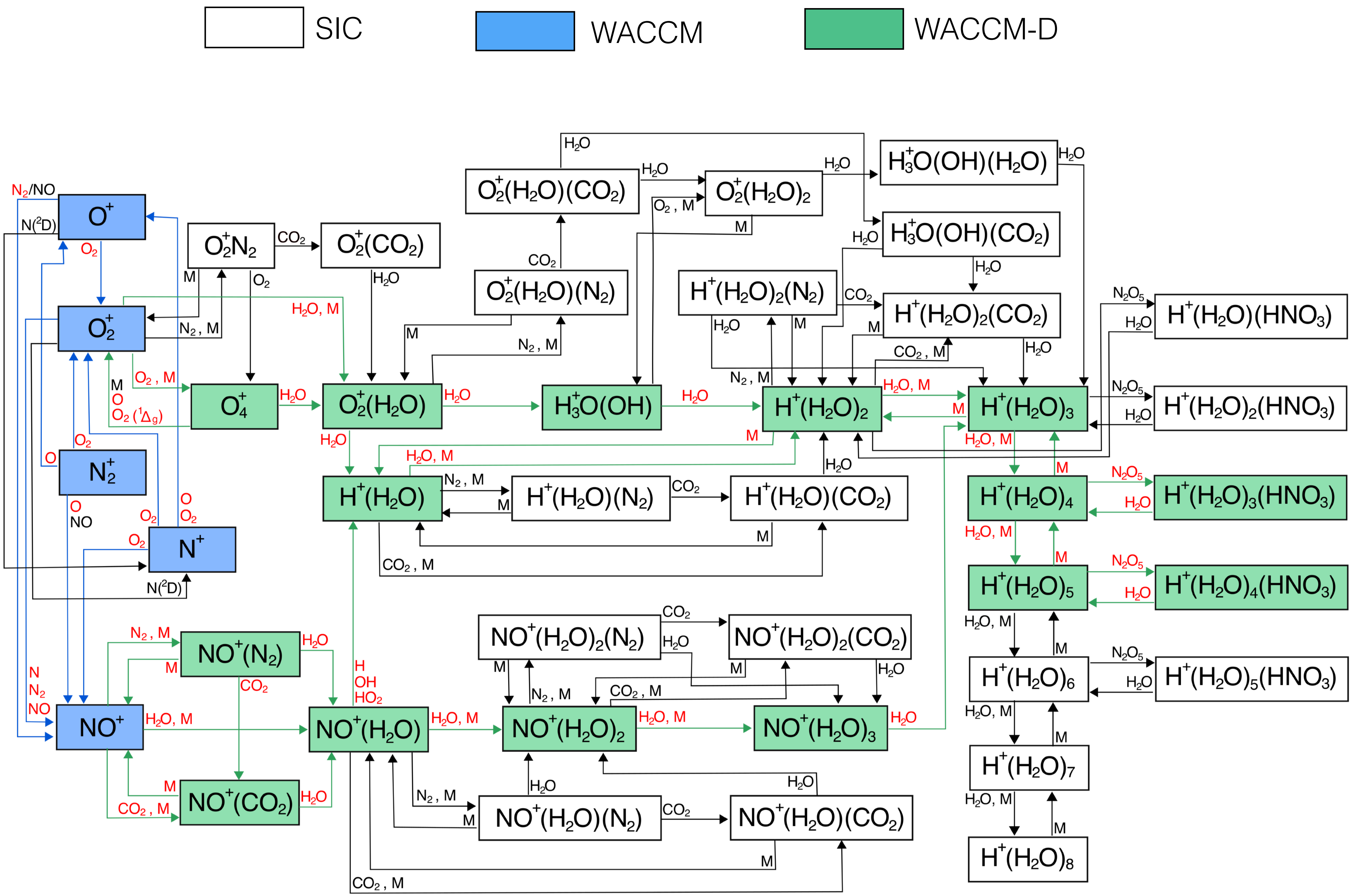
Positive ions



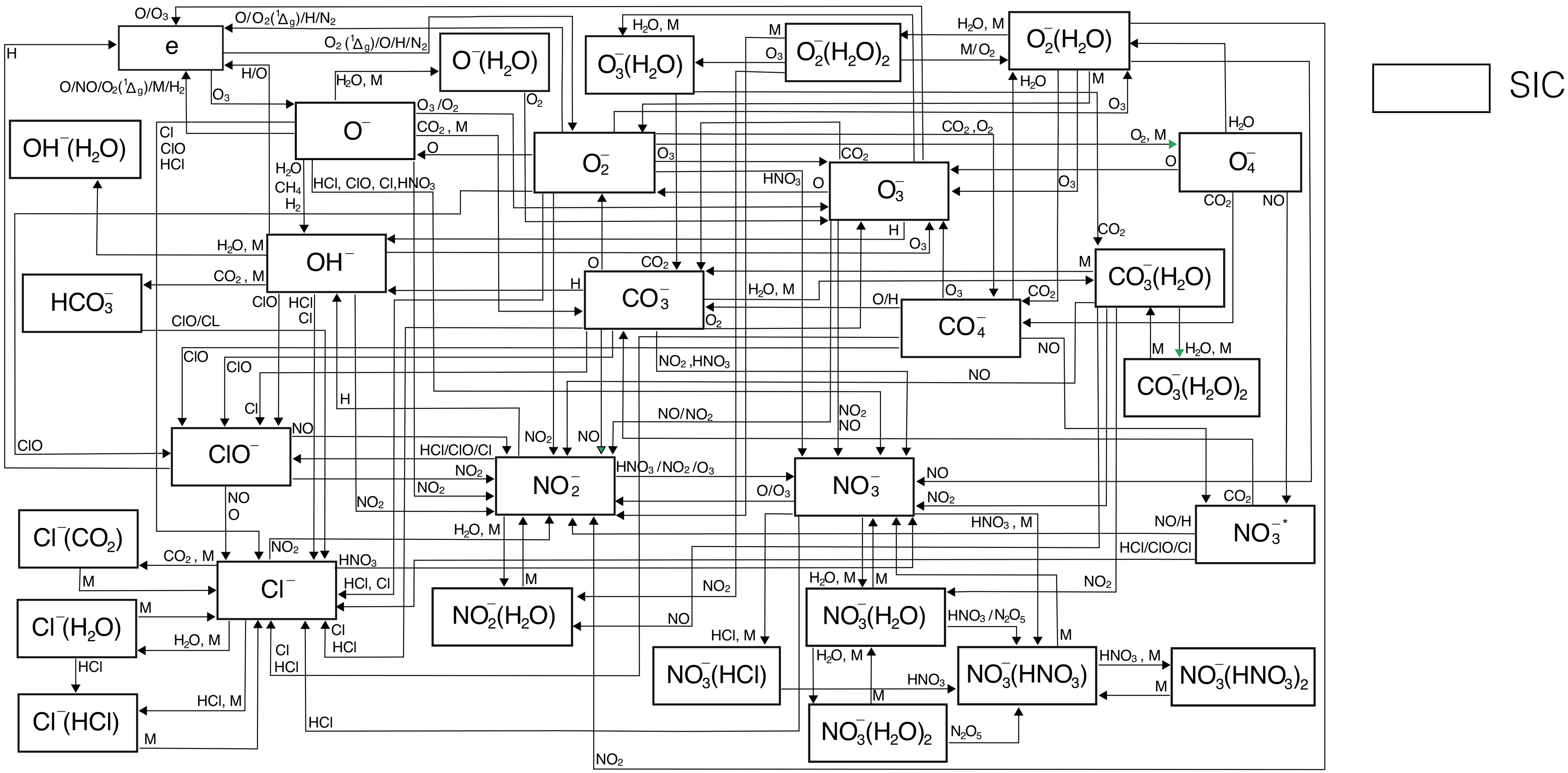
Positive ions



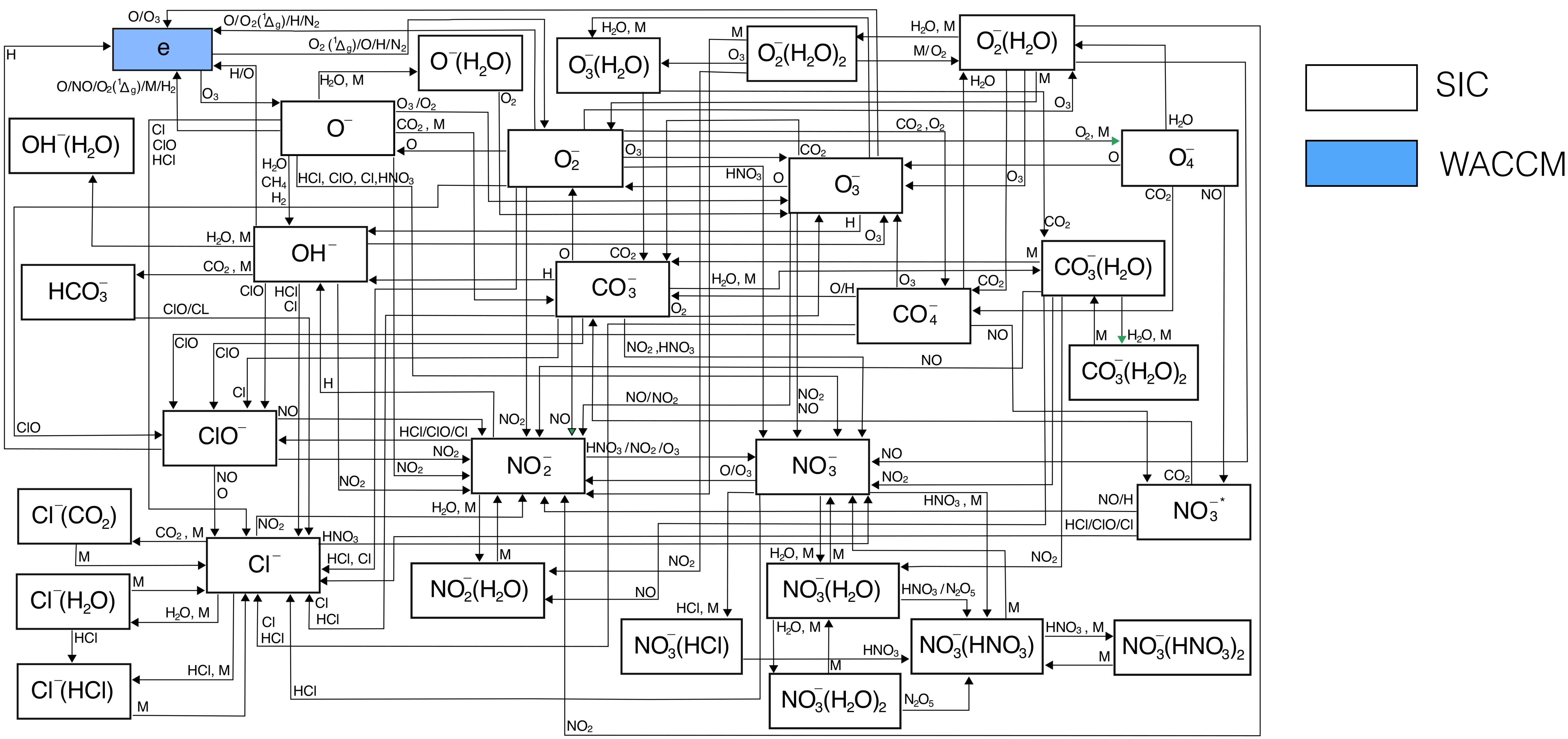
Positive ions



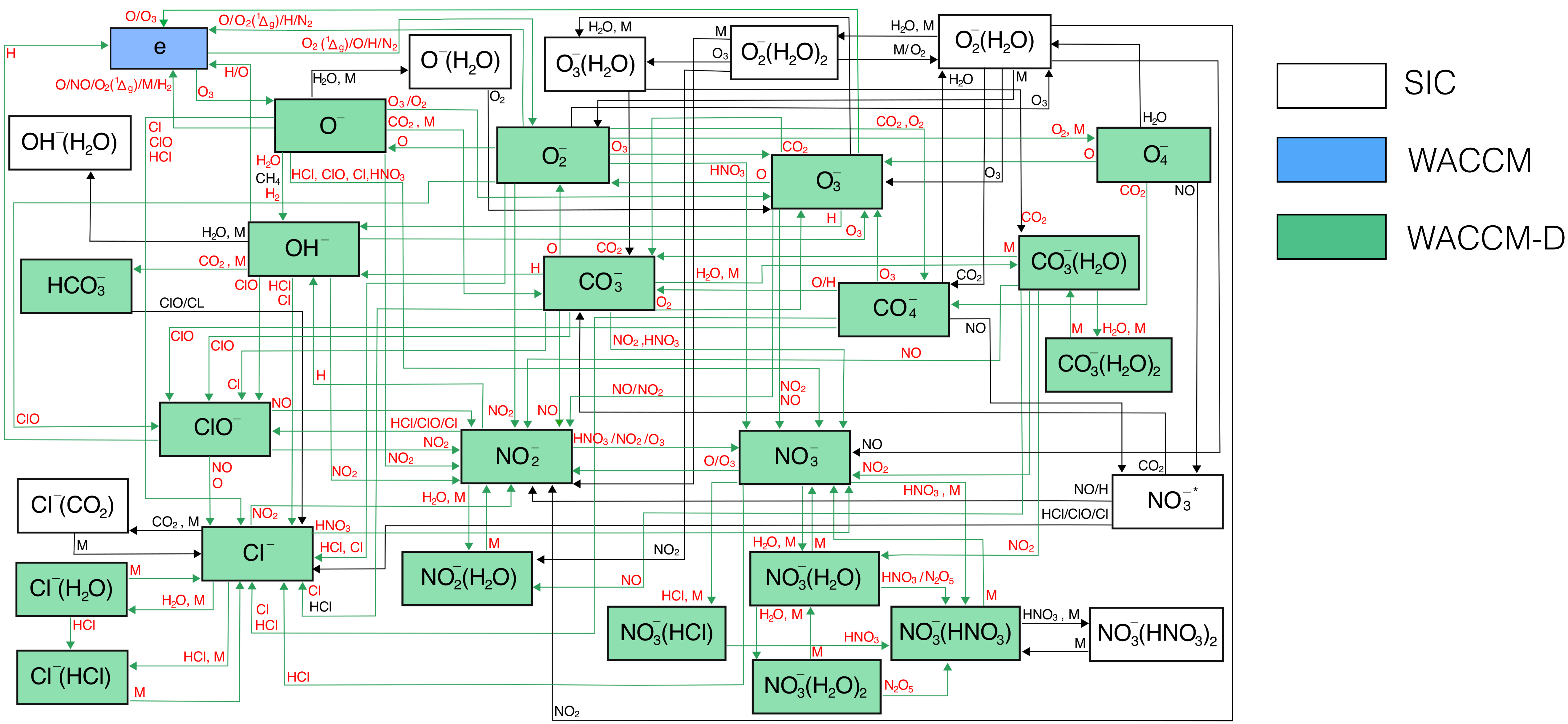
Negative ions



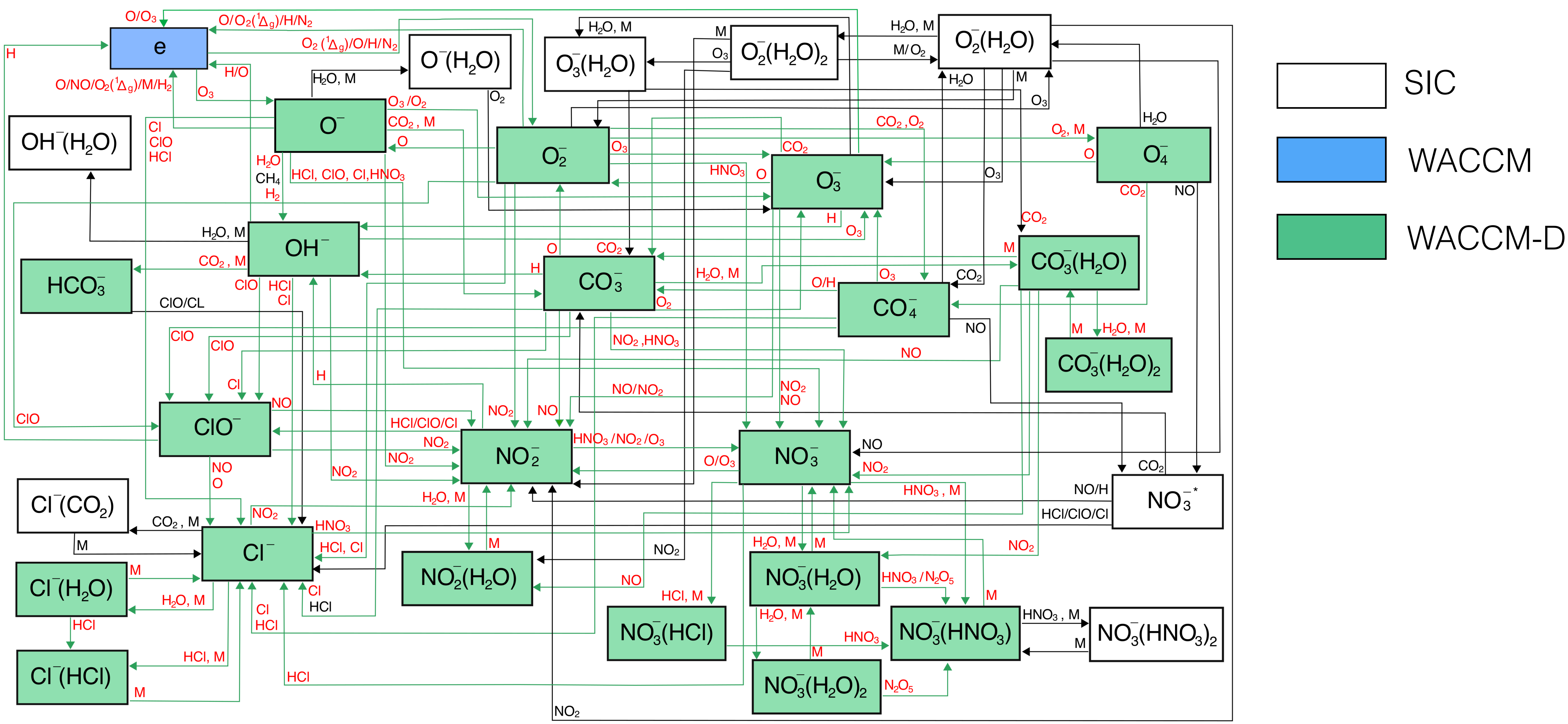
Negative ions



Negative ions



Negative ions



SIC

42 positive ions
30 negative ions
400 ion-neutral reactions
~1000 IIR reactions

→

Reduction:
ions: ~50%
reactions:~80%

→

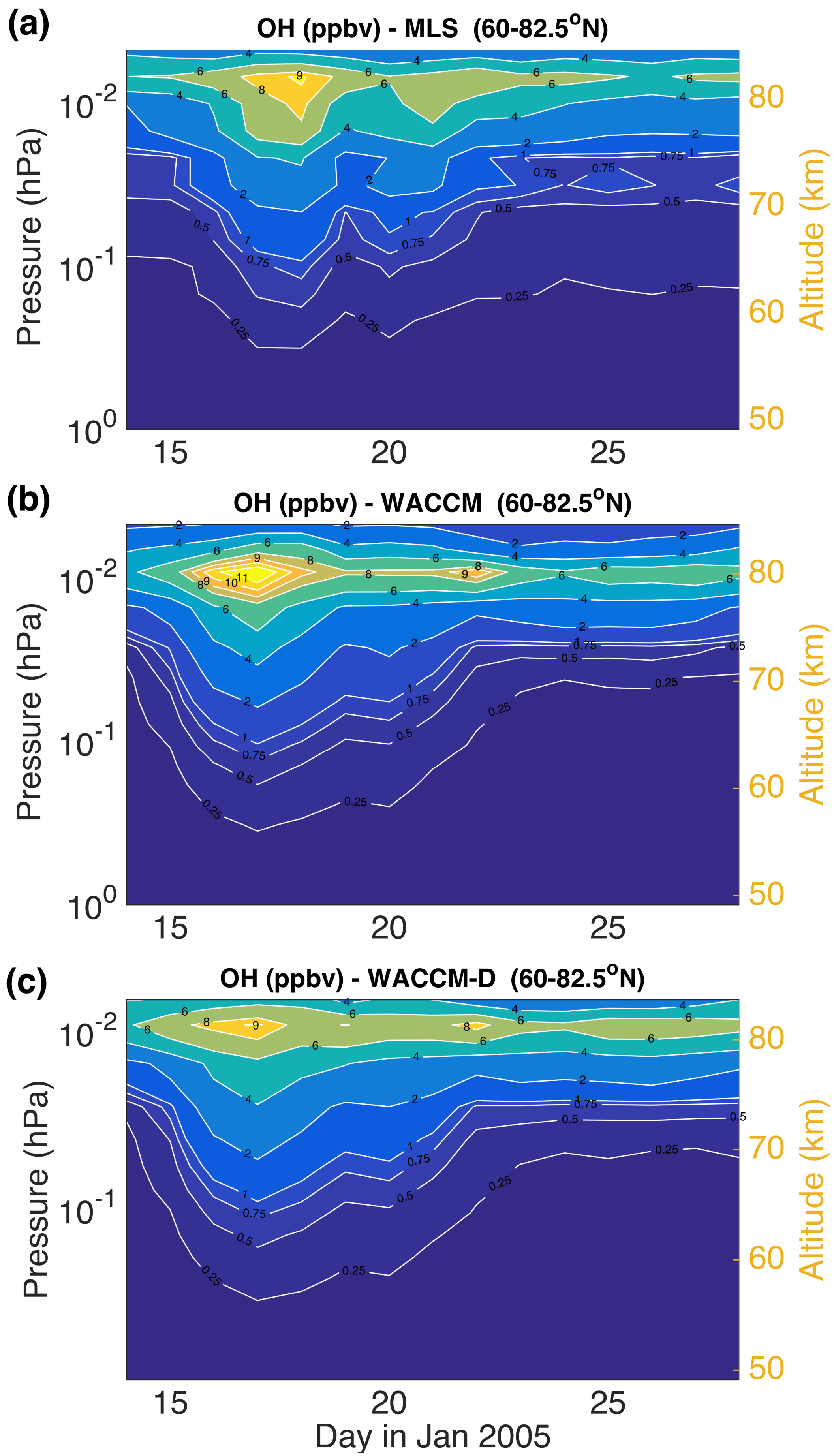
WACCM-D

20 positive ions
22 negative ions
166 ion-neutral reactions
126 IIR reactions

→

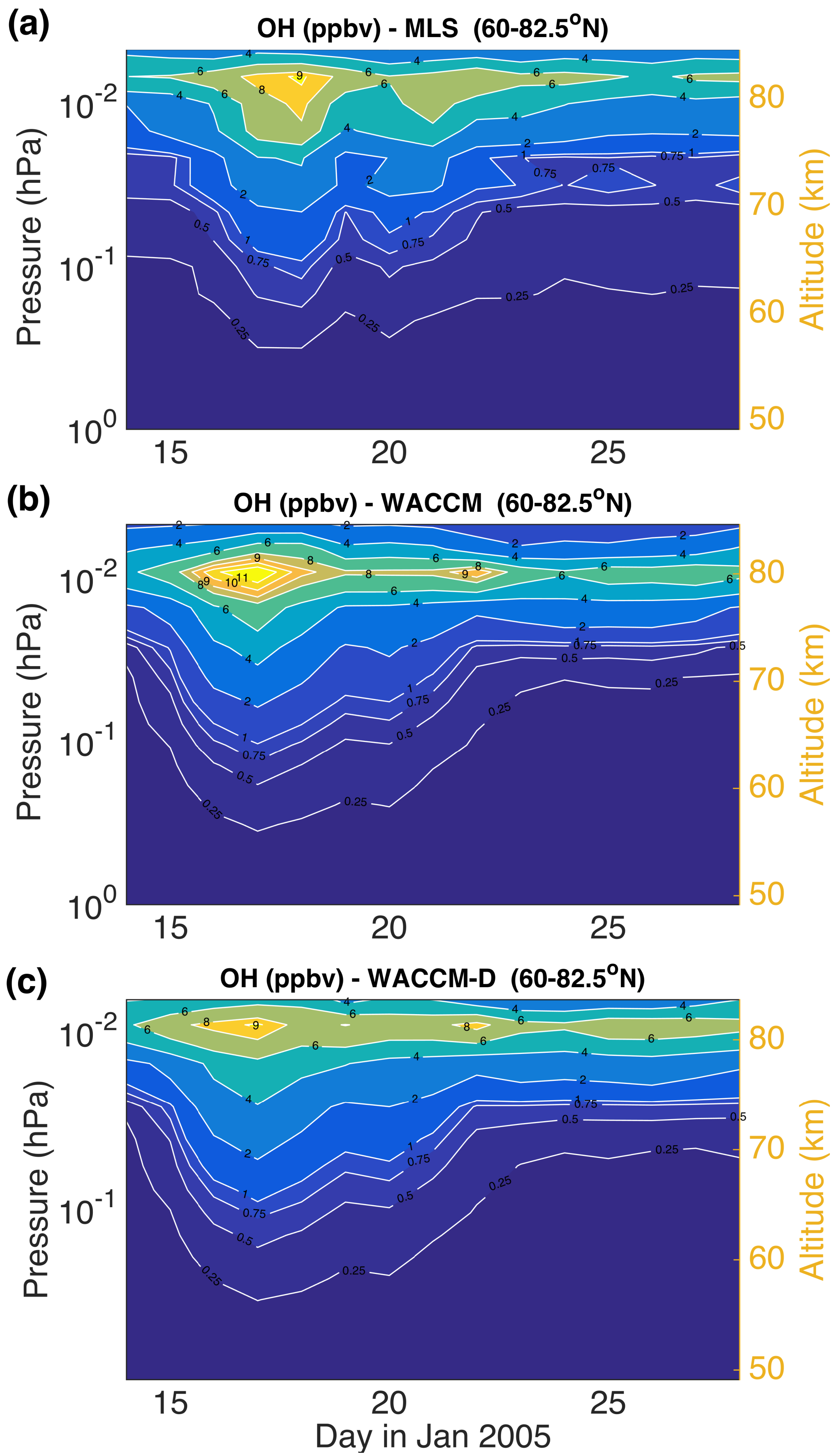
SD-WACCM:
2.1 simulated years/day
SD-WACCM-D:
1.1 simulated years/day

WACCM-D vs MLS: **OH**



2 model runs: SD WACCM and SD-WACCM-D for1-31 January 2005. WACCM output at Aura MLS times and locations.

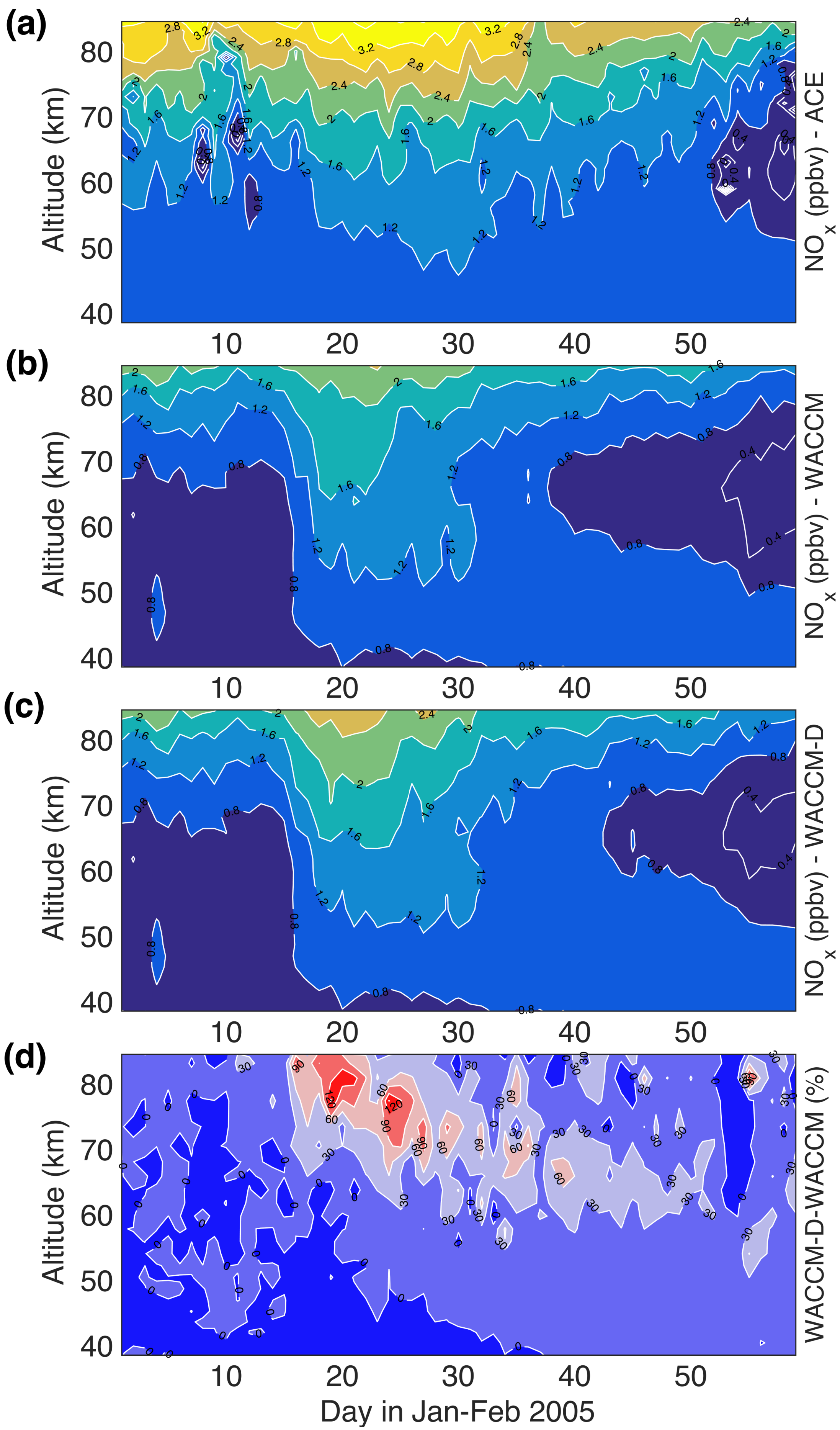
WACCM-D vs MLS: **OH**



2 model runs: SD WACCM and SD-WACCM-D for1-31 January 2005. WACCM output at Aura MLS times and locations.

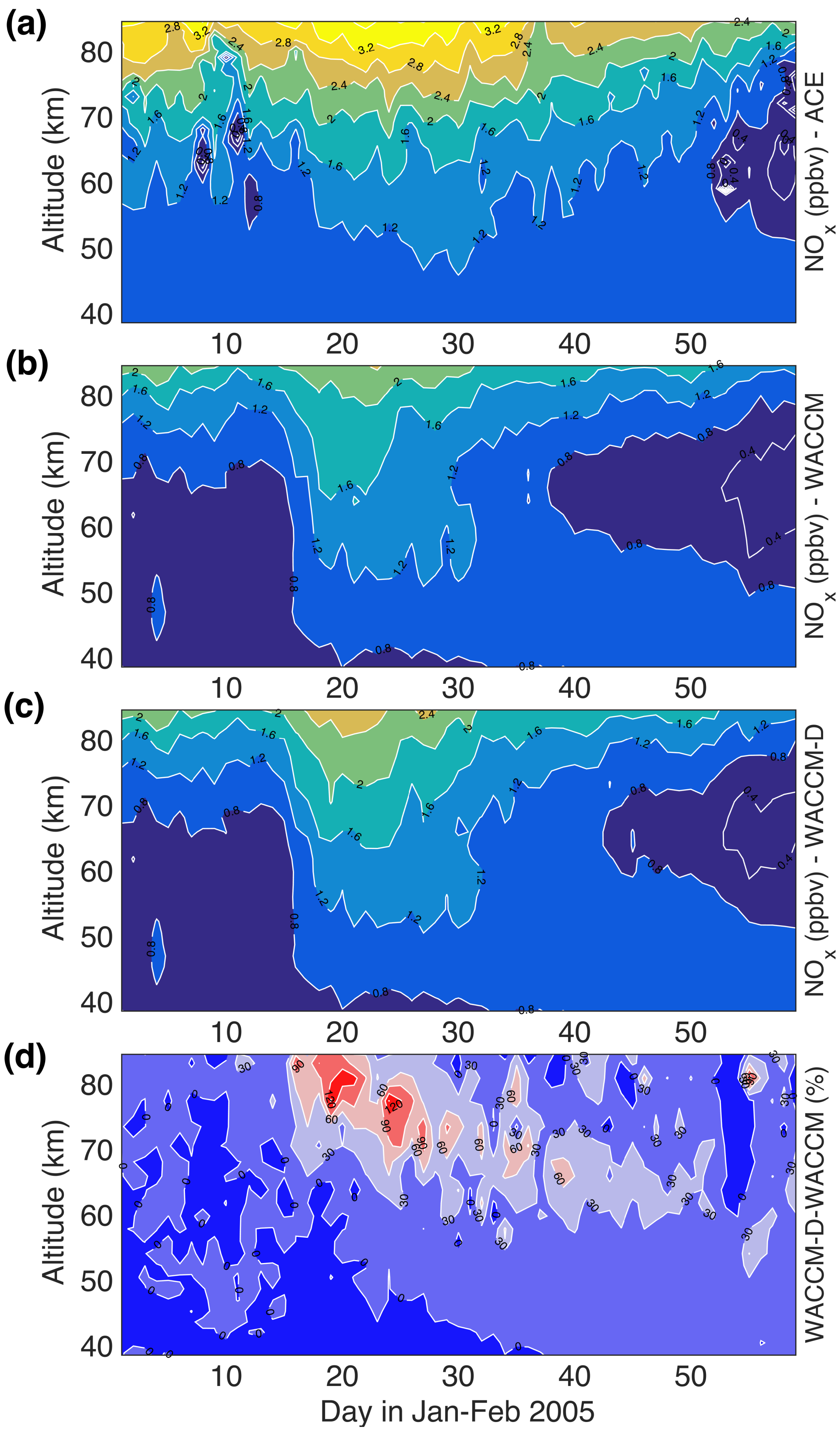
- significant perturbation observed in HOx as a consequence of SPE
- MLS data and model predictions, show large OH enhancement during the SPE at altitudes between 58–84 km
- the largest observed and modelled increase occurred on 17–18 January at altitudes 80–82 km
- WACCM predictions overestimate OH values by 25-50% at altitudes between 70-80 km
- WACCM-D OH enhancement are in better agreement with observations than predictions from WACCM.

WACCM-D vs ACE-FTS: **NO_x=NO+NO_2**



2 model runs: SD WACCM and SD-WACCM-D for 1 January - 28 February 2005. WACCM output at ACE-FTS times and locations.

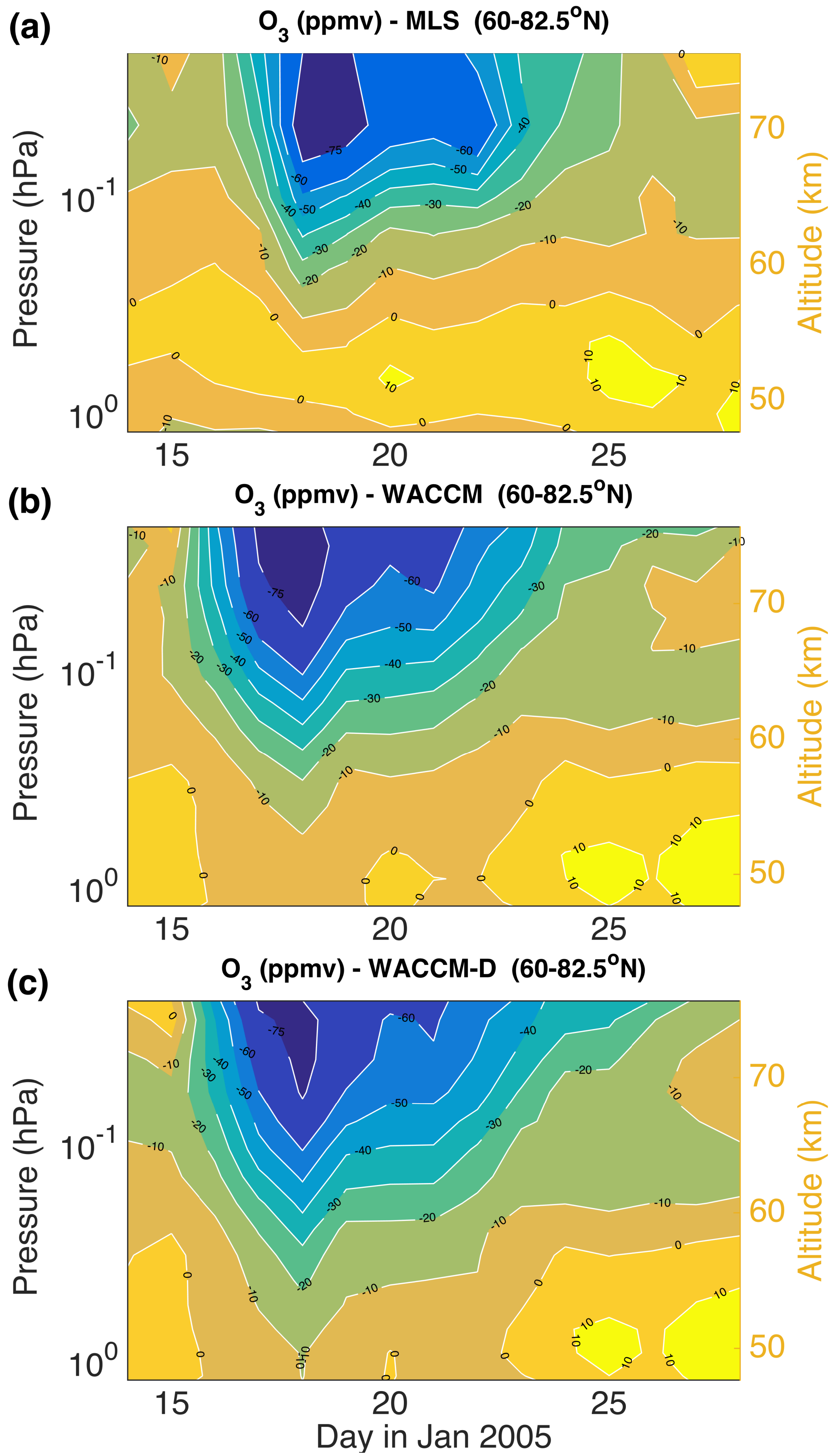
WACCM-D vs ACE-FTS: $NO_x = NO + NO_2$



2 model runs: SD WACCM and SD-WACCM-D for 1 January - 28 February 2005. WACCM output at ACE-FTS times and locations.

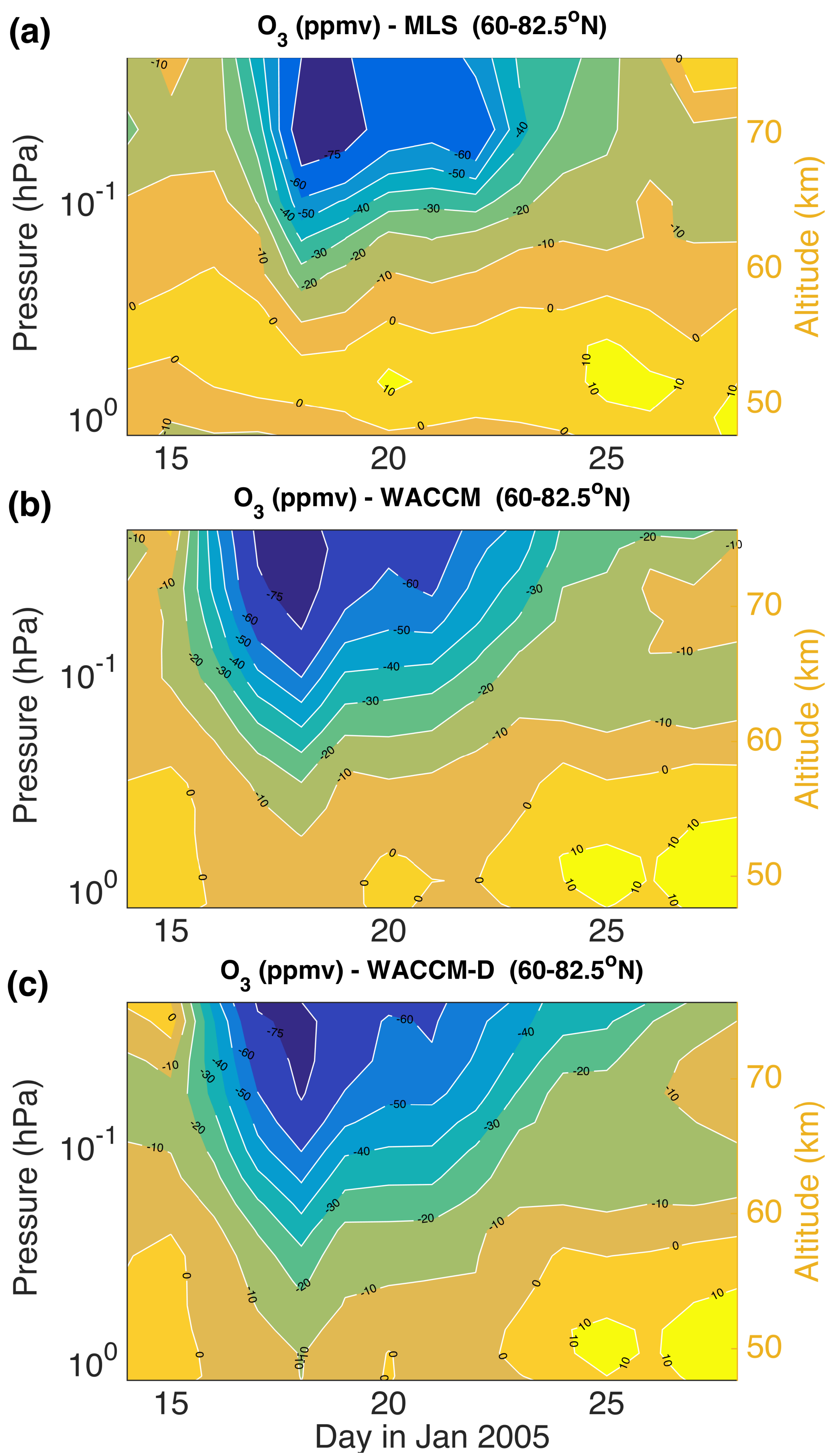
- during the whole January, large amounts of NO_X were observed with rather moderate response during and after SPE impact between 16-31 of January
- predicted NO_X shows distinctive peak which corresponds to the SPE event
- during the whole considered period NO_X values predicted by WACCM and WACCM-D are significantly smaller than ACE-FTS measurements
- WACCM-D improvement of NO_X of about 60–130% between day 16 and 40 is still not enough to reach the observed levels

WACCM-D vs MLS: O$_3$



2 model runs: SD WACCM and SD-WACCM-D for1-31 January 2005. WACCM output at Aura MLS times and locations.

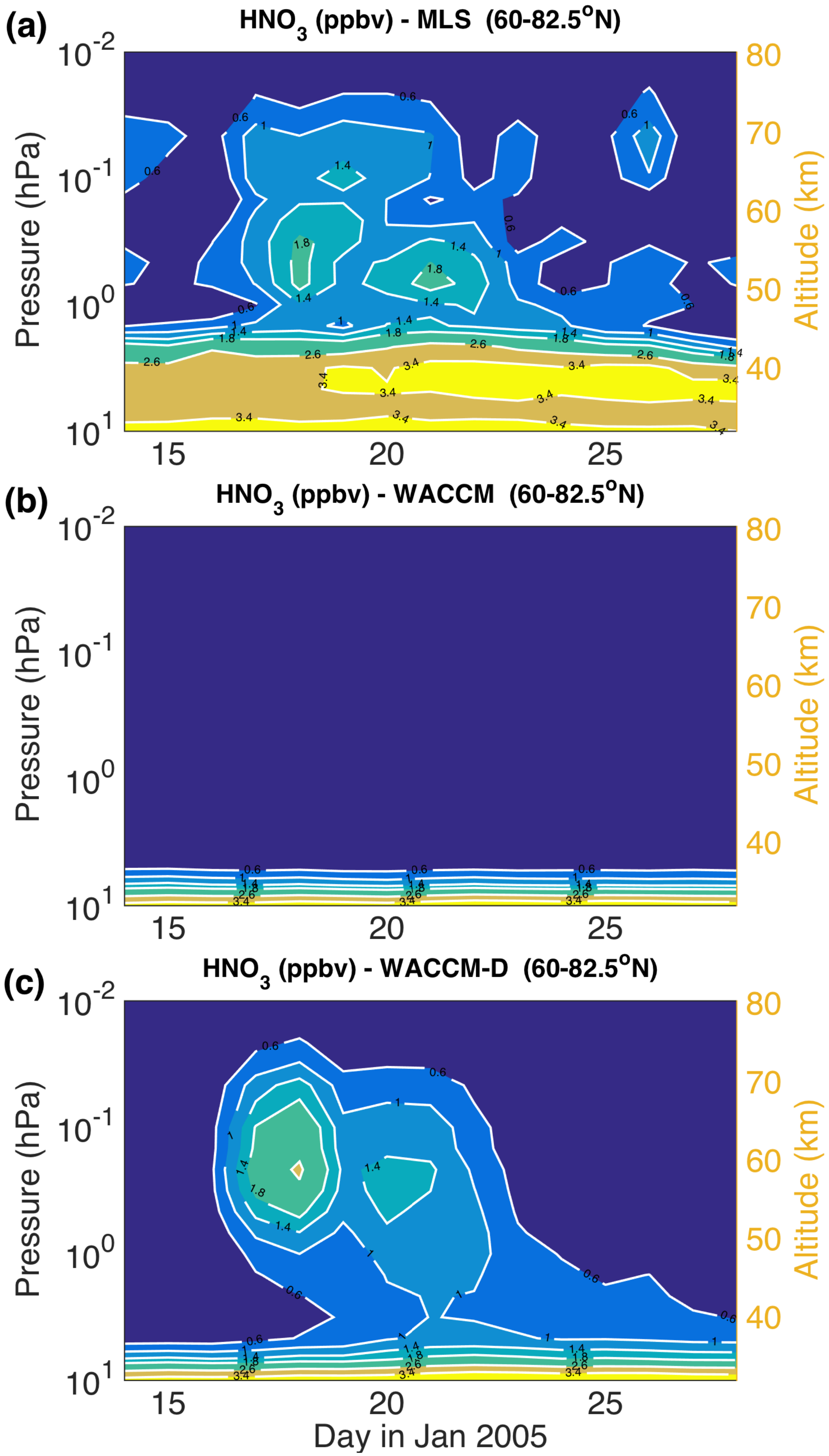
WACCM-D vs MLS: O_3



2 model runs: SD WACCM and SD-WACCM-D for1-31 January 2005. WACCM output at Aura MLS times and locations.

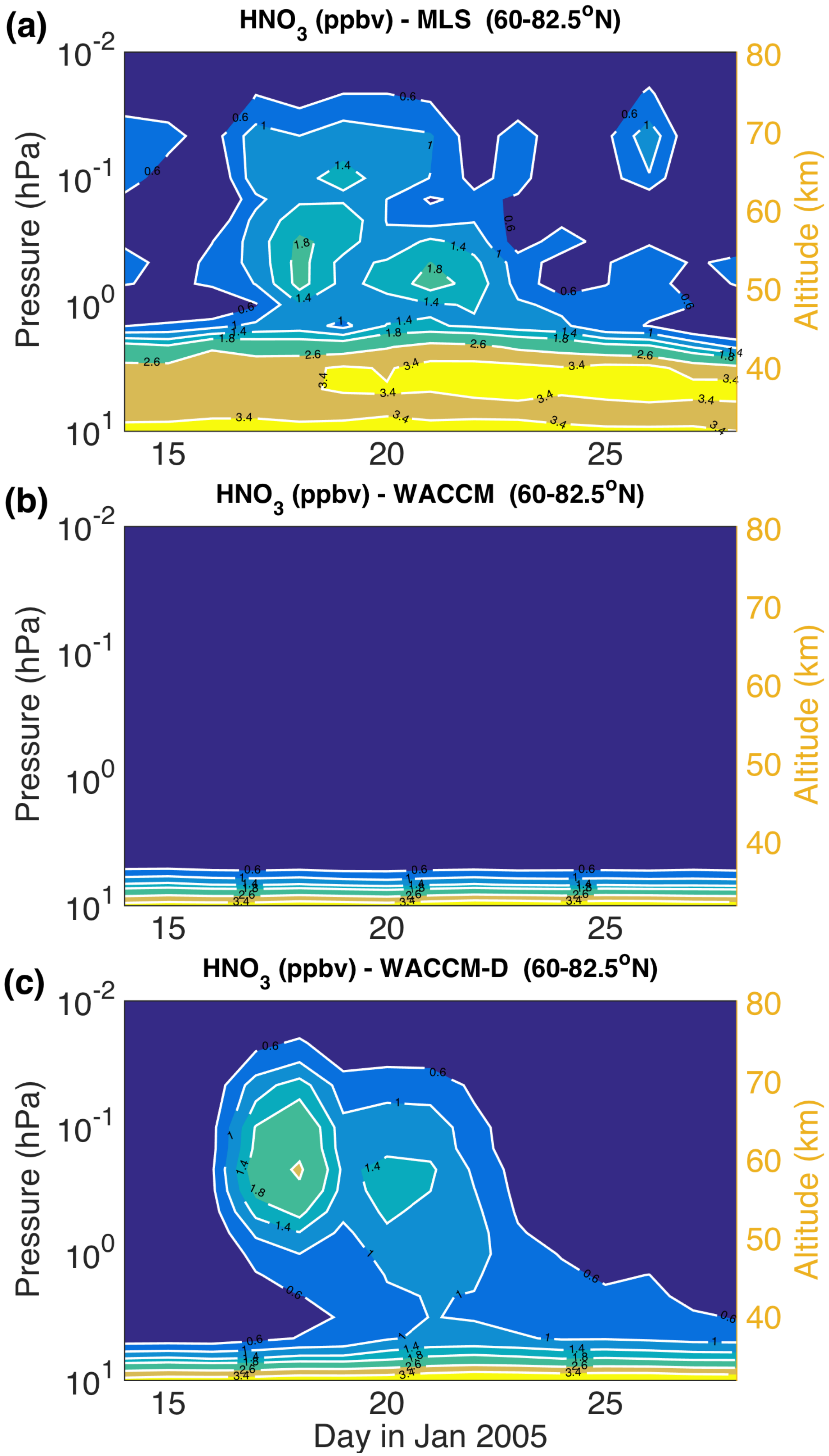
- during the SPE, ozone decreases up to about 80% are observed by MLS and predicted by WACCM and WACCM-D
- WACCM and WACCM-D are in reasonably good agreement with the observations considering the magnitude of the ozone changes
- The short-term ozone response does not change much but there is evidence of longer-term impact of ion chemistry on NO_x and ozone which can not be modelled with the ion chemistry parametrisation used in WACCM

WACCM-D vs MLS: HNO_3



2 model runs: SD-WACCM and SD-WACCM-D for 1-31 January 2005. WACCM output at Aura MLS times and locations. Aura MLS averaging kernels have been applied to WACCM output.

WACCM-D vs MLS: **HNO_3**



2 model runs: SD-WACCM and SD-WACCM-D for 1-31 January 2005. WACCM output at Aura MLS times and locations. Aura MLS averaging kernels have been applied to WACCM output.

- during the SPE, significant enhancement of MLS HNO3 at altitudes between about 40–75 km
- elevated HNO3 values (0.6–1.8 ppbv) lasted for about 10 days with maximum increase on January 17 and 21
- predicted HNO3 values by WACCM were ~100 times lower (0.03–0.04 ppbv) than seen by MLS observations
- WACCM-D reproduce observed HNO3 with a very good agreement:
  - the magnitude of the observed HNO3 changes (0.6– 2.5 ppbv)
  - duration of the enhancement (~10 days)
  - affected altitudes (40–75 km)

APEEP

- precipitation model for radiation belt electrons created by van de Kamp et al., [2015]
- Ap index as the driving input parameter, defining the level of magnetospheric disturbance
- reconstructed Ap record used to create an electron precipitation time series for the whole CMIP6 period
- atmospheric ionisation data set calculated based on an Ap-dependent electron flux model

EEP in the model

APEEP

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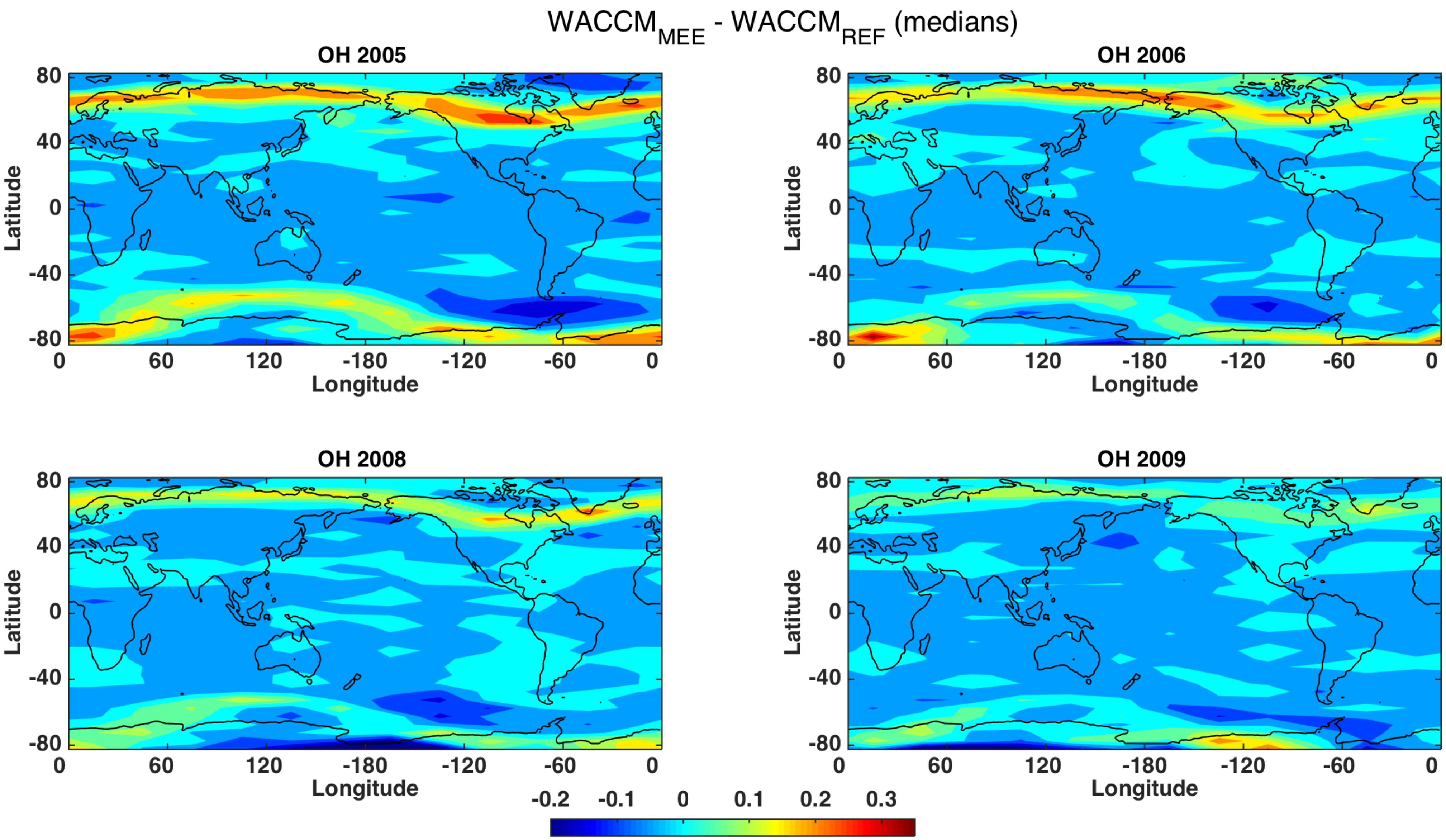
WEEP_CMIP5

compare APEEP output against original CMIP5 runs without EEP in order to show the significance of APEEP

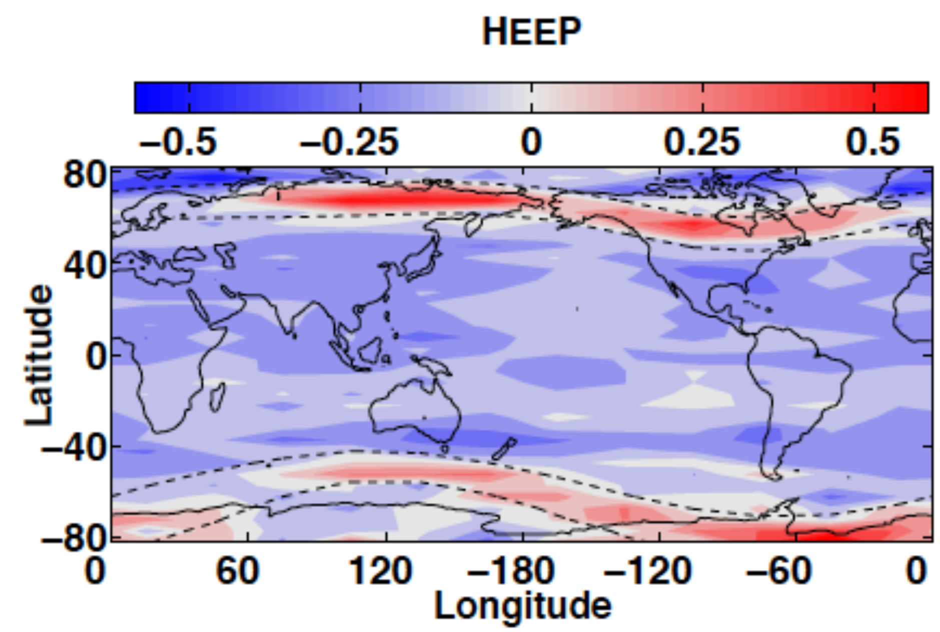
WEEP_DYN

compare high and low years of EEP to determine sources and mechanism of dynamical changes in the atmosphere

Proof of concept - OH example

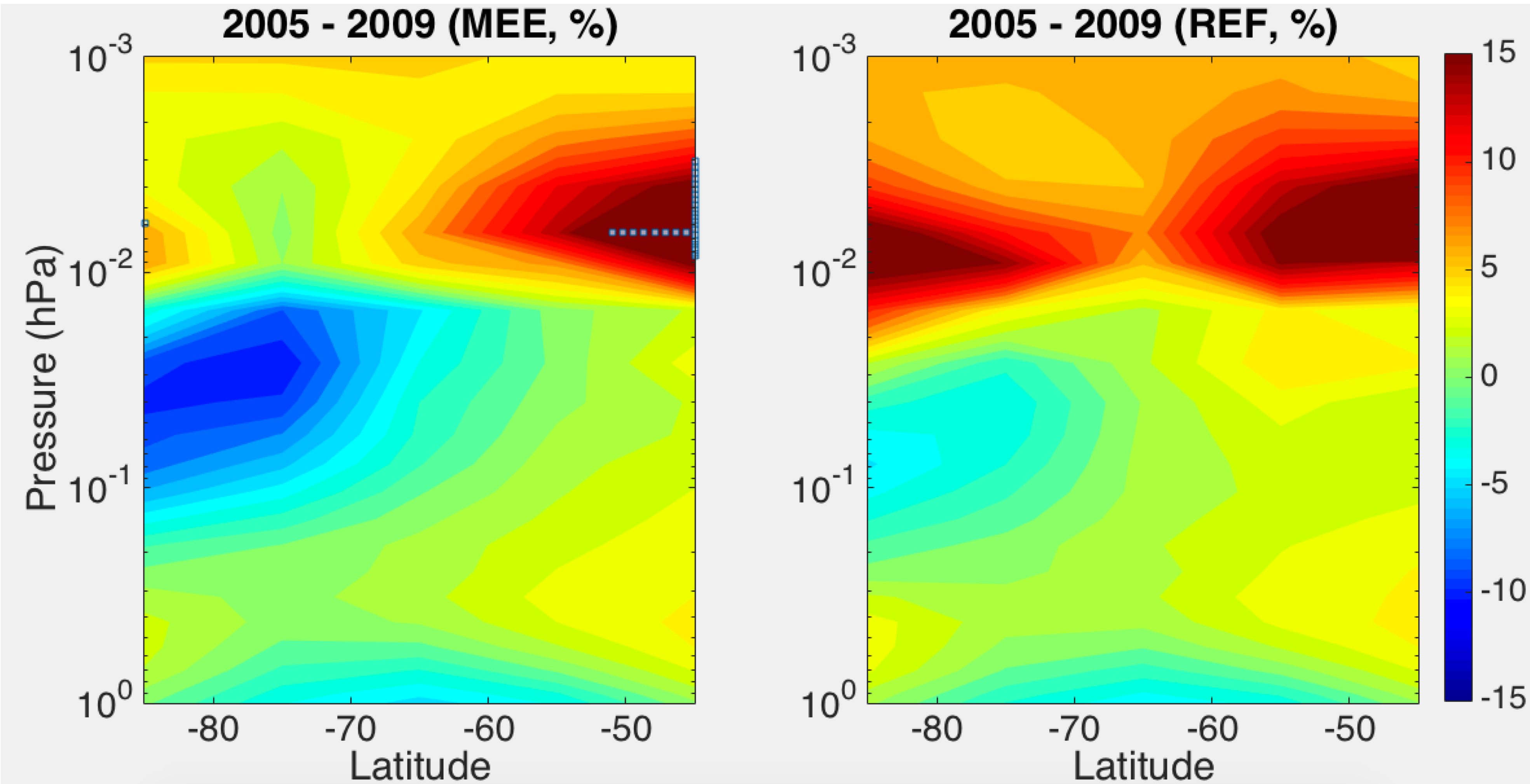


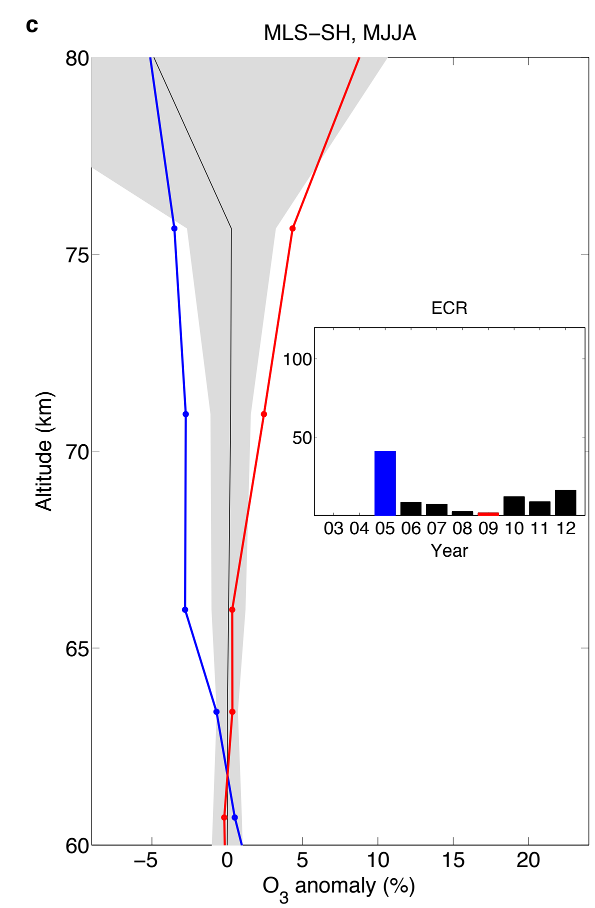
Andersson et al. 2014, ACP



Proof of concept - ozone example

Ozone relative changes % (MJJA, SH)





Andersson et al. 2014, Nature Comm.

Summary

- **WACCM-D** incorporates D-region ion chemistry to reproduce the neutral atmospheric effects caused by EPP in the polar region

- Including ion chemistry scheme in the model significantly improved the response of important neutral species to the energetic particle precipitation

- Including EEP source of ionisation will give us a complete picture of the importance of ion chemistry in the middle atmosphere in order to improve our understanding of solar influence on the atmosphere and climate.