Karlsruhe Institute of Technology

Mittlere Atmosphäre
Solare Variabilität
Klimawechselwirkung

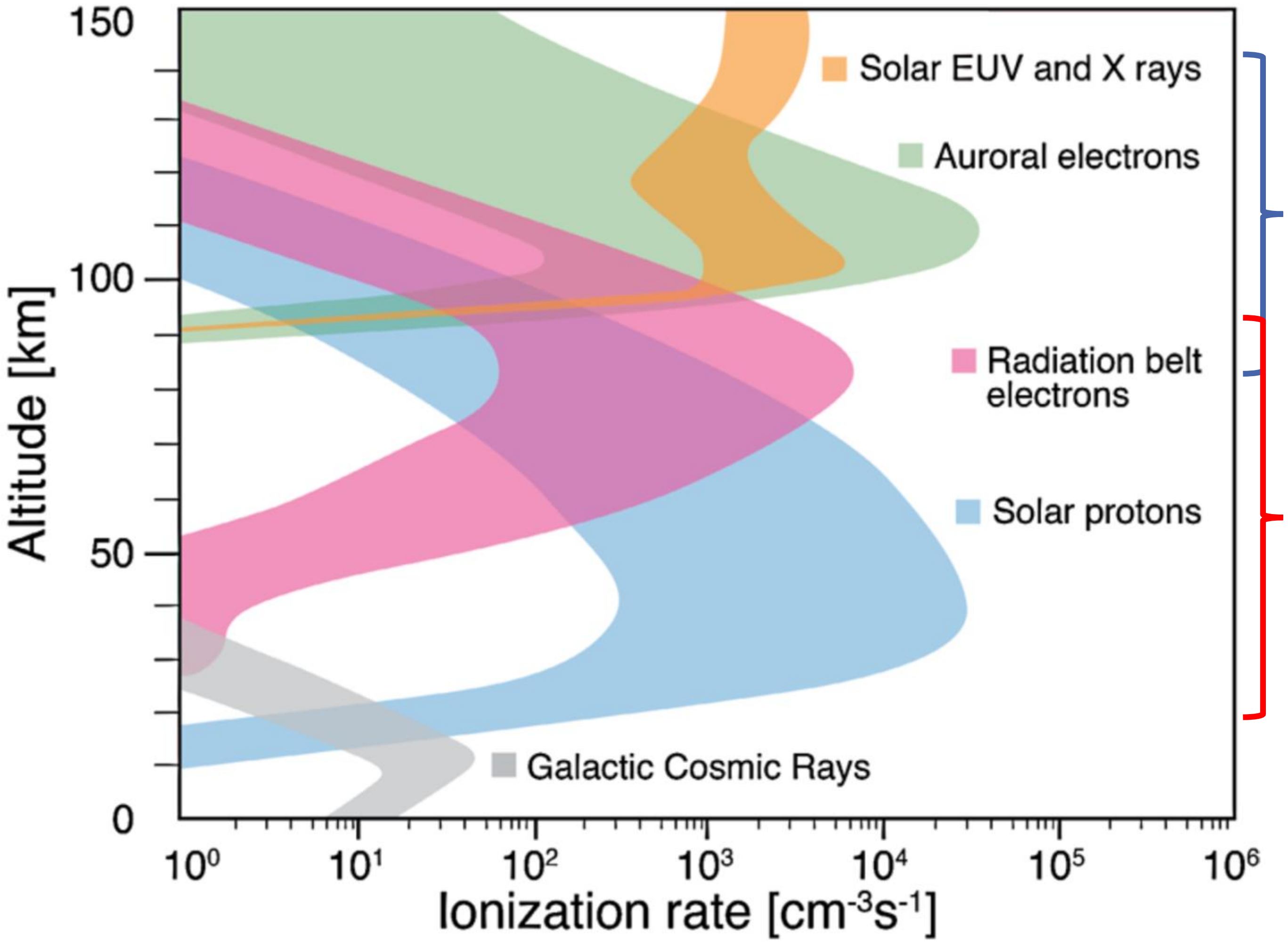
An assessment of the impact of (radiation belt) electron precipitation on the middle atmosphere

Miriam Sinnhuber

Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology

Aurora from the ISS, @ ESA/NASA

Atmospheric ionization by precipitating particles



Auroral:

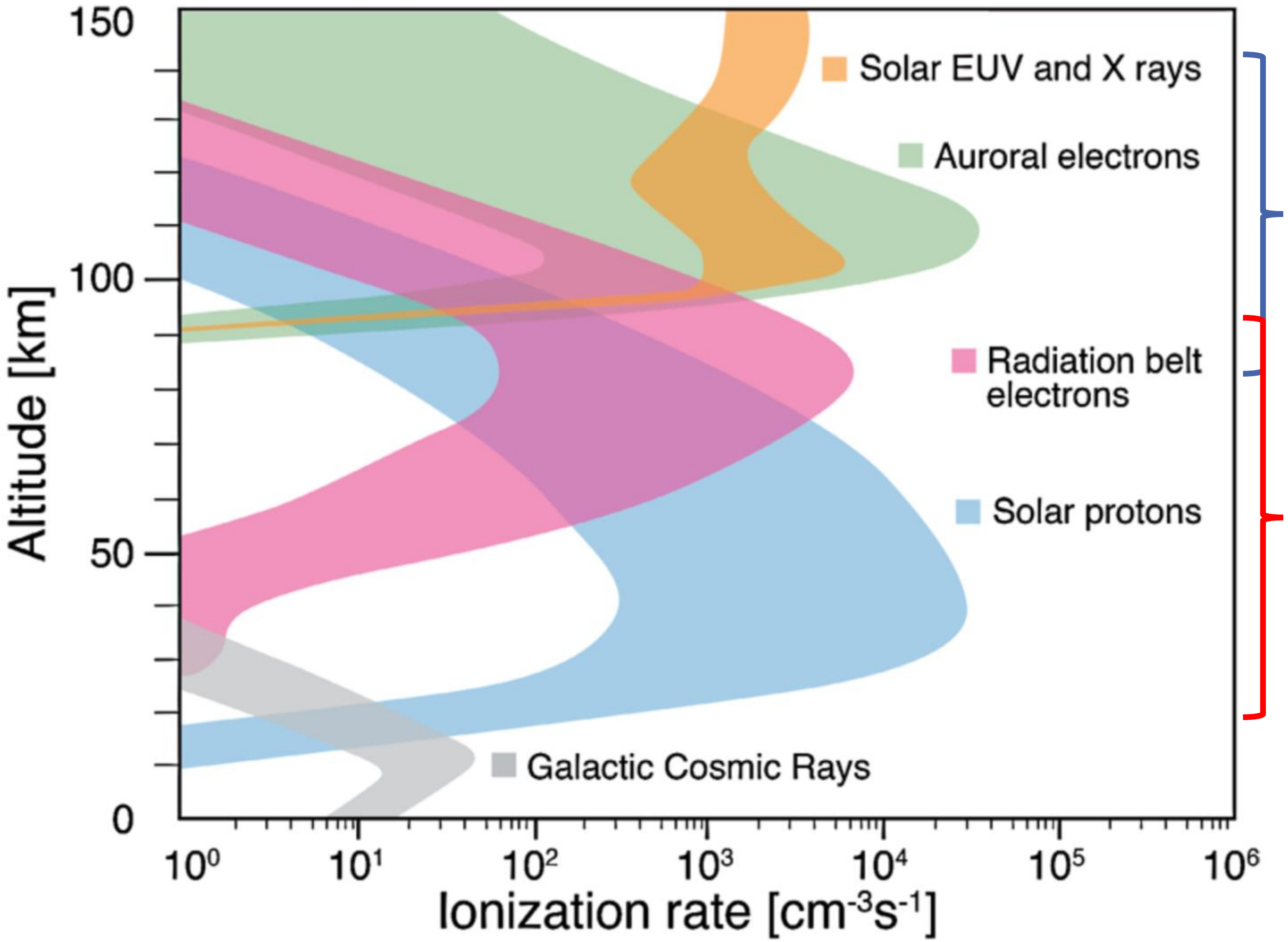
keV-hundreds of keV, mostly > 90km

Radiation belts:

10 keV to MeV, (upper) mesosphere

Mironova et al., Rev. Geophys., 2015

Atmospheric ionization by precipitating particles



Mironova et al., Rev. Geophys., 2015

Auroral:

keV-hundreds of keV, mostly > 90km

Radiation belts:

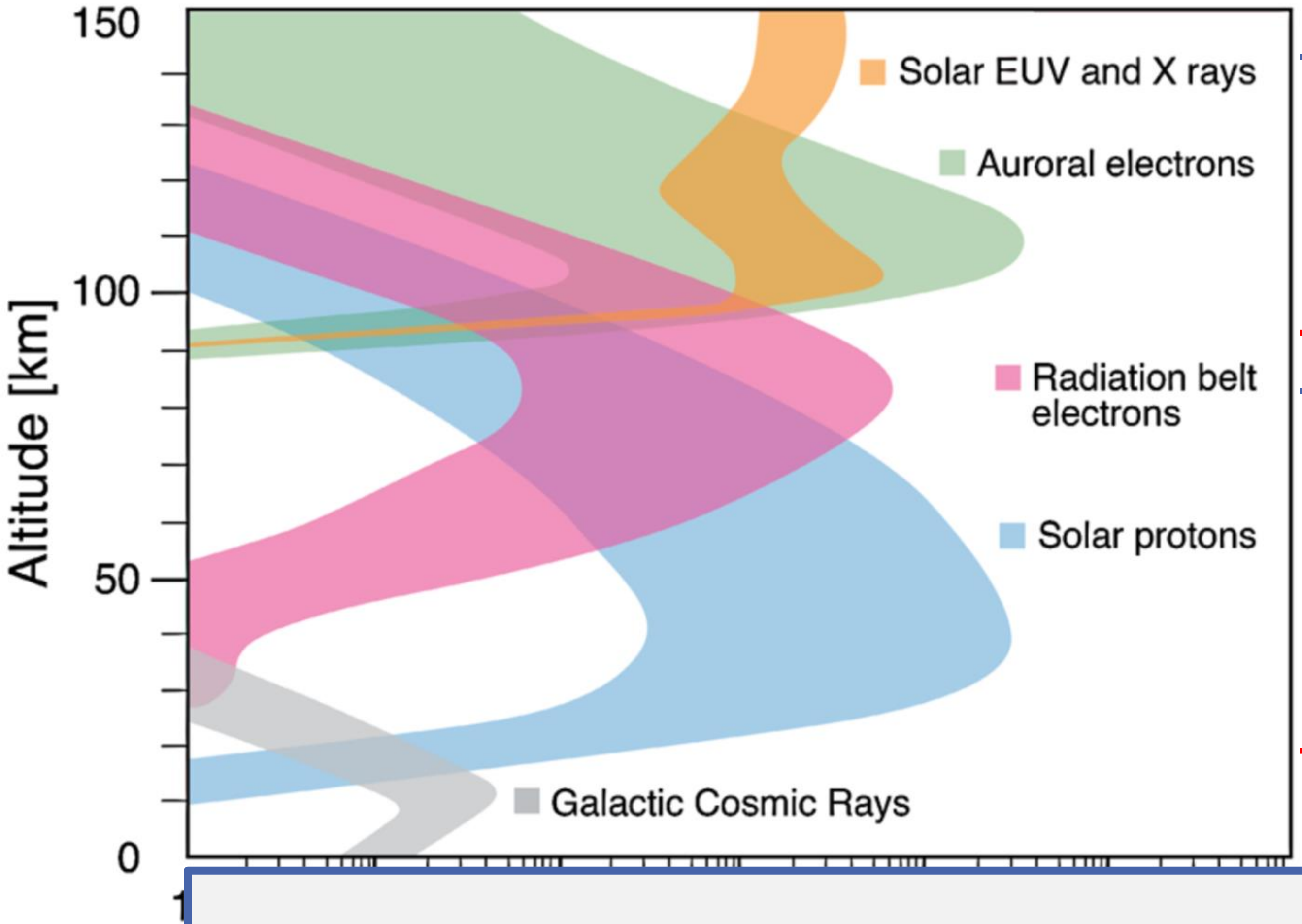
10 keV to MeV, (upper) mesosphere

Limitations of flux measurements:

- in coverage, energy resolution and range, definition of loss cone

Strength and energy range of precipitating flux uncertain

Atmospheric ionization by precipitating particles



Auroral:

keV-hundreds of keV, mostly > 90km

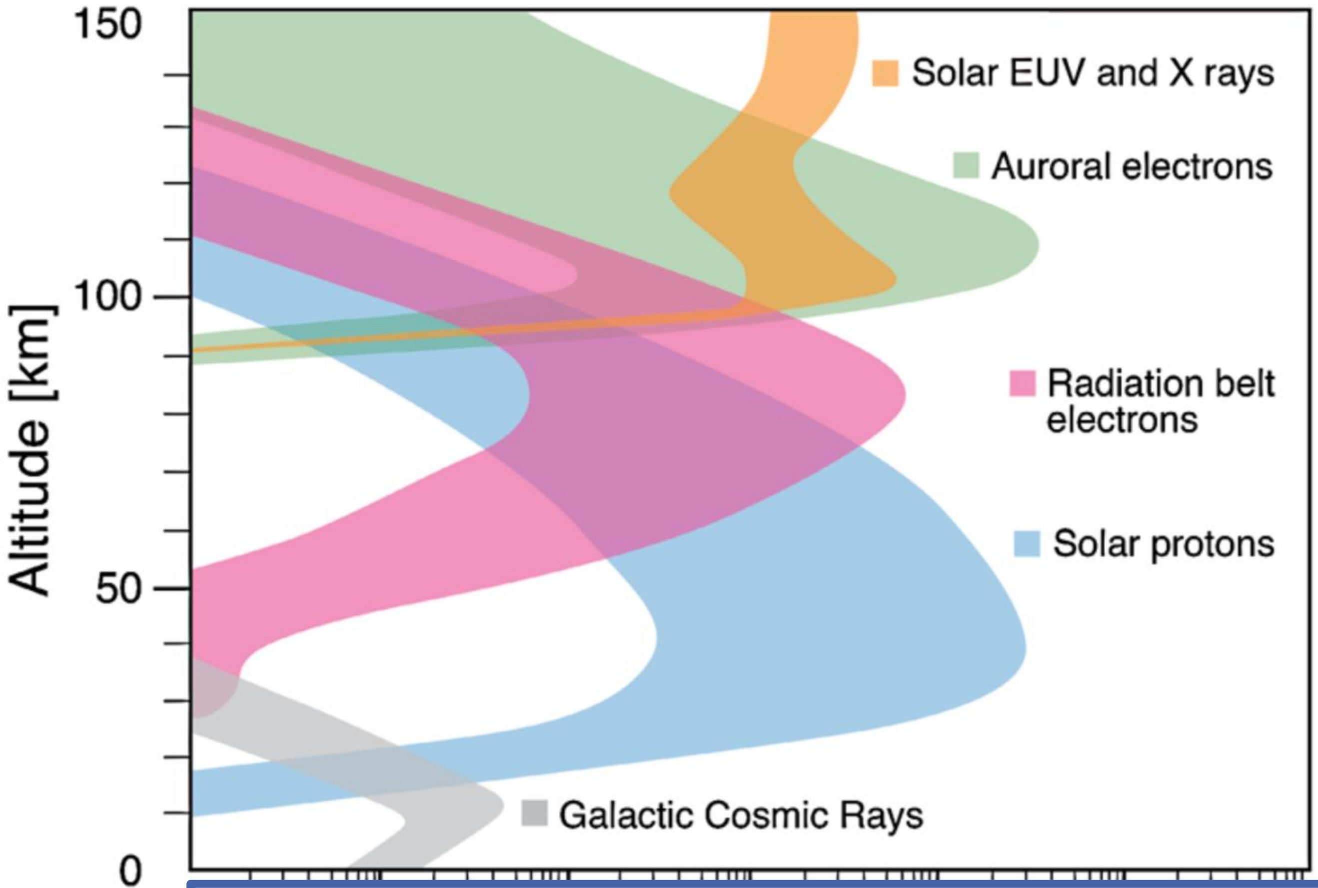
Radiation belts:

10 keV to MeV, (upper) mesosphere

Strength and energy range of precipitating flux uncertain

Can we use atmospheric observations to constrain this flux?

Formation of NO in the atmosphere



Upper mesosphere/lower thermosphere:

$O_2 + \mathbf{e^{-*}} \rightarrow O_2^+ + \mathbf{e^{-*}} + e^-$

$O_2^+ + N_2 \rightarrow NO^+ + NO$

$NO^+ + O \rightarrow O_2^+ + N$

…. *Nicolet, 1965, 1975; Jones+Rees, 1973; Rusch et al., 1981*

Stratosphere/mesosphere:

$N_2 + \mathbf{e^{-*}} \rightarrow N(^2D) + N + \mathbf{e^{-*}}$

$N(^2D) + O_2 \rightarrow NO + O$ *Nicolet, 1975*

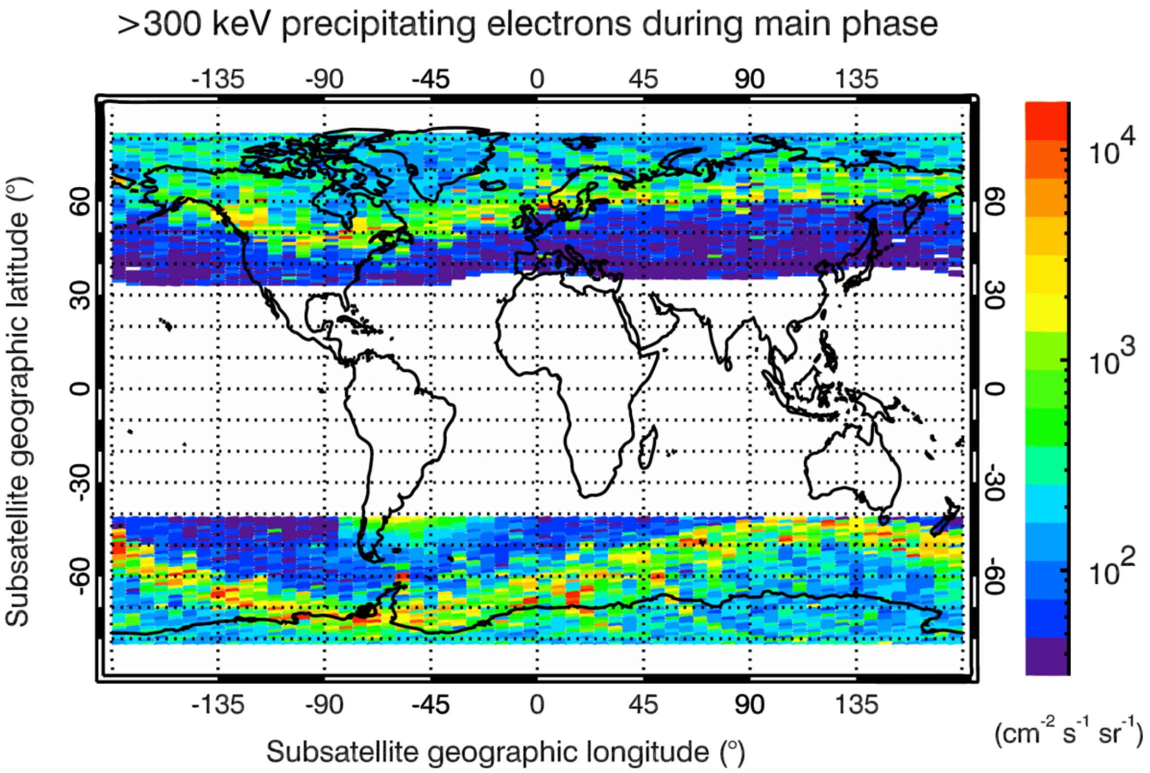
Stratosphere:

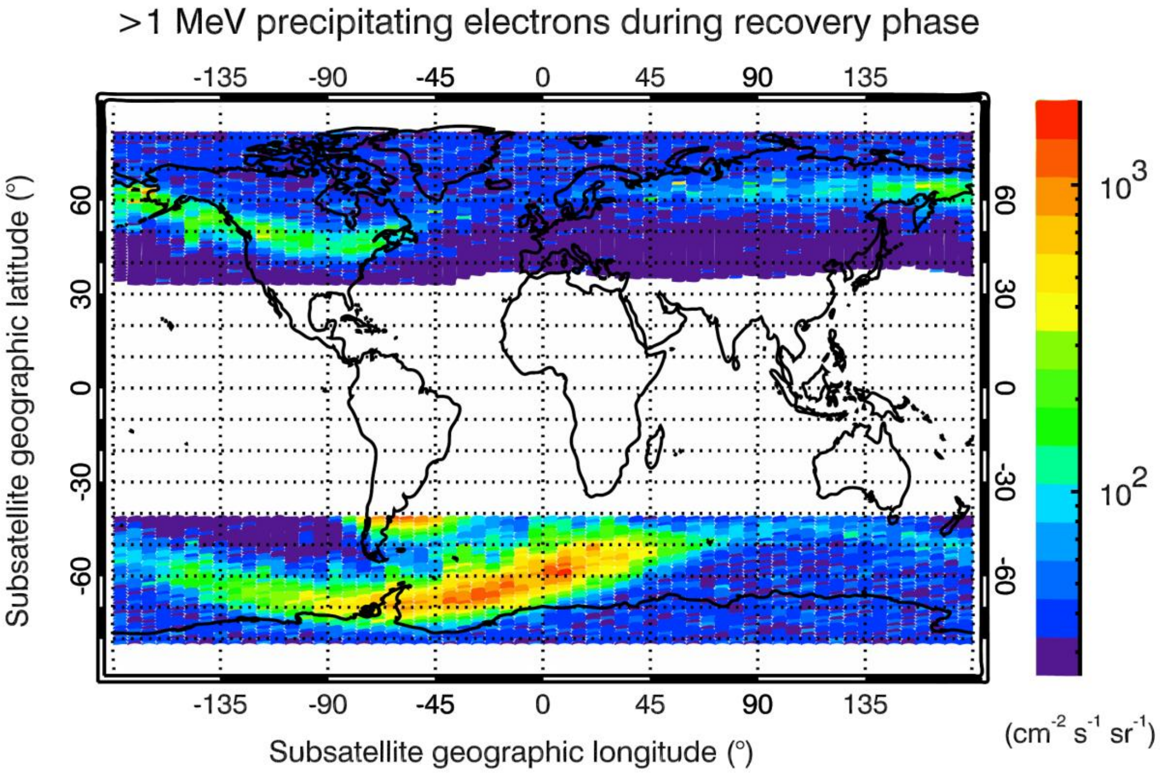
$N_2O + O(^1D) \rightarrow 2NO$ natural/anthropogenic

Above ~50 km, NO is a tracer for particle precipitation

Electron precipitation during geomagnetic storms

Average of 8 years of POES/MEPED 0° telescope


>300 keV precipitating electrons during main phase


>1 MeV precipitating electrons during recovery phase

→ Precipitation occurs in narrow band of geomagnetic latitudes

Horne et al., GRL, 2009

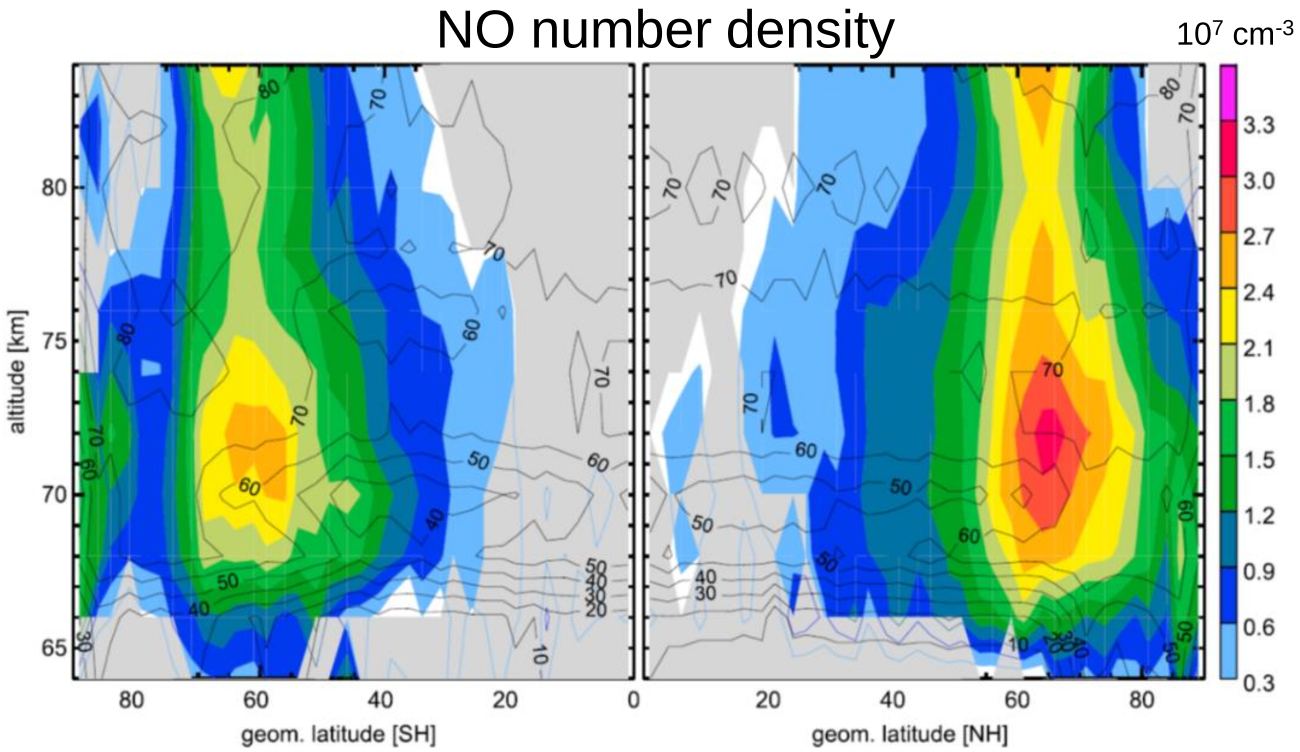
NO observations during high geomagnetic activity

SCIAMACHY/ENVISAT, 2002-2012 summer average, 64 – 84 km

Superposition of 10 years of NO during periods of high Ae show clear enhancement in the upper mesosphere:

65 – 84 km, 60-70° geomag. Lat.

→ Lower edge defined by instrument sensitivity



Sinnhuber et al., JGR, 2016

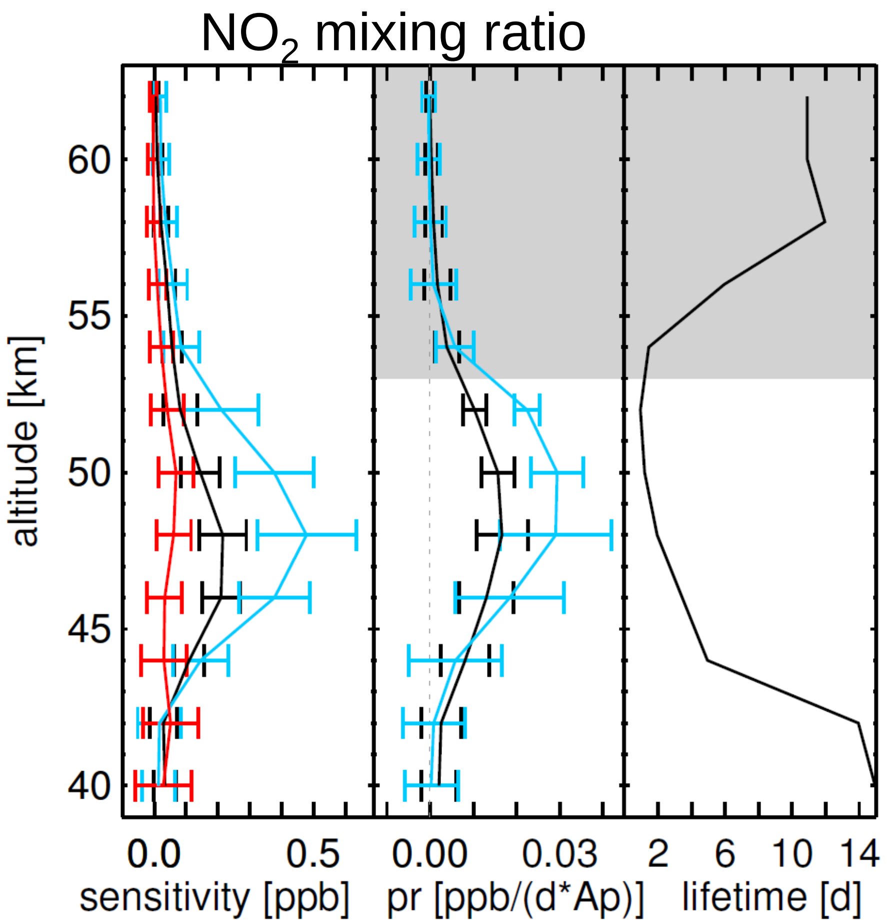
NO_2 observations during high geomagnetic activity

MIPAS/ENVISAT, 2007-2012 summer average, 39 – 62 km

Superposition of 6 years of NO_2 during periods of high Ap show (small) enhancement in the upper stratosphere:

46 – 52 km, 60-70° geomag. Lat.

→ Upper edge defined by reaction of NO with ozone forming NO_2



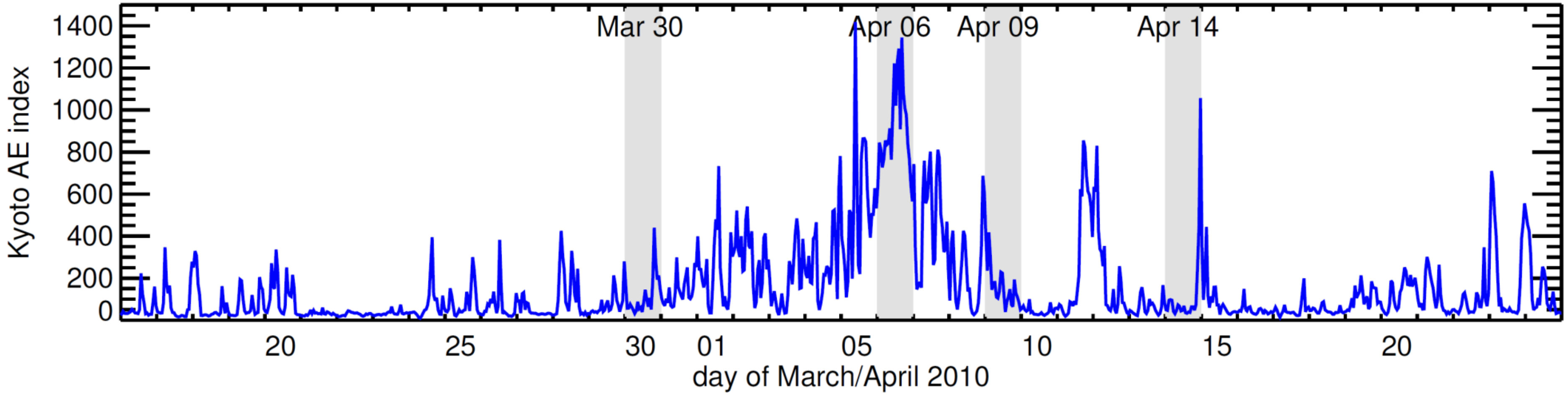
Friederich et al., ACP, 2014

NO formation during individual storms and substorms

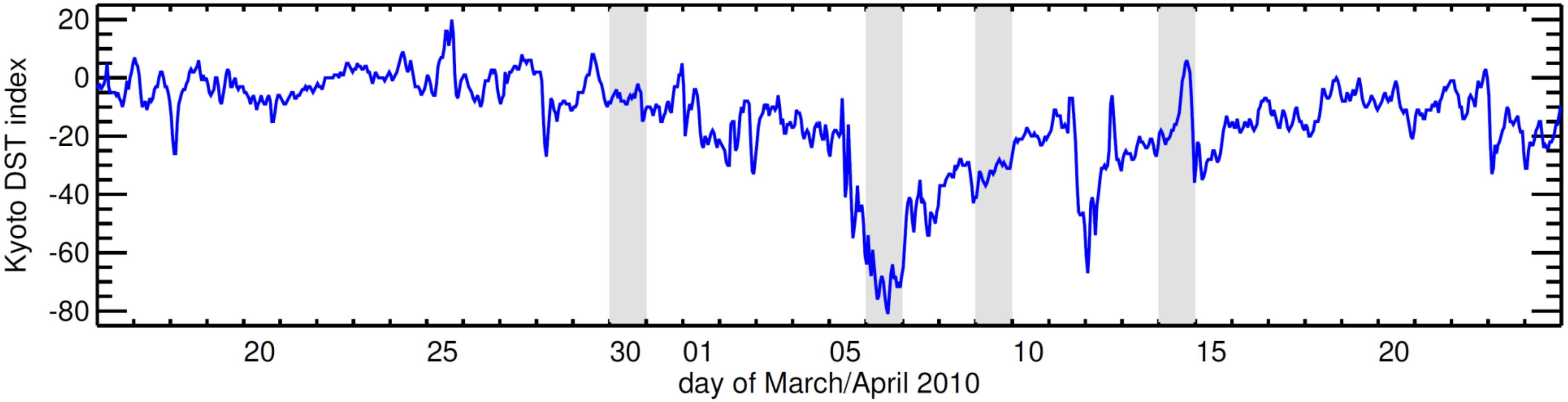
March/April 2010

March 30:
auroral substorm

April 5 - 9:
geomagnetic storm
5: onset 6: main 9: recovery



Ae

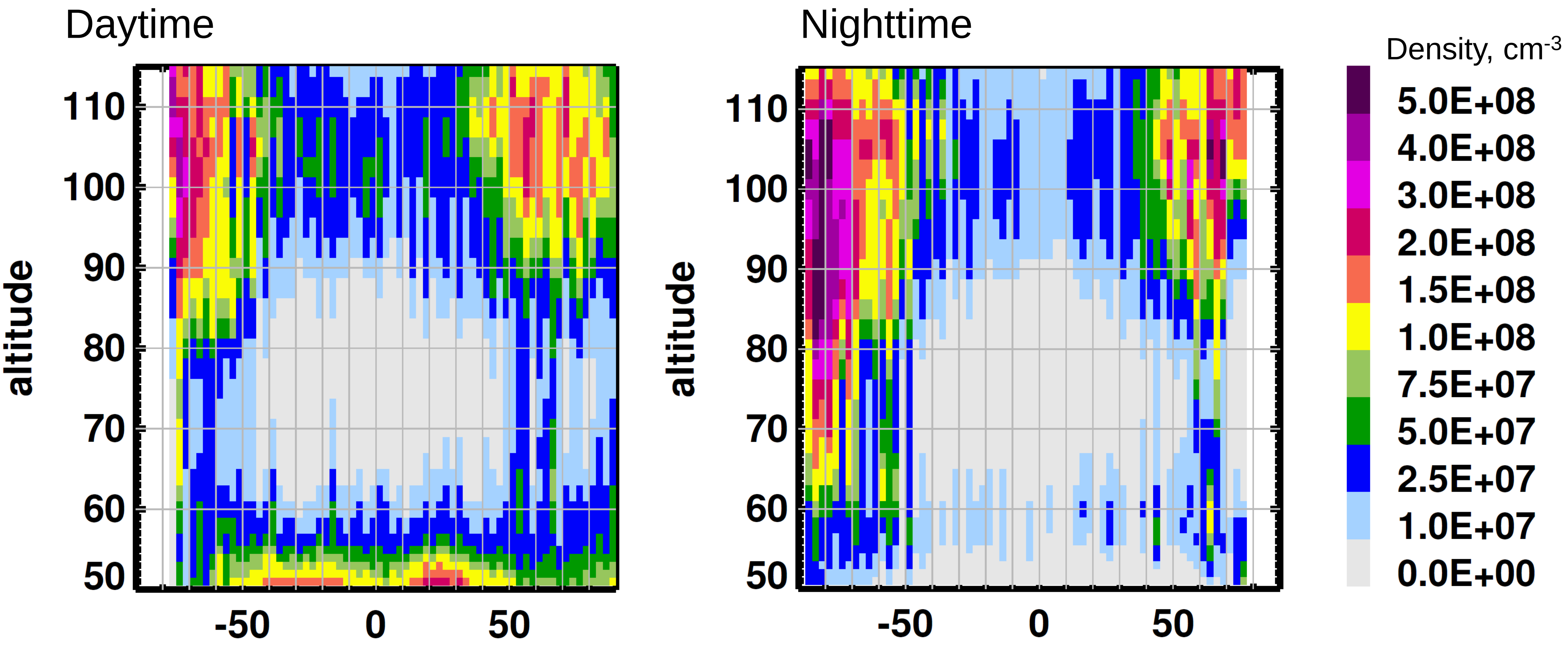


DST

Sinnhuber et al., JGR, 2022

NO formation during individual storms and substorms

MIPAS/ENVISAT v8, April 9: recovery phase of geomagnetic storm

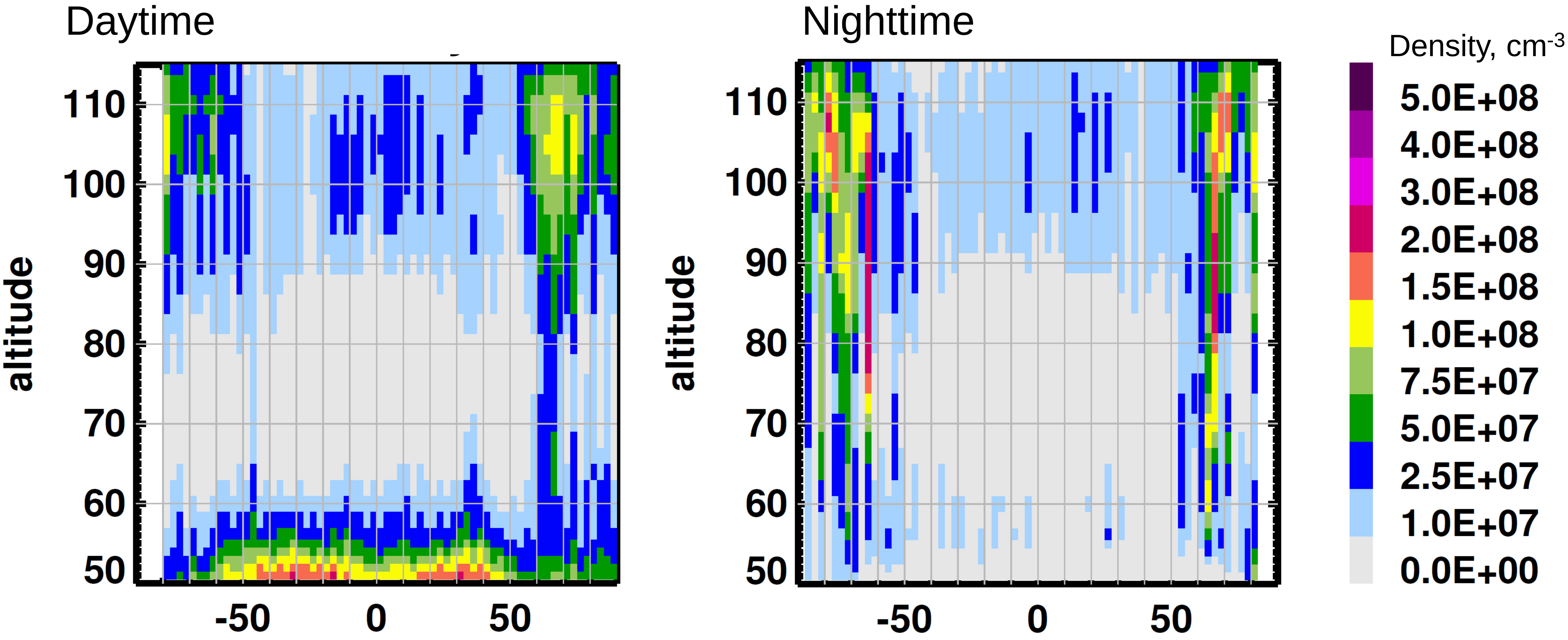


Enhanced NO in 50-70°N, 55 – 110 km. Lower edge not clear due to NO$_2$ formation

Sinnhuber et al., JGR, 2022

NO formation during individual storms and substorms

MIPAS/ENVISAT v8, March 30: substorm

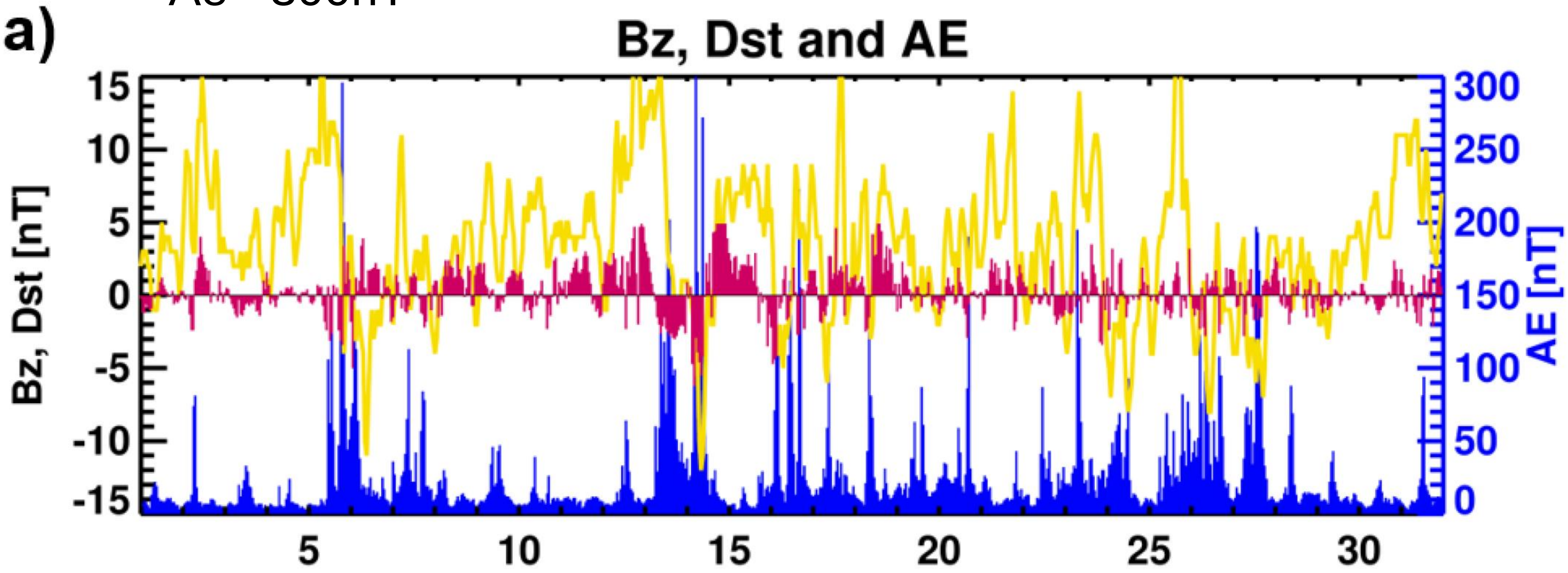


Enhanced NO in 60-70°N, 60 – 110 km. Lower edge not clear due to NO_2 formation

Sinnhuber et al., JGR, 2022

NOx formation during individual substorms

December 2009



December 14:
Ae ~300nT, negative Bz, DST ~-15 nT

December 5-6:
Ae ~300nT

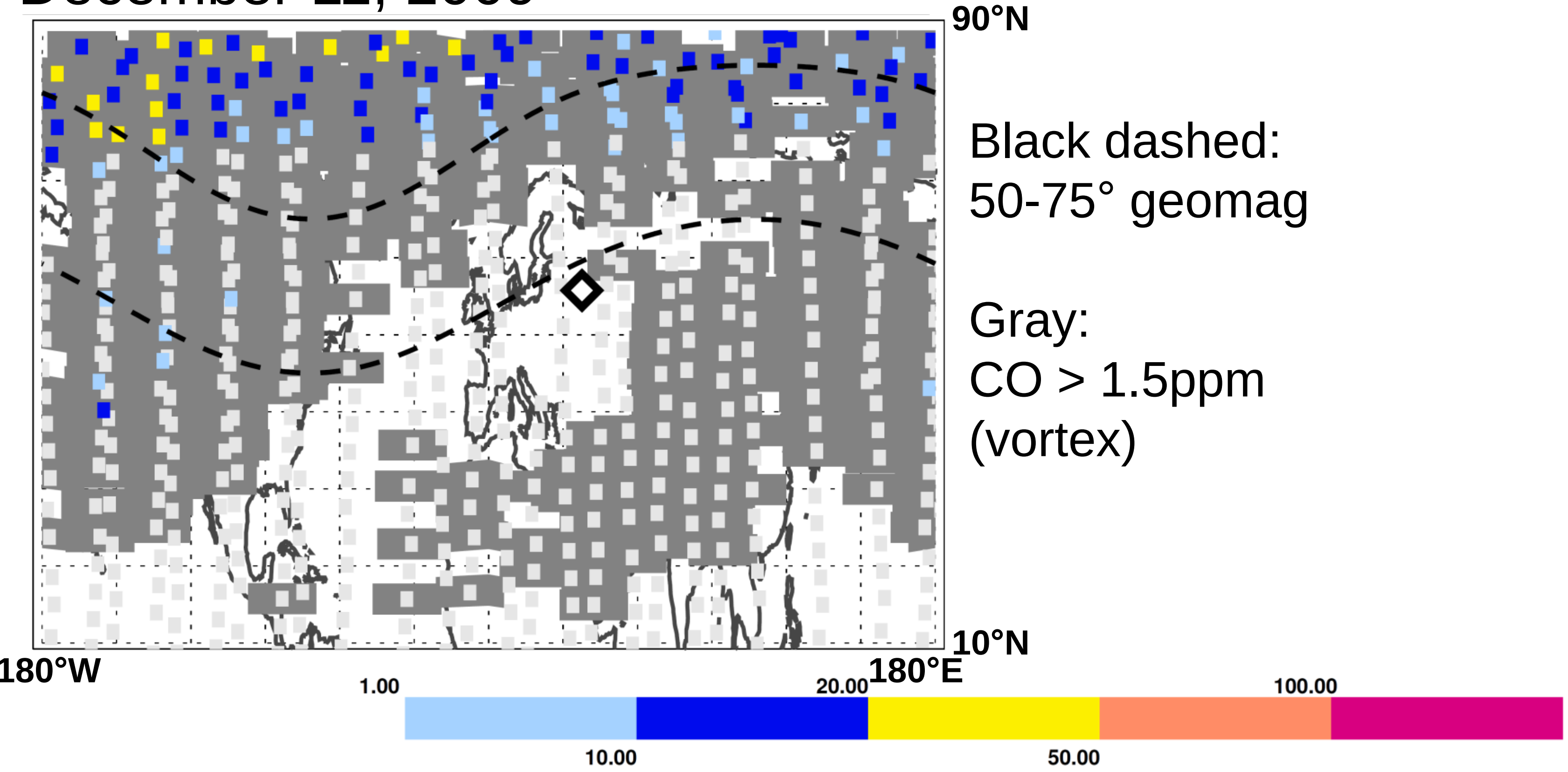
December 11:
quiet

Mironova et al., ACP, 2022

NOx formation during individual substorms

MIPAS v8, NO+NO_2 (ppb), 68 km

December 11, 2009



Black dashed:
50-75° geomag

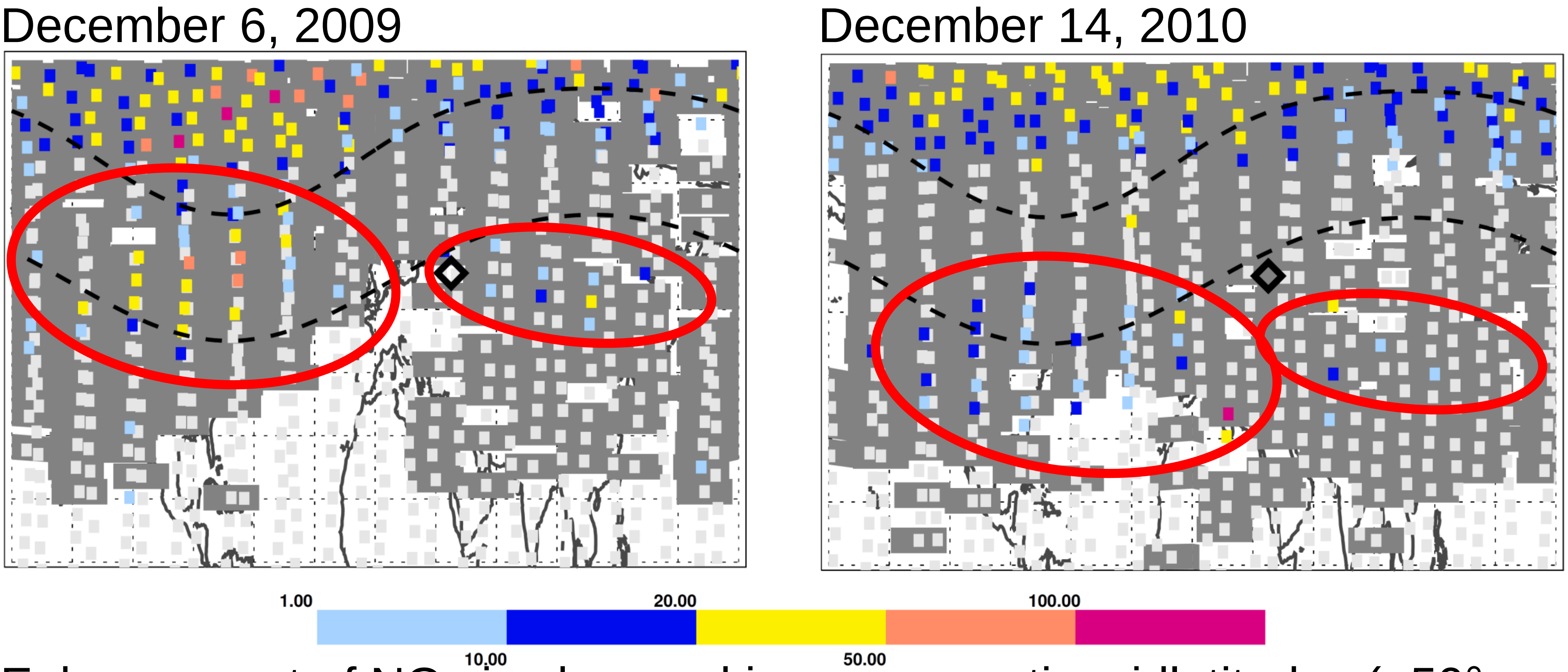
Gray:
CO > 1.5ppm
(vortex)

Enhancement of NOx at high latitudes: downward transport in polar winter vortex (indirect effect)

Mironova et al., ACP, 2022

NOx formation during individual substorms

MIPAS v8, $NO+NO_2$ (ppb), 68 km



Black dashed:
50-75° geomag

Gray:
CO > 1.5ppm
(vortex)

Enhancement of NOx is observed in geomagnetic midlatitudes (<50° geomag), possibly due to fast transport around vortex edge

On December 14, midlatitude precipitation observed by balloon over Moscow

Mironova et al., ACP, 2022

Summary

Observations show formation of NO (55 – 90 km) and NO_2 (46 – 55 km) during enhanced geomagnetic activity in geomagnetic latitudes 60-70°

In two cases, enhanced NOx was observed at geomagnetic midlatitudes during (slightly) enhanced Ae

→ Enhanced NOx could be due to transport within polar vortex, but midlatitude precipitation was also observed by balloon instrument on Dec 14, 2009

So, can NO observations be used to constrain electron precipitation?

→ In principle yes, however:

- not clear from the atmospheric observations what the source of the ionization is: altitude < 70km suggests >300 keV electrons
- More analysis clearly needed, e.g., full MIPAS v8 dataset

Thanks for your attention!

Aurora from the ISS, @ ESA/NASA

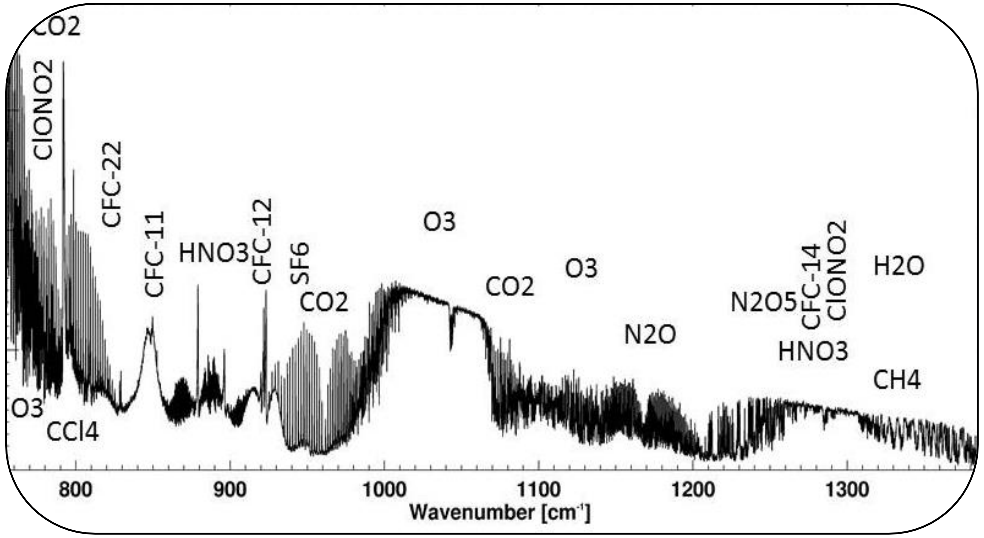
The Changing-Atmosphere IR Tomography Explorer

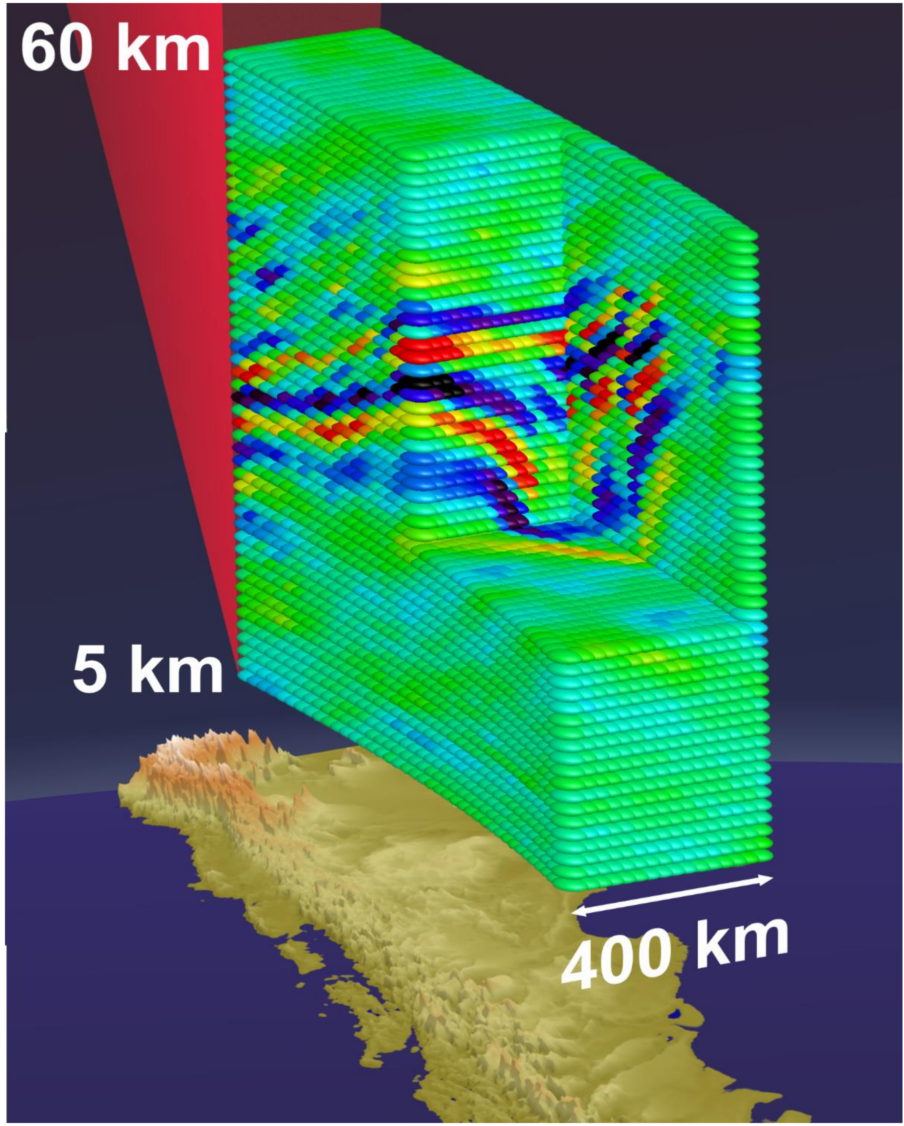
CAIRT: An ESA Earth Explorer 11 candidate

Infrared limb emission imager with instantaneous view from troposphere to lower thermosphere:

5-115 km, with **5x5x1 km** spatial resolution

Target species temperatures and **>29 trace gases** including **NO** and **ozone**, observed simultaneously



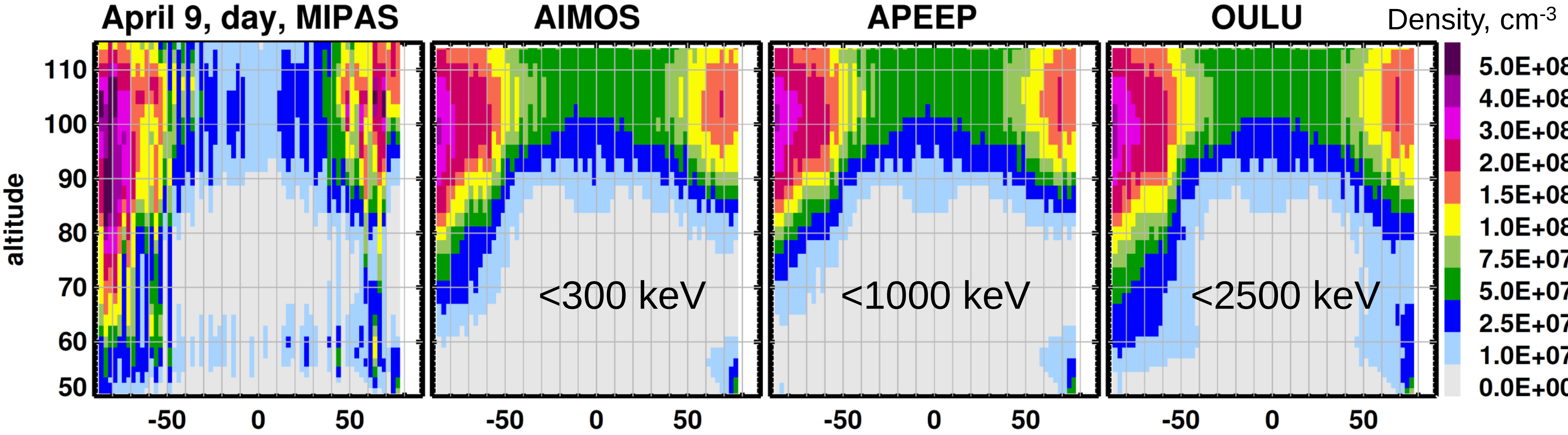


One of four candidates selected for phase 0, further down-selection to 1 in 2025; launch early 2030th

NO formation during individual storms and substorms

MIPAS/ENVISAT v8, April 9: comparison to model results with different ionization rate data-sets

Multi-model mean of WACCM6, HAMMONIA, KASIMA, EMAC using



Observations qualitatively not well reproduced by ionization rate data-sets: energy range of POES/MEPED, with uncertain upper energy range

Sinnhuber et al., JGR, 2022

Understanding the influence of the SPace Environment on Atmospheric Chemistry and dynamics

Fluxes of magnetospheric electrons in loss cone from VERB4D magnetospheric model

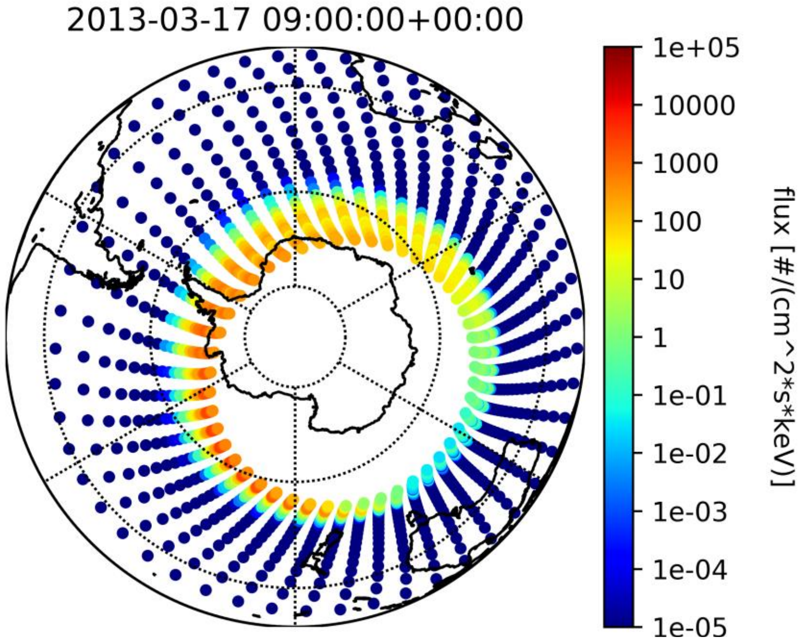
➡

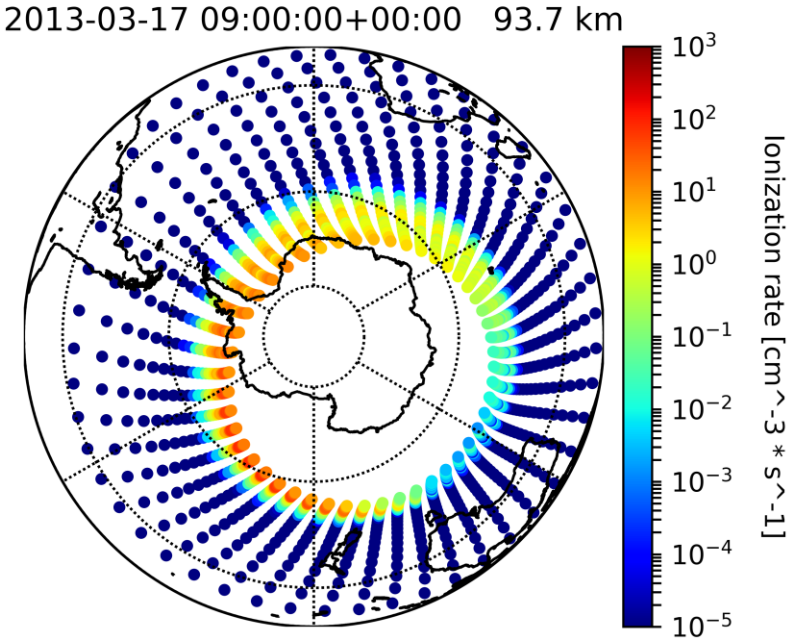
Atmospheric ionization rates

➡

Forcing for global model EMAC

30 keV





93.7 km

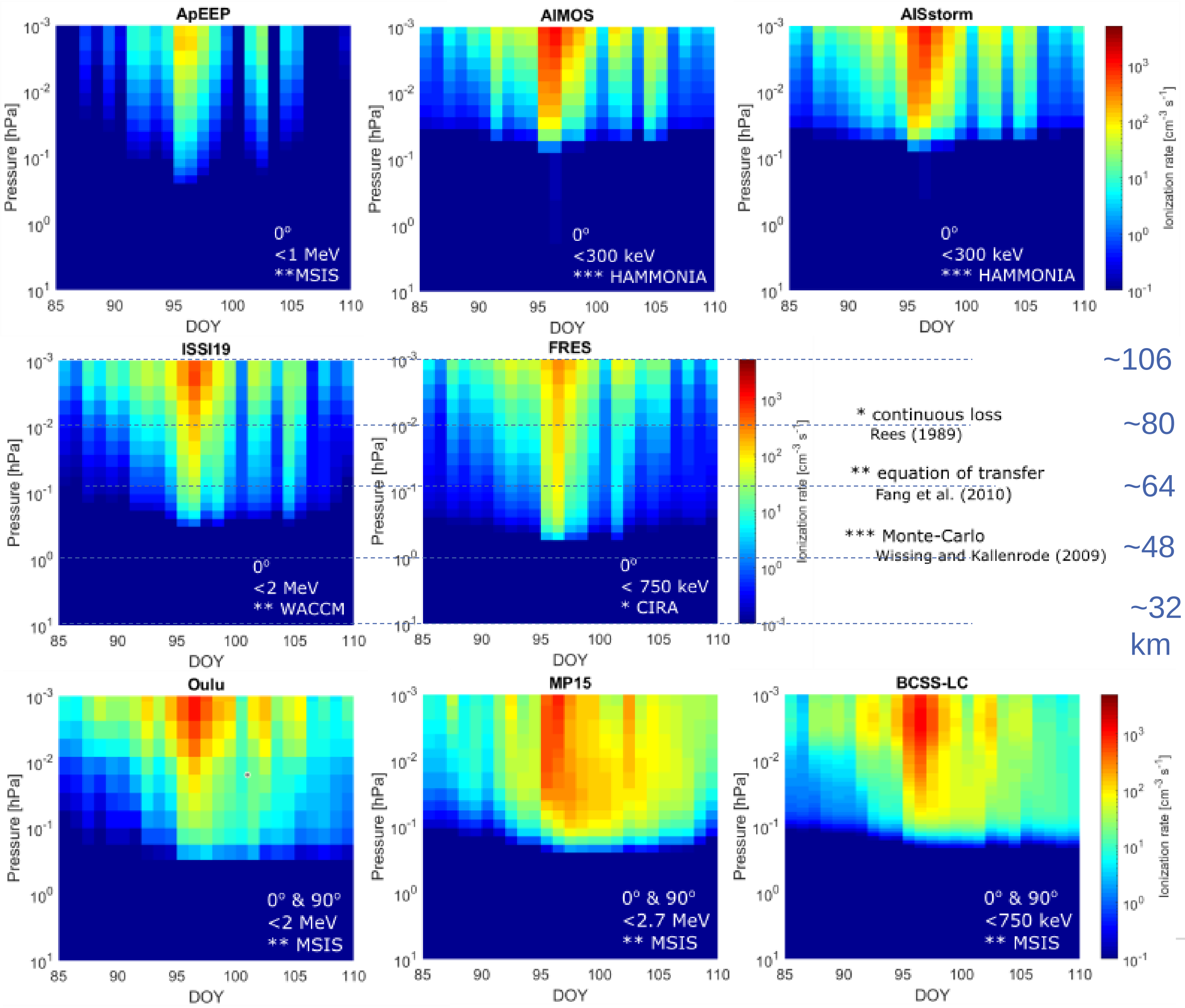
A. Grishina, Y. Shprits
Geoforschungszentrum Potsdam

F. Haenel, M. Sinnhuber
Karlsruhe Institute of Technology

Project SPEACH funded by the Deutsche Forschungsgemeinschaft DFG

Forcing data

Atmospheric electron ionization rates



Atmospheric ionization rates, 32-106 km from 8 different models, March-April 2010

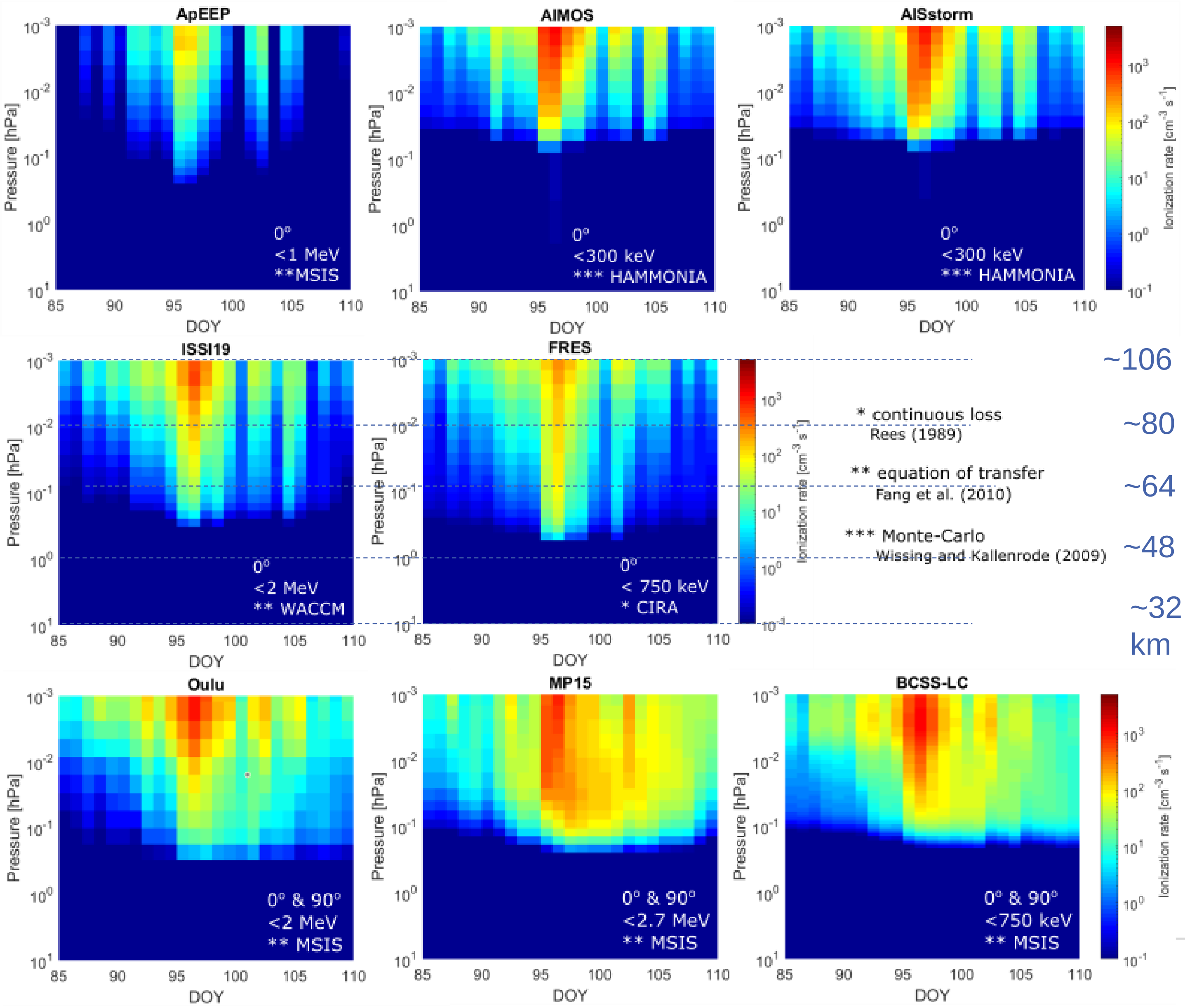
All based on POES/MEPED

- ○ Different energy ranges from <300 keV to <2.7MeV
- ○ Using 0° / 0°+90° telescopes
- ○ Energy deposition by equation of transfer / continuous loss / Monte Carlo
- ○ Using different atmospheres for energy loss

Nesse Tyssoy et al., JGR, 2022

Forcing data

Atmospheric electron ionization rates



Ionization rates differ by ~1 order of magnitude despite being based on same electron fluxes:

→ Clear need of observations of electron fluxes with

- Pitch-angle distribution
- Spectral (energy) resolution
- 30 keV – MeV

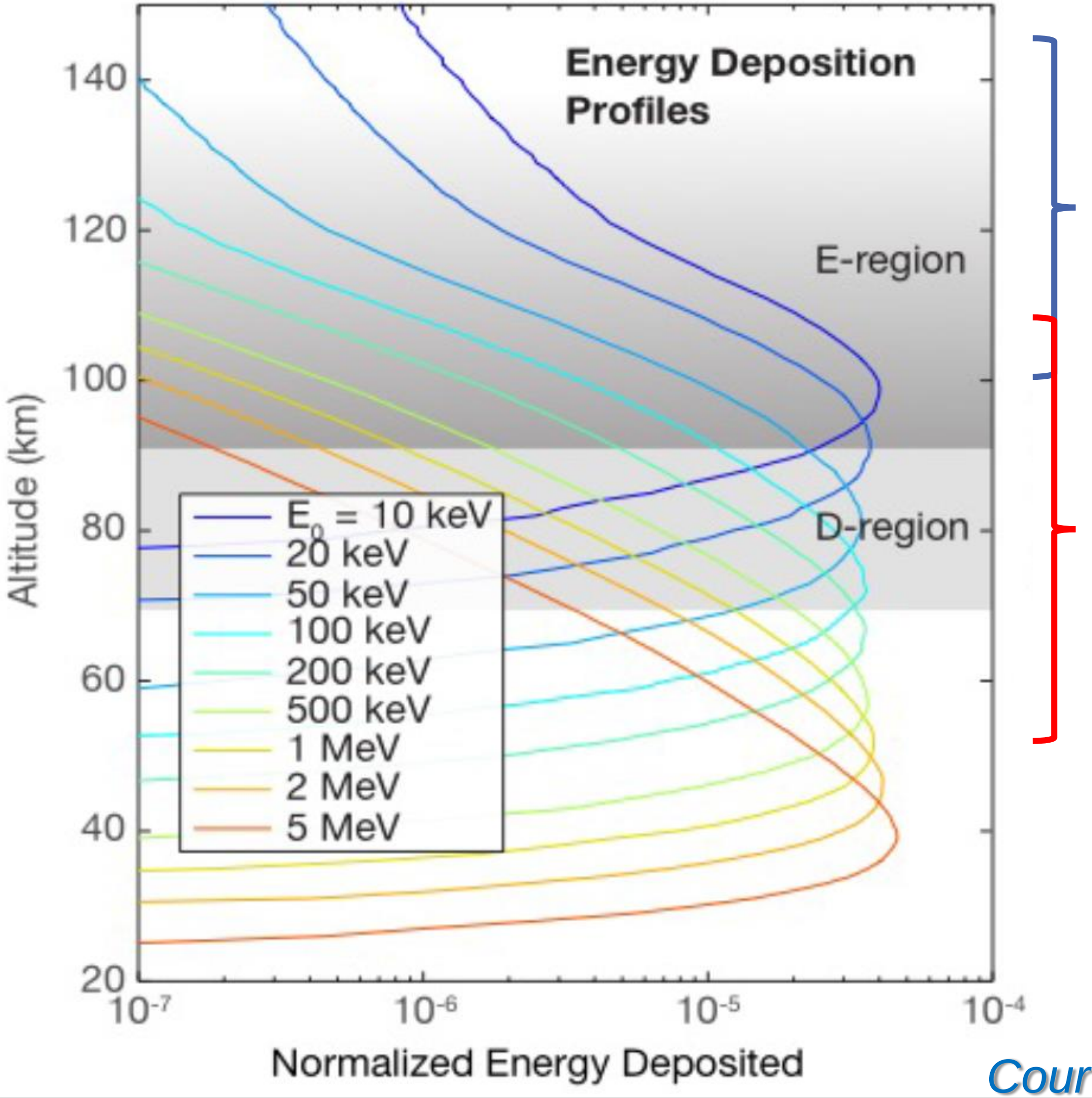
transfer / continuous loss / Monte Carlo

- Using different atmospheres for energy loss

Nesse Tyssoy et al., JGR, 2022

Atmospheric impact of electron precipitation

Energy deposition of precipitating electrons



Lower thermosphere (> 90 km):

Auroral (keV)

MLT (mesosphere/lower thermosphere) (50 - 115 km): Radiation belts

Radiation belts (10th of keV to MeV)

Courtesy of Robert Marshall, CU Boulder/ASEN