Measurements of Gas Phase Stratospheric Sulfur

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AGU Chapman Conference, Tenerife, 20-Mar-2018

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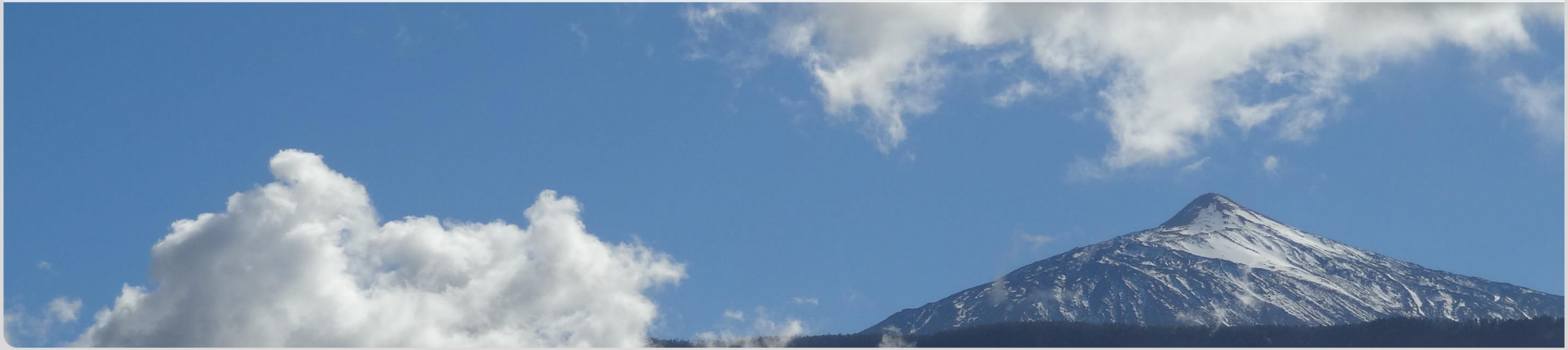

Acknowledgements:

Norbert Glatthor
Annika Günther
Björn-Martin Sinnhuber
Gabi Stiller
Thomas von Clarmann

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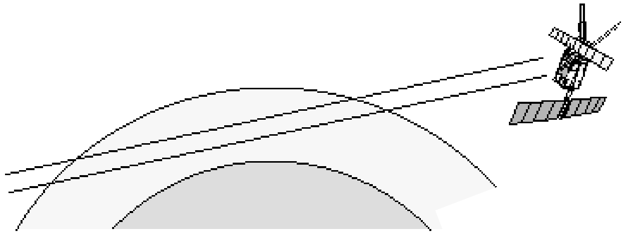
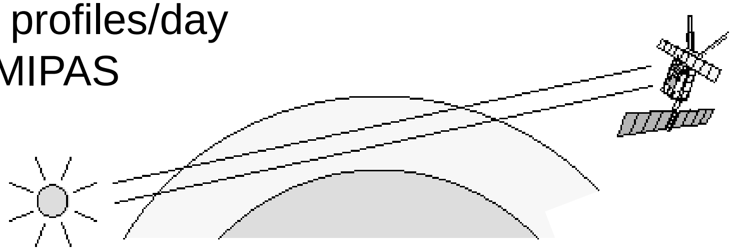
How to measure sulfur gases in the stratosphere?

Remotely from satellite

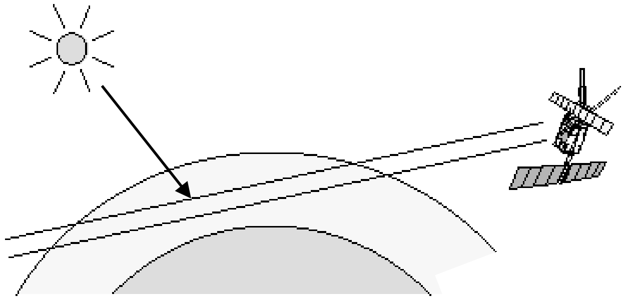


Limb emission (thermal IR, MW)
- Global coverage, day+night
- >1000 profiles/day
- MLS, MIPAS

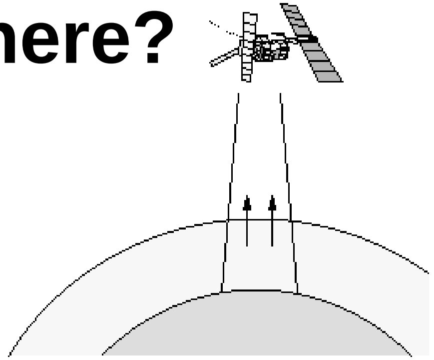
Limb
- High vertical resolution (< 4 km)
- High sensitivity
- Low horizontal resolution (200-500 km)
- Low across-track horizontal coverage



Solar occultation (IR)
- Very high sensitivity
- ~30 profiles per day
- ACE-FTS, ATMOS

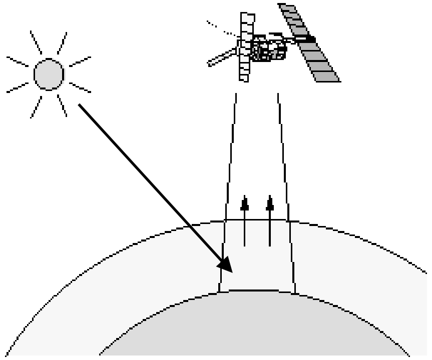


Solar scatter (UV/VIS)
- OMPS, SCIA, OSIRIS



Nadir (thermal IR)
- Global coverage, day/night+polar
- Low sensitivity in lower troposphere
- IASI, AIRS

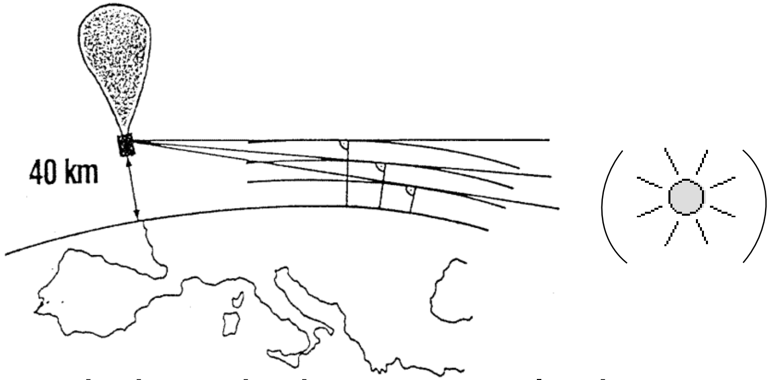
Nadir
- High horizontal resolution
- High coverage
- Low vertical resolution
- Low sensitivity



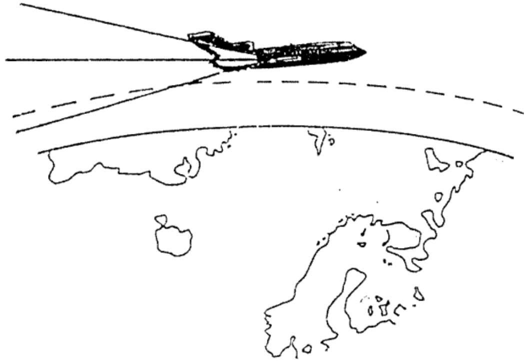
Nadir (UV/VIS)
- Sensitive down to ground
- TOMS, OMI

How to measure sulfur gases in the stratosphere?

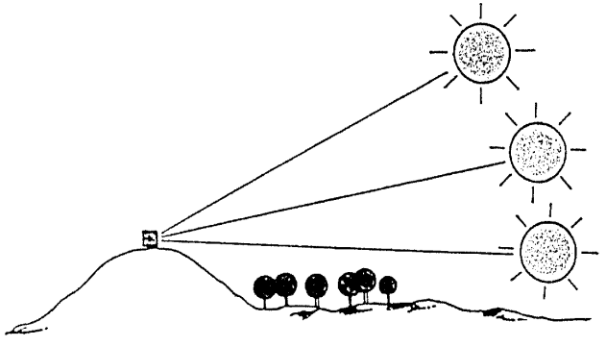
From ground, ship, aircraft, balloon



- Limb emission or occultation (MarkIV, MIPAS-B)
- In-situ



- Limb emission
- In-situ



- Solar absorption (IR) (NDACC-FTIRs)

MIPAS ‚sulfur datasets‘

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- **SO_2 volume mixing ratio profiles (2 datasets)**
  - Retrieval from mean spectra: 15-45 km, monthly+zonal averages,18 profiles/month (Höpfner et al., ACP, 2013)
  - Retrieval from single limb-scans: 8-20 km, high temporal and horizontal resolution, up to 1400 profiles/day (Höpfner et al., ACP, 2015)
- **OCS volume mixing ratio profiles (1 dataset)**
  - Retrieval from single limb-scans: 8-35 km, high temporal and horizontal resolution, up to 1400 profiles/day (upper troposphere: Glatthor et al., GRL, 2015, stratosphere: Glatthor et al., ACP, 2016)
- **H_2SO_4 aerosol volume density profiles (1 dataset)**
  - Retrieval from single limb-scans: 8-~33 km, high temporal and horizontal resolution, up to 1400 profiles/day (Günther et al., ACP, 2018)

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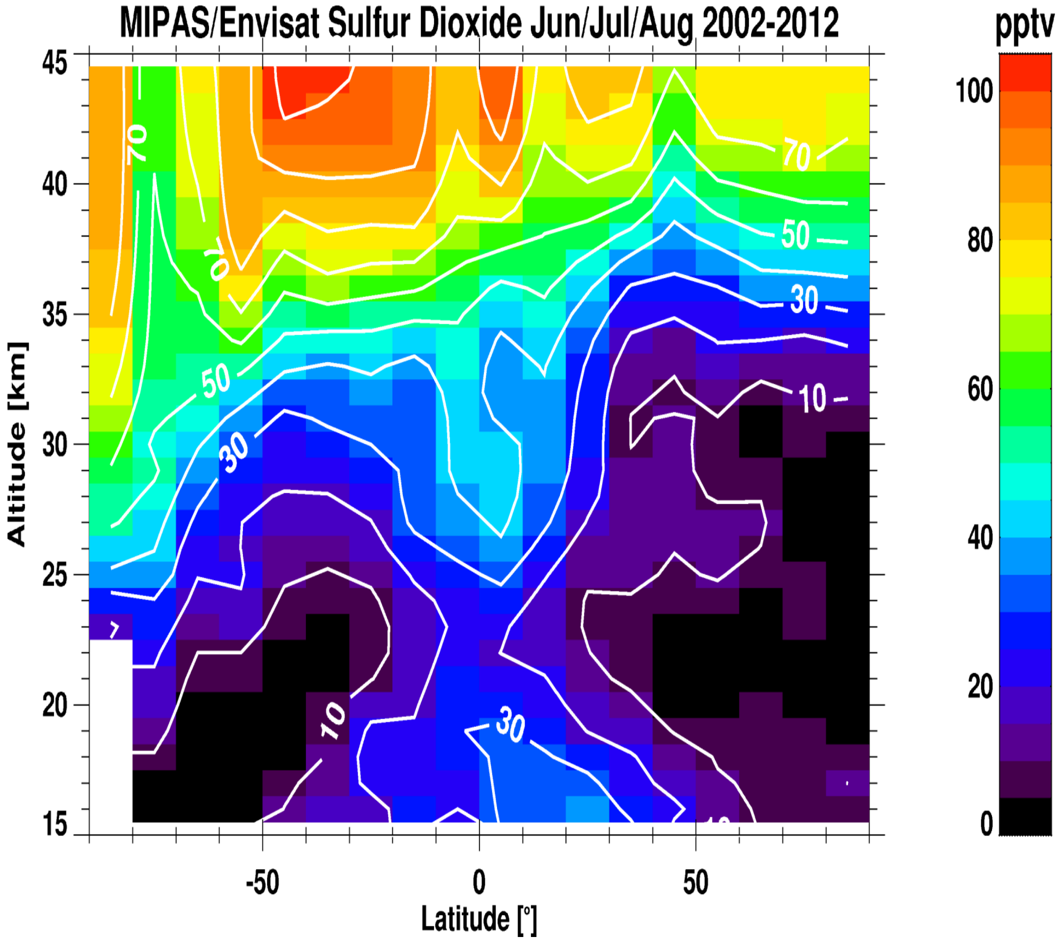
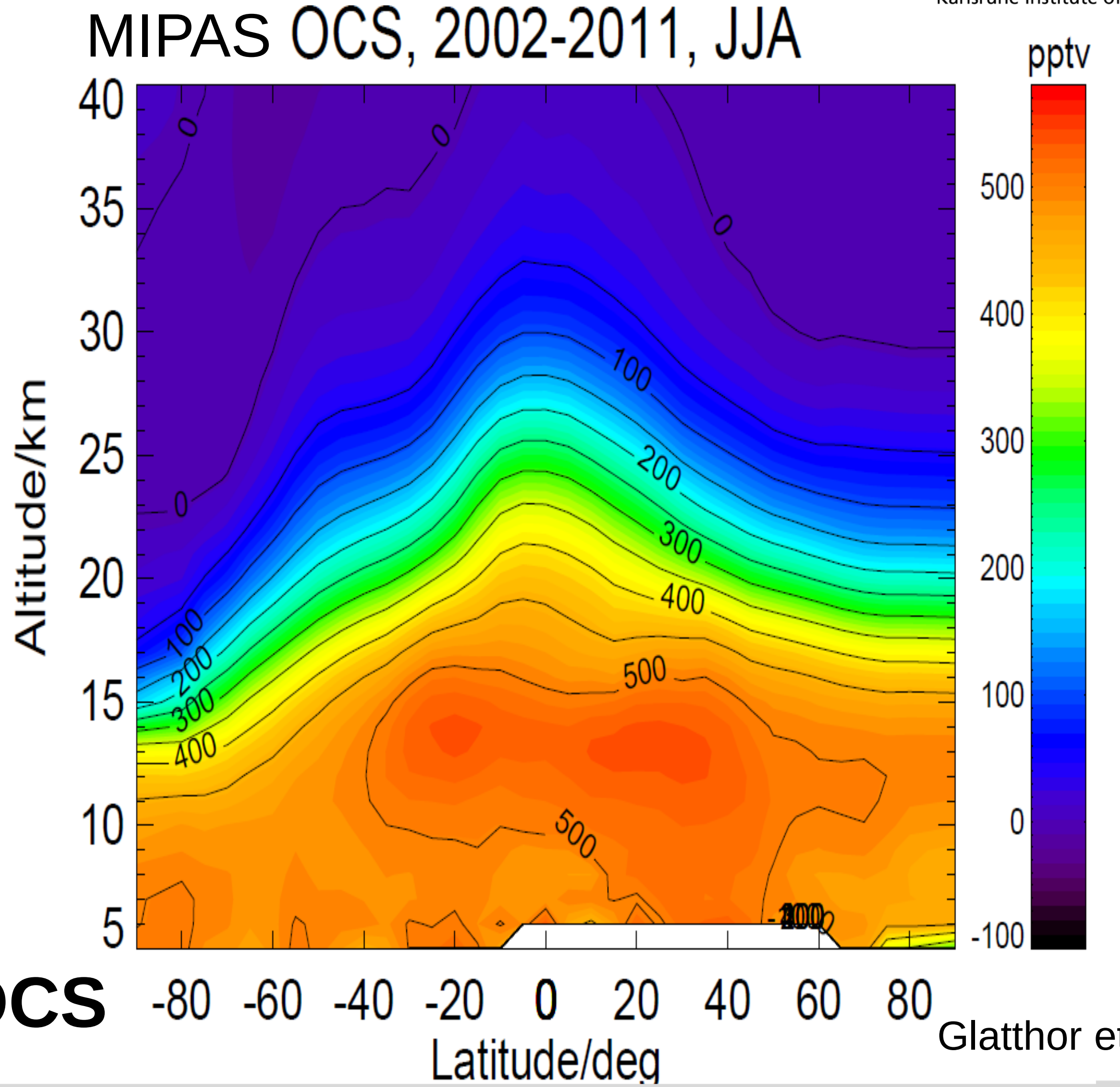


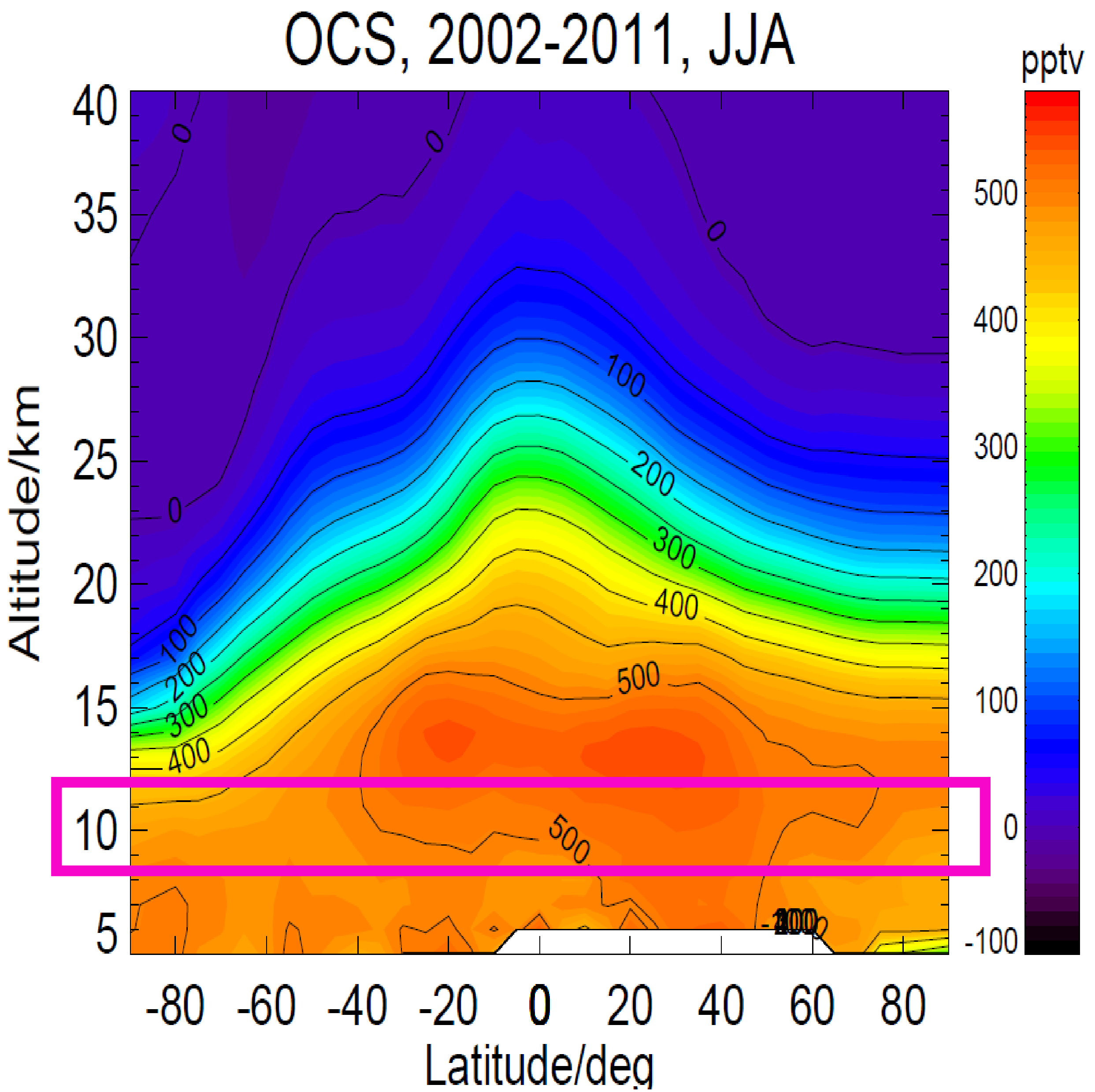
SO_2

Höpfner et al., 2013



OCS

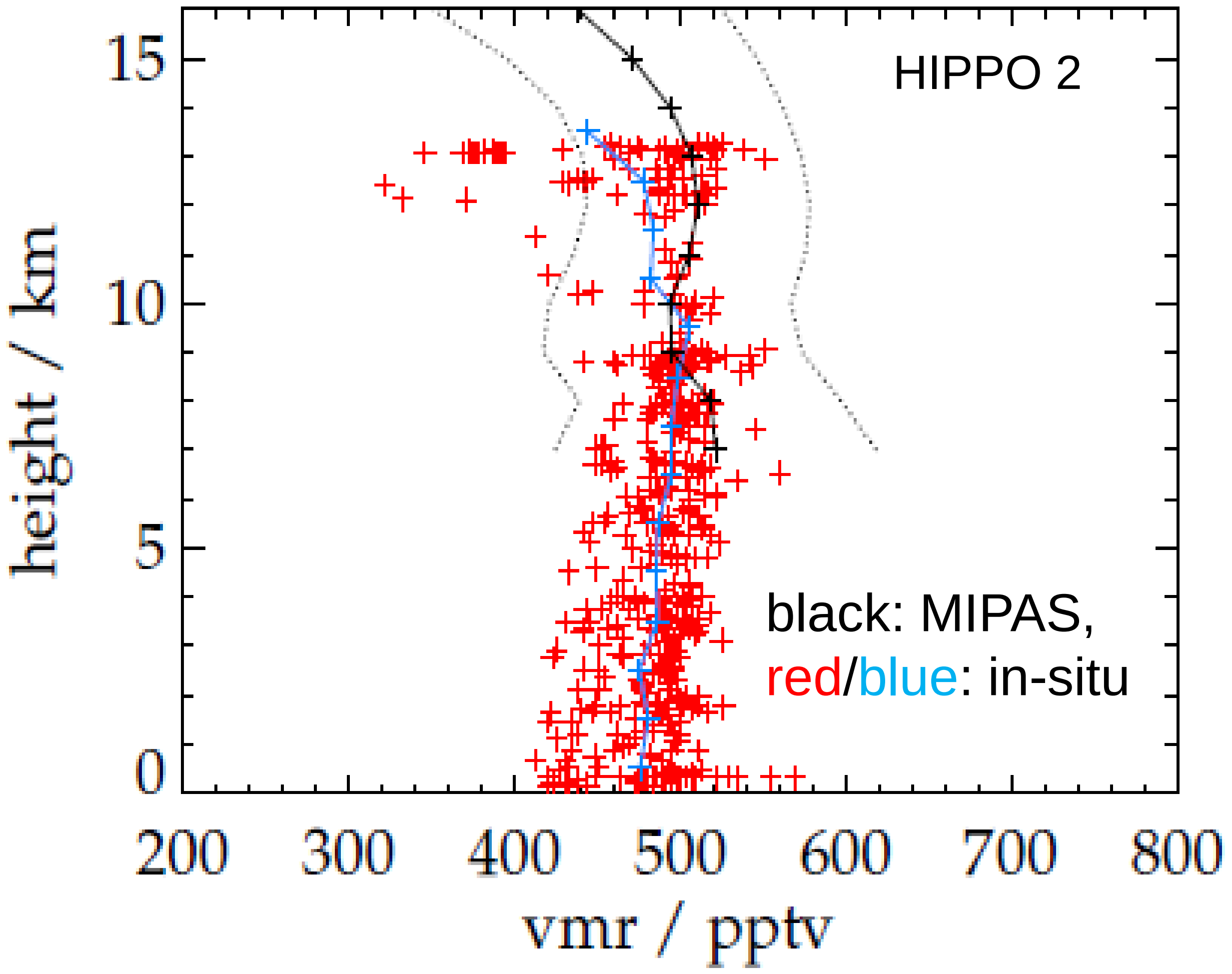
Glatthor et al., 2017



Glatthor et al., 2017

Comparison MIPAS OCS vs. airborne in-situ

MIPAS vs. in-situ aircraft



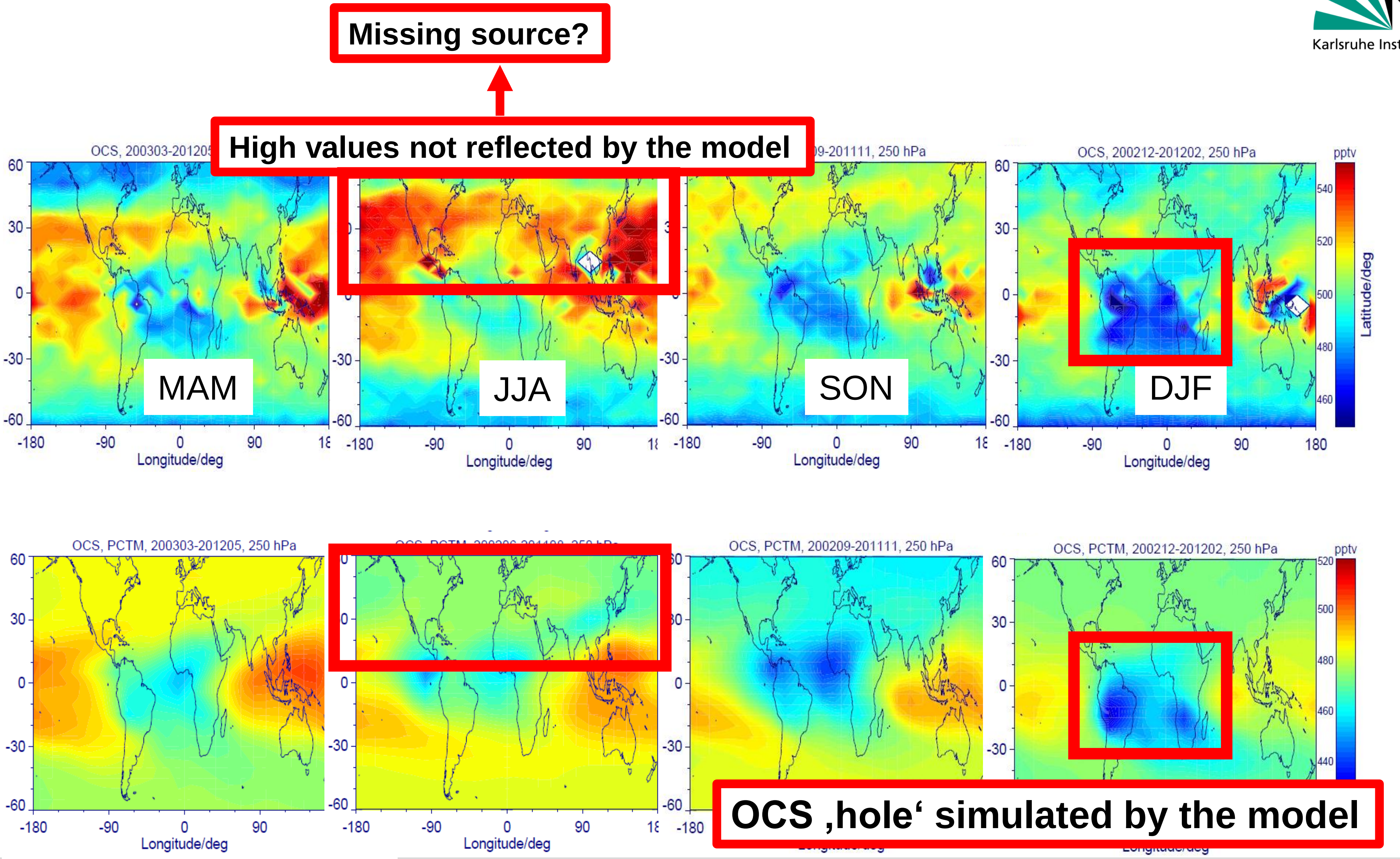
Glatthor et al., 2015 (suppl. mat.)

OCS in the upper troposphere

MIPAS

250 hPa

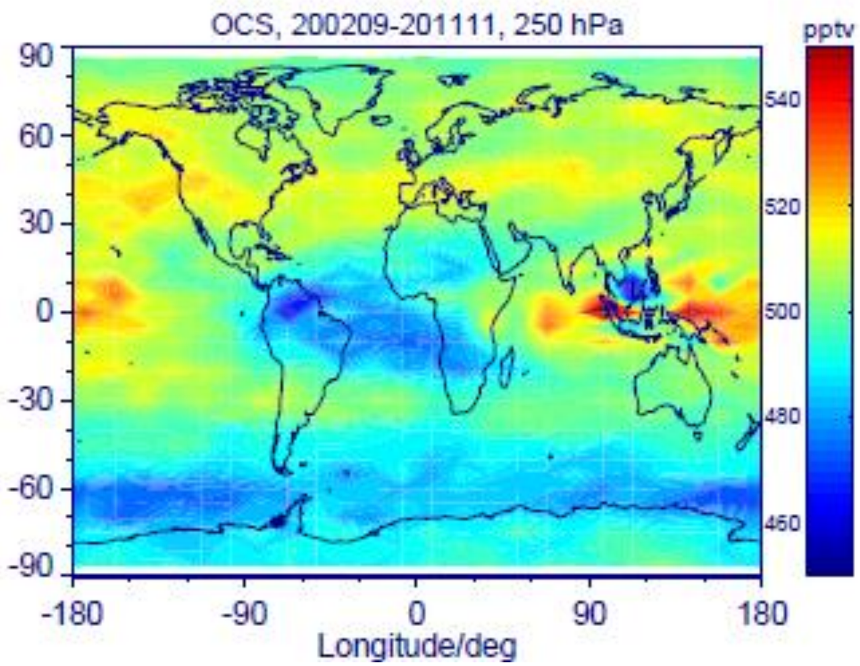
Model

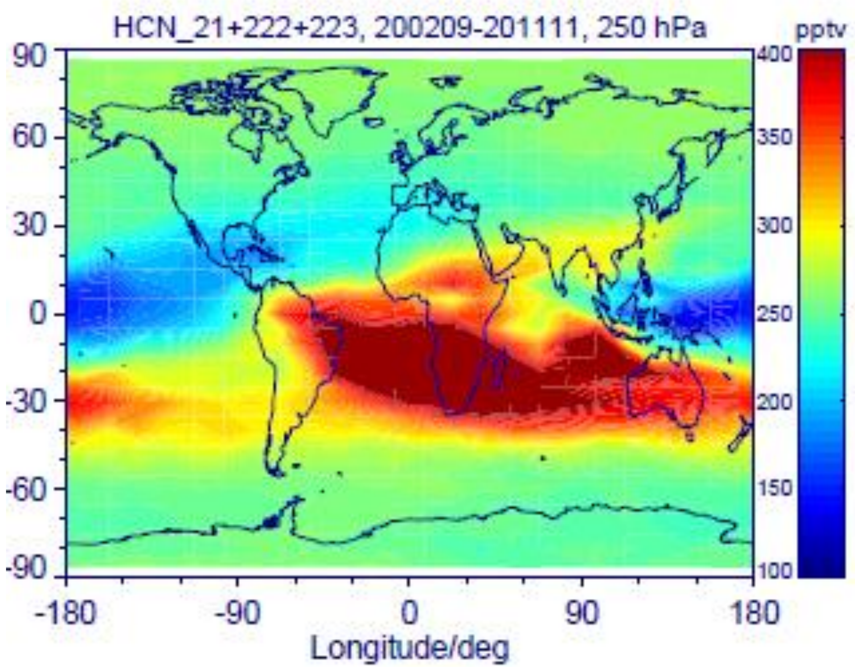


Glatthor et al., 2015

Biomass burning as a source of OCS?

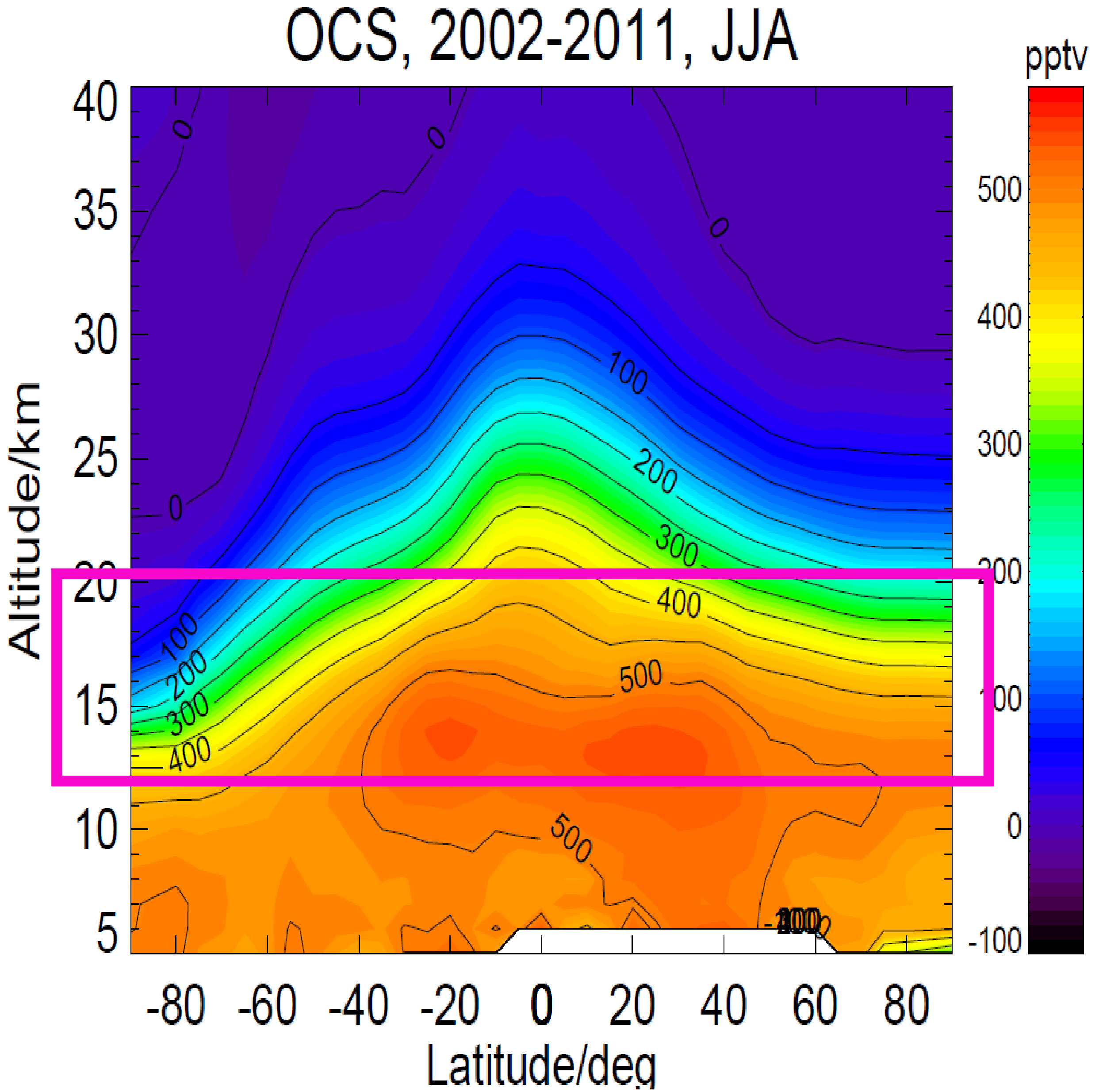
Biomass burning tracer HCN





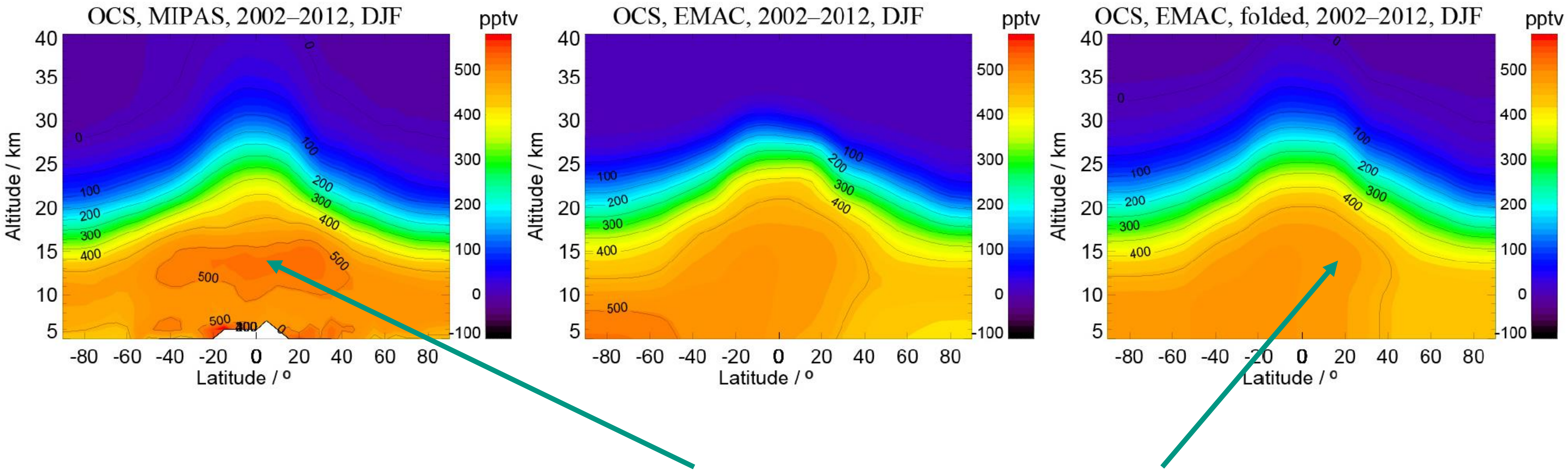
→ no obvious enhancement of OCS due to biomass burning

Glatthor et al., 2017



Glatthor et al., 2017

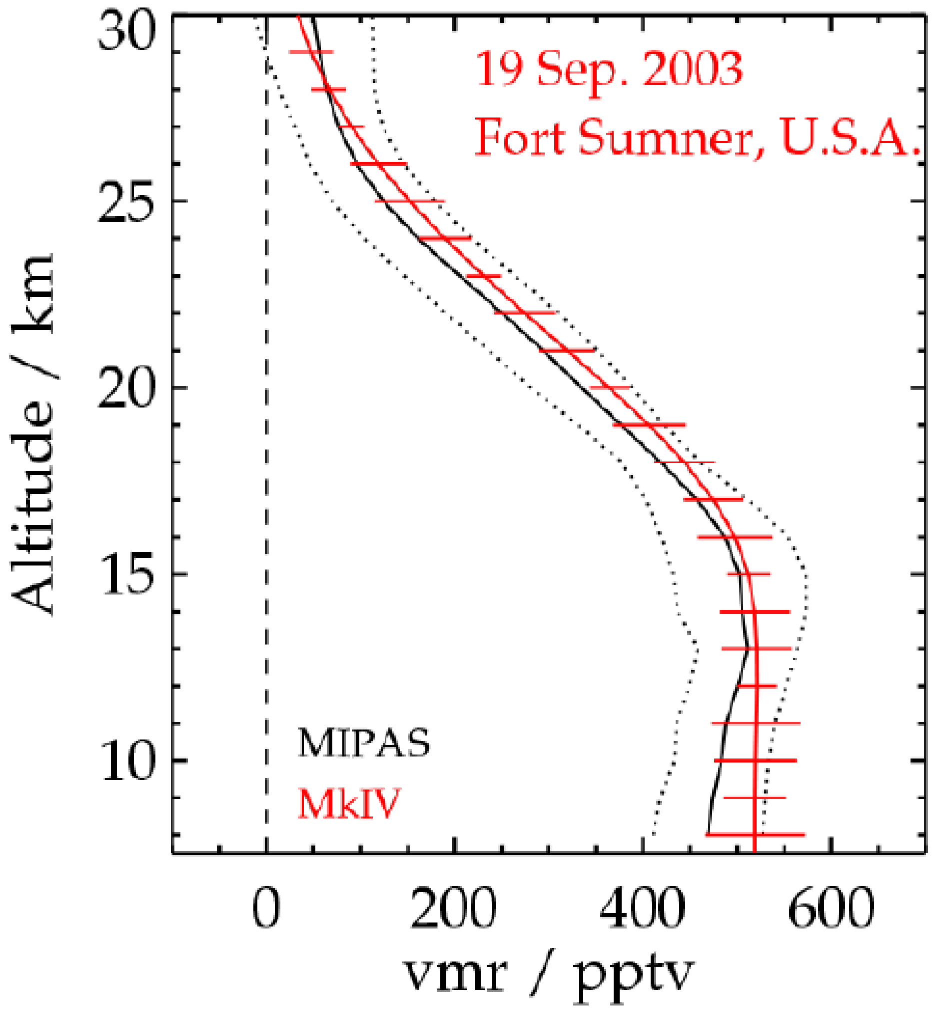
Upper tropospheric enhancement?



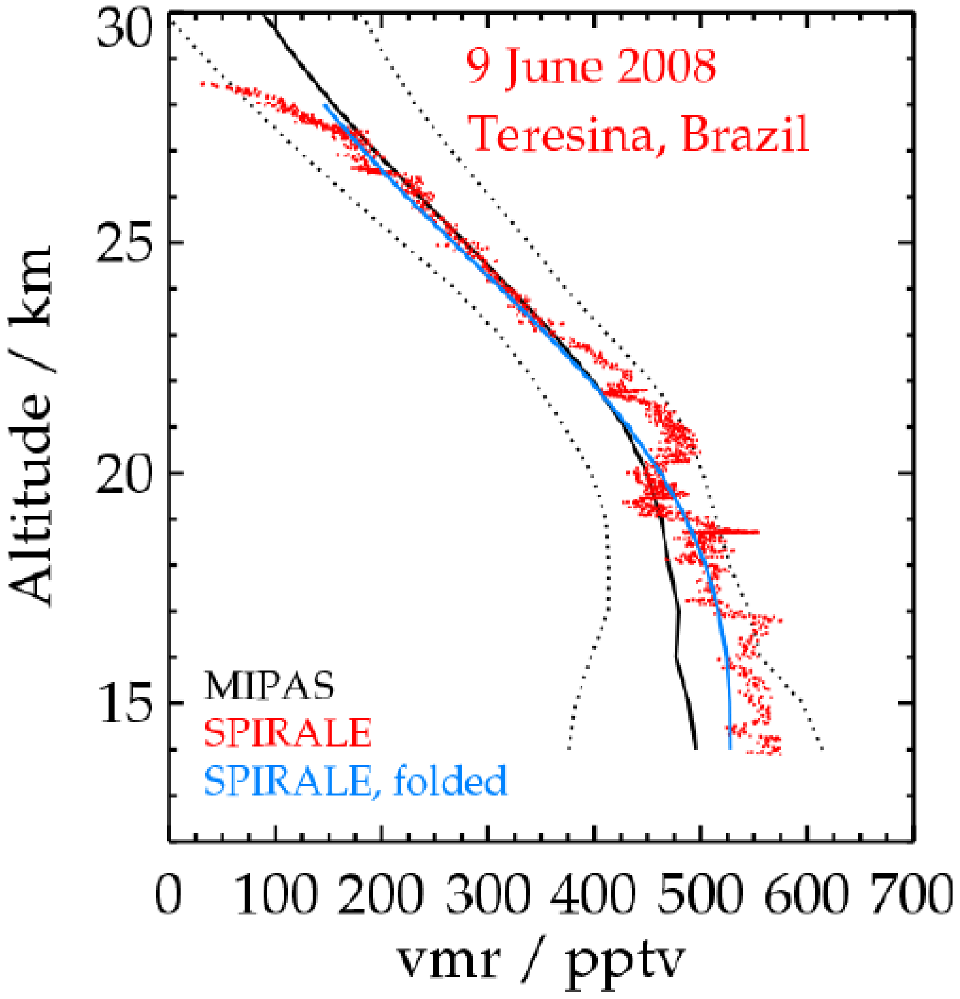
- The UT enhancement is visible in MIPAS but not (or much less) in model calculations

Comparison MIPAS OCS vs. balloon

MIPAS vs. MkIV balloon

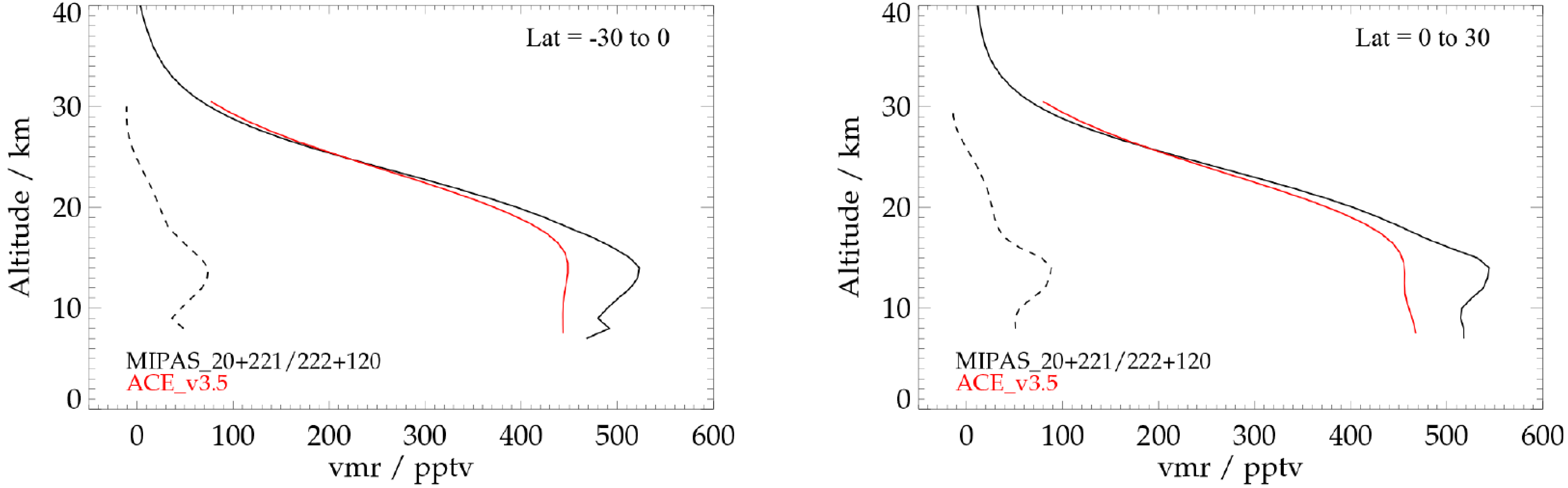


MIPAS vs. SPIRALE



Glatthor et al., 2015 (suppl. mat.)

Co-incident comparison: MIPAS vs. ACE-FTS



- Up to 20 km MIPAS values are ~50-70 pptv higher than ACE-FTS
- UT-"nose" not or only slightly visible in ACE-FTS

Global distributions: MIPAS vs. ACE-FTS

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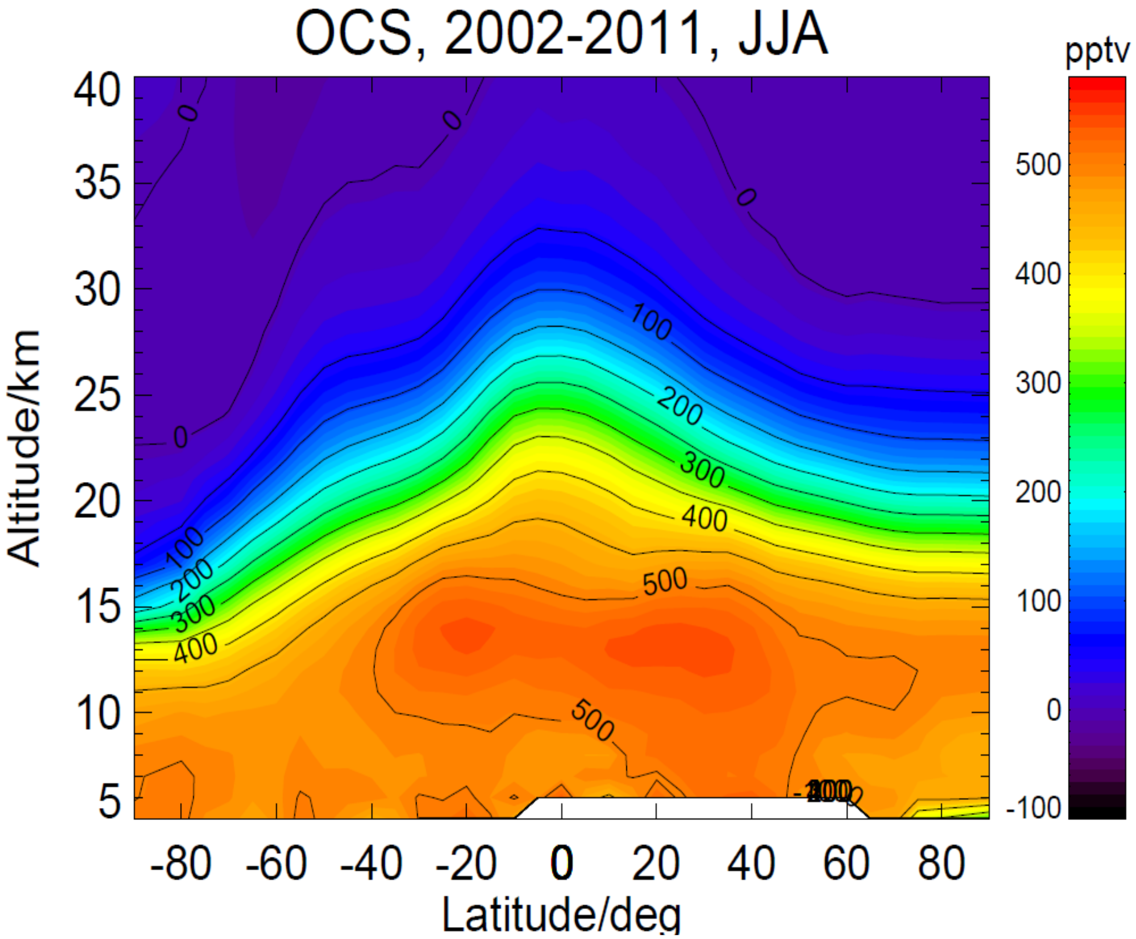
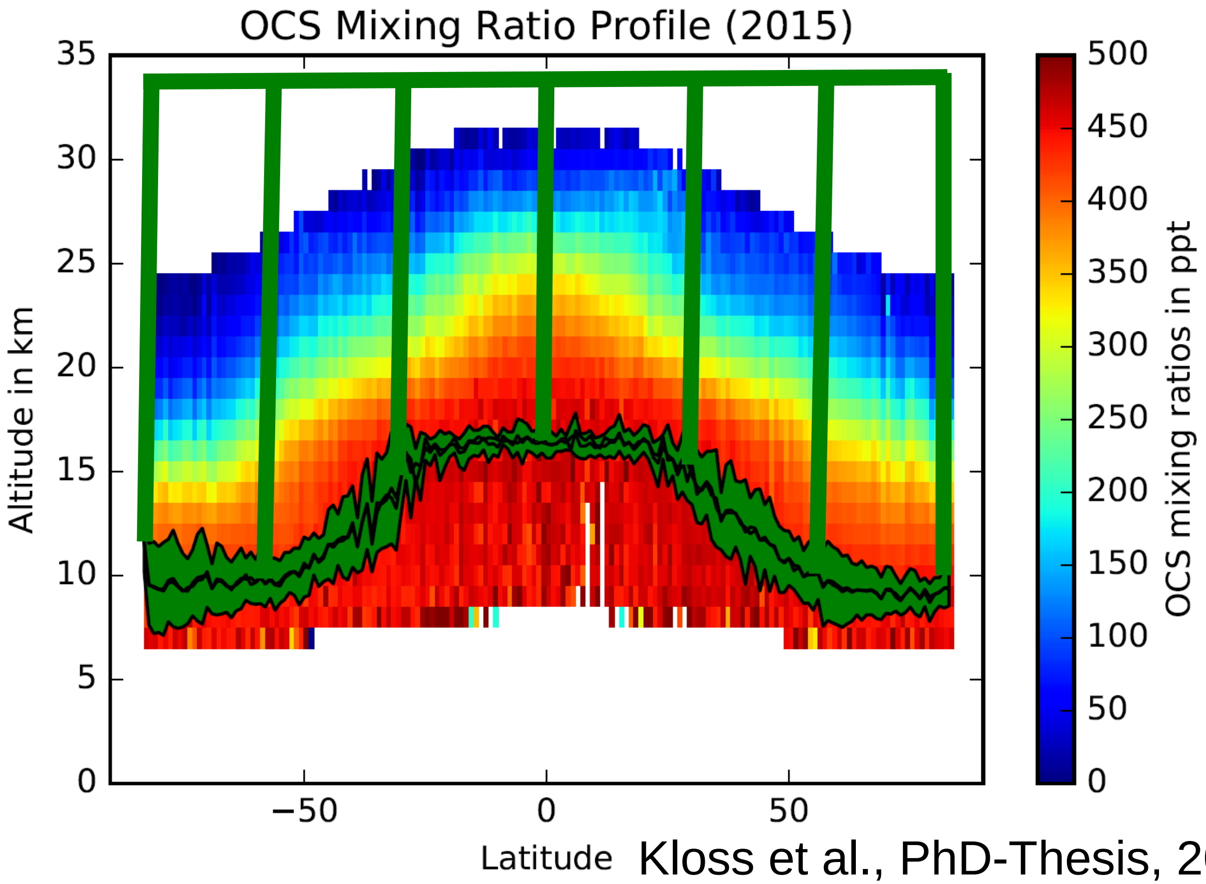


Glatthor et al., 2017



Kloss et al., PhD-Thesis, 2018

Stratospheric sulfur column in OCS

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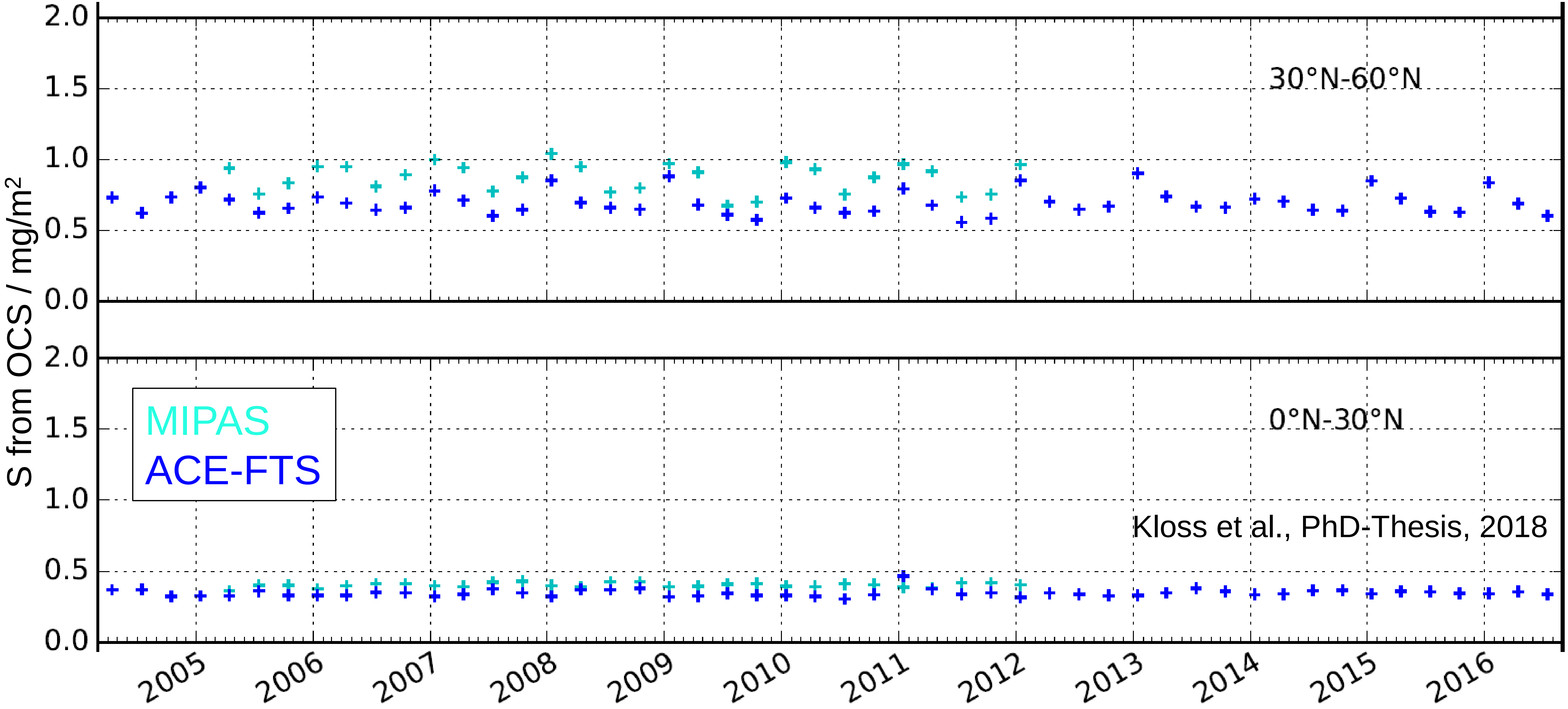
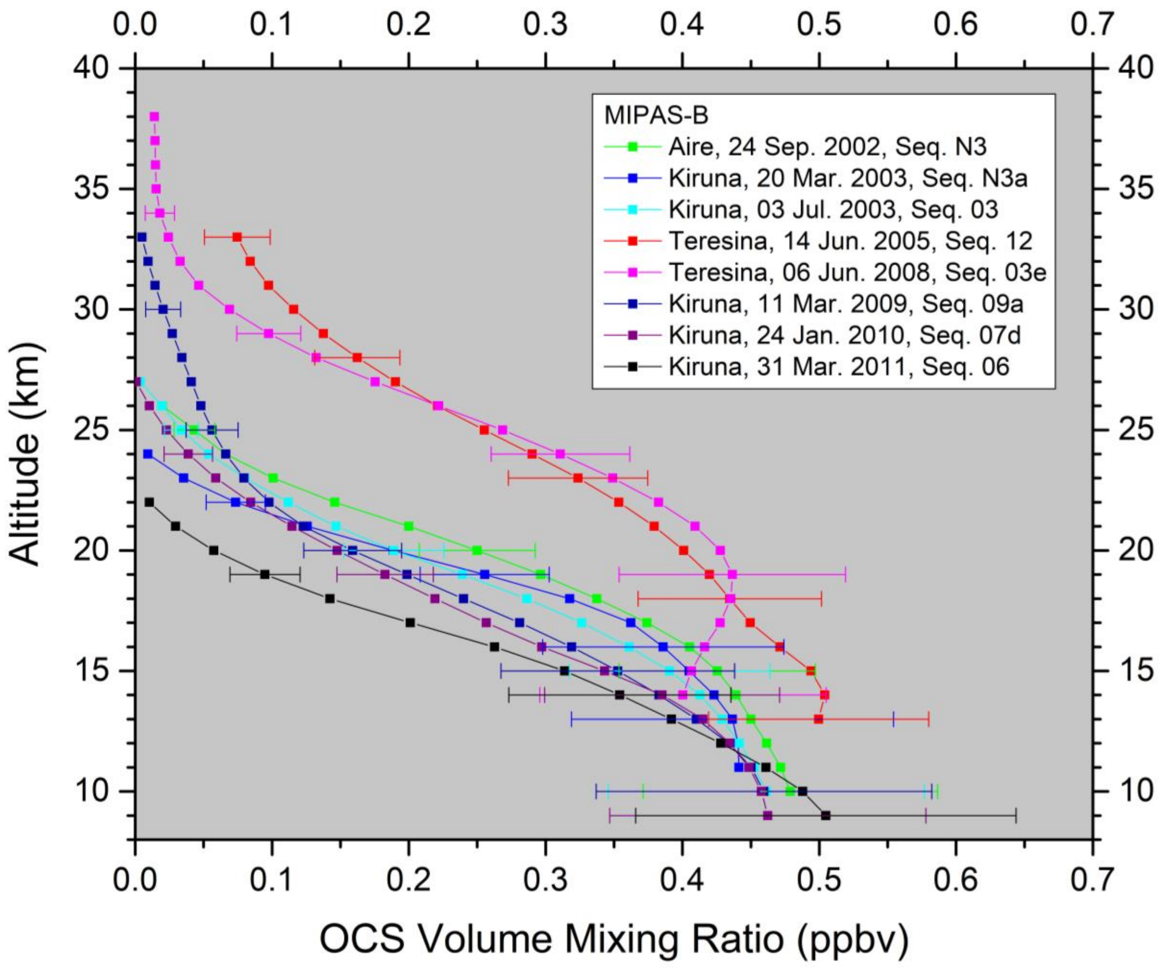
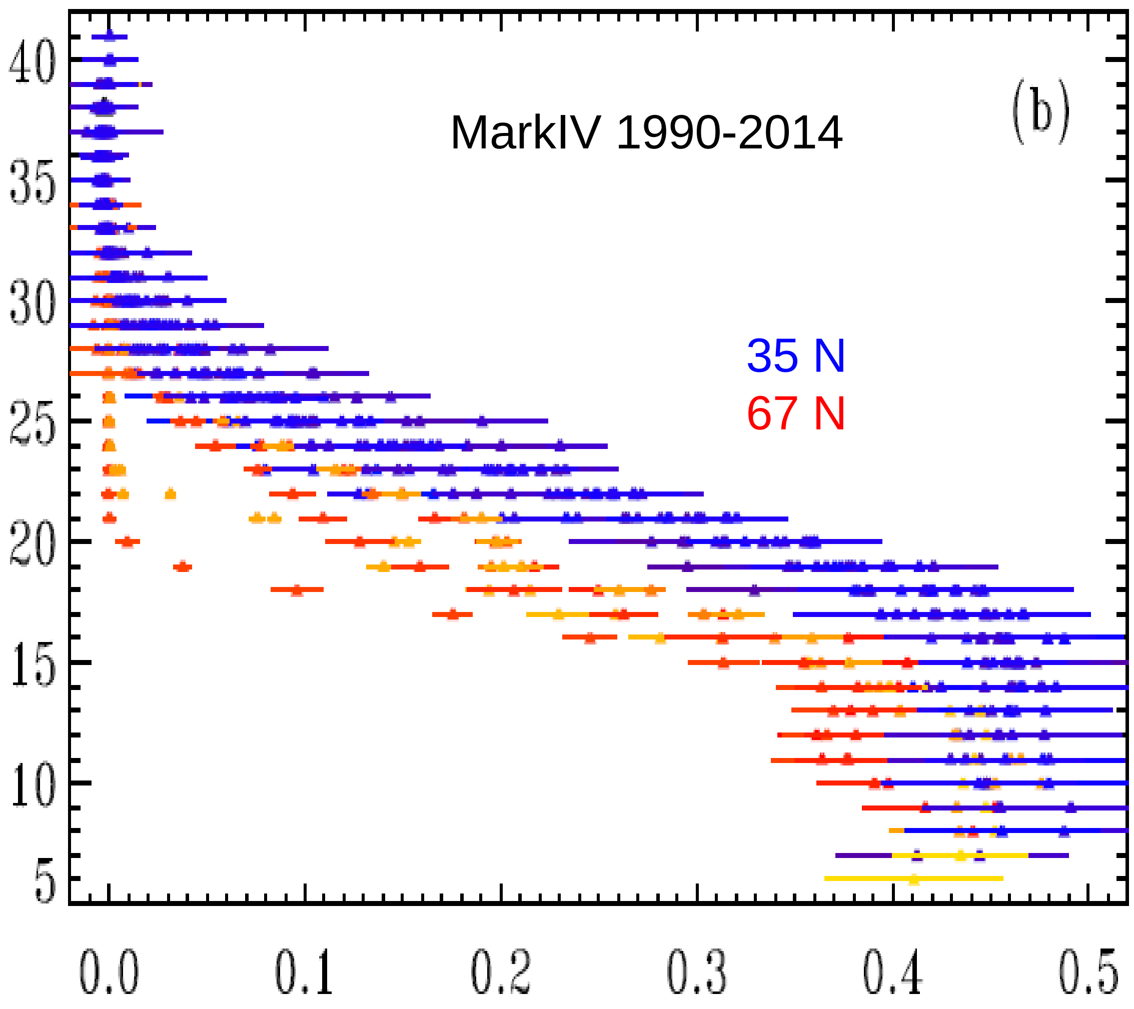


New datasets of OCS



Courtesy: G. Wetzel



Toon et al., 2018

Trends in OCS

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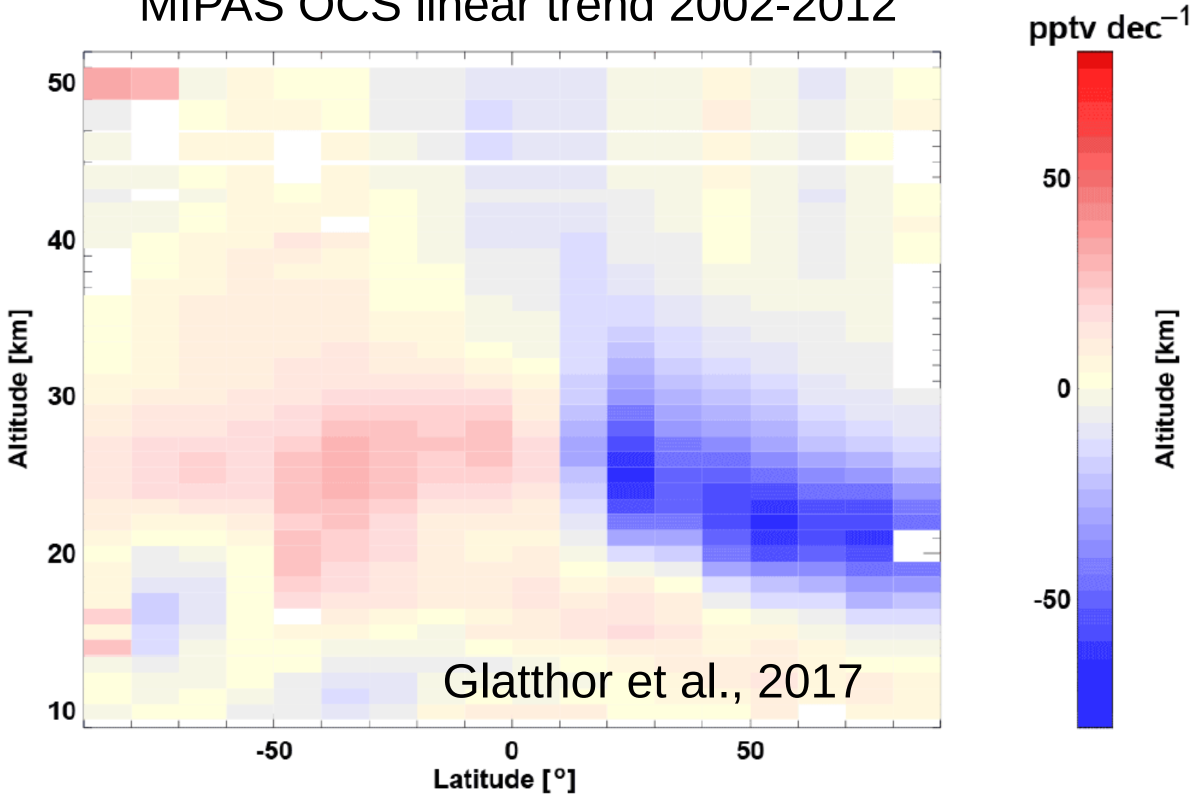
MIPAS OCS linear trend 2002-2012



Toon et al., 2018:

- “Balloon results yield no significant stratospheric trend.”
- “Tropospheric OCS, …, shows a 5% decrease during 1990–2002, followed by a 5% increase from 2003 to 2012. There was no discernible change since 2012.”

- Follows the trend in Age-of-air (from MIPAS SF_6)

The tropical upper troposphere SO_2 “background”

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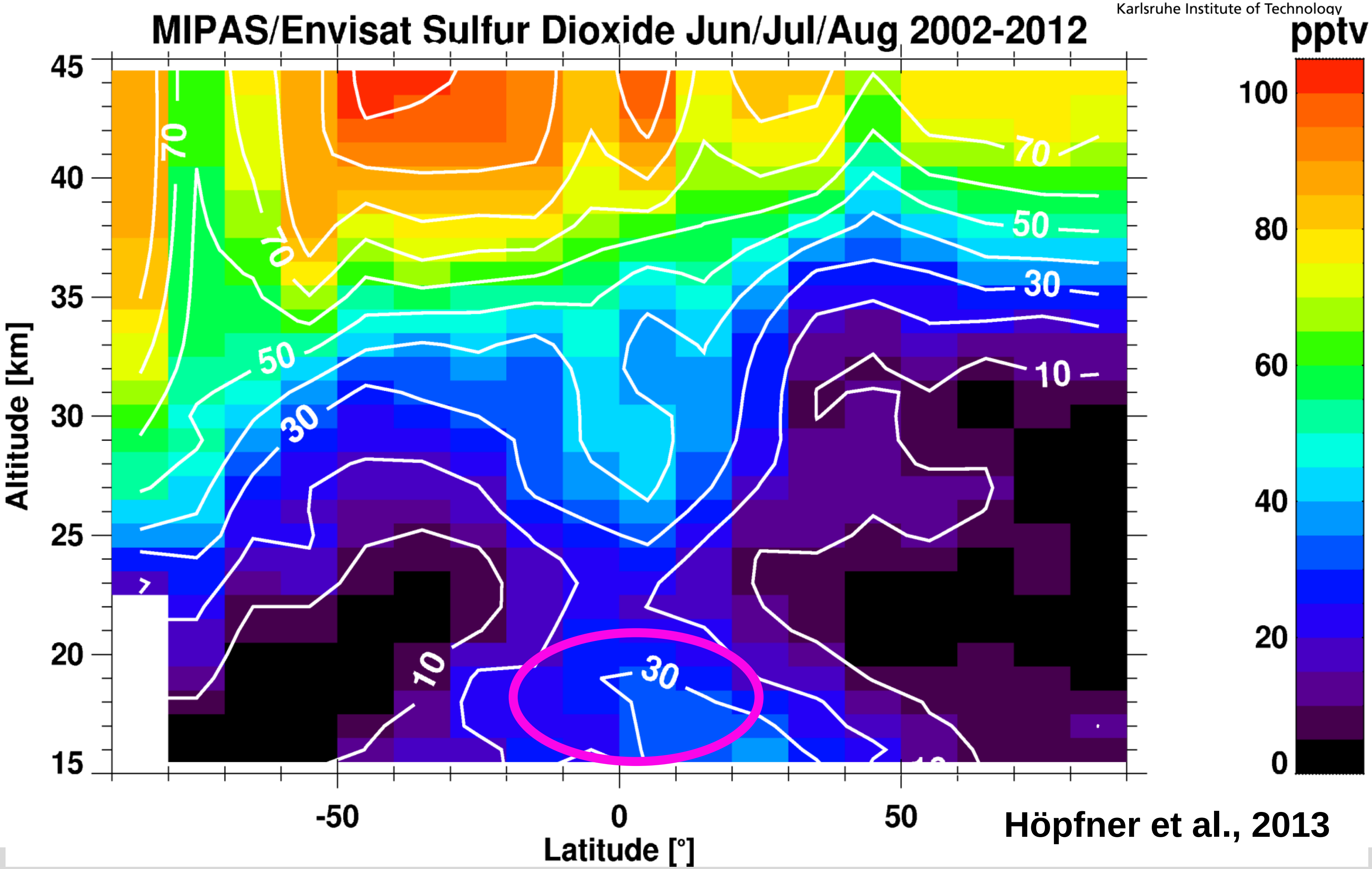
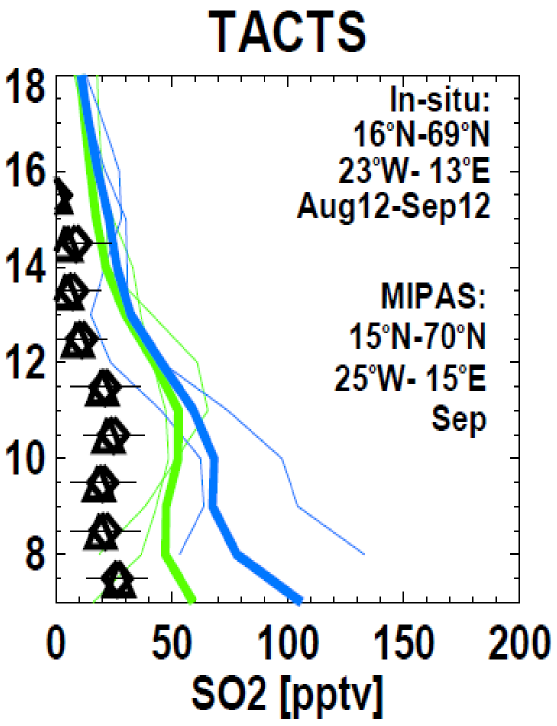
- Determines the input of SO_2 into the stratosphere



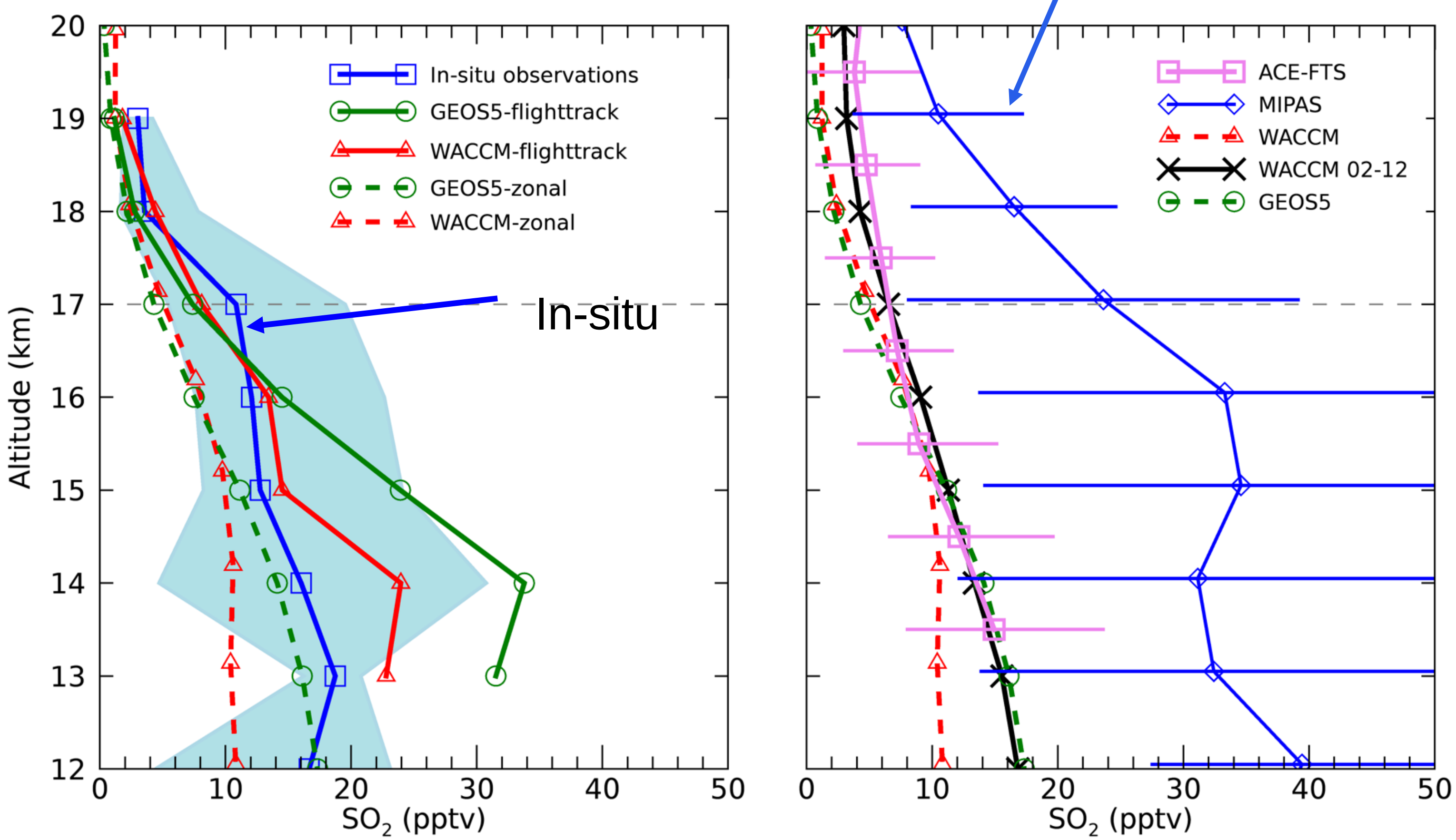
Höpfner et al., 2013

How much SO_2 is typically at the tropical tropopause?



Höpfner et al., 2015

MIPAS $\pm 1\sigma$ Estimated uncertainty of single scan dataset

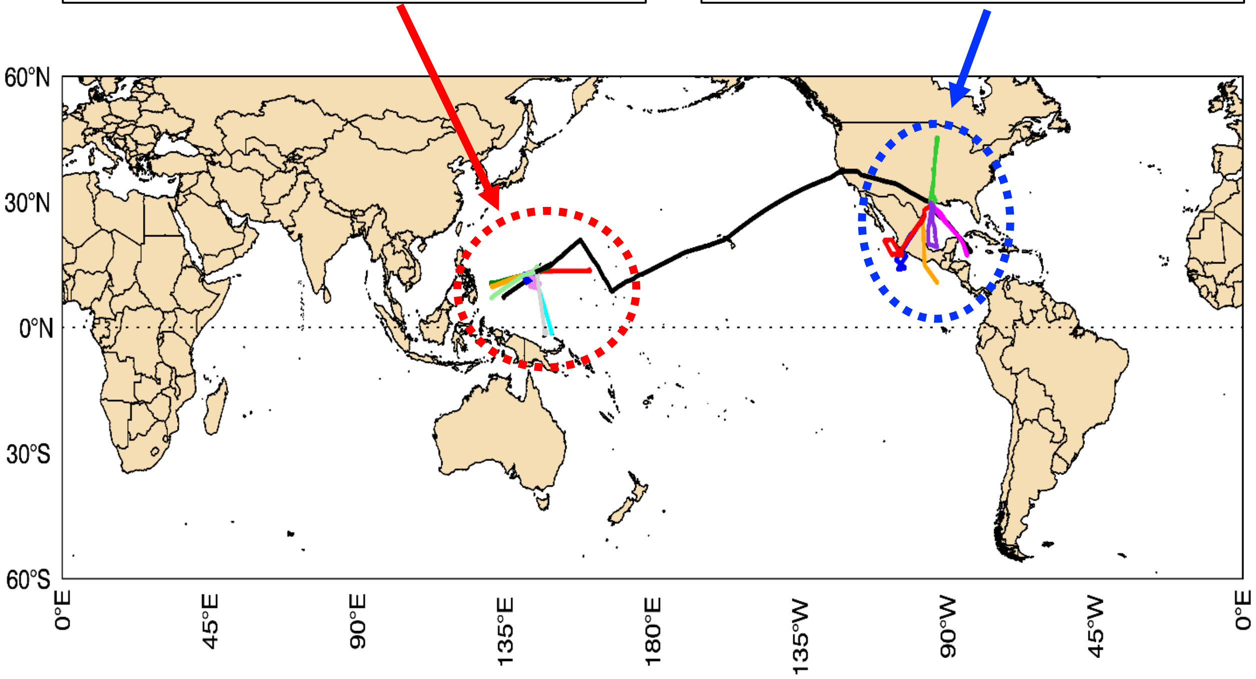


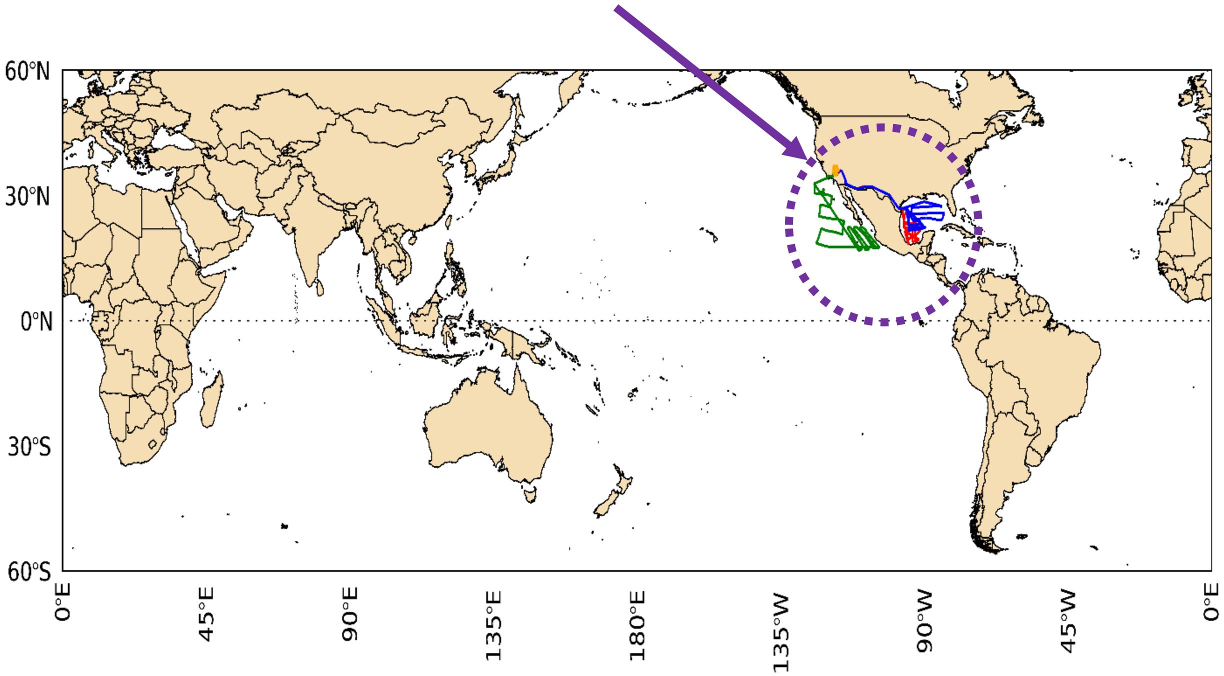
Updated from Rollins et al., 2017

POSIDON, October 2016

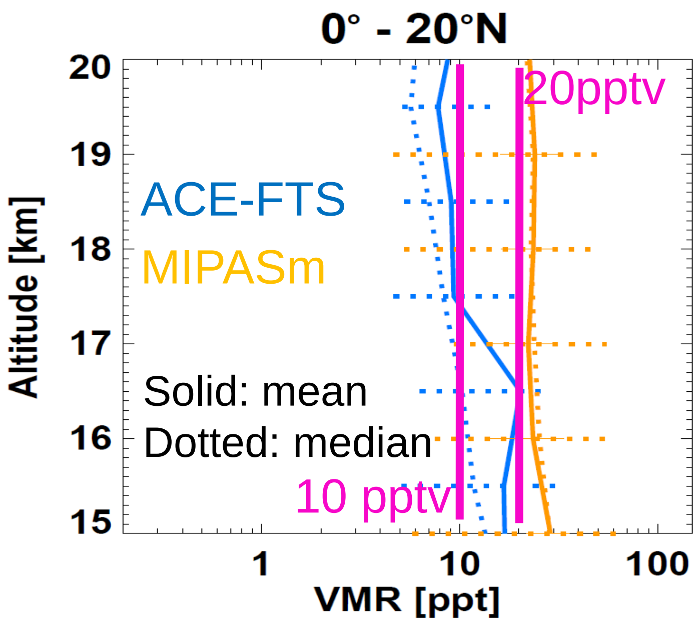
VIRGAS, October 2015

EPOCH, August 2017



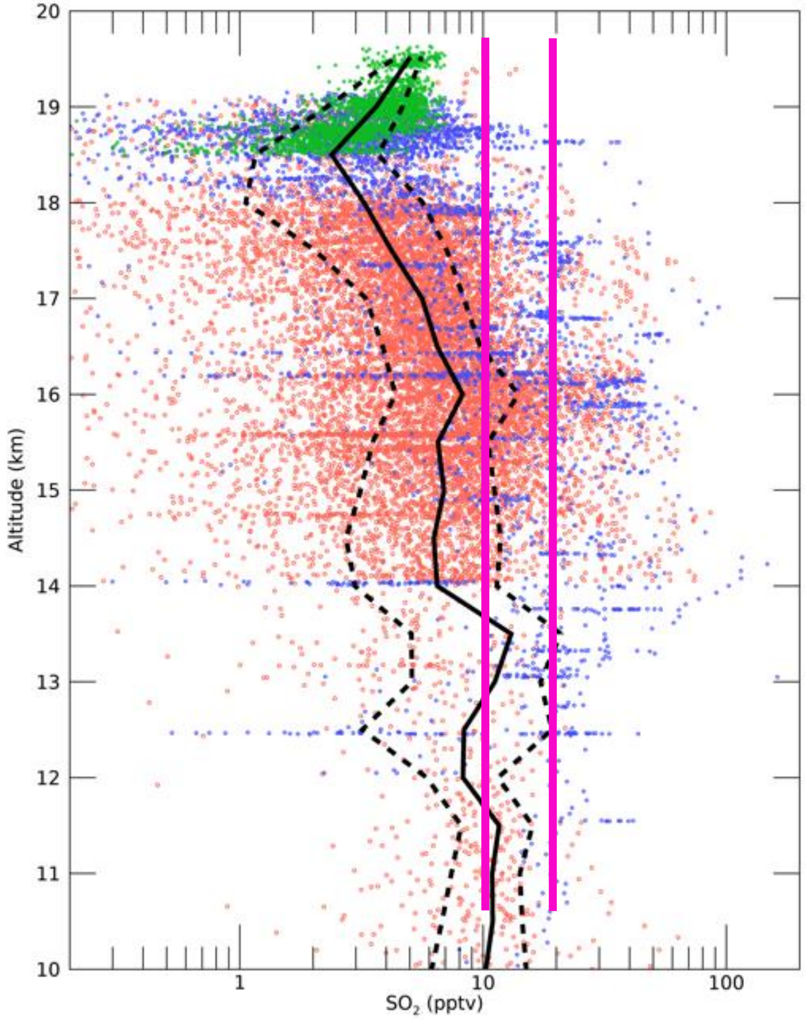


Courtesy: **A. Rollins**, T. Thornberry, R.-S. Gao



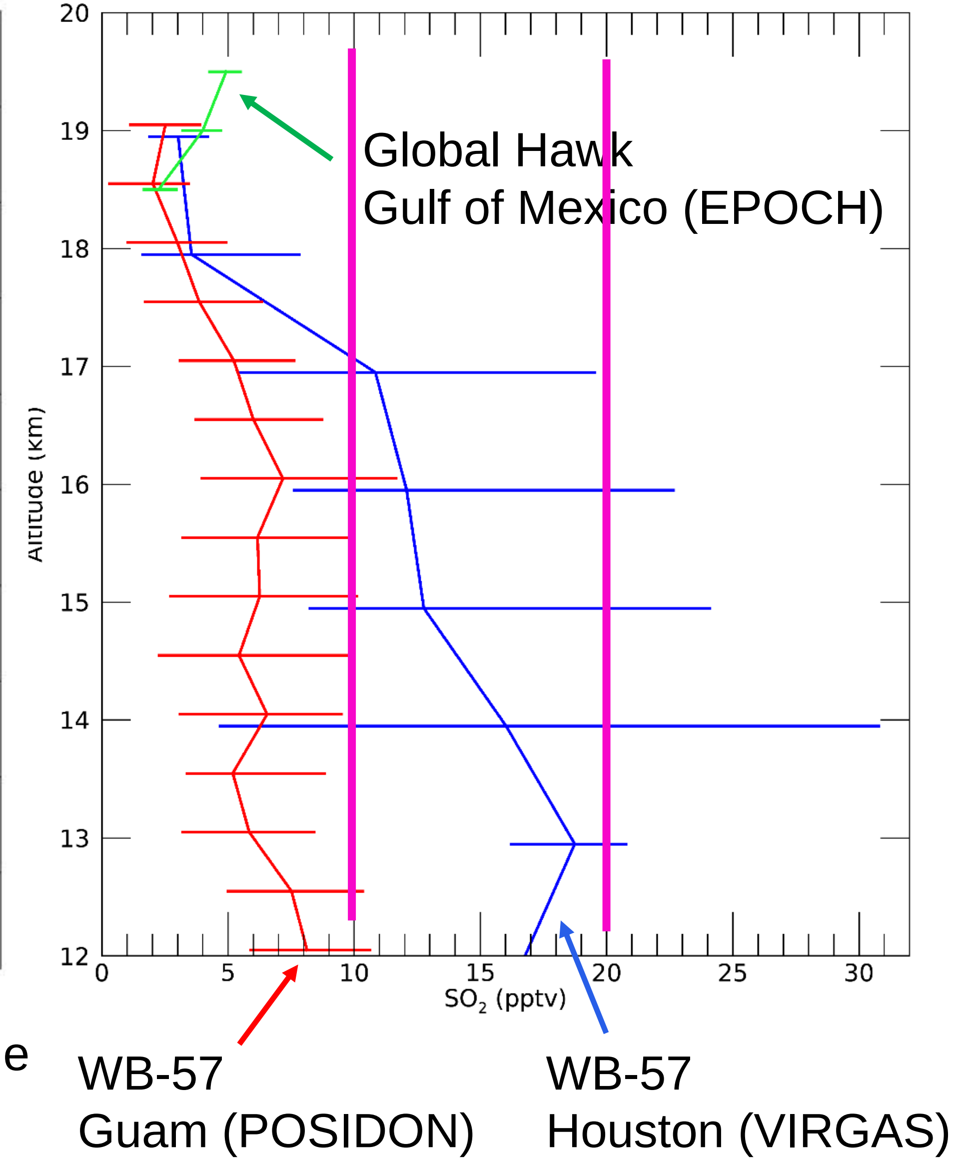
Both MIPAS datasets seem to have a positive bias (10-15 ppt) in the tropical UT (tbc)

WB-57: 2 S - 20 N
Global Hawk: 20 - 25 N



Lines show median and interquartile range

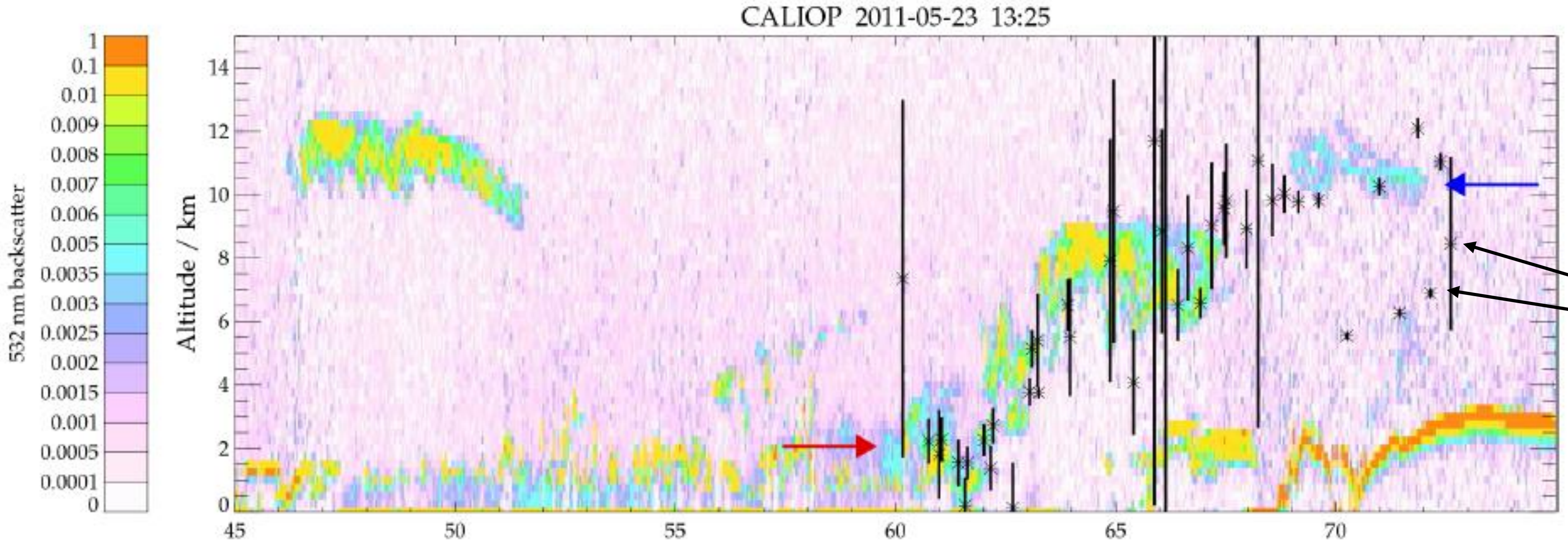
Statistics by mission, latitude < 25 N



Courtesy: **A. Rollins**, T. Thornberry, R.-S. Gao

M. Höpfner, IMK-ASF

Altitude resolved SO_2 observations by nadir sounders



IASI retrieved SO_2 altitude with error bar

Carboni et al., 2016

- “Despite the ability of IASI to retrieve the plume altitude, it could be difficult to distinguish, with only IASI data, if the eruption injects into the stratosphere or into the high troposphere.”

Lifetime of SO_2 in the UTLS

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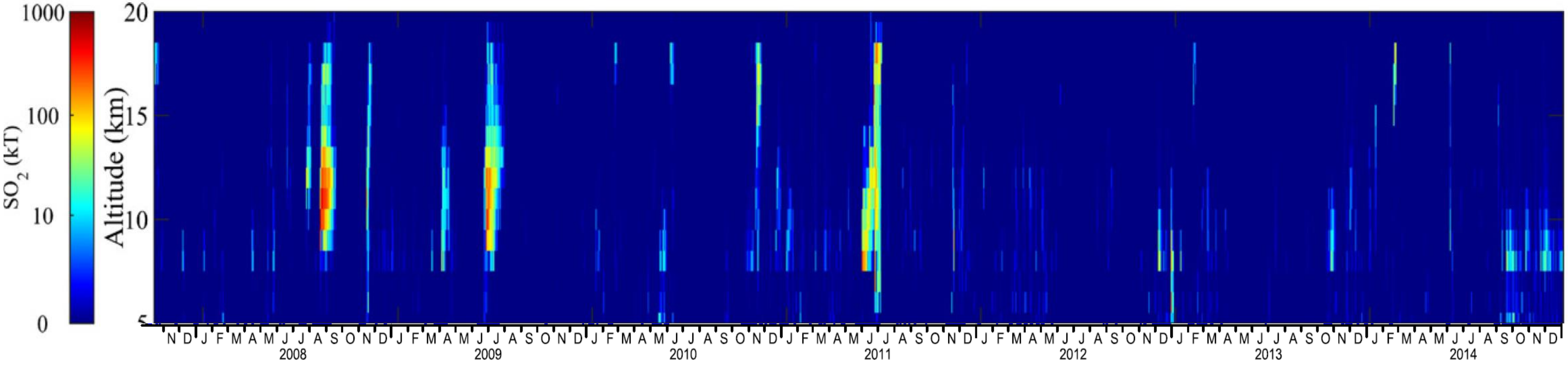
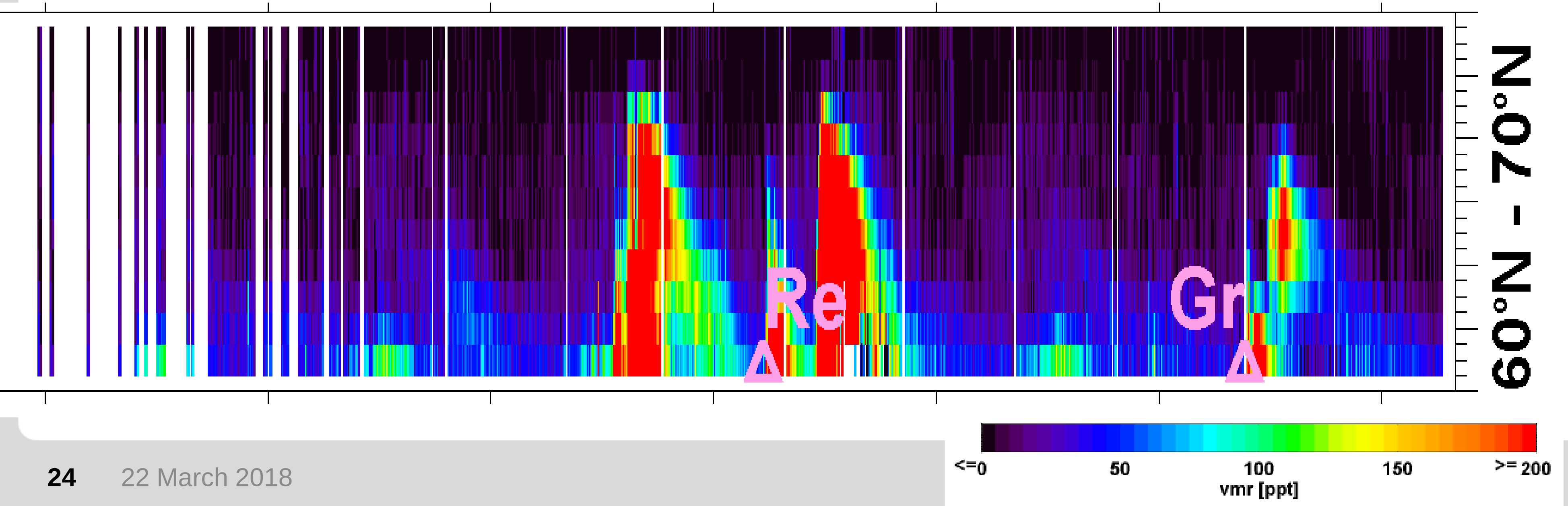
IASI
total mass

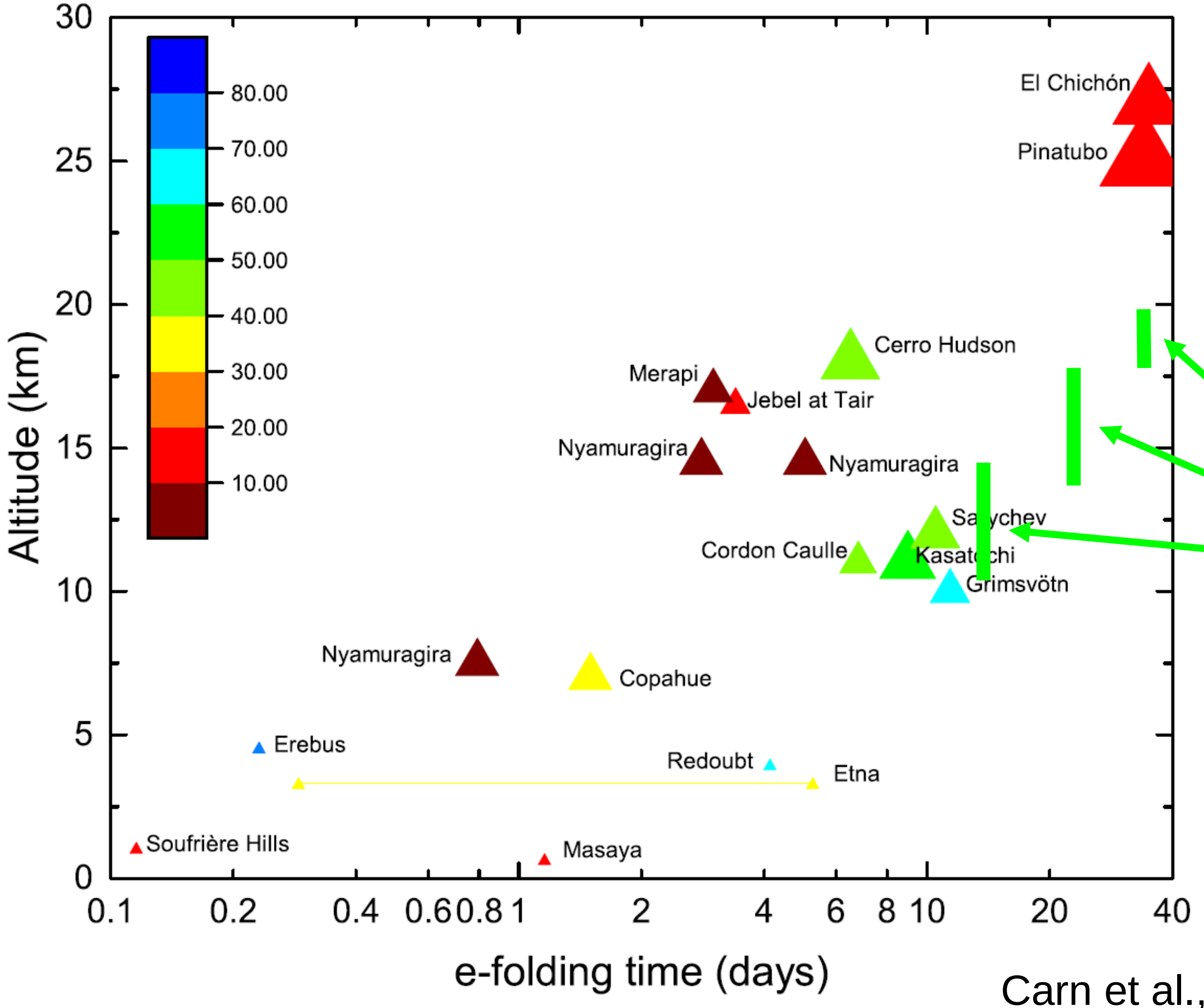
Clarisse et al., 2012, 2014
Carn et al., 2016





MIPAS SO_2 vmr

Lifetime of SO_2 in the UTLS



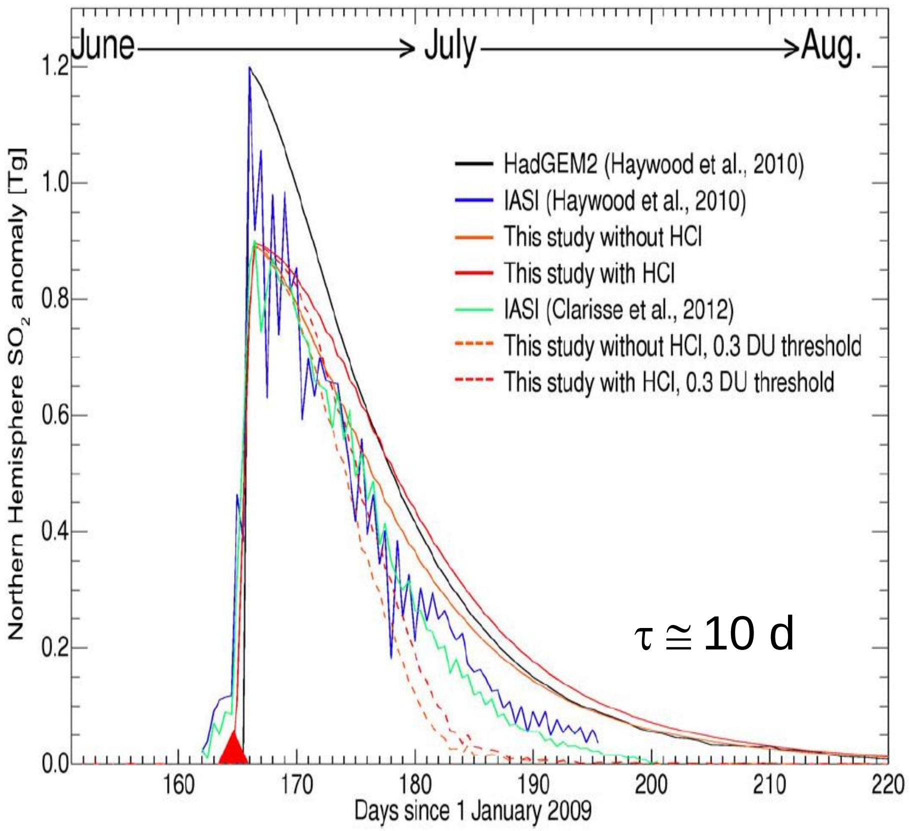
Carn et al., 2016

Sarychev SO_2 e-folding times from limb-sounders

Lifetime of SO_2 in the UTLS

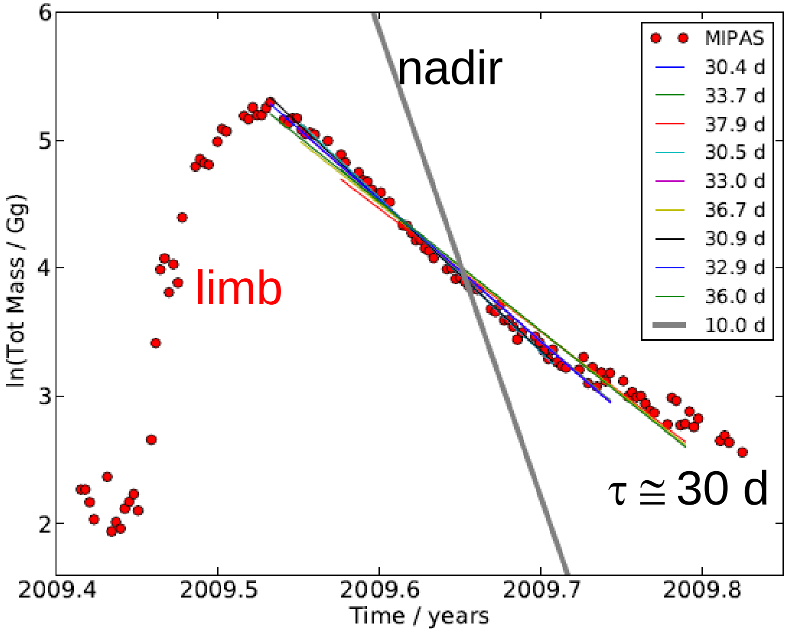
Sarychev

Nadir-Sounder IASI



Lurton et al., 2018

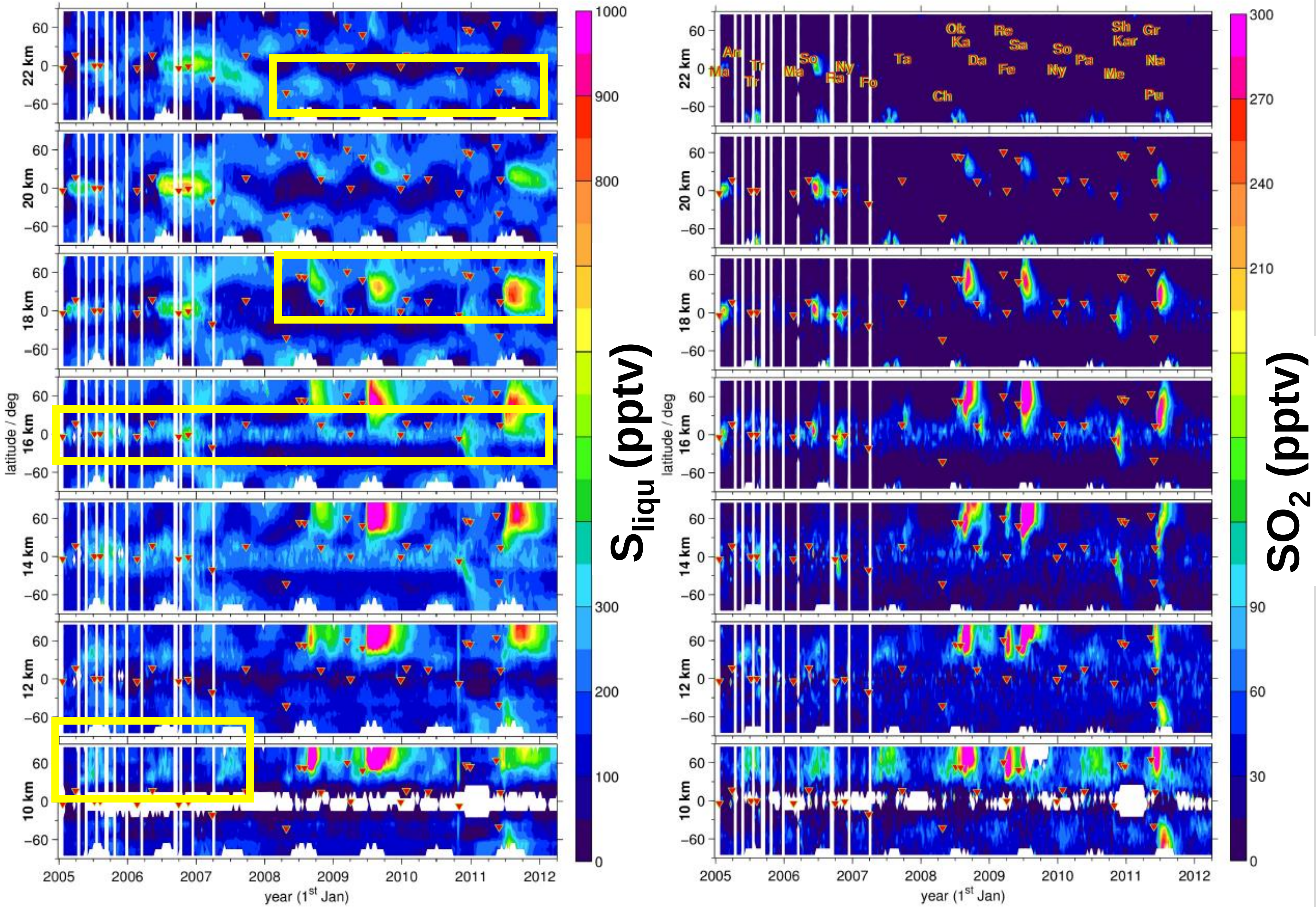
Limb-Sounder MIPAS (and MLS)



Nadir sounding instruments seem to underestimate the lifetime of volcanic SO_2 plumes in the UTLS:

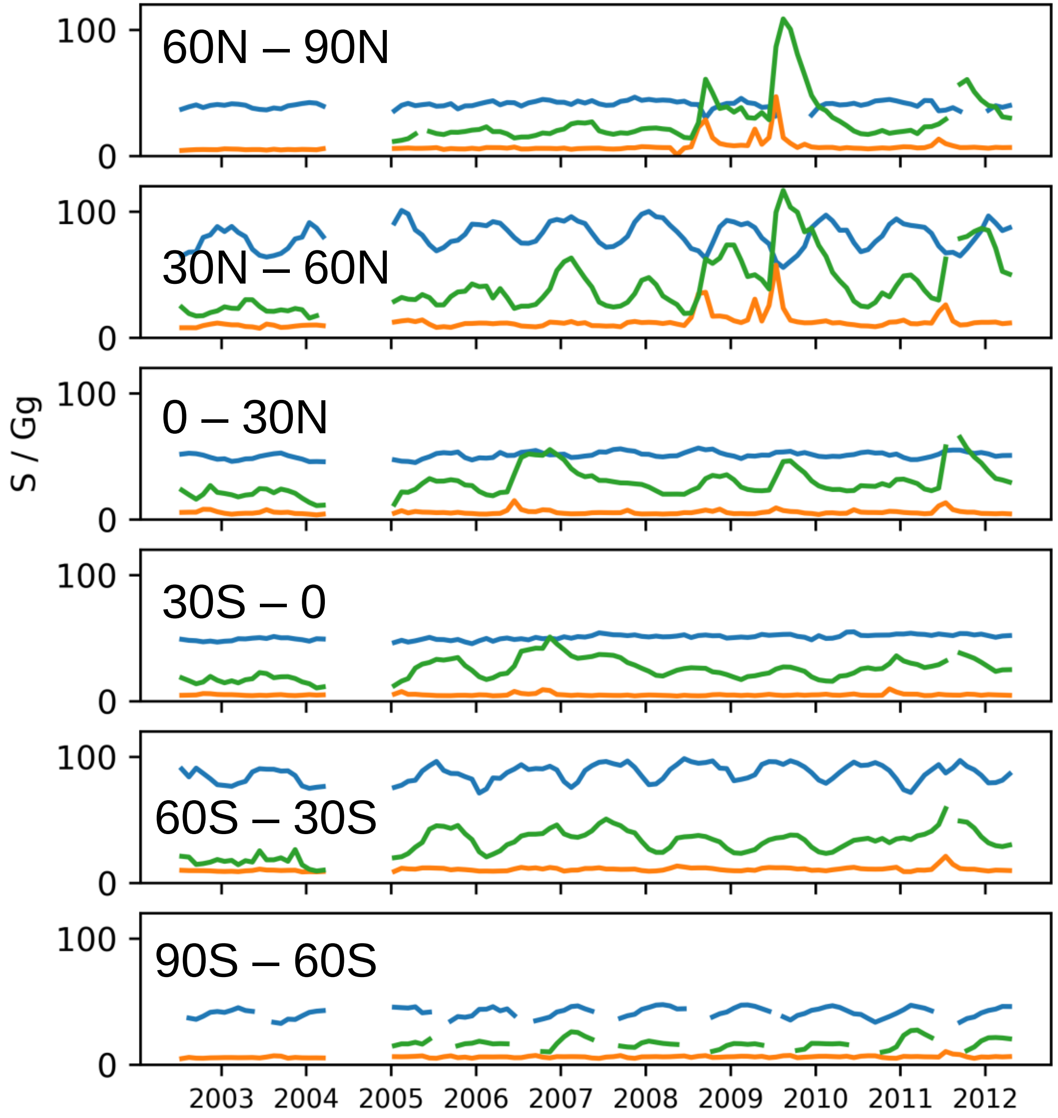
- Detection-limit of nadir sounders (global dilution of SO_2, e.g. Haywood et al., 2010)
- Combination of lower SO_2-lifetime at lower altitudes and nadir averaging kernels

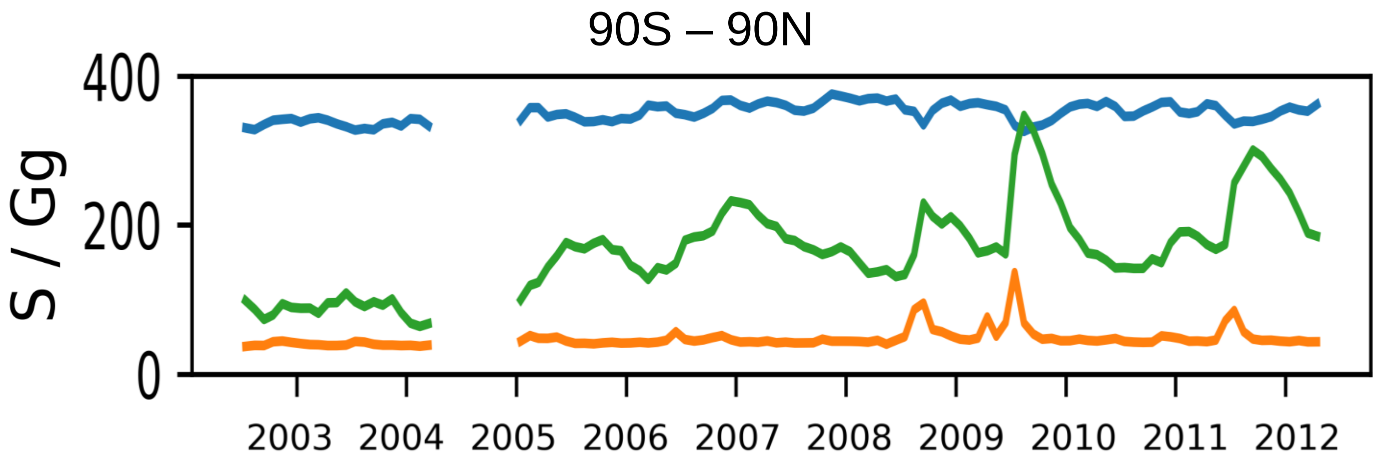
New MIPAS dataset on aerosol volume



Günther et al., ACP, 2018

MIPAS: total stratospheric sulfur burden (monthly means)





S_{OCS}

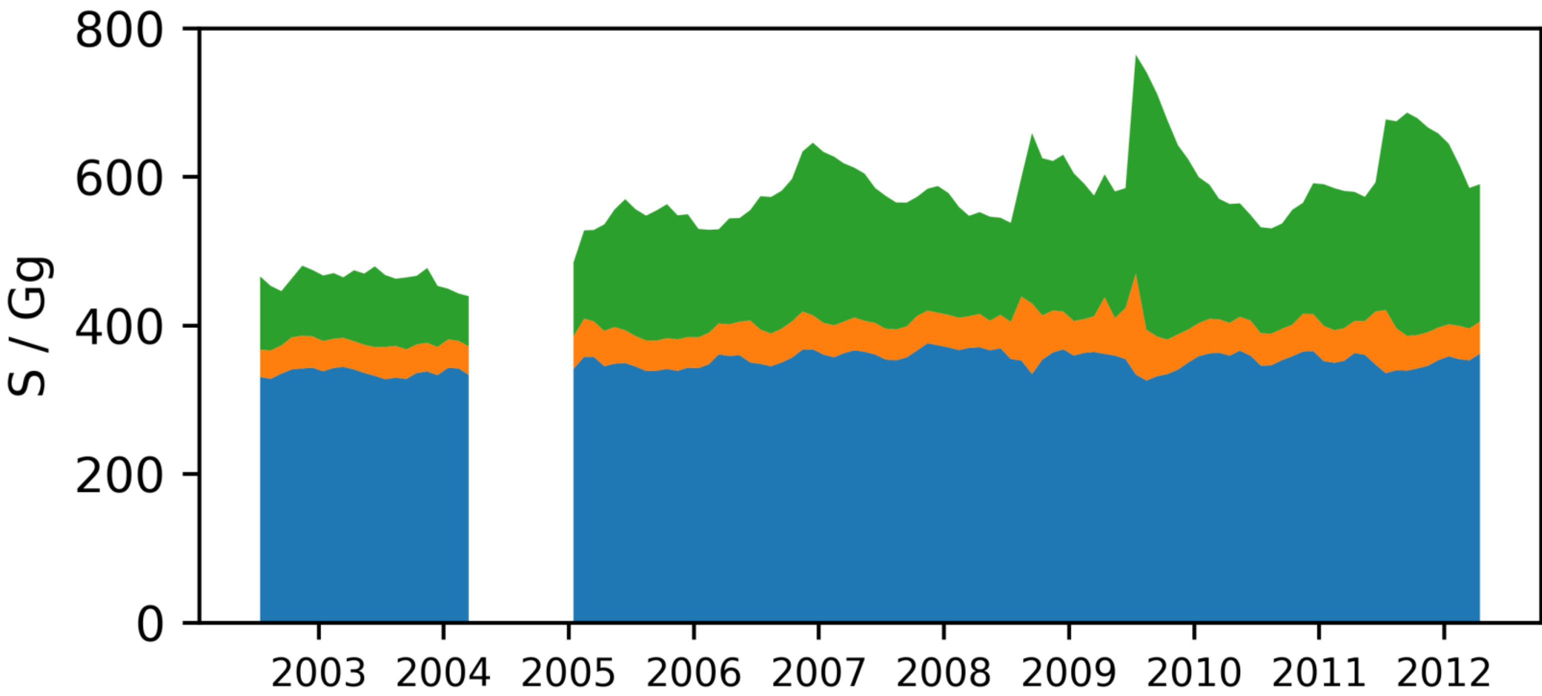
S_{SO_2}

S_{liqu}

Estimated errors:

- OCS ~10-15% (positive bias wrt ACE?)
- SO_2 ~20% (+large underestimation until 2-4 weeks after larger eruption)
- Aerosol ~20%

MIPAS: total cumulative stratospheric sulfur burden (monthly means)



Estimated errors:

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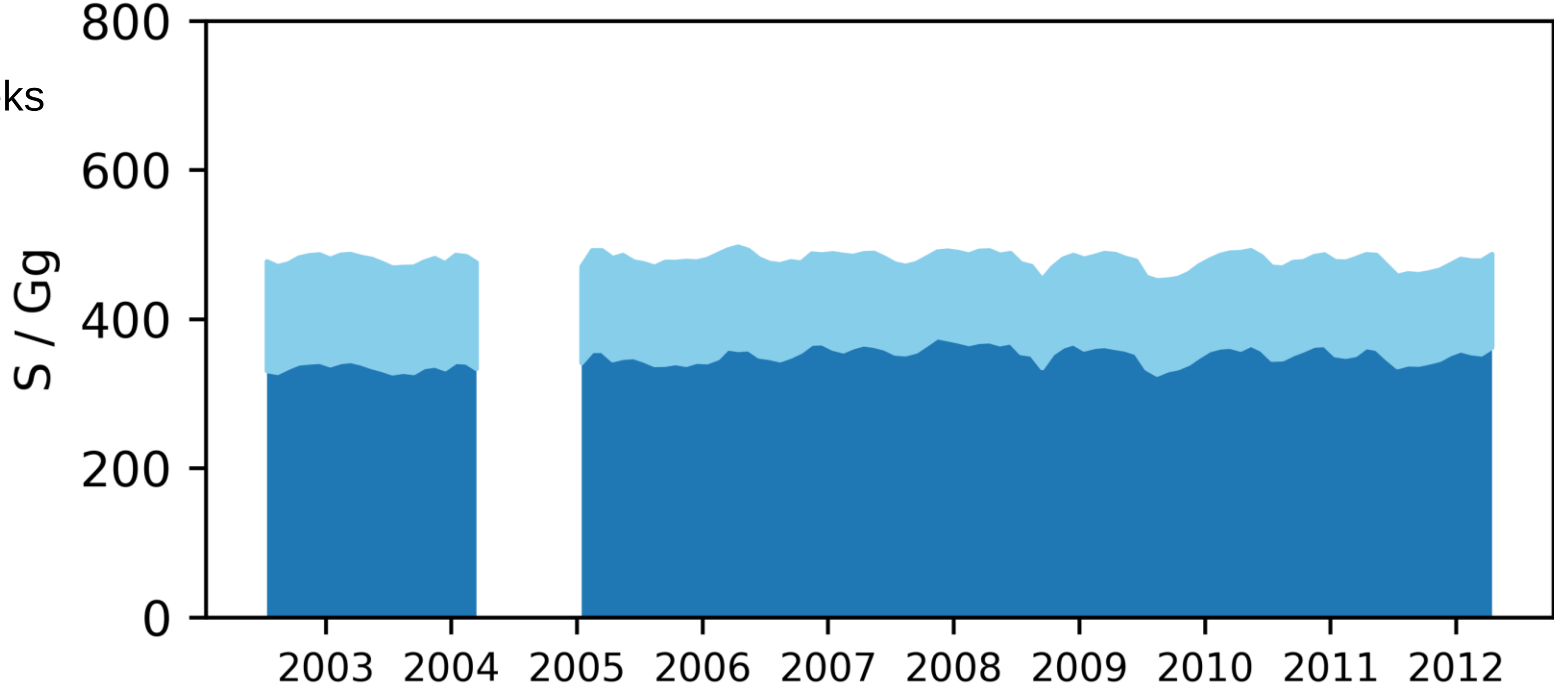
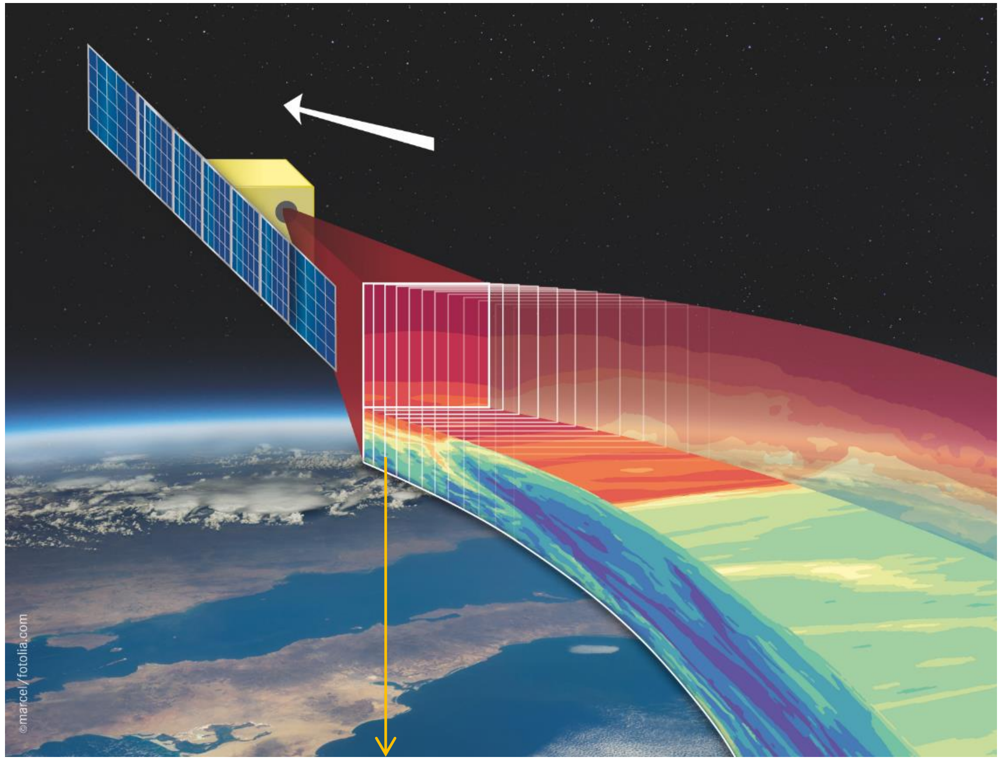


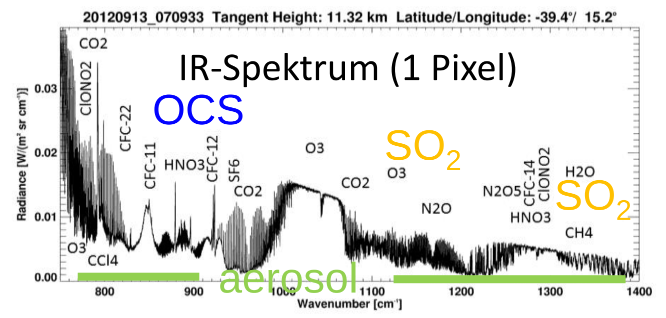
German proposal for an infrared imaging limb-sounder

GLORIA



MIPAS+++ with:

- Across-track sounding
- Strongly enhanced vertical and horizontal resolution



WR

WISSENSCHAFTSRAT

ATMO-SAT

2017

Bericht zur wissenschaftsgeleiteten Bewertung umfangreicher Forschungsinfrastruktur-vorhaben für die Nationale Roadmap

Summary

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OCS

- What is the effect of convection on the UT-OCS “hole”?
- How to explain the large UT OCS values over the W-Pacific in spring+summer?
- Does biomass burning really emit any OCS? If yes, where is it?
- Is there a tropical/subtropical upper tropospheric OCS-nose?
- Which instrument is right, MIPAS or ACE-FTS (OCS differ up to 20 km by about 50 pptv)
- Is there any stratospheric OCS trend not connected to changes in Age-of-air?

SO_2

- Are the new aircraft in-situ observations of < 10 ppt the “real” background values at the tropical upper troposphere? (supported by ACE-FTS)
- Do nadir instruments underestimate SO_2 lifetimes in the UTLS? If yes, is it an effect of sensitivity or of the lower peaking averaging kernel?

H_2SO_4(liqu)

- Is the summertime enhancement seen in the new MIPAS aerosol volume dataset real?
- What is the reason for the annual cycle of downwelling aerosols in the S-hemisphere?
- How well can the stratospheric total aerosol burden be constrained?