2D distributions of stratospheric and upper tropospheric trace gases in the Arctic summer measured during the first flight of the GLORIA balloon instrument

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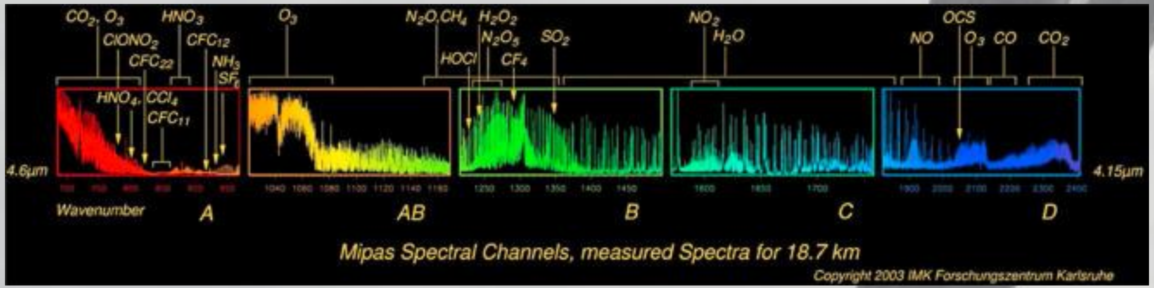
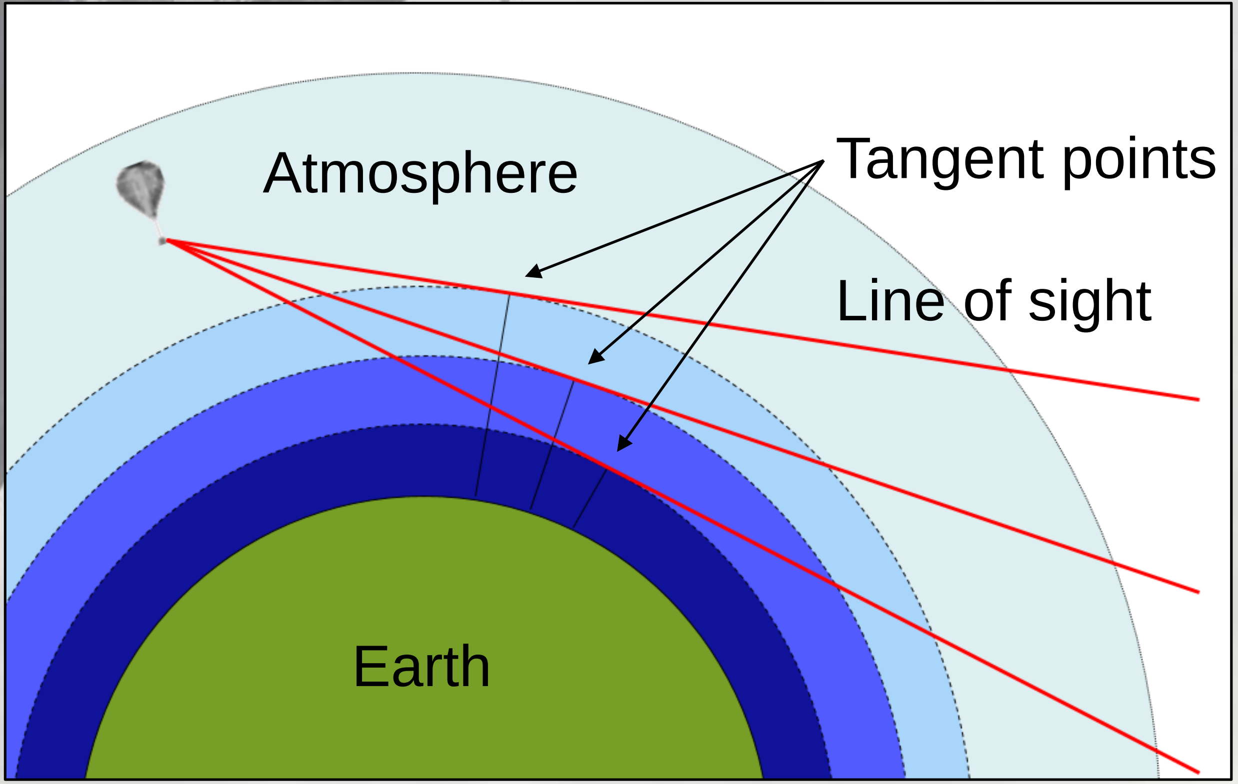
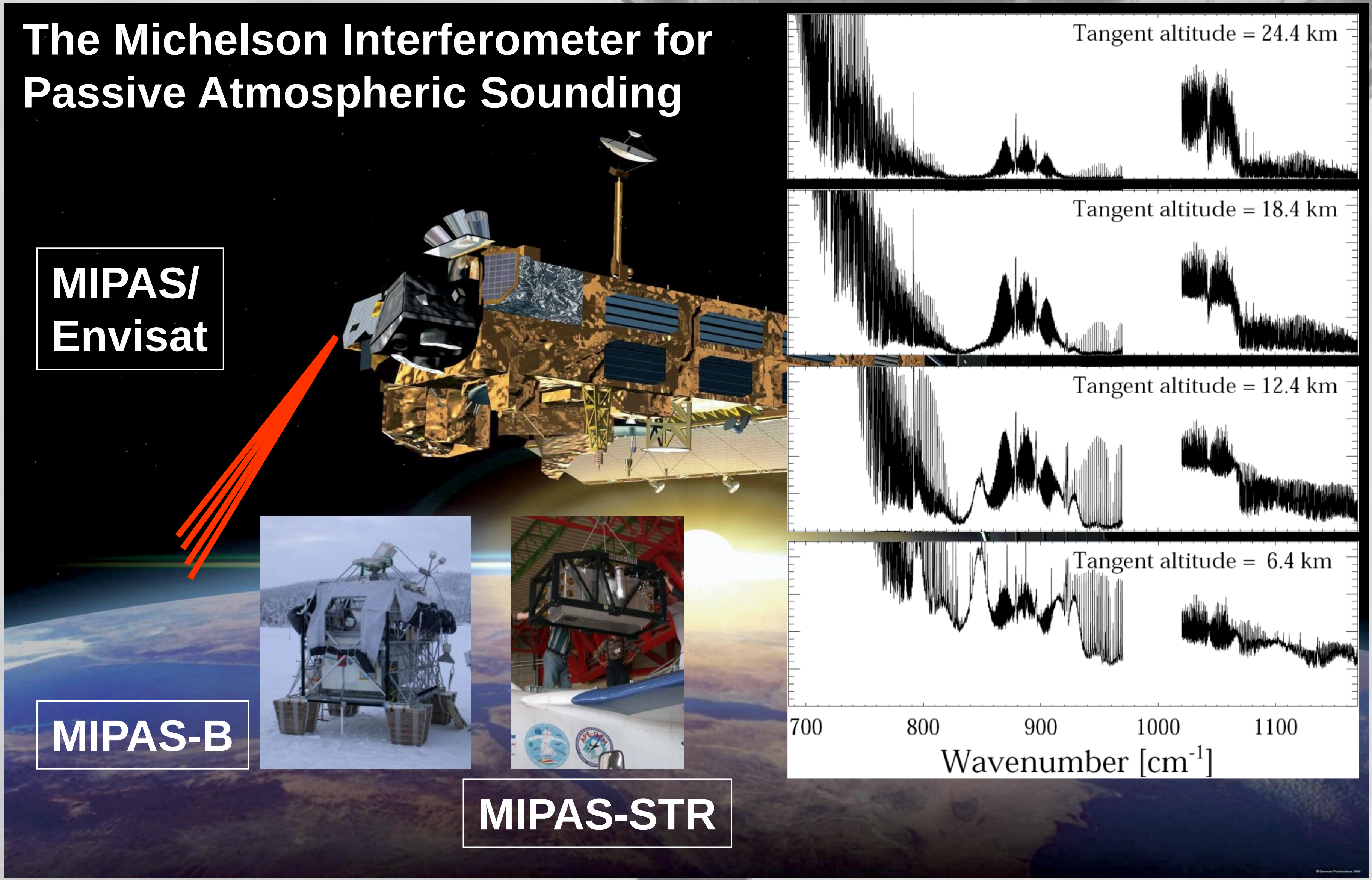
Mid-IR limb emission spectroscopy

- View through the atmosphere against cold space
  - → Measurement of thermal atmospheric emission
  - → Independent of a source like sun or moon
  - → High sensitivity due to long path through the atmosphere
- Different tangent altitudes
  - → High vertical resolution
- FTIR spectroscopy
  - → Separate rotational-vibrational spectral signatures of many trace gases





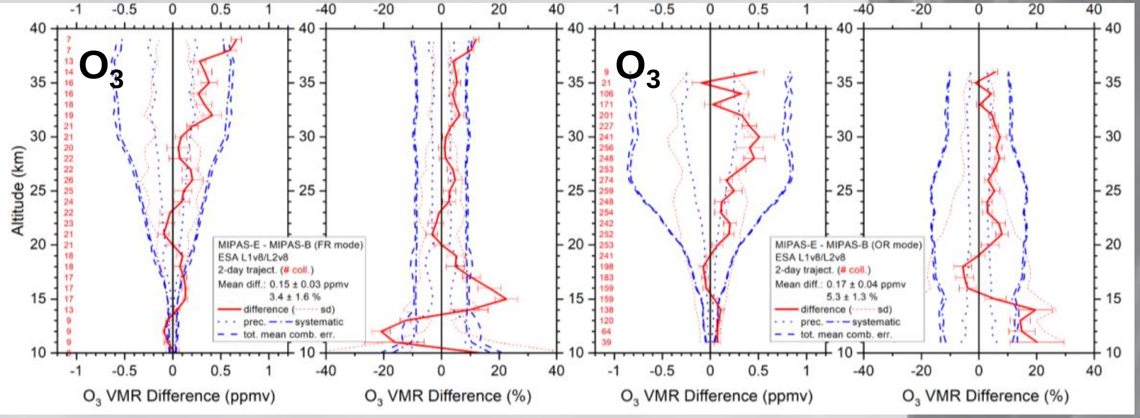
From limb-scanning MIPAS instruments …

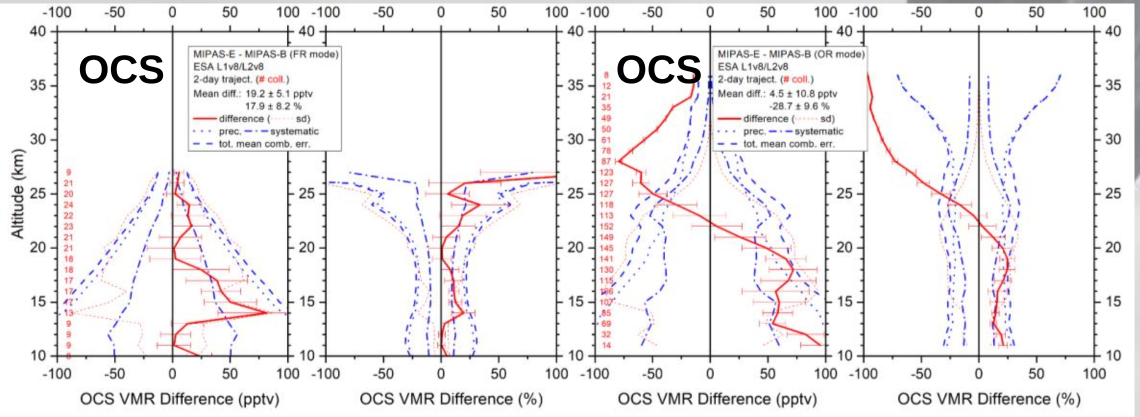


MIPAS-B highlights examples …

Validation of MIPAS ESA operational products

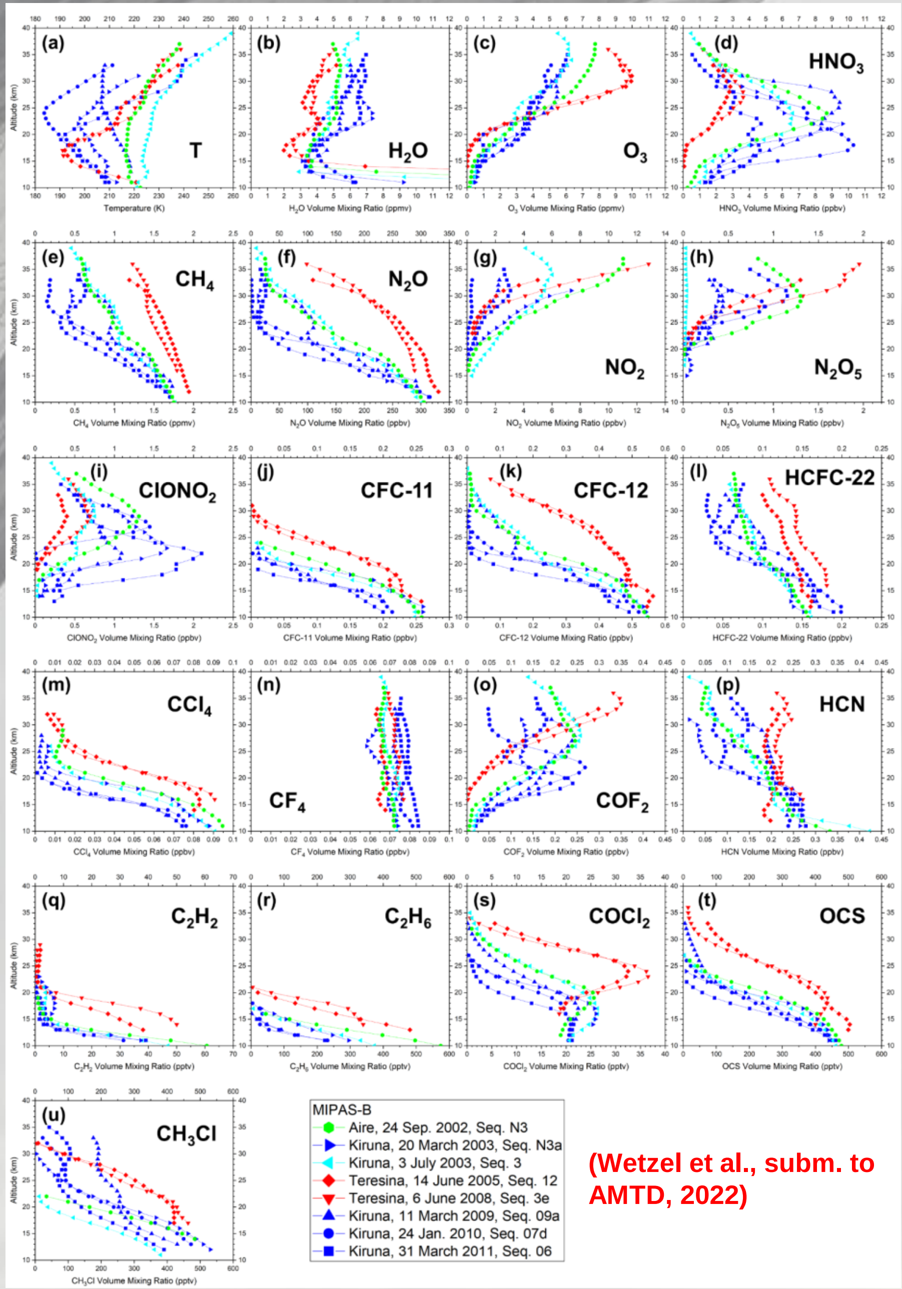
FR mode **OR mode**





For details, see MIPAS product quality readme file, available at:
https://earth.esa.int/eogateway/documents/20142/37627/README_V8_issue_1.0_20201221.pdf

new v8 species



(Wetzel et al., subm. to AMTD, 2022)

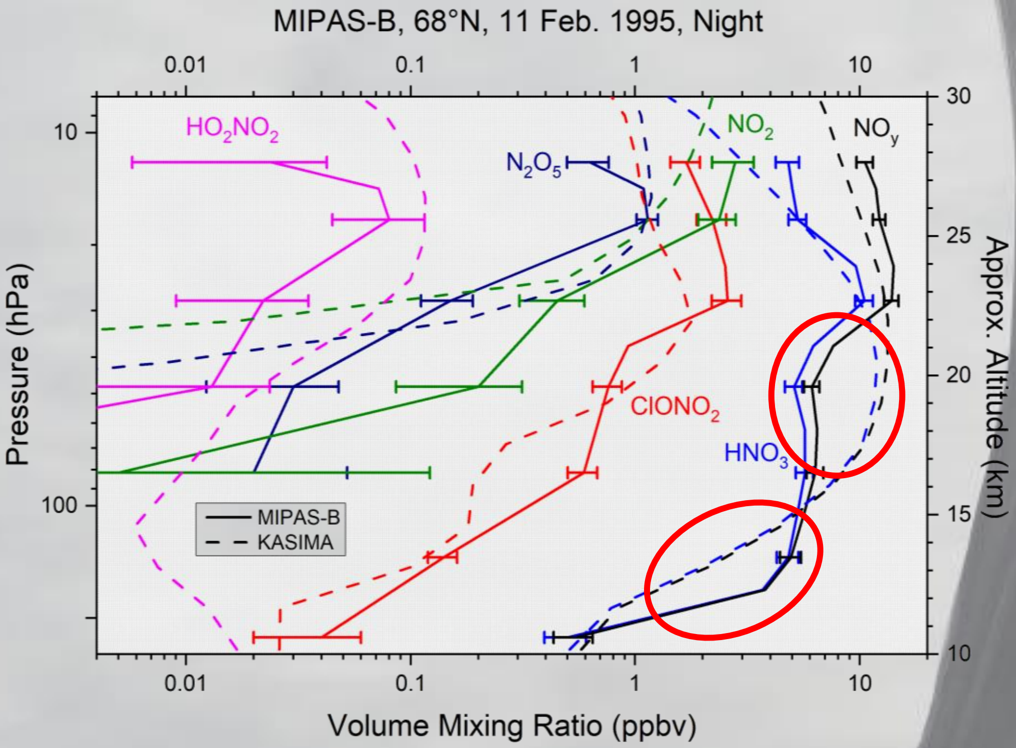
MIPAS-B highlights examples …

Karlsruhe Institute of Technology

Nitrogen partitioning and budget

Kiruna, 11 Feb. 1995 (02:00 - 04:38 UTC,~64°N, ~30°E, Seq. 03a - 06)

– – – First flight of MIPAS-B2 instrument – – –



$[NO_y]_{night} = [HNO_3] + [ClONO_2] + [NO_2] + 2\,[N_2O_5] + [HO_2NO_2]$

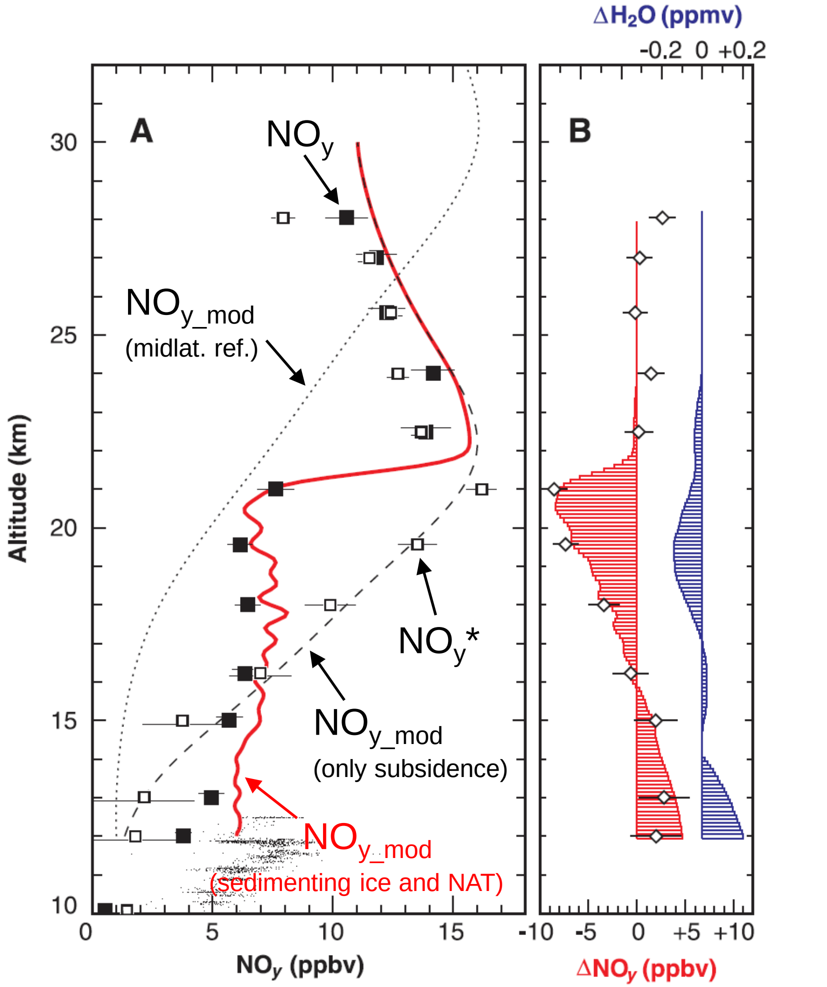


Fig. 1. (**A**) Arctic NO_y profiles in mid-February 1995. Symbols: squares, balloon-borne MIPAS-B observations (*12*); dots, aircraft-borne observations (*16*). Solid symbols are NO_y measurements; open symbols mark NO_y^* deduced from MIPAS N_2O measurements (*13*). NO_y^* represents the unperturbed case (without denitrification). The model calculations are denoted by lines [dotted line, mid-latitude reference NO_y profile (*28*); dashed line, scenario 0 with subsidence of air only (no particle sedimentation); red line, scenario 3 showing the effect of denitrification due to sedimenting ice and NAT particles]. (**B**) Vertical redistribution of NO_y (red) and H_2O (blue). In addition, measured ΔNO_y is shown (◇).

3D microphysical model:
2.5° x 2.5° x 100 m (alt.)
ECMWF meteorological data

(Waibel et al., Science, 1999)

MIPAS-B highlights examples …

Karlsruhe Institute of Technology

Chlorine partitioning and budget

Kiruna, 31 Mar. 2011 (02:00 - 04:38 UTC,~64°N, ~30°E, Seq. 03a - 06)

(Wetzel et al., ACP, 2015)

$[ClO_x]$ $= [ClO] + [HOCl] + 2\,[ClOOCl]$

$[Cl_y]$ $= \mathbf{[ClO_x]} + [HCl] + [ClONO_2]$

$[CCl_y]$ $= 2\,[CFC\text{-}12] + 3\,[CFC\text{-}11] + [HCFC\text{-}22] + 3\,[CFC\text{-}113] + 4\,[CCl_4] + [CH_3Cl]$

$[Cl_{total}]$ $= \mathbf{[Cl_y]} + \mathbf{[CCl_y]}$

$[Cl_y{}^*]$ $= 3.2008346 + 8.7786479\times10^{-6}\,[N_2O] - 2.9132361\times10^{-5}\,[N_2O]^2$

(from BONBON balloon observations in 2009 - 2011; as described in Engel et al., JGR, 2002)

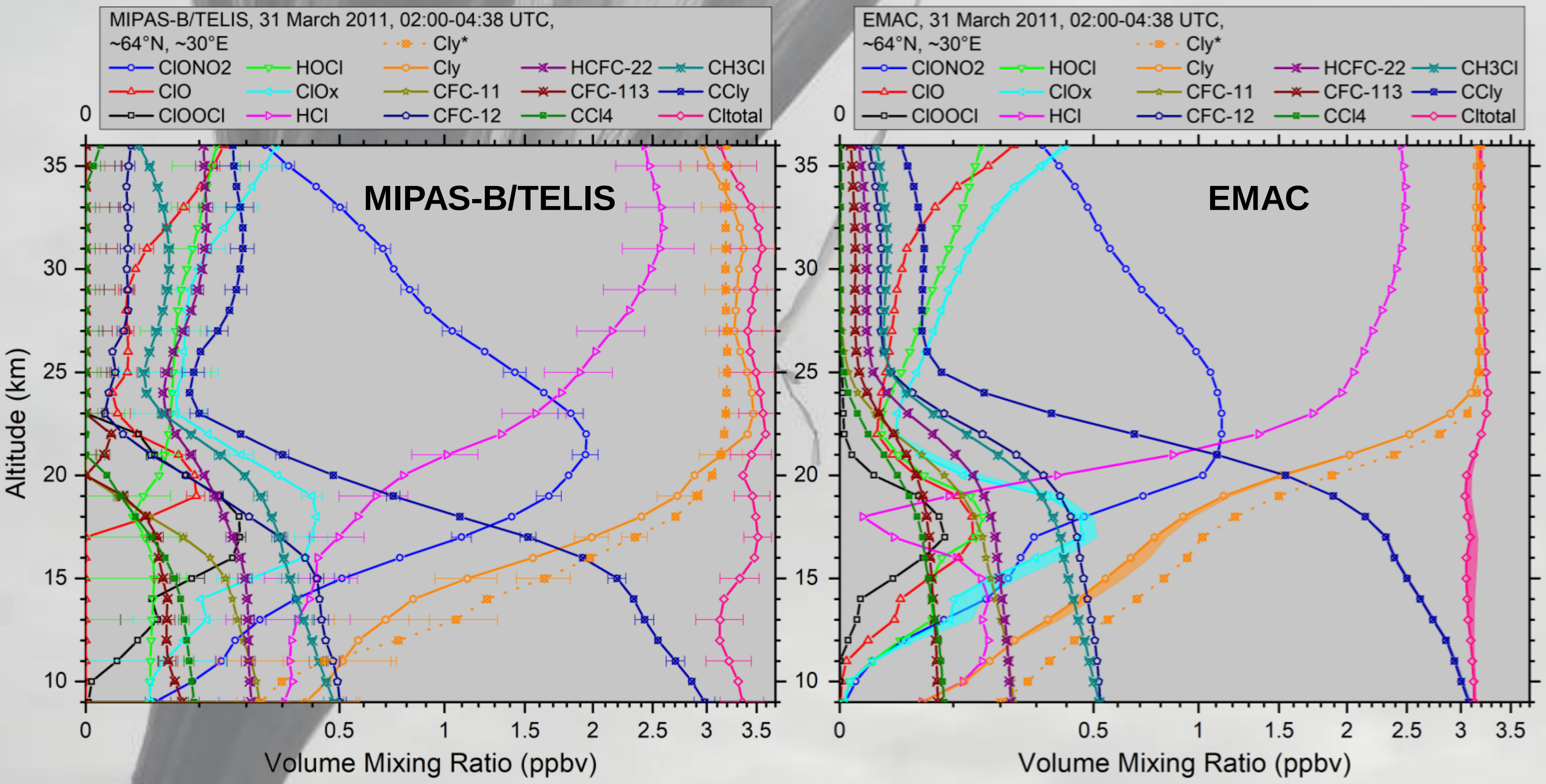
<u>ClOOCl calculated via:</u>

$[ClOOCl_{calc}] = ([ClO_{max}] - [ClO])/2$

where $[ClO_{max}] = [ClO_{noon}] + 2\,[ClOOCl_{noon}]$

(see Wetzel et. al., ACP, 2012)

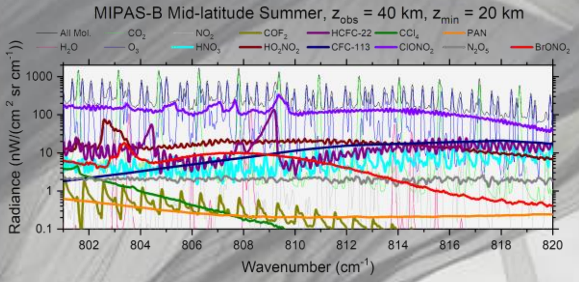
- First total chlorine partitioning observed by MIPAS-B and TELIS (TErahertz and submillimeter LImb Sounder).
- Strongest Cl_{total} and Cl_y peaks correlate with HCl and $ClONO_2$.
- **Cl_{total} (meas.): 3.41 ± 0.30** ppbv (> 24 km).



shaded region: minor chlorine species contained in EMAC (Cl_2, Cl, OClO, CH_3CCl_3) not measured.

MIPAS-B highlights examples …

$BrONO_2$ diurnal variation and total bromine



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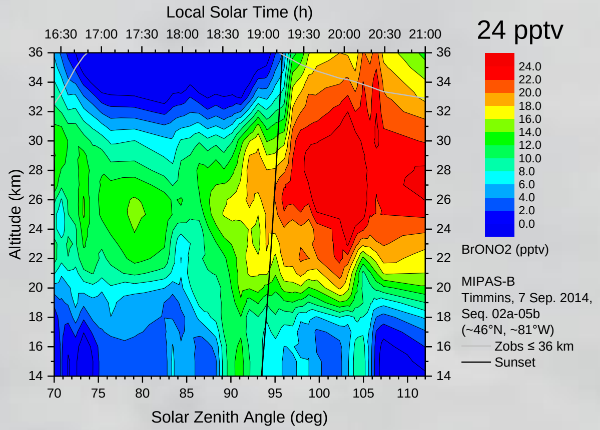
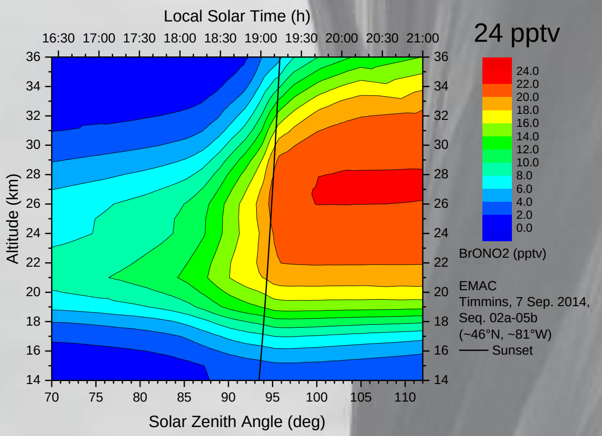
Sunset observation: Timmins (Canada), 7 Sep. 2014, Seq. 02a-05b, z_{obs} ~ 32-36 km, Lat. ~ 46°N, Lon. ~81°W

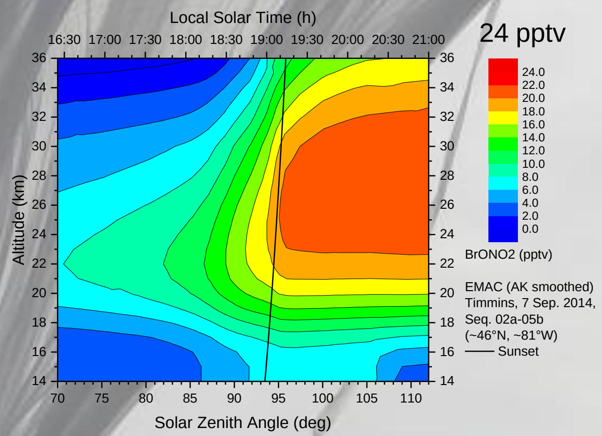
MIPAS-B 3-Pt. AA



EMAC

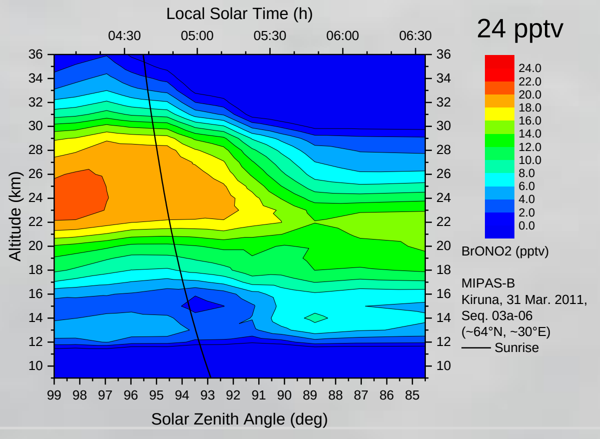


EMAC AK smoothed

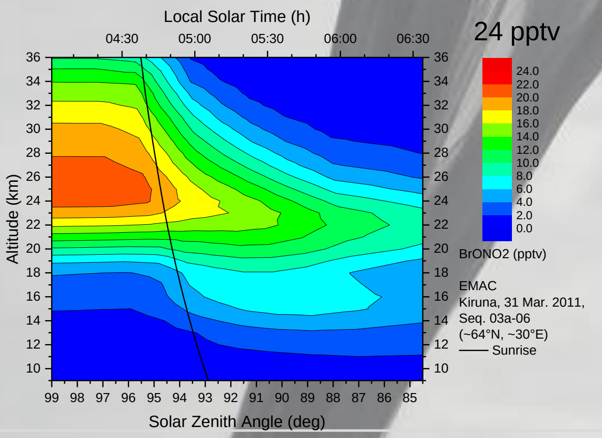


Sunrise observation: Kiruna (Sweden), 31 Mar. 2011, Seq. 03a-06, z_{obs} ~ 35 km, Lat. ~ 64°N, Lon. ~30°E

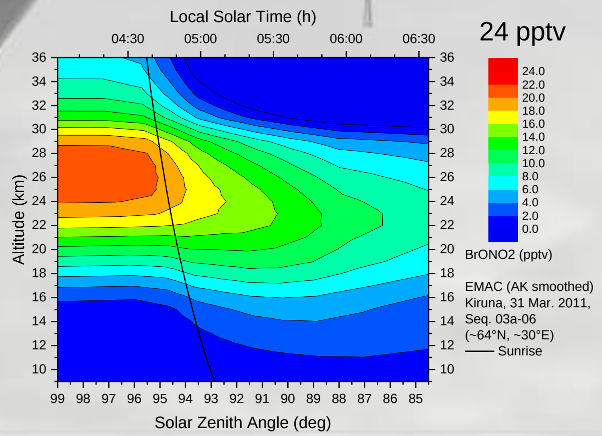
MIPAS-B 3-Pt. AA



EMAC



EMAC AK smoothed



Estimation of total bromine from nighttime $BrONO_2$

$$[Br_y\ (meas)] = [BrONO_2\ (meas)] \times \frac{[Br_y\ (mod)]}{[BrONO_2\ (mod)]}$$

MIPAS-B Br_y (night, SZA ≥ 99°) estimated from EMAC $BrONO_2/Br_y$ ≥ 0.9:

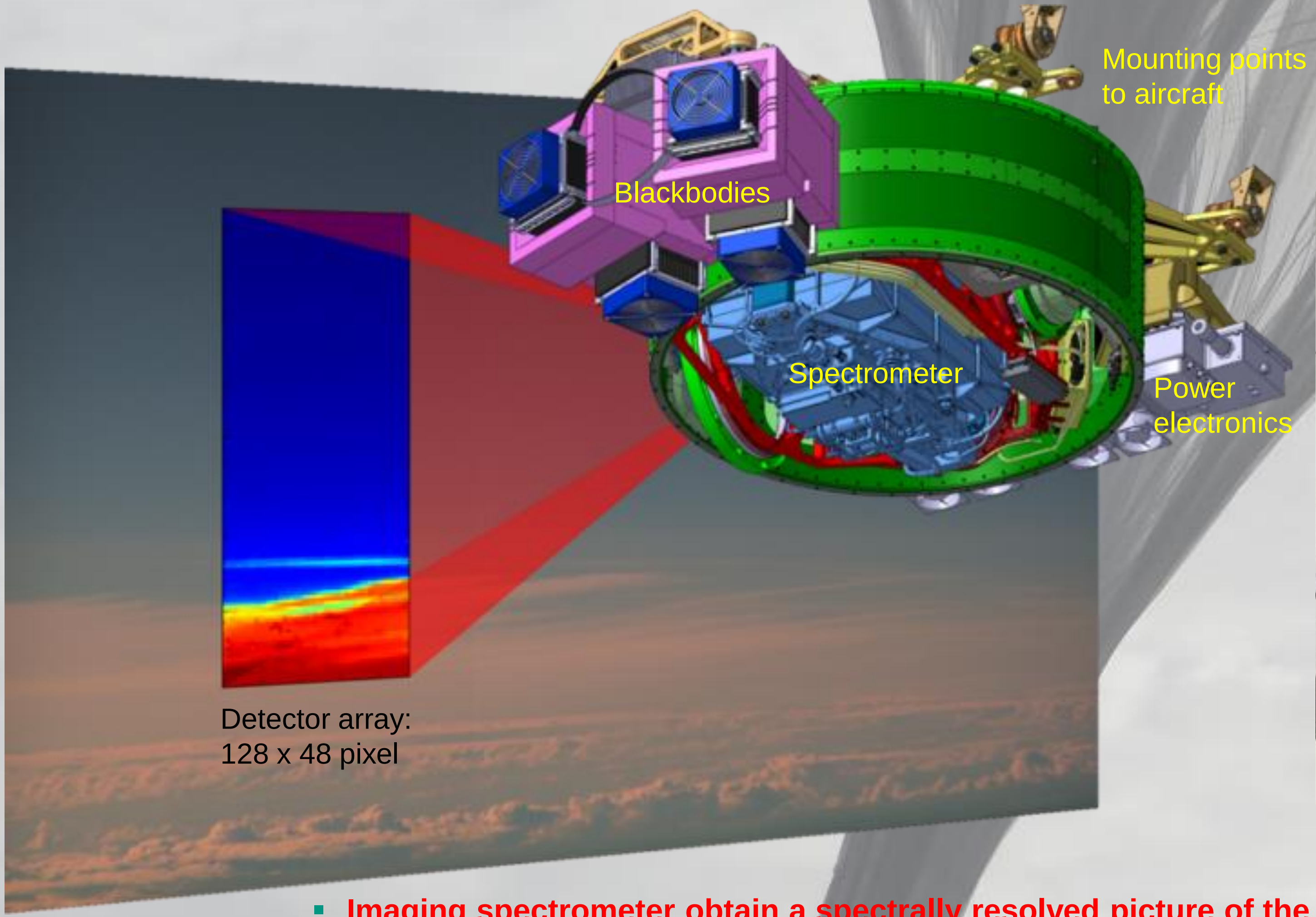
Br_y (21-29 km): **22.7 ± 1.9** pptv

MIPAS-B Br_y (night, SZA ≥ 96°) estimated from EMAC $BrONO_2/Br_y$ ≥ 0.8:

Br_y (23-29 km): **21.6 ± 2.2** pptv

(Wetzel et al., ACP, 2017)

… to limb-imaging GLORIA instruments



- **Imaging spectrometer obtain a spectrally resolved picture of the limb at once without the need to scan through the atmosphere**

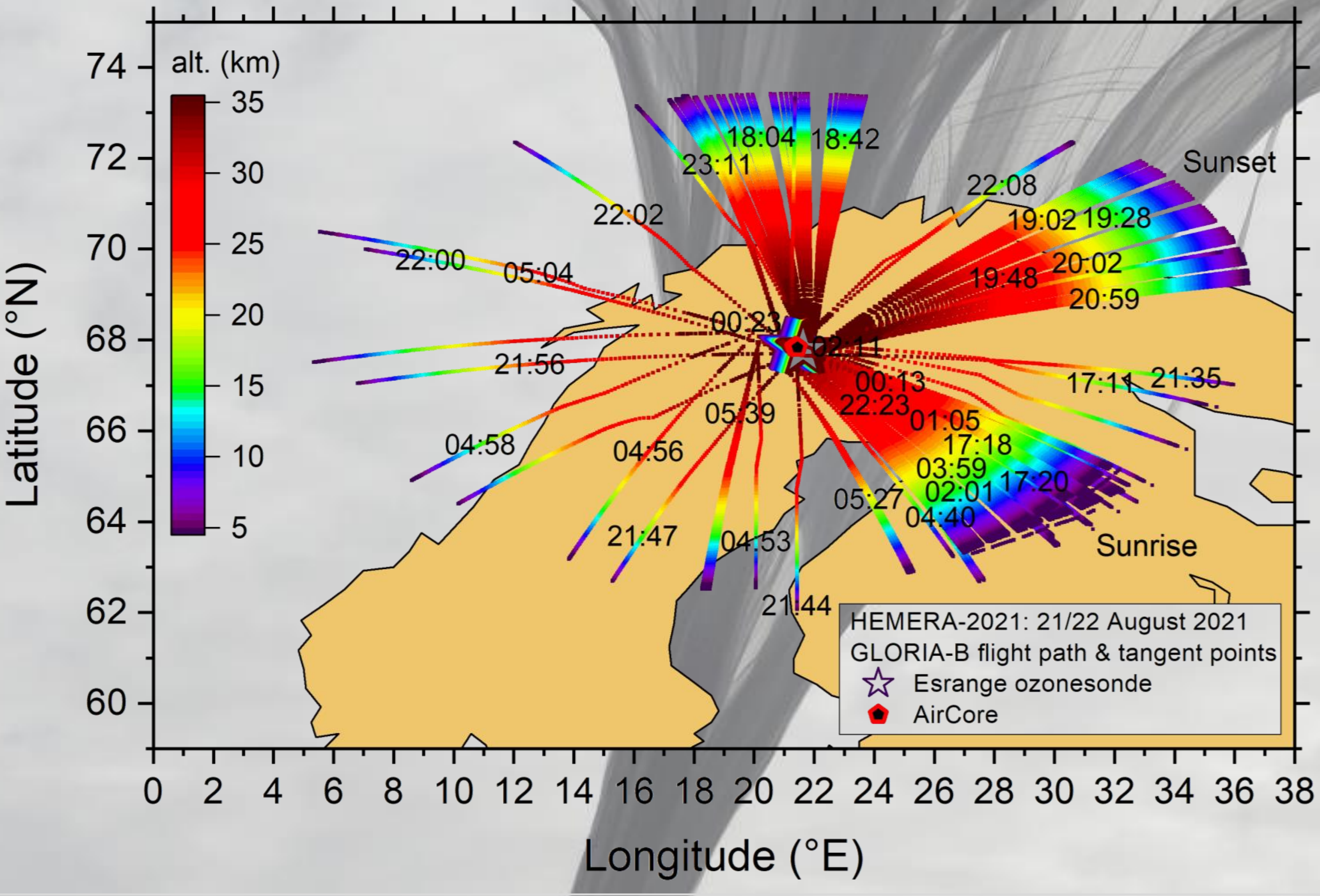
GLORIA@StratoBalloon ~36 km

Maiden flight during EU-project HEMERA
from Esrange/N-Sweden on 21 Aug 2021

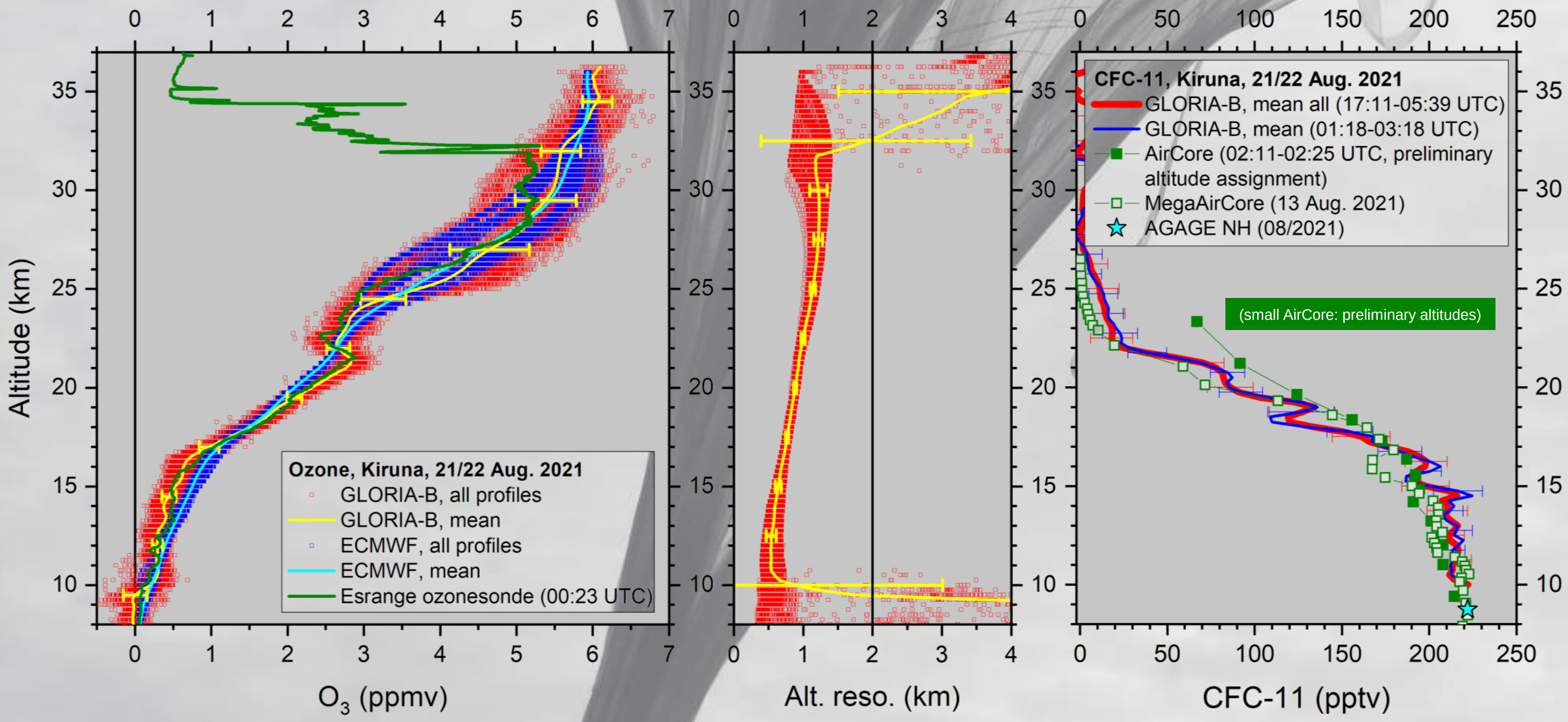
GLORIA@Geophysica ~20 km

GLORIA@HALO ~14 km

GLORIA-B tangent point position

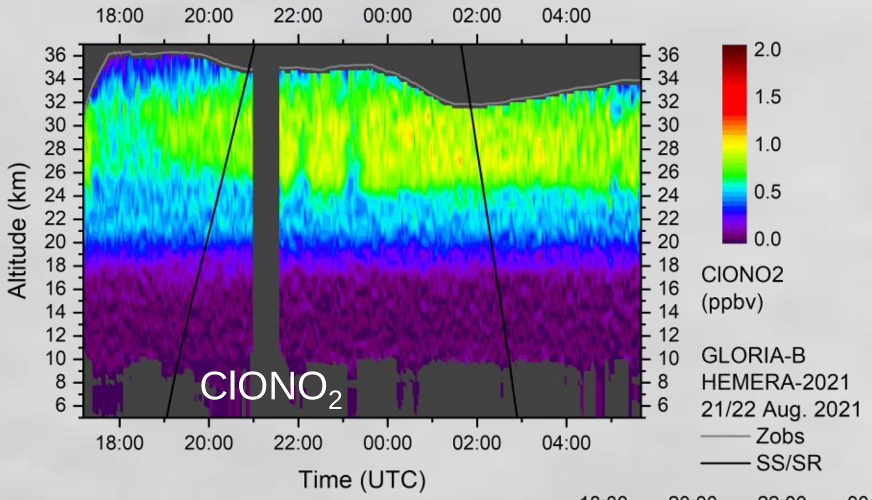


GLORIA-B measurements in comparison to ozonesonde and AirCore in-situ observations

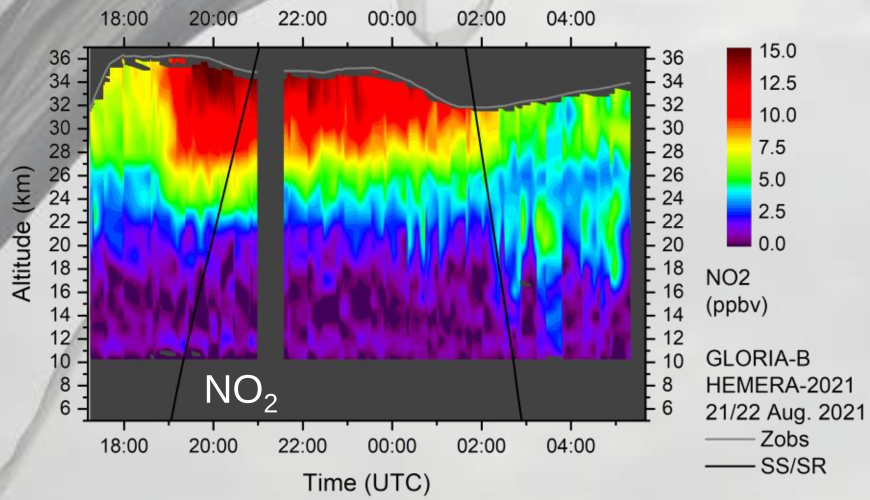


Investigation of diurnal cycle of many trace gases involved in ozone chemistry

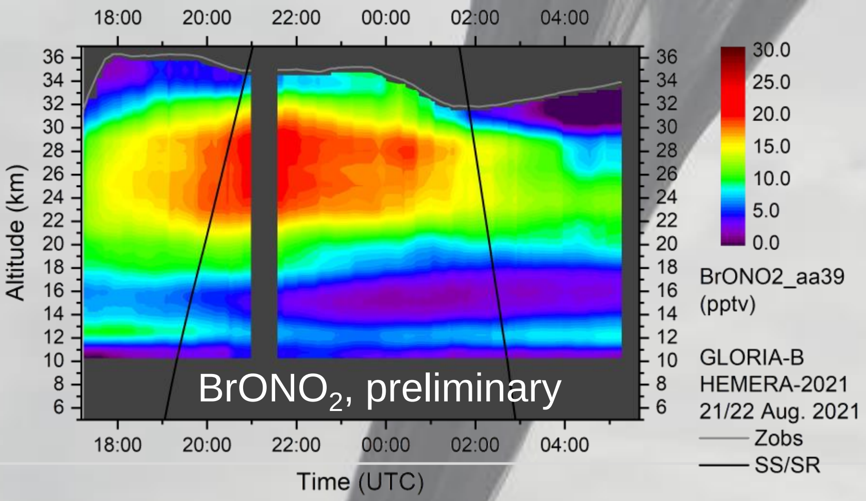
Chlorine species (e.g. $ClONO_2$)

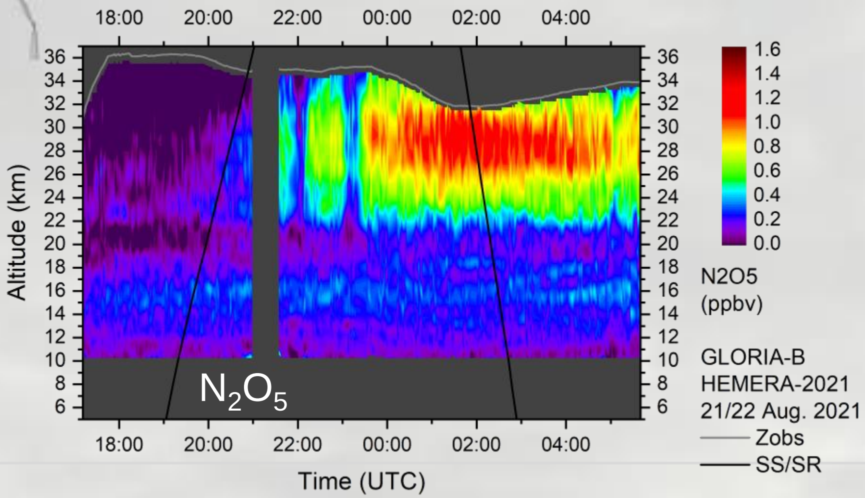


Nitrogen species (NO_2, N_2O_5)



Bromine species ($BrONO_2$)



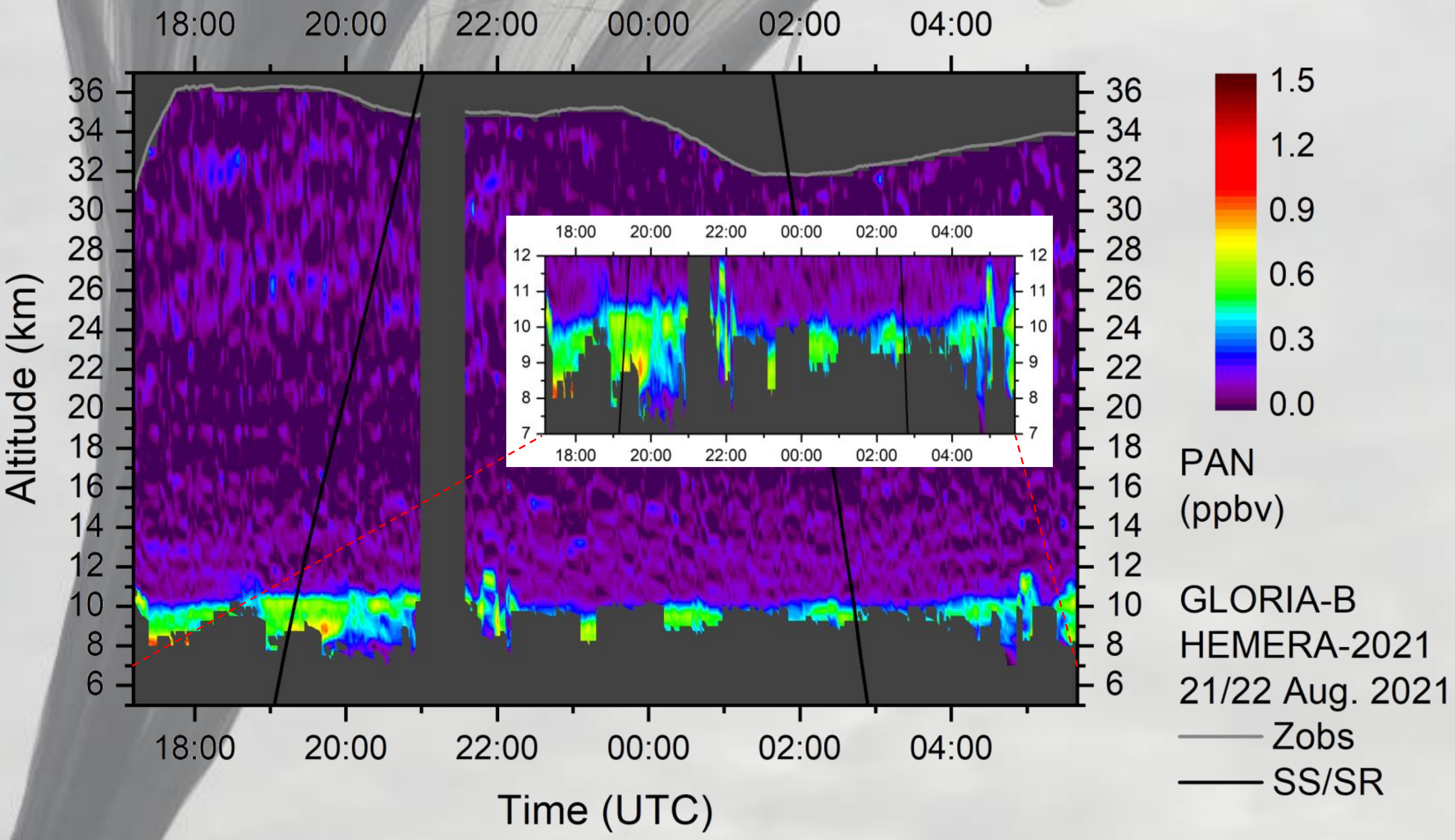


Investigation of pollution in the upper troposphere and stratosphere

Pollutant species (e.g. peroxyacetyl nitrate, PAN) from forest fires or export from the Asian monsoon

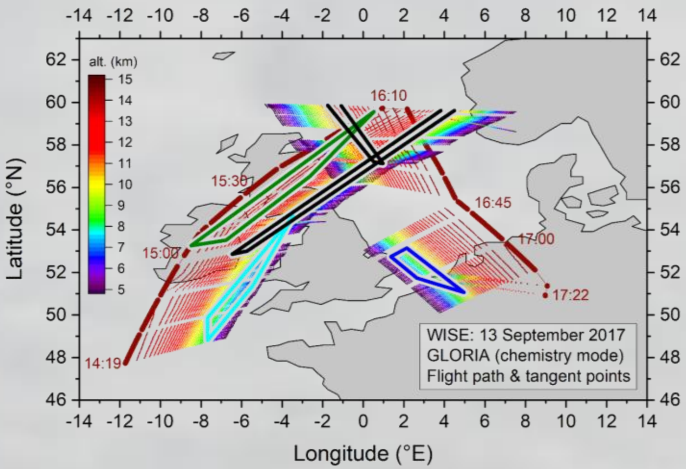
- PAN has a long lifetime of up to 5 months in the upper troposphere, it can be transported over far distances.

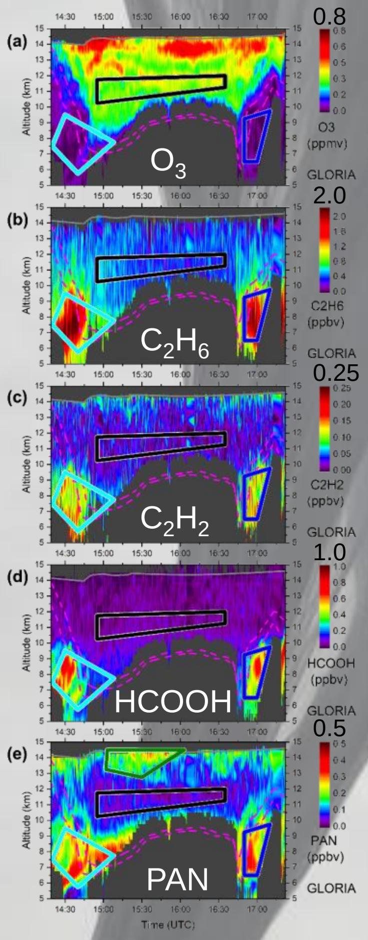
FIRMS fire counts 16-22 Aug. 2021

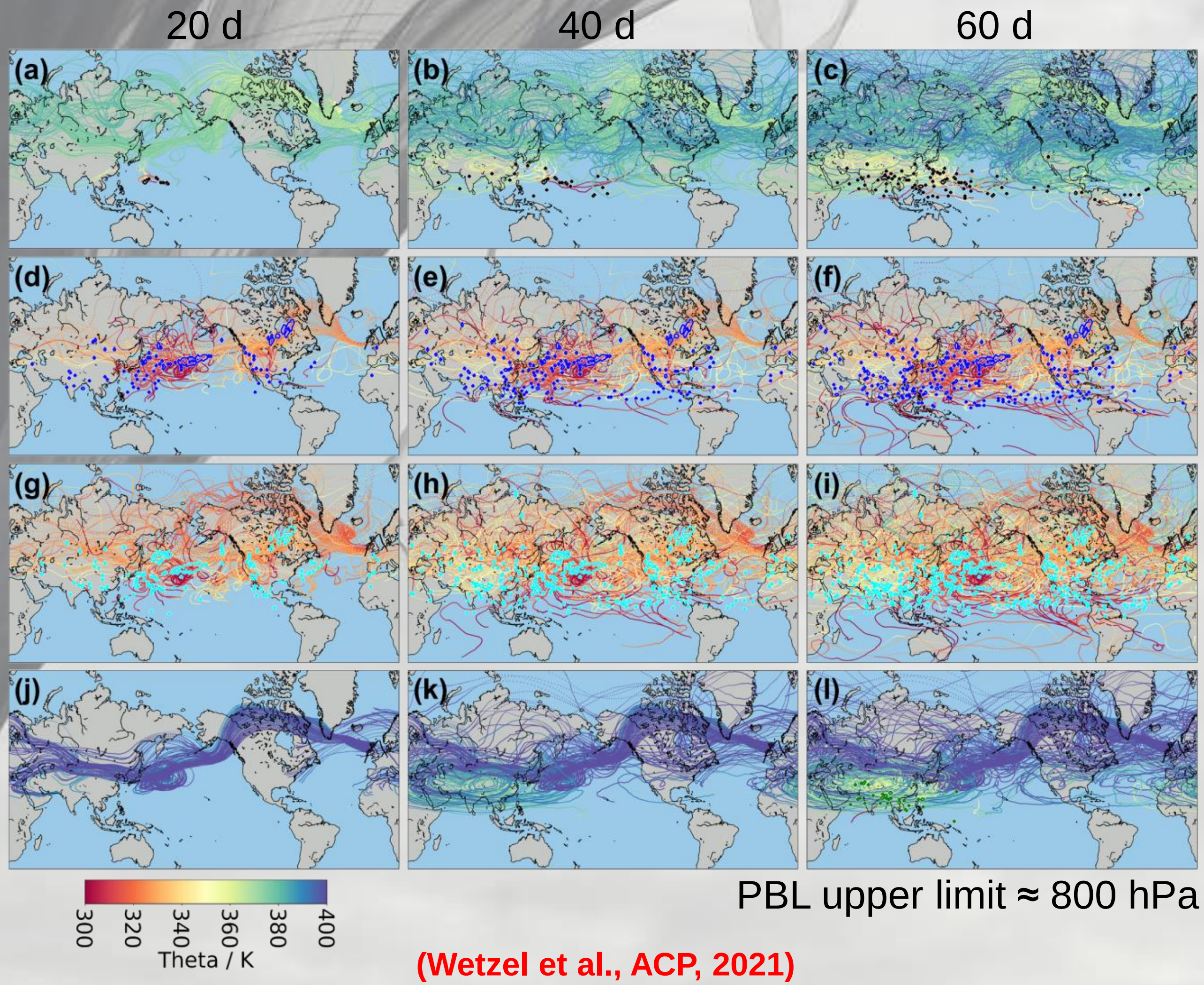


Investigation of pollution in the upper troposphere and lowermost stratosphere

HALO aircraft measurements over the British Isles during WISE campaign on 13 Sep. 2017 (flight from Oberpfaffenhofen, Germany)







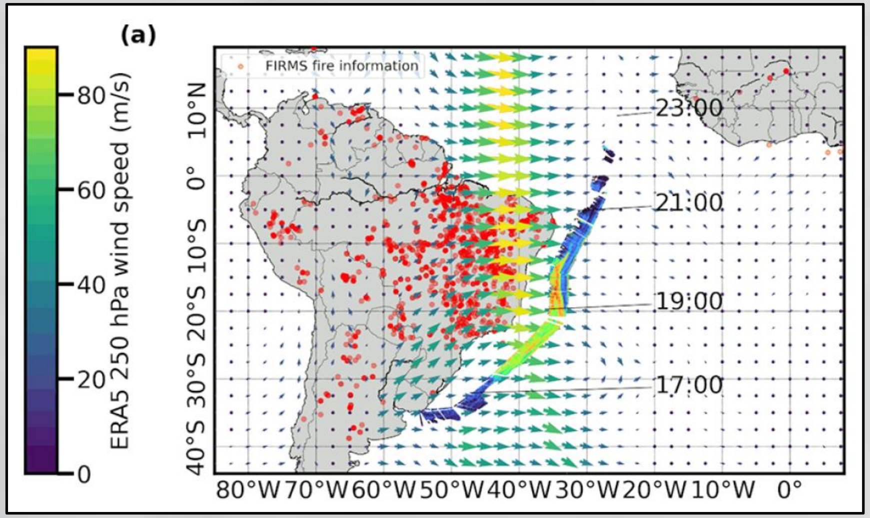
- Main sources of pollutant species are forest fires in N-America and anthropogenic pollution in S- and SE-Asia uplifted and moved within the Asian monsoon anticyclone.
- Pollutants are transported by strong tropospheric winds over large distances, depending on their particular atmospheric lifetime of up to months.

PBL upper limit ≈ 800 hPa

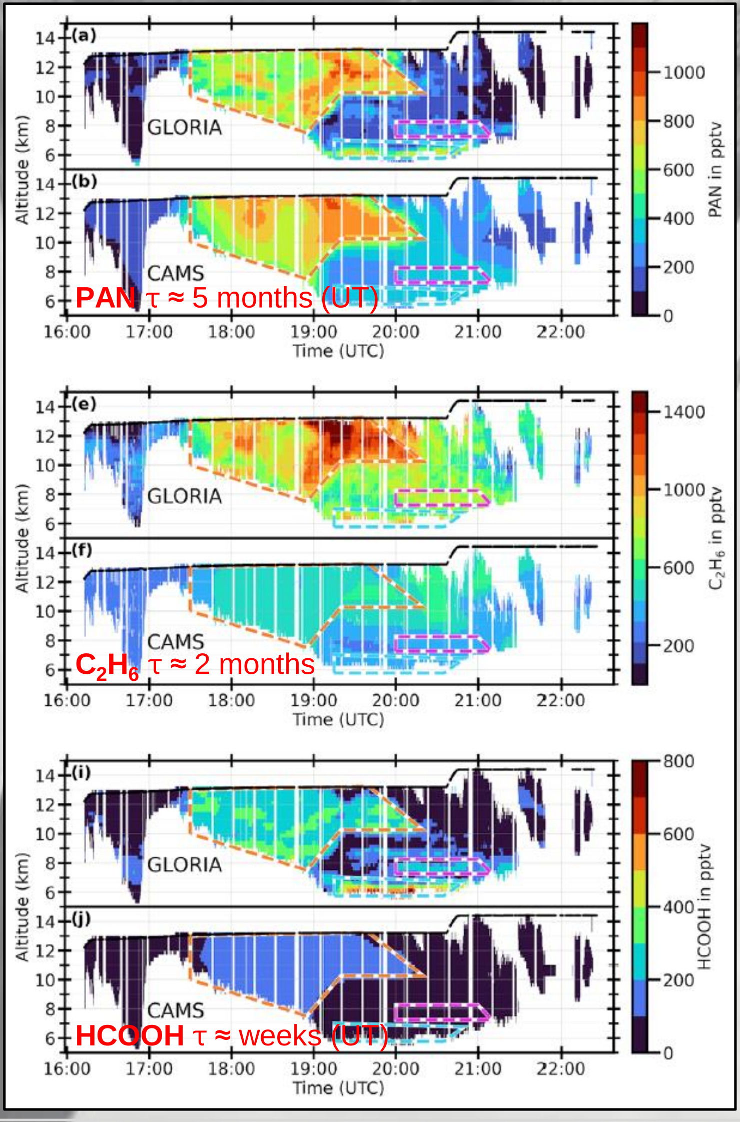
(Wetzel et al., ACP, 2021)

Investigation of pollution in the upper troposphere

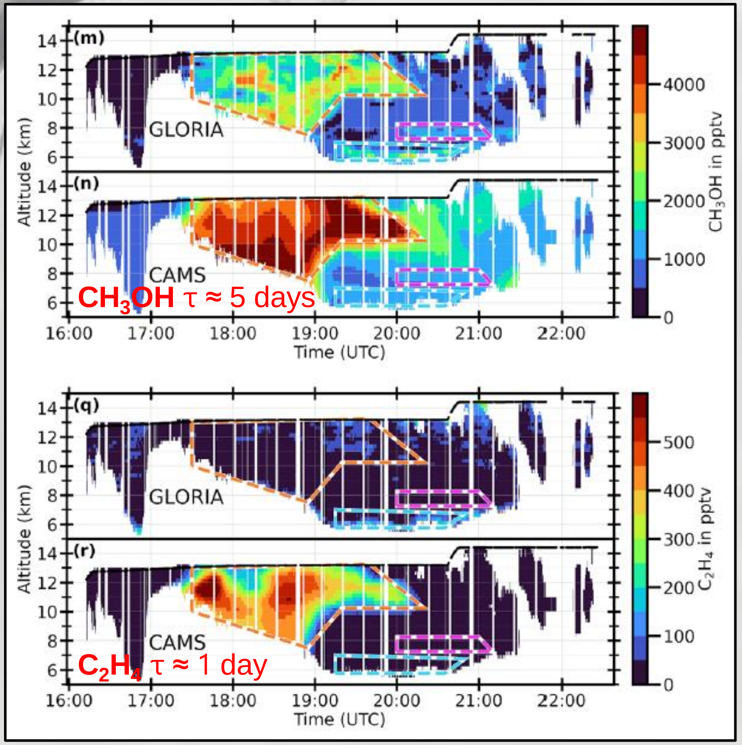
HALO aircraft measurements over the Tropical Atlantic during SouthTRAC campaign on 7 Oct. 2019 (flight from Buenos Aires, Argentina, to Sal, Cabo Verde).



Comparison to Copernicus Atmosphere Monitoring Service (CAMS) atmospheric chemistry model for data assimilation



(Johansson et al., ACP, 2022)



- Differences between GLORIA and CAMS are small in the case of PAN.
- Poorer agreement for other species seems to be most likely linked to model deficiencies in the representation of loss processes and emission strength.

Summary

- Maiden flight of limb-emission FTIR imager GLORIA on a stratospheric balloon: HEMERA-2 flight during the KLIMAT campaign, Esrange/Sweden on 21/22 Aug 2021
- Very successful measurements
- **Validation:**
  - First comparisons with in-situ data of ozone sounding and AirCore
  - Further: HEMERA-1 & SuperCLIMAT flights (CH_4, SF_6, CFC's, ...), Satellite MLS/Aura (O_3, N_2O, H_2O, …)
- **Science:**
  - Covering sun-set and sun-rise: photochemistry
  - Pollution in the UTLS
  - Dynamics, age of air
- **Upcoming:** Strato Science 2022 campaign, Timmins/Canada, Aug. 2022
- ➢ GLORIA is a demonstrator for ESA's 11th Earth Explorer mission candidate CAIRT (currently in selection process)

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*Changing-Atmosphere Infra-Red Tomography Explorer