



INFRARED LIMB SOUNDING OF CIRRUS CLOUDS: STATE OF KNOWLEDGE, RECENT PROGRESS, AND FUTURE PROSPECTS

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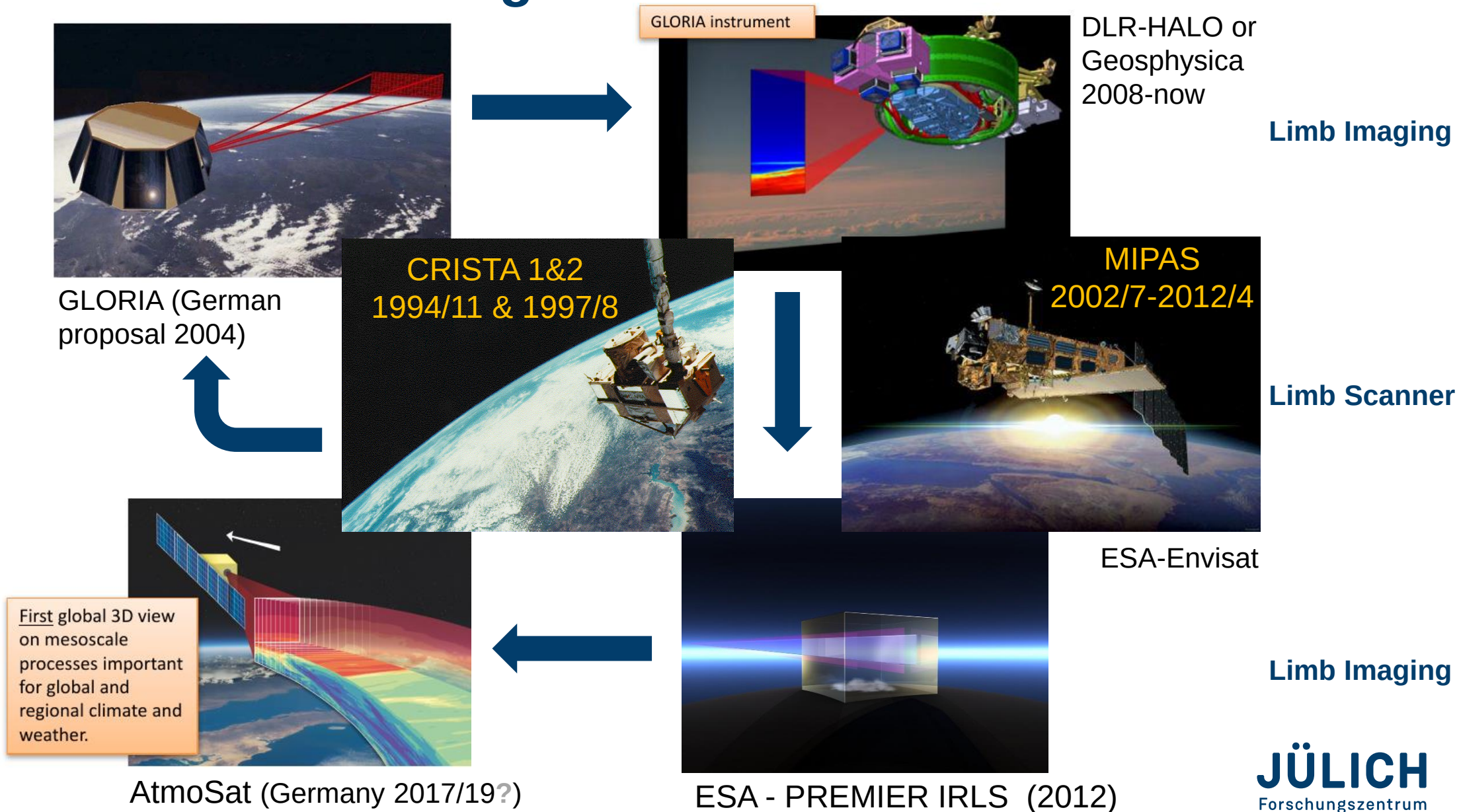
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CRISTA-MIPAS Heritage of IR limb sounder

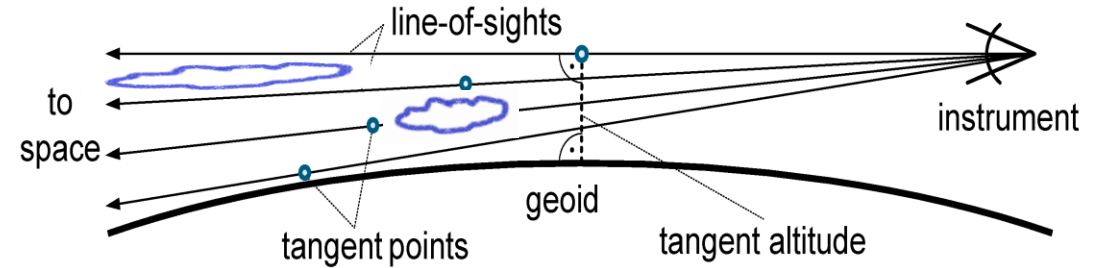
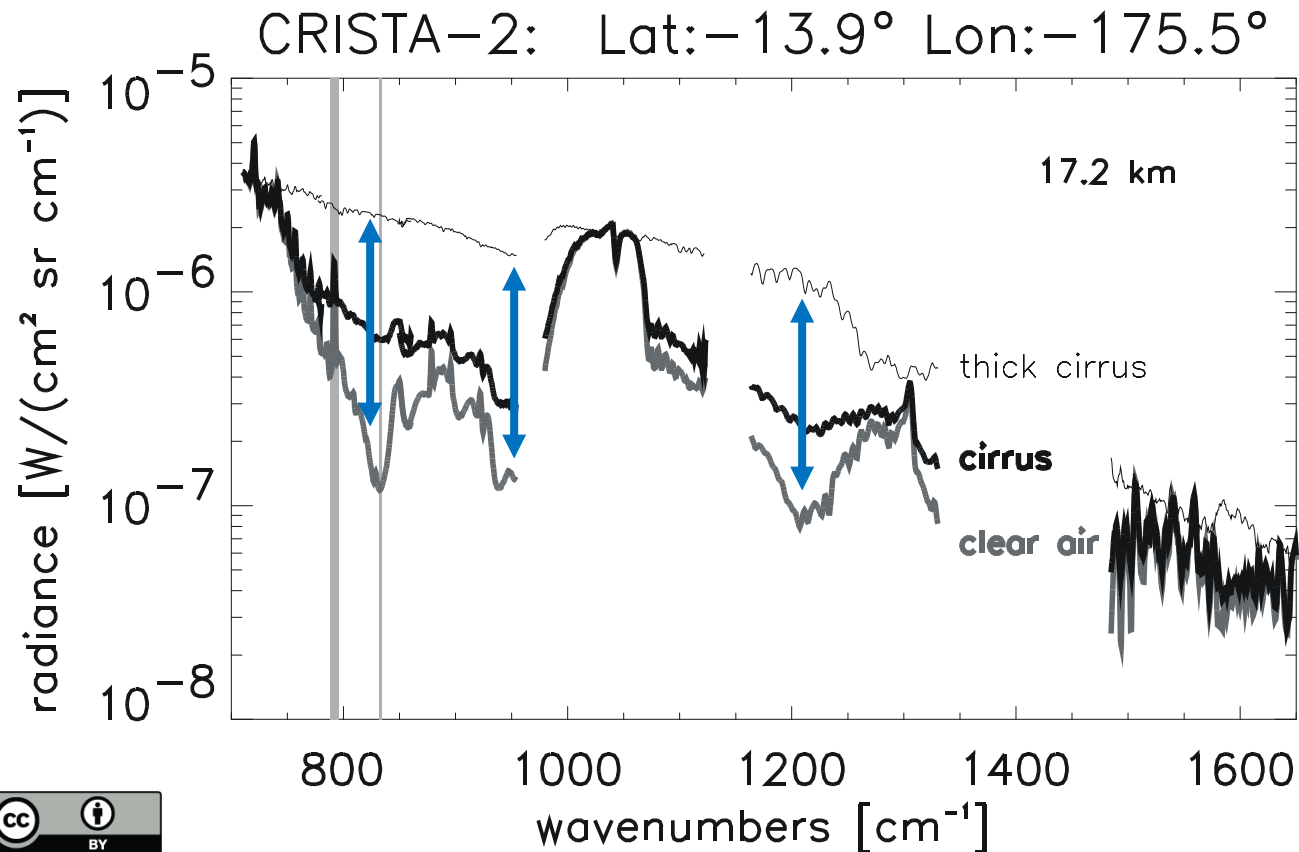


PROJECTS AND STUDIES ON IR LIMB SOUNDING

- CRISTA 1 & 2 Space Shuttle missions of ~7 days (1994/1997)
- CRISTA-NF airborne instrument on Geophysica, two campaigns in Darwin, Australia and Burkina Faso, Africa (2005 & 2006).
- **MIPAS** on Envisat, 10 years of pole covering IR high spectral resolution measurements (07/2002-03/2012), ESA MIPclouds study
- GLORIA satellite proposal (Germany): Global Limb Imaging idea and concept (2003/4)
- GLORIA-AB: airborne instrument for HALO aircraft (2008-now)
- ESA Earth Explorer 7 mission: PREMIER satellite proposal with Imaging IR Limb sounder (**IRLS**), finally not selected (2013)
 - Various studies on dynamics and trace gas retrievals
 - Extension: UTLS particulates measured by IRLS (2016-18)
- AtmoSat: proposal for German Research with GLORIA-like instrument (highly recommended by German Res. Council 2017, but finally not selected in 2019)
- GLORIA-Long-Duration-Balloon instrument development (ongoing)

INFRA RED LIMB CLOUD SPECTRA

- Strong cloud effects by enhanced emission in the window regions
- wavelength dependence $\Rightarrow$ particle type classification
 $\Rightarrow$ particle radius information



Caveat of IR Limb:

- cloud extent along the line of sight

Cloud Detection:

- Color ratio (CR) of $796 \text{ cm}^{-1} / 830 \text{ cm}^{-1}$ called *cloud index* (CI)
- Macro-physical quantities (e.g. CTH, occ. freq.)

[Spang et al., 2002, 2012]



Limb Ice Water Path and Area Density Path

- Area density:

$$A = \frac{3 \cdot V}{R_{\text{eff}}}$$

- Area density path for limb segment:

$$\text{ADP} = 3 \cdot \text{IWP} / (R_{\text{eff}} \cdot \rho_{\text{ice}})$$

- ADP line of sight integral:
(correlates with CI and Extinction)

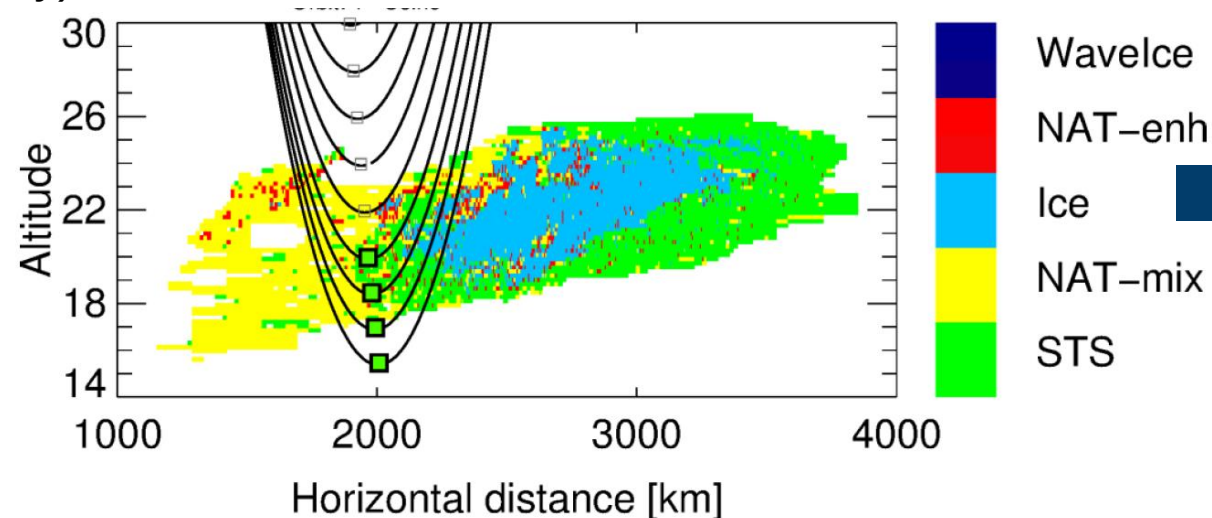
$$\text{ADP} = \int_{\text{obs}=0}^{\infty} A \, dx [\mu\text{m}^2 \text{cm}^{-2}] \quad [\text{Spang et al., 2012}]$$

- Limb Ice water path:
(defines the sensitivity)

$$\text{IWP} = \int_0^{\infty} \text{IWC} \, dx = \int_0^{\infty} V \cdot \rho_{\text{ice}} \, dx = \frac{1}{3} \int_0^{\infty} A \cdot R_{\text{eff}} \cdot \rho_{\text{ice}} \, dx$$

LOS Example:

CALIPSO lidar obs. of PSC
with MIPAS limb coincidence
[Spang et al, 2016]

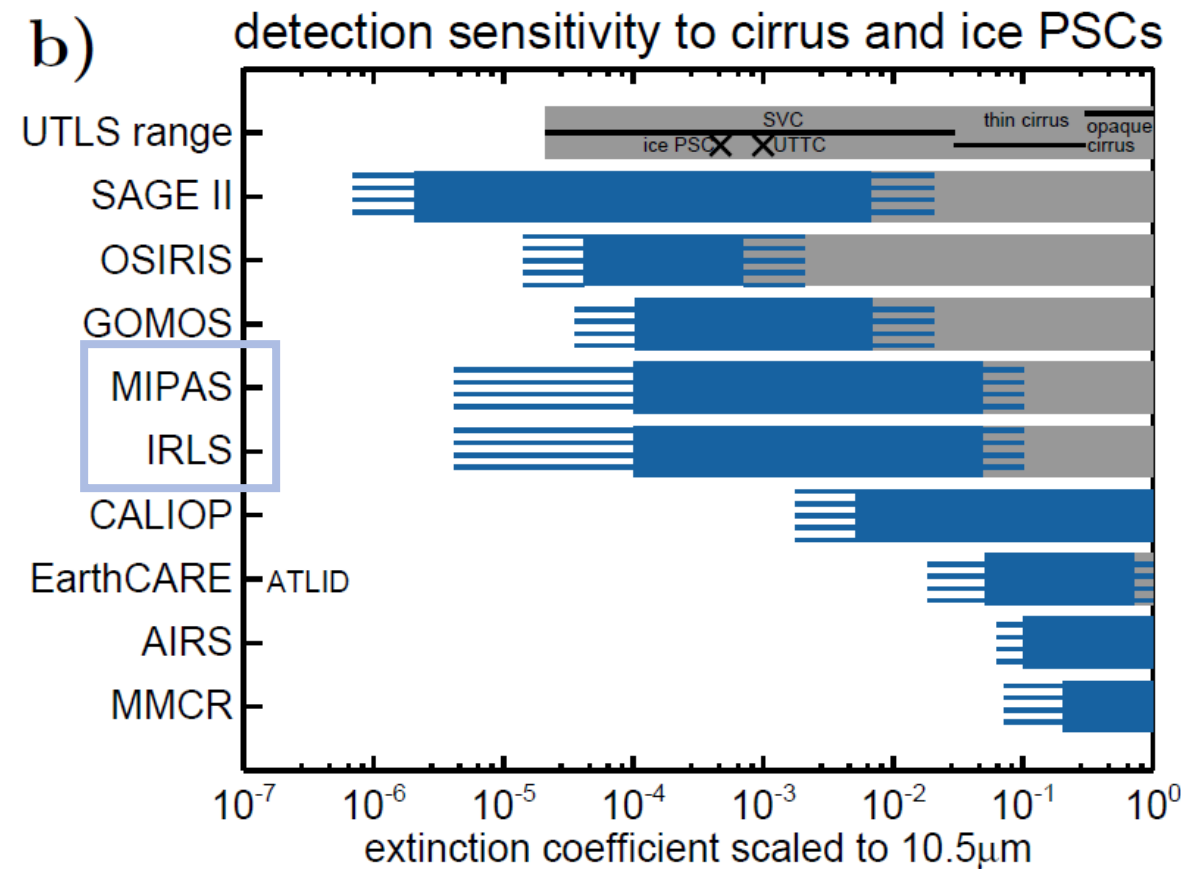
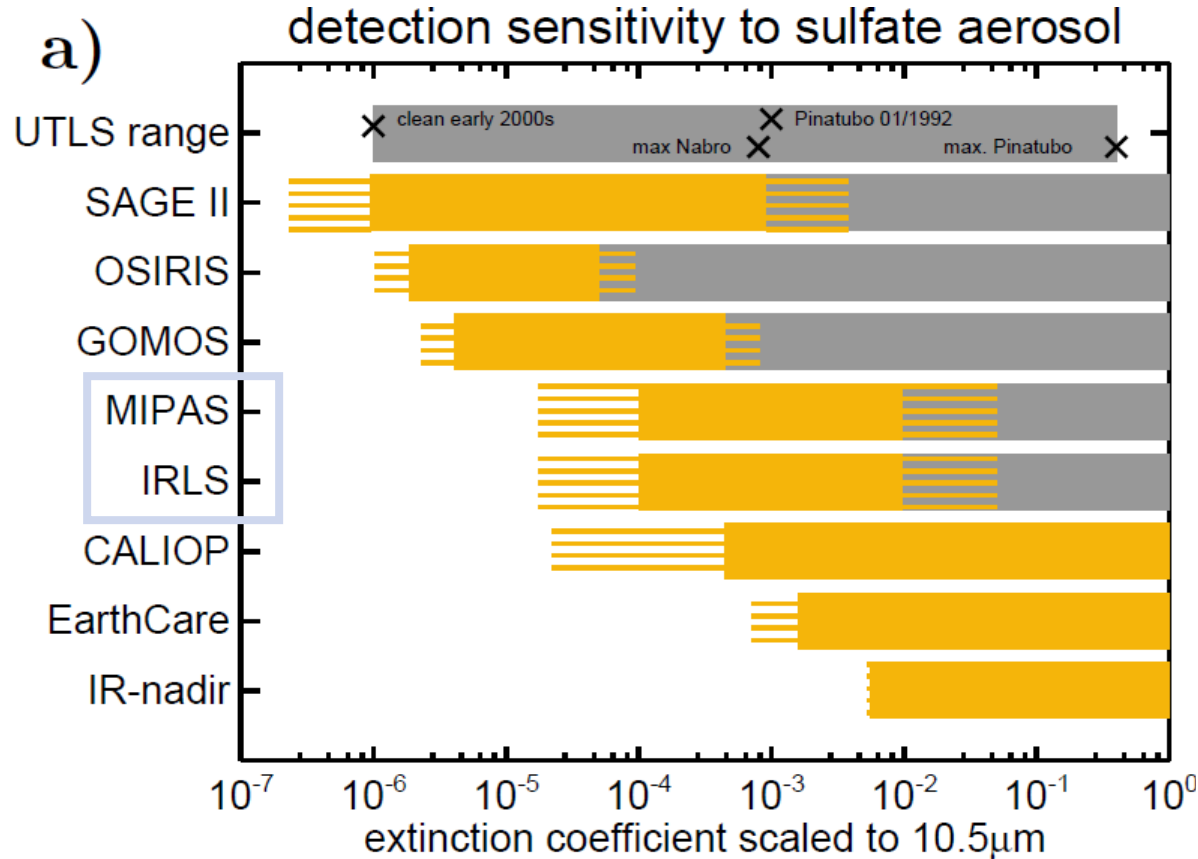


Limb
2D/3D
retrieval
needed



DETECTION SENSITIVITY: Aerosol & Cirrus

ESA study: Characterization of Particulates in the UTLS (PREMIER) [Griessbach et al., Final Report, 2018]



[Griessbach et al., in preparation for AMT]

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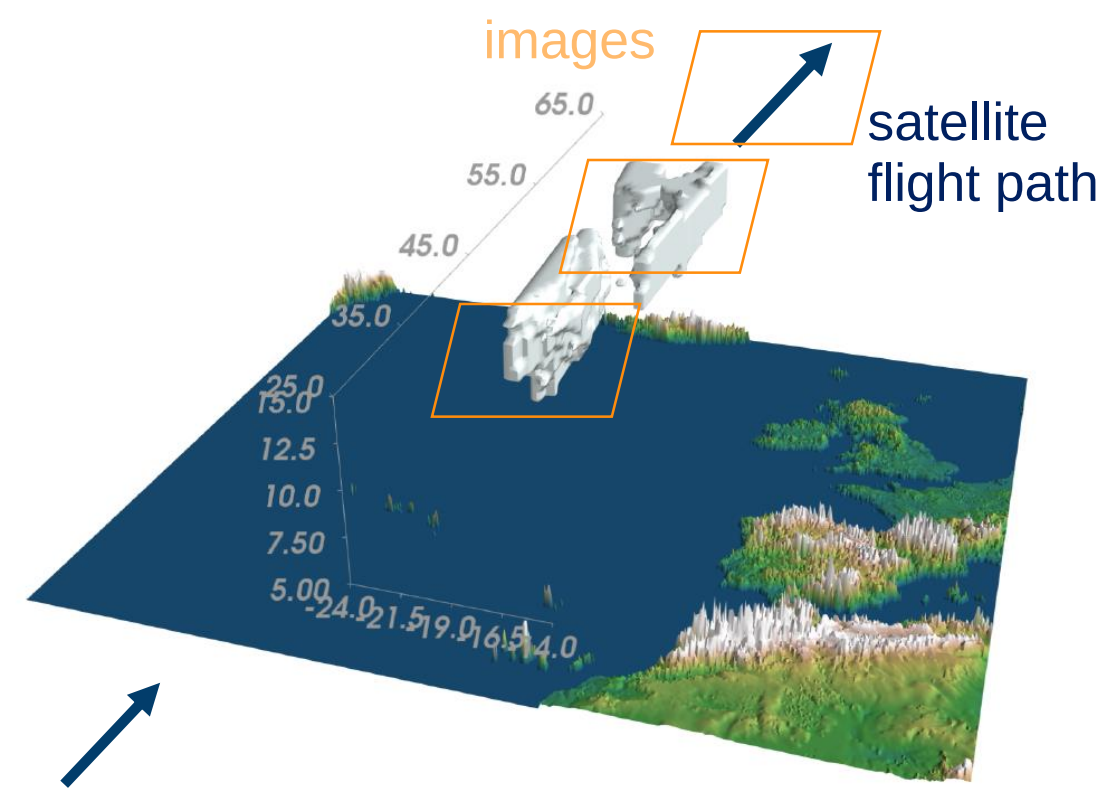
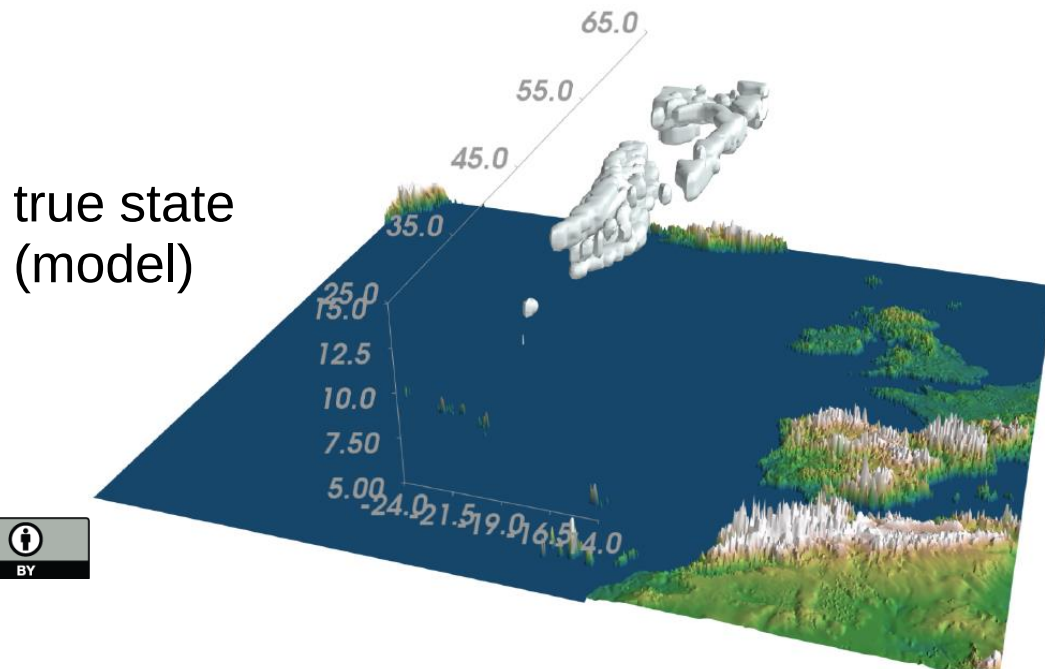
Detection thresholds IR limb: f (ice path)

$IWC_{1\text{km}} = 0.3 \text{ mg/m}^3$ ($\sim 0.1 \text{ ppmv}$)

$IWC_{100\text{km}} = 3 \cdot 10^{-3} \text{ mg/m}^3$

TOMOGRAPHIC RETRIEVAL

- **Radiative transport model: JURASSIC** with tomographic retrieval capabilities (temperature and trace gases, Ungermann et al. 2010, 2011)
- **Model (ClAMS-Ice):** delivers high resolution realistic IWC distribution
- IWC $\Rightarrow$ Extinction relation delivers a realistic 3D cirrus cloud distribution (below) $\Rightarrow$ RT modelled radiances

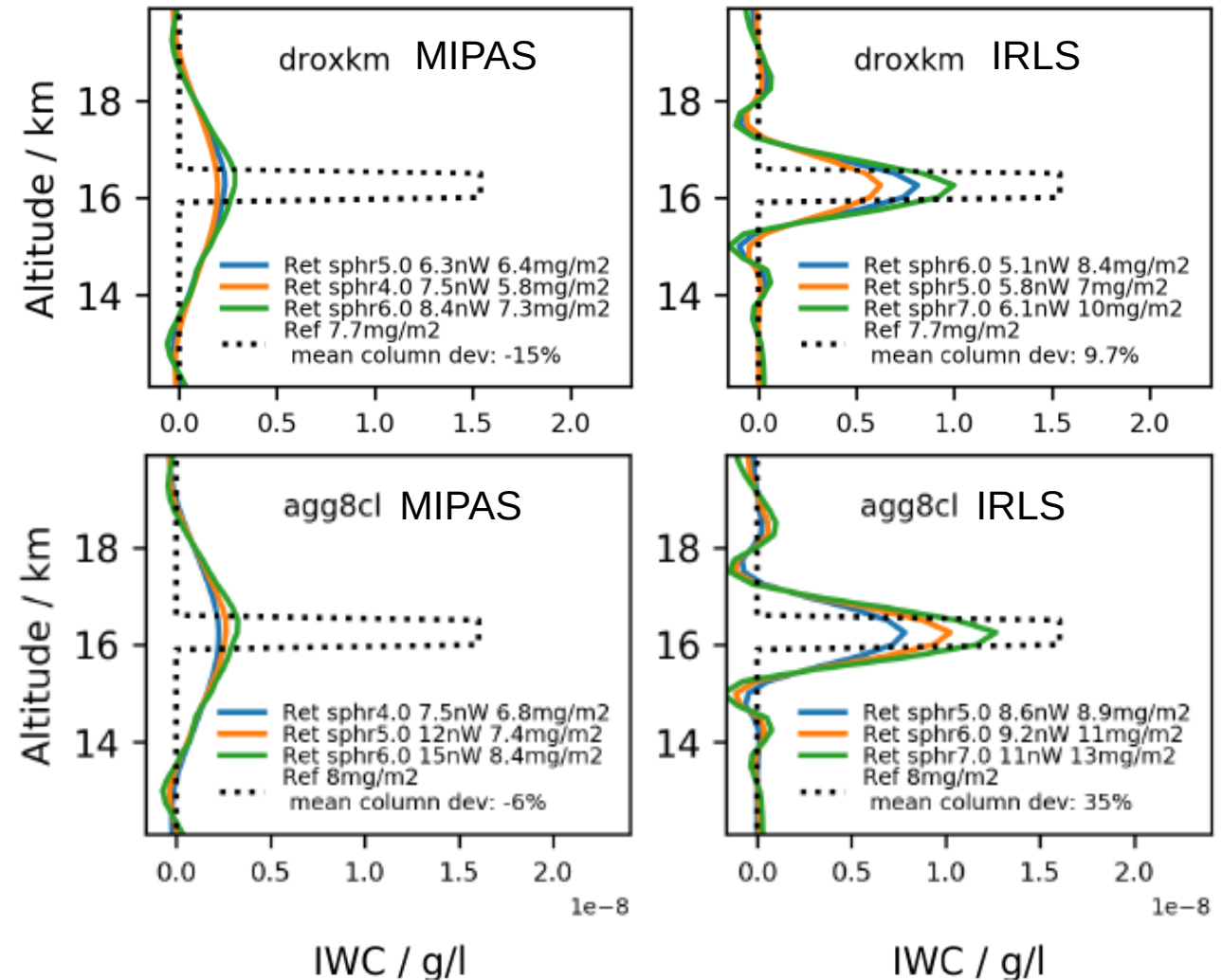


Result: ‘Tomographic’ 3D representation of a cloud structure with IR limb sounder (imaging) concept (**ATMOSAT / PREMIER**).

Source: Characterization of particulates in the upper troposphere/lower stratosphere. ESA final report, Griessbach et. al. (2018) and **Ungermann** et al. in preparation for AMT

MICROPHYSICAL RETRIEVAL FOR MIPAS AND IRLS

- Retrieval study for ultra thin tropical cirrus clouds (dotted)
- 1D, single scattering
- idealized retrieval of IWC and R_{eff}
- Various R_{eff} (color coded): best fit / minimizing error
- Spherical particles deliver good correspondence for vertical IWP with various particle habits (dotted line)
- Much better vertical resolution (1km) for IRLS



GLORIA

Description

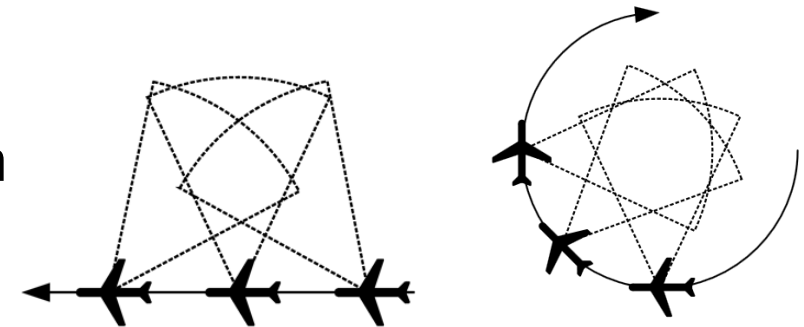
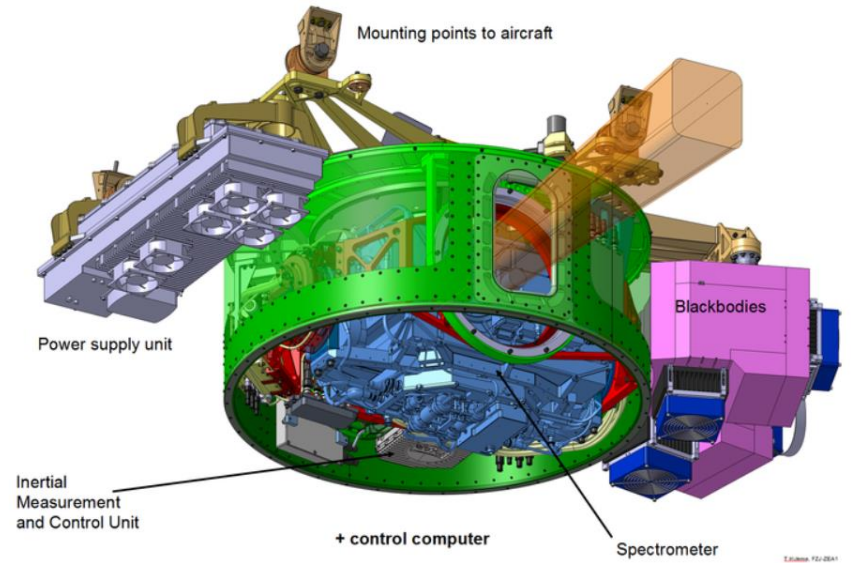
- **G**imbal**l**ed **L**imb **O**bserver for **R**adiance **I**maging of the **A**tmosphere.
- Infrared limb sounder ($780 - 1400 \text{ cm}^{-1}$).
- Imaging Michelson Interferometer + 2D detector.

Spatial sampling: $150\text{m} \times 150\text{m}$
(@10 Km tangent height)

Platform: HALO (Gulfstream) or
Geophysica

Three measuring modes:

- Chemistry mode: 0.0625 cm^{-1}
 - Premier mode: 0.2 cm^{-1}
 - Panorama mode: 0.2 cm^{-1}
- fixed viewing direction
changing viewing
direction

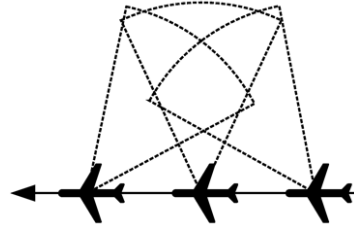


APPLICATION GLORIA: 1st Tomographic Cloud Retrieval

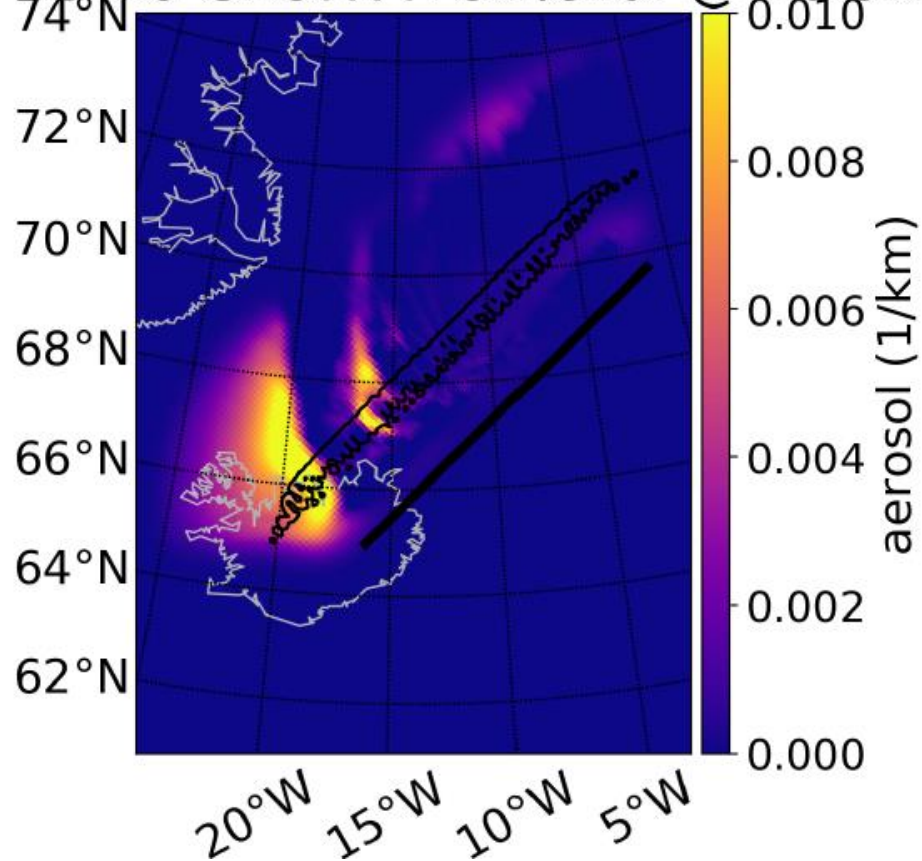
Make use of different viewing directions (panning) of the instrument

Horizontal and vertical extent of the cloud provide the tool for more accurate IWC retrievals

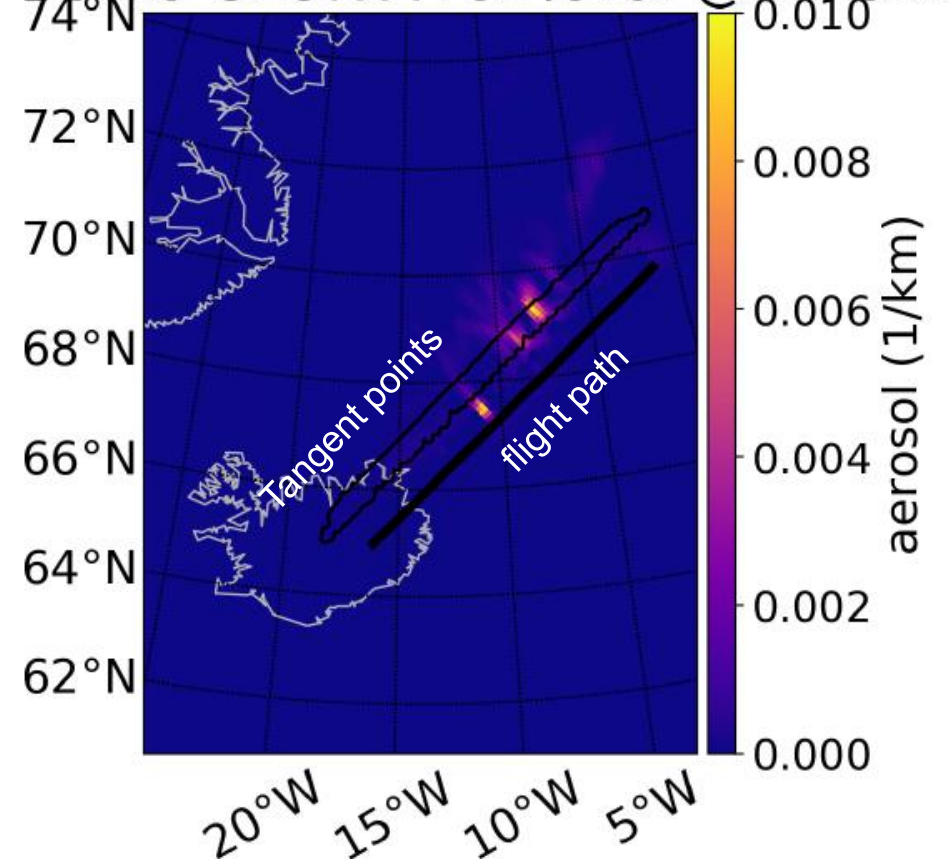
[Ungermann et al. in preparation for AMT]



2017-09-18 GLORIA retrieval @ 10.5km



2017-09-18 GLORIA retrieval @ 12.5km



SUMMARY & OUTLOOK

- Capabilities of IR limb sounding for cirrus have been improved for macro and microphysical quantities (CTH, base height, detection sensitivity, IWC / slant IWP, R_{eff} and shape/dimension of the cloud)
- Achieved by imaging capability (cross/long-track sampling or panning of instrument)
- Validation procedures are a challenge (especially for 3D tomography)
- Particle type classification (ice, background aerosol, volcanic ash, PSCs)

Future activities:

- IWC (and R_{eff}) retrieval for GLORIA (make use of in situ DB of particle size distributions)
- apply the IRLS/GLORIA tools to MIPAS (2D only, single scattering)
- make use of Machine Learning and AI tools for particle type classification

➤ PSC example: Sedona et al., AMTD, 2020 & Session AS3.24, EGU2020-8103

