# Limb sounding challenges in the context of IRS

C. Camy-Peyret

IPSL (Sorbonne Université/UVSQ) Paris, France

<claude.camy-peyret@upmc.fr>

EUMETSAT MAG MTG-IRS, 24-25 May 2018, Darmstadt, Germany

# Outline

- Past, current and future experiments using limb sounding
- MLS in the MW/sub-mm region
- ALTIUS
- AtmoSat
- ACE-FTS
- How MTG-IRS could benefit from limb sounders
- How limb sounders could benefit from MTG-IRS
- Possible strategies for specific target species
  - $H_2O$
  - $O_3$
  - CO
- Outlook

Note: Radio Occultation (GNSS) will not be covered

# MLS (JPL/NASA) in the A-train on Aura since 2004

Very well documented experiment, long time series, NRT delivery

Some products assimilated by some NWP centres or by CAMS

Very stable instrument (except for one dead channel)

Very sophisticated and robust retrieval algorithms for L2 products

Risk: at one point the platform or the instrument will cease operation

General approach to combine information from differents spectral regions like MW and IR as well as different geometries as limb and nadir on the same satellite (the best option) or on different satellites (co-registration differences)

# $H_2O$ from MLS (1/2)

https://mls.jpl.nasa.gov/products/h2o_product.php

How EOS MLS measures $H_2O$

The standard water vapor product is taken from the 190 GHz retrieval.

Due to the magnitude of changes with height in the upper troposphere, the vertical profile of water vapor is represented as piecewise-linear in the logarithm of water vapor mixing ratio versus logarithm of atmospheric pressure. For this reason, scientific studies using averages of MLS water vapor data should perform the averaging in logarithm of mixing ratio.

Quick Product Information for data version v4.2

- Swath Name: $H_2O$
- Status Flag: Only use profiles for which the Status field is an even number.
- Useful Range: 316 - 0.002 hPa

Download EOS Aura MLS $H_2O$ v4.2 data

# $H_2O$ from MLS (2/2)

## How $H_2O$ is part of MLS Science Objectives

Scientific objectives of MLS include quantifying upper tropospheric processes affecting climate change, and tracking recovery of the ozone layer.
The measurements of water vapor are crucial for both these objectives.

Water vapor is the dominant greenhouse gas in the troposphere. Its greatest influences on climate forcing is in the upper troposphere, and it is generally believed that water vapor amplifies the radiative forcing associated with the anthropogenic increases in carbon dioxide.
In the tropics upper tropospheric water vapor is closely linked to sea surface temperature and thus ocean-atmosphere coupling phenomena such as the El Nino southern oscillation can be observed.
Energy is released when water vapor condenses and large values of relative humidity, which is derived from water vapor and temperature, show where cloud formation is likely. Stratospheric water vapor influences stratospheric ozone chemistry both by providing a source of odd-hydrogen that destroys ozone and by influencing the formation of polar stratospheric clouds that trigger processes leading to large ozone loss in polar winter. Water vapor has been increasing in the stratosphere, believed due to changes near the tropical troposphere where water vapor enters the stratosphere.

# Tape recorder effect

Atmos. Chem. Phys., 17, 4337–4353, 2017
doi:10.5194/acp-17-4337-2017
Role of vertical and horizontal mixing in the tape recorder signal near the tropical tropopause
A. A. Glanville and T. Birner

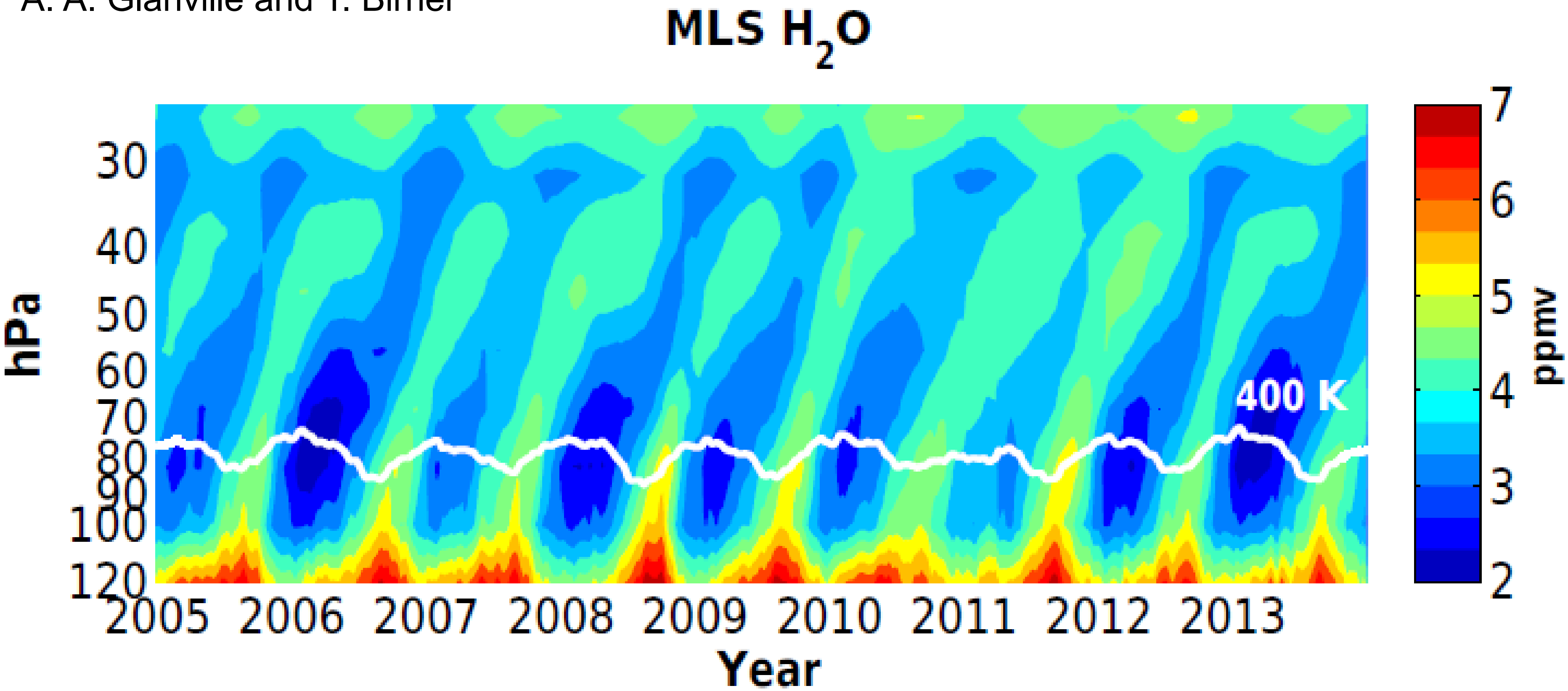



Figure 1. The zonal mean tropical (10 S–10 N) tape recorder signal of water vapor (the colored mixing ratio in ppmv) from the MLS observations. The white line marks the 400 K isentrope for reference.

# A climatology of measurements

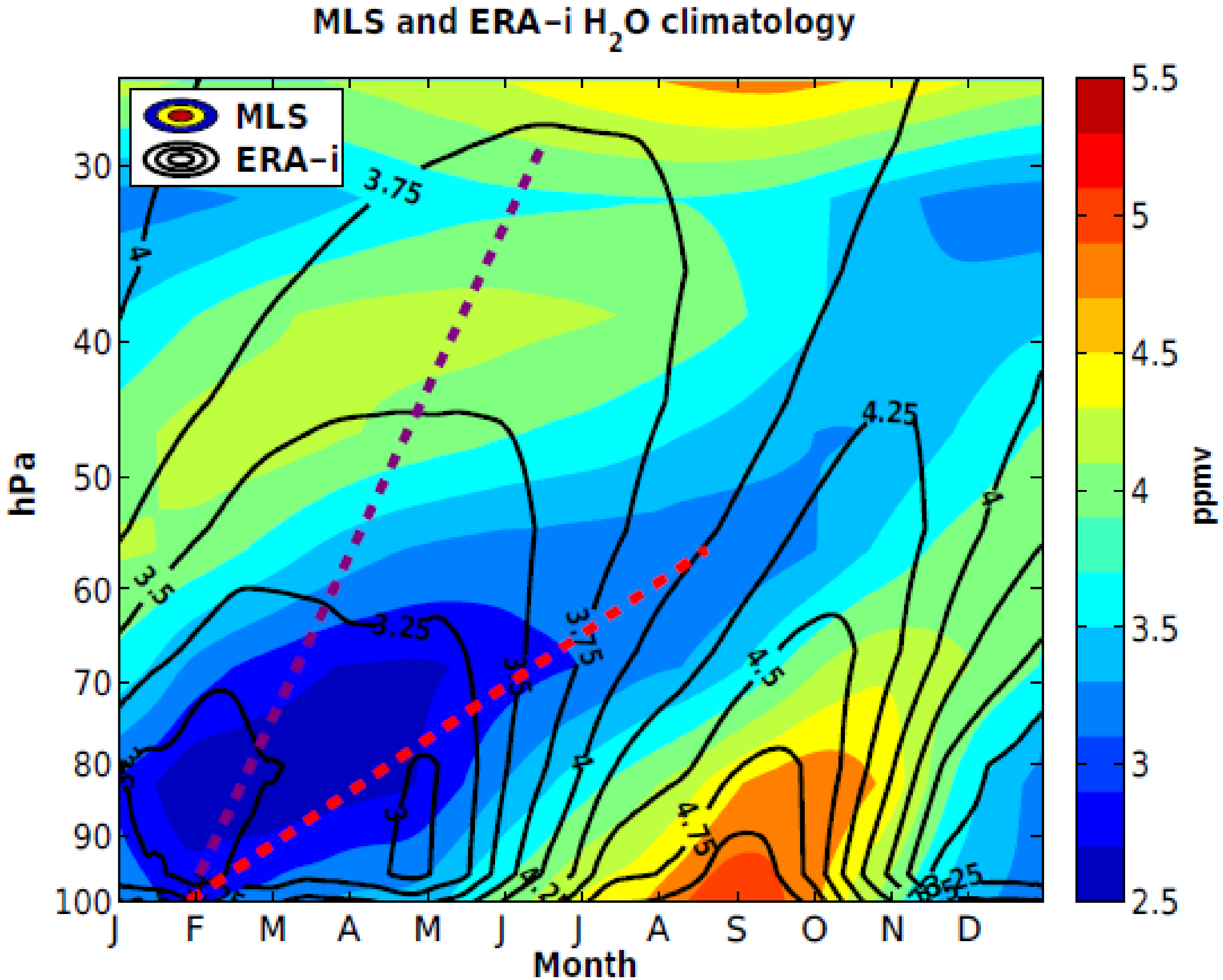



Figure 2. The climatological zonal mean tropical (10 S–10 N) tape recorder signal (the water vapor mixing ratio in ppmv) based on MLS (colors) and ERA-i reanalysis (black contours). The red and purple dotted lines roughly indicate the evolution of the dry minima with time for MLS and ERA-i, respectively.

# $O_3$ from MLS (1/2)

https://mls.jpl.nasa.gov/products/o3_product.php

How EOS MLS measures $O_3$

The standard product for $O_3$ is derived from MLS radiance measurements near 240 GHz

Quick Product Information for data version v4.2

- Swath Name: O3
- Status Flag: Only use profiles for which the Status field is an even number.
- Useful Range: 261 - 0.02 hPa

Download EOS Aura MLS $O_3$ v4.2 data

# $O_3$ from MLS (2/2)

## How $O_3$ is part of MLS Science Objectives

Ozone is a critical player in all three of the primary objectives of MLS: to track stability of the stratospheric ozone layer, to help improve predictions of climate change and variability, and to help improve understanding of global air quality.

MLS ozone measurements contribute to understanding of processes that control the expected recovery of the ozone layer as abundances of human-produced, ozone depleting substances decline in the coming decades.

Ozone, particularly in the upper troposphere (10 to 15 km), is an important greenhouse gas. While MLS does not measure ozone down to the Earth's surface, MLS measurements can be used to improve the vertical resolution of other sensors on the Aura satellite, allowing mid- and lower-tropospheric ozone to be distinguished the large amounts of ozone in the stratosphere and upper troposphere.

In the upper troposphere, ozone levels provide important information about the history of air parcels, with high ozone generally indicating descent from above and low ozone ascent from below.

# CO from MLS

https://mls.jpl.nasa.gov/products/co_product.php

How EOS MLS measures CO

The version 4.2 CO product is retrieved from radiances near the 230.5 GHz CO line

Quick Product Information for data version v4.2

- Swath Name: CO
- Status Flag: Only use profiles for which the Status field is an even number.
- Useful Range: 215-0.0046 hPa

Download EOS Aura MLS CO v4.2 data

How it is part of MLS Science Objectives

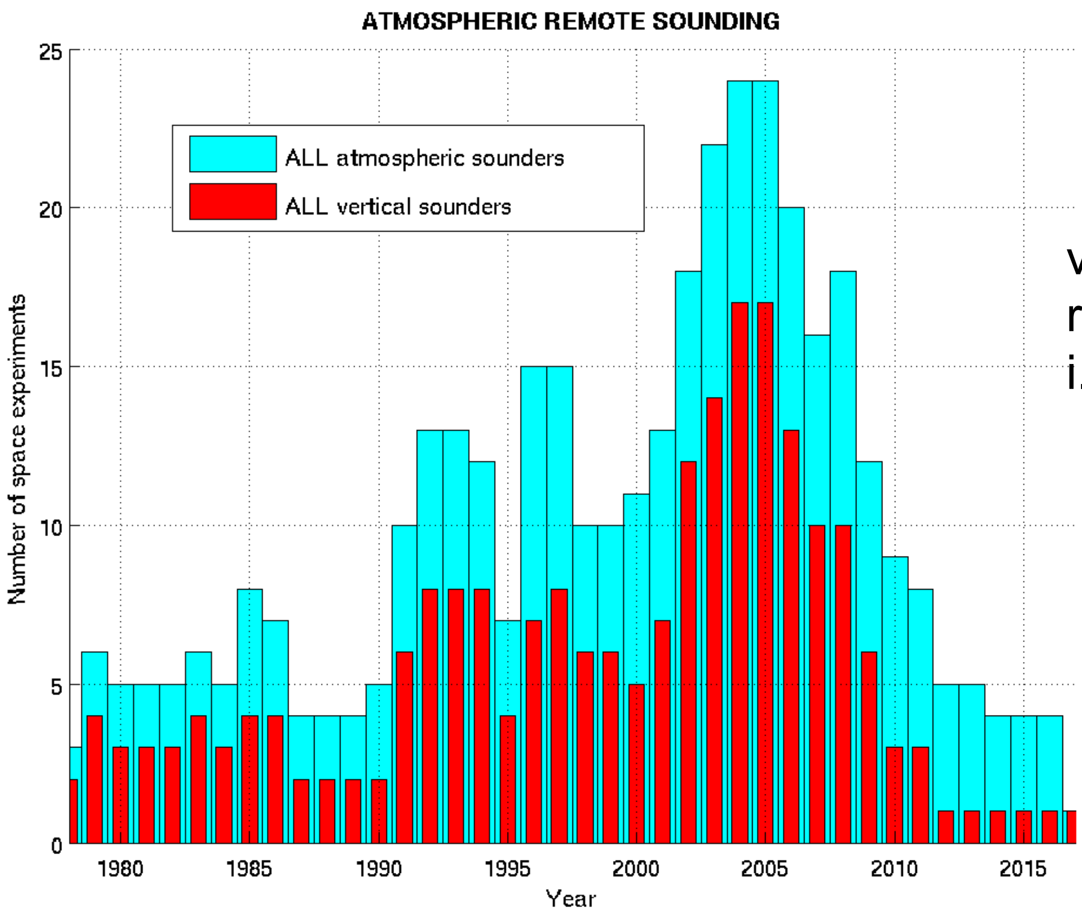
As a long-lived tracer, CO is valuable for diagnosing atmospheric transport and identifying the source of air masses. The MLS CO data help quantify long-range transport of pollution in the upper troposphere and the impact of upwelling from the troposphere and downwelling from the mesosphere on stratospheric chemistry.

# ALTIUS
# Atmospheric Limb Tracker for Investigation of the Upcoming Stratosphere

PI: Didier Fussen, BIRA-IASB
Initially in the Earth Watch programme
Programme decision acted
at the last interministerial conference

There is a **dramatic** decrease in the number of vertical atmospheric sounders: during the 2005-2006 period, 4 missions were interrupted:

SAGE II , HALOE, SAGE III, POAM III

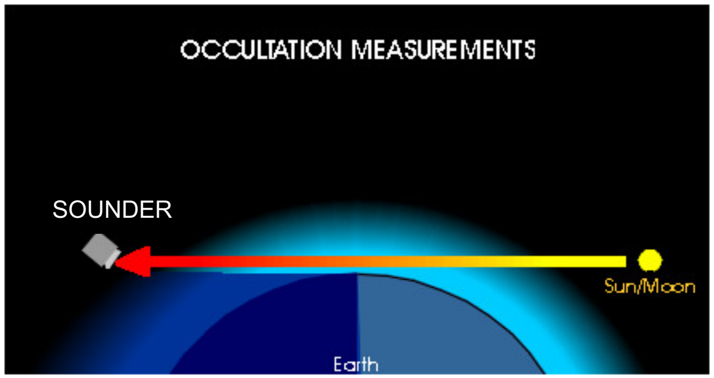


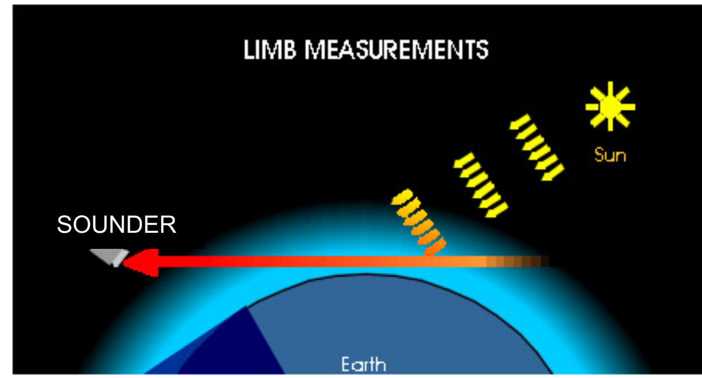

vertical=height resoved profiles i.e. limb sounders

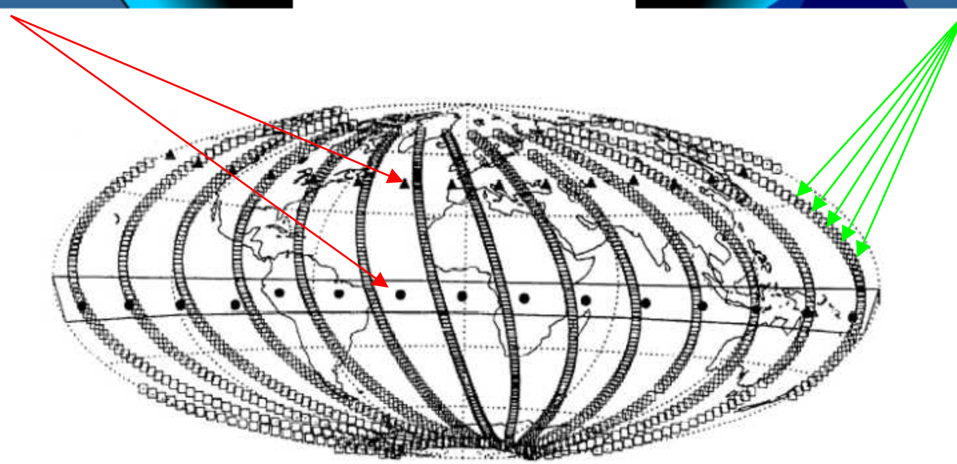
Coutesy: D. Fussen

Technological innovation is presently stimulating the field of vertical atmospheric remote sounding.

PAST → FUTURE



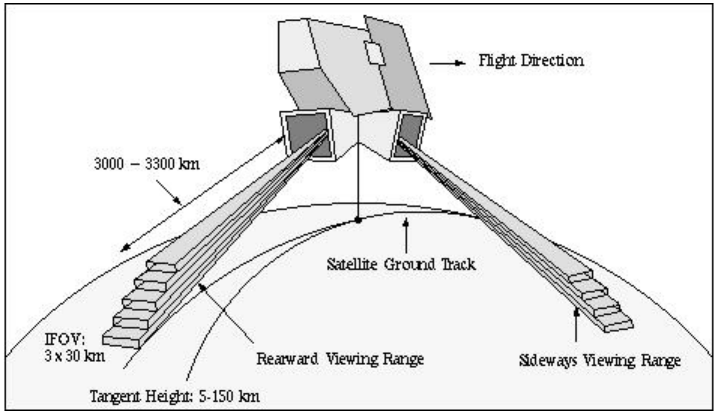



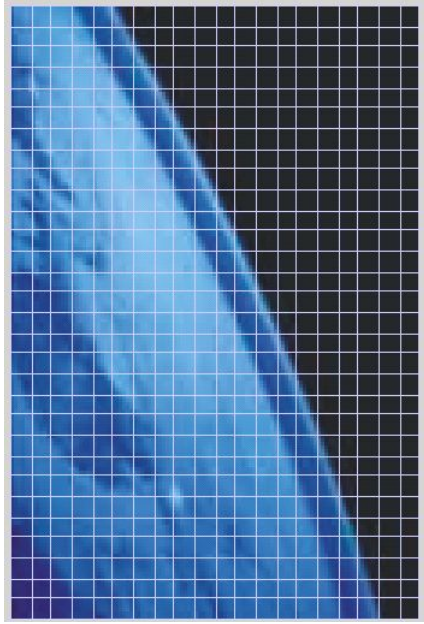
Limb sounding allows for a global coverage in 1-3 days

Coutesy: D. Fussen

PAST → FUTURE




LIMS
MIPAS (LWIR)
SCIAMACHY (limb)
SMR, OSIRIS



Limb scan

Filter, FTS or grating spectrometers

Vertical profiles

Full 2-D limb imaging

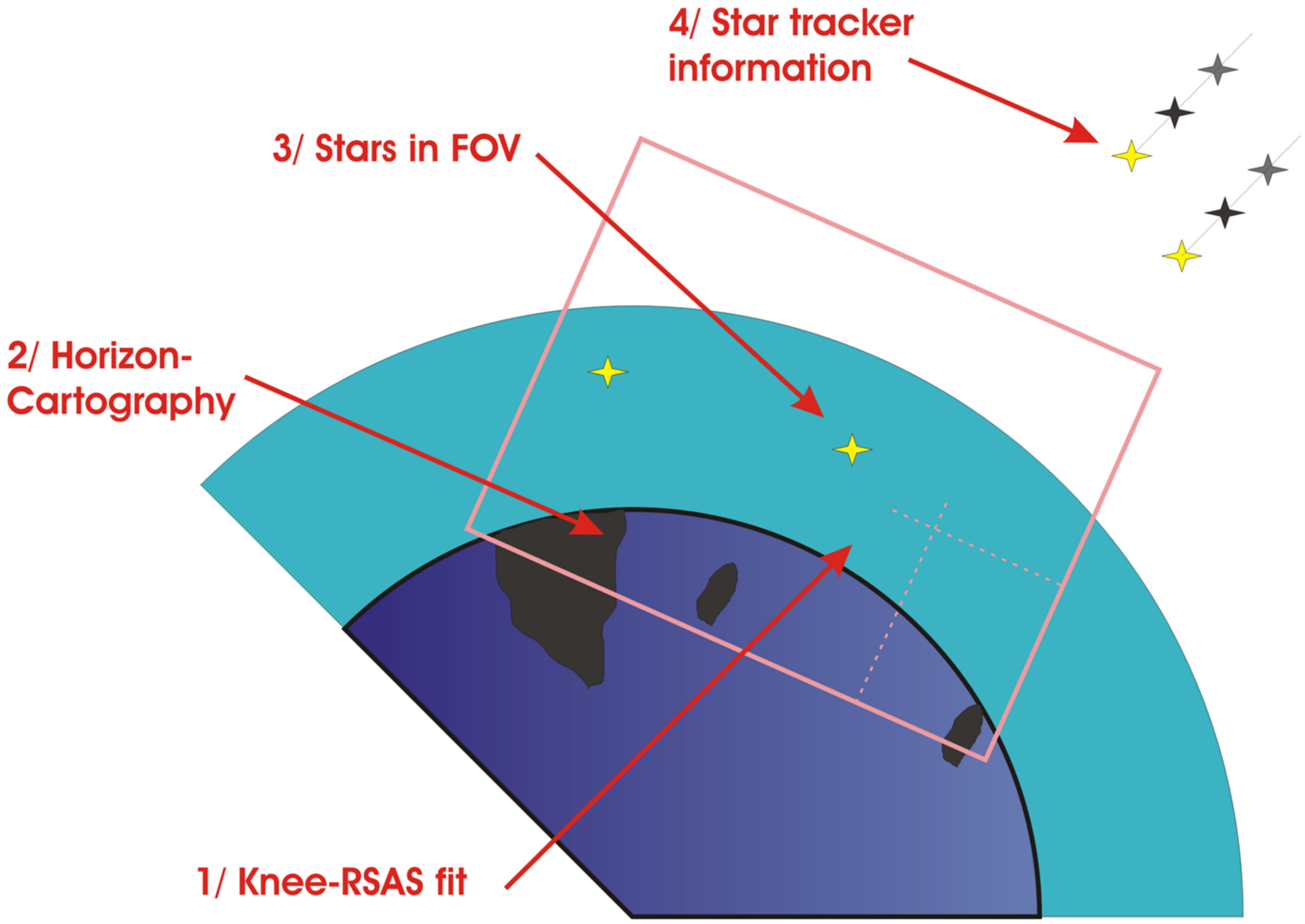
Acousto-optical filters

Vertical profiles and horizontal gradients

ALTIUS uses the simple concept of a spectral camera i.e. a combination of an AOTF filter with a 2-D imager → hyperspectral imaging of the limb

Coutesy: D. Fussen

# Altitude registration of ALTIUS FOV



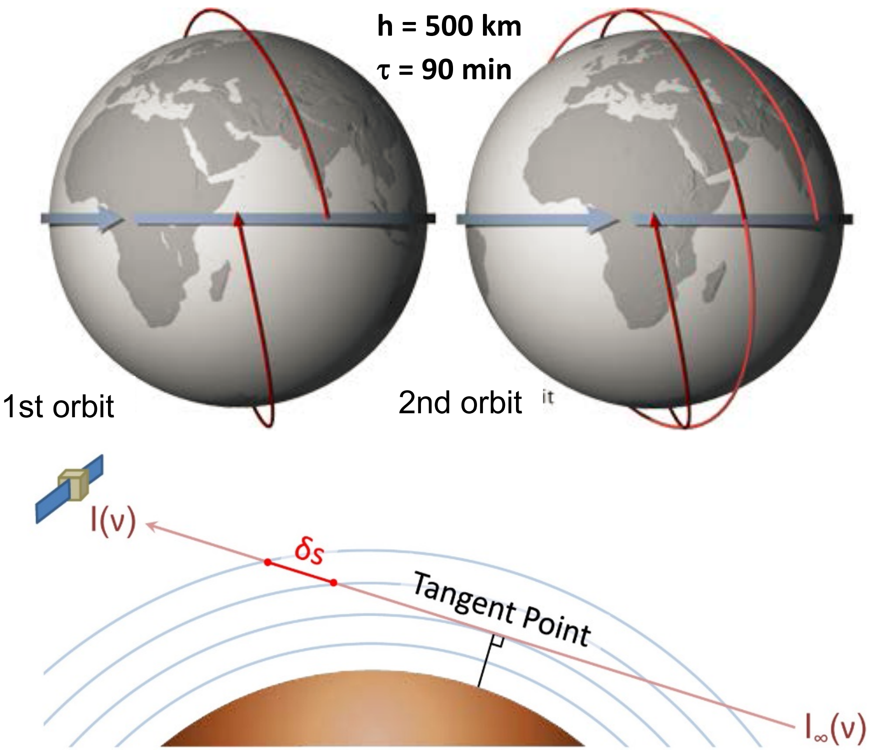

Coutesy: D. Fussen

# AtmoSAT

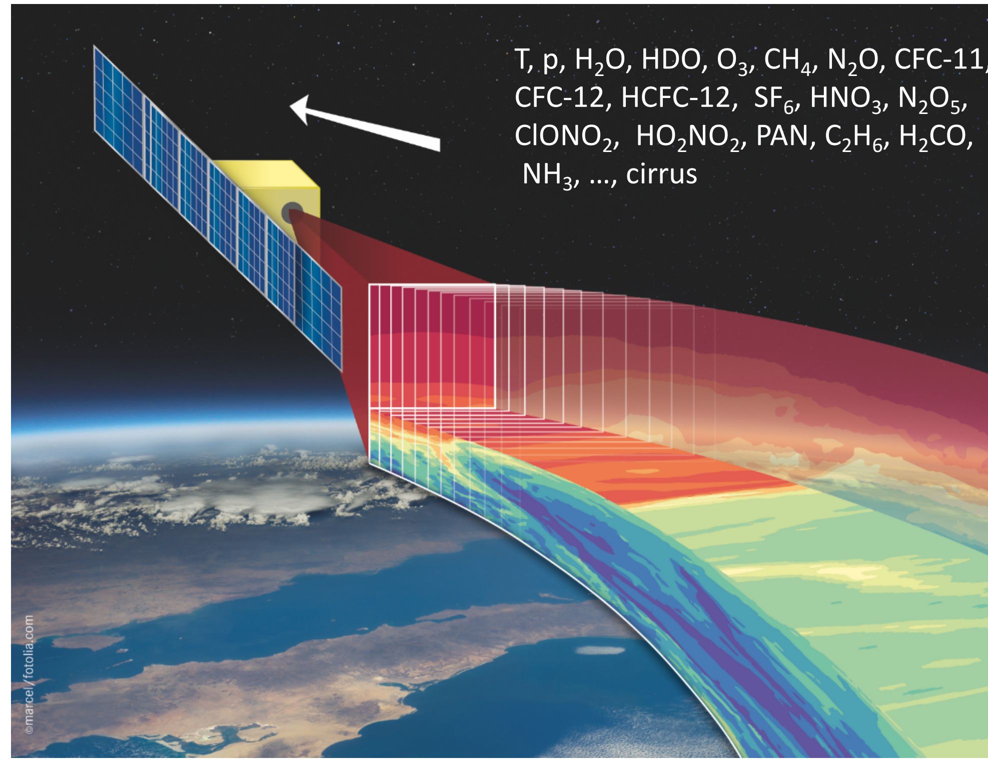
PI: J. Orphal, KIT
Support from DLR
and the German research organisations

# AtmoSat: research infrastructure to investigate the influence of the middle atmosphere (5 to 100 km) on global and regional *climate* and *weather*

## Limb sounding




## **3D** hyperspectral limb imaging




Addressing the looming limb gap!

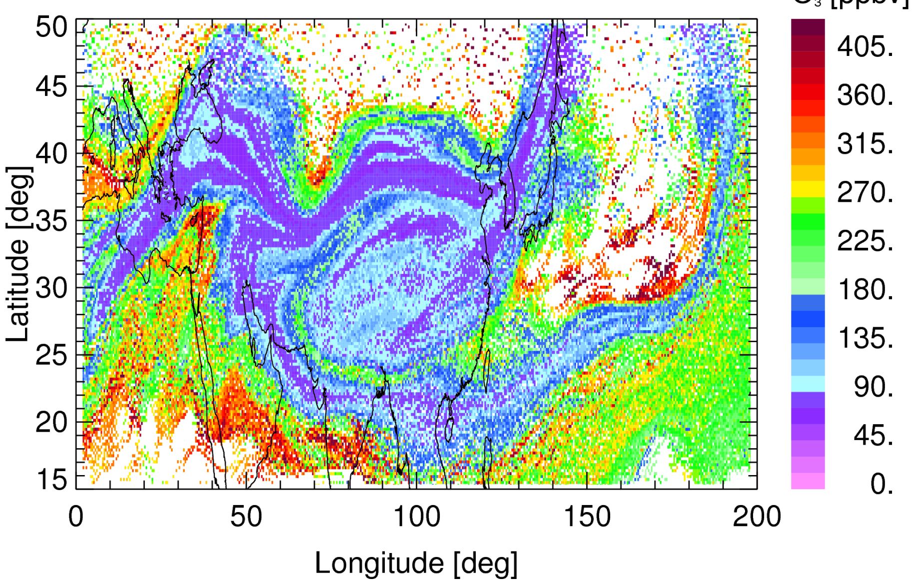
First global 3D view on meso-scale processes important for global and regional climate and weather.

Courtesy: J. Orphal

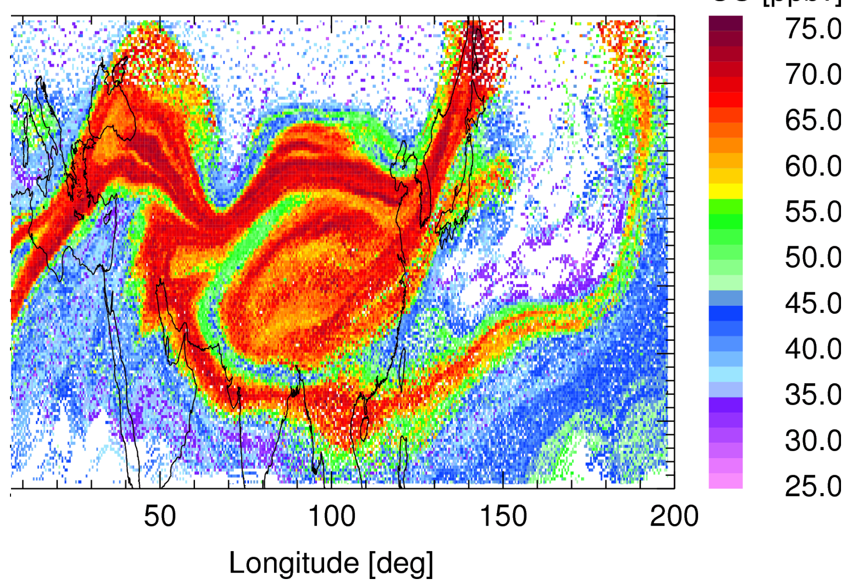
# Observation of atmospheric processes relevant for surface climate variability (stratosphere-troposphere exchange)

- Transport and mixing by the Asian Monsoon (420 K, ~18 km)

Ozone simulation, August 9, 2003




CO simulation

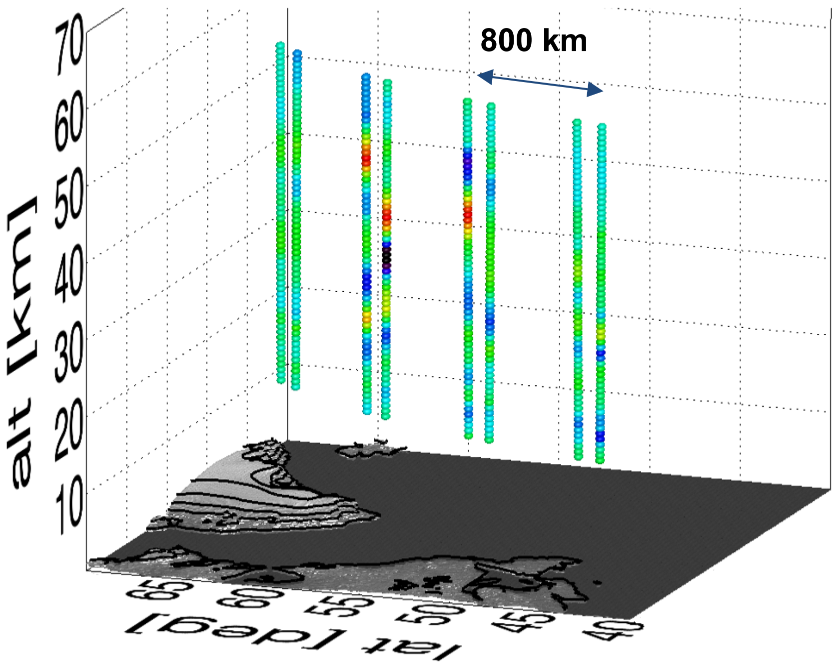



- First global space mission capable to resolve fine filamentary structures important for transport and mixing.

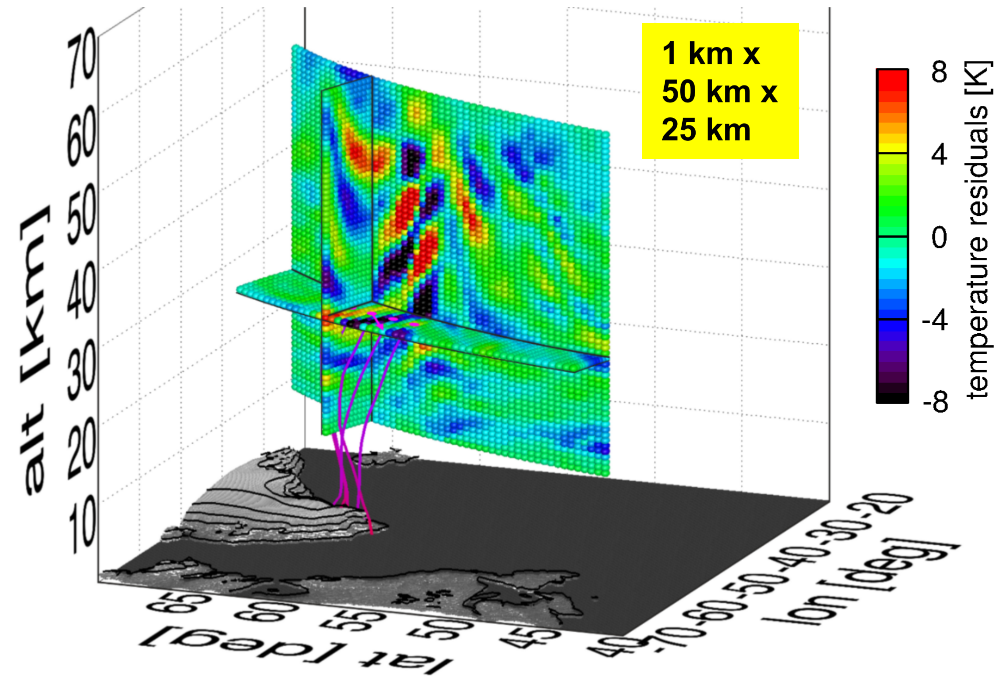
Courtesy: J. Orphal

# Observation of gravity-wave induced temperature structures

## Saber-like (2D)




## AtmoSat-like (3D)

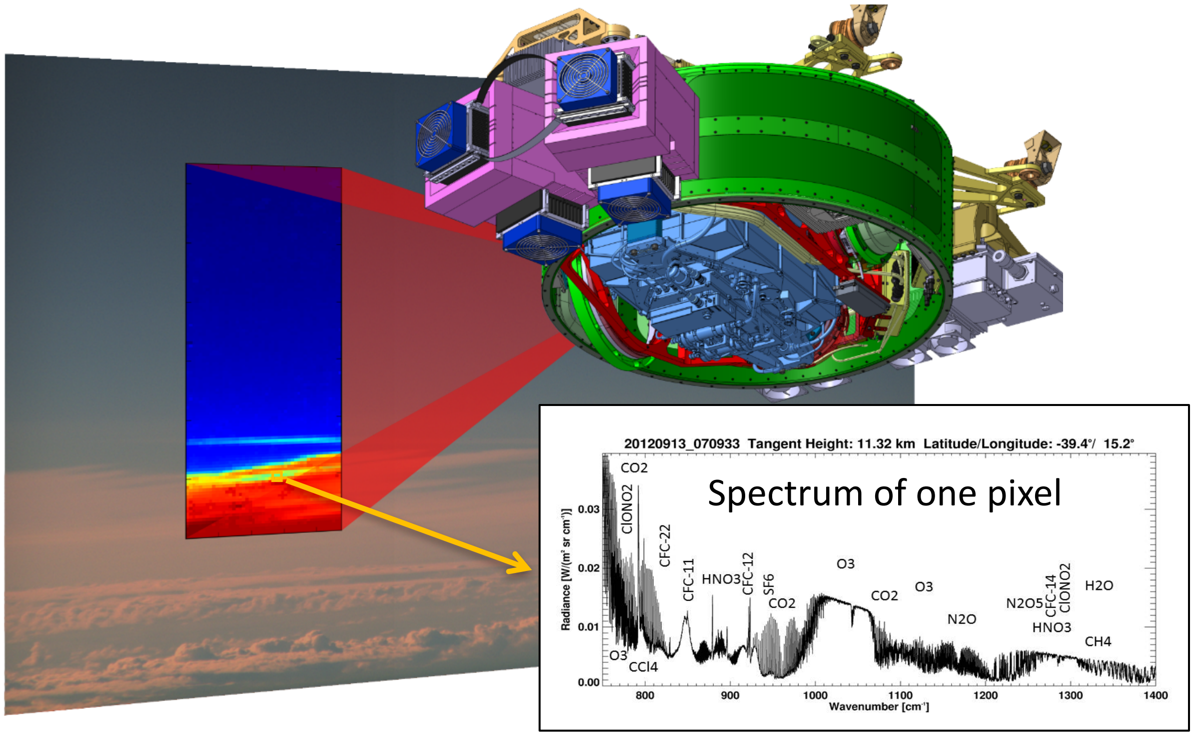


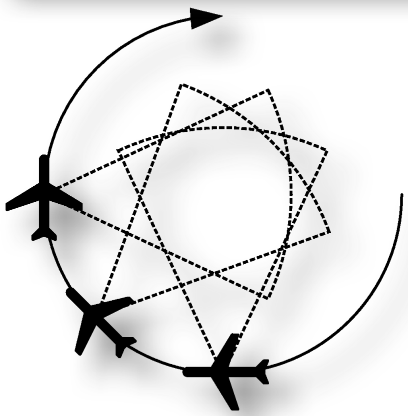

- First global observations of 3D wave vectors (3D momentum fluxes)

Observations (3D) → Improved process representation → Improved climate projections

Courtesy: J. Orphal

# Airborne demonstrator GLORIA



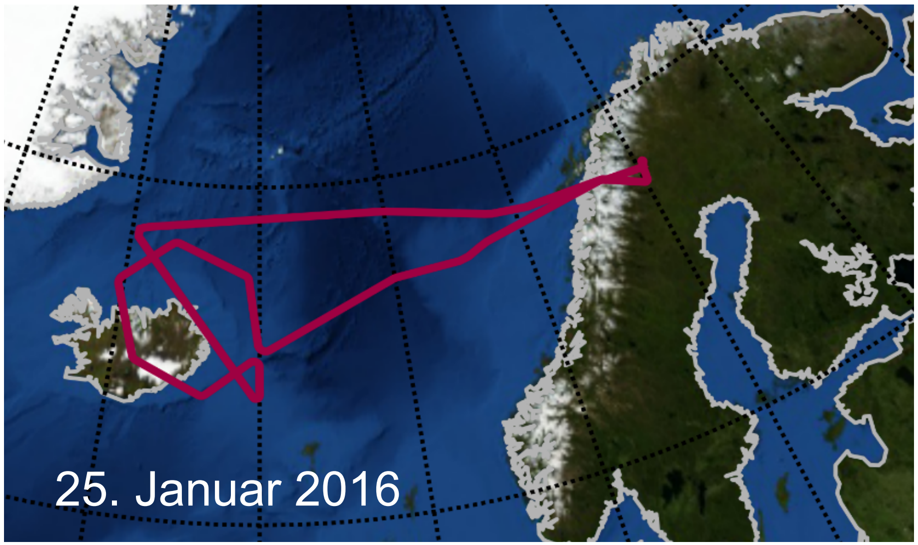
Temperature, $H_2O$, HDO, $O_3$, $CH_4$, $N_2O$, CFC-11, CFC-12, HCFC-12, $SF_6$, $HNO_3$, $N_2O_5$, $ClONO_2$, $HO_2NO_2$, PAN, $C_2H_6$, $H_2CO$, $NH_3$, ..., cirrus

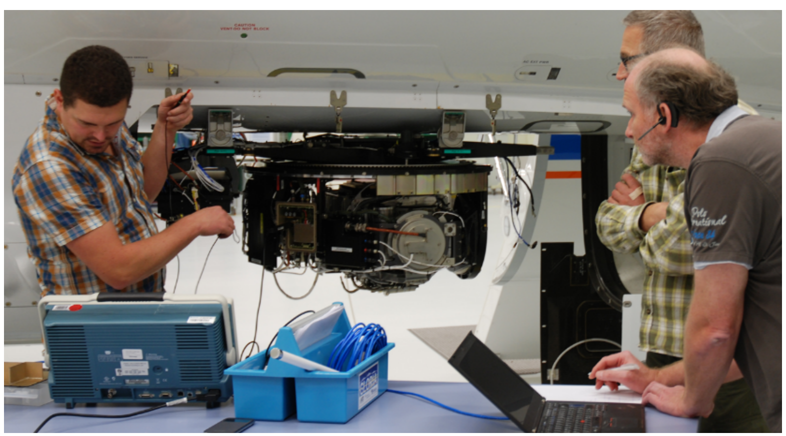
- Novel measurements on German research aircraft HALO

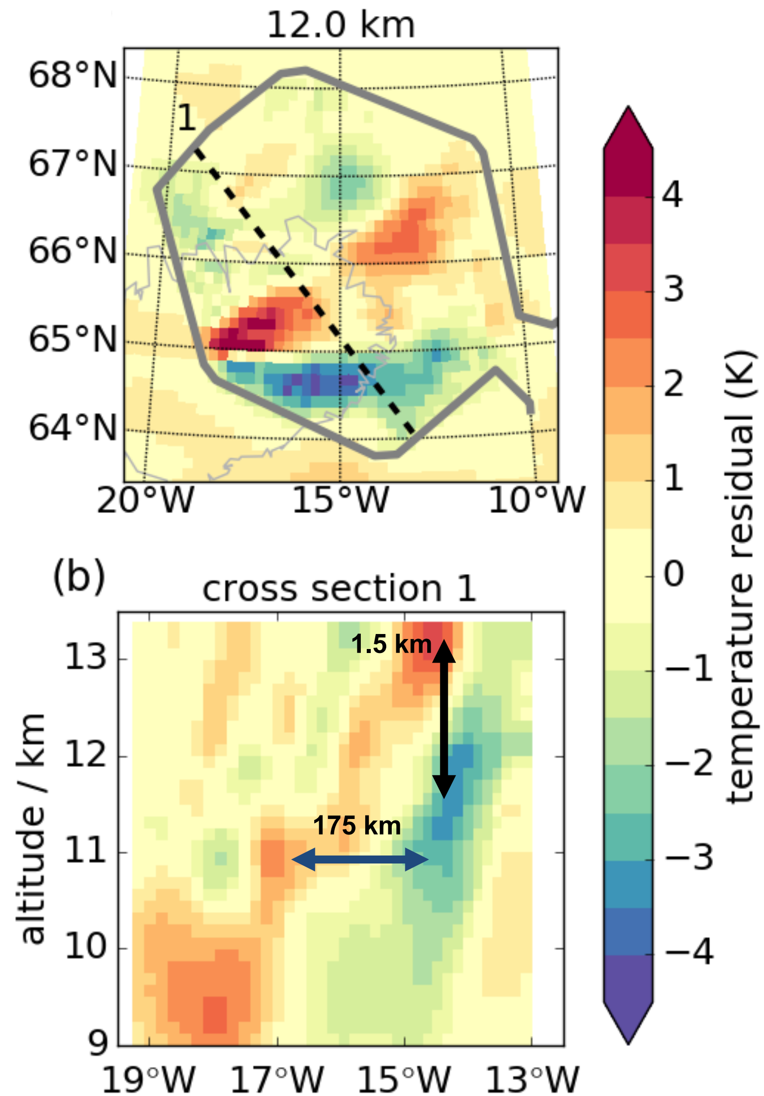
Courtesy: J. Orphal

# New developments since proposal submission

## First 3D tomographic observations of gravity waves






Courtesy: J. Orphal

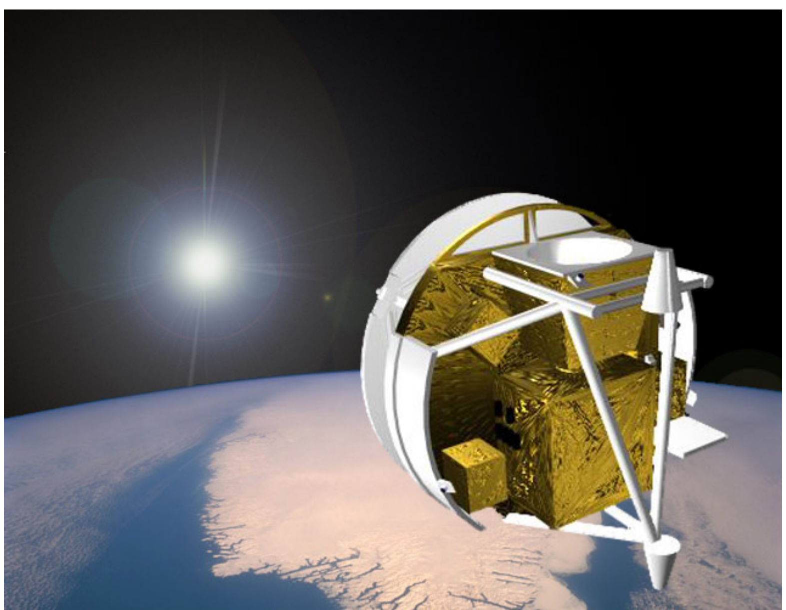
## Canadian perspective
## CSA (Canadian Space Agency)
## ABB provider of ACE-FTS and other FTS instruments

Courtesy: K. Walker

# ACE on SCISAT-1

## Atmospheric Chemistry Experiment (ACE) Satellite Mission:

Mission to measure atmospheric composition: profiles of trace gas species, cloud and aerosol extinction and temperature/pressure



**Launch date:** 12 August 2003

**Orbit:** 74° inclination at 650 km

**Measurement mode:** solar occultation

**ACE-FTS:**

- FTIR spectrometer, 2-13 μm at 0.02 $cm^{-1}$ resolution
- 2-channel visible/NIR imager, 0.525 and 1.02 μm

**MAESTRO:**

- dual UV / visible / NIR grating spectrophotometer, 285 to 1030 nm at ~1-2 nm resolution

**Pointing:** suntracker in ACE-FTS

Courtesy: K. Walker

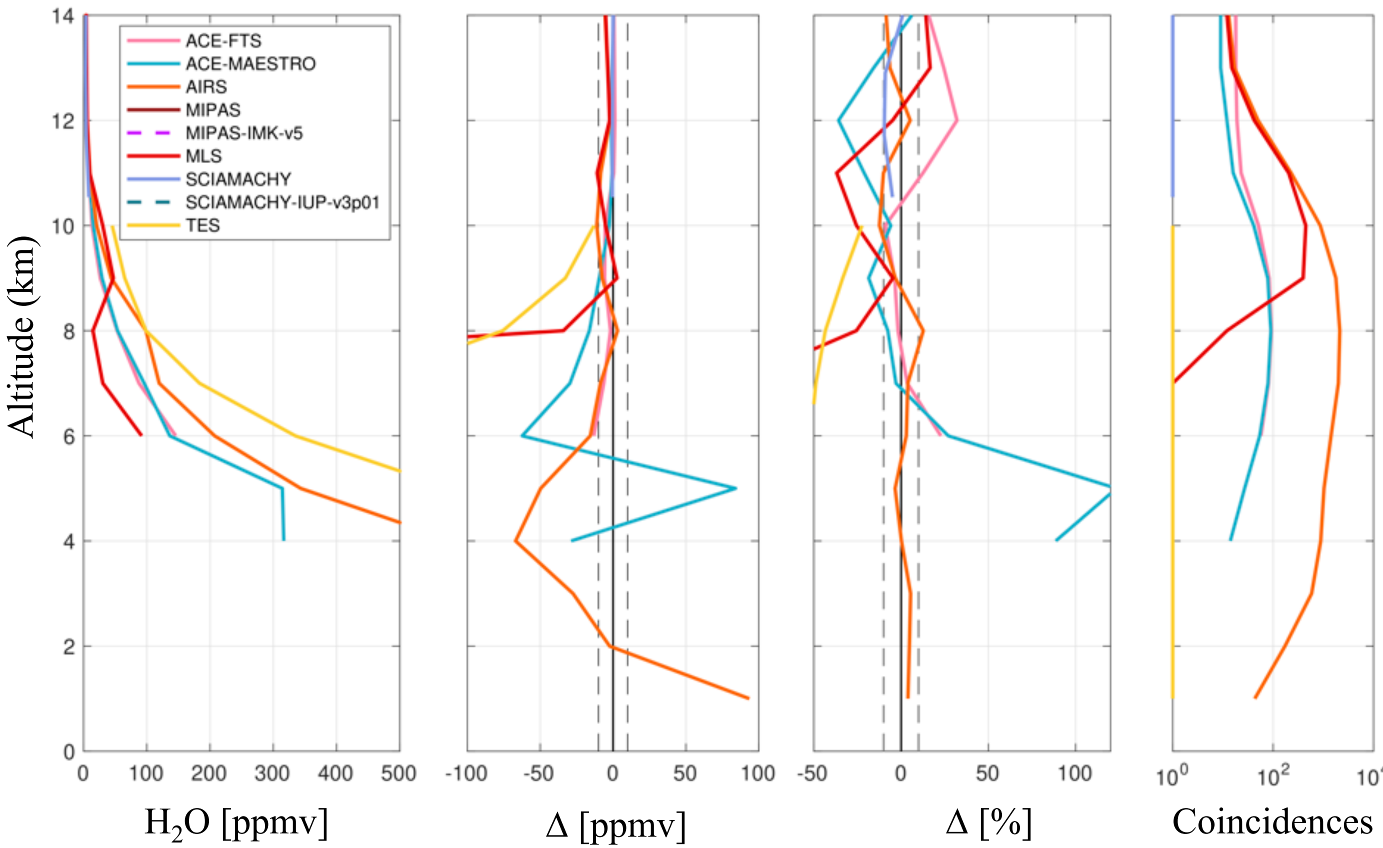
# ACE Data Products

- ACE-FTS profiles (current version 3.5; previous v2.2+updates):
  - Tracers: **$H_2O$, $O_3$**, $N_2O$, NO, $NO_2$, $HNO_3$, $N_2O_5$, $H_2O_2$, $HO_2NO_2$, $N_2$
  - Halogen-containing gases: HCl, HF, $ClONO_2$, CFC-11, CFC-12, CFC-113, $COF_2$, $COCl_2$, COFCl, $CF_4$, $SF_6$, $CH_3Cl$, $CCl_4$, HCFC-22, HCFC-141b, HCFC-142b
  - Carbon-containing gases: **CO,** $CH_4$, $CH_3OH$, $H_2CO$, HCOOH, $C_2H_2$, $C_2H_6$, OCS, HCN and pressure / temperature from $CO_2$ lines
  - Isotopologues: Minor species of $H_2O$, $CO_2$, $O_3$, $N_2O$, CO, $CH_4$, OCS
  - Research species: $CH_3CN$, acetone, $SO_2$, peroxyacetyl nitrate (PAN)…
- MAESTRO profiles (current version 3.13; validated version 1.2):
  - **$O_3$**, $NO_2$, optical depth, aerosol and water vapor **$H_2O$** (research version)
- IMAGERS profiles (current version 3.5; validated version 2.2):
  - Atmospheric extinction & aerosol extinction at 0.5 and 1.02 μm

Courtesy: K. Walker

# $H_2O$ profiles versus radiosondes

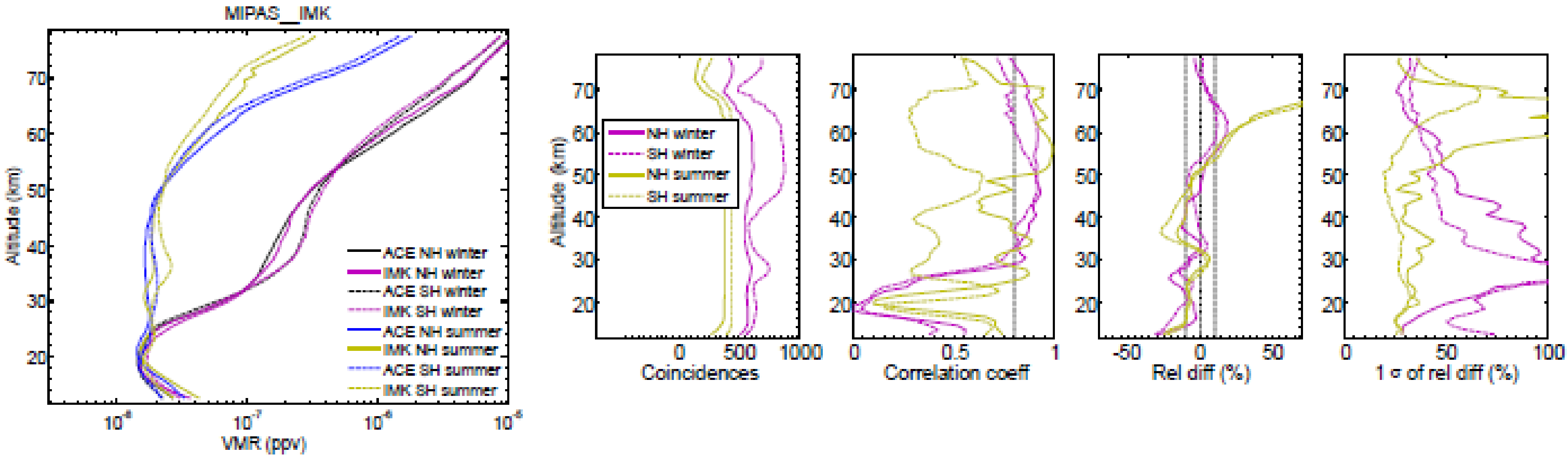
- Using coincident radiosondes from Eureka Weather Station (~80 N, 86W)
- Tropospheric performance shown for ACE-MAESTRO
- 2009-2017 period for comparisons

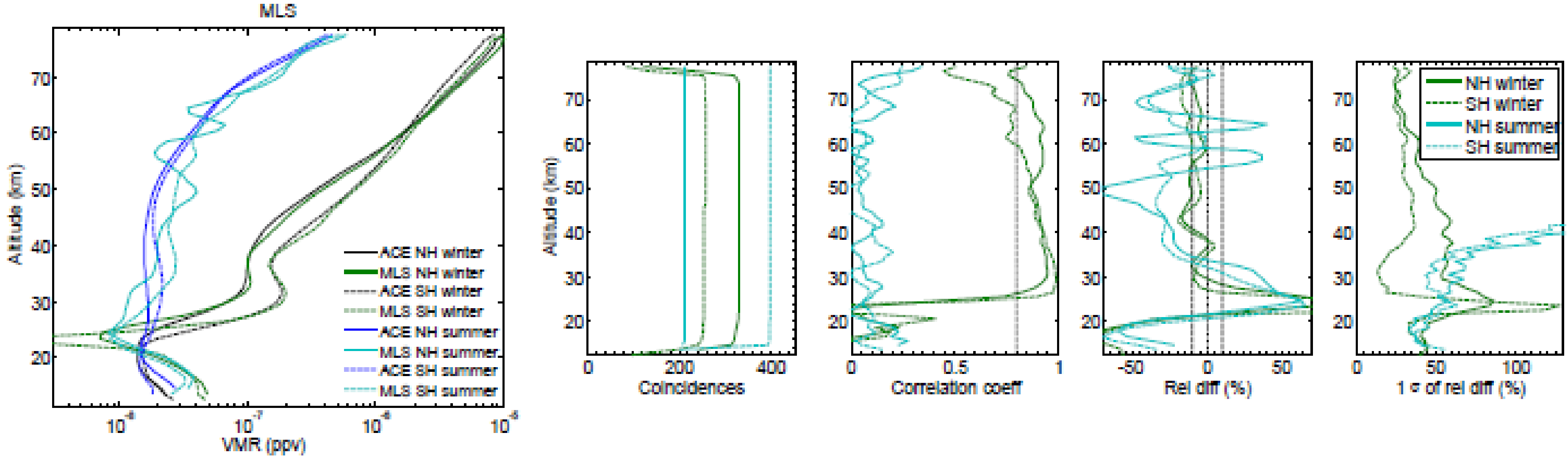



Calculated as (Satellite – Radiosonde); Relative to Radiosonde

**D. Weaver et al., in preparation.**

# Highlights: ACE/MIPAS/MLS CO






Courtesy: P. Sheese

# Possible strategies for specific target species

$H_2O$ → one of the prime target of MTG-IRS

$O_3$ → atmospheric photochemistry and dynamics

CO → atmospheric composition and transport

Limb sounders can complement the loss of sensitivity of MTG-IRS in the UT/LS (capacity to retrieve the vertical structure)

Limb sounders can help to confirm/assign a proper height (through $H_2O$ profiles) to AMV derived from MTG-IRS L2 products (optical flow method) with high temporal resolution and high horizontal resolution

# Possible strategies for MTG-IRS

- The number of limb sounders available when MTG-IRS is in orbit is limited
- The species that can be measured by other limb sounders are not always the ones that MTG-IRS can measure (example $CH_4$ from ACE-FTS)
- But two important species can benefit from the complementarity between nadir sounding and limb imaging: $H_2O$ (for meteorology and climate) and $O_3$ (for dynamics and chemistry)
- One other important species is CO (for air quality)
- IRS itself could be used (in a test mode) to check if limb imaging information is available/usable

# Outlook

- There is uncertainty on the duration of the availability of MLS data $\rightarrow$ examine if it is worth investing in commonalities with MTG-IRS for $H_2O$
- ALTIUS is decided and would provide NRT $O_3$ profiles that could be combined with MTG-IRS total or partial columns of ozone
- AtmoSat is another potential candidate for possible synergies with MTG-IRS
- The MAG may discuss priorities and promote synergies between MTG-IRS and the existing (or possibly future) limb sounders
- Need for studies initiated/supported by Eumetsat

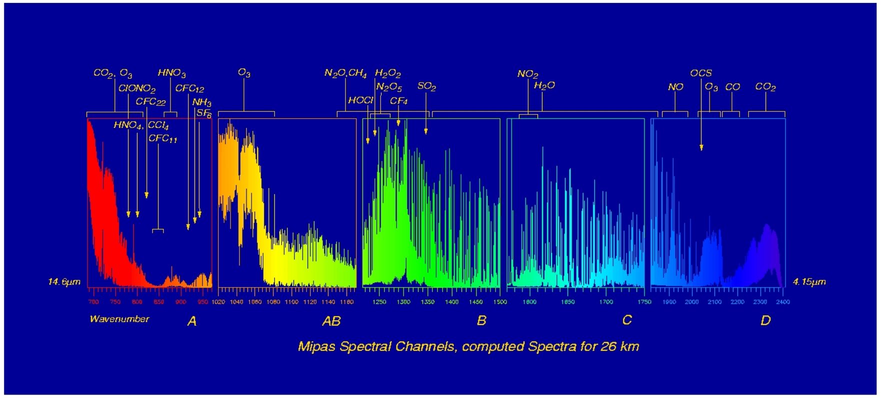
## STATEMENT OF GUIDANCE FOR GLOBAL NUMERICAL WEATHER PREDICTION (SoG for GNWP)
From Erik Andersson, ECMWF (11 May 2018)

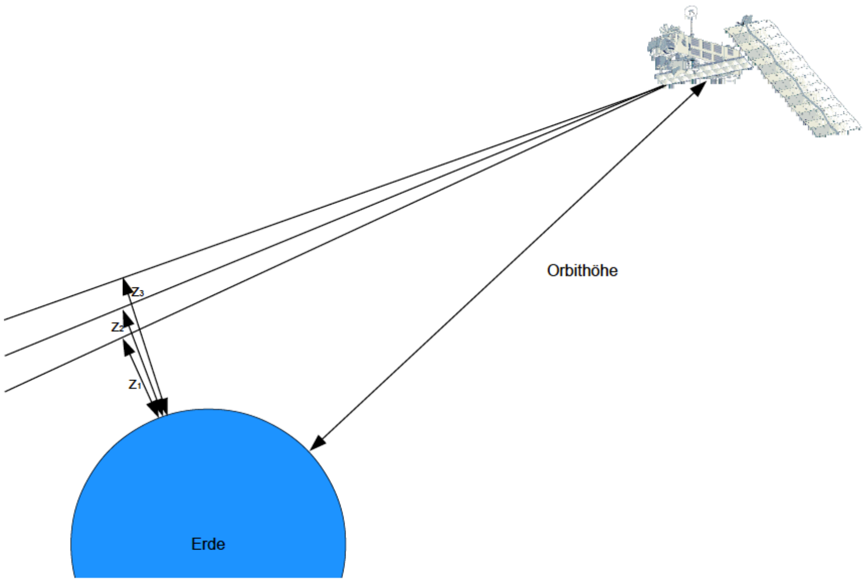
Great potential is offered by limb sounders (such as MLS) because they offer good vertical resolution and accuracy. However, these instruments are not envisaged to be included in the payload of any scheduled operational platform, and rely therefore on research missions. This has consequences in terms of long-term data continuity, and often also in terms of a data availability with a timeliness suitable for NWP (e.g. ACE-FTS). There is a clear unmet need for sustainable, longterm availability of limb sounders: In the USA, the NPP mission includes the OMPS suite of a nadir and a UV-Vis-NIR limb instruments. In the post-2020 timeframe, a number of missions are being considered with limb capabilities although still under definition and not yet with secure funding. In Europe, the ALTIUS limb tracker is in preparation for the ESA Earth Watch programme. Other limb instruments are under consideration in Canada (e.g. the Canadian Atmospheric Tomography System, CATS), and in Japan (SMILES-2 anticipated for 2023). In the USA, JPL is considering a new MLS-like instrument: the Scanning Microwave Limb Sounder (SMLS) that will improve the current MLS capability by simultaneously scanning both in azimuth and elevation providing complete global coverage with 6 or more repeat measurements per day, and currently being tested using an airborne prototype.

# Backup slides

# MIPAS observations of GHGs

- MIPAS was a limb sounder able to detect a wide range of species from the UT to the mesosphere
- Active from July 2002 to April 2012
- At IMK, we have derived 10-years data records of global distributions of ~30 species and isotopologues
- Among them are the greenhouse gases $CH_4$, $N_2O$, $SF_6$, CFC-11, CFC-12, HCFC-22, $SF_6$, $O_3$, $H_2O$, $CCl_4$, …
- $CO_2$ cannot be measured in the middle atmosphere below 70 km.
- Due to the limb sounding geometry, the sensitivity to low-abundant species is high.
- The lowest observation altitude is cloud top or ~ 6 km, whatever is higher.



# Canadian proposals for limb observations

- Heritage of ACE-FTS on SciSat-1 and OSIRIS on Odin
- CATS (Canadian Atmospheric Tomography System) in solar occulation (ACE-FTS follow-on): $O_3$, stratospheric aerosols, $NO_2$ and BrO (not selected)
- ALI (Aerosol Limb Imager) (ALI): aerosol extinction coefficient and particle size distribution, cirrus clouds
- SHOW (Spatial Heterodyne Observations of Water): water vapour in UTLS
- Raven (EE-9)