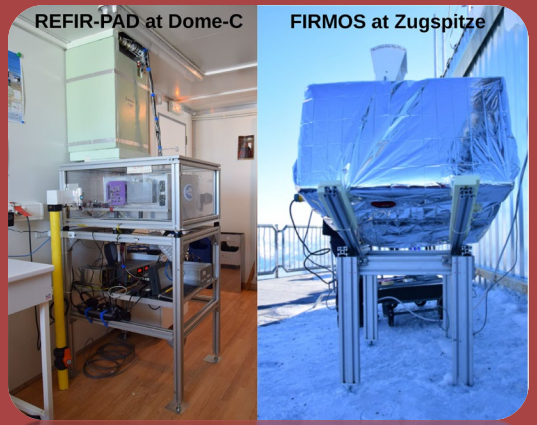

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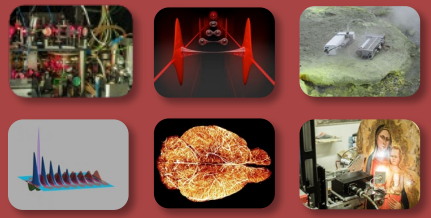
CONSIGLIO NAZIONALE DELLE RICERCHE



ALLIES of LIGHT

Ground-based and balloon-borne far-infrared spectral observations to support the preparation of the FORUM mission

Luca Palchetti

CNR-INO
ISTITUTO NAZIONALE DI OTTICA
CONSIGLIO NAZIONALE DELLE RICERCHE

2022 Living Planet Symposium
23-27 May 2022, World Conference Center
Bonn, Germany

The Team & Affiliations

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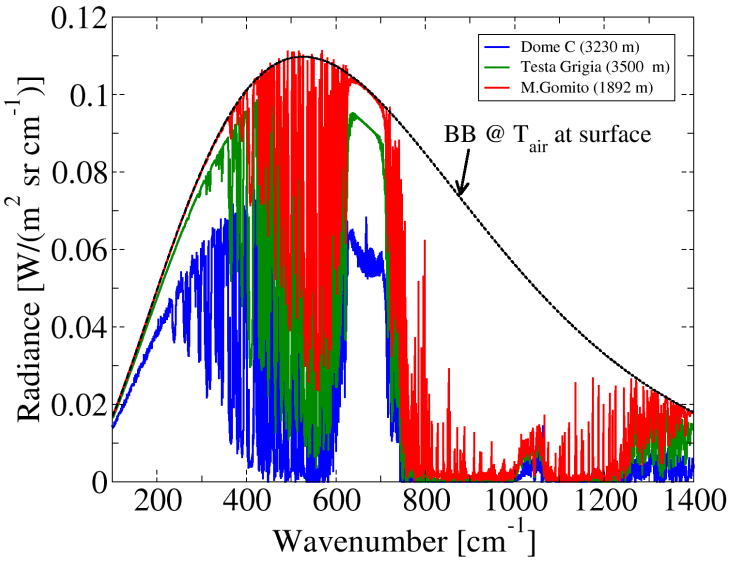
- (6) Atmospheric and Environmental Research, Lexington, MA, USA
- (7) Forschungszentrum Jülich GmbH, Jülich, DEU
- (8) KIT/IMK-IFU, Garmisch-Partenkirchen, DEU

Far Infrared (FIR) in ground-based and balloon-borne measurements

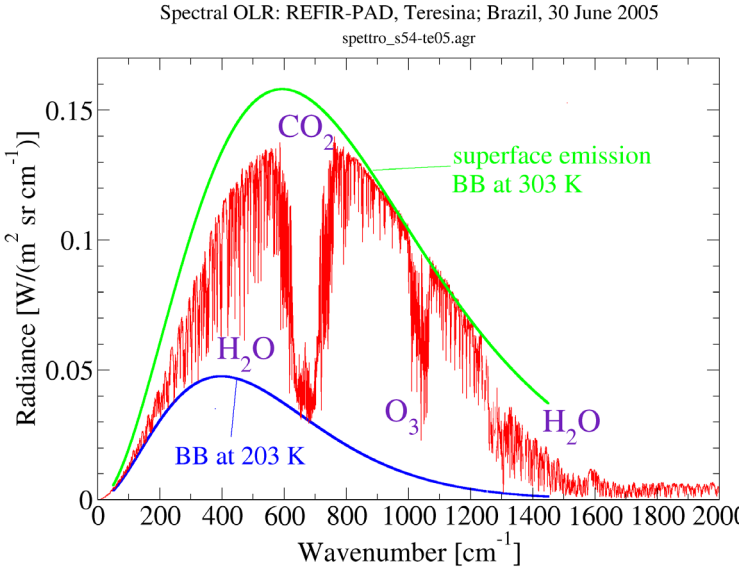
Ground-based zenith-looking observations require high-altitude and dry sites

FIR limited to wavenumber > 200-300 cm^{-1}



Balloon-borne nadir-looking observations (at about 35 km) are very close to satellite observations (FORUM-like measurements)

The whole FIR is accessible



Support to FORUM mission

Improvements of models in the FIR

- Water vapour spectroscopy and the continuum absorption
- Cirrus cloud radiative properties and better information on particle microphysics
- Snow/ice emissivity

Instrumental support

- Provide real measurements to test the data analysis tools under development
- Prepare a suite of instruments to be used for calibration/validation purposes

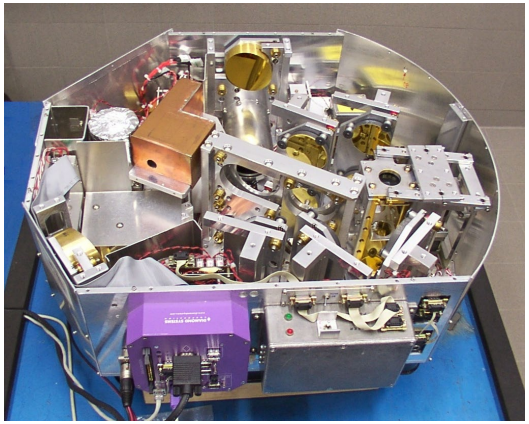
2 instruments were developed: REFIR-PAD and FIRMOS

The REFIR-PAD instrument

Radiation Explorer in the Far-InfraRed – Prototype for Applications and Development

2003-04

Mach-Zehnder Fourier Transform Spectrometer
Spectral coverage = 100-1500 cm^{-1},
Resolution 0.4 cm^{-1} double-sided
NESR in the range 0.6-2.5 $mW/(m^2\ sr\ cm^{-1})$
Absolute calibration error < 0.5 K
Small Payload: 62 cm dia., 55 kg weight, 50 W avg power



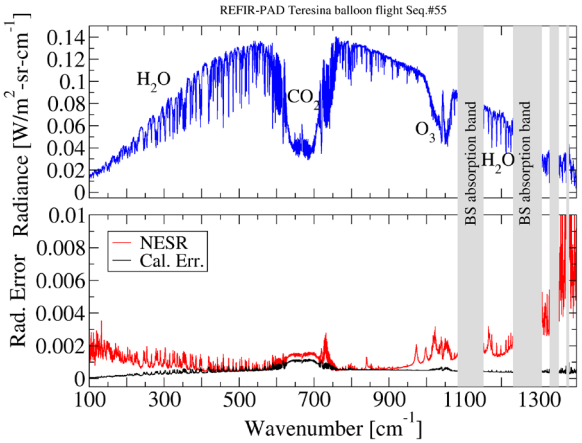
Poster section Day 5

Spectral OLR measurements from Teresina stratospheric flight (2005)

Flight

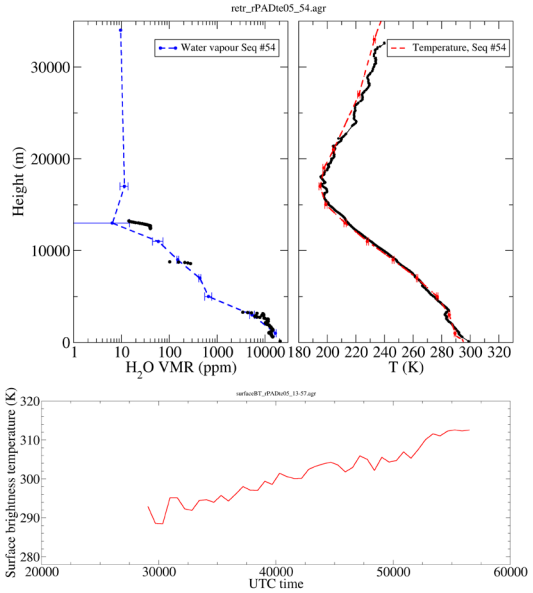
- North-East of Brazil (5° 5' S, 42° 52' W)
- Launch at night 03:36 LT - 30 June 2005
- Floating altitude at 34 km for about 8 h
- Landing 10 h later, 270 km south-west

Spectral measurement at nadir



Retrieval of the atmospheric state and surface properties

- Best fit with χ2 minimization based on LBLRTM FM https://doi.org/10.1029/2010JD014530
- Optimal estimation approach based on SACR FM (LBLRTM) https://doi.org/10.1016/j.jqsrt.2020.106927
- Optimal estimation approach based on KLIMA FM (HITRAN / AER)
- https://doi.org/10.4401/ag-6331

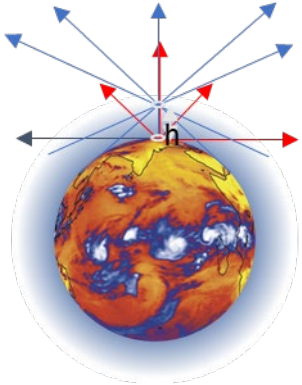


New fast code:
σFORUM
ASI
FORUMscince
Project

Flux measurements from Teresina stratospheric flight

Testing of the OLR flux calculation method, exploiting the wide spectral range

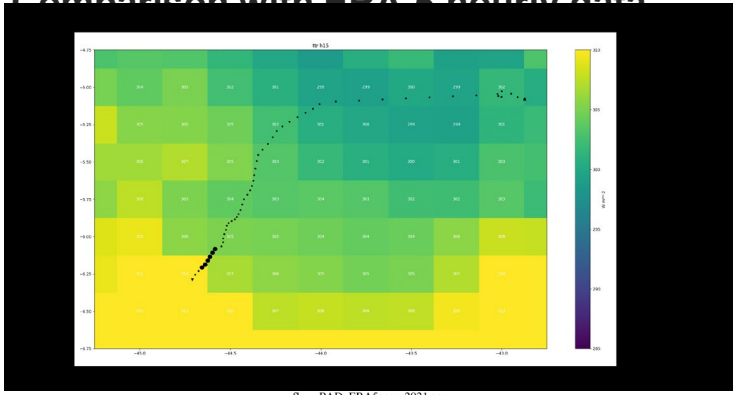
1. Radiance angular calculation from the retrieved atmospheric state
2. Numerical integration with Gaussian quadrature

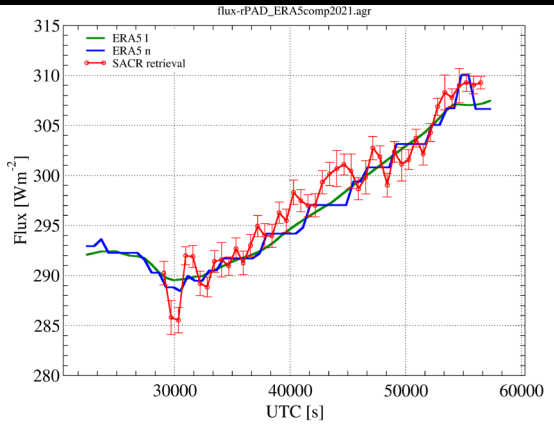


$$F_\nu = 2\pi \int_{\theta=0}^{\frac{\pi}{2}} I_\nu(\theta) cos(\theta) sin(\theta) d\theta$$

$$F = \int_0^\infty F_\nu d\nu$$

Comparison with ERA-5 hourly data



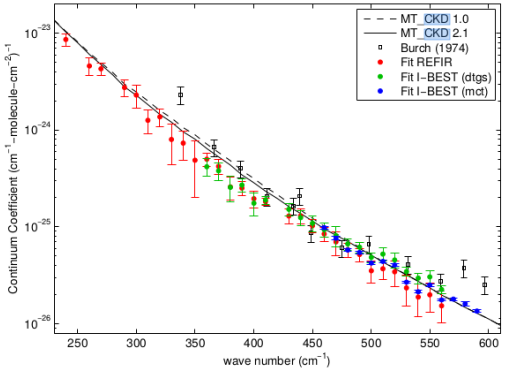


Improvements in water vapour spectroscopy from high-altitude ground-based measurements

2007, MT_CKD v2.1 by AER Inc. (used in LBLRTM radiative transfer model)

Comparison with measurement from Plateau Rosa 3500 m, Italian Alps 2007, (ECOWAR project)

Result: below 450 cm^{-1} the MT_CKD model overestimates the magnitude of the continuum coefficient

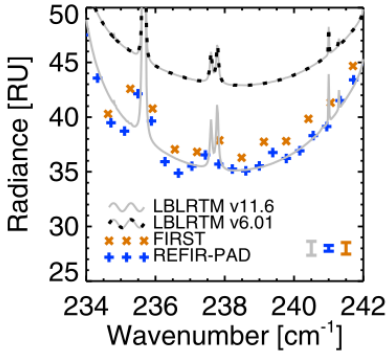


https://doi.org/10.1364/OE.16.015816

2009, MT_CKD v2.4

Comparison with measurement from Cerro Toco 5300m, Chile 2009 (RHUBC-II Campaign)

Result: confirmed the better agreement with LBLRTMv11.6 using MT_CKD v2.4



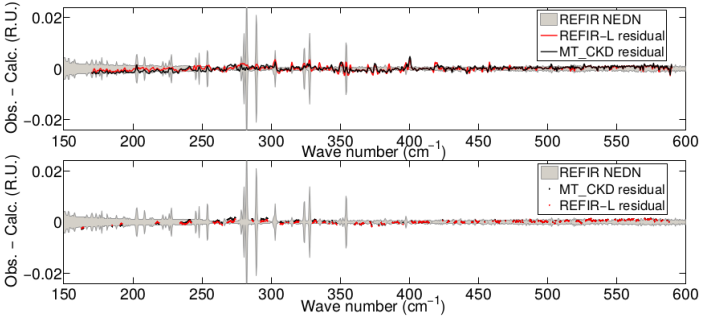
https://doi.org/10.1029/2012GL051542

Water vapour spectroscopy from high-altitude ground-based sites

2014, MT_CKD v2.5.2

Fit of the continuum absorption with measurements from Dome-C 3200m, Antarctica 2011-12, (PNRA PRANA Project)

Result: good consistency between observations and the model. Provided evidence toward needing to adjust absorptive line strengths in AER model



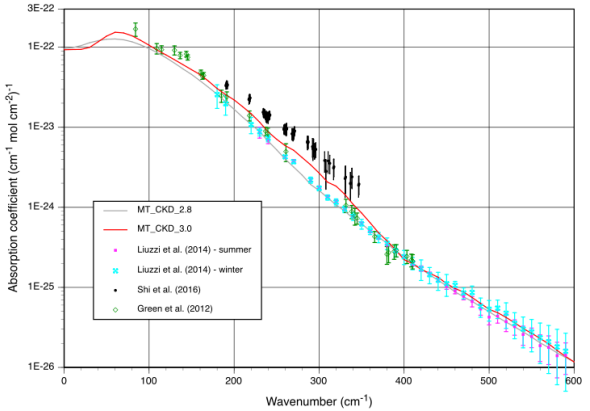
https://doi.org/10.1364/OE.22.016784

2016, MT_CKD v3.0

Spectroscopy improvements from measurement from Cerro Toco 5300m, Chile 2009 (RHUBC-II Campaign)

Results: the foreign continuum increased > 50% in part of the FIR , line widths of more than 20 lines changed >10%.

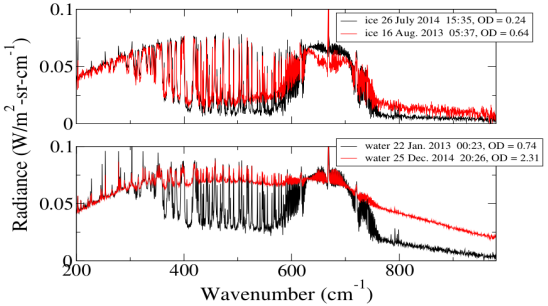
Effect of changes from v1.2 to v3.0: the net flux change can be as large as −0.6 W/m^2 and occurs in the upper troposphere.



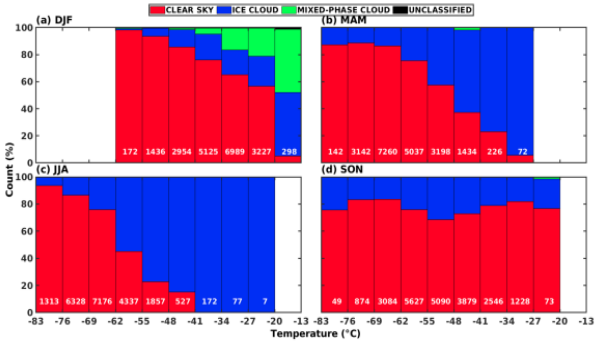
https://doi.org/10.1029/2018JD029508

Cirrus cloud properties from high-altitude ground-based sites

Measurements from Concordia station, 3200m, Antarctica 2013-14
Exploited synergy with collocated Backscatter/Depolarisation Lidar



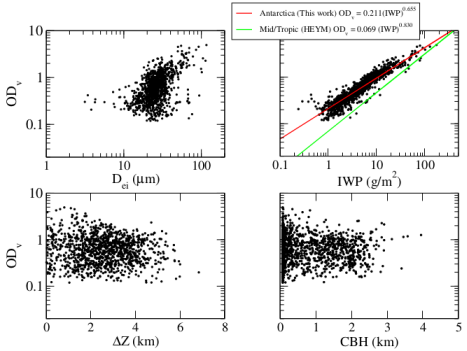
Machine learning cloud identification and classification (CIC code)



https://doi.org/10.5194/acp-21-13811-2021

Presentation in A1.10.1 session by T.Maestri

Retrieval of cirrus parameters (SACR code)

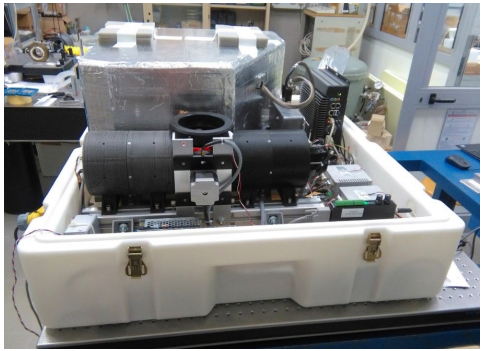


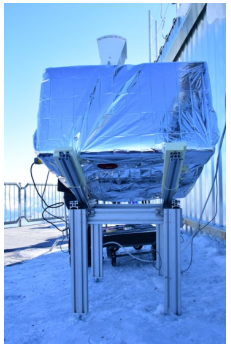
https://doi.org/10.3390/rs12213574

The FIRMOS instrument

Far-Infrared Radiation Mobile Observation System, 2018

Mach-Zehnder Fourier Transform Spectrometer
Spectral coverage = 100-1000 cm^{-1},
Resolution 0.25 cm^{-1} max. double-sided
NESR in the range 0.5-2.5 $mW/(m^2\ sr\ cm^{-1})$
Absolute calibration error < 0.5 K
Small Payload: 85x95x50cm size, 60 kg weight, 70 W avg power

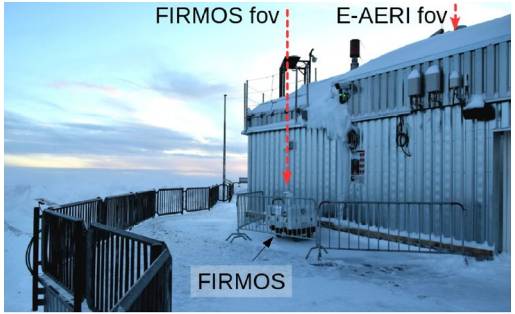


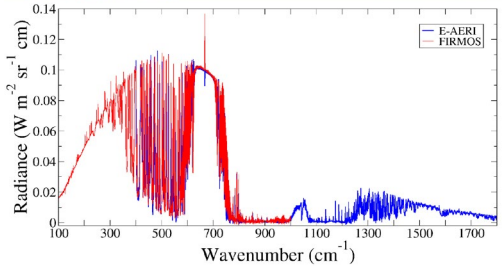


https://doi.org/10.5194/essd-13-4303-2021

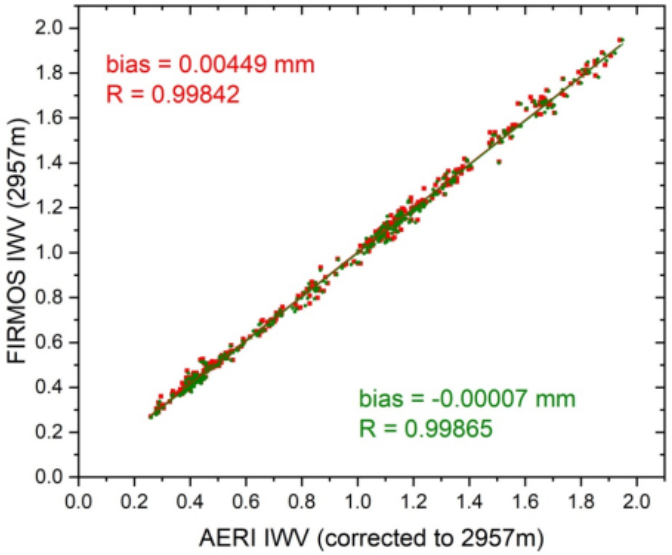
Comparison with MIR measurements

Spectral measurements of the DLR together with E-AERI instrument outside the KIT IMK-IFU Zugspitze laboratory



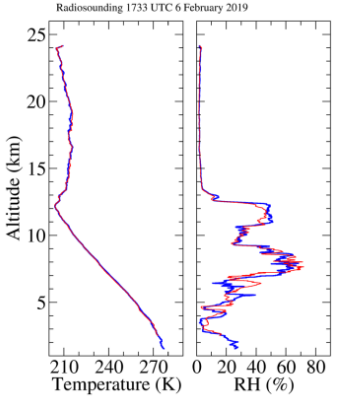


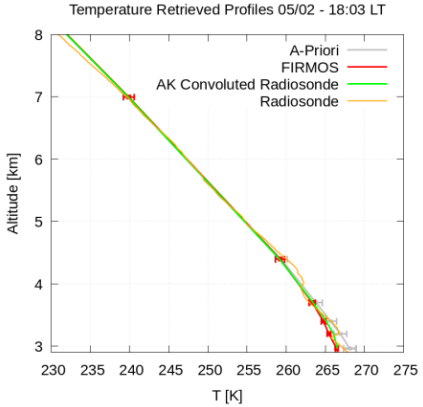
Comparison between the IWV retrieved with FIRMOS (FIR range) and E-AERI (MIR range) measurements

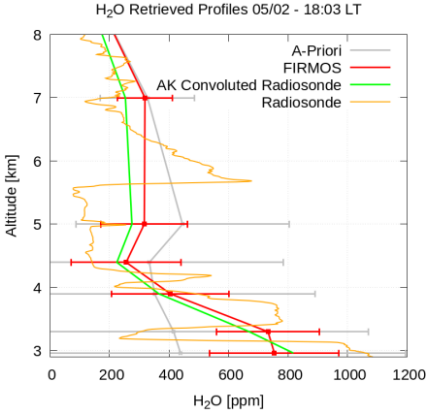


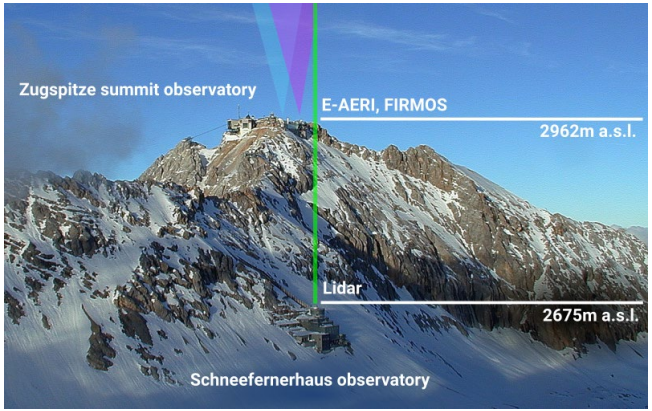
Under publication

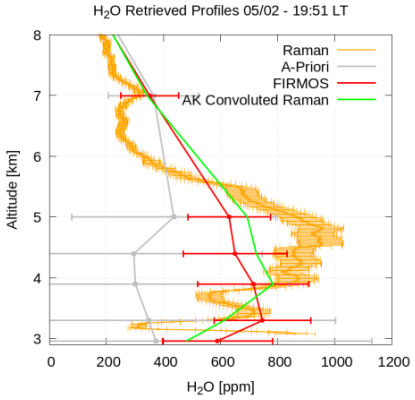
Retrieval studies and comparison with external measurement
Clear sky case







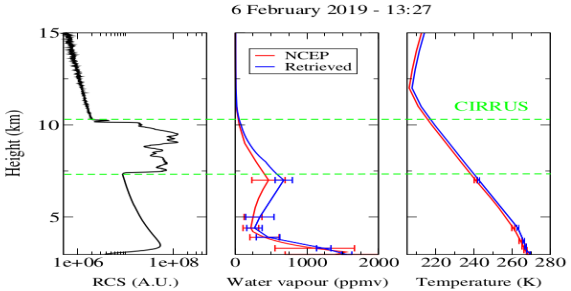


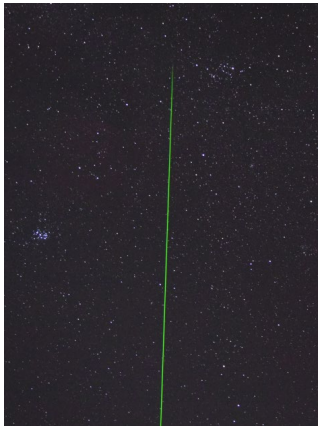


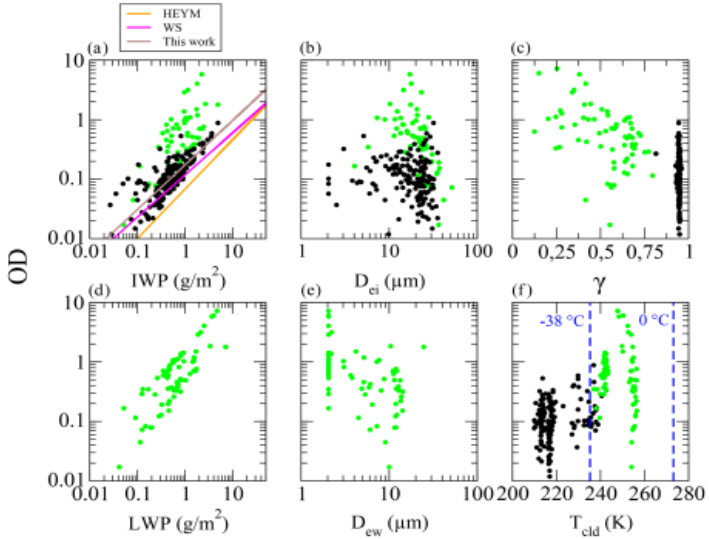
Under publication

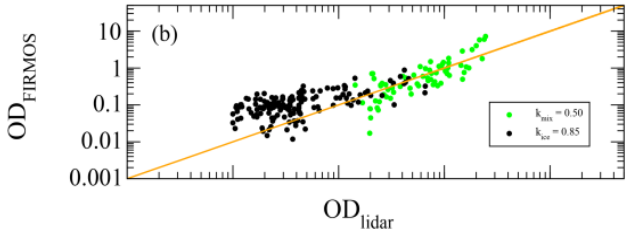
Retrieval studies and comparison with external measurement

Cirrus cloud case





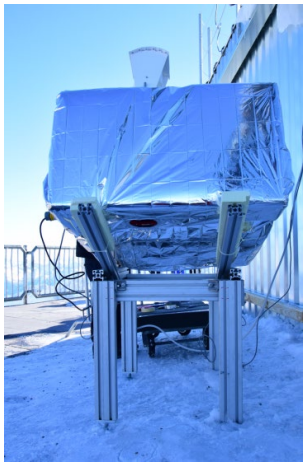


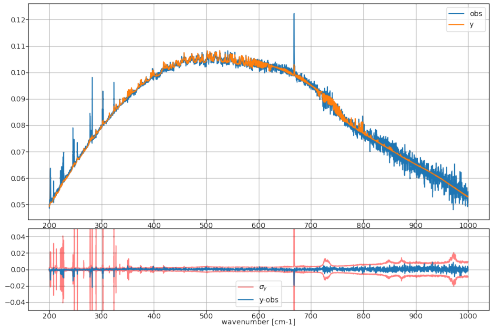


https://doi.org/10.5194/amt-14-6749-2021

Ice FIR emissivity: first measurements

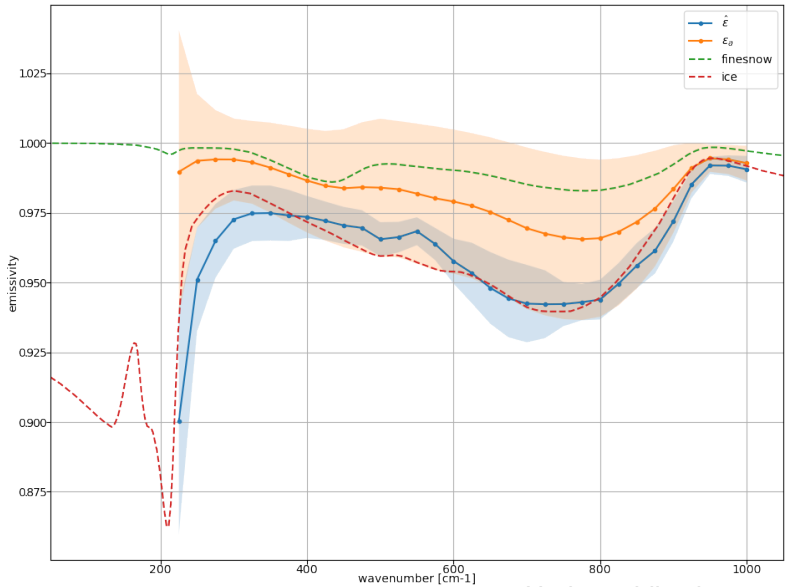
Spectral measurement of the upwelling radiance @13.5 degrees off-nadir





Retrieval with OE at 25 cm^{-1} resolution

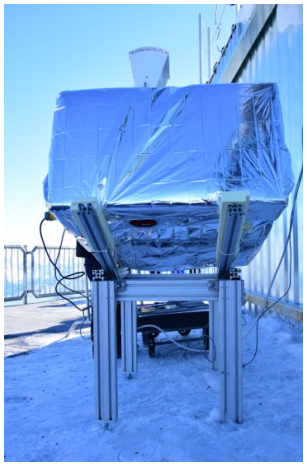
Comparison with ice model by Huang et al. (2016)

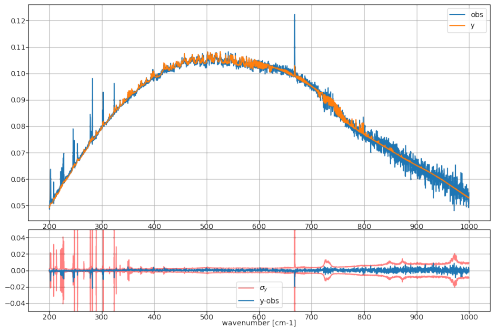


Under publication

Snow FIR emissivity: first measurements

Spectral measurement of the upwelling radiance @13.5 degrees off-nadir





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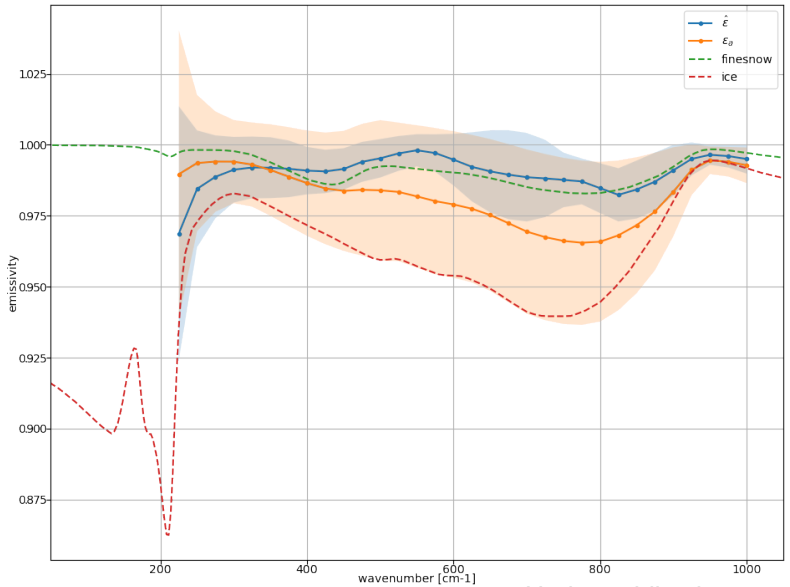

Under publication

Conclusions

- REFIR-PAD has been of support for the development of the idea of measuring the far infrared during the latest 20 years and it was the baseline design of the FORUM FTS proposed to ESA EE9 missions in 2017
- FIRMOS was developed after the FORUM selection to support the preparation of the mission with ad hoc activities which cannot be performed with REFIR-PAD installed permanently in Antarctica
- Both instruments contributed, and will continue to contribute, to support the preparation of the FORUM mission
- The application of REFIR-PAD from Antarctica and FIRMOS-B from stratospheric balloon can provide a suite of instruments able to perform calibration/validation measurements when FORUM is in orbit

Acknowledgements

- CNES Teresina Campaign
- ARM/DoE (Cerro Toco Campaign)
- PNRA (Antarctic Campaign)
- ESA (FIRMOS project)
- ASI (FORUM scienza project)

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