
Spectrally resolved measurement of the downwelling longwave radiance from an high-altitude station

Spectroscopic issues in the data analysis

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Outline

The REFIR instrument

- Overview of the REFIR-PAD spectroradiometer
- Level 1 and level 2 data analysis of REFIR-PAD measurements

The winter 2007 ground-based campaign

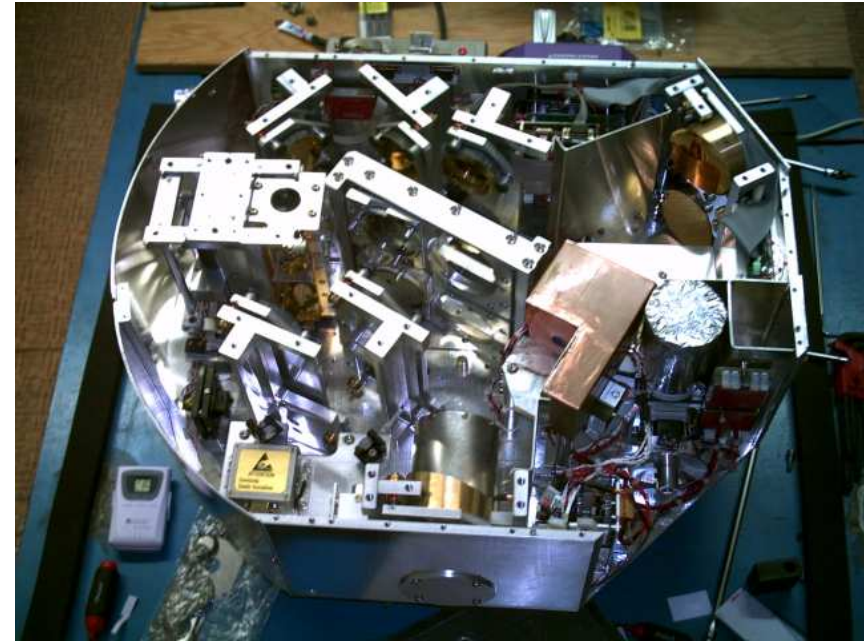
- Retrieval of atmospheric variables from REFIR-PAD data

Spectroscopic issues in the data analysis

- Three case studies in clear sky conditions, varying PWV
- Comparison with residuals from balloon-borne measurements

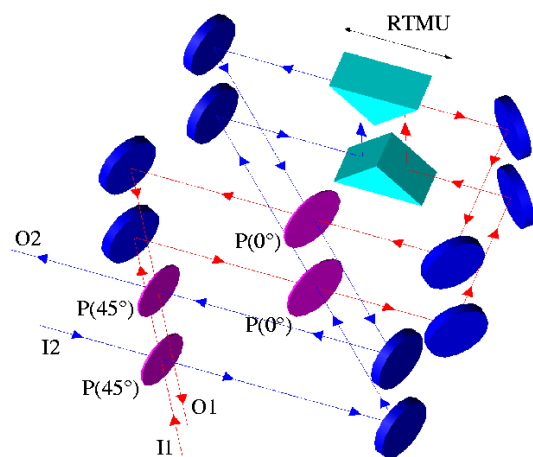
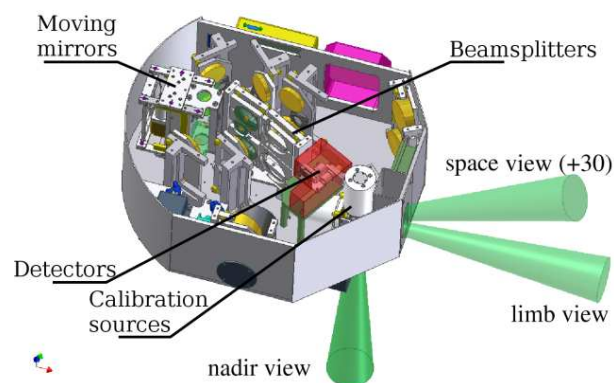
Conclusions

The REFIR-PAD instrument



Radiation Explorer in the Far InfraRed - Prototype for Application and Development

REFIR-PAD characteristics

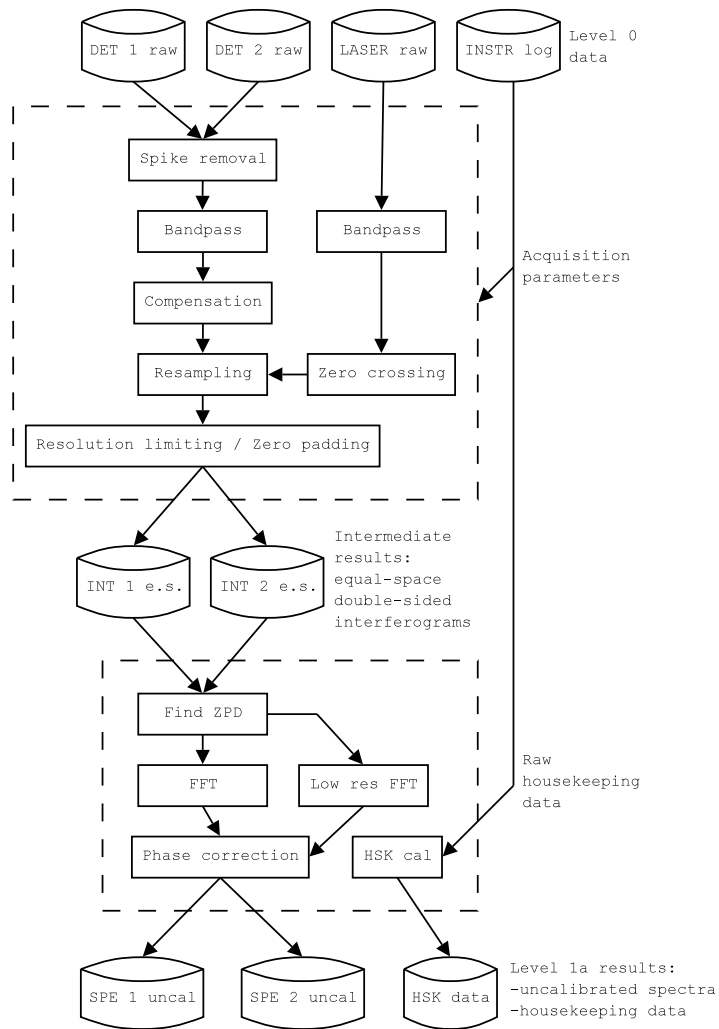


Instrument specifications:

Instrument type	Mach-Zender non-polarising FTS
Beam splitter	Ge-coated Mylar ($0.85 \mu\text{m}/2 \mu\text{m}$)
Spectral bandwidth	$100\text{-}1400 \text{ cm}^{-1}$
Spectral resolution	up to 0.25 cm^{-1} (double-sided)
Optical throughput	$0.01 \text{ cm}^2\text{sr}$
Field of view	133 mrad
Detector type	Pyroelectric (DLATGS)
Acquisition time	30-120 s
Acquisition frequency	20 kHz
Weight	55 kg
Power consumption	$\sim 50 \text{ W}$

→ Room temperature operation ←

Level 1 data analysis



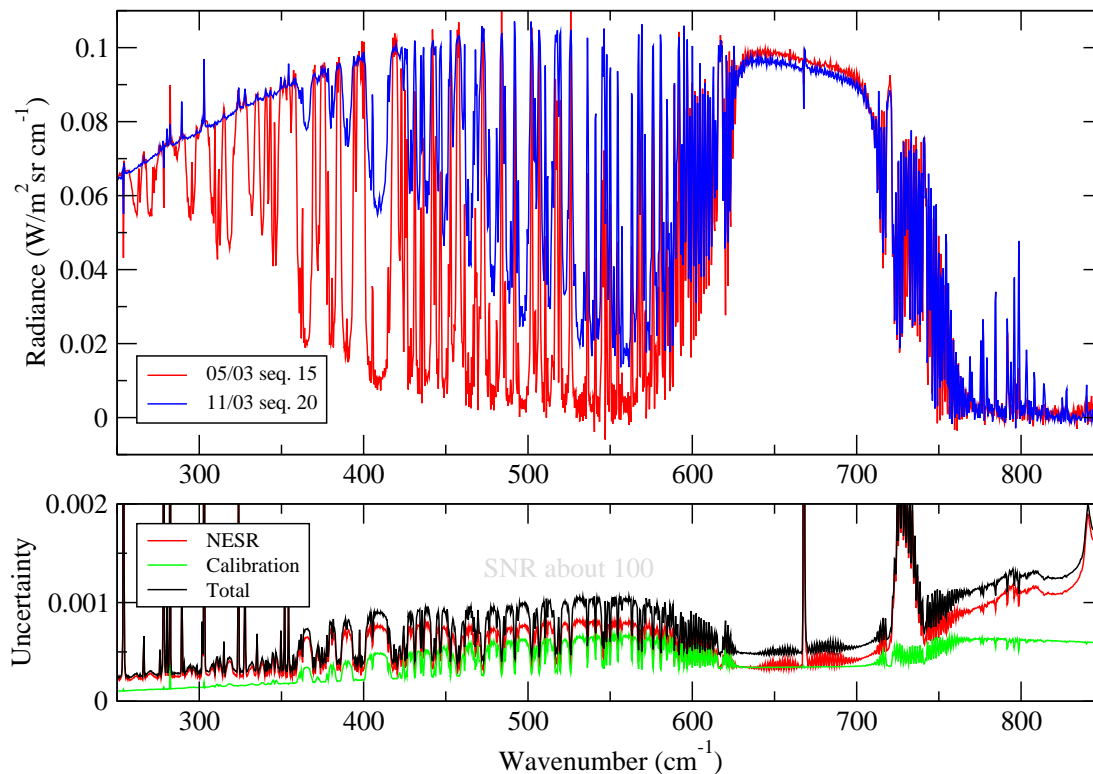
- Data resampling on reference laser fringes (Brault)
- Transformation and low-resolution phase correction
- Calibration through on-board reference blackbodies
- Estimation of random (NESR) and systematic (calibration error) components of measurement uncertainty

ACPD, 8, 367-401, 2008

Sample spectra

Sample spectra in different PWV conditions

REFIR-PAD, Testa Grigia 2007, clear sky



Typical Downwelling Longwave Radiance spectra resulting from 10-minute REFIR-PAD acquisition sequences, 0.5 cm^{-1} resolution

- Wide spectral range, $\sim 300 - 1100 \text{ cm}^{-1}$, depending on water vapour content for the FIR region
- SNR better than 100 in the FIR for a single acquisition sequence (4 atmospheric spectra + 4 calibrations)

Level 2 data analysis

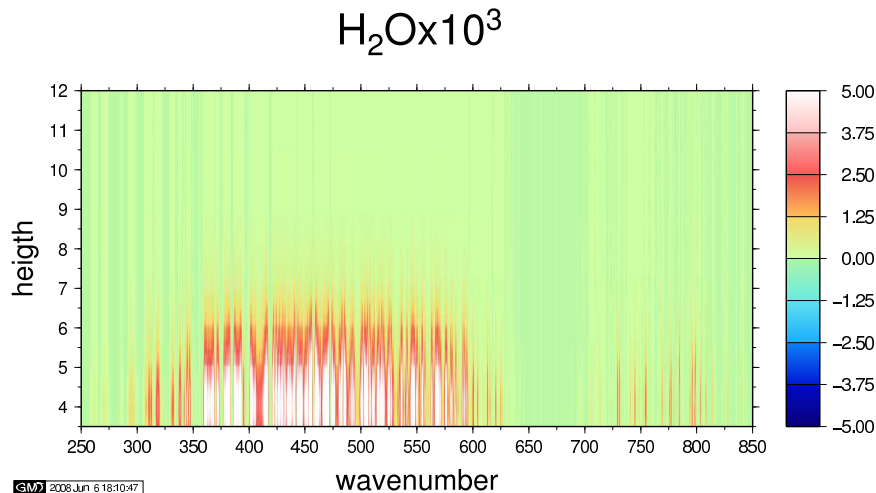
Forward model:

- LBLRTM version 11.3 radiative transfer model
- HITRAN 2004 spectroscopic database with 2006 updates (H₂O, HNO₃, N₂O)
- MT_CKD version 2.1 continuum model

Retrieval code:

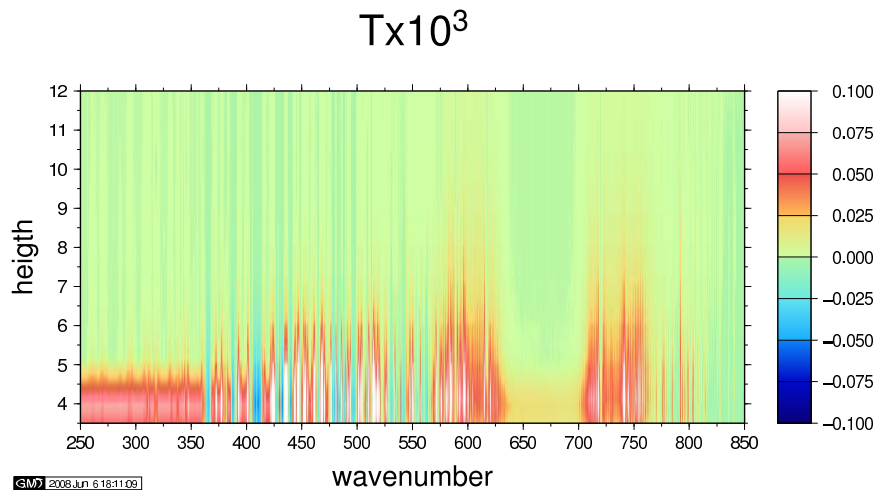
- Least χ^2 routine based on the MINUIT function minimization libraries (CERN)
- no constraints on fitted variables

Sensitivity to parameters



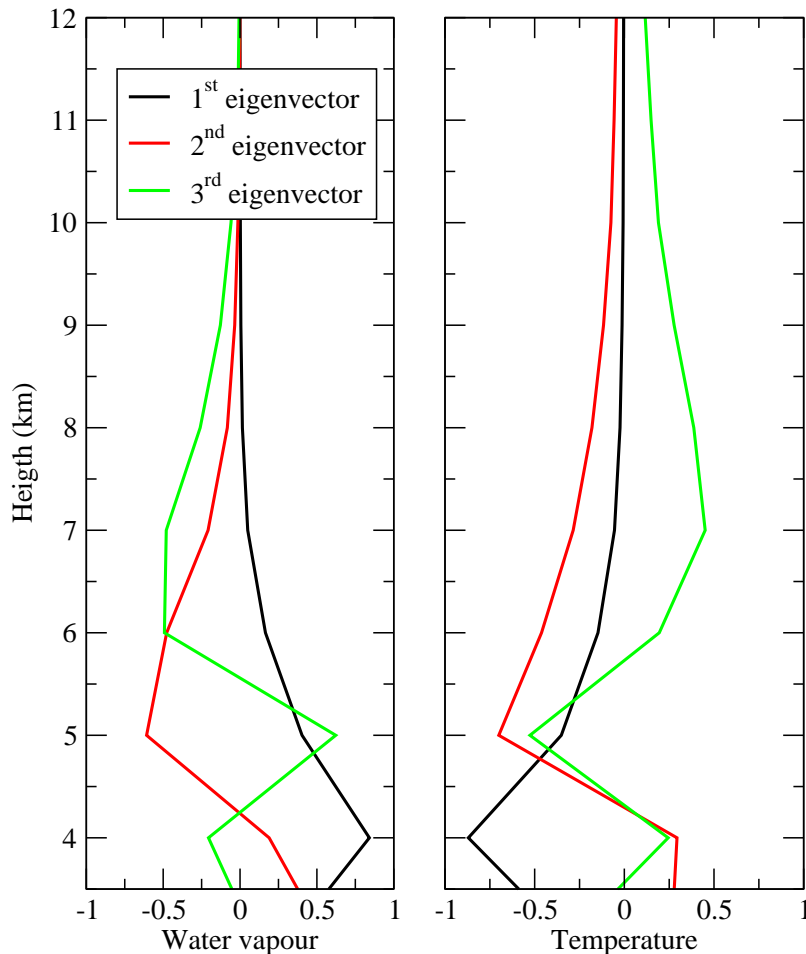
Analysis of Jacobian matrices for H₂O and Temperature:

- Spectral range used for retrieval: 300-650 cm⁻¹
- Data show sensitivity to atmospheric parameters up to 7-8 km



Vertical resolution

SVD decomposition of H_2O and T Jacobians, MLW standard atmosphere

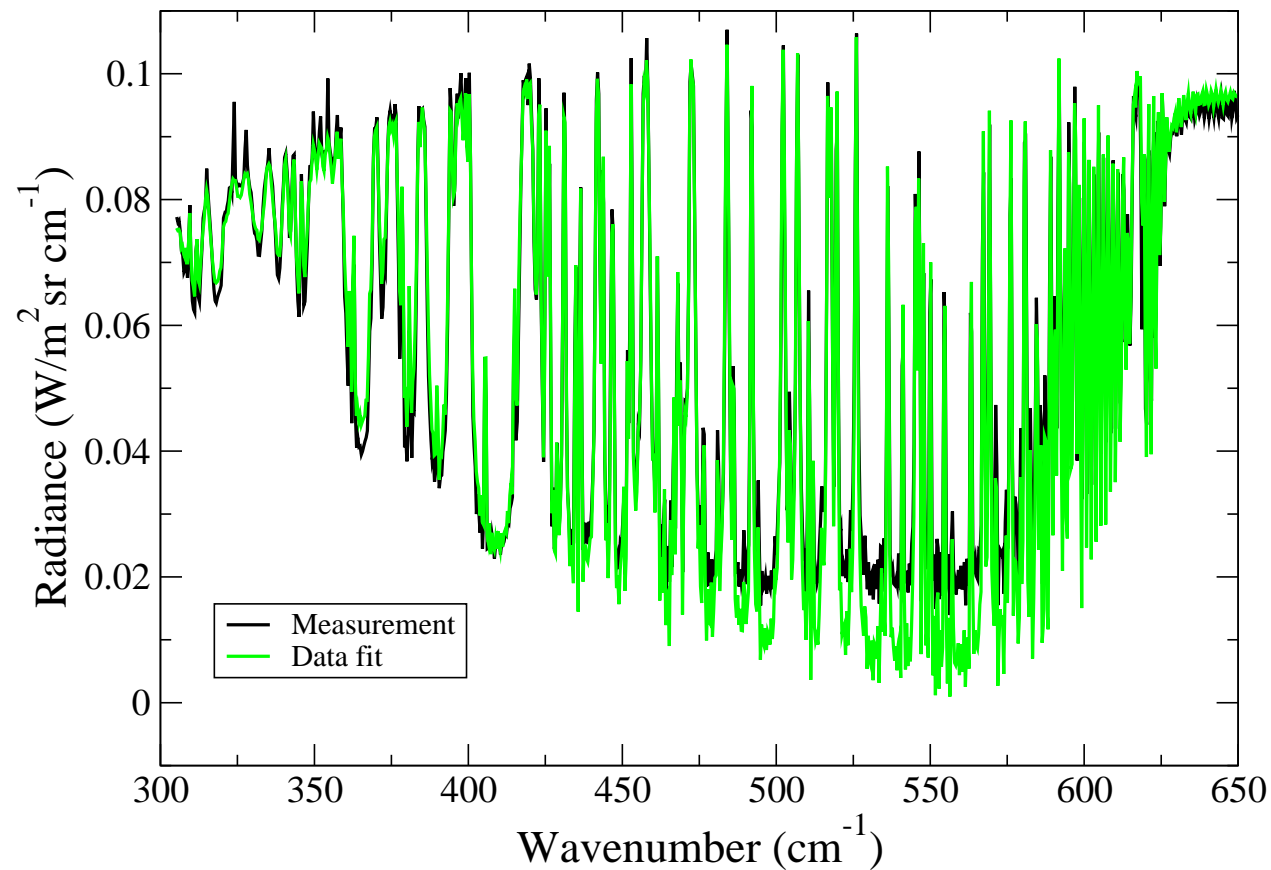


Singular Value Decomposition of Jacobian matrices:

- Main retrieval product (maximum sensitivity): total Precipitable Water Vapour (PWV)
- Vertical resolution 1-2 km: limited information on vertical profiles (2-3 points per variable)
- Presence of clouds give an extra atmospheric variable to be considered in the retrieval

Fitting without clouds

No cloud contribution in forward model \rightarrow overestimation of “high” water vapour \rightarrow wrong PWV



Effect of clouds on retrieval

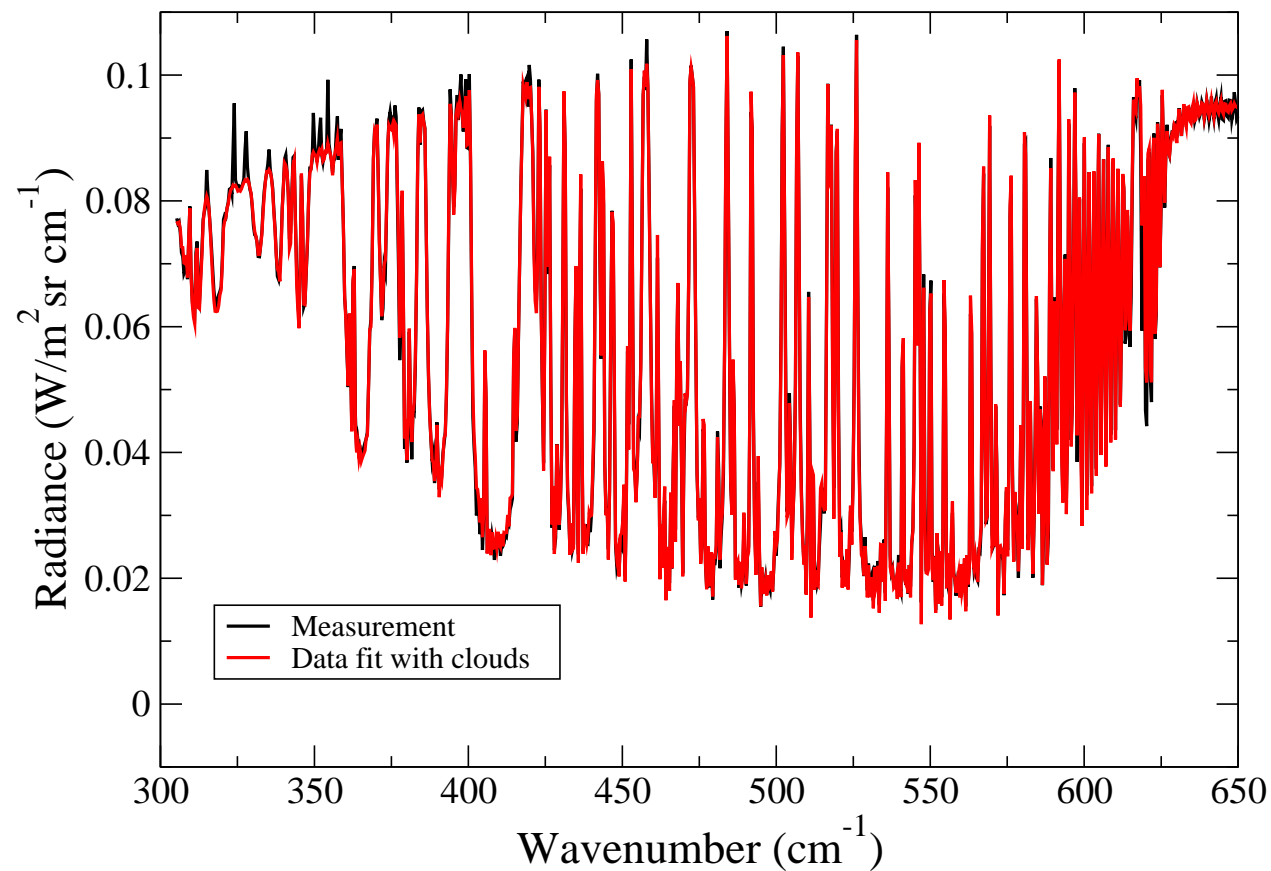


Measurements were performed only in **visually** clear sky conditions → possible problem due to subvisible cirrus clouds

- Cloud model included in forward model (LOWTRAN 7)
- Only one parameter retrieved: cloud optical density
- No sensitivity to cloud geometry if cloud layer above 7-8 km

Fitting with clouds

Added effect of clouds in forward model → correct PWV and vertical structure



The ECOWAR-COBRA campaign



ECOWAR: Earth COoling by WAter vapouR emission
COBRA: Campagna di Osservazioni della Banda Rotazionale del vapor d'Acqua

Spectrally resolved observations of Earth's emission spectrum in the water vapour rotational band (17-50 micron) to test models of atmospheric radiative transfer
 (Italian Ministry of University and Research, DM n. 287 23 feb. 2005, project # 2005025202)

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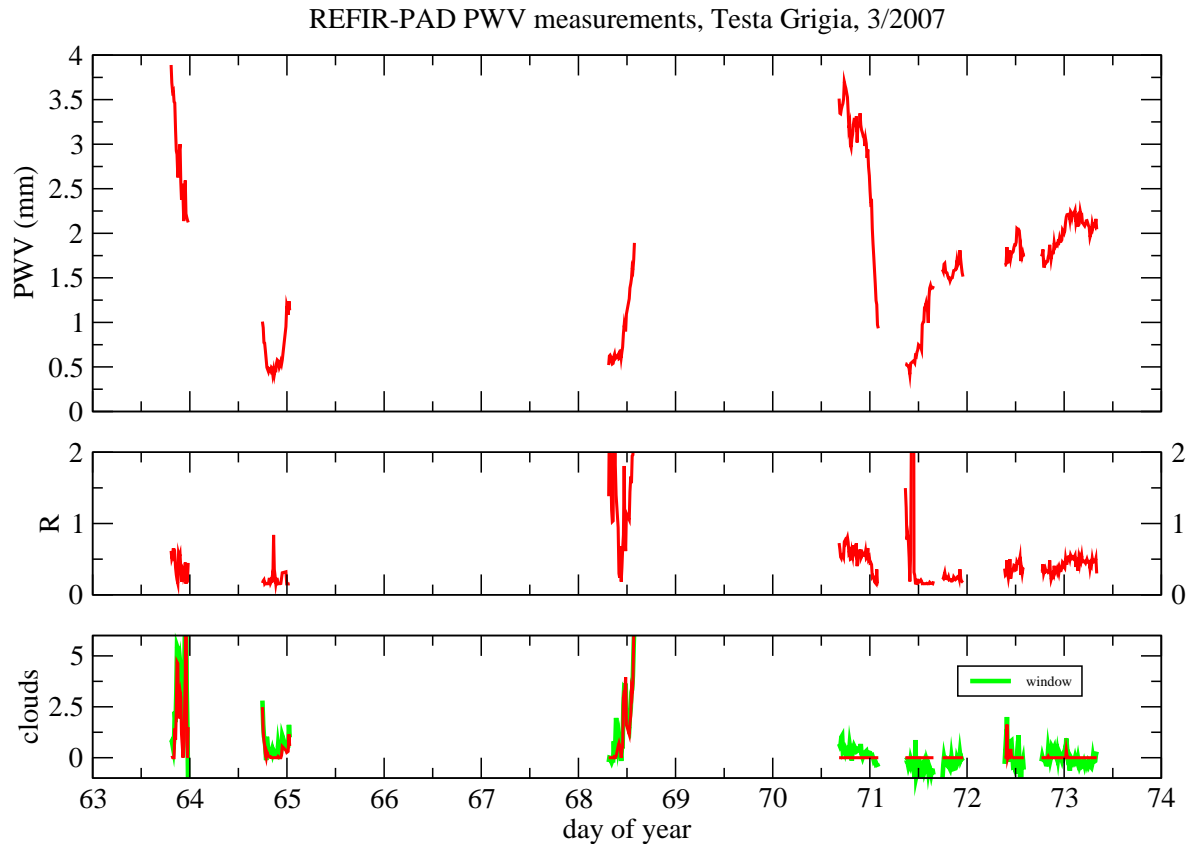
Thanks to the city of Valtournenche

REFIR-PAD at Testa Grigia



- Instrument installed in a C.N.R. high-altitude station in the Italian-Swiss Alps (3480 m. a.s.l.)
- During the campaign > 60 h of measurements on 7 days were acquired
- Measurements were performed in cold, dry conditions
- Meteorological conditions: mostly clear sky, subvisible cirrus present in few cases, varying PWV

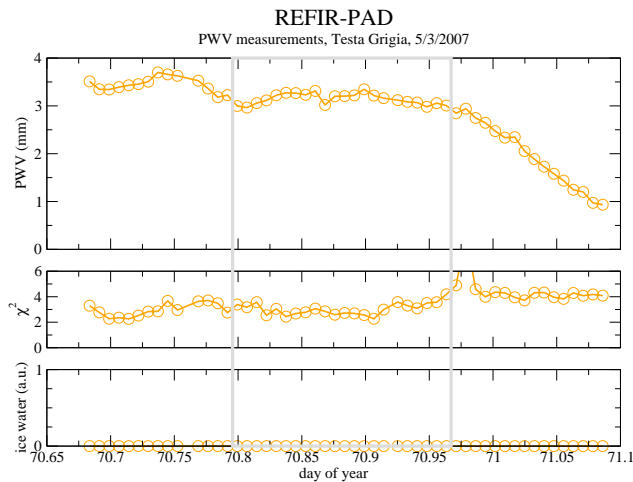
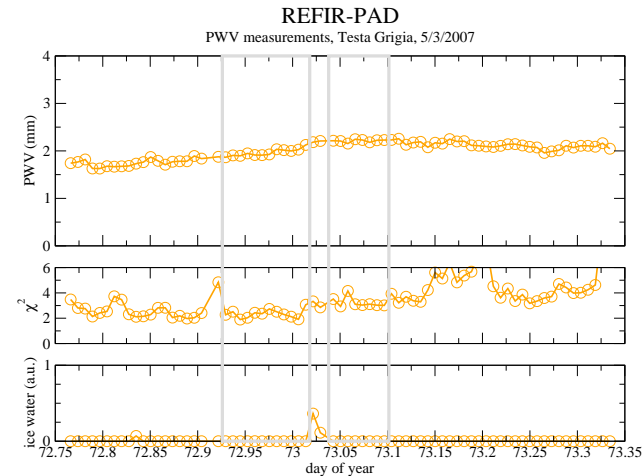
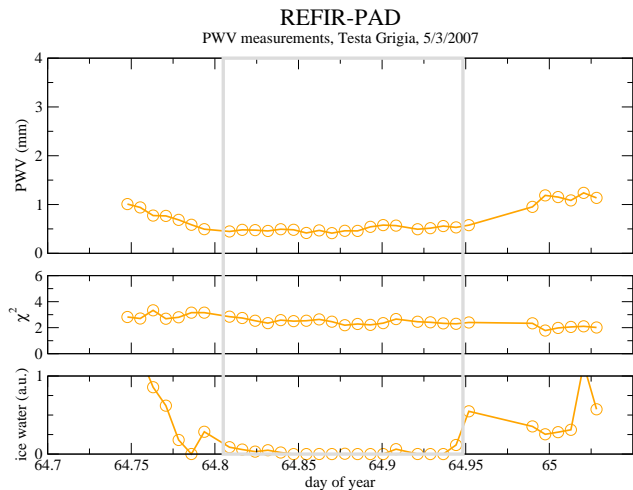
Sample retrieval



REFIR-PAD retrieval results for PWV, vertical water vapour structure and clouds optical density during the 2007 ECOWAR-COBRA campaign

- PWV values measured ranging from < 0.5 mm to 3-3.5 mm
- No clouds were detected in about 70% of the measurement time

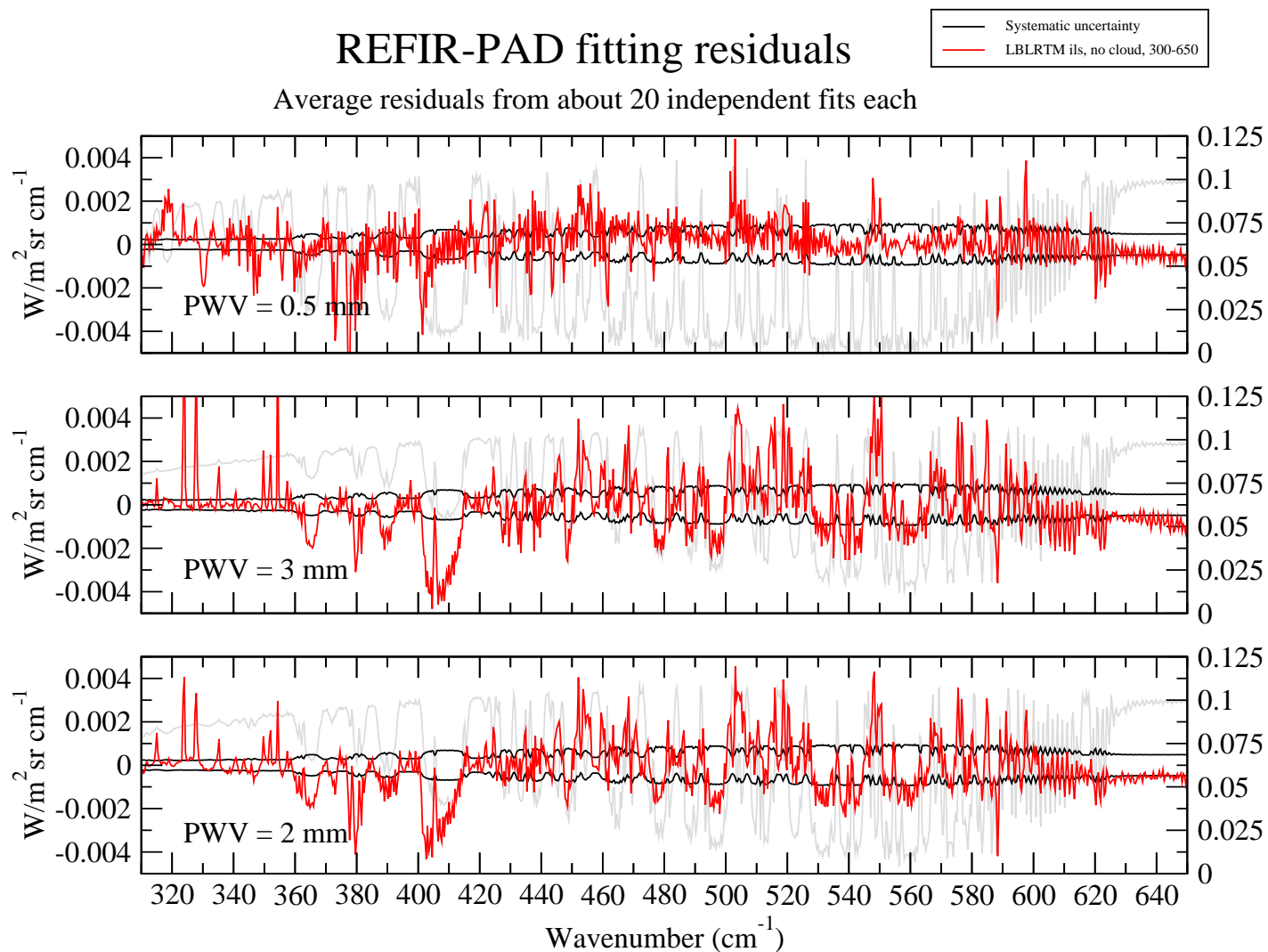
Clear-sky case studies



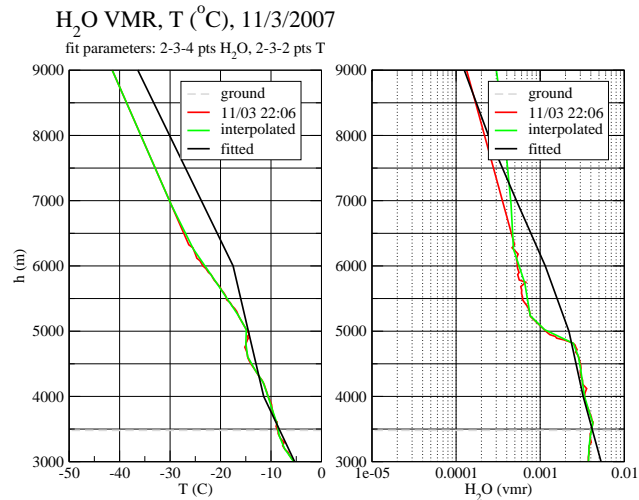
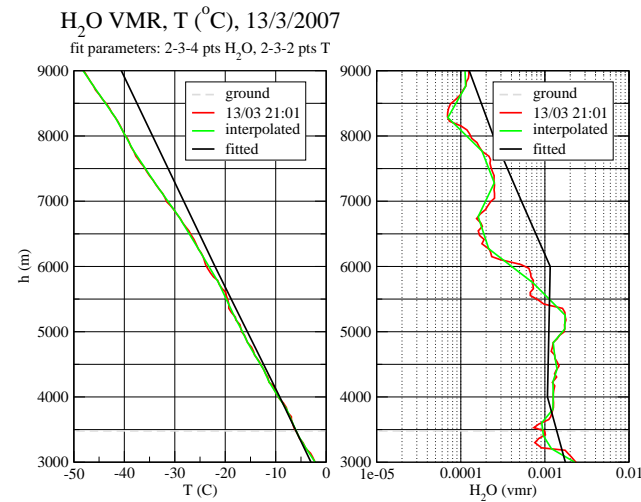
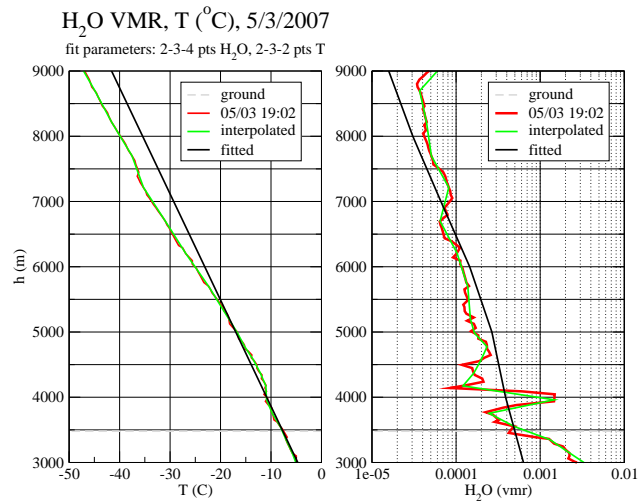
Three case studies featuring:

- Three different PWV values measured: 0.5 mm, 2 mm and 3 mm
- Almost constant PWV values for the duration of about 20 sequences ($\simeq 3$ h)
- Clear sky condition as detected by the retrieval process

Fitting residuals



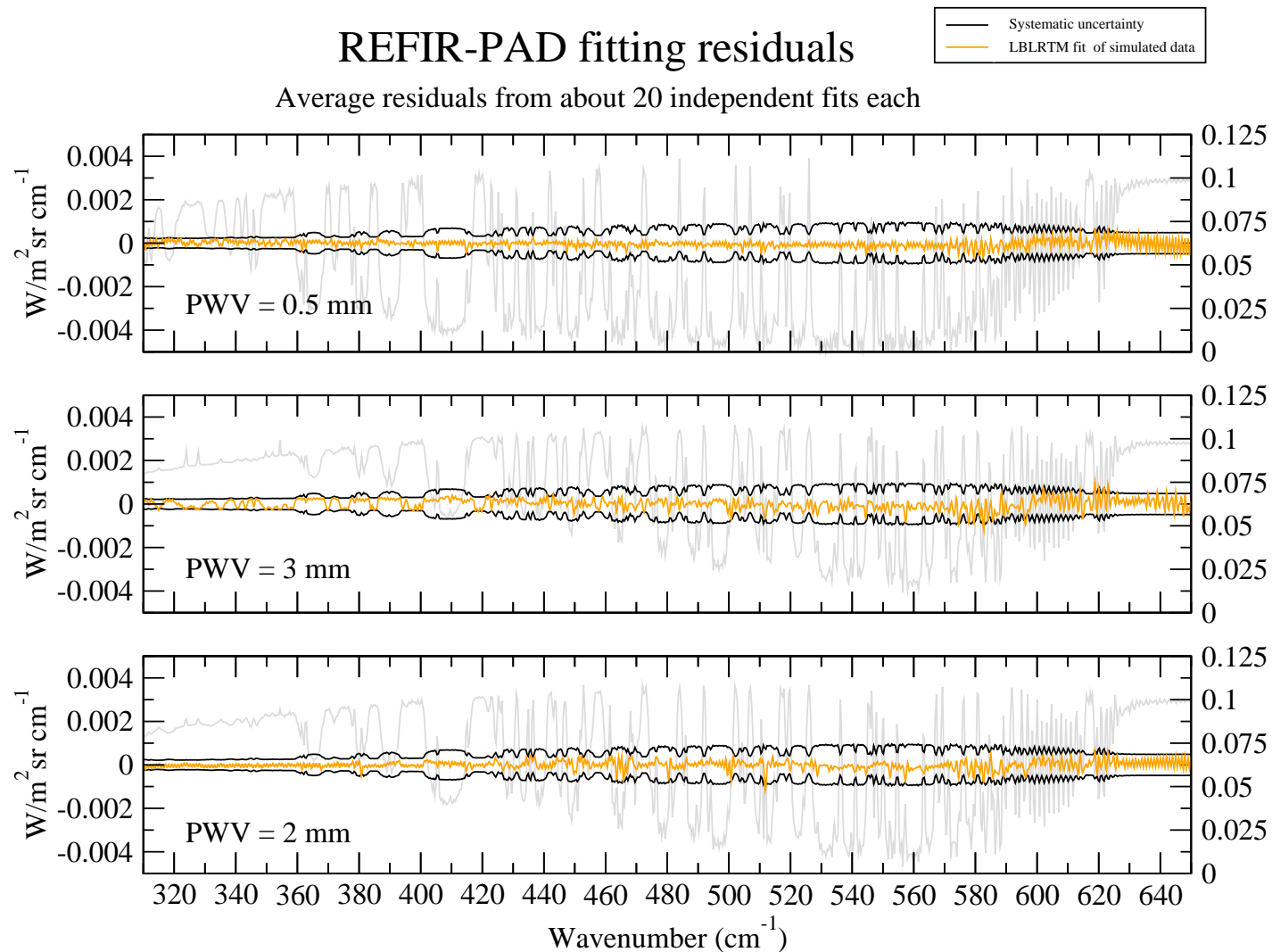
Validation: synthetic spectra



Test with simulations:

- Synthetic spectra using the same forward model used for retrieval
- Water vapour and temperature profiles interpolated from soundings

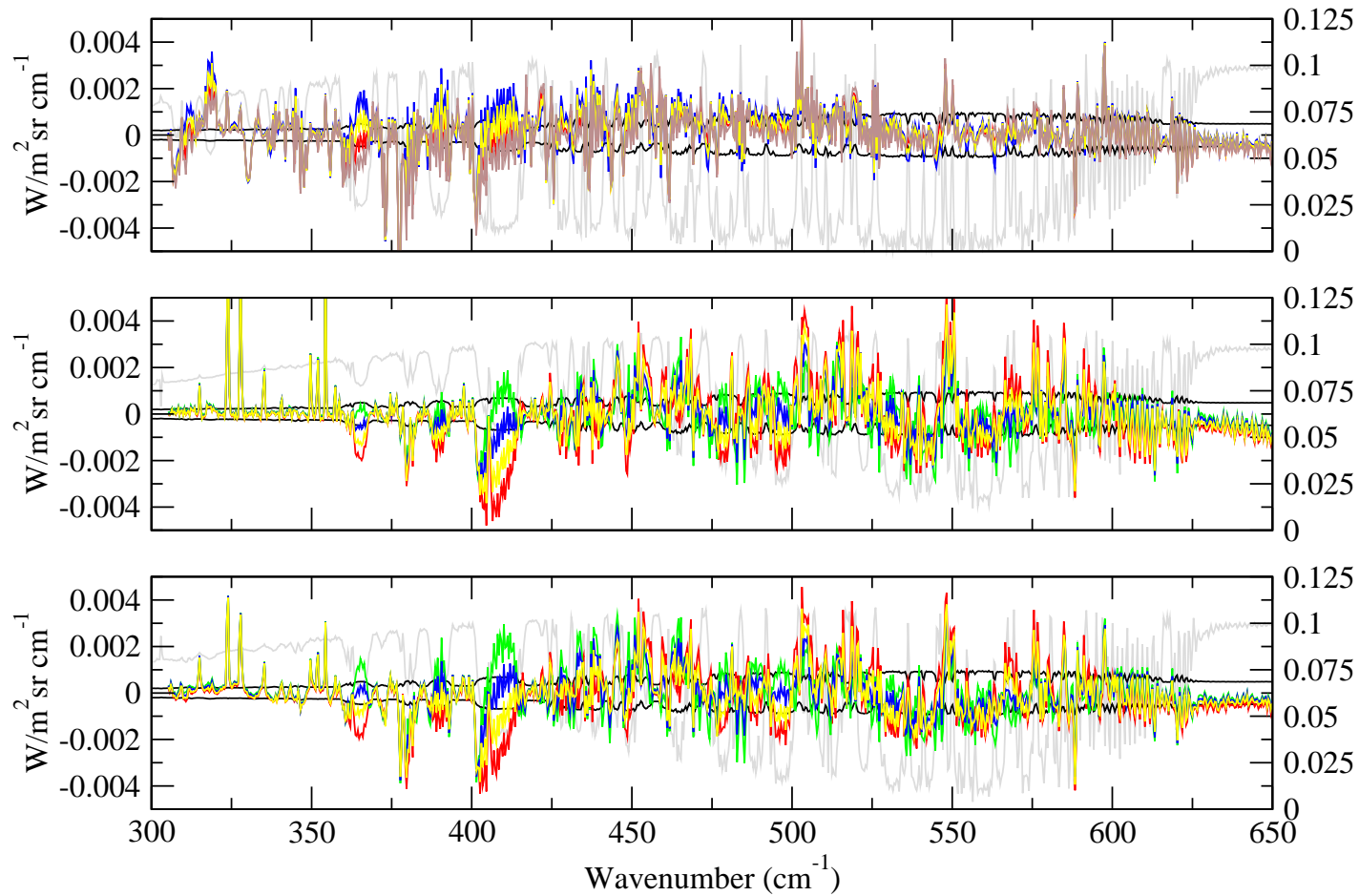
Residuals with synthetic spectra



Sensitivity to continuum

Fitting residuals - no cloud

REFIR-PAD fitted spectra average residuals (about 20 spectra each)



Balloon-borne nadir measurements



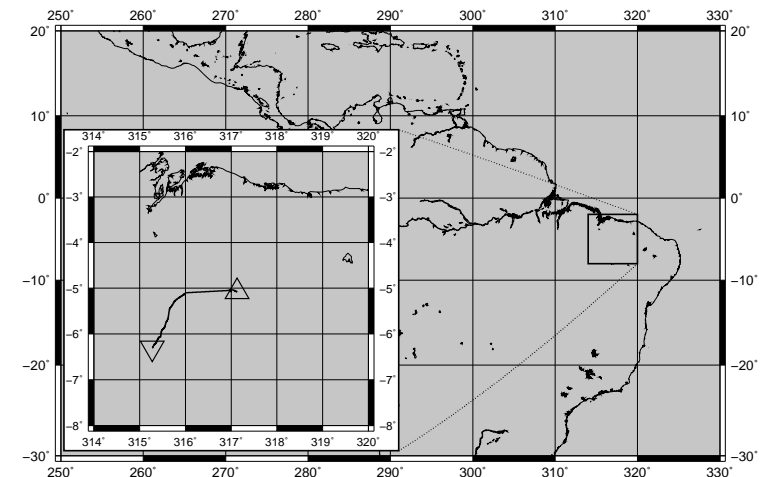
Stratospheric balloon launched in July, 2005 from Teresina, in the state of Piauí (North-East Brazil), 5.1 S 42.9 W, in mostly clear sky conditions.

Acknowledgements: The CNES balloon launch team.

Flight duration of about 9.5 h, of which 7.5 at the floating altitude of 34 km for a total distance covered of 270 km.

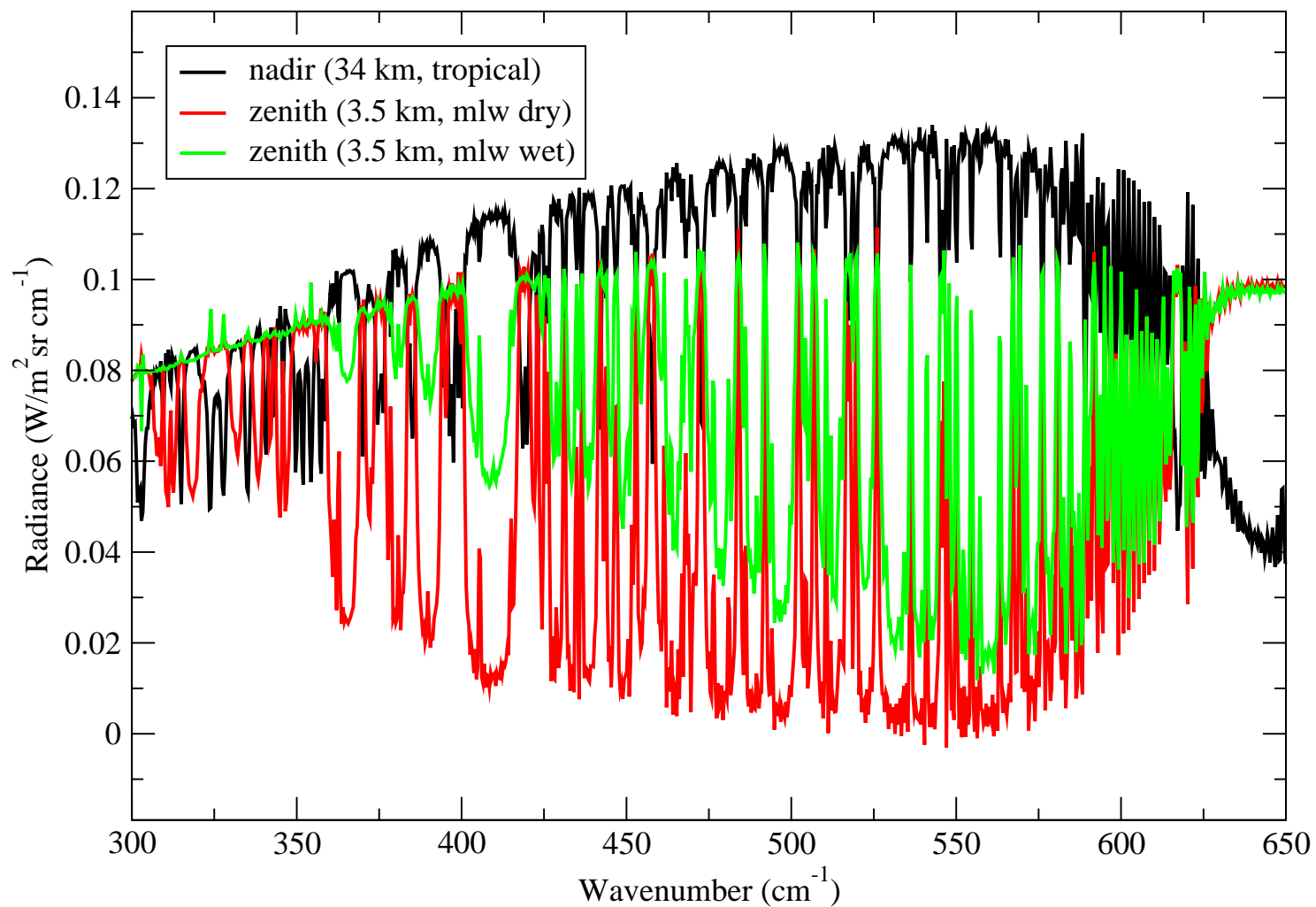
First spectrally resolved measurement of the OLR in the far-infrared with uncooled detectors

Atm. Chem. Phys., **6**, 5025-5030, (2006)



Nadir vs. zenith radiance

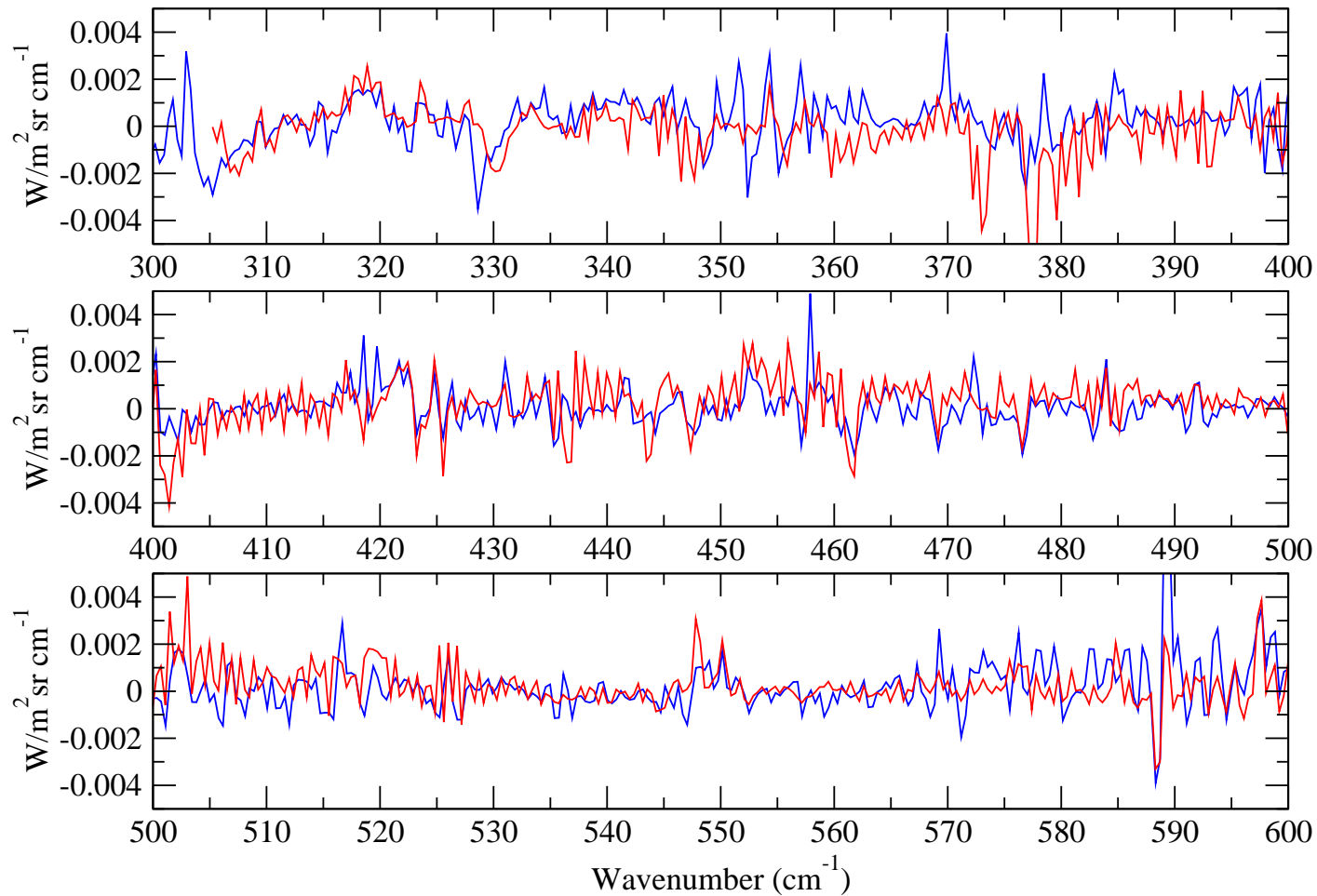
REFIR-PAD sample measurements, radiance units



Nadir vs. zenith residuals

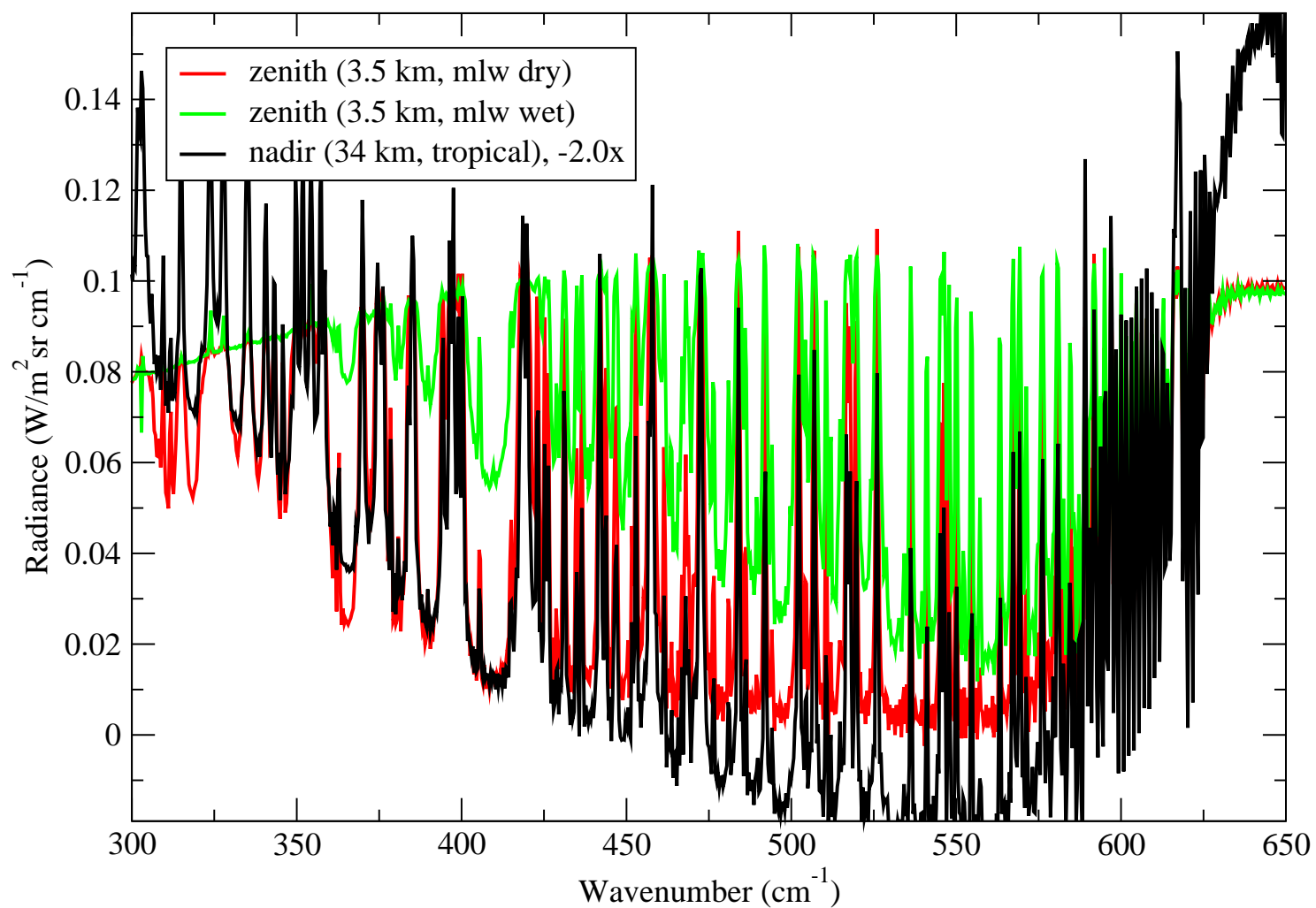
REFIR-PAD residuals comparison

Teresina 2005 (all flight, multiplied by -2.0) vs. Testa Grigia 2007 (18 sequences from 05/03)



Nadir vs. zenith radiance

REFIR-PAD sample measurements, radiance units



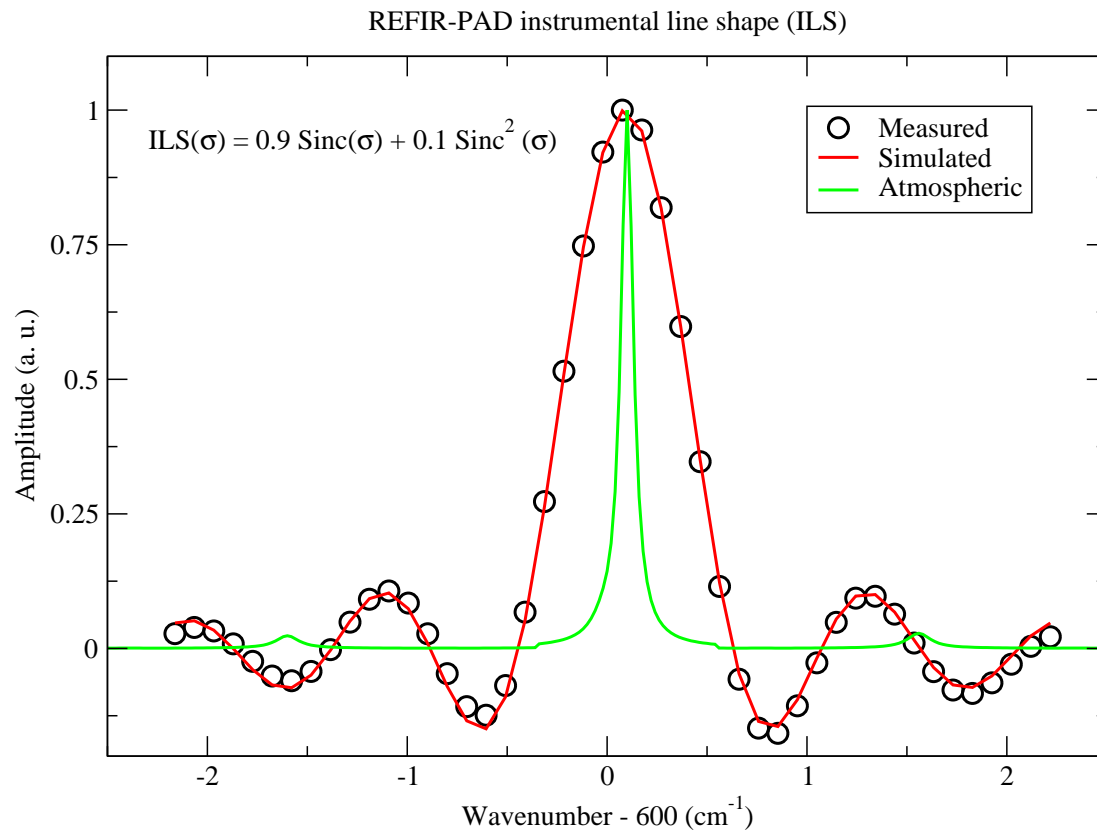
Conclusions

Spectroscopic issues in the far-infrared

- Analysis of REFIR-PAD measured downwelling radiances show evidence of systematic effects above measurement uncertainty
- Tests performed suggest that effects are not due to the instrument itself nor due to the analysis method
- Both continuum model and spectroscopic database issues could be present, solving which could improve greatly REFIR-PAD data products quality

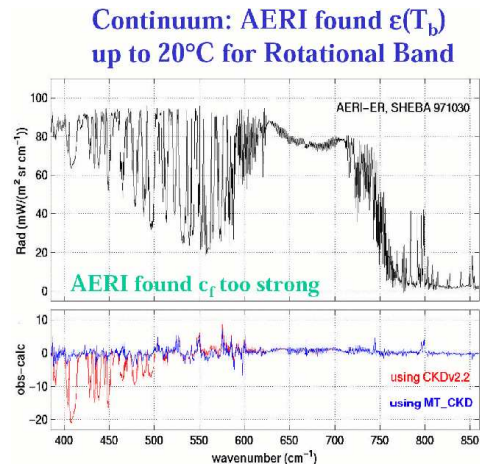
Spare slides

Instrumental line shape

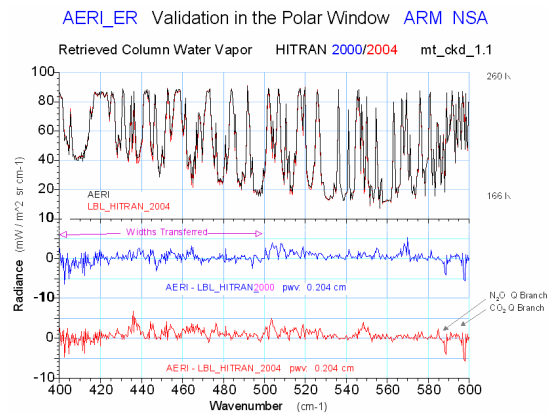


Instrumental line shape as a linear combination of sinc and sinc²
Combination coefficient fitted and averaged over multiple spectra

Residuals in literature



Clough, ASSFTS 2003
PWV $\simeq 3$ mm



Clough, IRS 2004
PWV $\simeq 0.2$ mm

Residuals comparisons

