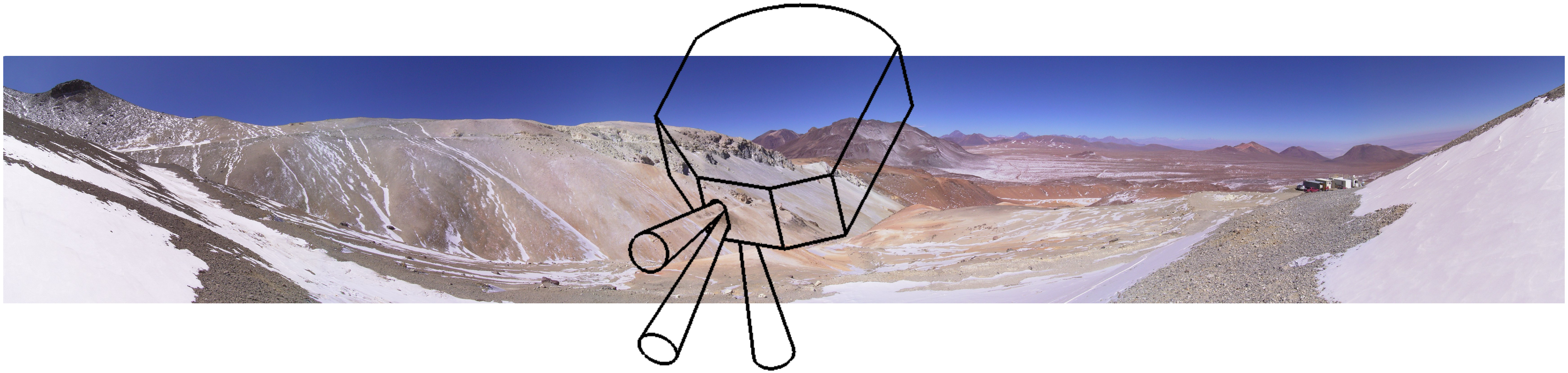
Analysis of data acquired by the REFIR-PAD spectroradiometer during the RHUBC-II campaign



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Outline

- Overview of the REFIR-PAD instrument in the zenith-looking ground-based setup
- REFIR-PAD measurements during the 2009 RHUBC-II campaign
- Level 1 data analysis and products
- Level 2 data analysis and products
- Radiometric validation
- Conclusions

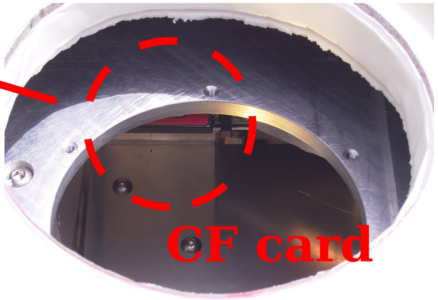
Instrument overview

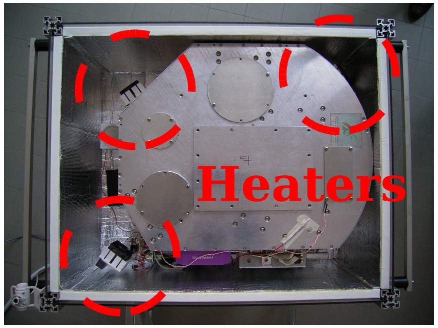
- Operating spectral range: 100-1400 cm^{-1}
- Spectral resolution: 0.5 cm^{-1} nominal (max 0.25 cm^{-1})
- Room temperature optics and detectors (DLATGS pyroelectric)
- Autonomous or remote controlled operation (wired or wireless ethernet link)

REFIR-PAD in the ground-based measurement configuration

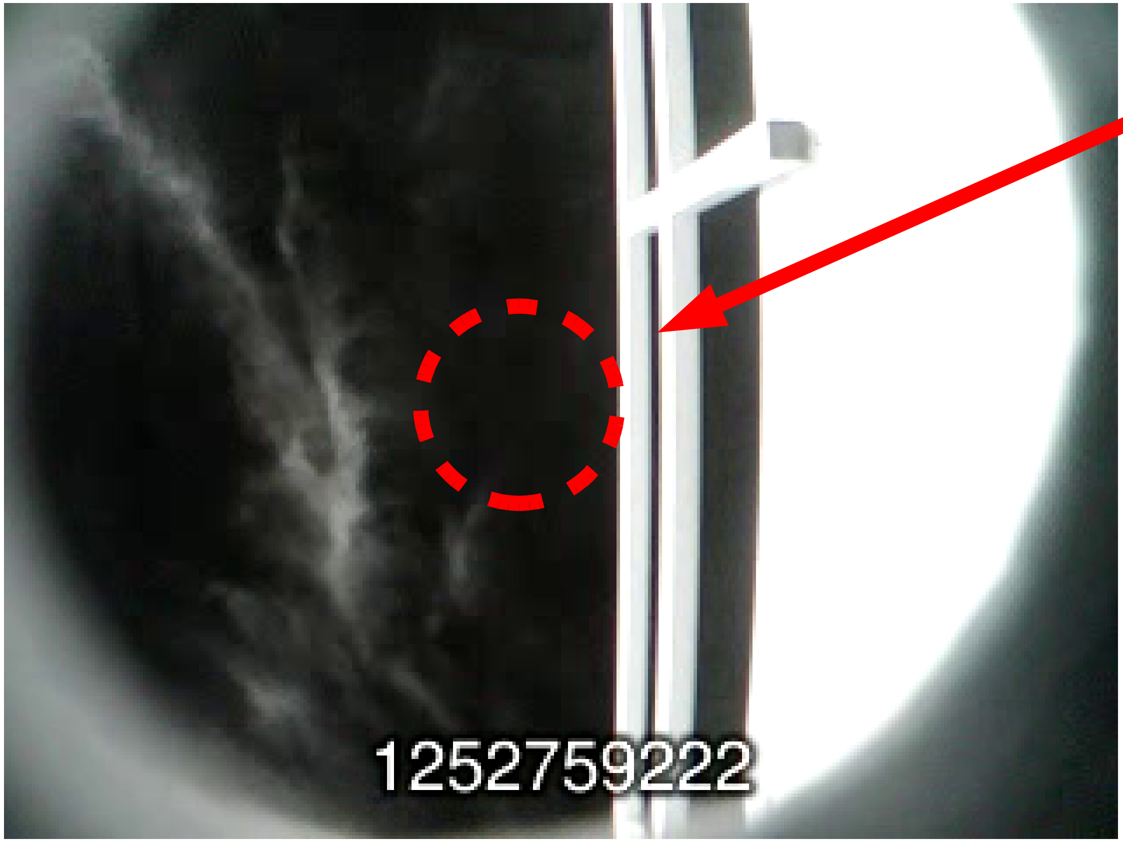
Instrument overview (II)

- Thermally insulated enclosure with active heating
- Auxiliary sensors: weather station and IR sky camera
- Removable solid state storage (CF card) for a fast data transfer procedure

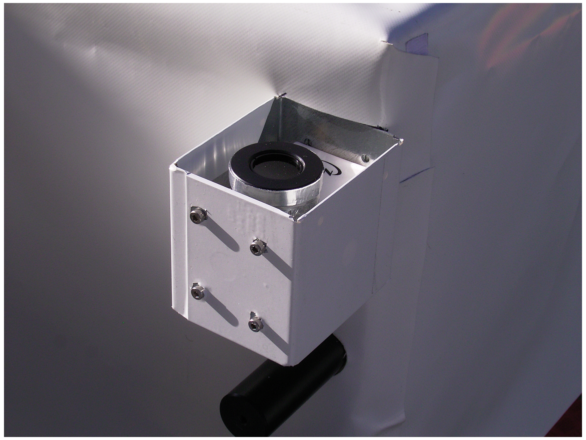




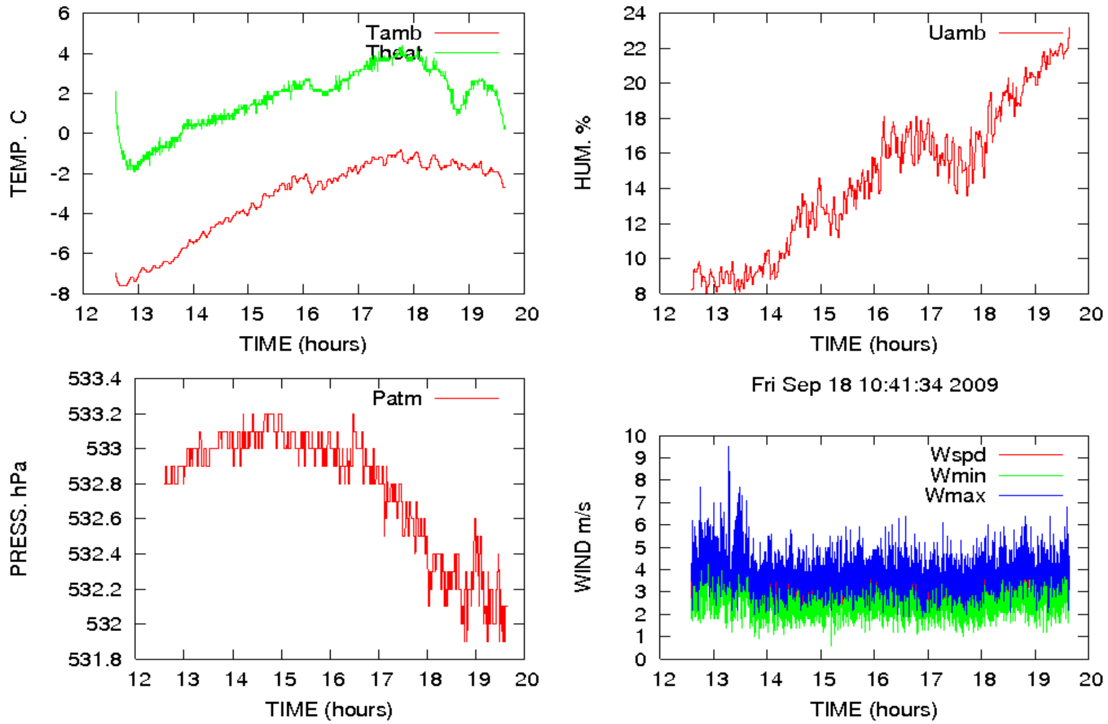
Near-infrared camera

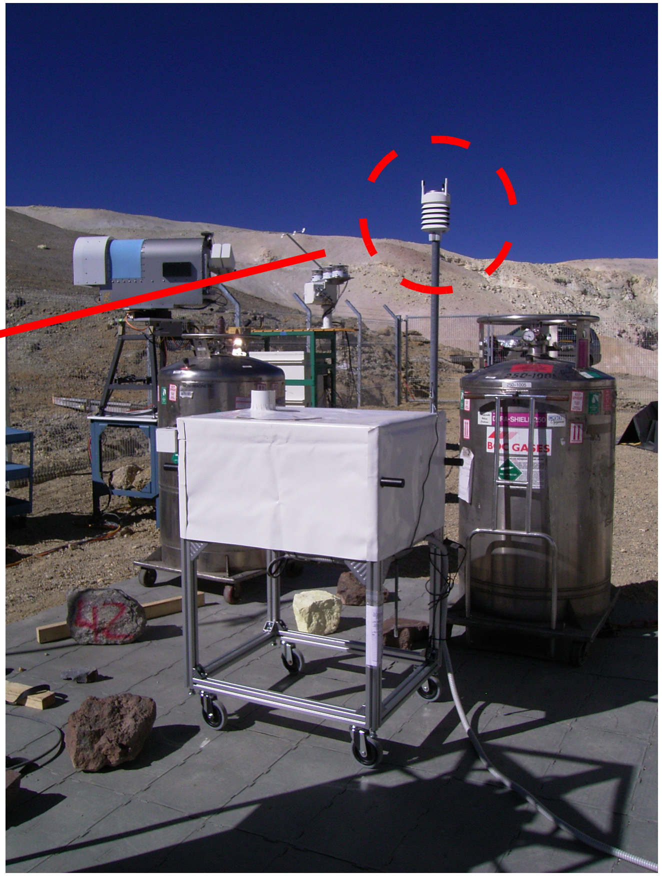


- IR-enhanced webcam with low pass filter @850 nm monitors cloud cover



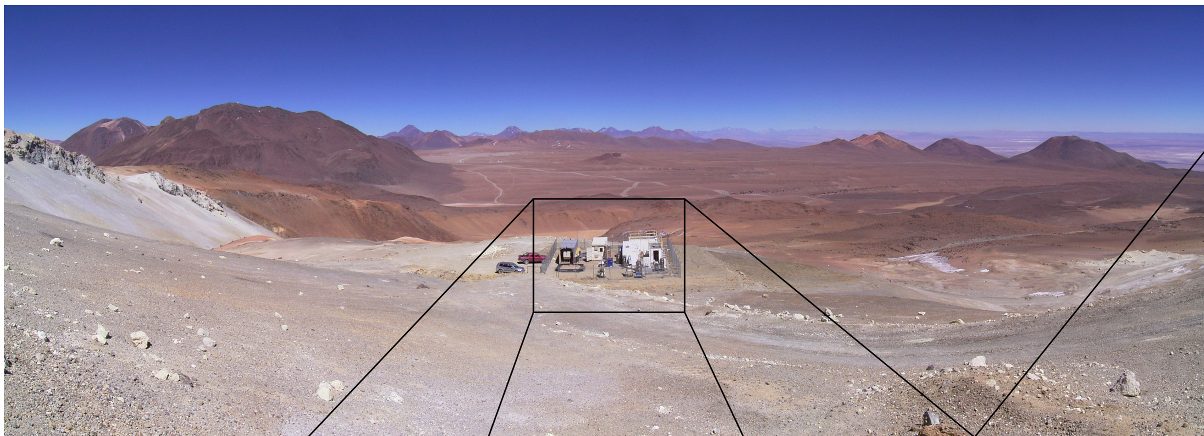
Ground parameters

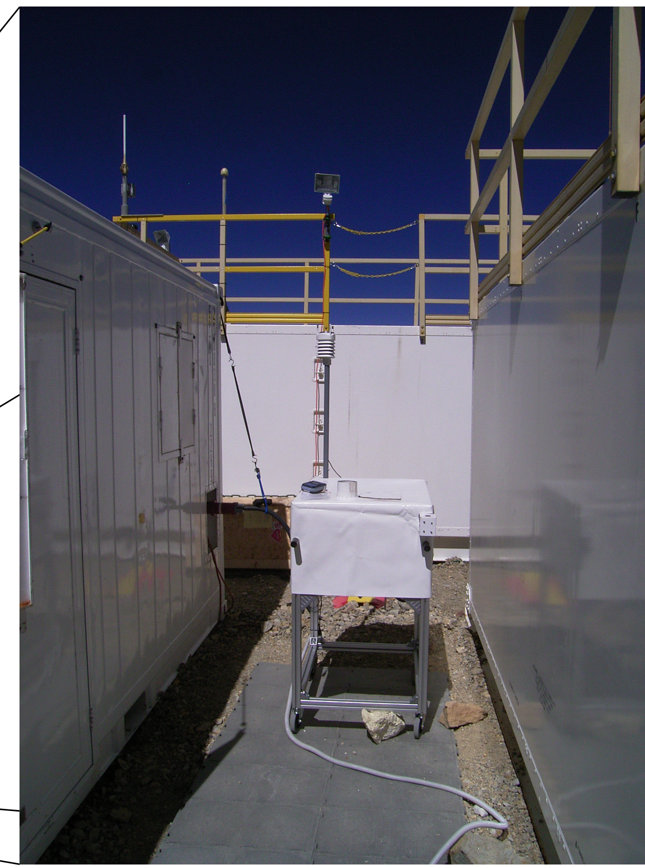




- Vaisala WXT520 weather station provides local atmospheric variables: p, T, RH, wind and precipitation

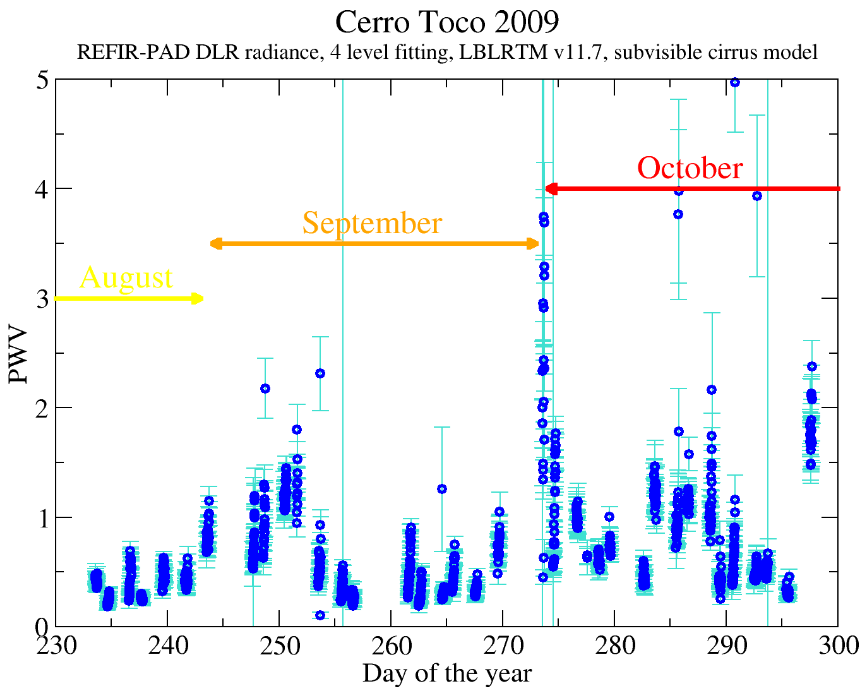
REFIR-PAD @ RHUBC-II

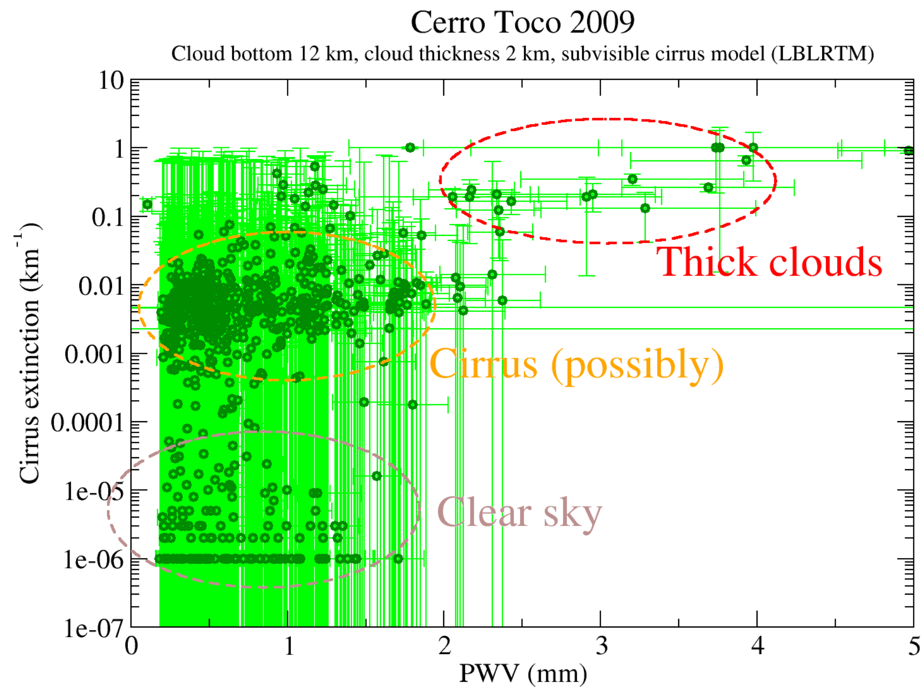




August-October 2009, RHUBC II Campaign, Cerro Toco, Chile, 5383 m a.s.l.

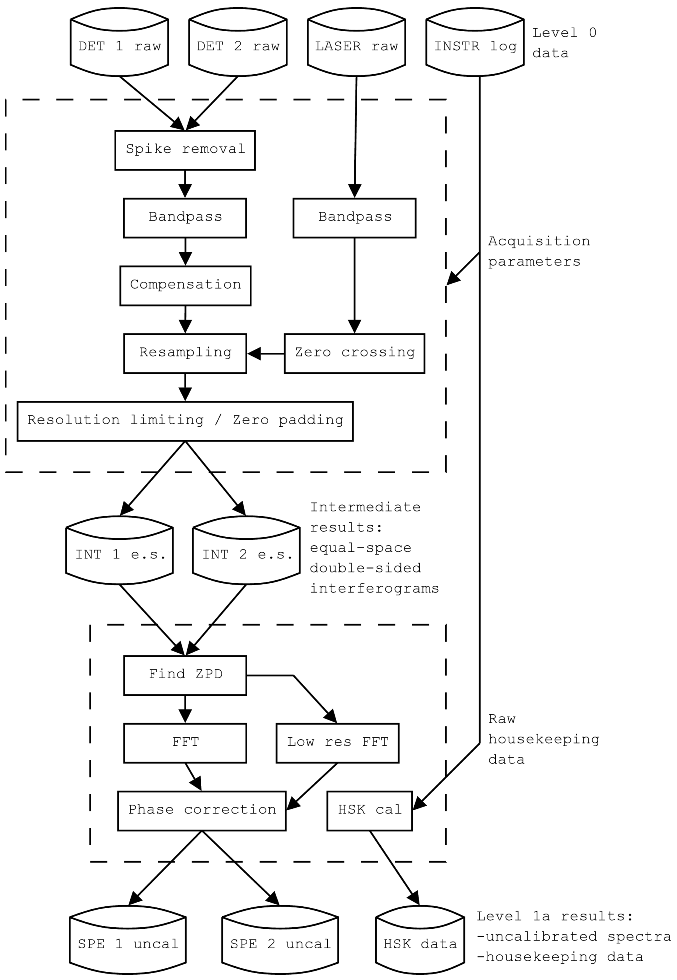
REFIR-PAD RHUBC-II dataset





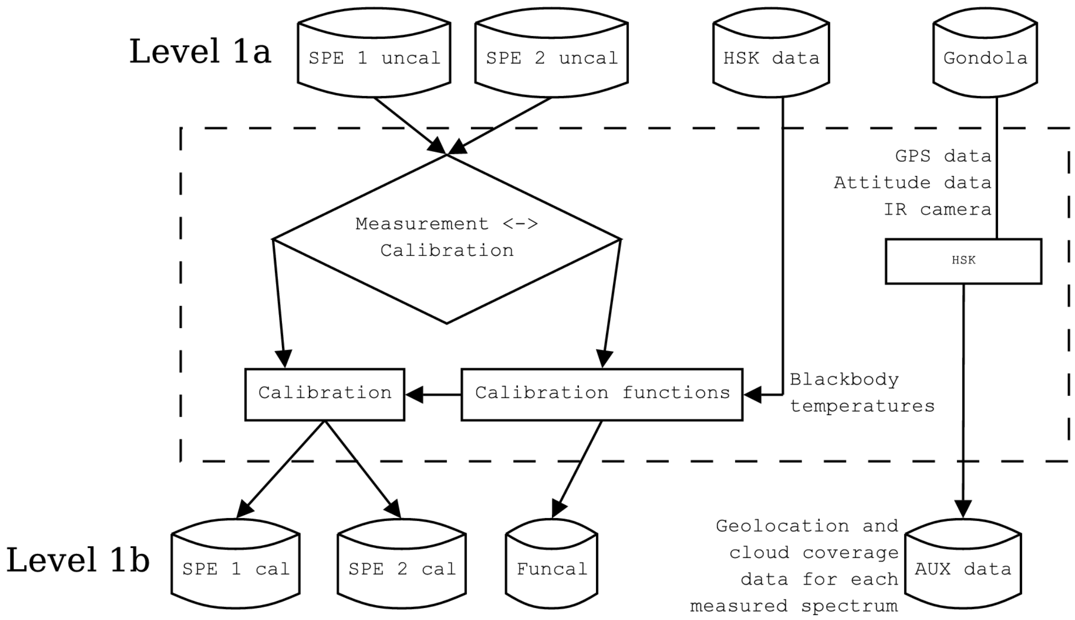
- About 3 months of operation (~40 measurement days)
- Extremely dry conditions, in some cases PWV < 0.2 mm
- Clear sky with frequent occurrence of thin cirrus

Level 1a data analysis



- Data acquisition performed in the time domain and resampled according to the Brault method
- Low resolution phase correction to reduce phase noise
- Frequency calibration performed calculating the reference laser wavelength from the position of atmospheric lines (needed only if laser operating temperature or current is changed)

Level 1b data analysis

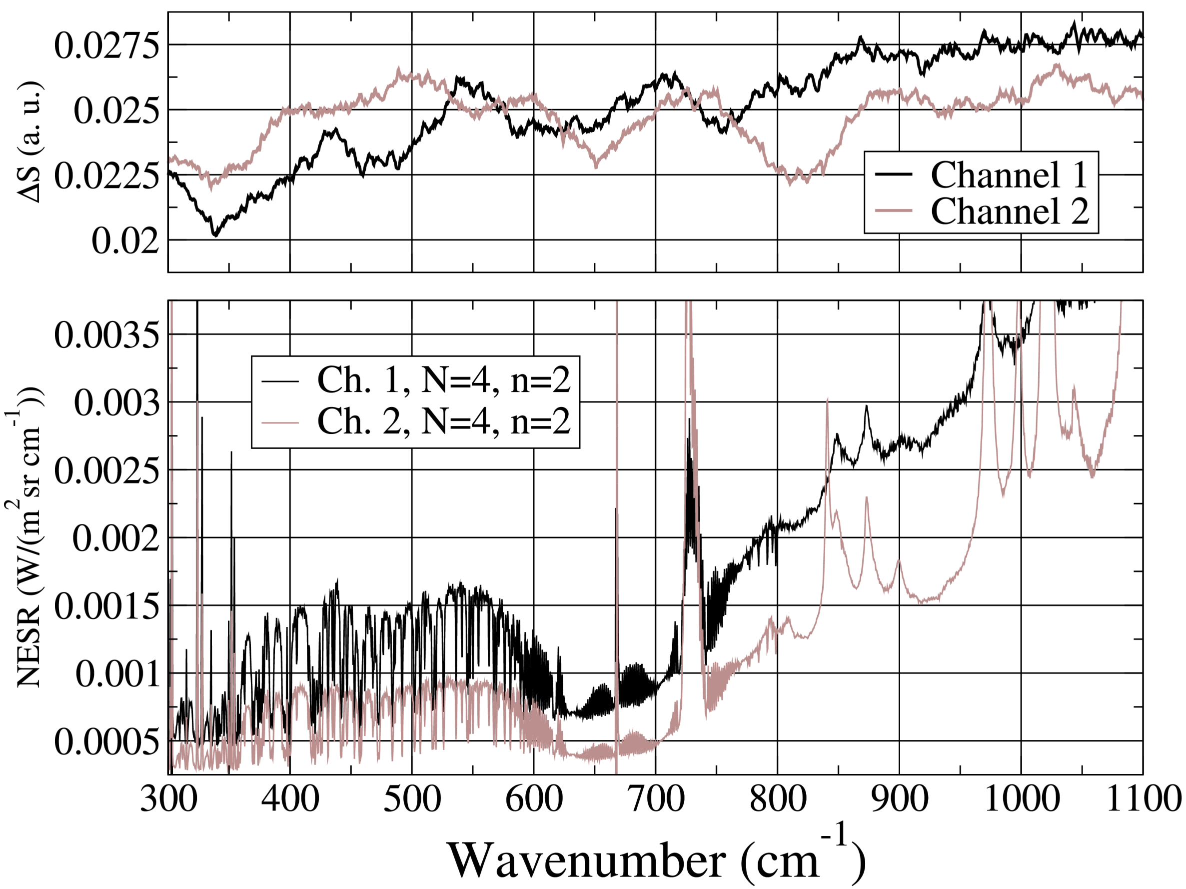


- A 2-point complex calibration gives the response function of the first input (F_1)
- Unbalance between inputs is measured in laboratory ($F_2/F_1 \approx 1$)

$$L(\sigma) = \Re\left\{\frac{S(\sigma)}{F_1(\sigma)} + \frac{F_2(\sigma)}{F_1(\sigma)} B_r(\sigma)\right\}$$

$$F_1(\sigma) = \frac{S_h(\sigma) - S_c(\sigma)}{B_h(\sigma) - B_c(\sigma)} \qquad \frac{F_2(\sigma)}{F_1(\sigma)} \approx 1$$

Radiometric uncertainty



- NESR component obtained from measurement noise through error propagation
- Calibration component also obtained through error propagation assuming a 0.3 K error in the blackbodies temperatures

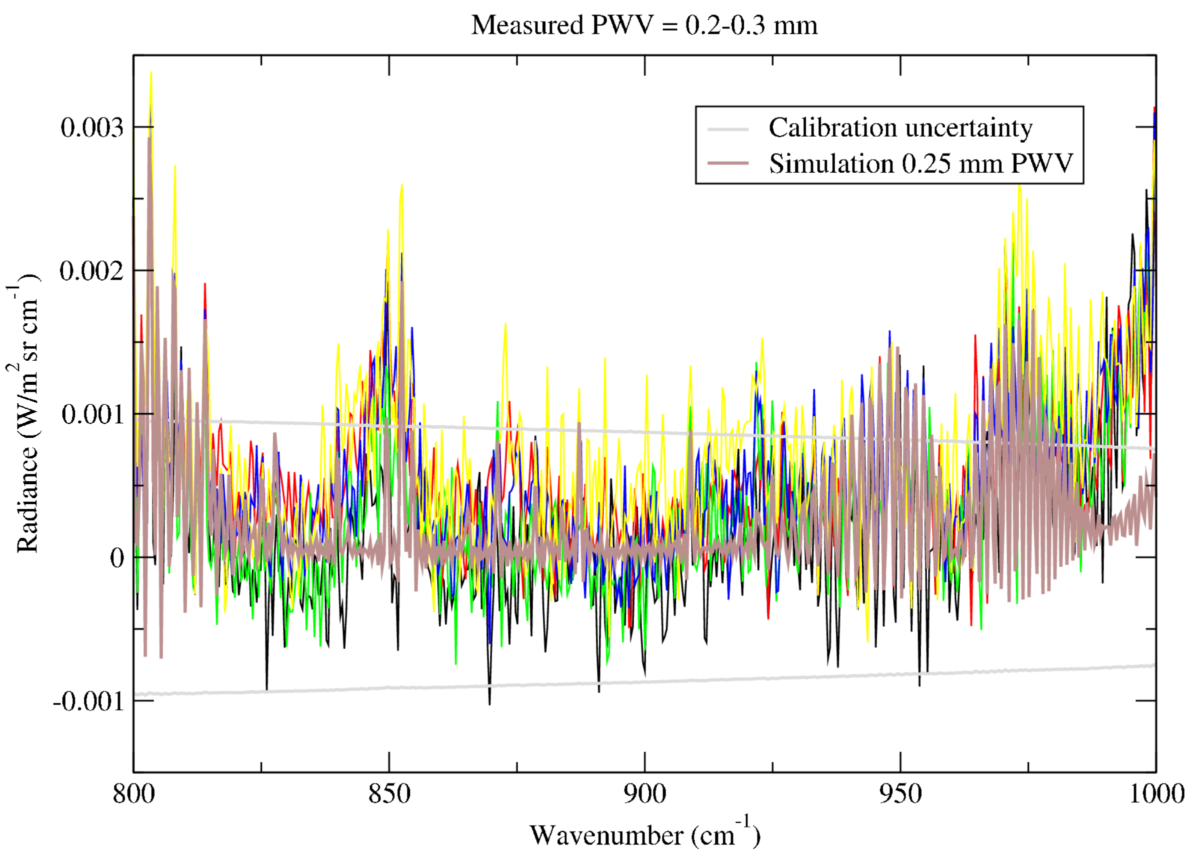
$$NESR=\sqrt{\frac{1}{N}+\frac{2}{n}\left(\frac{S}{S_h-S_c}\right)^2}\frac{\Delta S}{F_1}$$

Level 1 radiometric validation

Case studies:

- Radiance in the atmospheric window with very low water vapor column amounts (about 0.25 mm of total precipitable water vapor)
- Comparison of the brightness temperature in regions of total saturation with the measured temperature of the lowest atmospheric layers (sounding/meteo station)

Atmospheric window

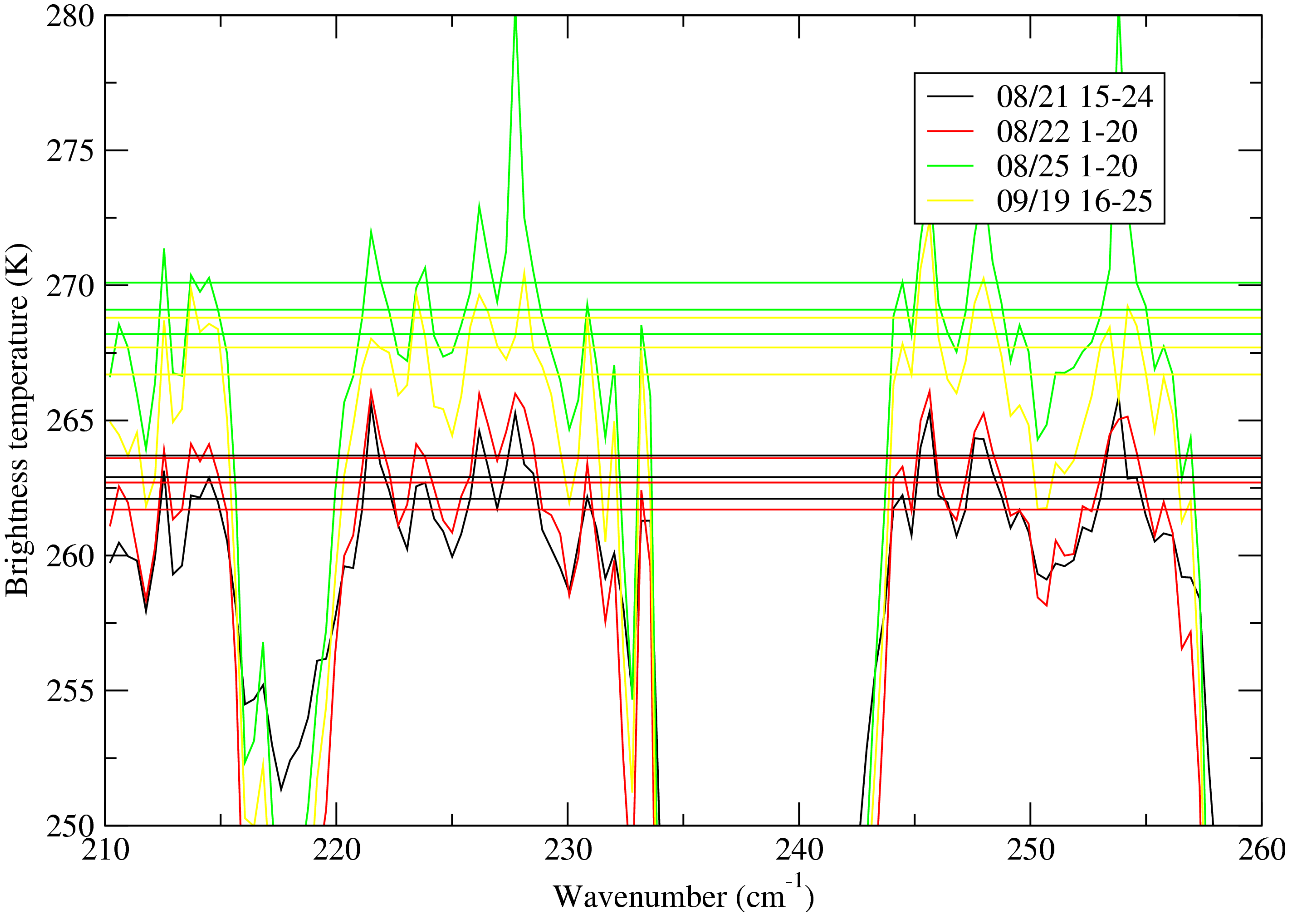


Calibration uncertainty (gray) corresponds to ±0.5K @ 280K

Radiometric accuracy measured in the 860-930 cm^{-1} region:

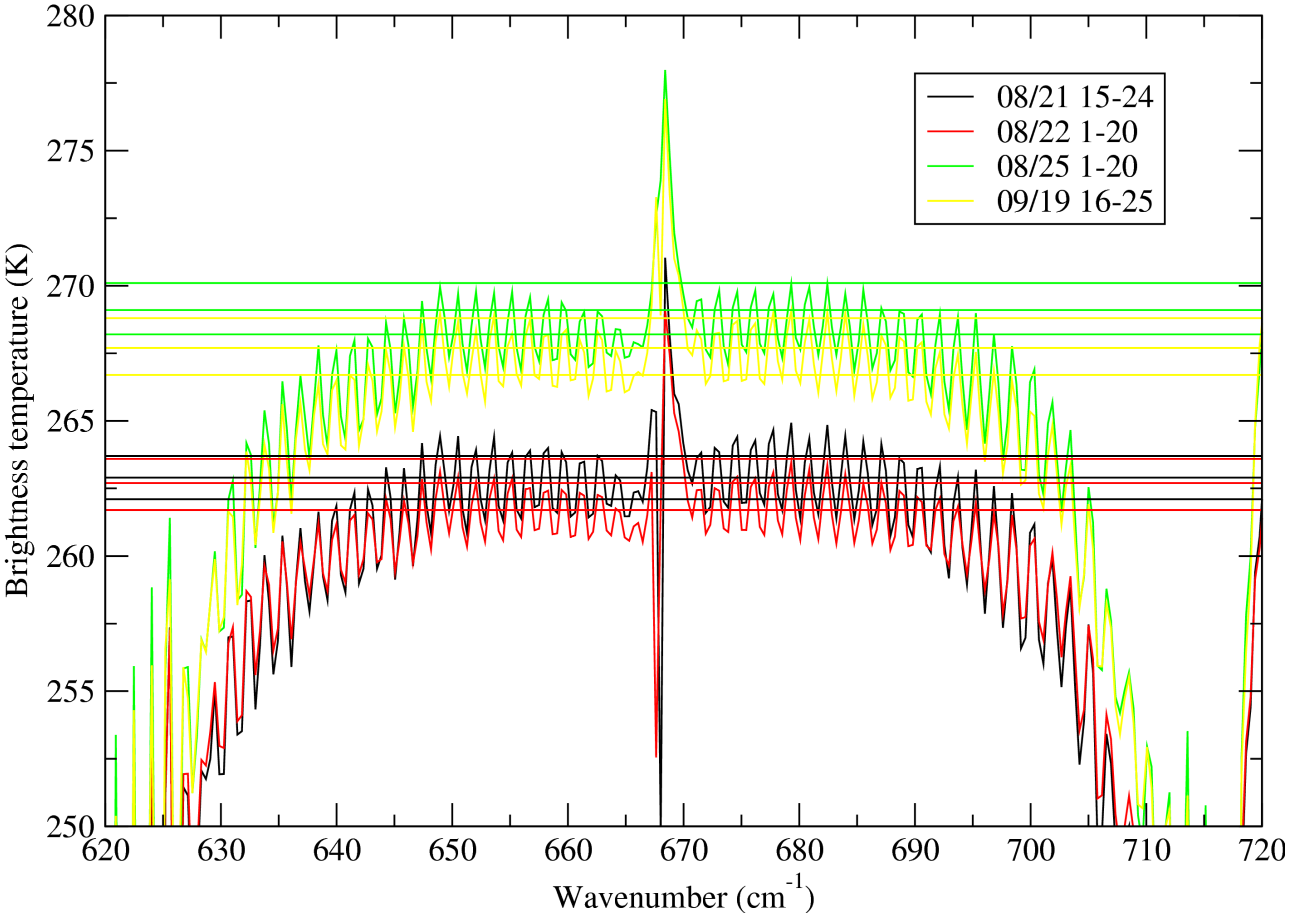
- ≈0.25K RMS
- >0.25K mean

H_2O saturation region



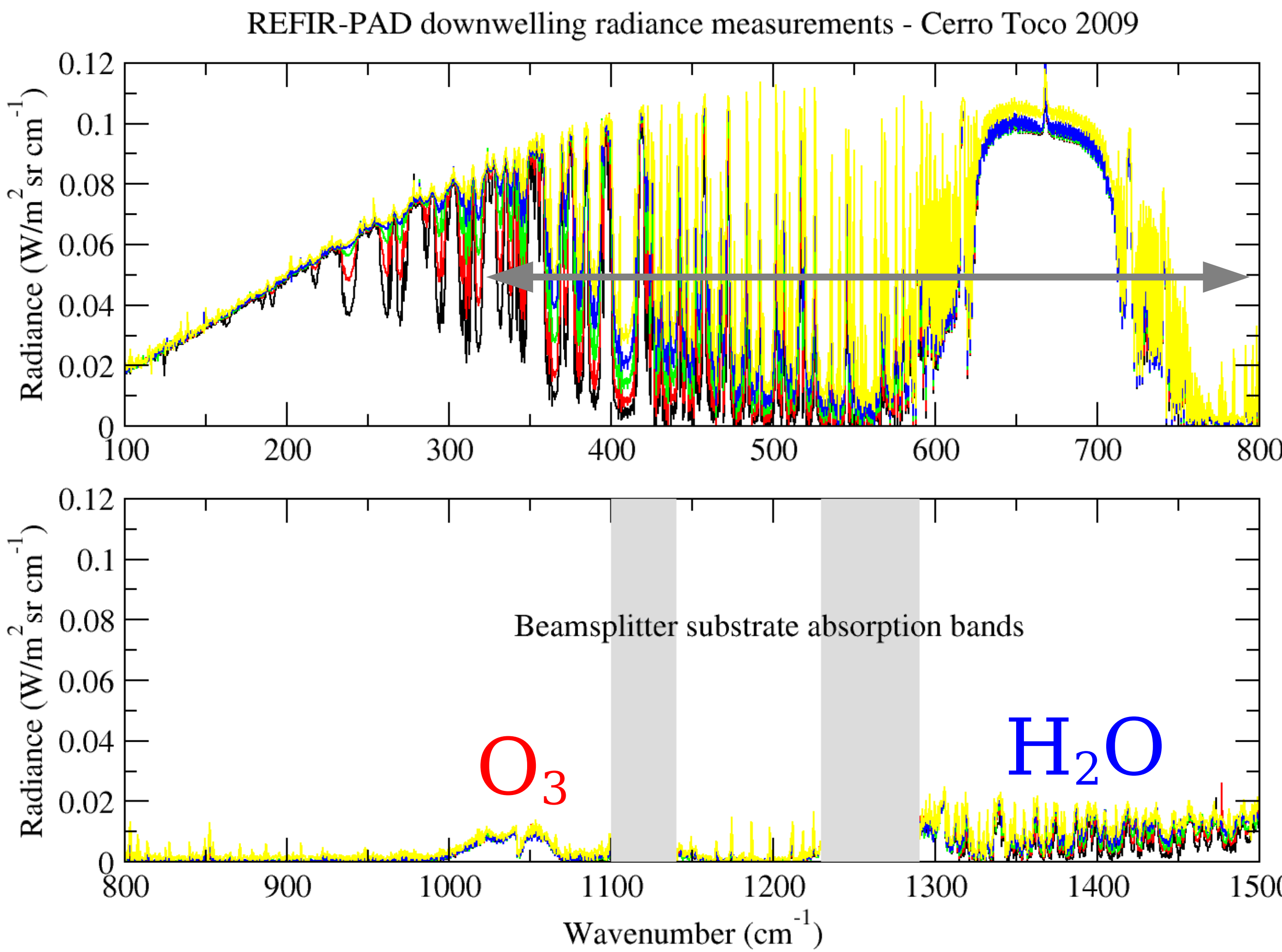
Brightness temperature spectrum compared with average, maximum and minimum temperatures measured in the first 200 meters of altitude

CO_2 saturation region



Brightness temperature spectrum compared with average, maximum and minimum temperatures measured in the first 200 meters of altitude

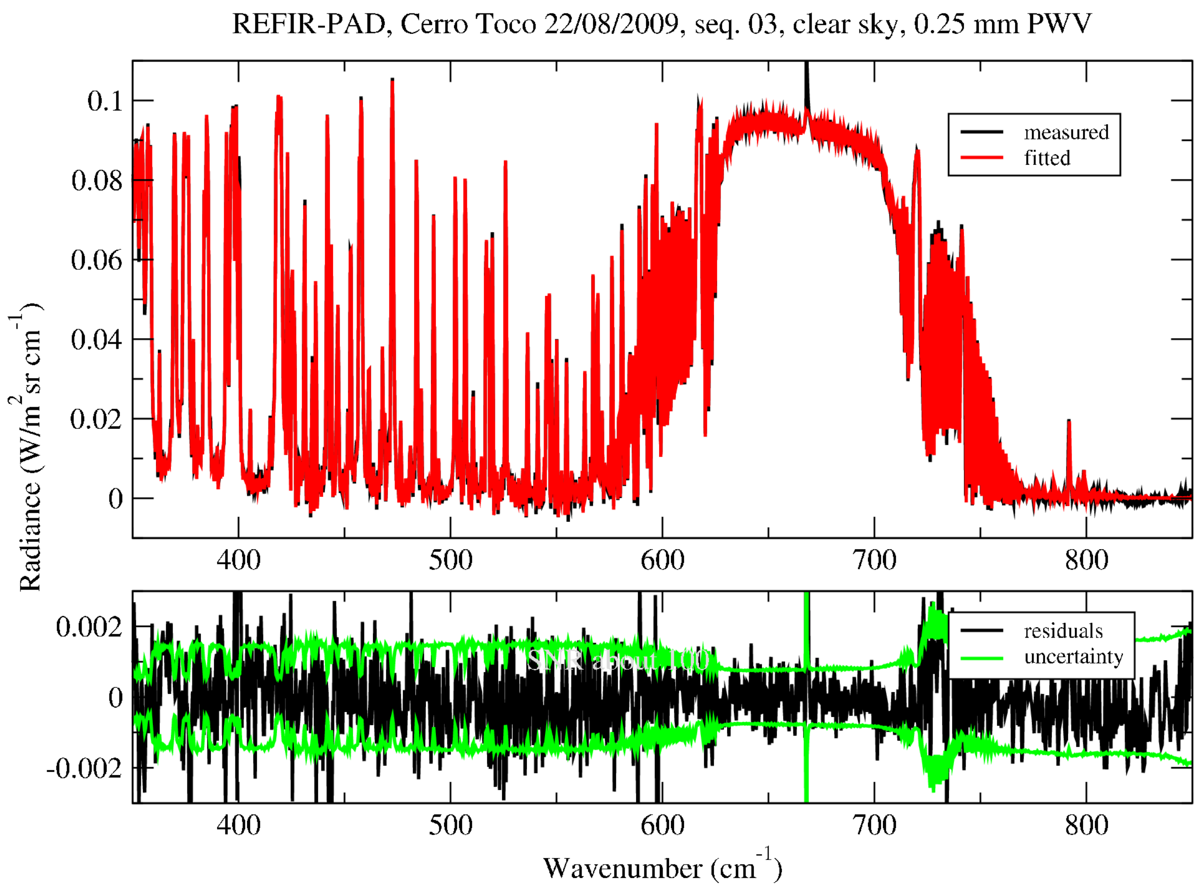
Level 1 products



Used for level 2 analysis (H_2O rotational band, CO_2 ν2 band)

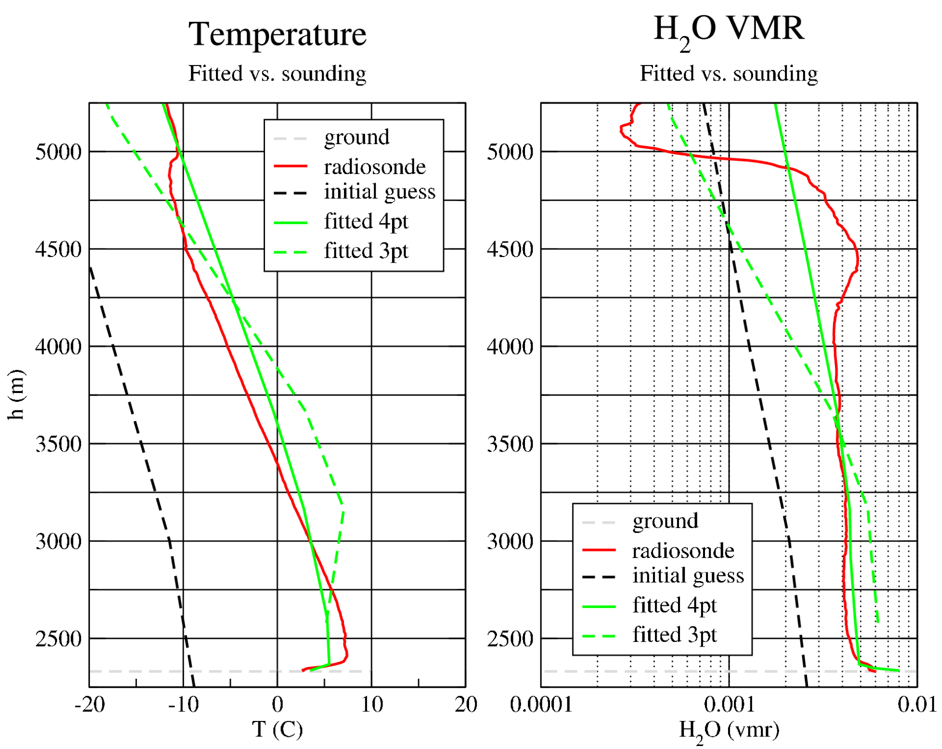
Extended spectral range (O_3, H_2O vibrational band)

Level 2 data analysis

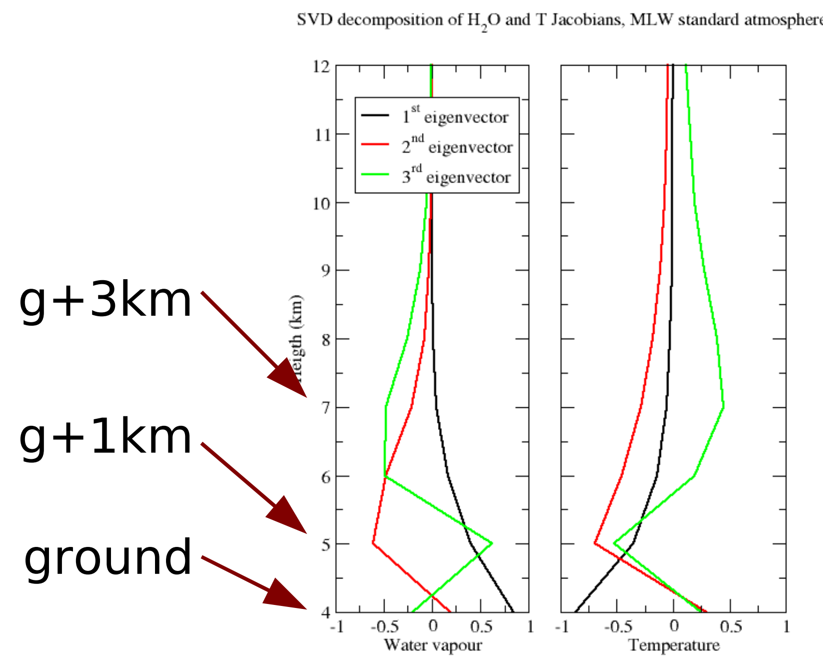


- LBLRTM v. 11.7 forward model
- MINUIT routines (from CERNLIB) to perform χ^2 minimization
- Fitted variables: 4 atmospheric levels per profile (H_2O, T), cloud optical thickness, ILS, frequency correction

Fitting variables selection

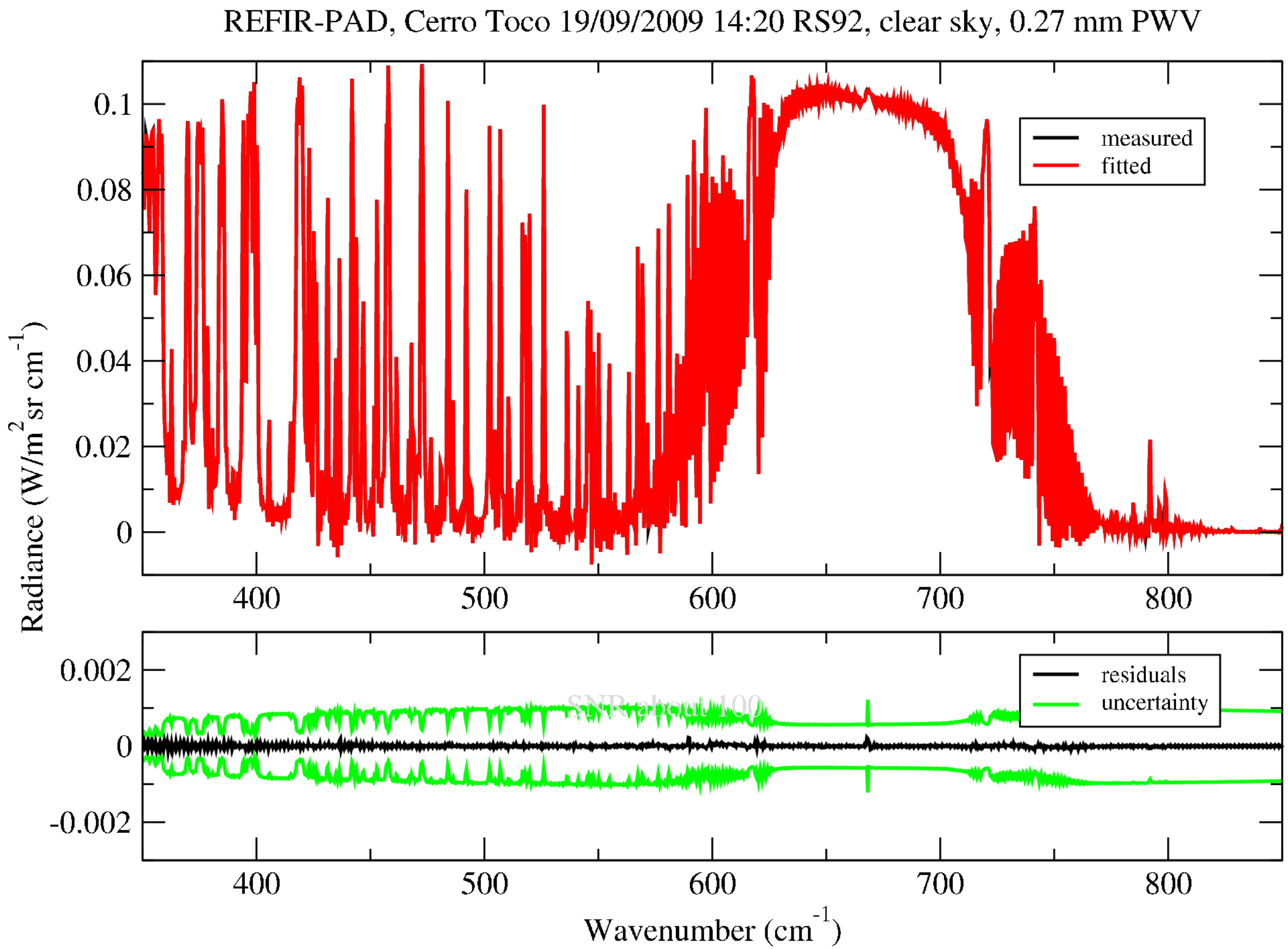


- Fitting levels spaced to reflect SVD eigenfunctions behaviour with height



- Added 1 fitted point 50 m above ground to take into account for surface effects

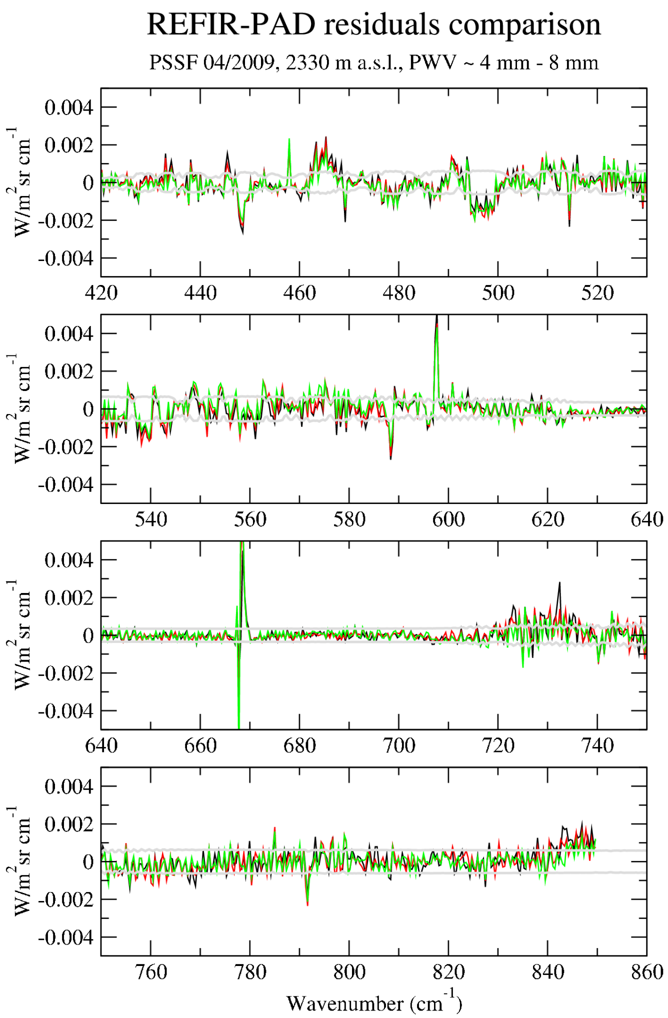
Test of fitting process



- LBLRTM simulated spectrum
- atmosphere from radio-sounding
- no error or noise added

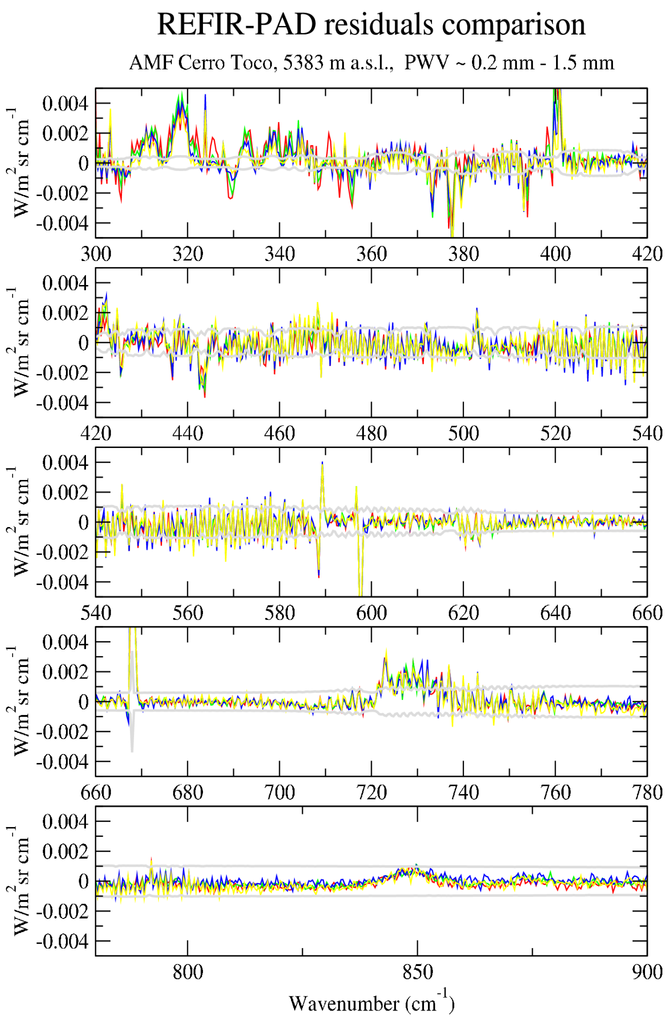
No significant residuals due to fitting process ($\chi^2 << 1$)

Residuals analysis (high PWV)



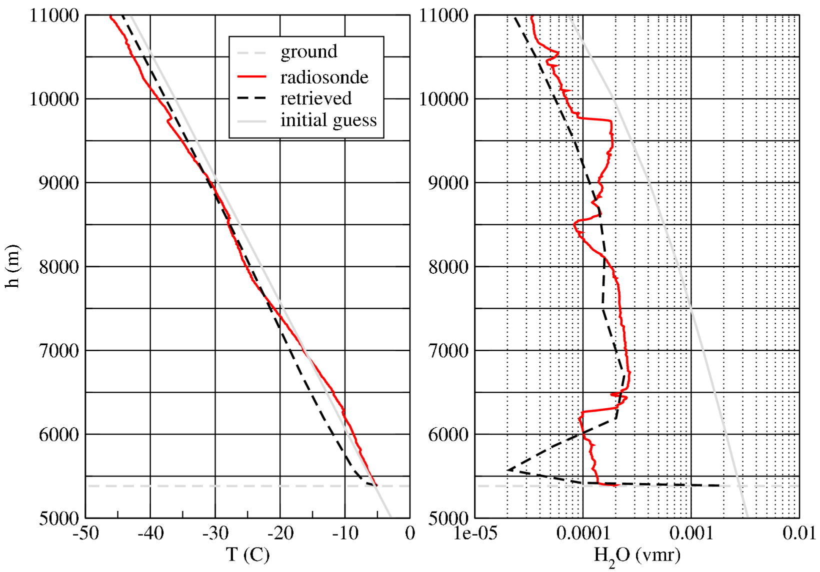
- features in the 450-550 cm^{-1} range significant above calibration uncertainty
- above 550 cm^{-1} model is validated with the REFIR-PAD measurement accuracy
- Spurious effects: CO_2 ν2 Q-branch (667 cm^{-1}), BS absorption (730 and 850 cm^{-1})

Residuals analysis (low PWV)



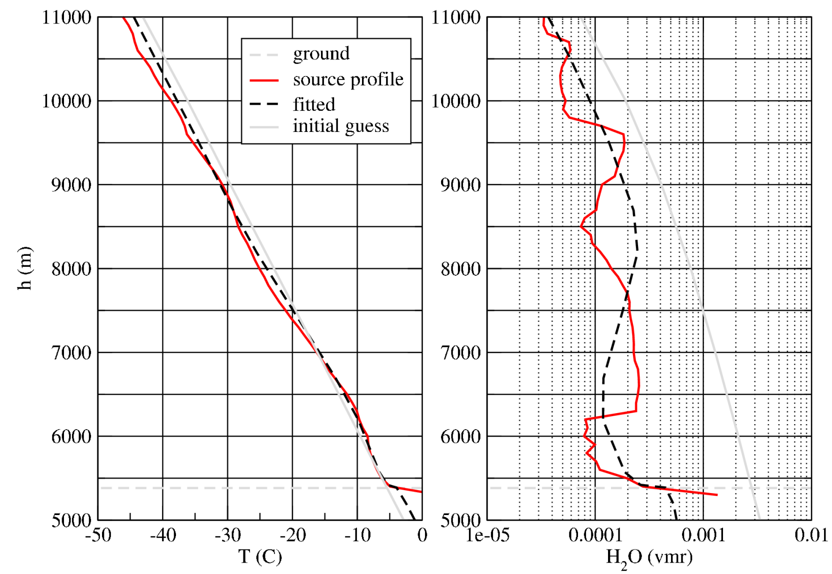
- features in the 300-400 cm^{-1} range significant above calibration uncertainty
- above 400 cm^{-1} model is validated with the REFIR-PAD measurement accuracy
- Spurious effects: CO_2 ν2 Q-branch (667 cm^{-1}), BS absorption (730 and 850 cm^{-1})

Fitting issues

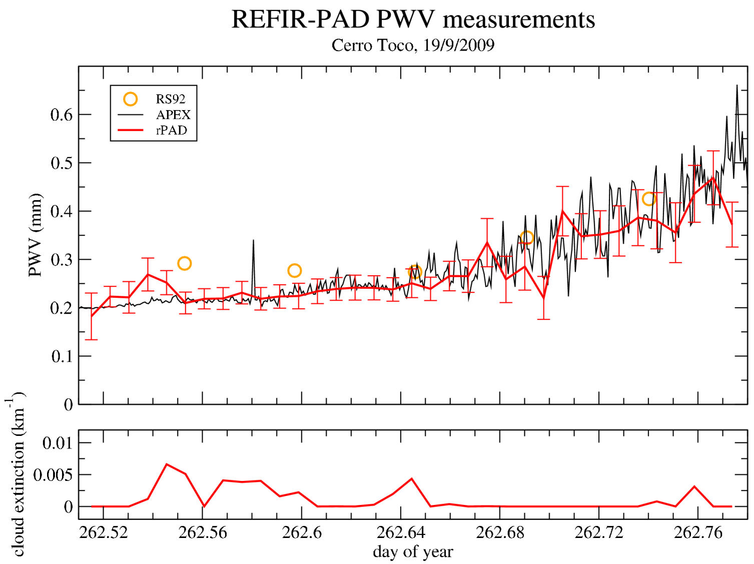


Actual measurement: T and H_2O profiles differ from soundings at lower altitudes

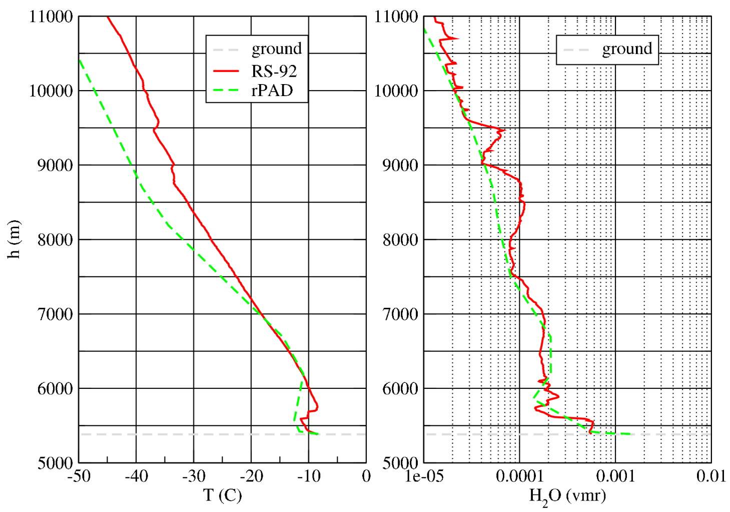
Simulated spectrum (with random noise added): profiles are more similar



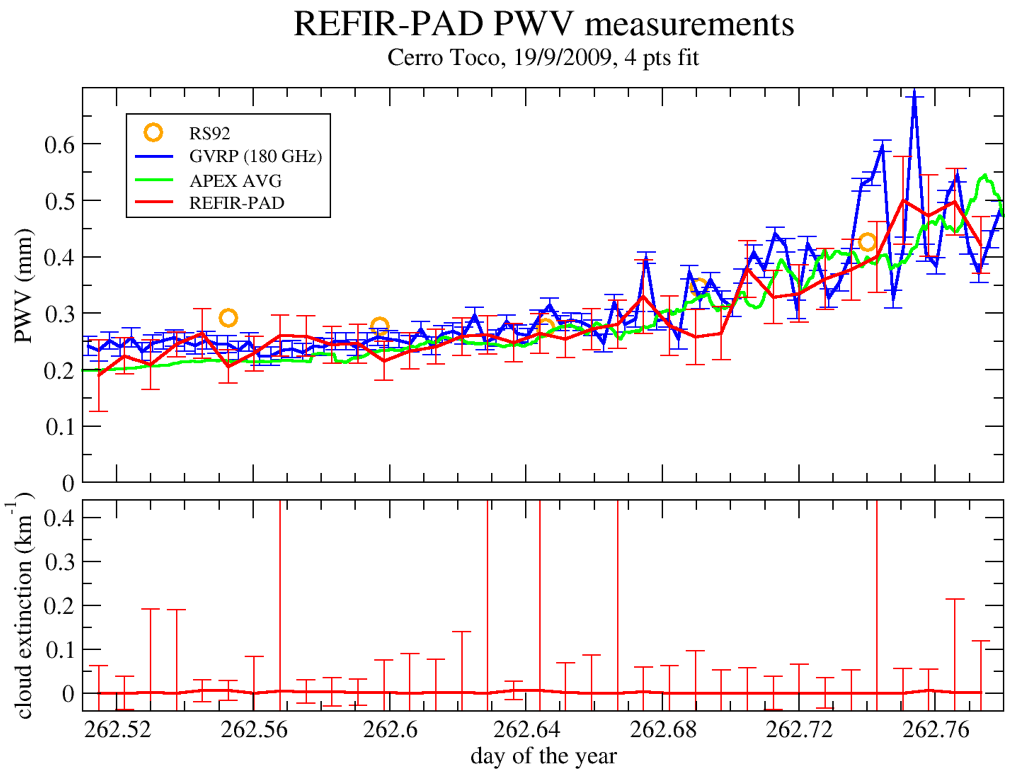
Level 2 products

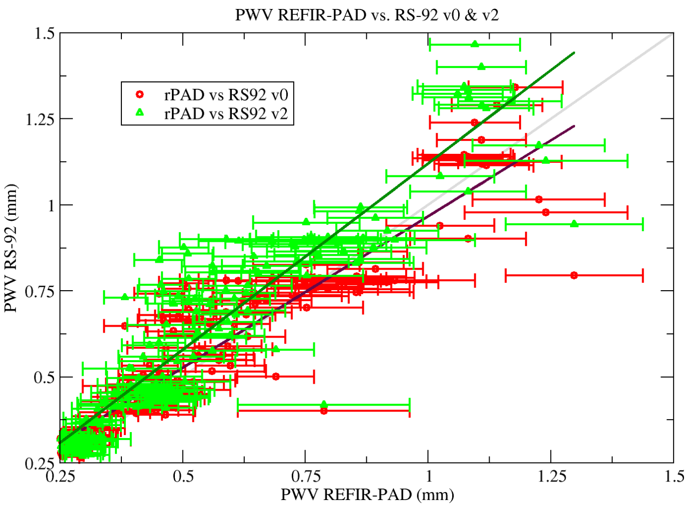


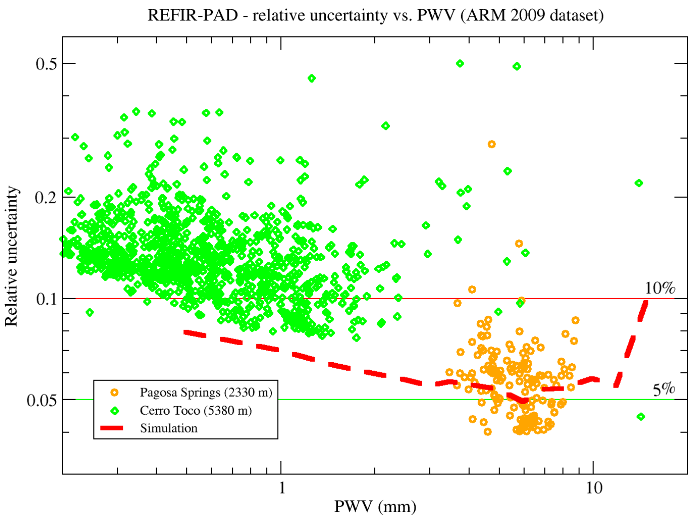
- Integrated water vapor column, cloud optical thickness
- Vertical water vapor and temperature profiles



Water vapor column

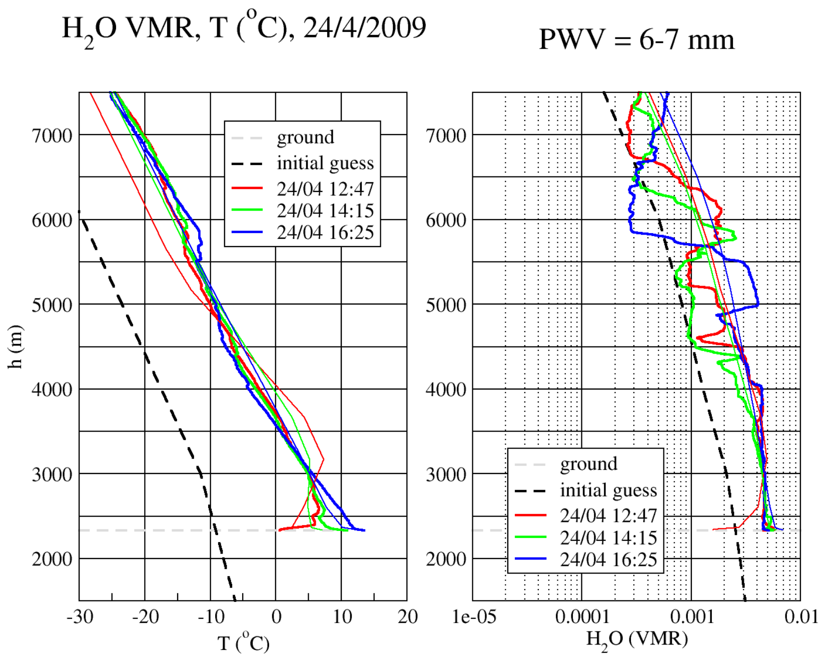






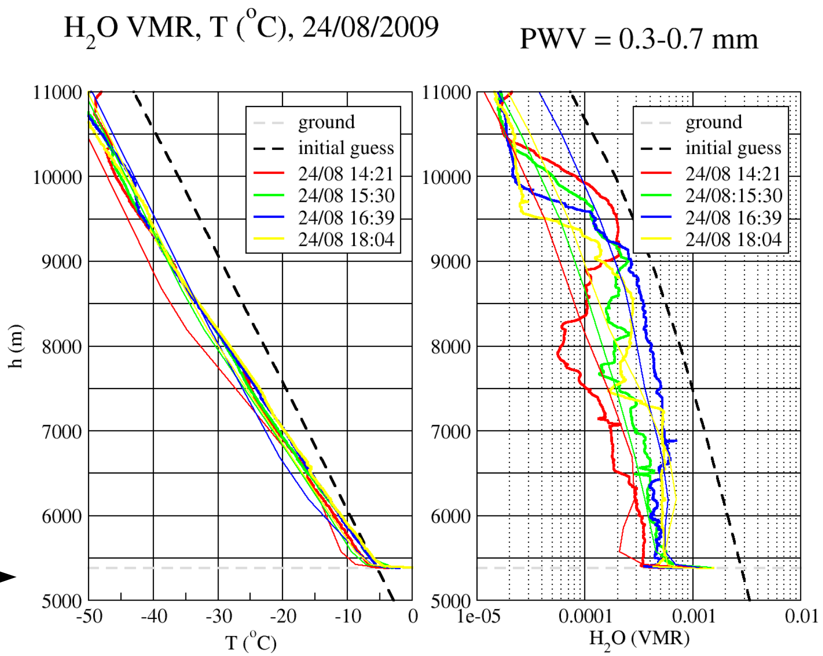
Relative uncertainty: 5%-20%

Vertical profiles (H_2O, T)



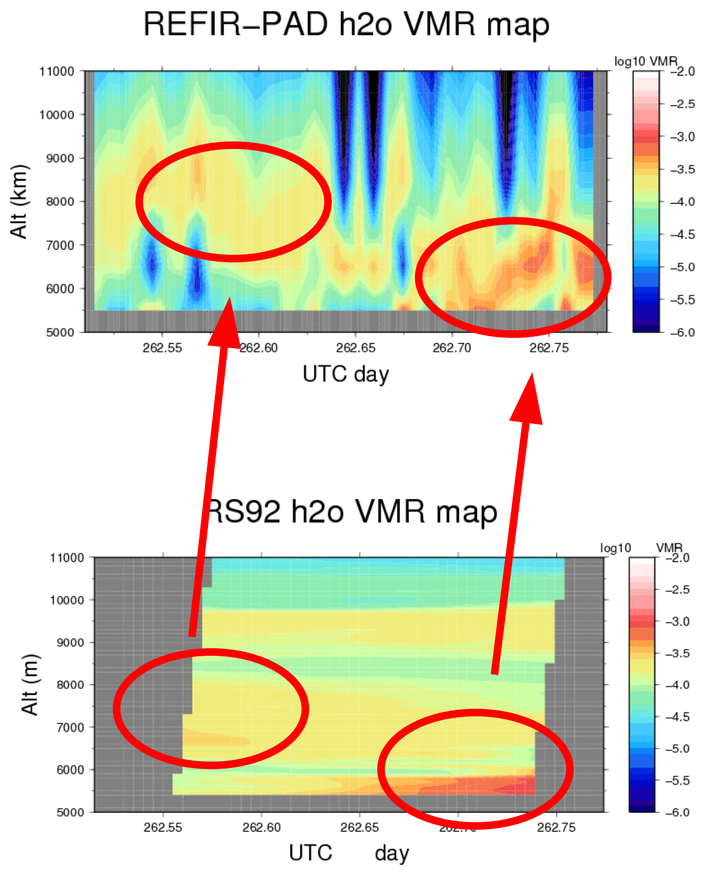
High total water column

Low total water column

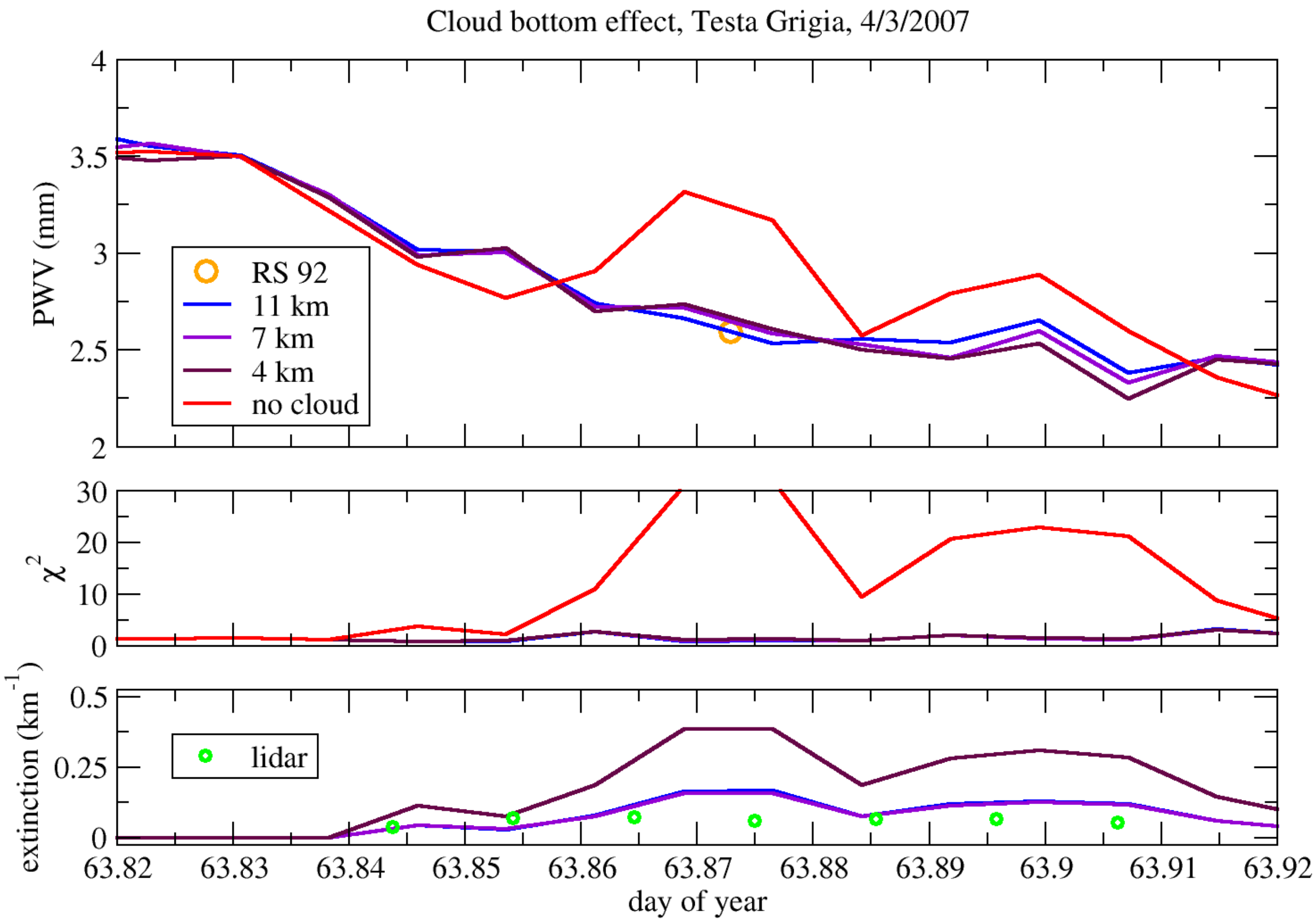


REFIR-PAD water vapor sounding

- RS-92: high vertical resolution, but low time resolution
- REFIR-PAD: better suited to resolve the evolution in time of the atmospheric state (but with a lower resolution of the vertical structure)



Cloud modeling

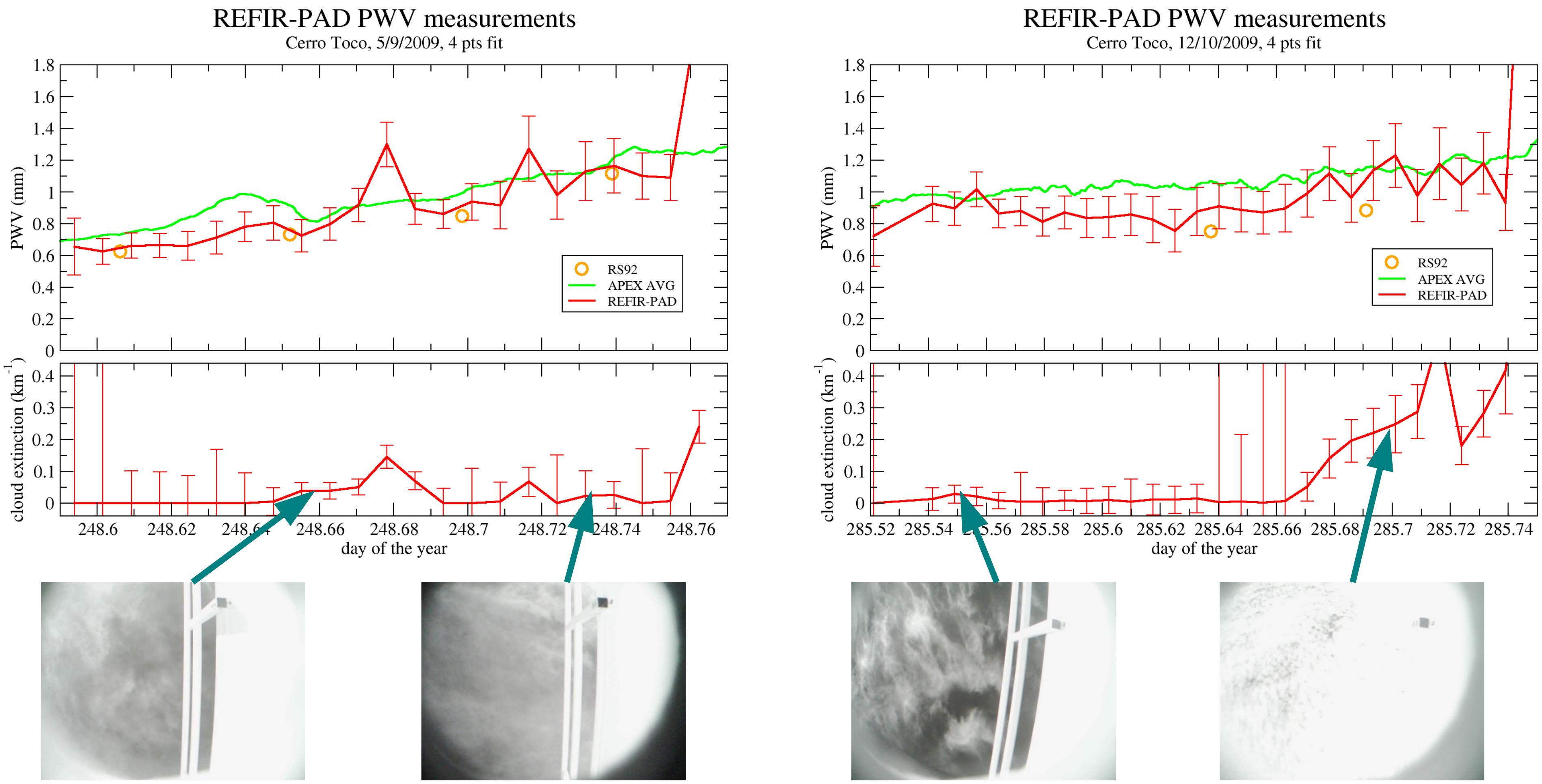


Cloud model provided by LBLRTM (from LOWTRAN 7)

subvisible cirrus, 2 km thick with cloud bottom at ~7 km above ground

fitted parameter: optical thickness (as extinction coefficient)

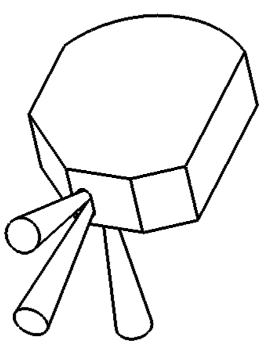
Cloud cover effect



Conclusions

REFIR-PAD RHUBC-II products:

- Level 1: calibrated spectral radiances with radiometric accuracy better than 0.5 K from far-infrared to atmospheric window (~0.25 K)
- Level 2: PWV with 5% to 20% relative uncertainty, cloud OT, T and H_2O profiles



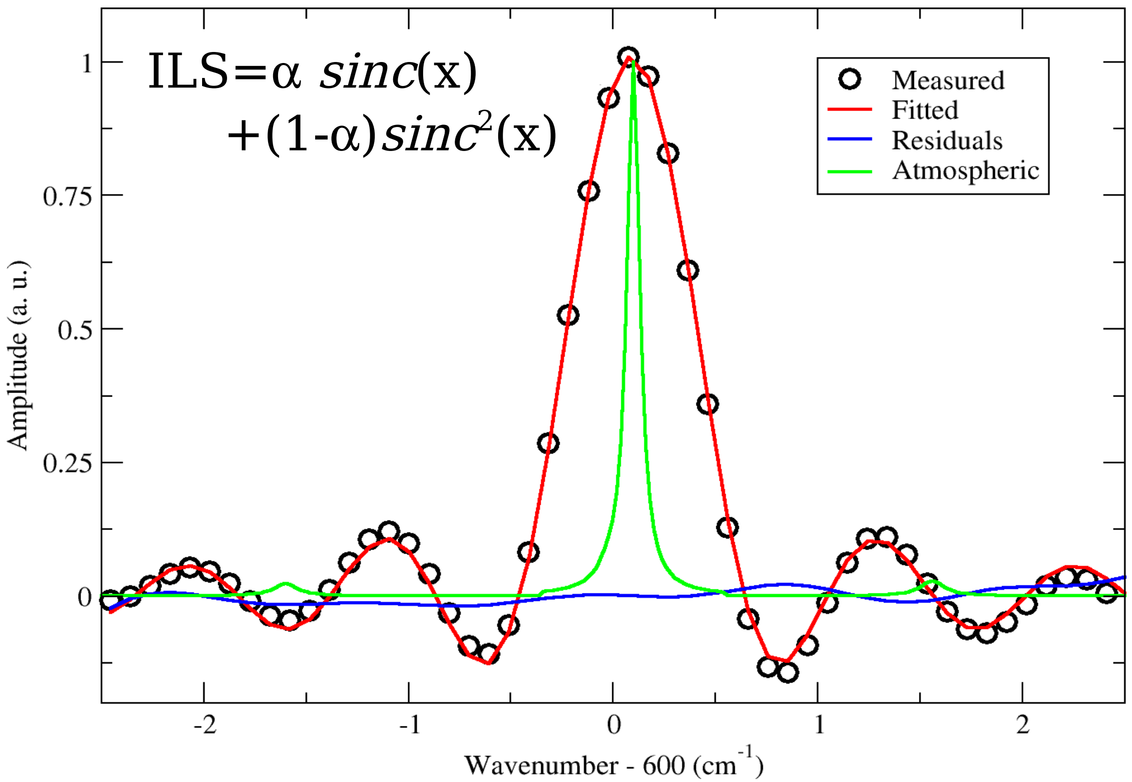
http://fts.ifac.cnr.it

References

- L. Palchetti, C. Belotti, G. Bianchini, F. Castagnoli, B. Carli, U. Cortesi, M. Pellegrini, C. Camy-Peyret, P. Jeseck, and Y. Tè, ``Technical note: First spectral measurement of the Earth's upwelling emission using an uncooled wideband Fourier transform spectrometer", *Atmospheric Chemistry and Physics*, **6**, 5025-5030 (2006)
- G. Bianchini and L. Palchetti, ``Technical Note: REFIR-PAD level 1 data analysis and performance characterization", *Atmospheric Chemistry and Physics*, **8**, 3817-3826, (2008)
- G. Bianchini, L. Palchetti, G. Muscari, I. Fiorucci, P. Di Girolamo, and T. Di Iorio, ``Water vapor sounding with the far infrared Refir-Pad spectroradiometer from a high-altitude ground-based station during the Ecowar campaign", *J. Geophys. Res.*, **116**, D02310, (2011)

Spare slides

Instrumental line shape



Linear combination coefficient α is fitted in level 2 analysis in order to take into account thermal misalignment effects (apodization)

$\alpha_0 \sim 0.90 - 0.95$ (divergence limit)