Retrieval of PWV from the analysis of spectrally resolved measurements of the DLR from an high-altitude station

RADIATION EXPLORER IN THE FAR INFRARED

REFIR-PAD

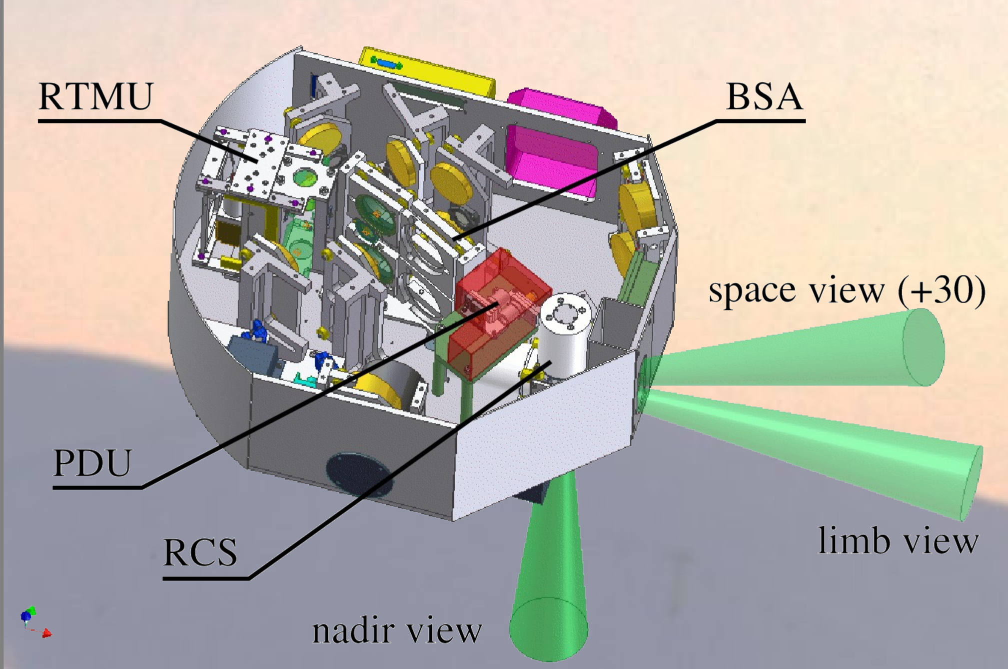
Giovanni Bianchini, Luca Palchetti, Bruno Carli

Istituto di Fisica Applicata "Nello Carrara" IFAC-CNR, Via Madonna del Piano 10, Florence, Italy

contact information: e-mail gb@ifac.cnr.it – website http://refir.ifac.cnr.it

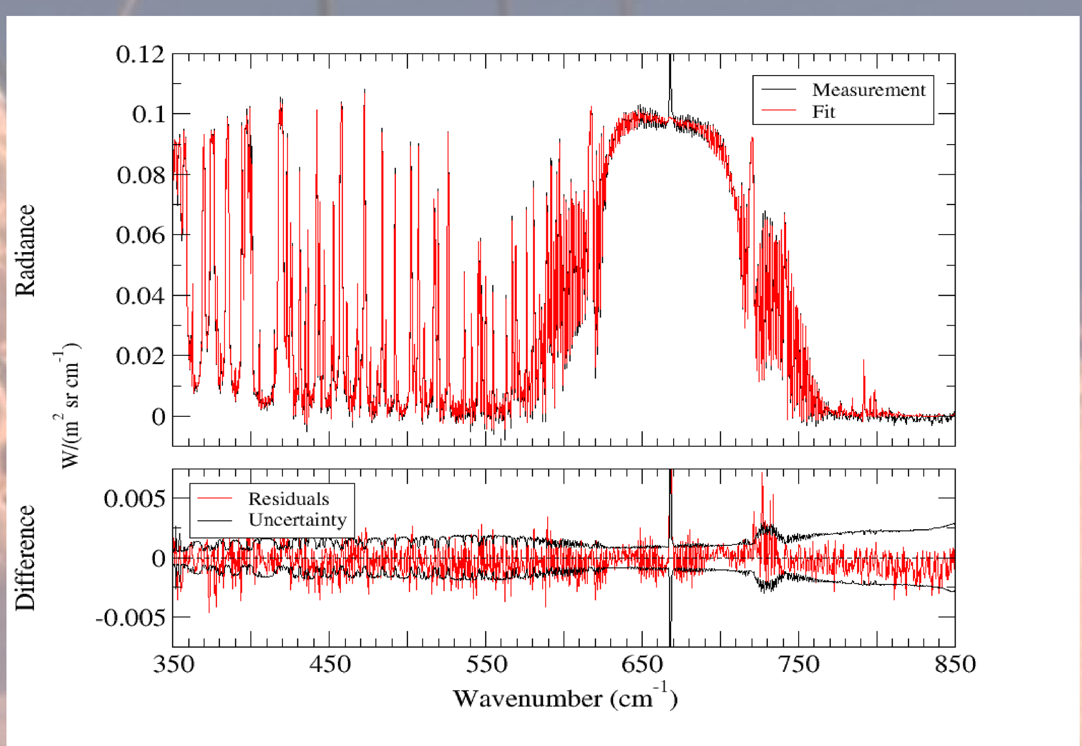
The measurement of the downward long-wave radiation (DLR) in its full spectral range is a very important tool for the characterization of the atmospheric components. From the ground typically the DLR is characterized in the mid infrared (MIR) where the transparency of the atmosphere allows to sound all the vertical structure. In the far infrared (FIR) spectral region, below 600 cm^{-1}, the observation from ground is usually performed only in very dry regions of the Earth, such as polar regions or high altitude mountain sites. Despite that, the FIR is very important because in clear sky conditions, from one third to one quarter of the total greenhouse forcing is calculated to occur in this spectral region, and even larger effects are expected to be present in cloudy conditions.

The Radiation Explorer in the Far-Infrared (REFIR) project has been developed with the scientific objective of performing high resolution spectral measurements of the atmospheric radiance down to the FIR region.



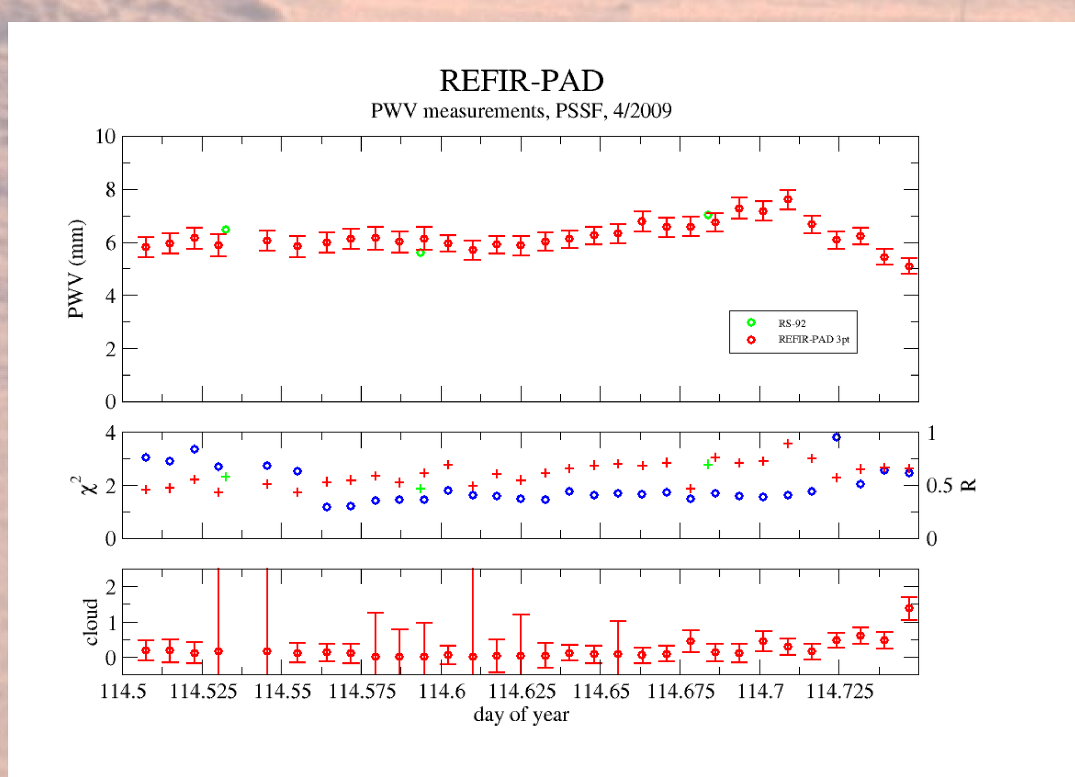
Schematic view of the REFIR-PAD instrument and its main components. The three viewing modes of the instruments, nadir, limb and space (30° above horizontal) are shown. The zenith view is obtained from limb view through an external folding mirror. RTMU: roof-top mirror unit (scanning mechanism), BSA: beam splitter assembly, PDU: infrared detector unit, RCS: reference calibration system.

REFIR-PAD measured DLR spectra were analyzed through a retrieval code based on the LBLRTM v11.6 forward model and the MINUIT function minimization routines available from CERN. The choice of atmospheric variables to be fitted must be performed keeping into account that the sensitivity of zenith-looking radiance spectra to atmospheric physical parameters, obtained from the Jacobian matrices of the DLR, peaks at the lowest atmospheric layers, and reduces notably after the first 5 km above ground. Moreover we must also take into account the low vertical resolution of the zenith-looking observation geometry with the REFIR-PAD spectral resolution. The best compromise between quantity of information retrieved from the spectra and low correlation between parameters is obtained fitting for each profile (WV, T) one point at ground level one 1 km above ground and another 3 km above ground, rescaling the initial guess profile above the higher point and below the lower one, and linearly interpolating the profile between the two fitted points.



In the figure to the left (top panel) the result of the fitting of a REFIR-PAD measured DLR spectrum is shown. The spectrum is obtained from the average of 8 acquisitions of 64 seconds each. The spectrum was acquired from 5400 m a.s.l. in extremely dry conditions (total PWV less than 0.3 mm).
On the bottom panel the fitting residuals are compared with the total a-priori uncertainty on the measured radiance. The χ^2 resulting from the fit is 2.7.

The water vapor VMR profile obtained from the fitting procedure is integrated to obtain the total precipitable water vapor (PWV) above the measuring site. This parameter is, in fact, the physical variable to which REFIR-PAD zenith-looking spectra show the most sensitivity.
The PWV values obtained from REFIR-PAD measurements along with the value obtained from RS-92K radio soundings performed from the measuring site are shown in the figure to the left. In this case the measuring site is 2400 m a.s.l. during springtime, with a much higher PWV.
The parameter R, shown in the central panel as crosses (right y axis) expresses the ratio between two water vapor semi-columns calculated with respect to a reference point, and provides an extra parameter to perform comparison with soundings and to get extra information on water vapour vertical distribution from REFIR-PAD data.



The main atmospheric parameter that can be retrieved from the DLR spectra is the PWV, to which the instrument has the maximum sensitivity, with relative errors generally lesser than 10% and typically of the order of 5% (see error analysis on the right).
It is also possible to split the total water vapor column in two parts, through the use of two fitted points, in order to extract further information about water vapor distribution with height. The result can be shown as a parameter that expresses the ratio between the two semi-columns and thus the general shape of the water vapor vertical profile (see figure above)

Between 2006 and 2007 the REFIR-PAD (REFIR-Prototype for Applications and Development) instrument was successfully deployed in various ground-based campaigns: on the 6th of February, 2006 from Monte Morello (610 m a.s.l., Sesto Fiorentino, Italy), on on the 13th and the 14th of March, 2006, from Monte Gomito (1892 m a.s.l., Abetone, Pistoia, Italy), between 5th and 15th of March, 2007, from the Testa Grigia CNR base (3480 m. a.s.l., Aosta, Italy)

REFIR-PAD installed at Monte Gomito in a polystyrene thermal shielding enclosure

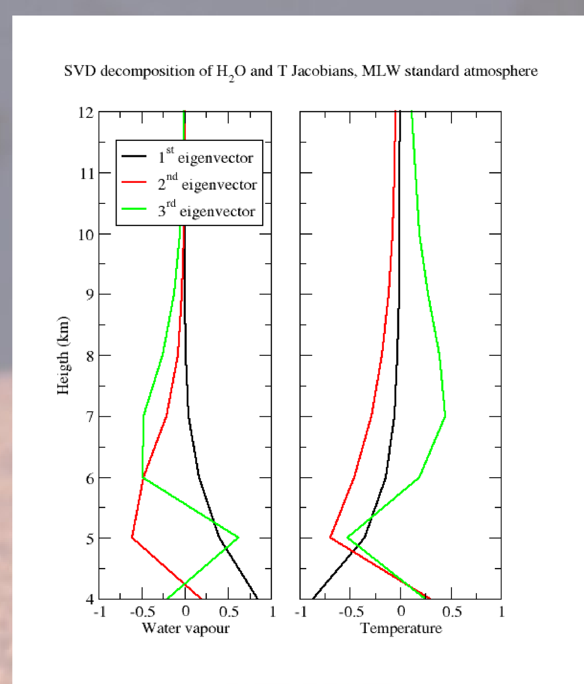
The altitude and the winter conditions guaranteed low water vapor content, which allowed to explore the FIR portion of the emission spectrum with great efficiency. From this site, the measurement of the DLR is also not perturbed by the planetary boundary layer and it can used for the evaluation of the cloud emission component in the atmospheric transparency windows.

REFIR-PAD installed at Testa Grigia in an aluminum frame, perspex and polystyrene thermal shielding enclosure

The ARM Mobile Facility at Cerro Toco

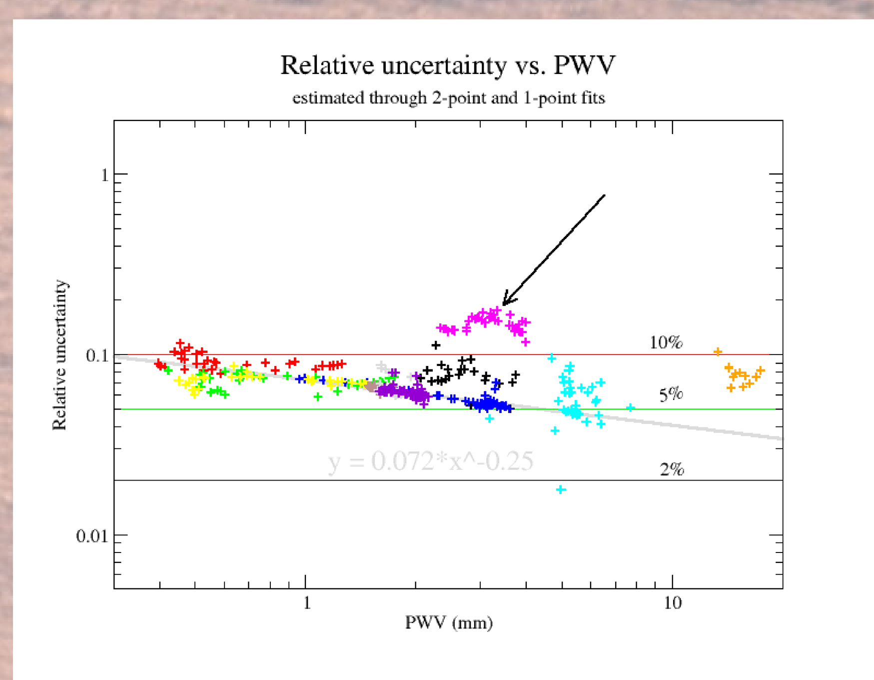
More recently, during 2009, REFIR-PAD has partecipated to the second "Radiative Heating in the Unexplored Bands Campaign" (RHUBC-II), held by the U.S. Atmospheric Radiation Measurement Program (ARM), first in a test campaign performed from Pagosa Springs (Colorado, USA, 2329 m a.s.l.) in April, and then in the measurement campaign from Cerro Toco (Chile, 5383 m a.s.l.) from August to October.

From the analysis of Jacobian matrices of the DLR we can deduce the sensitivity of REFIR-PAD measurements to atmospheric variables. Information on the water vapour content of the lower tropospheric layers can be obtained from the far-infrared spectral range between 350 and 650 cm^{-1}, while in the 550-800 cm^{-1}range it is possible to obtain temperature information from CO2 without water vapour contamination.
On the plot to the right are shown the first three eigenfunctions that can be obtained from the singular value decomposition (SVD) of the Jacobian matrices of water vapor and temperature in the case of measurements from 3500 m a.s.l. The eigenvalues decrease rapidly with the order of the eigenvector, indicating that the vertical information content of the spectra is low.



Errors on the fitted parameters depend on the correlation between the parameters themselves. In particular, in the case of water vapor, in the case of the fit of various profile points, the correlation coefficient is negative: an overestimate of the water content in a layer triggers an underestimate of the neighboring layers. This poses a limit on the maximum number of profile points that can be fitted without obtaining an oscillating behavior in the profiles.

Also, when calculating the total precipitable water vapor column from the measurements, the anticorrelation causes an overestimate of the errors. To overcome this problem, the error on the PWV value are obtained fitting a single profile point (i.e. rescaling the profiles), while the actual PWV value is obtained with the standard fit.
In the figure to the right is shown the result of this kind of calculation for different measurements performed in the 2006-2007 period from different measurement stations. The relative error versus the PWV value is plotted in order to extract a trend that can be used to perform a theoretical error estimate.
It should be noted that the errors obtained follow mostly a simple relation, while outliers generally evidence instrumental problems such as external noise sources or misalignment (see arrow in figure).



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