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The REFIR-PAD experiment

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Abstract. The spectrally resolved measurement of the upwelling radiation emitted from the Earth over the relevant spectral region from the far-infrared (FIR) to the mid-infrared is expected to improve the characterisation of the Earth radiation budget as a function of the atmospheric components that are responsible for this emission. In particular, the effect of water vapour in the upper troposphere and of thin clouds as cirrus can be characterised by taking advantage of their FIR signatures.
The REFIR-PAD (Radiation Explorer in the Far InfraRed – Prototype for Applications and Development) experiment is dedicated to this kind of measurements. In this paper, the results of a stratospheric balloon campaign performed in June 2005 from North-East Brazil are described.

Key words. Atmospheric composition – Earth radiation budget – Climate change – Fourier transform spectroscopy – Far infrared

1. Introduction

The Earth Radiation Budget (ERB) is the balance between the incoming energy from the sun, the outgoing longwave radiation (OLR) and the reflected shortwave energy from the Earth (Kiehl et al., 1997). Typically, the ERB is characterised by observing the overall energy balance divided into two wide bands, the longwave or thermal infrared and the shortwave including near infrared to ultraviolet. However in such a way, the dependence of radiation on the different atmospheric components which cause the emission is missed, and in particular for the OLR, it is missed the dependence on the greenhouse gases concentrations.

A proper characterisation of the ERB can be obtained by a spectral measurement of the OLR on its full relevant spectral range, from the mid-infrared to the far-infrared (FIR) region (Sinha et al., 1997). Unfortunately, neither spectroscopic measurements are available at the TOA that exploits the FIR region, nor space mission has been made or selected for future operations. Due to this lack of measurements, also the spectroscopy of water vapour needs to be improved in the FIR.

The REFIR-PAD (Radiation Explorer in the Far InfraRed – Prototype for Applications and Development) prototype is the first example of spectrometer in which recent technology developments have allowed uncooled high-accuracy operation over the longwave spectral region. The instrument is capable of measurements both in the nadir-looking geometry

Send offprint requests to: L. Palchetti from high-altitude platform and in the zenith-looking geometry from ground, and can be easily qualified for space applications.

REFIR-PAD main objective is to demonstrate the new instrument concept and the capability of its measurements to increase the accuracy of remote sounding of the upper tropospheric water vapour and cirrus clouds under different atmospheric conditions through TOA measurements of the OLR (Palchetti et al., 2008). Furthermore, through ground-based measurements, REFIR-PAD has proven to be an effective mean to characterise total precipitable water vapour (PWV) and cirrus cloud optical density (Bianchini et al., 2007). Line spectroscopy and continuum absorption of the FIR rotational water vapour band will also be refined by using field measurements provided by REFIR-PAD (Bianchini et al., 2008).

In this paper, the results obtained by REFIR-PAD with the first FIR spectral measurements of the OLR from balloon platform (Palchetti et al., 2006) are summarised.

2. Far-infrared measurement of the outgoing longwave radiation

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The importance of the FIR region for the calculation of the ERB can be understood by looking at Fig. 1 in which, in the upper panel, the spectra corresponding to the upward emission at the surface (black-dashed-line) and at the top-of-atmosphere (TOA) (black-continuous-line) of a tropical standard atmosphere are shown. At the surface the emission corresponds more or less to that of a blackbody at the temperature of the ground. At the TOA, the emission decreases by a factor that is a function of the spectral absorption of the atmospheric components, mainly water vapour, carbon dioxide, and ozone. The TOA spectrum shows these spectral signatures and it is limited by the surface emission, in regions where small absorption is present, and the emission pertaining the much colder tropopause, where the atmosphere is completely opaque.

We can define the greenhouse factor G as the difference between the surface emission and the emission at TOA. G is therefore indicative of the strength of the greenhouse effect. The bottom panel of Fig. 1 shows how this effect is mainly due to water vapour and carbon dioxide and that the water vapour in the FIR region is responsible for about 40% of the total effect. This consideration justifies the necessity of characterising and monitoring this spectral region for a complete understanding of the greenhouse effect.

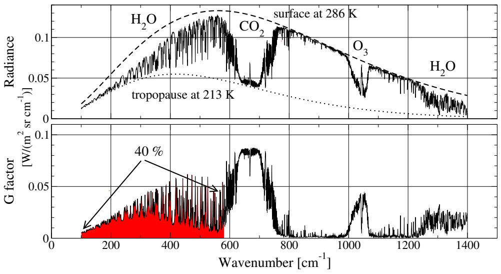

Fig. 1. OLR and greenhouse factor G.

Furthermore, the spectral measurement of the FIR emission, which is affected by the strong pure rotational water vapour band, can be used to increase the accuracy in the remote measurement of the water vapour vertical concentration profile and in particular in the upper troposphere, where more uncertainties are present with conventional techniques.

3. The REFIR-PAD spectrometer

The spectrally-resolved measurement of the atmospheric emission is performed with the required accuracy by using REFIR-PAD. The instrument is a compact Fourier transform spectrometer designed for balloon-borne applications. The optical scheme is based on the Mach-Zehnder interferometer with two input ports and two output channels, see Fig. 2. This solution allows to minimise alignment errors and to maximise the signal-to-noise ratio and the calibration accuracy. Table 1 shows the typical working parameters and performances of this spectrometer.

While one of the two input ports is used for the atmospheric measurement, the second port is used to monitor the instrument self interferogram by looking continuously at a known reference blackbody (BB) source, sta-

Table 1. Optical specifications and performances of REFIR-PAD.

Interferometer type	Mach-Zehnder
Detector	2 uncooled DLATGS
Spectral coverage	100–1400 cm^{-1}
Spectral resolution	0.5 cm^{-1}
Optical throughput	0.01 cm^2 sr
Field of view	0.133 rad
Acquisition time	32 s
NESR in 100–1000 cm^{-1}	0.8–2.5 mW/(m^2 sr cm^{-1})
Calibration error	0.1 K

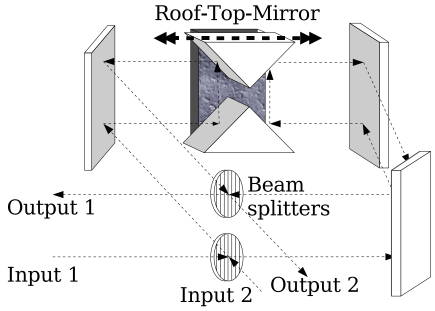

Fig. 2. Optical configuration of the interferometer.

Table 2. Electro-mechanical specifications of REFIR-PAD.

Weight	55 kg
Size	62 cm diam., 26 cm height
Power supply	18–30 V (50 W avg 70 W pk)
Telecommands	ON/OFF
Telemetry (opt)	1 channel RS232 at 9600 bit
Lines of sight	nadir, limb and space (+30°)

Table 3. Characteristics of the IASI-LPMAA gondola

Weight including payloads	495 kg
Height/Length/Width	1.4 m/2.0 m/1.2 m
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bilised near room temperature. The two output channels are coupled to pyroelectric detectors by means of Winston cone concentrators. The whole detector unit is temperature stabilised at a few degrees above room temperature. The pyroelectric detectors were operated with a 15 μm polypropylene window necessary to avoid contamination from atmospheric humidity.

The calibration of the atmospheric input radiance is performed by two reference BBs. The theoretical efficiency of these sources, internally coated with a Xylane-based paint, was estimated as better than 99.9% inside the operating spectral region. The BBs are mounted in a single unit with a rotating mirror that permits to switch between them and the atmospheric input port. The two BB sources are, respectively, stabilised a few degrees below room temperature with a Peltier cell, and heated to about 350 K through a stabilised heater.

4. Stratospheric balloon measurement

Thanks to the small size, weight and power consumption, summarised in Table 2 the instrument was easily installed as payload of opportunity on board the IASI-LPMAA stratospheric gondola during the Equatorial Large Balloon Campaign performed by CNES in North-East Brazil in June 2005.

The instrument was mounted on shock absorbers on the gondola frame near the IASI-Balloon interferometer, on a side where the access to nadir, limb and space (at +30° elevation angle) views was available (see Fig. 3). Table 3 shows the main characteristics of the gondola, which is balanced before the launch and stabilised in azimuth during the flight.

The launch was performed from the airfield of Timon, near Teresina (5°5′ S, 42°52′ W) in the nighttime at 3:36 local time with the sup-

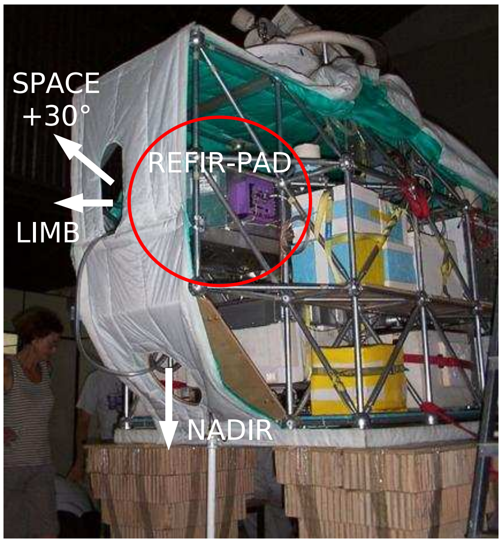

Fig. 3. Location of REFIR-PAD on board the IASI-LPMAA gondola.

Fig. 4. Final preparation on the launch pad.

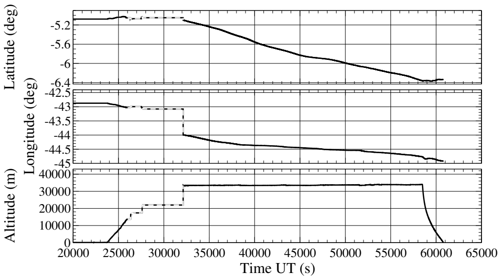

Fig. 5. Flight characteristics.

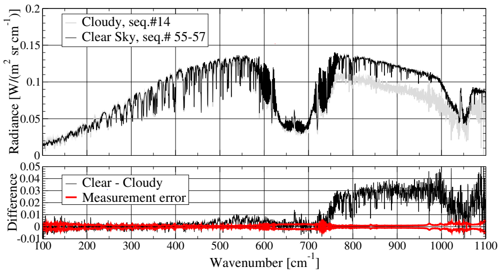

Fig. 6. Spectrally resolved OLR at the TOA in clear sky and cloudy conditions (top panel). The difference is compared with the measurement error in the bottom panel.

port of two auxiliary balloons. The usage of auxiliary balloons reduce the acceleration and oscillations when the main balloon (visible in background in Fig. 4) is left.

The flight reached the floating altitude of 34 km for about 8 h and landed at about 270 km South-West of Teresina. The flight profile is shown in Fig. 5.

5. Results

During the flight, the instrument acquired wideband spectra of the outgoing longwave radiation covering for the first time the FIR region of the thermal emission of the atmosphere with sufficient precision to study the effect of water both in vapour phase and in clouds. Since in this flight only 2 measurements are affected by low altitude clouds, which do not hit the FIR emission, see Fig. 6, the most important results are found only for water vapour in clear sky conditions.

Water vapour concentration and temperature profiles are calculated by using a fitting procedure. First, the spectral OLR is simulated by means of the radiative transfer equation (forward model) as a function of the input atmospheric state. Then the difference between simulation and measurement is minimised by varying the atmospheric state (retrieval). In such a way, the water vapour concentration and temperature profiles are retrieved for each calibrated spectral measurement, that is performed in about 10 minutes. The fitting procedure and performances are widely discussed in previous papers (see e.g. Bianchini et al. (2008)).

In Fig. 7, the retrieved water vapour and temperature profiles are compared with the analysis by ECMWF (European Centre for Medium-range Weather Forecast) and some nearby meteorological radio-soundings. The

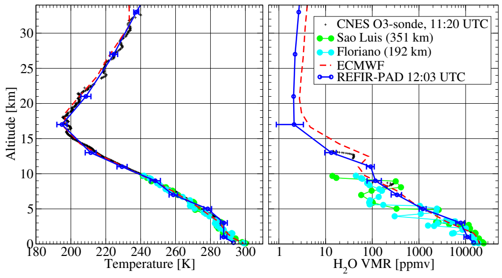

Fig. 7. Temperature and water vapour concentration profile comparison. In parenthesis is the distance between the balloon position and the meteorological radio-sounding station.

agreement among different measurement techniques is good for temperature (left panel), whereas some differences are found for water vapour (right panel). Below 11 km, water vapour is in good agreement with ECMWF estimates and radio-soundings, apart some fluctuations present in radio-soundings due to meteorological horizontal inhomogeneities of the atmosphere. Above 11 km, where no radio-sounding data are available, due to loss of efficiency of water vapour sensors at low pressure, a difference with ECMWF analysis is identified.

The different water vapour concentration in the upper troposphere produces an important variation in the estimation of the OLR flux. As shown in Ref. Palchetti et al. (2008), the FIR flux calculated with our retrieved atmospheric state is about 2-3 W/m^2 greater than the flux calculated with ECMWF data. This difference is greater than the radiative forcing on the climate system due to the increment of the carbon dioxide concentration since the pre-industrial time.

6. Conclusions

This measurement is the first example of how the wideband spectrum allows the simultaneous measurement of the outgoing longwave radiance over the whole spectral range involved in the thermal emission and the atmospheric components which greatly affect the emission itself.

Since the FIR emission mainly comes from the components in the upper troposphere, this kind of measurement has increased the sensitivity to the water vapour and clouds in the 10–20 km altitude range.

The differences, found with standard methods used to retrieved the atmospheric state, can give an important effect in the estimation of the Earth radiation budget that must be considered in climate models. More extensive field campaigns should be performed in order to confirm these results under different atmospheric conditions, also in presence of high altitude clouds, and in particular for mid-latitude and polar regions. Measurements in peculiar meteorological regions, such as the Mediterranean, are also of great importance for the radiative characterisation of the relatively unexplored upper troposphere.

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