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Validation of line and continuum spectroscopic parameters with measurements of atmospheric emitted spectral radiance from far to mid infrared wave number range

G. Masiello [a], C. Serio [a,*], F. Esposito [a], L. Palchetti [b]

[a] CNISM, Unità di Ricerca di Potenza, Università della Basilicata, Italy
[b] IFAC/CNR, Florence, Italy

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ABSTRACT

The latest release of a high-resolution transmission molecular absorption database along with two improved models of water vapor continuum absorption are used to check their impact on the improvement of state-of-art radiative transfer. Radiative transfer performance has been assessed using high mountains atmospheric emitted spectral downwelling radiance observations in the 360–1200 cm^{-1} spectral regions. These high mountains observations are particularly suited to check the behavior and performance in the water vapor rotation band. In addition, they also have allowed us to gain insight into understanding the quality of recent new compilation of lines and related treatment for the ν_2 CO_2 band and the O_3 band at 9.6 μm. Comparisons are made between forward calculations of atmospheric transmission spectra and spectral radiances measured using two ground-based Fourier transform instruments. The results demonstrate that water vapor absorption largely benefits from the recent improvement in the related continuum (both self and foreign). In addition, ozone absorption is very accurately reproduced and, although to a less extent, this is also the case of CO_2 absorption in the long wave ν_2 band.

1. Introduction

State of art radiative transfer models normally rely on the CKD approach [1] for the parameterization of water vapor continuum. This is a semi-empirical approach, which has been tuned on laboratory and atmospheric observations. In the recent years, taking advantage of new experimental and theoretical revisions a new model has been developed building on the original CKD formulation, named MT_CKD (e.g., see [2] and references therein).

After the 2007 ECOWAR (Earth COoling by WAter vapor Radiation) field campaign [3] new observations were made available, which for the first time extended down to far infrared at 260 cm^{-1}. These measurements allowed us to revise and improve the model MT_CKD version 2.1, mostly in the range 260–590 cm^{-1} [4]. This lead us to the ECOWAR-based revision, which we will refer to as MS_EP throughout the paper. Our improved parameterization has been recently validated with independent data recorded in the flight campaigns of the CAVIAR (Continuum Absorption by Visible and Infrared Radiation and its Atmospheric Relevance) project with the Imperial College TAFTS (Tropospheric Airborne Fourier Transform Spectrometer) far-IR spectro-radiometer instrument onboard the FAAM BAe-146 research aircraft [5].

Following the 2007 RHUBC-I (Radiative Heating in Underexplored Bands) polar arctic campaigns, MT_CKD authors have proposed and developed a new approach to the

* Corresponding author.
E-mail address: carmine.serio@unibas.it (C. Serio).

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problem of water vapor continuum, which includes also a modification of the line half-width parameters in addition to the definition of an appropriate foreign and self-continuum absorption [6]. Although the detailed formulation of this new scheme has not yet appeared in the peer reviewed literature, it has been incorporated within the LBLRTM (Line by Line Radiative Transfer Model) version 12 (see, e.g., the url http://rtweb.aer.com/), as MT_CKD module, version 2.5.2.

The main objective of this study is to validate the continuum module version 2.5.2 against ECOWAR observations and to provide a quantitative comparison with previous continuum modules, namely the MT_CKD v. 2.1 and MS_EP. For this validation we focus to the far infrared spectral region, whose radiative properties are mainly governed by water vapor absorption.

Nevertheless, the paper also deals with a quantitative assessment of line and continuum absorption parameters in the form used within state-of-art radiative transfer model, for the range 360–1200 cm^{-1}. This range includes the ν_2 CO_2 absorption band and the ozone band at 9.6 μm, that is two molecules which are of paramount importance, e.g., for applications to satellite meteorology and climatology. The spectral region also include other important radiatively active atmospheric gases, such as CH_4 and N_2O. The ν_2 band of N_2O at 588.77 cm^{-1} overlaps that of CO_2 and appears mostly saturated within zenith observations from ground-based instrumentation. The ν_4 methane band and the ν_1 band of N_2O both at $\approx$1300 cm^{-1} fall outside the range considered in this paper.

Spectroscopy of atmospheric molecules applied to satellite meteorology and climatology has largely improved over the past year thanks to the joint effort of scientists such as Barbe, Camy-Peyret and Flaud, whose work has dealt with many aspects of the experimental spectroscopy, notably that of O_3 (see, e.g., [7–10] and reference therein) and has touched many aspects of calibration/validation of models and data with, e.g., balloon borne instrumentation [11–13]. Also noteworthy, because within the mainstream of the motivations of this paper, is the Camy-Peyret long lasting contribution to IASI (Infrared Atmospheric Sounding Interferometer) [14].

This study is concerned with the validation of radiative transfer models in the range 360–1200 cm^{-1} with ground based instrumentation and aims at getting further insight into understanding the quality and accuracy of state-of-art spectroscopy. In this respect, the present work complements equivalent analysis performed with high spectral resolution infrared observations from satellite borne instruments, such as IASI (see, e.g., [15–18]) and AIRS (Atmospheric Infrared Sounder) [19].

The spectral observations used for this validation and inter comparison exercise have been measured during the 2007 ECOWAR campaign in the Alps and consist of emitted atmospheric radiance spectra recorded with two Fourier transform instruments along with radiosonde observations for temperature and water vapor. The spectra were recorded in the downwelling sky view mode.

For the calculations of synthetic radiances we will make extensive use of the LBLRTM code (e.g., see [21]). Our in-house φ-IASI package [20,15,22] will be also used for the purpose of radiance closure exercises.

The paper is organized as follows. Section 2 will outline the experimental set up: instrumentation and data. Section 3 will be mostly devoted to validate MT_CKD_2.5.2 in the far infrared. Section 4 is dedicated to a radiance closure exercise based on the spectroscopy embedded within LBLRTM v. 12. Conclusions will be shown in Section 5.

2. Experimental: instrumentation and data

2.1. Instrumentation

The data used in the present analysis have been acquired with two ground-based Fourier transform spectrometers (FTS), I-BEST (Interferometer for Basic Observations of Emitted Spectral Radiance of the Troposphere) [23] and REFIR-PAD (Radiation Explorer in the Far Infrared, Prototype for Applications and Development) [24]. The two instruments were operated in zenith looking mode, so that they measure the downwelling radiance. No scanning of the atmosphere was operated along the slant path, therefore observations refer to instruments local zenith angle of zero degrees.

I-BEST is a FTS instrument which can be operated with diverse detectors (MCT (mercury-cadmium-telluride) and/or uncooled DLaTGS (deuterated L-alanine-doped triglycine sulfate) pyroelectric technology) and covers the spectral range 200–1800 cm^{-1}. The configuration we use in this study adopts a MCT detector, with a spectral coverage 460–1800 cm^{-1}. The sampling rate is 0.3931 cm^{-1} for an unapodized spectral resolution, Full Width at Half maximum (FWHM) of 0.48 cm^{-1}. The instrument measures the absolute infrared spectral radiance of the sky by using a two points calibration approach where two stabilized infrared sources (blackbodies), with an error of approximately 0.1 K, filling the field of view, emit radiation at two temperatures that differ by at least 40 K from each other. These blackbodies are essential to provide a well known stable hot and ambient temperature reference for calibration of the downwelling sky view radiance. In its present version, I-BEST is equipped with two blackbodies characterized by an emissivity of 0.996 $\pm$0.002 [23] and a temperature accuracy of $\pm$0.1 K. The blackbody temperature has been tested to be uniform to within $\pm$0.03 K. One additional characteristic of our I-BEST is that the interferometer is embedded in a temperature stabilized enclosure, equipped with heater and programmable controller. During operation the enclosure is normally stabilized at 40$\pm$0.5 °C. The stabilization has the advantage of good instrument stability even in a fluctuating environment.

REFIR-PAD (henceforth simply REFIR) is a portable FTS operated with two uncooled pyroelectric detectors and covers the range 200–1100 cm^{-1}. The sampling rate is 0.3931 cm^{-1} for an unapodized spectral resolution, Full Width at Half maximum (FWHM) of 0.48 cm^{-1}. As I-BEST, REFIR was operated in zenith looking mode in order to measure downwelling sky view radiance.

Radiometric calibration of the instrument is achieved through three blackbody sources developed at the laboratory of one of the authors (L. Palchetti). The theoretical efficiency of these sources, which are internally coated