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Investigation of the water-vapor continuum in the THz region using a multipass cell

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Abstract

Laboratory absorption measurements of the water-vapor continuum in the far infrared region from 12 to 55 cm^{-1} (0.4 – 1.83 THz) were obtained using a multipass absorption cell, a Fourier transform spectrometer and a liquid-He-cooled bolometer detector. Measurements were made at a temperature, $T = 297$ K with water vapor and nitrogen pressures up to 2.2 and 81 kPa, respectively. The effects of the choice of lineshape function and far-wing cut-off factors on the reported continuum absorption are analyzed by modeling the resonant water-vapor spectrum using van Vleck–Weisskopf and Lorentzian lineshapes. Comparisons with available microwave data and model calculations are also presented.

Keywords: Far-infrared; THz; Water; Vapor; Cell; Lineshape

1. Introduction

The continuum-like contribution to atmospheric absorption is defined in practice as an excess of absorption unaccounted for by the resonance water-vapor spectrum. This excess was found to affect the atmospheric wave propagation over the broad spectral range from the microwave to the infrared [1–3]. Although numerous measurements have been performed in these regions, only a few broadband measurements exist in the far infrared (FIR) region between 10 and 100 cm^{-1}

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[4–6]. Some of these measurements were performed in situ over long propagation paths to enhance the weak continuum-absorption signals. While such measurements describe real atmospheric conditions, full control of the basic conditions of the medium such as temperature and partial pressures of the components can best be done in isolated sample cells in the laboratory.

There are several issues for the proper evaluation of water continuum absorption. The sum of the resonant water-vapor spectrum and the continuum absorption is measured in the experiment. The continuum absorption is defined as the difference between total measured absorption and the water-vapor discrete spectrum calculated for particular experimental conditions. As a result of the large difference between the contributions of resonant and continuum absorption, the latter must be measured between the resonance lines in the far-wing region. Precise modeling of the resonant water-vapor spectrum close to the absorption maxima is relatively simple from the available experimental and theoretical data. However, because the exact physical nature of the continuum is still not quantatively understood, there are much larger uncertainties related to the prediction of far-wing absorption. Therefore, a few basic choices must be made before applying a far-wing model. The first is the choice of a proper lineshape function to best describe the far-wing absorption of water vapor. The second is the choice of how far to extend the selected lineshape from the resonance maxima. Finally, a decision must be made on the number of water lines to consider. There has been no single approach to these issues in the far-infrared region. Most authors have explored the use of the van Vleck–Weisskopf (vVW) lineshape function [7], although this model was shown by Harde et al. [8] to predict larger far-wing absorption than measured experimentally in the THz region. For the second issue, there currently exist two different views of the spectral lineshape coverage. Typically, a 25-cm^{-1} (750 GHz) cut-off is applied [9] for reasons attributable to the nature of the far-wing beyond this range. Alternatively, Pardo et al. [4] found good agreement between the experimental and model data when no cuts-off were applied to both vVW and kinetic collisional lineshapes.

In this paper, we report the laboratory measurements of the water-vapor continuum in the 12–55 cm^{-1} (0.4$-$1.83 THz) spectral region. The measurements were performed at a temperature of $T = 297$ K using a FIR Fourier transform spectrometer equipped with a multipass absorption cell and a liquid-He-cooled bolometer detector. Experiments were performed with relatively high sample pressures of water vapor and high-purity nitrogen, up to 2.2 and 81 kPa, respectively, conditions similar to those at low altitude in the atmosphere. The effect of the lineshape function and frequency cut-off on the continuum absorption is explored by modeling the water-vapor spectrum using van Vleck–Weisskopf and Lorentzian lineshape functions.

2. Experiment

The multipass cell used in these experiments is shown in Fig. 1. It was designed as a unit to be coupled to the far-infrared Fourier transform spectrometer. A polarizing Michelson interferometer and a mercury lamp source provided the operational range from 7 to 250 cm^{-1}. An important coupling parameter in the design of the multipass cell was the 60-mm beam aperture of the interferometer. To avoid loss of signal, especially in the low-frequency range, the whole output beam from the interferometer was accepted by the input mirror (M1) of the cell. The head of the