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Fast radiative transfer modeling for infrared imaging radiometry

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Abstract

Fast radiative transfer codes have been developed for simulating the outgoing radiance (and corresponding brightness temperature) to be measured by the Infrared Imaging Radiometer (IIR) of the space Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission. Two simple codes (FASRAD and FASAA), for which scattering is neglected, as well as an accurate code (FASDOM), accounting for scattering and absorption with the Discrete Ordinate Method (DOM), are presented. Their accuracy has been estimated with a reference code including a line-by-line model and the DOM. Simulations have shown that the accuracy is generally better than 0.3 K on the brightness temperature for clear or cloudy atmospheres. This accuracy agrees with the expected one of future IIR measurements. In addition, the impact of scattering on the brightness temperature has been evaluated for semi-transparent liquid clouds in the IIR spectral range. Especially, simulations have shown that cloud microphysics retrieval might be possible with the Brightness Temperature Difference (BTD) between two IIR bands, using the couple of wavelengths (8.7–12 μm) or (10.6–12 μm). However, scattering strongly influences the radiation for shorter wavelengths. The error on the BTD with (8.7–12 μm) can reach 4 K when scattering is neglected, leading to large uncertainties in the retrieval of droplet effective radius.

Keywords: Infrared radiative transfer; Semi-transparent liquid cloud; Infrared scattering; CALIPSO mission

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1. Introduction

Determining predictions about global warming with great accuracy requires precise knowledge of atmospheric components. In particular, there are significant uncertainties in the modeled radiative effects of aerosols and clouds [1]. In this context, the CALIPSO mission [2] (Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations) will provide a set of instruments for the retrieval of geophysical parameters for accurate quantifications of aerosol and cloud radiative impacts. CALIPSO will fly with three co-aligned nadir viewing instruments including a backscattering Lidar, a visible Wide-Field Camera and an Imaging Infrared Radiometer (IIR). The IIR main objectives [3] are cloud identification and classification, cloud optical and microphysical parameter retrieval, assessment of cloud radiative impact and use of observations for process studies. Especially, semi-transparent clouds are of a great interest in the framework of the CALIPSO mission. These clouds have an essential role on the radiative budget and, consequently, on climate [4]. In addition, Giraud et al. [5] have pointed out that large Brightness Temperature Differences (BTD) may occur for cold liquid water clouds consisting of small supercooled droplets. These results suggest that cloud phase assumptions made in cirrus cloud retrievals using infrared split window signatures are not relevant. These results were obtained from POLDER (visible spectrum) and ATSR-2 (infrared spectrum) data and have shown potentialities of mixing observations from independent measurements. This kind of multispectral analysis will be attractive in the context of the future satellite mission CALIPSO, with the other satellites of the "A-Train".

An algorithm has been defined to optimize parameter retrieval [6] from CALIPSO observations. In this algorithm, the analysis of IIR measurements needs fast yet accurate calculations. The first aim of this study is to present specific radiative transfer codes for the simulation of the outgoing radiance and brightness temperature of the IIR. Fast codes have been developed with several levels of accuracy. In addition, a reference code, including a line-by-line code for gaseous absorption and a multiple scattering code for clouds, is available for validations. After a description of the radiative transfer schemes, inter-comparisons with the reference code are presented. The accuracy of the codes should be compared with the expected absolute calibration error on the brightness temperature, estimated to ± 0.3 K for all the IIR channels [6]. As an application, a theoretical study has been conducted to analyze the potential of the IIR bands for a characterization of semi-transparent liquid water clouds. The IIR spectral response is adequate for a characterization of clouds using infrared split window signatures from BTD [7,8]. The goals of the last part of this study are mainly (1) to evaluate the relative importance of scattering of infrared radiation in clouds and consequences for the analysis of future IIR measurements and (2) to estimate if multiple scattering is required in a radiative transfer code for an accurate determination of cloud microphysics. Indeed, a multiple scattering treatment is very time-consuming and incompatible with an operational data processing. Scattering is generally assumed to be negligible in the infrared spectrum [9]. However, some studies have also shown significant effects of scattering on radiation in the infrared window (8–13 μm), especially at the top of the atmosphere and for semi-transparent clouds [4,10–12]. The impact of scattering on the retrieval of cloud effective radius from BTD is discussed in the context of the IIR project.