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Inversion of CO2 in the Mars upper atmosphere from limb solar fluorescence measurements at 4.3 um by OMEGA/Mars Express and NOMAD/Trace Gas Orbiter

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Introduction

The ro-vibrational bands of CO2 around 4.3 μm and 2.7 μm are among the strongest atmospheric dayglow emissions in the IR in the terrestrial planets [1,2]. They are due to solar fluorescence, a typical non-local thermodynamic equilibrium (non-LTE) which, in the case of CO2 dominated atmospheres like Mars and Venus, offers an excellent opportunity for remote sounding in the limb up to very high altitudes [3,4]. We present here the adaptation to Mars of a non-LTE retrieval scheme for CO2 previously designed and applied to sounding the Earth upper atmosphere [5,6]. This is used to exploit two set of measurements of these non-LTE emissions: first, those carried out by the OMEGA spectrometer on board Mars Express (MEx) and obtained during several Mars years, and a few recent observations in the limb by the instrument NOMAD on board the Exomars Trace Gas Orbiter (TGO). An additional advantage of these datasets is the complementarity in local time with solar occultation observations, like those carried out by SPICAM/MEx or NOMAD and ACS/TGO.

The OMEGA/MEx dataset

The selected dataset is the same as used previously to confirm the non-LTE nature of the OMEGA limb emissions in the dayside [7]. The analysis and retrieval of these emissions are focused on tangent altitudes between 120 and 180 km. Details of the inversion performance on selected OMEGA orbits have been recently presented [8], including a detailed error analysis.

The retrieval scheme includes the implementation of the concept, its application to real data from OMEGA, sensitivity tests, conclusions on its performance, and recommendations for the systematic application to MEx orbital datasets.

The NOMAD LNO dataset

The NOMAD instrument has three channels: a miniature UV-visible spectrometer (UVIS) plus a dua channel (SO and LNO) IR spectrometer, capable of operating in different observation modes: solar occultation (SO, UVIS), nadir (LNO, UVIS) and limb off-the terminator (LNO) [9,10,11]. The LNO channel, covering the 2.2-3.8 μm spectral range, is mostly operating in a nadir configuration but a flip mirror permits limb pointing, a mode of operation used on several occasions since April 2018, when the TGO nominal operations started. Due to noise limitations, a combination of orbits and suitable averaging in the vertical are performed to build 1-D vertical profiles of Level 0 radiances. Radiometric and spectral calibration makes use of a non-LTE model [1, 8].

The non-LTE Retrieval Scheme

A retrieval scheme for non-LTE emissions is challenging for several reasons, in addition to the usual difficulties of error propagation, vertical resolution and compromise between information content and degrees of freedom. A first specific complication arises from the non-linearities of the emissions and their dependence on the target species. Secondly, the radiative transfer is complex if the emitting molecule is rich in optically thick ro-vibrational bands and is the major constituent of the atmosphere [2,8]. We present the design and performance of a non-LTE retrieval scheme for atmospheric composition based on a similar framework previously used in Earth's atmospheric sounding with the instrument MIPAS on board Envisat [14]. The scheme uses: (i) a generic non-LTE population model developed at the IAA/CSIC [12], (ii) the KOPRA line-by-line radiative transfer algorithm as forward model [6], and an inversion processor (RCP), jointly developed by the Institute for Meteorology and Climate Research (IMK) and the IAA/CSIC [13]. Calibration, cleaning of instrumental artifacts and formation of radiance vertical profiles were done before the inversion process, starting from non-calibrated data. A priori information is obtained from specific runs of the LMD-Mars Global Circulation Model [15].

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