Modification of the retrieval tool JACOSPAR for the Martian limb and solar occultation observations

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Introduction: Previous studies of the Martian atmosphere with limb/solar occultation observations generally use a radiative transfer code to retrieve atmospheric species. To reduce the potentially huge computational time, there are some approximations to the calculation system and to the scattering properties. For Limb observations, the pseudo-spherical approximation was found to be accurate within a few percent over a wide range of conditions and was two orders of magnitude faster than the exact Monte Carlo calculation with the accuracy of a few percent [1].

There are potential requirements for the fast and accurate radiative transfer code that treats the multiple scattering of light by aerosols in the fully spherical system. This study provides the realistic simulations of radiative processes for various types of application, including radiation budgets in cloudy conditions and remote measurements of clouds, aerosols, and gases.

JACOSPAR is a fast radiative transfer model with multiple scattering [2][3][4]. JACOSPAR has been already applied to the study of Earth's atmospheres to retrieve the slant column density of NO_2 and O_3 [5]. Here we present test simulations to optimize the code for the Martian atmosphere.

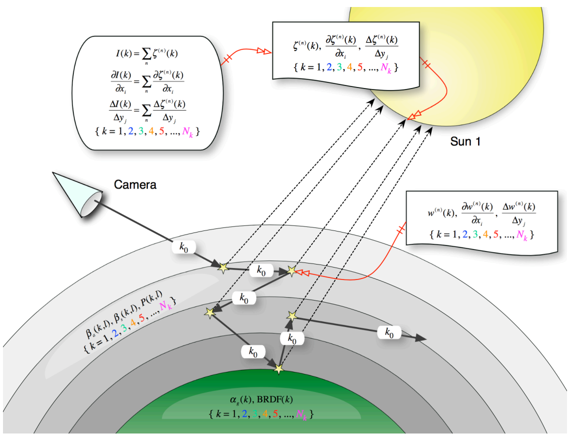

Figure 1: A scheme of dependent sampling method.

Methodology: JACOSPAR considers refraction and multiple scattering of light by aerosols in the full spherical atmosphere. It can calculate radiance and Jacobians effectively with requested accuracy by applying "backward Monte Carlo method" that treats absorption and scattering of the radiation as a probability process of the model photons and track its trajectory from observed point to the space. It also adopts the "Dependent sampling method (**Fig.1**)" [6] which simultaneously and multispectrally estimates the radiances and jacobians, reducing the calculation amounts. The radiation sources can be solar beam or internal thermal emission, so that the model can be applied to both solar and infrared spectra in the same framework. Single-scattering components are calculated analytically by integrating the source function. For multi-scattering components, JACOSPAR uses backward propagating Monte Carlo method.

In order to run the radiative transfer codes for Martian atmosphere, gases absorption coefficients and mixing ratio profiles, aerosols scattering/absorption coefficients, phase functions and vertical profiles, temperature and pressure profiles, and the solar spectrum, are required as input information. The absorption coefficients of CO_2, H_2O, and CO were calculated with the line-by-line method. The single scattering optical properties of dust and water ice in the Martian atmosphere were calculated with the Mie-theory [7] and then integrated with the modified gamma distribution [10]. The refractive indices of dust and water ice are referred to from Wolff and Clancy (2003) and Warren (1984), respectively [11][12]. The mixing ratio of the gases in the Martian atmosphere were assumed to be 95.32% of CO_2 at 0-79km, 300ppm of H_2O at 0-79km, and 800ppm of CO at 0-79km. A Martian vertical temperature-pressure profile selected from the Mars Climate Database has been considered[13]. The experiments in this study were carried out with 6 atmospheric layers with the limb observation geometry of OMEGA/MEx.

Results and Discussion: In order to validate the codes, a test simulation has been performed under the framework of UPWARDS project, by comparing with the codes, MITRA [13] which has been used for the retrieval of water vapor with PFS/MEx [14]. Comparisons of the outputs by the two codes are in excellent agreement with the accuracy of less than 1 % on average. This

demonstrated that these codes were ready to be applied to the data analysis of limb observations in the Martian atmosphere.
In addition to the validation, the output radiance and Jacobians have been investigated for each atmospheric layers, in order to confirm the JACOSPAR performance. By optimizing the number of the calculation points in the field-of-view, the calculation error of radiance and Jacobians related to the absorption less than 1% became comparable to the requested accuracy. The multiple scattering effect has been also addressed and optimized for the Martian atmospheric condition. Consequently, the absolute radiance varied 20-30% depending on whether or not the second scattering happened in the limb observation.
Here we also discuss the sensitive study of solar phase angle, the vertical resolution, the wavenumber resolution, under the assumption of the limb-geometry and solar-occultation measurements.

Future proospectives: This work gives the baseline for the retrieval of vertical profiles of gases and aerosols from OMEGA/MEx limb observation, as reported by companion paper in this workshop [15]. This study also can be applied to the observation of the NOMAD[16] and ACS[17] onboard of Trace Gas Orbiter (TGO).

References:

[1] Smith, M. D.: Vertical distribution of dust and water ice aerosols from CRISM limb-geometry observations, *JGR, Planets, Volume 118, Issue 2, pp. 321-334,* 2013
[2] Iwabuchi, H.: Efficient Monte Carlo methods for radiative transfer modeling. *J. Atmos. Sci.*, 63, 9, 2324–2339, 2006
[3] Iwabuchi, H., T. Suzuki: Fast and accurate radiance calculations for cloudy atmospheres using truncation approximation. *J. Quantitative Spectroscopy & Radiative Transfer*, 110, 1926–1939, 2009a
[4] Iwabuchi, H., T. Suzuki: Multiple-scaling method for anisotropic scattering and its applications to radiance calculations, *AIP Conf. Proc.* 1100, 41, 2009b
[5] Irie, H., Iwabuchi, H.: Quantifying the relationship between the measurement precision and specifications of a UV/visible sensor on a geostaticonary satellite. *Advances in Space Research, Volume 49, Issue 12, p. 1743-1749,* 2012
[6] Marchunk, G. I: The Monte Carlo methods in atmospheric optics, *Springer Series in Optical Sciences*, 1980
[7] Wiscombe, W.J.: Improved Mie scattering algorisms, *Applied Optics, vol. 19, May 1, p. 1505-1509,* 1980
[8] Kleinböhl, A.: Mars Climate Sounder limb profile retrieval of atmospheric temperature, pressure, dust, and water ice opacity, *JGR. Volume 114, Issue E10,* 2009
[9] Wolff, M.J., Clancy, T.R.: Constraints on the size of Martian aerosols from Thermal Emission Spectrometer observations, *JGR, Volume 108, Issue E9,* 2003
[10] Warren, S.G.: Optical constants of ice from the ultraviolet to the microwave, *Applied Optics (ISSN 0003-6935), vol. 23, April 15, p. 1206-1225*, 1984
[11] Forget, F.:Improved general circulation models of Martian atmosphere from the surface to above 80km, *JGR, Volume 104, Issue E10, p. 24155-24176,* 1999
[13] The INAF team of UPWARDS project, EU-H2020, UPWARDS Project Deliverable 1.1: Multiple-scattering radiative transfer code for atmospheric limb observations, 2016
[14] Sindoni, G, et al. : Retrieval of Water Vapour Vertical Profiles in the Martian Atmosphere using PFS/MEX data. Conference abstract, this workshop.
[15] Mahieux, A., et al. : Retrieval of gases and aerosols vertical profiles considering multiple scattering from OMEGA/MEx limb observations, conference abstract, this workshop.
[16] Vandaele, A.C., et al.: Science objectives and performances of NOMAD, a spectrometer suite for the ExoMars TGO mission, *Planet. Space Sci., 119, 233-249,* 2015
[17] Korablev, O., et al.: The Atmospheric Chemistry Suite (ACS) of three spectrometers for the ExoMars 2016 Trace Gas Orbiter, *Space Sci Rev, 214:7,* 2018