Modification of the retrieval tool JACOSPAR for the Martian limb observations

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A fully spherical radiative transfer (RT) code with multiple scattering is extremely computationally expensive. To reduce the computational time, some approximations are usually needed. Smith et al., (2013) applied the 'pseudo-spherical' approximation (Spurr, 2002; Thomas and Stamnes, 1999) to the retrieval of the vertical distribution of dust and water ice aerosols. It was found that the computed radiance under the pseudo-spherical approximation was accurate within a few percent and was two orders of magnitude faster than the exact Monte Carlo(MC) calculations. However, there are still some potential demands to treat fully spherical systems for the atmospheres under the multiple scattering conditions.

JACOSPAR considers refraction and multiple scattering of light by aerosols in a fully spherical atmosphere (Iwabuchi et al, 2006, 2009a, 2009b). It calculates the radiance and Jacobians effectively with requested accuracy by applying "backward Monte Carlo method" and "Dependent sampling method" (Marchunk 1980), reducing the calculation costs. JACOSPAR was applied to the Earth's atmospheres for the retrievals of the slant column densities of NO2 and O3 (Irie et al., 2012). Recently, EU UPWARDS project (D1.1) applied JACOSPAR to the limb observation of Mars. The radiance computed by JACOSPAR was compared with that by the independent MC code "MITRA" (Mayer and Kylling, 2005). In the altitude range from 0 to 80km (80 layers) the calculated radiances of both codes showed a good agreement with the uncertainty of less than 1 % on average. In this study, we performed a further optimization of JACOSPAR for the limb observation of Martian atmosphere. We conducted radiative simulations as following settings.

The absorption coefficients of Martian gases (CO2, H2O, and CO) were calculated with the line-by-line method under their mixing ratio profiles. The single scattering properties of dust and water ice were calculated with the Mie theory (Wiscombe 1980) and integrated with the modified gamma distribution (Warren 1984). The refractive indices of dust and water ice are referred to from Wolff and Clancy (2003) and Warren (1984), respectively. The mixing ratio of the gases in the Martian atmosphere were assumed to be 95.32% of CO2 at 0-79km, 300 ppm of H2O at 0-79 km, and 800 ppm of CO at 0-79 km. The vertical temperature pressure profiles were selected from the solar EUV average conditions of Mars Climate Database (Forget et al., 1999).

We modified two points of JACOSPAR code in order to stably calculate the radiance in the thin atmosphere of Mars. (1) In the upper atmospheric layer of Mars where the multiple scattering rarely happens, the radiance can vary 20-30% depending on whether the observed light is the single scattered one or multiple one. This can cause unstable computation results. Thus, we modified the threshold to decide the occurrence of the scattering event. (2) When considering the finite size of Field-Of-View (FOV), the radiance is averaged by taking the number of line of sights(LOSs) within the FOV. The LOSs were selected randomly in JACOSPAR. However, a slight difference of LOSs can cause significance on the

number of scatterings in the limb geometry. We modified to set the LOSs uniformly within the FOV.

Based on these modifications, we conducted the test simulations for the geometry of OMEGA/MEx limb observations in the altitude range from 0 to 60 km (6 layers). The analytical Jacobians for absorption and scattering by aerosols were compared with numerically calculated Jacobians by giving perturbations to the optical depth of each layer. The analytical and numerical Jacobians for absorption agreed well within 2%. Meanwhile, those for the scattering are within 10%. We note that the discrepancy of the Jacobian to the scattering shows larger values, which should be addressed in the future work.