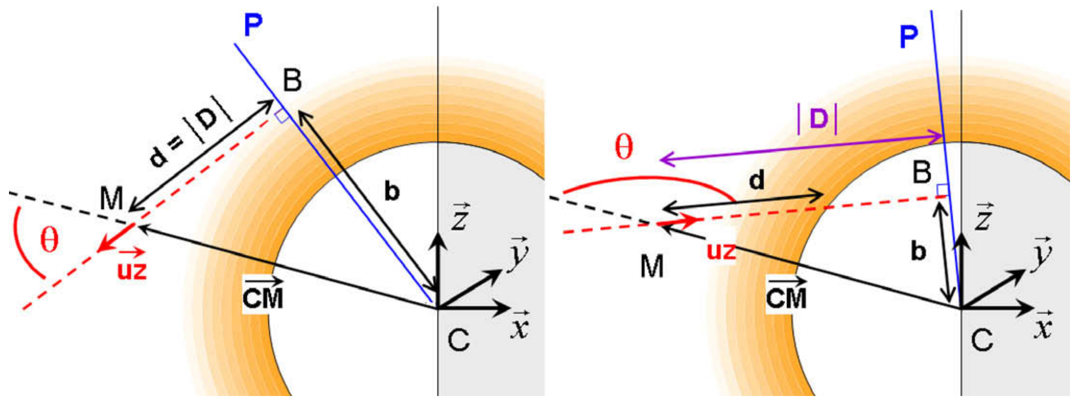

Fig. 4. Notations used for the calculation of the parameters "*d*" and "*b*" for (a) photons which trajectory do not intersect with the planetary body (type "A") and (b) photons which trajectory intersect the planetary body (type "B").

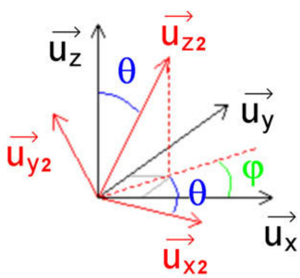

Fig. 5. Relation between the two bases linked with a photon before and after a scattering event.

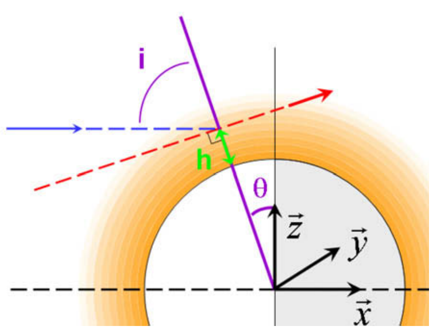

Fig. 6. Photon going out of the aerosols layer above the limb of the planetary body (red arrow). For this photon we need to calculate the solar zenith angle "*i*" compared to the initial direction prior to the last interaction (blue arrow), the altitude "*h*" (similar calculation as the impact parameter "*b*" in Fig. 5), and the azimuth. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

provides the fraction of the flux that reaches the surface, $I/F_{surface}$. The number of photons scattered by the surface of albedo A is then given by $A \times I/F_{surface}$. This irradiance is modified by the aerosols layer as it again passes through the atmosphere. This portion of a photon trajectory can be modeled using a plane-parallel code (e.g. Vincendon et al., 2007) if the observations are limited to moderate emission angles, or if not using the spherical code (angles typically greater than 60°). This second simulation provides a transmission factor T, as well as the fraction of photons emitted by the surface that goes back to the surface I/F_{back}. The normalized radiance (a.k.a., radiance factor or I/F) for a given set of parameters is then calculated by combining the results of these two simulations with the following equation:

$$I/F = I/F_{aerosols} + I/F_{surface} \times A \times T \times \left(\frac{1}{1 - A \times I/F_{back}}\right)$$

where the infinite sum of a geometric series (term in bracket) arises from the successive back and forth movements of photons emitted by the surface and scattered back toward the surface by aerosols.

This approach makes it possible to limit the number of simulations. Rather than computing all the radiative transfer for each surface albedo, the simulation is divided in two parts: from the Sun toward the surface and from the surface toward the spacecraft. The results are then combined using the above equation to provide the exact solution for all possible surface albedo value, A.

2.5. Validation

Our spherical Monte-Carlo code has been validated using the common validity domain of spherical and plane-parallel codes. In Fig. 7a and b, two examples of results of the spherical code are compared to that of the plane parallel Monte-Carlo code of Vincendon et al. (2007). Both models give similar results at moderate incidence angles. In addition, we have performed some comparisons between our model and the spherical model of Kattawar and Adams (1978) for a high solar zenith angle. Both spherical models predict observed radiances which differ by a few % only (Fig. 7c).

In Fig. 7d, we study the sensitivity of the model results to the sampling of the pre-calculated array. We compare model results obtained with the spatial sampling described in Fig. 2 (case 1) with samplings decreased by a factor of 2, 4 and 8 (cases 2, 3 and 4 respectively). Results begin to be affected by the sampling when it is reduce by a factor of 4 or more. Given the limited time gain between cases 1 and 2 (about 5–10% depending on optical depth), we have selected the conservative sampling of case 1.

3. First applications to observations of Mars and Titan at the terminator

3.1. Observations

In this section, we analyze at set of observations of Mars obtained by the *Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité* (OMEGA) onboard Mars Express and observations of Titan performed by the *Visual and Infrared Mapping Spectrometer* (VIMS) onboard Cassini. OMEGA and VIMS are imaging spectrometers observing in the 0.3–5.1 μm wavelength range. Their spatial resolution ranges from a few hundreds of meters/pixel to a few kilometers/pixel. The selected observations were obtained close to the terminator: solar zenith angles are greater than 70° and in-