Updated Radiative Transfer Model for Titan: Validation on VIMS/Cassini Observations of the Huygens Landing Site and Application to the Analysis of the Dragonfly Landing Area

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Abstract

Titan is a prime target for astrobiological research. Organic materials from atmospheric chemistry precipitate on the surface and are subject to geological processes (e.g. eolian and fluvial erosion) that lead to the formation of dune fields, river networks and seas similar to their terrestrial counterparts. The analysis of the surface reflectance in the near-infrared (NIR) allows to constrain the surface composition, which is crucial to understand these atmosphere/surface interactions. However, Titan's atmosphere prevents the surface from being probed in the NIR, except in 7 transmission windows where the methane absorption is sufficiently low (centered at 0.93, 1.08, 1.27, 1.59, 2.01, 2.7- 2.8 and 5 µm). We use an updated version of the Radiative Transfer (RT) model of Hirtzig et al. (2013), with updated gases and aerosols opacities, in order to better simulate atmospheric absorption and scattering and retrieve surface albedos in the 7 NIR transmission windows with an enhanced accuracy. Our RT model is based on the SHDOMPP and CDISORT (Evans, 2007 and Buras, 2011) solvers to solve the RT equations in plane-parallel and pseudo-spherical approximations respectively. We recently improved atmospheric inputs of the model with up-to-date gaseous CH_4, CH_3D, $^{13}CH_4$, C_2H_2, HCN and CO abundances profiles and absorption coefficients (Vinatier et al. 2007, Niemann et al. 2010; Maltagliati et al. 2015; Serigano et al. 2016; Rey et al. 2018; Thelen et al. 2019; Gautier et al. 2021), and improved aerosol optical properties. In particular, optical properties of Titan's aerosols are now computed from a fractal aggregate model (Rannou et al. 2003) constrained by measurements of the Huygens probe (Tomasko et al. 2008 and Doose et al. 2016). The new version of our RT model is benchmarked with the help of the most recent RT model for Titan (Coutelier et al. 2021) and validated using observations of the Descent Imager/Spectral Radiometer (DISR) onboard Huygens. Coupled with an efficient inversion scheme, our model can be apply to the Cassini's Visual and Infrared Mapping Spectrometer (VIMS) dataset to retrieve atmospheric opacity and surface albedos at regional and global scales. This will help to analyze future James Webb Space Telescope (JWST) observations of Titan (Nixon et al. 2016) and prepare the Dragonfly mission (Lorenz et al. 2018).

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ABSTRACT

Titan, the only moon in the solar system with a thick atmosphere and a methane-based hydrological cycle similar to the water-based cycle on Earth, is a prime target for planetary and astrobiological researches. Organic materials from atmospheric chemistry precipitate on the surface and are subject to geological processes (e.g. eolian and fluvial erosion) that lead to the formation of dune fields, river networks, lakes and seas similar to their terrestrial counterparts. The analysis of the surface reflectance in the near-infrared (NIR) allows to constrain the surface composition, which is crucial to understand these atmosphere/surface interactions. However, Titan's atmosphere prevents the surface from being probed in the NIR, except in 7 transmission windows (centered at 0.93, 1.08, 1.27, 1.59, 2.01, 2.7 and 5 μm). We use an updated version of the Radiative Transfer (RT) model of Hirtzig et al. (2013), with updated gases and aerosols opacities, in order to better simulate atmospheric absorption and scattering and retrieve surface albedos in the 7 NIR transmission windows with an enhanced accuracy. Our RT model is based on the SHDOMPP and CDISORT solvers (Evans 2007) and (Buras et al. 2011) to solve the RT equations in a plane- parallel and pseudo-spherical approximations respectively. We recently improve atmospheric inputs of the model with up-to-date gaseous CH_4, CH_3D, $^{13}CH_4$, C_2H_2, HCN and CO abundances profiles and absorption coefficients (Vinatier et al. 2007), (Niemann et al. 2010), (Maltagliati et al. 2015), (Serigano et al. 2016), (Rey et al. 2018), (Thelen et al. 2019), (Gautier 2021), and improved the photochemical aerosol optical properties. In particular, the optical properties of Titan's aerosols are now computed from a fractal aggregate model (Rannou et al. 2003) constrained by in situ measurements of the Descent Imager/Spectral Radiometer (DISR) onboard the Huygens probe (Tomasko et al. 2008) and (Doose et al. 2016). Our RT model is benchmarked with the help of the most recent RT model for Titan in the literature (Coutelier 2021) and validated using the in situ observations of DISR acquired during descent and once landed. Coupled with an efficient inversion scheme, our model can be apply to the Cassini's Visual and Infrared Mapping Spectrometer (VIMS) complete dataset for the retrieval of Titan's atmospheric opacity and surface albedos at regional and global scales. This will help to analyzing the near-future observations of Titan with the James Webb Space Telescope (JSWT) (Nixon et al. 2016) and preparing the future exploration of Titan by the Dragonfly mission (Lorenz et al. 2018).

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