RADIATIVE TRANSFER MODELLING IN TITAN'S ATMOSPHERE: APPLICATION TO CASSINI/VIMS DATA. T. Cornet[1], S. Rodriguez[1,2], L. Maltagliati[3], T. Appéré[4], C. Sotin[5], S. Le Mouélic[6], P. Rannou[7], A. Solomonidou[5], M. Hirtzig[8], B. Bézard[9], A. Coustenis[9], R.H. Brown[10], J.W. Barnes[11], K.H. Baines[5], B.J. Buratti[5], R.N. Clark[12], P.D. Nicholson[13]. [1]Laboratoire AIM, CEA Saclay, Gif sur Yvette, France. [2]IPGP, Paris, France. [3]Nature Astronomy, London, UK. [4]IPAG, Université Grenoble Alpes, Grenoble, France. [5]Jet Propulsion Laboratory, Caltech, Pasadena, USA. [6]LPG Nantes, Université de Nantes, Nantes, France. [7]Laboratoire GSMA, Université de Reims, Reims, France. [8]Fondation La Main à la pâte, Montrouge, France. [9]LESIA, Paris-Meudon, France. [10]LPL, University of Arizona, Tucson, USA. [11]Department of Physics, University of Idaho, Moscow, USA. [12]PSI, Tucson, USA. [13]Department of Astronomy, Cornell University, Ithaca, USA. (thomas.f.cornet@gmail.com)

Introduction: The atmosphere of Saturn's moon Titan is strongly absorbing and scattering in the infrared due to the presence of molecular gases (mostly N_2 and CH_4) and of a thick organic haze. Despite the presence of this thick atmosphere, the Cassini Visual and Infrared Mapping Spectrometer (VIMS) instrument is able to acquire images of Titan's surface through atmospheric transmission spectral windows centered at 0.93, 1.08, 1.27, 1.59, 2.01, 2.7-2.8 and 5 µm in the infrared [1]. Since 2004, VIMS contributed to reveal and investigate the geological diversity of the surface, populated by organic dark dunes [2], dark absorbing lakes [3,4,5], 5 µm-bright evaporitic deposits [6], possibly water-ice rich exposed icebed; but the interpretation of these features in terms of composition is often limited due to the heavy data processing required to disentangle atmospheric to surface contributions [7,8].

In this context, an accurate and fast radiative transfer model and inversion scheme has to be developed for Titan in order to massively invert the Titan VIMS dataset (125 flybys, tens of thousands of data cubes). We aim at developing such a model to determine the main chemical species present on Titan's surface and follow the atmospheric extinction evolution over time.

Radiative Transfer (RT) model description: We base our approach on the Radiative Transfer model developed by Hirtzig et al. [9]. The model consists in a plane-parallel radiative transfer solver (SHDOMPP) developed by Evans [10], fed by Titan's atmospheric properties. The atmosphere is divided into 70 layers, the pressure, temperature and molar mass of which are given by the Huygens/HASI measurements recorded during the descent of the module in 2005 [11]. The atmosphere is composed of gases (CH_4, N_2, CO, and C_2H_2) producing molecular and collision-induced absorption as well as Rayleigh scattering. Gas abundance profiles are set thanks to the Huygens/GCMS (CH_4) [12] or Cassini/CIRS (CO, C_2H_2) [13] measurements. The optical properties of the aerosols (single-scattering albedo, opacity, phase function) are primarily inherited from Huygens/DISR measurements in the visible-near infrared range [14,15] and from laboratory experiments [16]. These properties are then extrapolated to the VIMS infrared wavelength range (0.8 – 5.1 µm). Finally, the surface is considered lambertian.

The model is therefore calibrated for the atmospheric profile corresponding to the Huygens landing time and location, and is adapted to other time periods and locations by shifting the haze extinction profile by a given "haze factor", as in Solomonidou et al. [17,18]. Because the solver operates in plane-parallel geometry, our studies are presently mostly constrained to the low latitudes of Titan to avoid extreme viewing conditions.

Inversion optimization using Look-Up Tables: Inverting a single spectrum (pixel) with a classical approach is time consuming (~1-10 mins) and unrealistic for our work given the size of the VIMS archive. We adopted an inversion strategy based on the use of reference Look-Up Tables (LUTs) computed from the RT code for an optimized set of geometric conditions (incidence, emission, azimuth angles), haze factor and surface albedo, that allow to retrieve the specific conditions of the observation thanks to interpolations between LUT nodes. In doing so, the inversion is performed using the LUT itself, in two steps: 1) determination of a single haze factor needed to fit all atmospheric absorption bands; and 2) determination of the surface albedo for the same haze factor needed to fit the atmospheric windows at each window wavelength. This methodology allows to reduce the computation time by a factor of 10,000 with respect to classical inversions and to proceed to the inversion of regional mosaics of several VIMS cubes [19].

Preliminary results and conclusion: Figures 1 and 2 illustrate a test case consisting of a mosaic of the T13 and T17 flybys, acquired at a 5 months time interval. The mosaic of the raw data (calibrated in reflectance) taken in the atmospheric windows displays strong seams between the two flybys due to the different viewing geometries and associated optical pathway in the atmosphere, as well as an increasing blurring effects toward short wavelengths.

After the inversion, the strongest seams between T13 and T17 almost disappear in the surface albedo maps. The albedo and haze factor variations are consistently not correlated with each other, nor with the

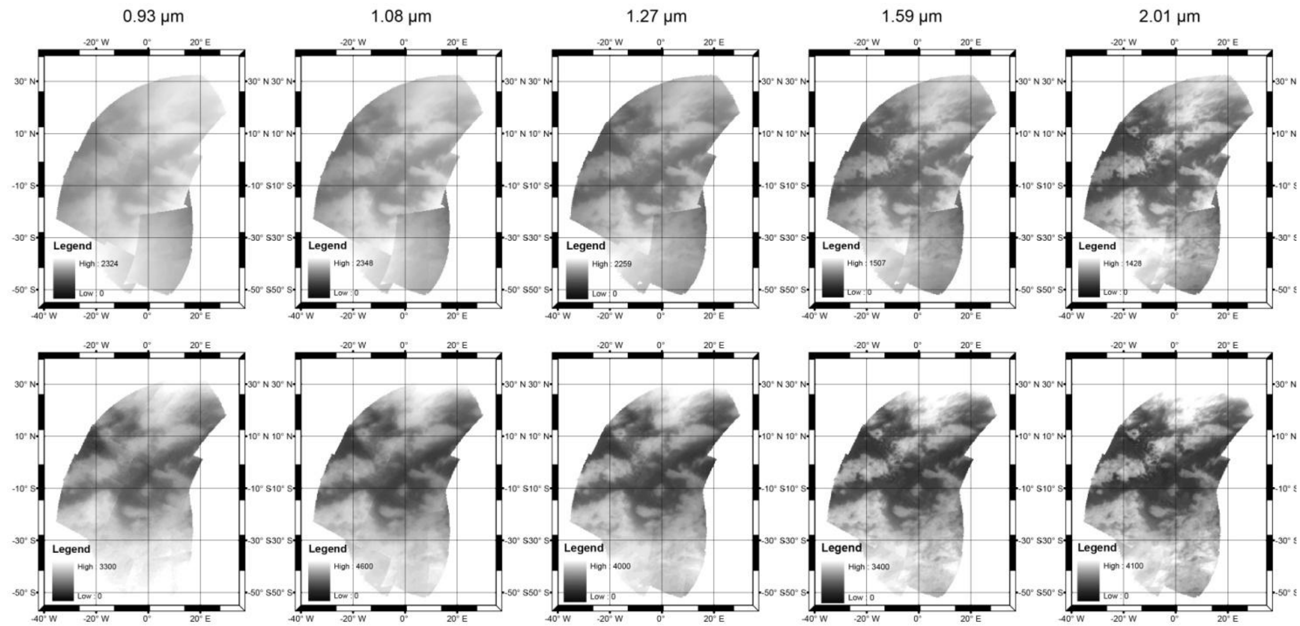

Figure 1: T13-T17 initial (top) and inverted (bottom) VIMS mosaics using our radiative transfer code based using a LUT inversion, for the atmospheric windows comprised between 0.93 and 2.01 µm. Units are in I/F×10^4.

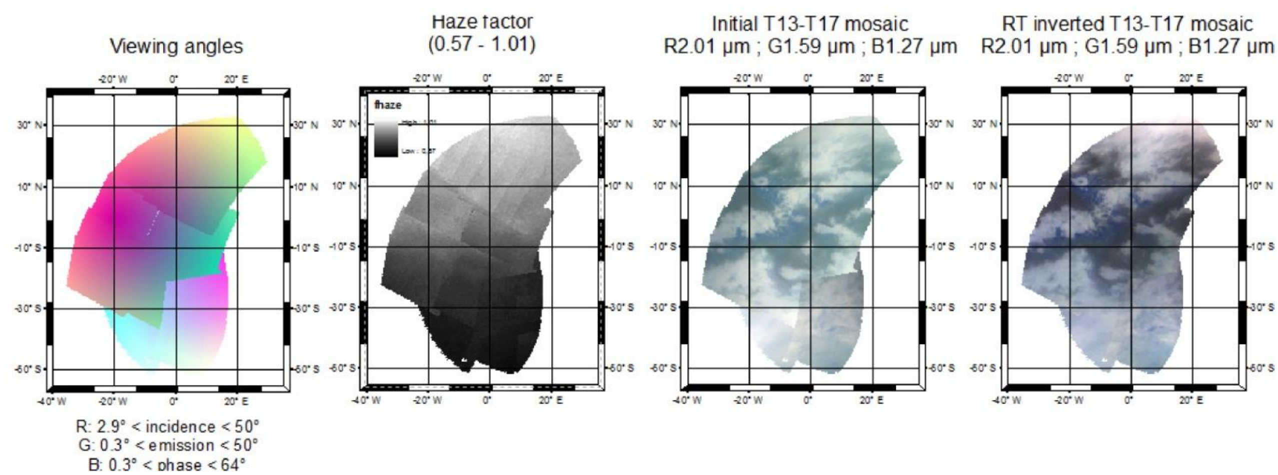

Figure 2: RGB color composite of the viewing geometry (red: incidence; green: emission; blue: phase), haze factor map and RGB color composites of single bands using the raw initial and RT inverted mosaics at 2.01 µm (red), 1.59 µm (green) and 1.27 µm (blue).

viewing conditions. The images in the atmospheric windows display also sharper details of the surface, especially at short wavelengths.

Further work will improve the atmospheric constraints on the aerosol optical properties. In doing so, we will adapt the model inputs to the pseudo-spherical/spherical geometries needed for the processing of VIMS data acquired with viewing angles > 60° thanks to the use of a new solver, such as DPSDISORT or SHDOM, and refine and extend (e.g. in wavelength) the constraints provided by the Huygens/DISR instrument on the atmospheric haze properties by using the VIMS dataset.

References: [1] Sotin C. et al. (2005), Nature. [2] Barnes J.W. et al. (2008), Icarus. [3] Brown et al. (2008), Nature. [4] Barnes et al. (2009), Icarus. [5] Cornet, T. et al. (2012), Icarus. [6] MacKenzie S. et al. (2014), Icarus. [7] Le Mouélic S. et al. (2012), PSS. [8] Hayne P.O. et al. (2014), Icarus. [9] Hirtzig M. et al. (2013), Icarus. [10] Evans K. (2007), JAS. [11] Fulchignoni M. et al. (2005), Nature. [12] Niemann H. et al. (2010), JGR. [13] Vinatier S. et al. (2010), Icarus. [14] Tomasko M. et al. (2008), PSS. [15] Doose L. et al. (2016), Icarus. [16] Khare B. et al. (1984), Icarus. [17] Solomonidou A. et al. (2014), JGR. [18] Solomonidou A. et al. (2016), Icarus. [19] Maltagliati L. et al. (2015), EPSC.

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