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Aerosols optical properties in Titan's detached haze layer before the equinox

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ABSTRACT

UV observations with Cassini ISS Narrow Angle Camera of Titan's detached haze is an excellent tool to probe its aerosols content without being affected by the gas or the multiple scattering. Unfortunately, its low extent in altitude requires a high resolution calibration and limits the number of images available in the Cassini dataset. However, we show that it is possible to extract on each profile the local maximum of intensity of this layer and confirm its stability at 500 ± 8 km during the 2005–2007 period for all latitudes lower than 45°N. Using the fractal aggregate scattering model of Tomasko et al. (2008) and a single scattering radiative transfer model, it is possible to derive the optical properties required to explain the observations made at different phase angles. Our results indicates that the aerosols have at least ten monomers of 60 nm radius, while the typical tangential column number density is about $2 \cdot 10^{10}$ agg m^{-2}. Moreover, we demonstrate that these properties are constant within the error bars in the southern hemisphere of Titan over the observed time period. In the northern hemisphere, the size of the aerosols tends to decrease relatively to the southern hemisphere and is associated with a higher tangential opacity. However, the lower number of observations available in this region due to the orbital constraints is a limiting factor in the accuracy of these results. Assuming a fixed homogeneous content we notice that the tangential opacity can fluctuate up to a factor 3 among the observations at the equator. These variations could be linked with short scale temporal and/or longitudinal events changing the local density of the layer.

1. Introduction

Since the beginning of exploration of giant planets in the 80s, Titan, the largest moon of Saturn, always focused a lot of attention on its unique thick haze atmosphere. Voyager 1 and 2 flybys, revealed the existence of a complex stratified succession of haze layers above Titan's main haze layer (Smith et al., 1981; 1982). One of these layers, the Detached Haze Layer (DHL), presented a large horizontal extent at 350 km and could be seen all along the limb surrounding Titan main haze between 90°S up to 45°N before merging with the north polar hood. Based on Voyager 2 radial intensity scans at high phase angles, Rages and Pollack (1983) were able to retrieve the vertical distribution of scattering particles and reveal an important depletion of the aerosol particle density below this layer. Toon et al. (1992) proposed the first explanation by an interaction of ascending winds with the vertical structure of the haze, yielding a secondary layer above the main layer. The aerosols are initially produced in a single production zone in the main haze then raised by the dynamics and stored inside the detached haze layer. On the other hand, Chassefière and Cabane (1995) presented a completely different formation scenario based on the photochemistry of polyacetylenes occurring at high altitudes producing fluffy aggregates trapped inside the detached haze layer. Finally Rannou et al. (2002); 2004) proposed with a global circulation model (GCM) that the detached haze is a natural outcome of the interaction between the atmosphere dynamics and the haze microphysics. Therefore, the detached haze is submitted to a seasonal cycle driven by dynamics.

The arrival of the Cassini spacecraft in the Saturnian System in 2004, was a unique opportunity to investigate the persistence of the detached haze layer over time. Porco et al. (2005) confirmed its presence 24 years after its discovery at an altitude near 500 km. This new location was first explained by Lavvas et al. (2009) as a secondary layer under the limit of the Voyager camera sensitivity. Their mechanism based on the sedimentation and coagulation

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Table 1
Dataset of 15 ISS NAC images used in this study, taken with CL1-UV3 filter combination (338 nm). The phase angle, the limb latitude coverage, the latitude of the photometric equator and the pixel scale are also listed below.

ISS ID	Date	Phase	Coverage	Lat. Photo.	Pixel scale (km)
N1506288442_1	2005/09/24	145°	90°S–25°N	37°S	5.5
N1506300441_1	2005/09/25	151°	90°S–30°N	46°S	5.5
N1509304398_1	2005/10/29	155°	90°S–25°N	51°S	6.1
N1521213736_1	2006/03/16	68°	90°S–65°N	19°S	7.3
N1525327324_1	2006/05/03	147°	90°S–55°N	33°S	7.2
N1540314950_1	2006/10/23	120°	65°S–55°N	2°S	5.7
N1546223487_1	2006/12/31	66°	70°S–65°N	6°S	7.4
N1551888681_1	2007/03/06	143°	75°S–35°N	49°S	7.9
N1557908615_1	2007/05/15	25°	80°S–10°N	76°S	7.8
N1557919415_1	2007/05/15	25°	80°S–10°N	75°S	8.2
N1559282756_1	2007/05/31	20°	85°S–10°N	80°S	7.7
N1562037403_1	2007/07/02	14°	90°S–30°N	58°S	7.8
N1567440117_1	2007/09/02	20°	90°S–55°N	22°S	7.9
N1570185840_1	2007/10/04	27°	90°S–60°N	28°S	7.3
N1571476343_1	2007/10/19	80°	85°S–60°N	11°S	8.2

of particles of mono-dispersed spheres was able to produce a detached haze at 500 km altitude independently of the dynamical transport. However, the systematic survey made by the repetitive flybys of Titan by Cassini showed that its altitude at the equator remains constant at 500 km between 2005 and 2007, decreases to 480 km at the end of 2007 and dropped suddenly at 380 km in 2009, around the northern spring equinox, before disappearing in 2012 (West et al., 2011). Finally, recent 3D GCMs (Lebonnois et al., 2012; Larson et al., 2015), more sophisticated than the previous 2D GCM, still producing the detached haze, give a description of the complete annual cycle of the detached haze layer and predict a reappearance in early 2015.

Our purpose is to characterize the physical properties of the detached haze layer before the equinox, while it was stable. We analyzed ISS images of the detached haze layer at different phase angles at UV wavelengths where the detached layer can be easily seen. Then we interpret the observations using a single-scattering radiative transfer model (Tomasko et al., 2008) with fractal aggregate particles to constrain the aerosol optical properties based on the monomer radius, the number of monomers per aggregate and tangential column number density. Finally we derive the local temporal/longitudinal variability of the detached layer during the 2005–2007 period.

2. Observations

To determine the properties of the aerosols in the detached haze layer, we made a survey over the ISS images taken with the Narrow Angle Camera (NAC) before its first decrease in altitude at the end of 2007 (West et al., 2011). We limit our analysis to the CL1-UV3 filter (λ=338 nm) to get the best contrast between the detached haze layer and the main haze (Fig. 1a) and to minimize the multiple scattering. Assuming Lambertian scattering and the albedo observations by Karkoschka (1994); 1998), we estimate that the multiple scattering is always less than 5% for UV wavelengths. We select images taken far enough from Titan to get the best latitude coverage on the limb and to get an accurate georeference calibration of data, but also close enough to get the highest pixel scale to probe properly the detached haze layer ($<$ 10 km). We also restrict our analysis to a short period of time between 2005 and 2007 to limit the temporal variability of the detached haze layer (1 Titan year = 29 Earth years). Among the acquired images only 15 (Table 1) satisfied the above criteria, covering a large range of phase angle (from 14° to 155°).

The radiance factor on the ISS images (I/F) is calibrated using the CISSCAL routines (West et al., 2010) and a Poisson Maximum-a-posteriori (PMAP) deconvolution is applied to improve the signal/noise ratio. Then the detached haze layer is automatically located at the maximum of contrast. Considered to be stable during this period (West et al., 2011), we use its altitude as a proxy to locate very precisely the center of Titan (Fig. 1b) by fitting an ellipse through these points. Therefore we are able to extract the I/F profile all along the limb of Titan according to the geographical coordinates and the illumination conditions during the acquisition.

The vertical I/F profile is sampled in latitude using 5° bins (Fig. 2a). The uncertainty of the intensity on each pixel represents the photon noise (between 2% and 5%) and the flat field uncertainty (1%). To account for the observed variability of the profile inside the latitude bin and altitude ranges, we sum-up all pixel uncertainties with a moving average box of 1.5 times the pixel scale (i.e. with an overlap of 50%) and containing at least 30 pixels (up to 150). Assuming a stochastic uncertainty distribution, the sum of these uncertainties is considered Gaussian and the value at 0.16 and 0.84 on the normalized cumulative uncertainty are equivalent to a Gaussian 1σ error (i.e. covering 68% of the integral). This uncertainty distribution provides average and variance values of the spatial variability. This method allows us to smooth the vertical profile and remove the outliers. Finally the local maximum I/F of the detached haze layer is extracted for each profile at all latitudes in the illuminated limb of Titan.

This process is applied to the whole image dataset. Fig. 2b represents the distribution of the local maximum I/F of the detached haze layer as a function of phase angle. The variability of the local maximum I/F of the detached haze layer is resampled using bins of 5° phase angle range in order to put similar weight on the different images at low and high phase angles.

3. Method

As mention before, we focus our study on the local maximum I/F of the detached haze layer. We consider that above the detached haze layer, the atmosphere of Titan is optically thin and the incoming flux from the Sun is not significantly attenuated down to the detached haze layer (i.e. the opacity along the incoming ray $\tau^0_{\text{ext}} \ll 1$ in the illuminated limb). We also neglect the multiple scattering inside and below the detached haze layer (evaluated at maximum to 5% at 338 nm). Then, in the limit of the single scattering approximation and the optically thin layers, the output flux can be simply described as:

$$I/F = \frac{\omega \cdot P(\theta)}{4} \cdot [1 - \exp(-\mathrm{N}_{\text{los}} \cdot \sigma_{\text{ext}})] \quad (1)$$

with ω the single scattering albedo, $P(\theta)$ the phase function at the scattering angle θ (corresponding to 180° – phase angle of the observation), σ_{ext} the extinction cross-section of the aerosols, and