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Spatial and temporal variability of Titan's detached haze layer during the Cassini mission

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Abstract

The 13 years of the Cassini mission provide a unique dataset monitoring the evolution of Titan's atmosphere during almost half a Titan year. We present here a systematic survey of the vertical extinction profiles retrieved between 300 to 700 km with an atmospheric limb multiple scattering model. We sampled the ISS NAC CL1-UV3 dataset on the entire Cassini mission, from 2004 (during the northern winter) to the end of the mission in 2017 (after the summer solstice). The spatial and temporal variations observed bring new perspectives on the cycle of the detached haze layer and its interaction with the dynamics.

1. Introduction

Titan is the only moon of the solar system with a thick hazy atmosphere. Above its main haze, the presence of a small *detached* haze layer was first observed by Voyagers [1] during the 80's flyby of Titan. The analysis of this strange feature by Rages & Pollack confirms the existence of an excess of extinction located around 350 km, associated with a peak of particles density and a local depletion 50 km below [2]. Its horizontal extent was very stable in altitude and reported at all the southern latitudes up to 45°N where it connects to the northern polar hood.

In 2004, 25 years later, Cassini ISS cameras reveal a similar haze layer located at 500 km [3]. Its altitude remains stable up to 2007 [4] when it starts to collaspe down to 380 km in 2010 and disappeared in 2012 after the equinox [5]. As predicted by 2-3D Global Circulation Models (GCMs) [6, 7, 8], the detached haze layer reappeared in 2016 [9] at 480 km but reveals a more complexe behavior than expected.

Therefore, a detailed analysis of the spatial variability of Titan's detached haze layer is required to fully understand these seasonal variations.

2. Data & Method

Our survey is conducted on 137 images taken by the Cassini Image Sub-System Narrow Angle Camera (ISS/NAC) with the ultra-violet (CL1-UV3) filters (Fig. 1) to get the highest temporal and phase coverage. The average time between two pictures is 40 Earth days (2.5 Titan days). Due to orbital constraints, no data were recorded between 03/08-01/09 and 10/10-09/11 but at least 90 % of our sample are separated by less than 120 Earth days (7.5 Titan days).

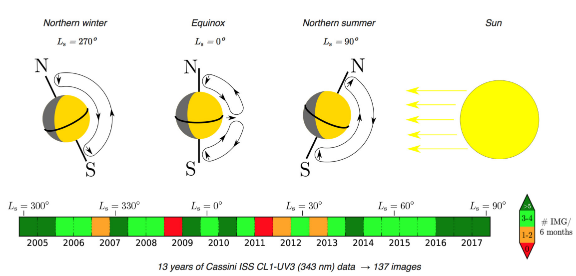

Figure 1: Seasonal evolution of Titan's illumintation and global scale circulation during the Cassini mission (2004-2017) with a color-coded time series of the ISS/NAC CL1-UV3 images used in this study.

The dataset is calibrated using CISSCAL and the signal to noise ratio on the limb profile is improved by deconvolving the images with a Poisson maximum a posteriori method (PMAP) using the point spread function (PSF) calculated in-flight [10]. The navigation of the images is initialized with the Spice routines and the location of the center of Titan is refined by searching the best alignment on the limb.

To retrieve haze extinction coefficient profiles from the I/F profiles, we calculated single-scatter I/F in a spherical-shell geometry between 300 and 700 km altitude [2, 11]. The multiple scattering is taken into account with a correction factor based on a plane-parallel radiative transfer model using atmosphere properties fitted on nadir observations (see [9] for more details).

3. Results

Between 2004 and 2007, the detached haze layer appears as a continuous layer at 500 km from the south pole to the north pole where its thickness increases before its junction with the polar hood at 60°N (Fig. 2).

Around the equinox in 2009, the depletion below the detached layer starts to drop down to 350 km. We notice that this drop appears quicker in the southern hemisphere. The merge with the main haze occurs in 2012 around 300 km with a similar patern as predicted by GCMs but with a temporal offset of 30° in solar longitude.

Between 2012 and 2015, no consistent detached haze is reported even if some sporadic local depletions could be observed. It's only in early 2016 that the detached haze reappears as a continuous layer from the northern hemisphere down to the south pole where it connects with the main haze.

Finally, in 2017 after the northern summer solstice, the detached haze layer splits into two layers at 520 km in the southern hemisphere and at 470 km in the northern hemisphere. This feature reveals a complex unanticipated underlying dynamics. This patern could be an early stage before the formation of a new persistant detached haze layer during the northern summer.

Additionally, when it was possible, we conducted a small-scale analysis to estimate the longitude and the dusk/dawn variability (not presented here). Our first results show second order variations which reveal short timescales events (alternation day/night, wave activity, …).

Overall, the observations match the large scale behavior prediected by the GCMs however we report a temporal offset during the collapse and the reappearance of the detached haze layer. We also show that the detached haze layer is not always a constant layer but varies with latitude, revealing a complex dynamics which should provide valuable constraints for future GCMs.

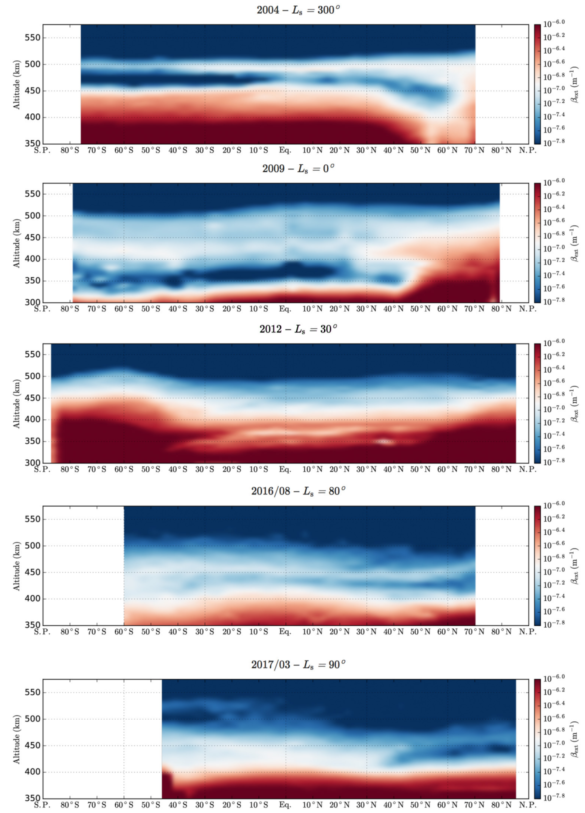

Figure 2: Latitudinal variability of the extinction profiles of the detached layer during the northern winter (top), the equinox (middle) and the northern summer solstice (bottom).

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