Icarus 311 (2018) 371–383

Contents lists available at ScienceDirect

Icarus

journal homepage: www.elsevier.com/locate/icarus

Mapping polar atmospheric features on Titan with VIMS: From the dissipation of the northern cloud to the onset of a southern polar vortex

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ARTICLE INFO

Article history:
Received 22 February 2018
Revised 23 April 2018
Accepted 23 April 2018
Available online 24 April 2018

Keywords:
Titan
Titan atmosphere
Titan clouds
Image processing
Infrared observations

ABSTRACT

We have analyzed the complete archive of the Visual and Infrared Mapping Spectrometer (VIMS) data in order to monitor and analyze the evolution of the clouds and haze coverage at both poles of Titan during the entire Cassini mission. Our objective is to give a cartographic synopsis from a VIMS perspective, to provide a global view of the seasonal evolution of Titan's atmosphere over the poles. We leave the detailed comparison with the Imaging Science Subsystem (ISS) and the Composite Infrared Spectrometer (CIRS) data sets to further studies. We have computed global hyperspectral mosaics for each of the 127 targeted flybys of Titan to produce synthetic color maps emphasizing the main atmospheric features. The north pole appears fully covered by a huge cloud as soon as the first observations in 2004 and up to the equinox in 2009 (Le Mouélic et al., 2012). The northern skies then became progressively clearer, after the circulation turnover in 2009, revealing the underlying lakes and seas to the optical instruments up to 2017. The reverse situation is observed over the south pole, which was mostly clear of such a high obscuring cloud during the first years of the mission, but started to develop a polar cloud in 2012. This feature grew up month after month until the end of the mission in 2017, with a poleward latitudinal extent of 75 °S in 2013 up to 58 °S in April 2017. Thanks to the spectral capabilities of VIMS, we have detected HCN spectral signatures over the north pole in almost all flybys between 2004 and 2008. These HCN signatures started then to show up over the south pole in almost all flybys between 2012 and 2017, so perfectly matching the timing and spatial extent of the northern and southern polar atmospheric features.

1. Introduction

The Cassini spacecraft entered in Saturn's orbit in July 2004. In thirteen years of operations, 127 targeted flybys of Titan, the biggest satellite of Saturn, have been performed. Titan is one of the most intriguing planetary bodies in the solar system, with a dense nitrogenous atmosphere and thick layers of atmospheric aerosols which completely mask the surface at visible wavelengths. We focus our study on the analysis of the global Cassini/VIMS (Visual and Infrared Mapping Spectrometer) data set acquired between 2004 and 2017, with a particular emphasis on the atmospheric polar features. The objective is to document the seasonal behavior of photochemical haze and the formation and evolution of clouds in the winter polar vortex. Convective methane clouds have generally been observed at 40 °S and at the pole in the sum-

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https://doi.org/10.1016/j.icarus.2018.04.028

mer hemisphere, in addition to a global subsiding ethane cloud in the winter hemisphere (Griffith et al., 2006; Hirtzig et al., 2006; Rannou et al., 2006; Rodriguez et al., 2011). First evidences for a vast ethane cloud covering the north pole have been reported as early as the second targeted flyby of Titan in December 2004 (Griffith et al., 2006). The first detailed imaging of this north polar feature with VIMS was obtained in December 2006, thanks to a change in inclination of the spacecraft orbit (Le Mouélic et al., 2012). During the first years of the mission, the northern lakes and seas that were not in winter night, were totally masked to the optical instruments by thick haze and clouds, whereas the surface of the southern polar regions was well illuminated and clearly visible in the methane windows (Porco et al., 2005; Barnes et al., 2009; Turtle et al., 2009). Subsequent flybys revealed that the north polar atmospheric feature was progressively vanishing around the equinox in 2009 (Rodriguez et al., 2009, 2011; Brown et al., 2010; Le Mouélic et al., 2012), consistently with the results of Global Circulation Models (Rannou et al., 2006). It revealed progressively the underlying lakes to the ISS (Imaging Science Subsystem) and VIMS instruments (Turtle et al., 2011; Barnes et al., 2011). Over the south pole, a high altitude cloud appeared in VIMS and ISS images acquired in May 2012 (de Kok et al., 2014; West et al., 2016), within which condensates of HCN were identified (de Kok et al., 2014; Teanby et al., 2017).

In this study, we have computed individual global maps of the north and south poles for each targeted flyby of Titan, using VIMS wavelengths sensitive both to clouds and surface features. This allows a more complete and detailed monitoring of the evolution of the north polar cloud than was done before by using a selection of individual flybys only (Le Mouélic et al., 2012). This study largely extends the time period of the monitoring, from 2004 to 2017. It also provides a detailed investigation of what has been acting over the south pole from the beginning up to the end of the Cassini mission. In the first section, we describe the data processing that we have performed on the global VIMS archive. The second section focuses on the evolution of the north polar features, from the first observations of the vast global cloud to its complete dissipation. The third section presents the concomitant evolution over the south pole. The fourth section discusses the spectral detection of the HCN at both poles, before concluding.

2. Data processing

During 13 years of operation, VIMS has acquired more than 60,000 hyperspectral data cubes of Titan. The general description of the VIMS instrument can be found in Brown et al. (2004). The VIMS IR part of the instrument acquires individual images up to 64×64 pixels, with a 256 wavelengths spectrum between 0.88 and 5.10 µm for each pixel. We applied the standard radiometric calibration pipeline described in Barnes et al. (2007), and further refined by Clark et al. (2018), labeled RC19. Within all the VIMS observations of Titan, we have systematically analyzed all the cubes covering the two polar regions taken between the T0 (2 July 2004) and T126 (17 May 2017) flybys. The surface of Titan can be observed through seven infrared methane windows at 1.08, 1.27, 1.59, 2.01, 2.69, 2.78 and 5 µm (Sotin et al., 2005). However, it should be pointed out that the surface feature observations contain portions of the atmosphere even within these methane windows due to opacity.

In a first step, we have computed for each Titan flyby a global mosaic of all the individual VIMS cubes, after sorting the cubes by increasing spatial resolution. A visual inspection has been carried out to remove spurious individual images affected by calibration issues or too extreme observing geometries. These mosaics have then been projected using an orthographic projection centered on the north and south poles. It should be noted that when the viewing direction is not straight over the pole, the clouds at different altitudes might appear slightly shifted compared to the surface. In order to extract the relevant information from this set of hyperspectral mosaics, we computed two series of RGB false color composites, which have been designed to catch both atmospheric and surface features. The dynamic of the color stretch is the same for all the images throughout the mission, so that all the maps can be compared with each other. Our first color composite is similar to the one used in the Le Mouélic et al. (2012) study of the north polar region, with the red corresponding to the average of 14 spectral channels between 4.88 and 5.10 µm, the green to the 2.78 µm channel and the blue to the average of five spectral channels between 2.00 and 2.06 µm (pink, light green and light blue bars in the spectrum of Fig. 1a and corresponding image in Fig. 1b). The northern and southern polar atmospheric data also display a particularly bright and diagnostic spectral signal at 4.78 µm related to the presence of condensed (solid or liquid) HCN (Clark et al., 2010; de Kok et al., 2014). We therefore computed a second set of RGB composites with the red controlled by the 4.78 µm channel, the green by the 2.89 µm channel and the blue by the 2.01 µm channel (red, green and blue bars in the spectrum of Fig. 1a and corresponding image in Fig. 1c). This second set of maps is designed to catch the presence of the condensed HCN component, which would appear with a dominance of reddish tone, and its evolution with time. This will be discussed latter in the paper.

3. Temporal evolution of the north polar atmospheric features during 13 years: from a “mammoth cloud” to clear skies

Fig. 2 shows the complete set of flybys’ mosaics orthographically re-projected over the north pole, using the second RGB composite emphasizing the 4.78 µm spectral feature. Observations were acquired at varying observing geometries and spatial resolutions, depending on both orbital constraints and instrument time allocation during each flyby. This figure illustrates the time evolution of the observed features, independently of the illumination/acquisition geometries and the quality of the available data. We decided to use the same color stretch, with the same thresholds, to display all the images, so that they can be directly compared with each other. This complete set of re-projected mosaics allowed us to select the images representative of the main evolution stages of the clouds structures.

Fig. 3 displays a selection of representative mosaics over the north pole from T0 to T126. We choose to display these mosaics using the color composite with red = 5 µm, green = 2.78 µm and blue = 2.0 µm, showing more finely the seasonal evolution of the polar haze cap opacity and enhancing the surface features when distinguishable. This northern area was partly in the polar night during the northern winter, from October 2002 to August 2009. The north polar cloud is detected very early in the mission (Griffith et al., 2006), as shown also on our Tb mosaic (December 2004) in the upper left view in Fig. 3. One can distinguish in greenish tones the outer boundary limit of the most opaque part of the haze which extends up to about 45–50 °N (Rannou et al., 2012). The core of the cloudy structure begins poleward of 70 °N (distinguishable in orange), but is not entirely visible due to the polar night. The same feature can be seen in the T10 mosaic (15 January 2006), indicating that the structure of the cloud is only slowly varying in this period of time. The new observation geometry at T23 offers a vision of the polar cloud with a better contrast, thanks to a change in inclination of Cassini’s orbit and lower emergence angles. For the first time, we can distinguish subtle longitudinal heterogeneities within the north polar cloud.

A slight thinning of the cloudy and hazy structure is observed near the north pole between T38 (5 December 2007) and T46 (3 November 2008). The most obvious start of the cloud breakdown