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Evolution with seasons of the organic content on Titan : from its atmosphere to the surface

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Abstract

Saturn's Earth-like satellite Titan has a thick and dense atmosphere consisting of nitrogen (98.4%), methane (1.6%) and trace gases such as hydrocarbons and nitriles. The condensed organics are deposited on the surface and the atmosphere-surface-interior interactions shape the ground. In particular, Titan's methane cycle, similarly to the Earth's hydrologic cycle, plays an important role in these exchanges by transporting methane at all layers. We analyse spectroscopic data from the Cassini/CIRS instrument in the far-infrared and spectro-imaging data (0.8-5.2 μm) from Cassini/VIMS to study Titan's surface changes consisting of a multivariable geological terrain.

Keywords: (Icy moons, Titan, seasonal effects)

1. Introduction

Titan is one of the most promising moons from the astrobiological perspective in particular because of its large organic content in the atmosphere and on the surface. These chemical species evolve with time. We have monitored Titan's stratosphere from the equator to the poles since the beginning of the Cassini mission. Titan revolves around Saturn on its course around the Sun which lasts about 30 years, so that a season on Titan is about 7,5 years. We will describe especially the seasonal evolution near Titan's poles and equator from 2012 until the last flyby of Titan in 2017. In our research (Coustenis et al. 2016; 2018 and references therein) we have reported on the observed strong temperature decrease and onset of a strong enhancement of several trace species such as HC_3N and C_6H_6 at Titan's south pole, while previously observed only at high northern latitudes. This is due to the transition of Titan's seasons from northern winter in 2002 to summer in 2017 and, at the same time, the advent of winter in the south pole. An opposite effect was expected in the north, but observed with certainty only after 2015. We find that while the North pole continues to decrease in abundances, the South pole is finally also reduced in abundance in 2017. We have obtained thus significant results which set constraints on GCM and photochemical models.

2. Atmosphere

We explored Cassini/CIRS data which cover the far-IR range from 10 to 1500 cm^{-1} . By applying our radiative transfer code (ARTT) to Cassini Composite Infrared Spectrometer (CIRS) data taken during Titan flybys from 2004-2010 and to the 1980 Voyager 1 flyby values inferred from the re-analysis of the Infrared Radiometer Spectrometer (IRIS) spectra, as well as to the intervening ground- and space- based observations (such as with ISO), we study the stratospheric evolution over a

Titanian year (V1 encounter $\text{Ls}=9^\circ$ was reached in mid-2010) [1,2]. CIRS nadir and limb spectral [1-5] show variations in temperature and chemical composition in the stratosphere during the Cassini mission, before and after the Northern Spring Equinox (NSE) and also during one Titan year.

We have monitored the seasonal evolution near Titan's poles and equator from 2004, beginning of the Cassini-Huygens mission and until the last flyby of Titan in 2017. The 2017 data we have acquired and processed here are very important as they also show that the Southern pole is finally exhibiting a significant decrease in abundance. Indeed, in the Titan south pole stratosphere some molecules had preserved their enhancement until end of 2016, before suffering a sudden and large drop in abundance in 2017. [1,2]. This is indicative of a non-symmetrical response to the seasons in Titan's stratosphere that can set constraints on photochemical and GCM models.

We performed an analysis of spectra acquired by Cassini/CIRS at high resolution since the beginning and until during the last year of the Cassini mission in 2017 and describe the temperature and composition variations near Titan's poles and at the equator over almost two Titan seasons ([3]. In previous papers [1,2], after the 2010 equinox, we have reported on monitoring of Titan's stratosphere near the poles and in particular on the observed strong temperature decrease and compositional enhancement above Titan's southern polar latitudes since 2012 and until 2014 of several trace species, such as complex hydrocarbons and nitriles, which were previously observed only at high northern latitudes. This effect followed the transition of Titan's seasons from northern winter in 2002 to northern summer in 2017,

while at that latter time, the southern hemisphere was entering winter.

Our data show a continued decrease of the abundances which we first reported to have started in 2015. The 2017 data we have acquired and analyzed here are important because they are the only ones recorded since 2014 close to the south pole in the far-infrared nadir mode at high resolution. A large temperature increase in the southern polar stratosphere (by 10-50 K in the 0.5 mbar-0.05 mbar pressure range) is found and a change in the temperature profile's shape. The 2017 observations also show a related significant decrease in most of the abundances which must have started sometime between 2014 and 2017. We set our findings in context with other results and describe via comparisons with current photochemical and dynamical models the new constraints we bring forward to improve them.

3. Surface

We also investigate Titan's low-latitude and midlatitude surface using spectro-imaging near-infrared data from Cassini/Visual and Infrared Mapping Spectrometer [4,5]. We use a radiative transfer code to first evaluate atmospheric contributions and then extract the haze and the surface albedo values of major geomorphological units identified in Cassini Synthetic Aperture Radar data. We find significant differences in the composition among the various areas. We compare with linear mixtures of three components (water ice, tholin-like, and a dark material) at different grain sizes. Our results show a latitudinal dependence of Titan's surface composition, with water ice being the major constituent at latitudes beyond 30°N and 30°S, while Titan's equatorial region appears to be dominated partly by a tholin-like or by a very dark unknown material. The albedo differences and similarities among the various geomorphological units give insights on the geological processes affecting Titan's surface and, by implication, its interior. We discuss our results in terms of origin and evolution theories.

4. Conclusions

In our work, we show strong variations in the thermal and chemical structure of Titan near the south pole and significant ones near the northern pole as they evolve seasonally, while the equatorial latitudes remain rather unaffected throughout the Cassini mission. Using the very last data from Cassini, we set constraints on photochemical and circulation models, which need to account for the asymmetry found in the poles' behavior.

We have shown that the south pole of Titan is now losing its strong enhancement, while the north pole also slowly continues its decrease in gaseous opacities and has not picked up again. It would have been interesting to see when this might happen, but the Cassini mission ended in September 2017. Perhaps future ground-based measurements can pursue this investigation and monitor Titan's atmosphere to characterize the seasonal events.

All of the organics falling from the atmosphere are deposited in the surface where they contribute to the formation of the geological shapes we see today and which are due to exogenous and endogenous processes, like aeolian, erosional, cryovolcanic, etc. We have studied in particular Tui Regio, Hotei Regio and, Sotra Facula regions, suggested as volcanic-like candidates [e.g. 4,5]. We find albedo changes with time in various locations of Titan's surface. Such variations may be indicative of cryovolcanism, which would bring methane into Titan's atmosphere and account for its replenishment.

References

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