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Atmospheric chemical and thermal structure evolution after one Titanian year

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Abstract

We analyze Cassini Composite Infrared Spectrometer (CIRS) data taken during the numerous Titan flybys from 2004-2010 and compare them to the 1980 Voyager 1 flyby values inferred from the re-analysis of the Infrared Radiometer Spectrometer (IRIS) spectra. Seven years after Cassini's Saturn orbit insertion, we look at the evolution of the chemical composition by combining these recordings and the intervening ground- and space- based observations, we have in hand almost a complete picture of the stratospheric evolution within a Titan year.

The fulfillment of one Titanian year of observations provides us for the first time with the opportunity to evaluate the relative role of different physical processes in the long-term evolution of this complex environment. By comparing V1 (1980), ISO (1997) and Cassini (2010) we find that a reversal of composition near the equator from autumnal equinox to vernal equinox (1996 min -2009 max, half a year), as well as some differences in polar enhancement at the same era as Voyager.

1. Observations

We have probed Titan's stratosphere using CIRS looking for temporal variations in temperature and composition within the duration of the Cassini mission and with respect to the remote infrared measurements acquired during the Voyager encounter in 1980, exactly a Titan year ago in 2010 (Ls of about 9° corresponding to the V1 encounter is reached again in mid 2010).

We have re-analyzed all the Voyager 1 /IRIS data with the most recent spectroscopic data and using the radiative transfer code that was applied to the first V1 retrievals [1] and ISO inferences [2] as well as more recent Cassini spectra analyses [3,4]. The re-analysis shows that the V1 retrievals in 1995 were correct for all molecules and latitudes except for the species where the spectroscopic parameters have significantly changed recently.

2. Modeling

Our radiative transfer code was also applied to CIRS spectral averages corresponding to flybys binned over 10° in latitude for both medium (2.5 cm^{-1}) and higher (0.5 cm^{-1}) resolutions and from nadir and limb data both. In analyzing the spectra, we search for variations in temperature [5] and composition at northern (around 50°N), equatorial and southern (around 50°S) latitudes. Latitudinal variations were previously inferred in a number of works [3,4-6,9]. We look here for variations in temperature and composition as the season on Titan progresses and compare them to V1/IRIS, ISO and other ground-based reported composition values (Coustenis et al., 2012, in preparation).

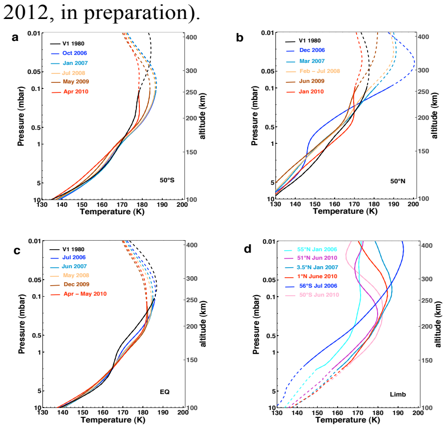

Figure 1: Temperature. Retrieved thermal profiles from CIRS and V1/IRIS data at 50°S (panel a), 50°N (panel b) and equator (panel c) for the 2004-2010 nadir data and IRIS 1980 data, and from several dates near the South, the North and the equator from CIRS limb data (panel d).

With this study we seek to set constraints on seasonal, photochemical and circulation models and to make predictions as to the spatial variations of the chemical composition on Titan from a time when the season is exactly the one of the Voyager encounter and then moves towards summer solstice in the north during the Cassini extended Solstice mission.

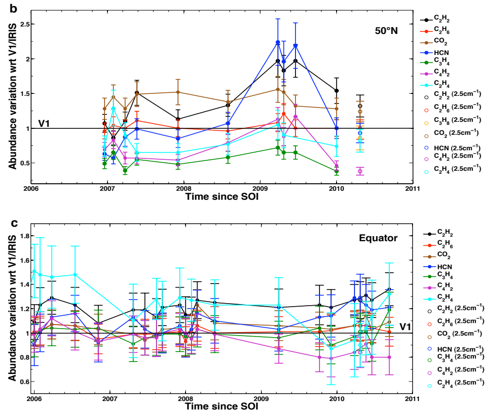

Figure 2: Composition. a) 50°N variations of the stratospheric Titan abundances with respect to the V1/IRIS values at the same latitude (normalized as 1) b): equator. The circles represent values of the abundances at lower resolution (2.5 cm^{-1}) for 2010 flybys.

3. Results

Seeing temporal variations of the atmospheric chemical composition and thermal structure informs us on the impact of different processes such as:

Photochemistry The main energy source defining Titan's chemical composition is Solar radiation, while energetic particles from Saturn's magnetosphere, as well as galactic cosmic rays have also a significant contribution. All these energy sources vary temporally in magnitude during the course of one Titan year.

Dynamics The temporal and spatial (due to Titan's inclination) variations in the energy input to Titan's atmosphere is a driver for changes in the advection patterns, which in turn provide a stronger variability in the latitudinal abundances of photochemical species.

Aerosols Both the changes in the energy field and on the dynamics affect the production and evolution of aerosols in Titan's atmosphere. The dramatic drop of the detached haze layer around equinox is a demonstration of these processes in the mesosphere, while the variable north/south asymmetry in Titan's albedo reveals the consequences of seasonal changes in the aerosol properties deeper in the atmosphere.

Clouds/Lakes The lower atmosphere and the surface are not impartial to the seasonal changes in the atmosphere. The variability in insolation and chemical composition results to variations in the formation of clouds and precipitation already observed by Cassini.

The return of today's abundances close to the Voyager values (at the same season) is an indication that, as for the Earth, the solar radiation dominates over the other energy sources even at 10AU. Nevertheless, the differences observed (complex hydrocarbons haven't reached the same enrichment level at the N pole) indicate that the other processes could be at play as well, for example the variability of the solar insolation itself through the 11-year solar cycle.

4. Interpretation

No variations are expected from any GCM or photochemical models in the completion of a year in Titan's stratosphere, so our findings from Voyager to Cassini are unexpected. Models will have to adapt.

Variations were predicted within a year in the stratosphere especially from an equinox to the next, but mostly at the poles where we don't have data. The data we have show differences at mid-latitudes and are in agreement with the expected variations pattern, but the associated magnitude at different latitudes will now have to be constrained. This is the first time any such information is provided as an input.

From one of the very rare models showing HCN variations over a Titan year starting in 2000 [10] we see that it corroborates our finding of higher abundances at the spring equinox, although only for one molecule. Refining the monitoring of these variations will require us to get well beyond the Cassini mission and all the way to around 2027 !!!

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