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Long-term chemical composition and temperature variations on Titan

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Abstract

Nine years after Cassini's Saturn orbit insertion, we look at the evolution of the thermal and chemical composition of Titan's atmosphere by combining Cassini CIRS recordings and the related ground- and space- based observations. The fulfillment of one Titanian year of space 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 automnal equinox to vernal equinox (1996 min -2009 max), as well as some differences in polar enhancement at the same era as Voyager.

Analysis of the data

We use CIRS spectra to look for temporal variations in stratospheric 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 also 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 [3] and ISO inferences [4] as well as more recent Cassini spectra analyses [5-11].

Our radiative transfer code (ARTT) was applied to that and also 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 [1] and composition at northern (around 50°N), equatorial and southern (around 50°S) latitudes. Latitudinal variations were previously inferred in a number of works [4,5-7,8]. In our recent work [2] we have determined the temperature variations in Titan's stratosphere during the Cassini mission (Figure 1).

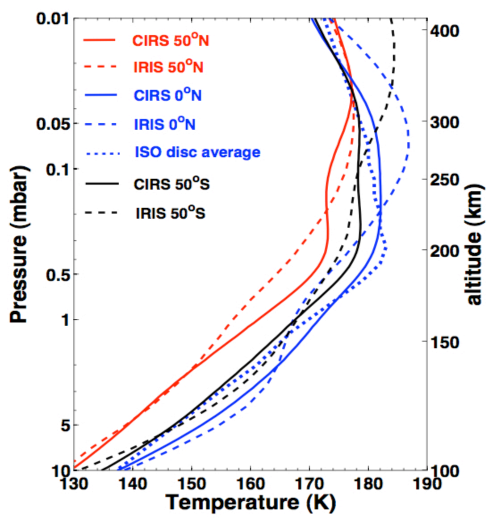

Figure 1. Retrieved thermal profiles from CIRS nadir data at 50°N, equator and 50°S. Same for temperature structure from V1/IRIS data (1980). Also the disk-average ISO profile from 1997 is plotted. From Coustenis et al. (2013).

We also estimated the abundances of the trace gases in Titan's stratosphere from 50°S to 50°N. We found no significant temporal variations at mid and southern latitudes during the Cassini mission. We monitored and quantified the compositional enhancement at 50°N, and got indication for a maximum at the time of the Titan northern spring equinox (NSE, mid-2009), followed by a sharp decrease of the gaseous chemical content within the next Earth year or so. Our results are compatible with recent findings [9]. We further look 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., 2013, in preparation).

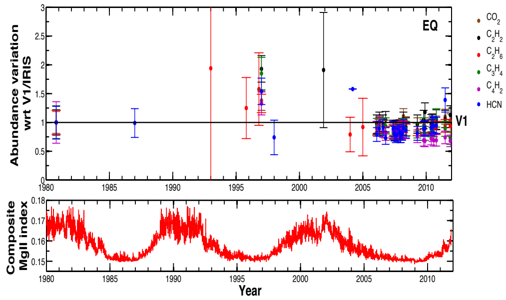

Figure 2: Variation of Titan's stratospheric composition from the time of the V1/IRIS encounter (marked as 1 here in 1980) until the Cassini era and Titan's spring northern equinox, passing through the ISO data in 1997.

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.

Findings

The peak in abundance is observed around the northern spring equinox, during which we know a rapid change in the atmosphere took place. Indeed, short-term variations observed during the Cassini mission can arise from changes in the circulation around the time of the equinox. The collapse of the detached aerosol layer suggests that the dynamics during this period go through a rapid transition which should also affect the gas distribution. The rapid decrease after mid-2009, for which the most straightforward explanation is that the vortex has shrunk somewhat, would be consistent with the weakening thermal gradient we find here and that of the winds also reported [8,9]. The finding also ties into the location of the maximum temperature gradient, which appears to be moving northward over the winter/spring season ([9], Fig. 3). If 50°N is emerging from the vortex core, it would cause a large reduction in the abundances, hence explaining our observations. Thus, decreasing abundances at 50°N could be due to a weakening vortex with reduced lateral mixing across the vortex boundary [9].

Another cause could be the spatial variations in the energy input to Titan's atmosphere (due to Titan's inclination) as a driver for changes in the advection patterns, which in turn provide a stronger variability in the latitudinal abundances of photochemical species. Changes in the solar output during the 11-year cycle can potentially affect the chemical production rates in Titan's atmosphere. On the other hand, during the Cassini mission, the Sun has been stable going through an extended minimum with the first weak signs of increased output observed towards the end of 2009. The chemical lifetimes in Titan's stratosphere (at 200 km) range between ~1 year for C_2H_4 and C_3H_4, up to ~20 years for HCN, which are longer than the time-scales of some of the rapid changes observed. Thus, the temporal variability observed during the Cassini mission is more likely related to changes in the atmospheric circulation patterns due to progression of seasons.

The fulfillment of one Titanian year of observations in August 2010 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. We find that a return to the 1980 abundance values is achieved for most molecules at all latitudes, indicative of the solar radiation being the dominating energy source at 10 AU, as for the Earth, in agreement with predictions by GCM and photochemical models. The exceptions set important constraints. We find that wrt V1 the stratospheric chemical composition shows higher values near the northern fall equinox (near 1997) and lower ones at the spring equinox (near 2009).

The cause could be spatial changes (due to Titan's inclination) in the energy input to Titan's atmosphere as a driver for changes in the advection patterns, circulation, etc which in turn provide a stronger variability in the latitudinal abundances of photochemical species after some time.

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