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Chemical composition and temperature structure of Titan's stratosphere

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Abstract

We have explored 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. We find indication for a weakening of the temperature gradient with warming of the stratosphere and cooling of the lower mesosphere. In addition, we infer precise concentrations for the trace gases and their main isotopologues and find that the chemical composition in Titan's stratosphere varies significantly with latitude during the 6 years investigated here, with increased mixing ratios towards the northern latitudes. In particular, we monitor and quantify the amplitude of a maximum enhancement of several gases observed at northern latitudes up to 50°N around mid-2009, at the time of the NSE. We find that this raise is followed by a rapid decrease in chemical inventory in 2010 probably due to a weakening north polar vortex with reduced lateral mixing across the vortex boundary. By comparing the Cassini/CIRS results from both the limb and the nadir observations with past V1 (1980) and ISO (1997) inferences we find indication for seasonal variations.

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 compare CIRS recent results [5-11] with results from the Voyager 1/IRIS [3] and ISO data [4].

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).

We use the most recent spectroscopic parameters and a radiative transfer code (ARTT) that was applied to the V1 and ISO retrievals but upgraded over time.

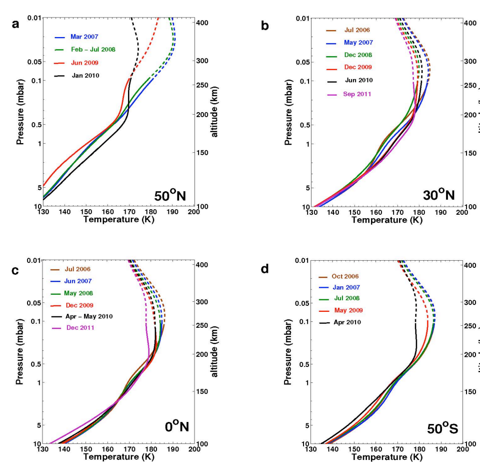

Figure 1. Retrieved thermal profiles from CIRS nadir data at (a) 50°N, (b) 30°N, (c) equator and (d) 30°S. The typical error bars uncertainty is about 0.7 K at 1 mbar and at most 4 K at 5 mbar. Dashed lines indicate the altitude levels above which, the temperature has higher uncertainties. From Bampasidis et al. (2012).

In this work, we estimate the abundances of the trace gases in Titan's stratosphere from 50°S to 50°N. We find no significant temporal variations at mid and southern latitudes during the Cassini mission. We monitor and quantify the compositional enhancement at 50°N, and find 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 the findings of Teanby et al. (2010) in that we find HCN and C2H2 to display a rapid increase in northern latitudes up to mid-2009 while the abundances at equatorial and southern latitudes remain stable. CO2 presents no latitudinal variations anywhere because of its long photochemical lifetime.

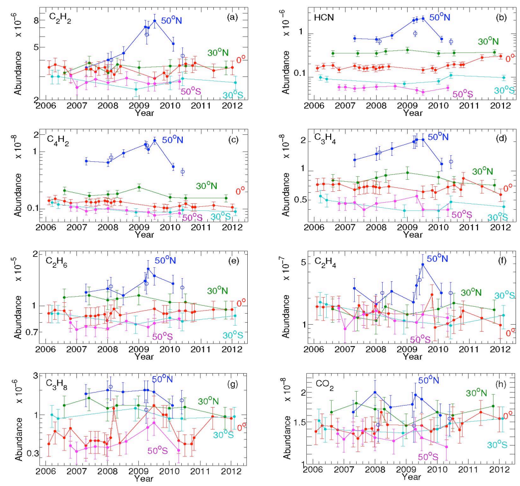

Figure 2. Time-latitude composition variations for the major trace gases of Titan's stratosphere: (a) C2H2, (b) HCN, (c) C4H2, (d) C3H4, (e) C2H6, (f) C2H4, (g) C3H8 and (h) CO2. The latitudes investigated from 2006 to 2012 are: 50°S (violet), 30°S (light blue), equator (red), 30°N (green) and 50°N (blue). Connected filled circles are high resolution observations (0.5 cm-1), while open circles are medium resolution data (2.5 cm-1) for 2008, 2009 and 2010 (and sometimes coincide with the higher resolution values). The 3-σ estimated error bars are indicated. From Bampasidis et al. (2012).

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.

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