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Seasonal changes in Titan's atmospheric composition observed by Cassini: implications for atmospheric circulation

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Abstract

Titan's obliquity of 26.7° causes large seasonal variations in solar illumination during its 29.5 year orbit around the sun. This leads to dramatic atmospheric changes - including changing circulation patterns, which can be indirectly observed using minor gases as tracers. We use a seven year dataset (2004–2011) of mid-infrared spectra measured by Cassini's Composite InfraRed Spectrometer (CIRS) to document such seasonal variations. During this time period the season has progressed from northern winter to northern spring, passing through equinox in mid-2009. Data taken before the equinox show an intense stratospheric polar vortex highly enriched in trace gases, and a single south-to-north circulation cell. Following northern spring equinox, dramatic changes in atmospheric temperature and composition were expected. Our analysis of the equinox and post-equinox periods shows that abundances of trace gases at the north pole have now begun to increase. We propose that increases in north polar trace gases are due to a seasonal reduction in gas depletion by horizontal mixing across the vortex boundary. A simultaneous slight gradual increase in south polar HCN suggests a weakening of the overall circulation, which is consistent with this idea. This indicates that Titan may soon enter its transitional circulation regime.

1. Introduction

Titan's atmosphere mainly comprises N_2 (98%) and CH_4 (2%), but includes many trace species formed by upper atmosphere photochemical processes [1]. Stratospheric abundances of these gases can be measured using mid-IR spectral emission features and used as tracers of vertical advection [2].

Over Cassini's entire mission (2004–2017) models predict first a single south-to-north cell with north polar subsidence and southern upwelling, second a short-lived transitional two-cell phase with equatorial upwelling and subsidence at both poles, and finally a full reversal of the initial circulation into a north-to-south cell [3].

During Cassini's prime mission (2004–2008) trace gas abundances were enhanced at northern latitudes relative to southern and equatorial regions [4, 5, 2], indicating a single south-to-north meridional stratospheric circulation cell and a north polar vortex.

Here we use the full seven year time series of data from Cassini's Composite InfraRed Spectrometer (CIRS) covering 2004 – 2011 to determine seasonal variations in stratospheric trace gas abundance - updating our recent 2010 study [6].

2 Observations and Methods

CIRS is a Fourier transform spectrometer covering the spectral range 10–1500cm^{-1}, with an adjustable spectral resolution of 0.5–15cm^{-1}. CIRS is fully described by [7]. Here we use nadir data taken with CIRS' mid-IR focal planes (FP3 and FP4) taken at 2.5cm^{-1} and 0.5cm^{-1} spectral resolution. These data provide the most complete latitude and time coverage. Atmospheric temperature and composition were retrieved using NEMESIS [8] - a non-linear optimal estimation technique using the correlated-k approximation. Temperature profiles and abundances of C_4H_2, C_3H_4, CO_2, HC_3N, HCN, C_2H_2, C_2H_6 and C_2H_4 were determined. Composition determinations are sensitive to the middle and upper stratosphere (5–0.05mbar).

3. Results

The figure shows variations of temperature and composition with latitude and time at the 0.7mbar pressure level, covering northern winter to northern spring, and indicates a large number of atmospheric changes.

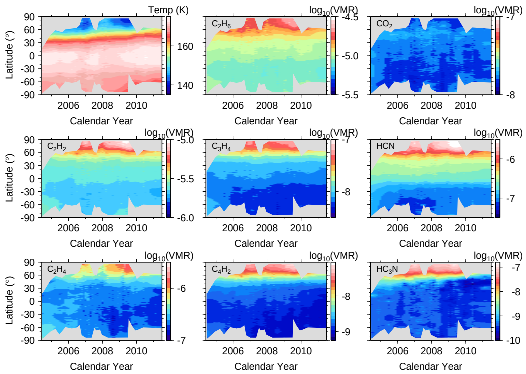

Figure 1: Seasonal changes in temperature and composition at 0.7mbar observed over the entire Cassini mission so far.

Temperature: Both north and south poles exhibit cooling at 0.7mbar as the season progresses; and the region of maximum temperature gradient (around the vortex boundary at 30–50°N) has moved northwards by about 15°.

Composition: Spatially, trace gases have relatively uniform abundances at southern and equatorial latitudes, with significant subsidence-induced enrichment at northern latitudes [2]. CO_2 does not vary significantly with latitude due to its long photochemical lifetime. Equatorial and low latitude abundances remain relatively stable with time; although an initial enriched cap of gas over the south pole (most visible in C_2H_2 and C_2H_4) has dissipated. South polar HCN increases somewhat during 2008–2010 and HC_3N appears to be confined to more northerly latitudes as the season progresses. North polar abundances of most trace species increase dramatically during 2009 relative to their 2008 values. The north polar increase is most pronounced for HCN and C_2H_2 and least pronounced for HC_3N and C_4H_2. The south polar HCN increase is a more subtle effect.

4. Discussion and Conclusions

Our preferred explanation for the observed temperature decrease and trace gas increase within the northern vortex is a weakening meridional circulation cell, combined with a shrinking polar vortex wall, and reduced trace gas loss by horizontal mixing across the vortex boundary. These changes suggest the atmosphere may soon enter the long-awaited transitional period. The first sign of this new regime is the recent increase in south polar HCN abundance - indicating weakening southern uplift. As subsidence in the southern circulation cell develops we eventually expect abundance increases for other trace gases coupled with temperature increases caused by adiabatic heating in the upper stratosphere. This will be monitored during Cassini's Solstice Mission, which is due to run until 2017. The 13 year mission length will eventually give coverage of almost half a Titan year and provide even more stringent constraints on Titan's seasonal variability.

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References

[1] Wilson, E. H., Atreya, S. K., 2004. Current state of modeling the photochemistry of Titan's mutually dependent atmosphere and ionosphere. J. Geophys. Res. 109.

[2] Teanby, N. A., et al., 2009. Dynamical implications of seasonal and spatial variations in Titan's stratospheric composition. Phil. Trans. R. Soc. Lond. A 367, 697–711.

[3] Hourdin, F., et al., 1995. Numerical Simulation of the General Circulation of the Atmosphere of Titan. Icarus 117, 359-374.

[4] Flasar, F. M., et al., 2005. Titan's atmospheric temperatures, winds, and composition. Science 308, 975–978.

[5] Coustenis, A., et al., 2007. The composition of Titan's stratosphere from Cassini/CIRS mid-infrared spectra. Icarus 189, 35–62.

[6] Teanby, N. A., et al., 2010. Seasonal changes in Titan's polar trace gas abundance observed by Cassini. ApJ 724, L84-L89.

[7] Flasar, F. M., et al., 2004. Exploring the Saturn system in the thermal infrared: The Composite Infrared Spectrometer. Space Sci. Rev. 115, 169–297.

[8] Irwin, P., et al., 2008. The NEMESIS planetary atmosphere radiative transfer and retrieval tool. J. Quant. Spectro. Rad. Trans. 109, 1136–1150.