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Seasonal changes in Titan's middle-atmosphere chemistry and dynamics

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Abstract

Titan is the largest satellite of Saturn and is the only moon in our solar system with a significant atmosphere. Titan's middle-atmosphere (stratosphere and mesosphere) circulation usually comprises a single hemisphere to hemisphere meridional circulation cell, with upwelling air in the summer hemisphere and subsiding air at the winter pole with an associated winter polar vortex. Titan has an axial tilt (obliquity) of 26.7°, so during its 29.5 Earth year annual cycle pronounced seasonal effects are encountered as the relative solar insolation in each hemisphere changes. The most dramatic of these changes is the reversal in global meridional circulation as the peak solar heating switches hemispheres after an equinox.

Titan's northern spring equinox occurred in August 2009, and since then many middle-atmosphere changes have been observed by Cassini that were previously impossible to study (1,2,3,4). Here we present a detailed analysis of the post equinox changes in middle-atmosphere temperature and composition measured with Cassini's Composite InfraRed Spectrometer (CIRS), use these to infer changes in atmospheric circulation, and explore implications for atmospheric photochemical and dynamical processes. Our results show that the meridional circulation has now reversed (1).

1 Observations

Observations comprise nine years of Cassini/CIRS data - spanning northern fall to northern spring. CIRS' vantage point on Cassini allows detailed views of the polar regions and provides the best dataset yet for studying Titan's seasonal processes. CIRS covers the spectral range 7-1000 μm, or 10-1400 cm^{-1} with a resolution of 0.5-15 cm^{-1} (5). This spectral range provides a way to measure both temperature and composition of the atmosphere on a global scale.

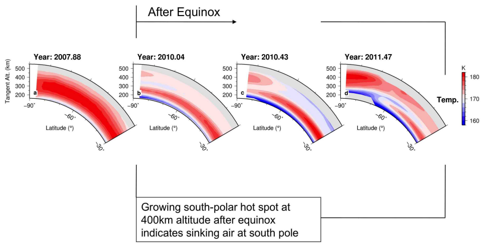
We focus on observations taken at resolutions of 0.5, 2.5, and 13.5 cm^{-1} covering 600-1400 cm^{-1}. This range provides the best spatial resolution and sensitivity to most of Titan's IR-active trace species. Data were observed in both nadir (downward) and limb (horizontal) viewing configurations to provide complementary horizontal and vertical resolution.

2 Methods

Infrared CIRS spectra were inverted using the NEMESIS optimal estimation retrieval suite (6), which employs the correlated-k approximation and a non-linear inversion scheme. We determined atmospheric temperature profiles and the abundances of C_4H_2, C_3H_4, CO_2, HC_3N, HCN, C_2H_2, C_2H_6, C_6H_6 and C_2H_4 by fitting a synthetic spectrum to the observed CIRS spectra.

3 Results

Figure 1 shows cross sections of temperature at the south pole either side of equinox derived from CIRS limb data. An atmospheric hot spot develops soon after equinox over Titan's south pole at ∼400 km altitude - indicating sinking air that is being compressed and heated adiabatically. This observation shows that the circulation direction over the south polar region has now reversed compared to earlier in the mission



Growing south-polar hot spot at 400km altitude after equinox indicates sinking air at south pole

Figure 1: Temperature cross-sections of Titan's south polar atmosphere, showing development of a south polar hotspot soon after equinox, which indicates south polar subsidence and a reversal of the middle-atmosphere meridional circulation.

(7). The transition happens almost immediately after equinox, showing Titan's atmospheric dynamics respond rapidly to changes in solar heating. Simple energy balance calculations imply vertical velocities over the south pole of 0.5-2 mm/s (downwards).

Figure 2 shows cross sections of atmospheric composition approximately one and two years after equinox. Unlike temperature, atmospheric composition does not respond immediately to changes in atmospheric circulation. However, after two years south polar subsidence has produced significant enrichment of trace gases, with some gases (HC_3N) increasing in abundance by up to three orders of magnitude. These large increases are produced by prolonged transport from the upper atmosphere photochemical source regions and suggest that subsidence must extend to perhaps 600 km or more. Observed trace gas enrichments also imply subsidence velocities of 2 mm/s.

4 Discussion

Our results show that Titan's atmospheric circulation extends higher than previously thought - to perhaps 600 km or more - and can change surprisingly rapidly. These detailed observations of the reversal process provide stringent new constraints for numerical models (8,9). The polar observations are especially important as changes in these regions are the largest and most rapid anywhere on the planet, so provide the best window into Titan's dynamics. Further observation of Titan's atmosphere during Cassini's solstice mission promise to further illuminate processes occurring in its complex atmosphere.

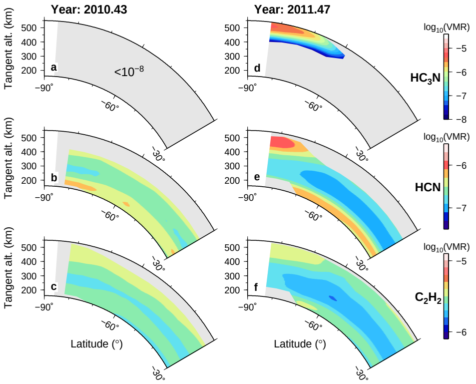


Figure 2: Cross sections of composition through Titan's south polar atmosphere. Two years after equinox trace gas abundances over the south pole have increased by up to three orders of magnitude - indicating prolonged subsidence from high altitudes.

Acknowledgements

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