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Seasonal Evolution of Saturn's Polar Atmosphere from a Decade of Cassini/CIRS Observations

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Abstract

Saturn's polar regions are subjected to extreme insolation variations over its 29.5 year orbit due to the gas giant's 26-degree axial tilt, causing seasonal changes to the thermal structure, chemistry, dynamics and cloud properties of the polar environments. Cassini's high inclination orbits permit detailed scrutiny of Saturn's high latitudes in a dataset that now spans a decade (a third of a Saturn year, 2004-2014), five years either side of the northern spring equinox in 2009. Thermal infrared Cassini/CIRS spectra (7-16 µm) from all mission phases are inverted to determine the rate of change of polar temperatures, wind shears, tropospheric phosphine (as a tracer of vertical mixing) and stratospheric hydrocarbons (tracers of middle atmospheric circulation and chemistry). Cassini's unique vantage point allows us to track these parameters as the summer southern pole receded into autumn and the winter northern pole emerged into spring sunlight. Results show the most rapid changes to temperature and composition occurring poleward of 70° in each hemisphere, in excess of expectations from simple radiative climate models. Small cyclonic vortices persist at both poles throughout the Cassini mission, while the broad stratospheric vortices are seasonally variable. The signature of the northern hexagon is still present in the tropospheric thermal structure. At the time of writing, an infrared-bright polar vortex is beginning to emerge at the northern spring pole, consistent with the historical record of Saturn observations from the 1980s (previous northern spring, [4]).

1. Introduction

Saturn's polar atmosphere provides an extreme test of our understanding of atmospheric chemistry and dynamics, being the apex of a planet-wide circulation system and the site of a unique connection between the atmosphere and the wider charged-particle planetary environment. This investigation builds on the snapshot of polar conditions observed by Cassini/CIRS in 2005-2007 [2], which revealed a striking asymmetry in temperature structure from the summer to the winter pole, with an extended warm stratospheric `hood' over the summer pole (approximately 70-90°S) but absent from the cold winter pole. In addition, ground-based observations [4] discovered a compact, warm cyclonic vortex within 2-3° of Saturn's southern summer pole, which was found to be mirrored at Saturn's northern winter pole [2], suggesting that these cyclonic polar vortices and their `hurricane-like' eyewalls [5] are persistent features on Saturn irrespective of the season. This investigation uses a decade of Cassini observations to study the stability of the polar cyclones, the seasonal evolution of the summer stratospheric vortices, and search for evidence of compositional variations.

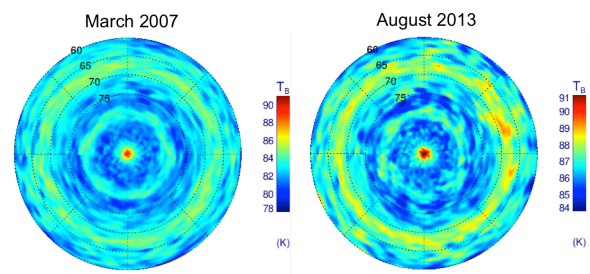

Figure 1 *Comparing 150-mbar brightness temperatures (16.4 µm) in 2007 and 2013, showing the continued presence of the north polar cyclone and hexagonal wave.*

2. Data and Methodology

Cassini/CIRS observes Saturn in both targeted observations and during sequences led by other instruments. Although the latter tend to be noisier as the CIRS focal plane motion is more random, they provide an essential addition to the time-series of polar observations. This study uses all available high-latitude data at spectral resolutions of 2.5 cm^{-1} and 15.0 cm^{-1} to produce a comprehensive time series of seasonal change (Fig. 1). Latitudinally-resolved spectra from each month of the Cassini mission are inverted using an optimal estimation retrieval algorithm (NEMESIS, [6]) to determine the spatial distributions of temperature and gaseous composition.

3. Results

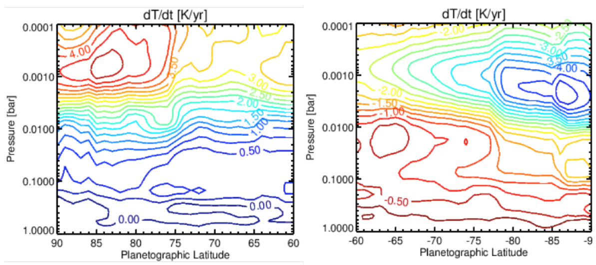

Figure 2 *Rates of change of temperature from 2004-2014 assuming linear variation, showing localised heating/cooling over the stratospheric polar vortices.*

- Localised hot cyclonic vortices (Fig.1) [2] (and their associated hurricane-like appearance [5]) persist at both poles of Saturn throughout the observation period, irrespective of season. These vortices extend from the troposphere into the stratosphere, and are likely due to adiabatic heating associated with subsidence over the poles themselves.
- Saturn's south polar stratospheric 'hood' (the region of bright emission poleward of the prograde jet at 74°S) has cooled substantially as winter approaches (from 164 K at 90°S at 1 mbar in 2004 to 131 K in 2014). The most rapid cooling is in the 0.5-5.0 mbar region at ~4K/yr. Fig. 2 shows how the cooling is strongest within the 'hood' itself due to the enhanced hydrocarbon coolants found there. A cool band (centred at 72-73°S) has formed in the stratosphere, altering the zonal wind shear on the peripheral vortex jet.
- The warming of the northern stratosphere (4.5 K/yr, Fig. 2) also appears to be enhanced poleward of the 77°N jet compared to lower latitudes, with 1-mbar temperatures rising from 122 to 145 K at 90°N between 2004 and 2014. The localisation is consistent with a north polar stratospheric vortex, isolated from lower latitudes and mirroring that at the south.
- Stratospheric ethane and acetylene have responded differently to the seasonal heating – ethane has increased by 0.4 ppm/yr within the north polar stratospheric vortex, compared to 0.1 ppm/yr outside (Fig. 3). Acetylene has also increased at the north pole, but shows less sensitivity to the boundary at the edge of the polar vortex. At the south pole, both species are decreasing in concentration, although the depletion appears fastest within 5° of the pole, suggesting that a combination of chemical and dynamical processes are influencing these species.
- We see no evidence for the temporal variation of the ammonia and phosphine distributions.

We will discuss the dynamical implications of these results for tropospheric and stratospheric circulation, and our expectations for the remainder of the Cassini mission as we approach northern summer solstice in 2017.

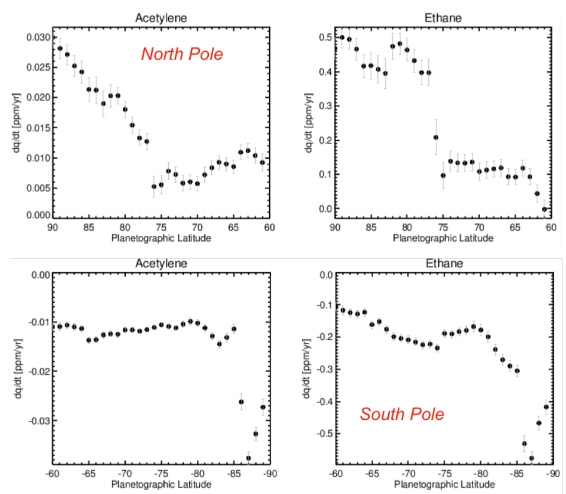

Figure 3 *Rates of change of hydrocarbon abundance at 1 mbar (ppm/yr), showing the different behaviour of each gas at the north and south pole.*

Acknowledgements

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