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# Saturn's stratospheric equatorial oscillation and wave activity through the Cassini epoch

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## Abstract

Thermal infrared spectra acquired by Cassini/CIRS in limb viewing geometry in 2015 are used to derive 2-D latitude-pressure temperature and thermal wind maps in Saturn's stratosphere. These maps are compared to previous observations from 2005 and 2010 to study the evolution of the vertical structure of Saturn's equatorial oscillation between 20 hPa and 0.01 hPa. CIRS nadir spectra are also used to map stratospheric temperatures with longitude. Twelve datasets are selected at different epochs (2005–2015) in the tropical region (20N–20S) : planetary thermal waves are observed in each dataset, suggesting that they are ubiquitous in Saturn's equatorial stratosphere.

## 1. Introduction

Like the Earth and Jupiter, Saturn's stratosphere harbors a periodic equatorial oscillation of its zonal wind and temperature vertical profiles [1, 5]. By analogy with the Earth Quasi-Biennal Oscillation, these oscillations are thought to be driven by interactions between upward-propagating waves and the mean zonal flow, leading to a vertical oscillation of the zonal wind profile and a descent of wind extrema through the stratosphere. The period of Saturn's Quasi-Periodic Oscillation (QPO) is estimated to 14.7 years, making its observational study a challenging task.

Zonal wind speeds have never been directly measured in Saturn's stratosphere, so that the study of the QPO is done indirectly, through the measurement of associated temperature anomalies that develop in thermal wind balance. Due to the sharp vertical oscillation of the temperature profile on relatively small vertical scales (two temperature and zonal wind extrema are separated by ∼two scale heights), these temperature anomalies have been best resolved using Cassini radio-occultation soundings [6] or thermal infrared spectroscopic measurements in limb-viewing geometry by Cassini/CIRS [3]. These two studies monitored the descent of the temperature anomalies between 2005/2006 and 2009/2010 with a great vertical extent and resolution but a poor temporal coverage.

In parallel, nadir observations by Cassini/CIRS can provide unique longitudinal coverage of the temperature, which is highly valuable to study planetary wave patterns. Currently, our knowledge of equatorial waves activity is limited to the observation of a Rossby-gravity wave of wavenumber 9 in 2005 and 2006 [4]. Here we continue to monitor the descent of Saturn's QPO with the analysis of Cassini/CIRS limb measurements acquired in 2015. We complete this study by analysing CIRS nadir data acquired between 2005 and 2015 to monitor the activity of equatorial, planetary thermal waves.

## 2. Cassini/CIRS observations

In 2015, spectra of Saturn's thermal infrared radiation were recorded in limb viewing geometry at 17 latitudes between 77N and 77S by the Composite Infrared Spectrometer (CIRS) onboard Cassini. At each latitude, the 10-detector arrays of focal planes FP3 and FP4 are set perpendicular to the limb of the planet and simultaneously record spectra acquired at 10 different tangent altitudes in the range 590–1450 $cm^{-1}$. We employ the radiative transfer model coupled to the inversion algorithm described in [2] to retrieve vertical temperature profiles from the $\nu_4$ methane band (1200–1370 $cm^{-1}$, probing the middle stratosphere from 0.01 to 5 hPa) and the $H_2$ and He collision-induced continuum (590–660 $cm^{-1}$, probing the lower stratosphere from 1 to 30 hPa). By combining these temperature profiles we obtain the pressure-latitude temperature map shown in Fig. 1 between 20N and 20S.

We have also selected CIRS nadir spectra acquired between 20N and 20S with 360° longitudinal coverage in 2005/2006, 2009/2010 and 2015, *ie.* three epochs for which we have previously retrieved temperature

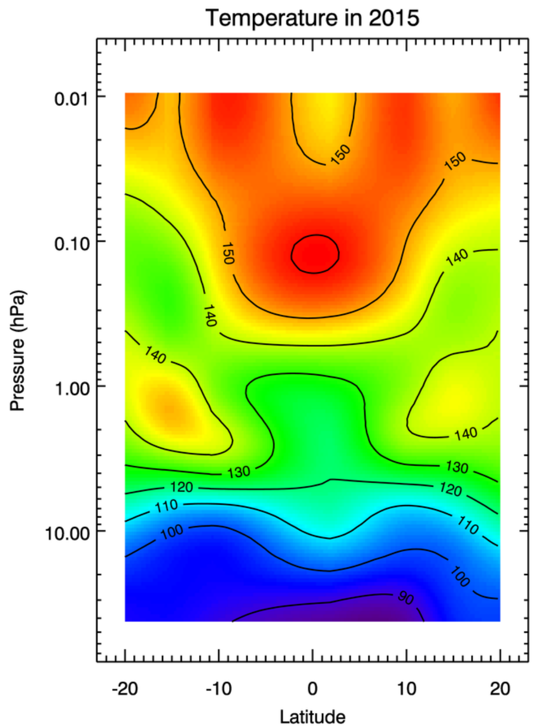


Figure 1: Temperature map (in Kelvin) obtained from Cassini/CIRS limb data acquired in 2015.

profiles from limb datasets. Individual nadir spectra were co-added in 4°-wide latitude bins and 10°-wide longitude bins with a step of 5° in longitude. We employ the same algorithm to retrieve vertical temperature profiles. In nadir geometry, the $H_2$ and He continuum emission probes upper tropospheric temperatures (80–250 hPa) while the methane emission band probes mid-stratospheric temperatures (0.5–5 hPa).

# 3. Results

## 3.1. The evolution of Saturn's QPO

Between 2010 and 2015, Saturn's tropical stratosphere have warmed and cooled in a complex way. Local temperature minima and maxima seen in 2010 have become local maxima and minima in 2015, with changes up to 20K. These extreme changes reflect a change in circulation associated to the descent of the wind extrema. Using the modified thermal wind equation integrated along cylinders, we derive a map of the thermal zonal wind relative to the 20-hPa level that can be compared to previous maps obtained from 2005 and 2010 CIRS limb observations. In 2015, the temperature meridional gradients translate into a local equatorial thermal wind minimum at 0.56-hPa of -100 m/s (relative to the 20-hPa level), surrounded by two local wind extrema, at 5.3 hPa and 0.2 hPa. The descent rate of the oscillation pattern is found faster in the upper stratosphere than in the lower stratosphere, varying between 0.4 and 0.2 scale height per (Earth) year, consistent with a greater wave flux momentum absorbed in the upper stratosphere. This descent rate remains consistent with the previously derived 14.7-yrs period for Saturn's QPO [5].

## 3.2. Planetary waves

Twelve planetary thermal waves are reported at latitudes 15°N, 15°S or the equator, with wavenumbers between 1 and 9 and amplitudes in the range 2-4K. In two cases we were able to identify them as Rossby waves. This study shows that planetary waves are likely ubiquitous in Saturn's tropical regions and provide constraints to future numerical models.

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