EPSC Abstracts
Vol. 12, EPSC2018-471, 2018
European Planetary Science Congress 2018

Saturn's stratospheric thermal structure, composition and dynamics revealed by Cassini/CIRS limb observations

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Abstract

Throughout the Cassini mission, the Cassini Composite InfraRed Spectrometer (CIRS) has acquired thermal infrared spectra in limb viewing geometry that we analyzed to map the temperature and the meridional distribution of five hydrocarbons from the lower to the upper stratosphere (10 mbar – 10 microbar). The exceptional longevity of the Cassini mission enabled us to uniquely investigate the seasonal and temporal changes over almost half a Saturn year to reveal the dynamical and chemical processes that govern Saturn's stratosphere.

In this abstract we review our most important findings: 1) the discovery of an equatorial oscillation in temperature and thermal wind, along with the study of its evolution ; 2) thermal and chemical signatures of the meridional circulation in the middle/upper stratosphere and 3) the detection of benzene and hydrocarbon aerosols in the polar regions, likely produced by ion chemistry in the auroral regions.

1. Cassini/CIRS limb observations

The Composite InfraRed Spectrometer (CIRS) recorded spectra of the thermal emission of Saturn's atmosphere in nadir and limb-viewing geometry [1]. We exploited data acquired by Focal Planes 3 and 4 (FP3 and FP4), which covered the spectral range 580-1400 cm^{-1} with a spectral resolution varying between 0,5 and 15 cm^{-1}. In limb viewing geometry, the 2x10 detector arrays of FP3 and FP4 were set perpendicular to the limb of the planet, so that each detector probed a different tangent altitude. The projected field of view of one of these detectors was typically 50 to 90km, which is of the order of the atmospheric scale height (~60 km). Hence, the strength of the limb observations was to probe the atmosphere with a much greater vertical coverage and resolution than the nadir-viewing data. Furthermore, in limb geometry, the long atmospheric path favored the detection and measurement of trace species in the middle stratosphere.

2. Data analysis

We employed the forward radiative transfer model coupled to the bayesian inversion method described in [3] to retrieve vertical temperature profiles from the analysis of the ν_4 methane band (1200-1370 cm^{-1}) and of the H_2-H_2 and H_2-He collision-induced emission (590-660 cm^{-1}). These temperature profiles are constrained between 20 mbar and a few µbar. Secondly, vertical profiles of the volume mixing ratio of various hydrocarbons can be retrieved from the analysis of their emission bands, such as ethane (centered at 822 cm^{-1}) and acetylene (730 cm^{-1}).

3. Results

In the equatorial regions, we have discovered an Equatorial Oscillation [2,5,9] where the mechanical forcing by upward propagating waves induces temperature anomalies of up to ±20K in the thermal structure and ±200 m/s in the zonal wind field. Our studies show that this oscillation has a temporal period of about 15 terrestrial years (half a Saturn year) and resembles the terrestrial Quasi Biennal Oscillation (QBO) that affects Earth's stratosphere. Outside the equatorial regions, our survey of the thermal structure [3,10] reveals that the seasonal warming and cooling trends observed by CIRS are, to first order, consistent with the predictions from a radiative equilibrium climate model [6]. One notable exception is that the region under the ring's shadow is found warmer than expected from the radiative model, both in 2005 and 2015.

We also studied the spatial distribution of hydrocarbons, by-products of the methane photochemistry, which also undergo significant seasonal change in the upper stratosphere [3,4,10] In

2005, a local maximum of hydrocarbons was observed at 20°-30°N, at odds with the low photochemical production in this region (under the ring's shadow at that time). Together with the high temperature anomaly, we had interpreted this result as the signature of a downwelling branch of the meridional circulation. In 2015, not only has this local maximum vanished, but a new maximum was building in the opposite hemisphere, at 15°-25°S. We suggest that the hydrocarbon and temperature anomalies observed in 2015 in Saturn's upper stratosphere reflects the reversal of a seasonal circulation cell.

Finally, in the we detected stratospheric benzene and hydrocarbon aerosol signatures in both polar regions [7,8]. The amount of benzene and its vertical profile are clearly at odds with predictions from neutral photochemical models and strongly suggest production by ion chemistry. The spectral signatures of Saturn's polar aerosols most strikingly mimic the signatures of Titan's stratospheric aerosols [11]. We assigned the detected vibration modes to aromatic and aliphatic hydrocarbons. The aerosol mass loading was estimated to lie in the range $1-4 \times 10^{-5}$ g cm^{-2} , an order of magnitude less than on Jupiter, which is consistent with the order of magnitude weaker auroral power at Saturn. Nevertheless, we demonstrated that the radiative effects of aerosols is important in the polar regions and could at least partly explain the large seasonal temperature variations observed in these regions.

Acknowledgements

We acknowledge support by CNES and thank the Cassini/CIRS team for all their work over the years.

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