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Seasonal Variations of Hydrocarbons in Saturn's Stratosphere

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Abstract

We present a study of the seasonal variations of hydrocarbons in the stratosphere of Saturn. Meridional variations of the abundances of hydrocarbons such as acetylene (C_2H_2) and ethane (C_2H_6) have previously been determined, in particular using observations from the Cassini/CIRS (Composite Infrared Spectrometer) instrument. Such studies have used Cassini data obtained during the prime mission (2004 - 2008) therefore studying Saturn from shortly after summer solstice to 'autumn' in the Southern Hemisphere. With the occurence of the vernal equinox in August 2009, Saturn's northern hemisphere is now approaching summer solstice. We aim to determine the response of the hydrocarbon photochemistry as a result of seasonal changes.

1. Introduction

The stratosphere of Saturn is host to a rich hydrocarbon photochemistry. Solar ultraviolet radiation photolyses methane, the products of which undergo further reactions, producing other hydrocarbons such as acetylene (C_2H_2) and ethane (C_2H_6). Production is greatest in the higher stratosphere (at pressures less than 0.1 mbar) - see Table 1. Vertical diffusion then transports the hydrocarbon products into the lower stratosphere ($\sim$1 mbar). The abundances of these by-products are expected to vary both in height in the atmosphere and in latitude due to the changing ultraviolet insolation.

The Cassini/CIRS (Composite Infrared Spectrometer) instrument has provided a wealth of data with high spatial resolution, sounding both the troposphere and stratosphere of Saturn. Several previous studies have mapped out the vertical and meridional abundances of hydrocarbons using these observations ([1], [2] & [3]).

At $\sim$1 mbar, the meridional C_2H_2 and C_2H_6 abundances are expected to match an annually-average profile of the ultraviolet insolation since their photochemical lifetimes are long compared to the Saturnian year at this altitude (Table 1) ([4]). While this is true of the observed acetylene distribution at this altitude, the ethane distribution deviates from prediction, showing enhanced abundance towards the south (summer) pole ([1], [2] & [3]). This is believed to be evidence of meridional stratospheric transport from hydrocarbon-rich equatorial regions to the summer pole.

These conclusions are drawn from Cassini observations obtained during the prime mission (from 2004 to 2008) therefore representing Saturn's atmosphere shortly after Summer Solstice to 'Autumn' in the Southern Hemispere. With the vernal equinox in August 2009, the Northern Hemisphere is now warming, approaching its Summer Solstice in 2017. Cassini/CIRS observations from 2004 to 2009 have previously been analysed for the seasonal response of temperature and ortho-to-para H_2 fraction ([5]), but the response of the hydrocarbon photochemistry remains to be determined. This study aims to determine the response of Saturn's stratospheric photochemistry with the changing season.

High-emission angle/limb spectra will sound the upper stratosphere where photochemical models show the greatest seasonal variation in the abundances of C_2H_2 and C_2H_6. In the upper stratosphere, we expect enhancements of both acetylene and ethane in the northern hemisphere with a slight time delay comparable to their predicted production timescale (Table 1). Photochemical models also show a significant response of the acetylene and ethane abundances in the higher stratosphere with ring shadowing ([4]). The temporal response of the atmosphere at latitudes that experience ring shadowing will also be studied.

Near-nadir observations will sound hydrocarbons in the lower stratosphere ($\sim$1 mbar). Photochemically, there should be no hydrocarbon enhancement at these altitudes as the production timescale is too long compared to the Saturnian year (Table 1). Any observed enhancement, therefore, will imply meridional transport from the equator (as concluded of the southern

Pressure	Photochemical Timescales (years)					
	C_2H_2			C_2H_6		
	Production	Loss	Net	Production	Loss	Net
1 μbar	1	3	3	3	10	3
1 mbar	3	3	100	300	1300	600

Table 1: The production, loss and net photochemical time constants of C_2H_2 and C_2H_6 at -36^o during southern summer solstice (L_s $\sim$270^o) as predicted in [4]. These are defined as n/Q, n/L and $n/|Q-L|$ respectively, where n is the species concentration and Q and L are the production and loss rates respectively. The 'net' timescale describes the stable lifetime of a chemical species. Values are approximate, having been read from Figure 7 of [4].

hemisphere during its summer) or vertical transport from the upper stratosphere. The rate of enhancement of either C_2H_2 or C_2H_6 will provide timescale constraints of these processes.

The most recent Cassini data will also provide coverage of the recent eruptions of storms in the northern hemisphere ([7]). Although not related to seasonal forcing, studying the hydrocarbon abundances in proximity to the storms will provide interesting insight into the vertical and horizontal dynamics around such storms.

2. Analysis

Cassini/CIRS data will be resolved latitudinally and temporally. Near-nadir and high emission angle/limb observations will be used to acheive sensitivity throughout the stratosphere. The vertical atmospheric profiles will be retrieved using the NEMESIS inverse radiative transfer retrieval tool [6]. Initially, the temperature will be retrieved using the collision-induced spectrum between 600 and 700 cm^{-1} (tropospheric sensitivity) and the CH_4 ν_4 band ($\sim$1300 cm^{-1}) (stratospheric sensitivity). The acetylene and ethane abundances will subsequently be retrieved using their band features at $\sim$730 cm^{-1} and $\sim$820 cm^{-1} respectively.

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