Changes in the temperature of Saturn's stratosphere from 2002 to 2004 and direct evidence of a mesopause.

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Introduction: The state of a planetary stratosphere is intricately linked to the radiation it receives from its host star. The stellar flux impinging on the the planetary stratosphere affects the temperature and chemistry occurring there. The revolution of the planet about its orbit coupled to the planets axial tilt can cause variations in the amount of flux captured by the planet at a given latitude over the period of a year even if the flux output of the star is constant. This variation of stellar flux at a given latitude during the orbit of a planet is what causes seasons.

Saturn, with its axial tilt of 27°, experiences seasonal forcing much like the Earth, albeit with far less solar flux and a year equal to 30 Earth years. In an attempt to measure the effect seasonal forcing has on the temperature structure of Saturn's stratosphere, we have started a long term observing program. By observing Saturn with a high-resolution mid-infrared spectrograph in the ν_4 band of methane, we can infer the stratospheric temperature between the pressure levels of 10 and .01 mbar. We present latitudinally resolved observations of Saturn's southern hemisphere from 2002 and 2004. We have analyzed the data using a line-by-line radiative transfer model and inferred stratospheric temperatures and winds. We compare the temperatures from the two observing runs and the predictions of a stratospheric seasonal climate model [1]. The zonal winds in the southern hemisphere, between the 10 and 0.01 mbar pressure levels, will be shown and discussed.

The 2004 observations taken in a different wavelength region than those in 2002 show distinct self absorption cores in the strongest CH_4 emission features (Fig. 1). The absorption cores are direct evidence for the existence of a Saturnian mesopause, ie. a temperature minimum occurring at altitudes above the stratosphere.

Observations: Using TEXES, the Texas Echelon cross-dispersed Echelle Spectrograph [2], mounted on the NASA Infrared Telescope facility we observed Saturn on September 13th and 14th 2002 and October 15th 2004 UT. We achieved a spectral resolving power of 80,000 with the 1.4 arcsec wide slit. All the observations were taken with the slit oriented along the celestial N/S direction and the instrument operating in nod mode [2].

During the 2002 observations the sub-Earth point was at -26° planetocentric latitude. Saturn was at an L_S of 268.4°, where southern summer solstice is L_S=270°, and had an equatorial diameter of 18.2 arcsec. The 2004 observations occurred when Saturn was at an L_S of 296.8° and had an equatorial diameter of 18.3 arcsec. The sub-Earth point was at -21.9° planetocentric latitude. The spectral regions studied on the two different dates were 1228-1231.6 and 1244.5-1250.5 cm^{-1} for 2002 and 2004 respectively. The CH_4 emission lines in the 1248 cm^{-1} region have larger intensities than those in the 1230 cm^{-1} region. This causes them to be more sensitive to high-altitudes (or low-pressures) in Saturn's atmosphere.

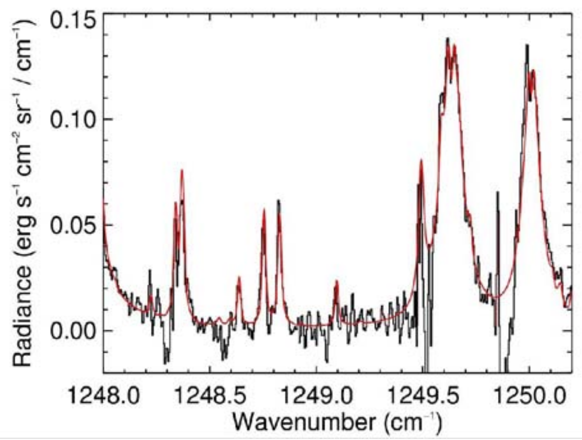

Figure 1: A portion of the 1248 cm^{-1} spectrum that contains CH_4 emission from -85° latitude. The Saturnian airmass of the observation was 2.4. The data in black show distinct absorption cores in the 1249.62 and 1250 cm^{-1} emission lines which are produced by a decreasing temperature profile above the few tenths of a mbar level in Saturn's atmosphere.

Results: Greathouse etal. [3] found that an equator to south pole temperature gradient of ~ 9 K between the pressure levels of 5 and 0.05 mbar could reproduce the 2002 data (Fig. 2). The initial analysis of the 2004 observations indicate an increase of the temperature gradient between equator and south pole to ~ 15 K at pressure levels of 5 to .1 mbar, but an overall decrease in the temperature at the 0.05 mbar level relative to the 2002 observations (Fig. 3). There are two possible explanations for these results, one could be observational while the other could be physical. Our results could differ due to the change in spectral settings chosen between 2002 and 2004. The 2002 spectral setting is less sensitive to the 0.05 mbar level in comparison to the 2004 setting. A systematic test concerning a possible altitude bias on our temperature retrievals will be presented in the poster. The physical effect is that of Saturn's stratosphere reacting to the changes in Saturnian season. The observations in

2002 were taken very near southern summer solstice. The temperatures found, presented in Figure 2, show a general trend of increasing temperature with increasing southern latitude. This trend is seen to have increased in Figure 3 for pressures greater than 0.1 mbar. This increase in equator to pole temperature variation in the lower stratosphere could be a result of thermal inertia causing a phase lag between the seasonal heating and physical temperatures. The decrease in temperature at the 0.05 mbar level occurring between 2002 and 2004 may be a reflection of the increase in hydrocarbon coolants produced during the summer season at high altitudes and latitudes (see [4]).

Although the change of spectral settings has increased the uncertainty in the observed temporal change in temperature, it has offered us a definitive answer to the possible existence of a mesopause in Saturn's atmosphere. The 2004 data exhibit a pronounced self-absorption core at the center of the strongest CH_4 emission lines (Fig. 1). The strength of the self-absorption features are stronger in near limb observations compared to center of disk observations. This is conclusive evidence that in October 2004, the south pole of Saturn exhibited a mesopause.

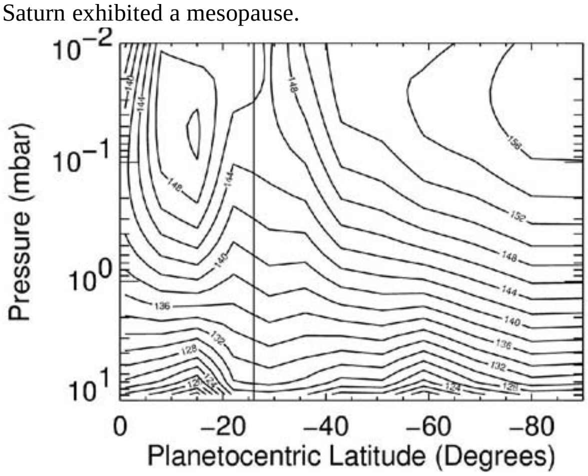

Figure 2: A plot of Saturn's stratospheric temperature in Kelvin inferred from CH_4 emission spectra taken in September 2002 when Saturn was at an L_S=268.4°. The vertical line indicates the sub-Earth and sub-Solar point at the time of the observations.

Conclusions:

We report conclusive evidence for the existence of a mesopause in Saturn's atmosphere. We also find the equator to south pole stratospheric temperature gradient has increased by ~ 5 K between 2002 and 2004. This increase of the equator to pole temperature gradient at 5 mbar was predicted by [1], though it seems to be occurring approximately two Earth years earlier than was predicted. At the highest altitudes probed, we observe an overall decrease in temperature between 2002 and 2004 that may be indicative of an increase in the amount of coolants in the upper stratosphere. In fact an increase in hydrocarbon abundances is predicted for very high altitudes during the Saturnian summer by the photochemical/seasonal model of Moses etal. [4]. This effect could also be an observational artifact which will be discussed fully in the poster.

This work comes at an exciting time for the study of Saturn. The Cassini spacecraft started it's 5 year tour of the Saturnian system in June 2004. The high spectral resolution of TEXES coupled with the high spatial yet lower spectral resolution of Cassini will severely constrain future climate and photochemical models of Saturn. Future observations of Saturn from both TEXES and Cassini will help us understand the temporal variations we are just now beginning to unveil.

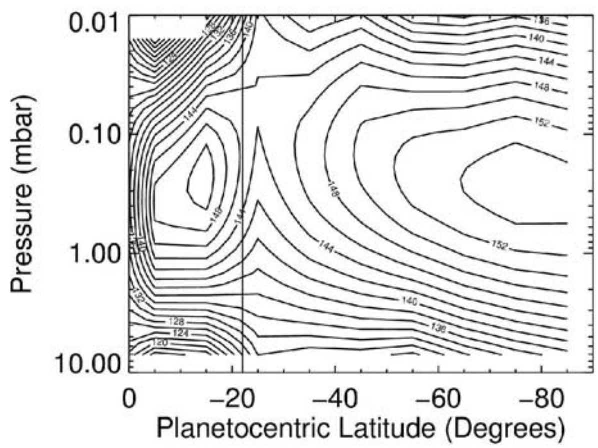

Figure 3: A plot of Saturn's stratospheric temperature in Kelvin inferred from CH_4 emission spectra taken in October 2004 when Saturn was at an L_S=296.8°. The vertical line indicates the sub-Earth and sub-Solar point at the time of the observations.

References:

[1] Bezard B. and Gautier D. (1985) *Icarus*, *61*, 296-310. [2]Lacy J. H. et al. (2002) *PASP*, *114*, 153-168. [3] Greathouse T. K. et al. (2004) *submitted to Icarus.* [4] Moses J. I. et al. These proceedings.

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