Tholin sensitivity to atmospheric methane abundance and the implications for multiple stable states of Titan's climate system.

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Introduction

Titans surface temperature is controlled by the competing greenhouse effect from methane and hydrogen gasses, and the antigreenhouse effect from the organic haze. The greenhouse on Titan raises the surface temperature by an estimated 9 K while the antigreenhouse lowers the temperature by 21 K [1]. A greenhouse/antigreenhouse model was created by McKay et al. [1, 2] to explore these effects. Lorenz et al. [3] expanded this model to make it more physical and examine the stability of Titans atmosphere throughout its history. Lorenz et al. [3] assumed that the production rate of haze is only proportional to the UV flux; however, this picture recently became more complicated. Sciamma-O'Brien et al. [4] found that the tholin production rate in their lab experimental study depended on in situ methane concentration, peaking near the current methane mole fraction on Titan. Trainer et al. [5] also found that the tholin production depended on methane concentration as well.

In this study we attempt to assess the effects of the methane dependence on tholin production and optical properties on the stability of Titans climate. To do this we produce tholins using a nitrogen/methane gas mixture in a low pressure cold plasma. We analyze the production rate and optical properties of the tholins. We then incorporate these results into a Titan greenhouse/antigreenhouse model and report on the climatic stability of Titans atmosphere through time.

Experimental Setup

We flowed the methane and nitrogen gas mixture with gas flow controllers (Model 3200: KOFLOC) through our experimental apparatus the quartz reaction tube (diameter = 51 mm; length = 300 mm) at 170 Pa. We created 5 tholin samples using the initial gas mixtures of 2, 4, 6, 8, and 10 percent methane. We then turned on the radio frequency (RF) generator (13.56 MHz; 300 W: Nihon Koshuha Co. Ltd.) to induce the cold plasma. The thickness of the tholin samples and their real and imaginary (n, k) refractive indices in the wavelength from 190 nm to 830 nm were measured with spectroscopic ellipsometry (UVISEL FUV, HORIBA corp.). The incidence angle of light was kept at 60 degree. The ratio of the amplitude diminution and the phase difference induced by reflection on the samples were analyzed.

Initial conc. (%)	In situ conc. (%)	Prod. rate (nm/hr)
10.0	4.34	234
8.0	3.52	440
6.0	2.30	569
4.0	1.18	517
2.0	0.50	423

Table 1: The initial and in situ methane concentrations in our experiment and the tholin production rate.

Experimental Results

We simply calculate the production rate of our tholins as the thickness in the center of the collection disk divided by the reaction time. We find that the highest production rate is at an initial (in situ) methane concentration of 6% (2.3%), which is consistent with the results of Sciamma-O'Brien et al. [4]. The experimental results of tholin production rate (Table 1) suggest that, if atmospheric methane concentrations become much higher than that of current Titan, the antigreenhouse would become less effective due to the low tholin production rate.

Figure 1 shows the real and imaginary indices of refraction, n and k, of the tholins formed in the present study compared with those of previous studies [6, 7, 8, 9, 10].

The k values of our tholins systematically vary with the methane concentration by several tens of percent at short wavelengths, below 500 nm. The tholin formed at lower methane concentrations (i.e., lower methane partial pressures) tends to have higher k values.

Climatic implications

The discrepancies between the our experimental results and those of Khare et al. [6] is interesting, however, for this study we are focusing on the relative differences between the indices of refraction and the production rate of aerosols which will have climatic effects under conditions of changing methane.

We employ a semi empirical model similar to that of Lorenz et al. [3] and McKay et al. [2] to inspect the climatic implications of the varied haze production and

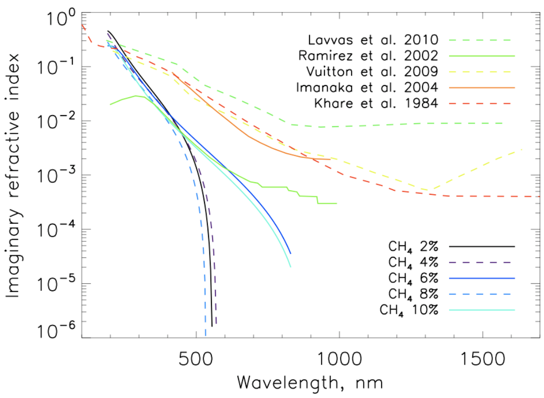

Figure 1: Figure 1: The imaginary refractive indices of our samples compared with other laboratory and modeling efforts.

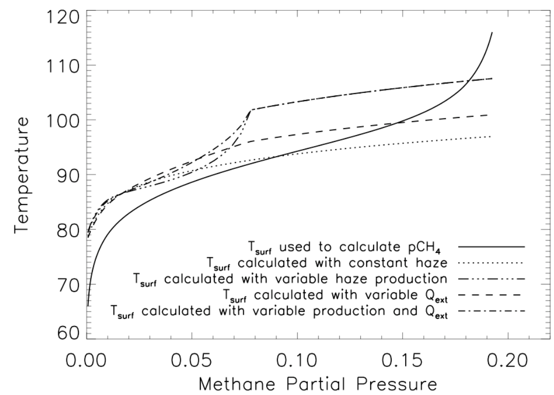

Figure 2: Figure 2: Surface temperature calculated for different atmospheric gas concentrations and model variations. Where the dashed and dotted lines cross the solid line are stable points for Titan's atmosphere.

optical coefficients. In their model the haze production is a function of UV flux only, whereas we have scaled the haze production as well as the visible optical depth with the stratospheric methane abundance based on our experimental results.

The effect of the variable haze production is stronger than the effects from the optical properties, however both lead to warmer equilibrium points for Titan's atmosphere. We find that the Titan atmosphere will inevitably go to a runaway greenhouse as the solar luminosity increases over time. Depending on the initial conditions chosen, this could happen in the near geologic future.

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