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Condensation of Ices in Titan's Stratosphere

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Abstract

The destruction of methane and nitrogen molecules in Titan's upper atmosphere results in the production of many hydrocarbon and nitrile species that reach their condensation temperatures in the stratosphere. Evidence for stratospheric ices has been seen spanning Voyager, ground-based, and Cassini data sets. Microphysical studies of these ices have been conducted using Titan-CARMA.

1. Introduction

Photochemistry in Titan's upper atmosphere produces a number of trace species formed from the combination of carbon, hydrogen, and nitrogen liberated from the destruction of CH_4 and N_2 molecules. [1] showed that as these gaseous species descend through the colder regions of Titan's atmosphere, they are likely to condense onto the organic particles from the visible haze layer. Voyager IRIS observations of the north polar hood indicated the presence of C_4N_2 (dicyanoacetylene) ice crystals, with a cloud top near 90 km [2]. More recently, [3] reported emission features, in the Cassini CIRS data, centered around 90 km which were consistent with HCN and HC_3N ices; these features were most abundant at, but not exclusive to high northern latitudes, extending as far as 58^o S. In addition to providing condensation nuclei for methane clouds in Titan's troposphere, these ice particles will contribute to the opacity of Titan's stratosphere and so detailed knowledge of their altitude, location, and particle size is important.

2. Modeling

Titan-CARMA (Community Aerosol and Radiation Model for Atmospheres) is a column microphysics and radiative transfer model that has been adapted to simulate the formation of methane, ethane, and other ice clouds in Titan's troposphere and stratosphere [4].

The model solves the continuity equation for a particle *n* of volume *v*, with the form

$$\frac{\partial n}{\partial t} = -\frac{\partial}{\partial z}(nv_{fall}) - n_{gas}K_{diff}\frac{\partial[n(v)/n_{gas}]}{\partial z} + \frac{1}{2}\int_0^v K_{coag}(v', v-v')n(v')n(v-v')dv' - \int_0^\infty K_{coag}(v', v)n(v)n(v')dv' + P(v) - L(v) \quad (1)$$

For cloud particles, the production and loss terms are

$$P(v) - L(v) = J(v) - \frac{\partial}{\partial v}\big(G(v)n(v)\big) \quad (2)$$

Particles are transported vertically through sedimentation (regulated by fall velocity, v_{fall}) and eddy diffusion (with coefficient K_{diff}); though due to their sizes, haze particles generally move through diffusion and cloud particles generally fall. All particles are also subject to coagulation (with coagulation kernal K_{coag}). Collisions between involatile particle groups are generally handled by the equations for Brownian coagulation. Coalescence kernels are calculated for cloud-cloud collisions. The production term, *P(v)* in Eqn. 1 describes the creation of haze particles, such as by photochemistry. Haze particles are lost, *L(v)*, through nucleation to produce cloud particles, *J(v)*. Nucleation follows the classical theory as described in [5]. Cloud particles then interact with the volatiles through condensational growth and evaporation (regulated by the growth kernel, *G(v)*). All particle groups are represented by a number of radius bins.

3. Results

Figures 1-3 show and example of ice condensation layers produced by a model simulation run using the Cassini RSS temperature profile near 50^o S [6].

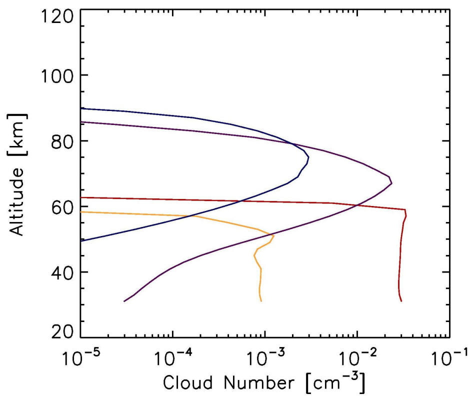

Figure 1: Ice layers in Titan's stratosphere. Number density of HC_3N (blue), HCN (purple), C_2H_2 (red), and C_2H_6 (orange) are shown as a function of altitude.

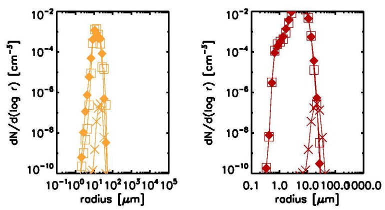

Figure 2: Size distributions for the C_2H_6 (orange) and C_2H_2 (red) ices shown in Fig. 1, for altitudes of 40 km (squares), 50 km (diamonds), and 60 km (x).

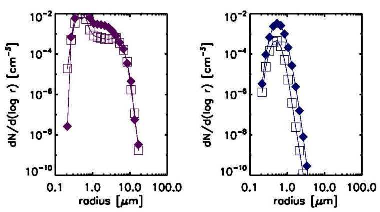

Figure 3: Size distributions for the HCN (purple) and HC_3N (blue) ices shown in Fig. 1, for altitudes of 60 km (squares) and 70 km. Both peak at a radius of 0.5 µm for 80 km altitude.

4. Conclusions

A number of factors including temperature profile, vapor pressure equation, volatile abundance, nucleation critical saturation, and coagulation efficiency will affect the altitudes of the individual ice layers. Additionally, some ices are likely to serve as condensation nuclei for others.

References

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