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Condensation in Titan's lower atmosphere

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Abstract

We present a self-consistent description of Titan's aerosols-clouds-gases system and compare our results with the optical properties retrieved from measurements made by the Descent Imager / Spectral Radiometer (DISR) experiment on the Huygens probe [4]. Our calculations include the condensation of methane, ethane and hydrogen cyanide on photochemical aerosols produced in the thermosphere. Our results suggest that the two distinct extinction layers observed by DISR below 80 km are produced by HCN and methane condensation, respectively, while for the Huygens' equatorial conditions simulated here, the contribution of ethane clouds to the total opacity is negligible

1. Introduction

In Titan's lower stratosphere and troposphere, the sharp temperature drop results in the condensation of methane and of the photochemical species on the aerosol's surface. Measurements by the DISR experiment provide evidence for this process at low latitudes [4]. Analysis of the observations showed that the optical properties of particles can be fitted by different laws, above 80 km, between 80 and 30 km, and below 30 km, respectively. More specifically the constraints set by the observations on the aerosol extinction profile, their single scattering albedo, and the wavelength dependence of their opacity, indicate that the size of the particles changes at these altitudes due to the addition of a different mass on their surface. In a recent publication, we demonstrated that a pure aerosol simulation was able to reproduce the measurements above 80 km, but failed to match the observational constraints at lower altitudes [2]. In the current work we include in the simulation the condensation of photochemical gases and methane on the aerosols, thus providing a self-consistent description among gases, aerosols and condensates.

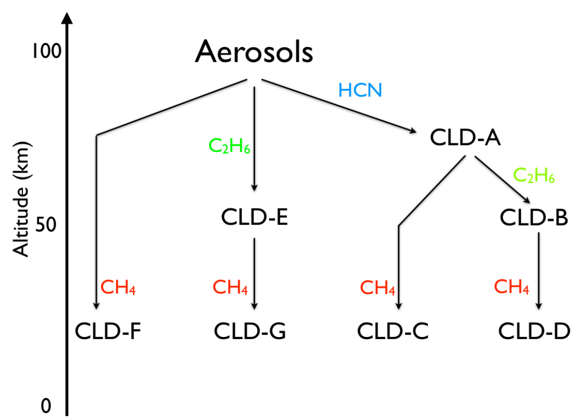

Figure 1: Chart of possible cloud types produced from the condensation of the three gas species considered in the calculations.

2. Model Description

The model used here is based on the microphysical model described in [2], but has been extended to include nucleation and condensation on the aerosols. The gas species we consider are HCN, C_2H_6 and CH_4. HCN has the largest mass flux among the nitrogen containing species and condenses at a much higher altitude compared to other species with similar mass fluxes. Ethane is the photochemical product with the largest mass flux, while methane provides the largest mass flux for condensation in the troposphere. Other species such as C_2H_2 and HC_3N also have significant mass fluxes for condensation, but they both condense at a similar altitude range as the above species and have a smaller mass flux from them. The fact that several species may condense implies the existence of a variety of cloud particle types. For example, ethane can condense on pure aerosol particles, but also on aerosol particles on which HCN has already condensed. In order to account for all combinations for the three condensates we consider, we define seven cloud types, summarized in Fig.1.

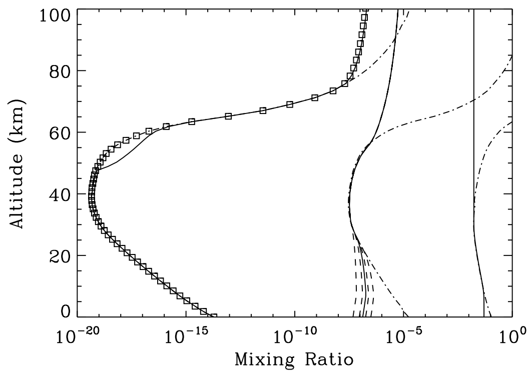

Figure 2: Calculated mixing ratios (solid lines) of the three gases used in the calculations (HCN, C_2H_6 and CH_4 from left to right) compared to their saturation mixing ratios (dash-dotted lines). The boxes correspond to the HCN calculated profile if the contribution of GCR is not considered. The dashed lines present the sensitivity of the calculated ethane profile on the atmospheric mixing in the troposphere with surface eddy coefficients of 300, 500, 700 (solid line), 1000, and 2000 $cm^2\ s^{-1}$, from right to left. The eddy profile is of constant slope between the surface value and a value of 700 $cm^2\ s^{-1}$ at 40 km.

3. Results

Our results suggest that the two distinct extinction layers observed by DISR below 80 km are produced by HCN and methane condensation, respectively, while for the Huygens' equatorial conditions simulated here, the contribution of ethane clouds to the total opacity is negligible. The HCN mass flux is comparable to the mass flux of aerosols, thus the majority of the HCN cloud particles have a similar size with the aerosol particles, they are HCN-coated aerosols. When the production of HCN from GCR impact at these altitudes is included in the calculations, the gaseous HCN abundance remains above the saturation limit (Fig.2), thereby leading to the continuous condensation of HCN on the aerosols. Ethane cloud particles have sizes between 2 and 10 μm depending on altitude, and methane clouds grow to an average size of $\sim$100 μm before starting to evaporate below 10 km. The aerosols released from the evaporating CH_4 clouds are turbulently mixed and re-enter the methane condensation region above 10 km. Thus, they generate a local increase in the methane cloud particle density that is consistent with the local opacity increase at 11 km retrieved from DISR images [1]. Below 30 km, the opacity is governed by the simultaneous presence of clouds and aerosols. This coexistence is indicated by the observed wavelength dependence of the opacity, which requires the contribution of both opacity sources as demonstrated by the calculations. We also provide an estimate of the ethane gaseous abundance close to the surface, as well as of the response of this result to different atmospheric mixing rates. Our calculations suggest that ethane remains sub-saturated below 20 km and that ethane clouds evaporate before reaching the surface. This conclusion is based on the assumption that gas molecules are lost at the surface, as soon as they reach it and therefore is sensitive to the efficiency of atmospheric mixing. Nevertheless, for all mixing profiles we tested, the ethane profile remains sub-saturated in the lower troposphere (Fig.2). Recent results from the analysis of GCMS measurements [3], verify that the atmosphere close to the surface is sub-saturated with respect to ethane, in agreement with our conclusion. Thus, among the gas species we consider in our model the only condensate reaching the surface is HCN, the gas abundance of which remains close to its saturation limit in the troposphere (Fig.2).

Acknowledgements

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