EPSC Abstracts
Vol. 6, EPSC-DPS2011-1547-1, 2011
EPSC-DPS Joint Meeting 2011

Near-infrared light scattering by methane clouds

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Abstract

Calculations of the near-infrared phase function and single-scattering albedo of methane clouds are presented. The absorption spectra of liquid and solid methane are used to calculate the complex index of refraction. An analytical expression for the cloud particle size distribution is used. The cloud scattering properties are tested in a radiative transfer model of Titan's atmosphere, with a peak in the cloud particle size distribution near 0.5 mm that is consistent with microphysical models of clouds. A physical model of cloud scattering can be used to quantify the cloud opacity predicted by general circulation models that include methane thermodynamics, and such predictions can be directly compared with observations.

1. Introduction

Clouds composed primarily of methane have been observed extensively on Titan (e.g., [5, 1]) and can be used to diagnose the atmospheric dynamics [10] and surface-atmosphere exchange [4]. We follow closely the work of Hansen & Pollack [7], where scattering by terrestrial clouds was studied, and apply this methodology to calculating the scattering properties of methane clouds.

2. Methods

The real and imaginary components of the index of refraction n_r and n_i for methane are calculated from absorption spectra $\alpha(\lambda)$ [6] using the Kramers-Kronig dispersion relation

$$n_i(\lambda) = \alpha(\lambda)/4\pi \quad (1)$$

$$n_r(\lambda) = 1 + \frac{2}{\pi}\mathcal{P}\int_0^\infty \frac{n_i(\lambda')\lambda'}{\lambda'^2 - \lambda^2} d\lambda' \quad (2)$$

and compared with literature data [8], Figure 1.

The cloud particle size distribution is given by

$$N(r) \propto r^6 \exp(-6r/r_m) \quad (3)$$

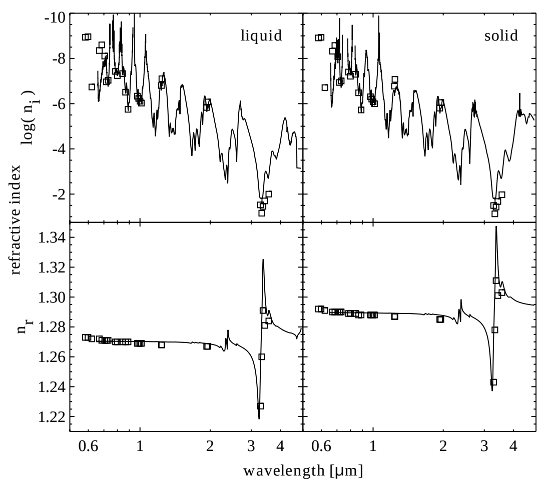

Figure 1: Complex refractive index for liquid and solid methane calculated from absorption spectra [6] (*solid lines*), with datapoints from the compilation of Martonchik & Orton [8] (*squares*).

where number of particles at a given radius r is $N(r)$, which has a peak value at r_m. Mie scattering calculations are performed at each radius for the phase function $p_r(\theta)$ and single scattering albedo ω_r. Properties for a distribution of droplets are calculated by taking the sum over r and weighting by the normalized size distribution, $\bar{n}(r)$, for example:

$$p(\theta) = \sum_{r=r_0}^{R} p_r(\theta)\bar{n}(r)dr \quad (4)$$

Phase functions $p(\theta)$ for various size distributions are presented in Figure 2 and the single scattering albedo spectra are illustrated for two distributions in Figure 3.

3. Applications

Using a particle size distribution with $r_m \sim 0.5$ mm is consistent with the microphysical modeling of clouds on Titan [3]. The scattering properties of such a cloud

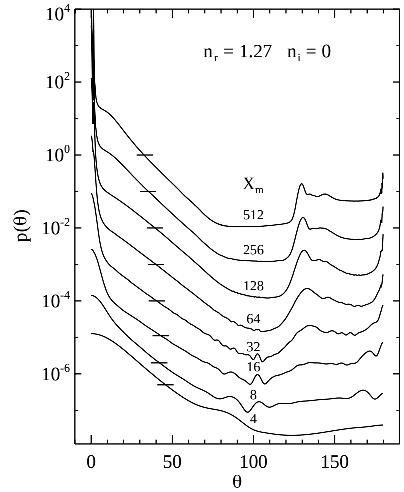

Figure 2: Single scattering phase functions characteristic of the 1–2 μm region, for particle size distributions peaking at a given particle size parameter, $x_m = 2\pi r_m/\lambda$. Curves offset with bar at $p(\theta) = 1$.

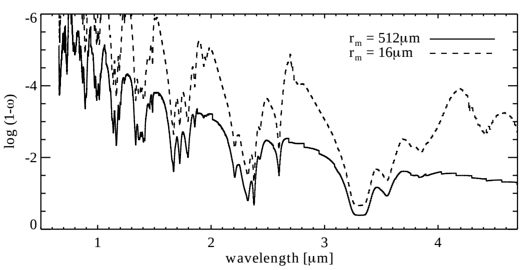

Figure 3: Spectra of the single-scattering albedo, ω, for two particle size distributions.

can be used in radiative transfer models of Titan's atmosphere [2]. Although the optical depth, τ, of a cloud would be a free parameter in such models, predictions can be made for the amount of precipitable methane that is expected to be observed on Titan from circulation models [10]. Mitchell et al. [9], present a simulation of Cassini/ISS observations based on precipitation in a 3D circulation model, Figure 4.

The wavelength-dependent scattering properties of clouds presented here can be extended to the analysis of Cassini/VIMS observations throughout the near-IR for cloud-top altitude and opacity retrieval. Calculation of ethane optical constants from absorption spectra may allow for discrimination of of pure methane and mixed methane-ethane clouds.

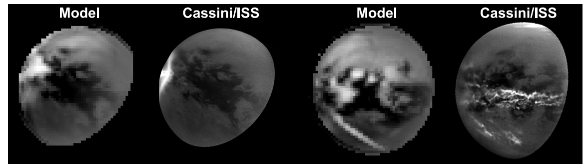

Figure 4: Radiative transfer simulations of 938nm Cassini/ISS observations, with cloud opacities determined using predictions from a GCM. Adapted from Mitchell et al. [9].

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