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High-latitude depletion of methane on Uranus

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Abstract

Sromovsky et al. [5] showed that at low latitudes a compact methane cloud layer of low opacity was compatible both with STIS spectra [2] and with radio occultation results [4] when reanalyzed with a reduced He mixing ratio and with a deep methane mixing ratio near 4%. But at high latitudes good spectral fits require methane to be depleted in the upper troposphere, suggesting a meridional flow with descending gas at high latitudes.

1. Introduction

Using most of the vertical cloud structure inferred by Karkoschka and Tomasko [2], but replacing their diffuse middle tropospheric haze layer with two compact layers, Sromovsky et al. [5] showed that the upper compact layer matched both the STIS spectra and the Voyager refractivity profile using a He volume mixing ratio (VMR) of 0.116 and a methane VMR near 4%. The alternative cloud structures of [2] and [5] are compared in Fig. 1 for 5° S. The putative methane cloud sheet near 1.2 bars has an optical thickness of about 0.3, and a particle radius near 1.2 μm, assuming conservative Mie scattering for this layer. The middle tropospheric cloud sheet near 1.7 bars has an optical depth of about 1.3, assuming the same scattering properties as assumed by [2] for their diffuse layer. This is the most prominent layer inferred from near-IR observations of [1], as indicated by the dashed line in Fig. 1. These two compact layers are well constrained by the spectral observations, but the compact deep layer we used is not well constrained, allowing optical depth and pressure to trade off over a wide range. The difference between the compact and diffuse cloud models becomes less apparent when their cumulative vertical optical depths are compared, as in Fig. 1B. The spectral observations alone cannot distinguish these options, but the compact version is a better match to the occultation results. The question addressed here is whether the compact layer structure is plausible at latitudes outside the region covered by the radio occultation (2-7° S).

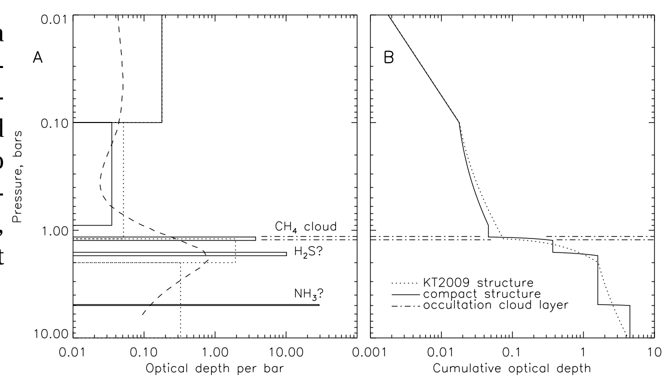

Figure 1: Optical depth per bar (A) and cumulative optical depth (B) for a vertically diffuse model (dotted) based on [2] and our compact layer model (solid) fit to a 5° S STIS spectrum using our F1 vertical profile of temperature and methane. The dashed line in A is the optical depth per bar at 1.6 μm from Fig. 5 of [1]. Figure adapted from [5].

2. Latitude dependence

The spectral observations we used are the calibrated spectral data cubes of [2], which were derived from Hubble Space Telescope observations made in 2002 at nearly zero phase angle. The center-to-limb scans at each wavelength at each latitude of interest were fit to a smoothly varying empirical function, which we then interpolated to the same set of zenith angle cosines (0.3, 0.4, 0.6, and 0.8), providing both spectral and angular constraints on the cloud band at each latitude. This yielded a reduced noise, as did our spectral averaging over a boxcar of 36 cm^{-1}.

Our attempts to fit STIS observations with the same methane vertical distribution and the same vertical temperature structure derived for the occultation latitude were very successful over a wide range of latitudes (20° N to 30° S), with little variation in the compact cloud model parameters except for a declining optical depth towards the northern hemisphere and little variation in the quality of the fits. The fit quality was measured by the overall χ^2 value for the entire spectral range from 0.55 to 1.0 μm, by the χ^2 value at 0.825 μm, which is where the collision-induced absorption of H_2 is prominent, and the linear fit error at 0.825 μm at a zenith angle cosine of 0.8 (for deepest penetration). But at higher southern latitudes overall fit quality and especially the fit quality near 0.825 μm both deteriorated dramatically as latitudes increased towards the south pole. To achieve a reasonable fit quality we needed to reduce the methane mixing ratio in the upper troposphere by a significant factor, confirming previous results of [2]. We tried to constrain the degree of depletion and depth of depletion using a variety of methane profiles. Those shown in Fig. 2 provided the best overall fits, though slightly different profiles, similar those suggested by [3], can also provide reasonable fits.

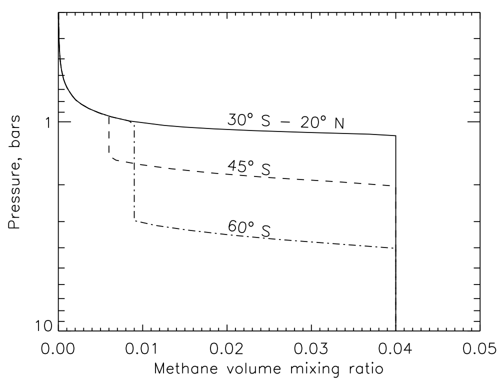

Figure 2: Methane profiles providing the best fits to STIS spectra at the indicated latitudes. Figure adapted from [5].

3. Summary and Conclusions

Although replacing the middle tropospheric cloud layer of [2] with two compact layers provides an enhanced capability to fit latitudinal variations in the vertical cloud structure, we still needed to reduce the upper tropospheric mixing ratio of methane by large factors to a depth of about 2 bars at 45° S and 3-4 bars at 60° S. This depletion suggests a meridional circulation illustrated in Fig. 3, in which methane-moist gas rising at low latitudes is dried out by the cold trap, where it forms a thin methane ice cloud. In this conceptual model the return flow involves descent of this dry gas at high latitudes, causing a local reduction in the methane mixing ratio to the depth of the descent.

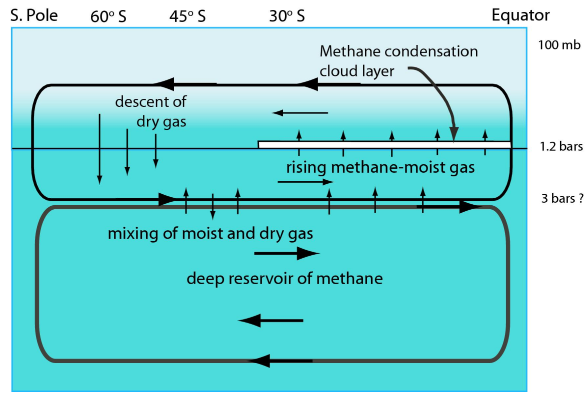

Figure 3: Schematic of methane depletion through condensation that dries ascending air at low latitudes, leading to depleted methane in descending regions at high latitudes. Figure adapted from [5].

Acknowledgements

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