MODELING THE STABILITY OF LIQUID METHANE ON TITAN. N. Chopra¹, E. G. Rivera-Valentin², A. Lupsay-Kuti³, and V. F. Chevrier², ¹Dept. of Astronomy, University of Wisconsin-Madison (nchopra2@wisc.edu), ²Arkansas Center for Space and Planetary Sciences, University of Arkansas.

Introduction: Recent studies have provided evidence for small radar dark patches on Titan suggesting scattered liquid bodies [1]. Confirmation of hydrocarbons, especially methane, in Titan’s atmosphere and on the surface as found by Huygens Probe [2] strongly suggests methane-based lake composition. Some studies have predicted a seasonal lake shoreline shift on Titan concurrent with a methane cycle [3]. In order to understand lake dynamics and replicate the seasonal cycle, we construct a coupled heat and mass transfer model and study the stability of pure liquid methane under Titan’s conditions.

Methods: We modeled a 1m² column of pure liquid methane that is not in direct contact with the regolith and has no lateral heat exchange. We assume the liquid methane column is vertically well mixed and use the basic construct by Rivera-Valentin et al.[3].

Heat Flux: The heat flux incident on Titan’s surface is dependent primarily on direct solar radiation and atmospheric thermal radiation [4]. Titan has a strong interplay between the greenhouse (21 K) and anti-greenhouse (9 K) effects causing its surface temperature to be 12 K higher than its effective temperature, but due to high pressure induced opacity of CH₄ and N₂, the atmospheric radiation, mainly the greenhouse effect, drives the incident surface heat flux on Titan [4]. We use the following equation set to calculate the heat flux absorbed by the surface.

\[ Q = I_{\text{sun}} (1 - A) \cos(z) f_{\text{surface}} \quad (1) \]

\[ Q_{\text{atm}} = \frac{1}{2} I_{\text{sun}} \cos(z) f_{\text{atm}} \quad (2) \]

where \( I_{\text{sun}} \) is the solar flux received at Saturn’s orbit, \( z \) is the zenith angle, \( f_{\text{surface}} \) is the fraction of insolation that reaches the surface [4], \( f_{\text{atm}} \) is the fraction of heat flux absorbed in the troposphere [4] and \( A \) is the albedo of the surface. We assumed the thermal properties of porous icy regolith. [5].

Evaporation Model: Under Titan’s atmospheric conditions, methane is buoyant and so its mass transfer will be analogous to free convection and should follow the form of Ingersoll’s equation, which has well described the sublimation of water-ice under Martian conditions [7]. We do however incorporate the thermal gradient existent above the sublimating species. The modified Ingersoll equation describing the mass transfer of a buoyant species is given by:

\[ J = 0.17D_{\text{CH}_4 / \text{N}_2} \Delta \eta \left( \frac{\Delta \rho}{\rho} \right) \left( \frac{g}{\nu^2} \right)^{1/3} \quad (3) \]

where \( D_{\text{CH}_4 / \text{N}_2} \) is the diffusion coefficient of CH₄ through N₂, \( \Delta \eta \) is the methane vapor density gradient between the surface and the ambient atmosphere, \( \Delta \rho/\rho \) is density difference ratio between the surface...

Fig 1: Experimental data by of methane’s saturation vapor pressure at Titan relevant temperatures versus a theoretical fit [8].

Fig 2: Ethane’s vapor pressure at low temperatures that are found on present day Titan is negligible. It would be therefore proper to assume that ethane drizzles down through Titan’s atmosphere but then becomes a permanent component on the surface.
and the atmosphere, and $\nu$ is the kinematic viscosity of the of N$_2$. The surface concentration condition is considered as the saturation vapor pressure of methane as shown in Fig 1, which is approximately linear function at the lower temperature (90 K-100 K) regimes of Titan. We do not consider the evaporation of ethane, which would not follow an Ingersoll diffusion since it is not buoyant under Titan atmospheric conditions, because of its low saturation vapor. As seen in Fig 2, at Titan temperatures, ethane's saturation vapor pressure approaches zero and thus is expected to be a permanent component of the surface [1].

Results and Discussion: Our heat transfer model was compared to data from the Cassini Composite Infrared Spectrometer (CIRS). Simulated temperature results are consistent with average surface temperature data except for at poles [6].

After verification, we used simulated temperatures as inputs to model evaporation of liquid methane. In order to get a complete picture of the amount of liquid methane evaporation on Titan, we calculated the evaporative flux at different latitudes in steps of 20°. It can be seen in Fig 4 that that evaporative cooling on Titan has minimal effect on mass flux from an evaporating column of liquid methane. This is indeed expected at lower temperature regimes. The evaporation rate near the equator is around 0.3 m at years end consistent with the lower limit provided by Mitri et al. [9].

Conclusion: On present day Titan, evaporative cooling is insignificant. This is a direct consequence of small daily temperature ranges that exist on Titan. Equitorial evaporation rate of 0.3 m at years end implies that in order for a methane lake to be stable at that latitude and for any shoreline variations to be observed, the lakes should be deeper than 0.3 m. Otherwise, total lake evaporation is expected. For a 1 m deep methane lake, the lifespan would approximately be 3.33 Titan years. This is expected to be sufficient for a seasonal methane cycle to sustain the lake.

In order to better simulate Titan conditions, we shall incorporate other physical processes that prevail on Titan (e.g. methane precipitation). This would allow us to apply our improved model in order to fully understand the evolution of Titan lakes.

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