HYDROCARBONS LAKES ON TITAN. Giuseppe Mitri[1], Jonathan I. Lunine[1,2], Adam P. Showman[1], [1]Lunar and Planetary Laboratory, University of Arizona. Tucson, USA (mitri@lpl.arizona.edu), [2]Istituto Nazionale di Astrofisica, Rome, Italy.

Introduction: Titan has a massive atmosphere with a pressure at surface level of ~1.5 bars. In the atmosphere the molecular nitrogen N_2 is the dominant constituent (~94 percent) and the methane CH_4 is the second most abundant component (~5 percent) [1]. The atmosphere of Titan is photochemically active with an efficient production of ethane, ethylene, acetylene and propane as minor components. At the present photolysis rate, methane mass in the atmosphere is photodissociated in $\sim 4 \cdot 10^7$ years [2]. During the Voyager mission, the hypothesis was advanced that large areas of Titan's surface would be covered by liquid hydrocarbons [2,3]. Since Cassini-Huygens indicates that such oceans are not present, the atmospheric methane abundance likely results from a recent outgassing episode from the interior [4]. If methane outgassing activity only supplies methane to the atmosphere, then we expect that the outgassing episode is $\leq 10^7$ years ago. On other hand, a large volcanic outburst of methane (for example $\sim 10^8$ years ago) could saturate the atmosphere. This would have led to formation of some small lakes. This reservoir would release methane into the atmosphere and allow atmospheric methane to exist to the present time.

The Descent Imager Spectral Radiometer (DISR) Experiment on the Huygens Probe does not show evidence of exposure of liquid at the landing site [5], but liquids are present just below the surface [1] and the surface science package accelerometry data admits either wet or dry surface materials [6]. Otherwise during the descent, DISR has shown networks of channels and valleys-like features that strongly suggest fluvial erosion processes of liquids (likely methane and ethane with dissolved nitrogen [7]). Cassini remote sensing (Radar and Cassini Imaging) highlight that network channels are common features on the surface [8,9]. The Cassini narrow-angle camera during the Titan flyby on the June 6, 2005 detected a dark area in the South Polar Region with smooth boundaries (~230 km per 70 km) that could be a dry lakebed or a lake of liquid hydrocarbons [8].

Clouds with two distinct morphologies have been detected on Titan. Near the South Pole are observed large storms. Clouds as spots are detected between -37° and -44° latitude and between 0°±90° and 90°±40° longitude [10]. These clouds suggest a correlation with surface processes [10].

In this paper we address two questions: (i) Are the observations of atmospheric methane relative humidity and thunderstorms/cloud frequency consistent with a "desert planet" containing only tiny fractional lake coverage? (ii) If any are observed, are hydrocarbon lakes stable on the surface of Titan?

Stability of hydrocarbons lakes: We determine the evaporation rate E [kg m^{-2} s^{-1}] of liquid methane and of a mixture of methane, ethane and nitrogen on the surface of Titan with the bulk aerodynamic method [11,12], using direct measurements of pressure, ground wind velocity, temperature-, air density- and humidity-profiles by Huygens instrumentations. The evaporation rate is given by [11,12]

$$E = \rho_{air} K \left(q^* - q \right) u_r \qquad (1)$$

where ρ_{air} is the density of the air (5 kg m^{-3}), K is the transport coefficient, q^* and q are the saturation specific humidity and the specific humidity respectively, and u_r is the horizontal component of the wind speed relative to the surface. We compute that, an atmospheric reference height of z_r = 1 m, the transfer coefficient K ~0.0013 for a liquid hydrocarbon body on the surface of Titan.

The evaporation rate on the surface of Titan depends on the wind speed, humidity, ground temperature, and composition of the hydrocarbon mixture. The density of liquid methane is of 453.4 kg m^{-3} and of liquid ethane is of 654.1 kg m^{-3} at a temperature of 92.5 K. The evaporation rate for the expected conditions at the Probe landing site of a pure liquid methane body is $0.8 \cdot 10^4$ kg m^{-2} yr^{-1} and of a mixture of methane (mole fraction 0.35), ethane (mole fraction 0.60) and nitrogen (mole fraction 0.05) is $1.8 \cdot 10^4$ kg m^{-2} yr^{-1}, for a wind velocity of 1 m s^{-1}, ground temperature of 93.7 K and a methane mole fraction in the atmosphere near the surface of $4.92 \cdot 10^{-2}$.

If a lake is present on the surface, the large evaporation of liquid hydrocarbons implies rapid changes of lake surface elevation (given by evaporation rate divided by density) of the order of ~20-40 m yr^{-1}. Therefore, the shorelines of a hydrocarbon lake on the surface of Titan must experience large changes over time. For example, for a slope of 10^{-2} (100 m elevation change over 10 km distance), lakes would retreat at up to several km yr^{-1}. This estimate is an upper limit, because rainfall into the lake's watershed will supply methane back into the lake, hence counteracting the hydrocarbon evaporation. On the other hand, if lakes cover only a small fractional area of Titan, then a large fraction of the methane may fall as rain outside the lake's watershed (for a watershed diameter of 100 km and a mean tropospheric horizontal wind speed of u ~1 m s^{-1}, for example, this only requires the lag between evaporation and rain formation to exceed 10^5 s). Presumably, if lakes are disappearing in some regions, they are appearing in others, so shorelines could be moving in either direction. The rapid shoreline changes predicted here suggest that repeat Cassini observations of putative lake-like features should be performed at intervals of a year or more: any shoreline changes would provide evidence that candidate lake-like features are actually lakes.

Clouds and Thunderstorms: Here we show that the observations of the atmospheric methane relative humidity and thunderstorm/cloud frequency are consistent with a "desert planet", containing only tiny fractional lake coverage. We consider that whole troposphere dynamically overturns on a time scale τ_{over}. Then, the globally averaged vertical flux is given by $\dot{M} \sim p/g\tau_{over}$, where p is the atmospheric pressure and g is the gravity. The globally averaged vertical flux of methane is $\dot{M}_{CH_4} \sim EA$, where A is the fractional area of Titan covered by lakes (defined as any area where methane can rapidly evaporate from the surface). The ratio between $\dot{M}_{CH_4}$ and $\dot{M}$ is, approximately, q. We find

$$q \sim q^* \left[1 + \frac{p}{\rho_{air} K u A \tau_{over}} \right]^{-1} \sim q^* \left[1 + \frac{0.05}{A} \left(\frac{10 yr}{\tau_{over}} \right) \right]^{-1} \qquad (2)$$

where the numerical estimate on the right uses $\rho_{air} = 5$ kg m^{-3}, $u = 1$ m s^{-1}, $g = 1.35$ m s^{-1}, and $K = 0.0013$.

Equation (2) gives the relationship between the relative humidity and the fractional lake coverage. Large relative humidities can be accommodated by small fractional lake coverage. For tropospheric overturning timescales of ~10 – 100 yr, a 50% relative humidity can result from evaporation from lakes covering only 0.004 – 0.04 of the surface. On other hand, if we consider that are not present lakes on the surface ($A = 0$), then the specific humidity $q = 0$ and, with our model, we cannot explain the observed high humidity on the surface of Titan.

The existence of very few lakes is consistent with a nearly saturated atmosphere with convective cloud activity. From a geomorphic prospective, convective clouds can cause occasional intense rain and flash flooding, which would produce erosional features despite the fact that not much of the surface is covered with liquid. The energetics of such storms have been considered elsewhere [14].

Surface/atmosphere interactions: Lakes and Volcanoes: It has been suggested recently [13] that observed convective clouds might come from the outgassing of methane volcanoes. To explain the atmospheric methane abundance, it is only necessary that the total atmospheric methane reservoir was erupted within the last 10^7 yr. For a current atmospheric methane column abundance of 6000 kg m^{-2}, the required methane volcanic outgassing rate is only $6 \cdot 10^{-4}$ kg m^{-2} yr^{-1}. The evaporation rate from a lake is $1 - 2 \cdot 10^4$ kg m^{-2} yr^{-1}. Therefore, the volcanic outgassing required to explain the atmospheric methane reservoir is equivalent to lake evaporation if lakes cover only $10^{-7} - 10^{-8}$ of Titan's surface. Stated another way, even only 0.1% of Titan is covered by lakes, the lake evaporation would exceed the required volcanic outgassing by a factor $10^4 - 10^5$. This would translate directly into the relative probability of thunderstorms from the two sources: for every $10^4 - 10^5$ thunderstorms caused by evaporation of methane from lakes, only one thunderstorm can be expected to result from a volcanic methane outgassing. If any surface control on thunderstorms exists (as emphasized by both Roe et al. [2005] and Griffith et al. [2005]), then it is much more likely to result from local surface/atmosphere interactions than from volcanism. Evaporation from locally confined lakes would be a prime candidate.

Conclusions: We have demonstrated that the high relative humidity of ~50% on the surface of Titan can result from lakes evaporation covering only 0.004 – 0.04 of the whole surface. Even if only a small value of the surface of Titan is covered by hydrocarbons lakes, the atmosphere is nearly saturated and, therefore, can generated thunderstorms. Repeat observations of regions where candidate lake features have been seen by Cassini would be of high value during the prime mission but (especially) over an extended mission that would permit a 6 year or longer time baseline.

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