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RAINDROPS ON TITAN

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ABSTRACT

Some of the aspects of methane precipitation on Titan are considered. In particular, descent velocities are computed. It is found that raindrops fall much slower than on Earth. Additionally, the maximum size of raindrops on Titan is over 9mm, compared with under 6mm on Earth. The composition of drops will vary with altitude. Implications of these properties for Titan and the Huygens mission are considered.

INTRODUCTION

Titan's clouds and aerosols have been the focus of considerable scientific activity in recent years. The photochemical haze at high altitude has been the subject of much work in the past, but more recently there has been investigation of the possibly thick clouds in the troposphere, and the potential presence of precipitation. This paper explores some of the aspects of precipitation on Titan, and rain in particular.

It is interesting to note that the discoverer of Titan, Christiaan Huygens, considered that clouds and liquid (and by implication, rain) should be present on other planets:

> *"But since 'tis certain that the Earth and Jupiter have their Water and Clouds, there is no reason why the other Planets should be without them. I can't say that they are exactly of the same nature with our Water; but that they should be liquid their use requires, as their beauty does that they be clear. For this Water of ours, in Jupiter or Saturn, would be frozen up instantly by reason of the vast distance of the Sun. Every Planet therefore must have its Waters of such a temper, as to be proportion'd to its heat: Jupiter's and Saturn's must be of such a nature as not to be liable to Frost..."* /1/

CLOUDS AND PRECIPITATION ON TITAN

Titan as seen from the Earth or the Voyager spacecraft is featureless as a result of the thick haze in the atmosphere. No individual clouds (or surface features) can be seen. However, Toon et al. /2/ have noted that IR spectral fits can be improved by considering the effects of tropospheric methane clouds with large droplets. The presence of clouds implies the possibility of precipitation, but precipitation may be very different from that on Earth owing to the differing physical conditions on Titan (see Table 1)

	Earth (0km)	Titan (0km)	Titan (40km)
Gravitational Acceleration (ms^{-2})	9.81	1.35	1.31
Atmospheric Density (kgm^{-3})	1.23	5.3	0.7
Raindrop Liquid Density (kgm^{-3})	1000	600 (?)	600 (?)
Atmospheric Temperature (K)	278	94	72
Atmospheric Viscosity (Pa-s)	1.8×10^{-5}	8.2×10^{-6}	6.9×10^{-6}
Raindrop surface Tension (Nm^{-1})	0.073	0.017 (?)	0.017 (?)

TABLE 1. Parameters for Raindrop Physics

It is believed /3,4,5,6/ that the lapse rate, as measured by the Voyager 1 radio-occultation experiment, rules out the presence of clouds below about 5km. Clouds above about 35km are unlikely since this would imply that the methane concentration in the atmosphere increases with altitude, at odds with the expected stratospheric photochemical depletion of methane.

Because nitrogen (the dominant atmospheric constituent) is fairly soluble in liquid methane, and the equatorial temperature varies throughout the troposphere from about 94K at the surface to about 72K at the 40km tropopause, the equilibrium composition of droplets varies with altitude /5,7/ with a maximum N_2 liquid fraction of about 25%

Above an altitude of 14km (a pressure of 700 mbar), the equilibrium state of the CH_4-N_2 mix is solid, so any droplets should freeze /5/. Since the number of nucleation centres for freezing may be limited, clouds of supercooled droplets are also possible (as found on Earth). Descent of the Huygens probe through such clouds could lead to the deposition of some methane ice on the probe as it descends through the clouds. Some slight degradation of scientific measurements may occur as a result, although as the probe descends into the warmer lower troposphere, the ice should melt and fall off long before the probe reaches the surface/8/.

Unlike water, methane will contract on freezing, so (barring the formation of delicate crystal structures like terrestrial snow,) one might expect frozen precipitation to fall faster than the original liquid droplets. However, freezing of a methane-nitrogen drop would be accompanied /5/ by an exsolution of a fraction of the dissolved nitrogen - perhaps the associated bubbling or frothing might cause the frozen droplet to be porous, or even break apart.

COMPOSITION OF DROPLETS

It has been argued /5/ that vertical motion of rain droplets on Titan will be detected by the instrumentation on the Huygens probe by virtue of the fact that the precipitation will not be in equilibrium with its surroundings as it descends (since the liquid phase equilibrium nitrogen concentration increases with altitude.) This suggests one such technique might be measurement of refractive index: the Surface Science Package (SSP) being developed at University of Kent includes a refractometer which is intended to measure the refractive index (and hence infer composition) of the hypothesized Titanian ocean. This device, based on total internal reflection from a curved prism /9/, is able to detect even a thin fim of liquid on its surface, such as would be deposited as the probe descended through clouds or rain.

However, it has been shown /10/ that falling raindrops on earth posess well-developed internal circulation (a ring vortex) such that the internal composition should be well-mixed (internal equatorial velocities are about 1 per cent of the terminal velocity of the drop, so droplets will turn themselves 'inside out' within a few seconds.) Further, measurements in a NASA study to determine the suitability of nitrogen as a pressurant for liquid methane fuel systems on advanced aircraft /11/ found that the rate of solution of nitrogen in methane was very high. Thus we would expect any precipitation to rapidly attain equilibrium composition with its surroundings. The thick atmosphere and low gravity conspire to give droplets very low descent speeds (see later), such that droplets have plenty of time to attain equilibrium. Hence, any precipitation or cloud droplets deposited on the SSP refractometer are likely to be of a composition in equilibrium with that of the surrounding atmosphere.

TERMINAL DESCENT VELOCITIES

A first step in considering cloud physics (convection required to support clouds, droplet collision and growth rates, evaporation of droplets etc.) is to calculate the terminal descent velocity of drops on Titan. Tables of such speeds for terrestrial raindrops are available from experimental data. For Titan, the author has created a model /8/ which takes into account the differing gravitational acceleration on Titan, the different atmospheric viscosity and density, and the different raindrop fluid density and surface tension (see table 1). Note that raindrops larger than about 0.2 mm fall too quickly (at Reynolds numbers too high) for Stokes' Law to be valid, so this model takes into account the variation of drag coefficient with Reynolds number. Additionally, for larger droplets, the terminal velocity can only be reasonably predicted by taking into account the flattening of the droplet (caused by a balance between aerodynamic and surface tension forces.) This model accurately predicts terrestrial descent velocities over the full raindrop size range. Applying parameters for Titan to the model, we obtain the results given in figure 1. It is seen that drops on Titan fall considerably slower than their terrestrial counterparts.

Toon et al. /2/ suggested that Titanian droplets would break up beyond sizes of 3mm. The maximum size of a drop on Earth (6mm) is reached when the Weber Number (a ratio of aerodynamic to surface forces) equals 4 (corresponding to a flattening of the droplet to a height-to-diameter ratio of about 0.6.) Applying this condition to the Titan model suggests that Titan droplets should remain intact up to diameters of 10mm or so (although whether such droplets would be able to grow to such a size is of course another question.)

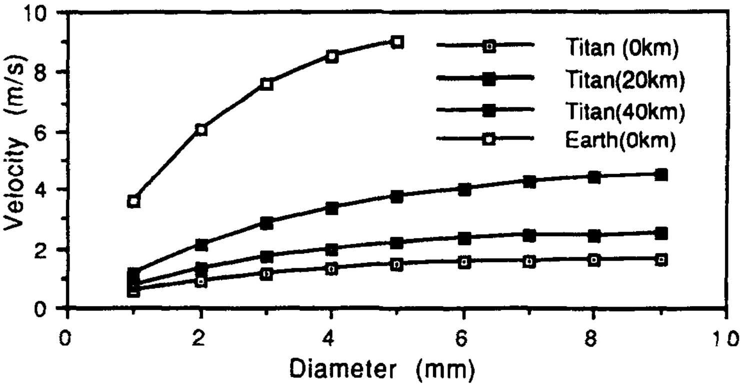

Figure 1 : Terminal Descent Velocities of Raindrops

Despite the large potential size of raindrops, the comparatively low descent speed of droplets suggests that erosion due to rain is not a significant weathering process on Titan (unless rainfall is extremely frequent.). Mechanical effects of droplet impingement scale with the impact pressure, which varies as the square of velocity. Since the descent rates for even the largest droplets are one fifth of raindrops on Earth, impact pressures will be one-and-a-half orders of magnitude lower.

Further, assertions /12/ that water ice (the most likely 'bedrock' on Titan's surface) could be heavily eroded by surface flows were based on measurements of anomalously high solubility (of order 10^{-5}) of water ice in cryogenic fluids /13/). These measurements have been subsequently shown to be in error (infra-red absorption, originally attributed to water dissolved in methane and nitrogen, was later found to have been due to sidebands of carbon dioxide absorption). Later experimental data shows (in accordance with theory, noting the non-polarity of methane as a solvent) that water solubility in cryogens like methane and nitrogen is less than 10^{-8} /14/.

It must be noted that during their fall through the undersaturated lower atmosphere, droplets will slowly evaporate. Drop evaporation is usually calculated by assuming diffusive heat and mass transport augmented by an emipirical factor to take into account the ventilation of the drop by the relative motion of the atmosphere as the drop falls /15/. As a drop evaporates, it shrinks, such that the rate of evaporation also falls. However, the terminal descent velocity also reduces in magnitude. Evaporation rate increases with higher temperature and lower humidity. A terrestrial raindrop can descend through several kilometres of even 25% saturated air, largely by virtue of its high descent velocity. Initial calculations suggest that for teh nominal atmospheric model (based on radio-occultation measurements at the equator) a 9mm raindrop on Titan will completely evaporate in a descent of 3km or so in an atmosphere 70% saturated (compare this distance with the expected lower clouddeck altitude of 3-5 km.) Thus, at the equator, only elevated terrain should be washed by rainfall. Near the poles, where the atmosphere may be cooler, rainfall down to the surface may be more frequent. Griffith et al./6/ have suggested that in places rainfall may wash dark organic material (photochemical aerosol) from the brighter icy surface, accounting for the near-IR albedo of Titan being higher than that of organic material.

CONCLUSIONS

Raindrops on Titan fall slower, and could possibly be somehat larger, than their terrestrial counterparts.

The descent rates of droplets are slow, and the rate of solution of nitrogen in droplets is high, such that droplets should be at equilibrium with the surrounding atmosphere. It will not, therefore, be possible to detect the vertical movement of droplets by measuring their composition alone.

In the absence of strong surface winds, rainfall is probably a comparatively weak agent of geomorphological evolution on Titan, as a result of the gentle fall of Titanian rainfall and the weak solubility of the ice bedrock in it.

The rate of evaporation of pure methane raindrops, combined with their low descent velocities, is such that for expected values of methane humidity (70%) even large drops cannot descend through large vertical distances before evaporating. Thus how (or indeed, whether) precipitation can penetrate to the surface is a question for future work. Dissolved ethane and possibly other solutes will doubtless play a major role. The sensitivity of evaporation rate to relative humidity and temperature should be investigated as there may be a consequent latitudinal variation in the frequency and severity of rainfall.

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