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Titan's Aerosols and Wave Damping on Seas

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Titan, the enigmatic large moon of Saturn, is the unique satellite of the solar system surrounded by a dense atmosphere. Thick layers of photochemical organic aerosols shroud the surface, and particles sediment to the ground. In polar regions, large lakes and seas of liquid hydrocarbons have been discovered by *Cassini/Huygens* mission. Together with other atmospheric products like large molecules and "organic snows", haze aerosols particles sediment above the Titan's seas region. These materials run into liquid bodies where they can form floating slicks. This scenario is discussed and we show that a deposited layer, floating at a marine surface may have major consequences, particularly on the wave formation. Titan's hydrocarbons seas appear as a place much more favorable to wave damping, due to the presence of a slick, than Earth ocean, where such a phenomenon is observed. This properties is compared to *Cassini* radar observations, which have revealed surprisingly smooth ocean surfaces.

1. Introduction

Titan, the main satellite of Saturn, is the only satellite of the solar system possessing a dense atmosphere, which ground pressure is comparable to that of the Earth. However, the most striking feature of Titan is perhaps the presence, in its atmosphere, of a thick layer of haze. The *Voyager* and *Cassini/Huygens* missions have inspired many works focused on aerosols distribution and properties, and now a vast literature is available on this topic [for a review, see for instance: 18].

Beside this, the Cassini orbiter instruments have revealed a collection of dark features dotting the polar regions of Titan [13, 16]. These geomorphological characteristics are interpreted as lakes or seas (depending on their size) of liquid hydrocarbons. These structures were found at both poles and involve diameters up to more than thousand kilometers. Since organic material produced in the atmosphere should be the subject of sedimentation to surface, and could form large depositions [10], the question of the interactions between the haze particles, large molecules or "organic snowflakes", and the liquid hydrocarbon surface, emerges naturally. To understand the fate of these materials at the surface of Titan's lakes, a first parameter to be investigated is their floatability.

2. Nature of Material that can be Deposit on Titan's Seas Surface

Observations show the presence of a more or less uniform layer of haze over the entire Titan's globe. This haze has its origin in the photochemistry initiated by solar radiations. The end-products of these processes are recognized to be aggregates of organic material [8]. Each haze particles is built by aggregation of small entities called "monomers", which, if considered to be spherical, have a radius around 50 nm [12, 14]. One aggregate, containing several thousand monomers, has a fractal structure [8]. Due to their fluffy structure, haze particles are coupled with the atmospheric gas, but Global Circulation Models (GCM) predict the sedimentation of dry aerosols, corresponding of about 3.3×10^{-7} m per Titan year, uniformly distributed over Titan's surface. In the case of dry aerosols, the sedimentation rate changes with latitude, reaching maxima of $\sim 10^{-5}$ m within a few degrees from poles. In addition to these particles, formed at high altitude, other "exotic snows" may be produced in the troposphere. Indeed, many organic simple species are formed by stratosphere, for instance HCN, C_2H_2, C_4H_{10}, C_6H_6, ... [7] and may form crystals that could aggregate in the form of "snow grains" when falling in the troposphere. In this context, HCN is a good candidate since its production rate seems to be comparable to that of haze aerosols. Finally, *Cassini* instruments detected molecules in Titan's thermosphere, with large charge/mass ratios up to 10,000 [17]. In addition, the presence of polycyclic aromatic hydrocarbons above an altitude of ~ 900 km has also been suggested [9].

In summary, if a marine slick can be formed: it can be composed by haze aerosols, exotic cryo-snows and/or large "surfactant" molecules.

3. The Floatability of Titan's Aerosols

Two distinct effects may be invoked when the floatability of an object is questioned: (1) the Archimedes' buoyancy, (2) the effect of surface tension. The first mentioned effect requires estimations for both aerosol monomers and Titan's seas liquid densities. The second one demands some knowledge about the monomers density and also data concerning the values of surface tension and contact angles. For a long time, the monomers are recognized to be formed by molecules harboring a large number of carbon atoms [11]. A few articles report density measurements on Titan's aerosols laboratory analogs, the tholins produced during laboratory experiments. The bulk mass density of these analogues is around $1.3 - 1.4$ g cm^{-3}, so more than thousand kg m^{-3} [15, 6, 5, 1], but, determinations around 0.4 g cm^{-3} have been also found. As a consequence, according to these first considerations, the majority of aerosols should sink to the depths of Titan's seas, while a small part could remains at the surface since the liquid has a density in the range $0.5 - 0.8$ g cm^{-3}.

It is well known that small bodies heavier than the supporting liquid, including small objects made of iron, can float under the influence of the so-called capillary force. Even some animals, bugs of the family of the *Gerridae* (water striders) take advantage of this kind of force to survive at the surface of water [3]. We now discuss a possible Titan's aerosols flotability driven by cryogenic liquid surface tension. We were able to determine the maximum thickness e of the aerosols layers that can be hold by sea surface

$$e \sim \frac{3\,\sigma\,|\cos\theta_c|}{r\,g_{\mathrm{Tit}}\,\rho_{\mathrm{mono}}} \qquad (1)$$

where σ is the surface tension of the liquid, r the radius of monomers, g_{Tit} the Titan's ground gravity, ρ_{mono} the density of monomers and θ_c the contact angle. Surprisingly, this result does not depend on the "porosity" of the aerosols. For perfectly non-wetting particles (*i.e.* $\theta_c \simeq 180^{o}$), numerical estimate can be obtained for e, assuming typical values for involved physical quantities. Namely, we fixed the surface tension σ to 2×10^{-2} N m^{-1}, the real value depends on the precise chemical composition of the liquid, but should be around the nitrogen value. For the density of monomer material we choose 800 kg m^{-3}, value between the density of liquid methane and that of liquid water. The Titan's surface gravity is well known and equals 1.352 m s^{-2}. All this yields to $e \sim 10^3$ m, such an extremely large value, compared to the size of a monomer or even of an aerosol particle, means that the physical process, limiting the thickness of a possible aerosols slick, is not included in this crude estimation. Two major limiting effects have been identified: (1) the value of the contact angle θ_c, (2) the production rate of organic aerosols. Even if the contact angle of organic material, produced by atmosphere chemistry, is not well known, if not unknown, the poor solubility of tholins (and other species relevant in Titan's context) suggested a weak wettability of a part of matter sedimenting to the ground.

4. Influence of a Floating Slick on Wave Generation

As demonstrated in [2] the presence of a floating slick over a Titan's sea has a strong damping effect on waves. This effect, can reduce the wave amplitude by one or two order of magnitude. Even if the deposited layer has only a monomolecular thickness (due to "surfactant" molecules) the damping effect can be significant. This property can explain the surprisingly smooth sea surfaces observed by *Cassini* [19, 20, 4].

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