

Cloud-Aerosol and Cloud-Lake Interactions on Titan. Xinting Yu¹, Yue Yu¹, Julia Garver², Xi Zhang¹,

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Introduction: Titan's nitrogen-methane atmosphere has enabled rich photochemistry to occur in its upper atmosphere. The photochemistry can create simple hydrocarbons such as ethane, ethylene, acetylene, benzene, and nitrogen-incorporated organics such as hydrogen cyanide, and cyanoacetylene, etc (Horst, 2017). These simple organics are further processed to form complex organic haze particles that can grow up to ~ 1 μm before they reach the surface (Tomasko et al., 2005). Methane and many of the photochemically produced simple organics are condensable in certain altitudes of Titan's atmosphere to form clouds. Cassini has observed clouds made of various compositions, including methane, ethane, hydrogen cyanide (HCN), cyanoacetylene (HC_3N), dicyanoacetylene (C_4N_2) (e.g., Anderson et al., 2018). In order to form sufficient observable clouds, heterogenous nucleation is needed for efficient cloud growth. On Earth, water can efficiently nucleate on various species including sea salt, mineral dust, biological debris, anthropogenic aerosols and form clouds. On Titan, the complex organic hazes are proposed to be the main heterogenous cloud condensation nuclei (CCN) for the observed cloud species (e.g., Griffith et al., 2006).

Curtis et al., (2008) studied the adsorption of methane and ethane on the laboratory produced Titan haze analogs, "tholin", and found that tholin can serve as good cloud seeds for methane and ethane clouds on Titan. However, the viability of other kinds of cloud growth on the haze particles has not been studied yet. Laboratory experiments require low temperature nucleation experiments of these hydrocarbon liquids and can be difficult to perform. We approach this question in a different way by first measuring the surface energy (γ_s) of Titan aerosol analogs "tholin" (Yu et al., 2017, 2020), which can then enable us to theoretically predict the haze-cloud interactions in Titan's atmosphere. By using the surface energy of tholin (γ_s) and surface tensions (γ_l) of various organic species of interest, we can calculate contact angles (θ) between the possible liquid condensates and tholin. This could help us estimate whether haze particles can be good CCN for a certain liquid on Titan. A contact angle study between the cloud-coated aerosol particles and Titan's lake liquids could also inform us on the interaction of the haze and liquid species in Titan's lake. Cordier & Carrasco (2019) suggests the possibility a floating layer of sedimented haze material on Titan's lake surface that can potentially dampen the surface waves, while Yu et al.,

(2020) suggests this scenario is unlikely to happen for the aerosols. However, we would like to test here if cloud-coated aerosols can float on Titan's lakes.

Methods: With the known surface energy of two substances, we can use the wetting theory to estimate the contact angle formed between the two materials (Owens & Wendt, 1969). The surface energy of Titan's haze analogs, "tholin" are measured previously with both the contact angle and the direct force measurements (Yu et al., 2017, 2020). Most cloud condensates in Titan's atmosphere will condensate directly from the gas phase to the solid phase, so even though their surface tensions for the liquid phase are known, we have to estimate their solid surface energy with their latent heat of sublimation and vaporation using the methods described in Guez et al., (1997). Titan lakes contains three main liquid components: nitrogen, methane, and ethane, and here the contact angles will be estimated using the surface tensions of these three end member components.

Results and Discussion:

Cloud condensates-aerosol interactions. We calculated the contact angles between possible organics condensates and Titan's aerosols using tholin made with cold plasma as the analog material. We found lots of cloud condensates would completely wet the tholin surface (see Table 1). Tholin is hardly soluble in most non-polar hydrocarbon liquids (e.g., He & Smith, 2014), which indicate the Titan haze particles may not be the most ideal cloud condensation nuclei (CCN). But insoluble particles could still serve as CCN if the solid-liquid contact angle is less than 30° (e.g., Mahata & Alofs, 1975) which is the case between tholin and most cloud condensates on Titan. Thus, we suggest that Titan haze particles are likely good cloud seeds for most cloud condensates on Titan.

Table 1: Calculated contact angle between possible cloud condensates and tholin made with cold plasma (Yu et al., 2020). Literature contact angle is from Rannou et al., (2019) for tholin produced in another laboratory.

Species	θ this work	θ literature
Methane (CH_4)	0°	6.3°
Ethane (C_2H_6)	0°	15.0°
Acetylene (C_2H_2)	19.4°	n/a
Ethylene (C_2H_4)	35.8°	

Propane (C ₃ H ₈)	0°	
Diacetylene (C ₄ H ₂)	0°	
Benzene (C ₆ H ₆)	42.7°	
Cyanogen (C ₂ N ₂)	31.5°	
Hydrogen cyanide (HCN)	0°	

Cloud condensates-aerosol interactions. We also calculated the contact angle formed between the cloud-coated aerosols and the lake liquids. Note that a few cloud condensates would turn into liquid form before they reach to the surface, including: methane, ethane, propane, ethylene. For the rest of the cloud condensates that are able to remain in their solid form before they fall towards the lakes, using three lake liquid end members, we found that most of them would be completed wet by the lake liquids end members. Liquid ethane has the largest surface tension among the three lake liquid end members, so it would likely form the largest contact angle with the cloud condensates. And the only cloud species that has a non-zero contact angle is hydrogen cyanide (HCN) with liquid ethane. Based on force balance between the capillary force and gravity, if the cloud-coated aerosols are denser than the lake liquids, a non-zero contact angle would mean the substance would likely float on the lakes (Yu et al., 2020). Thus, it is possible to have solid HCN ices floating on ethane-dominated Titan's lakes.

Table 2: Calculated contact angle between lake liquid end members and cloud condensates.

Species	θ with L-N ₂	θ with L-CH ₄	θ with L-C ₂ H ₆
Acetylene (C ₂ H ₂)	0°	0°	0°
Diacetylene (C ₄ H ₂)	0°	0°	0°
Benzene (C ₆ H ₆)	0°	0°	0°
Cyanogen (C ₂ N ₂)	0°	0°	0°
Hydrogen cyanide (HCN)	0°	0°	38.4°

Conclusion and future work:

With the surface energy of tholin, we estimated the contact angle between a list of organic condensates on Titan and tholin and found that most cloud condensates have small contact angles with tholin ($\theta < 30^\circ$). This indicates that the Titan haze particles are likely good cloud condensation nuclei for most condensable species on Titan. While when the cloud-coated haze particle sediment towards Titan's surface, and reach the lakes, most of the cloud-coated aerosols would likely sink into the lakes, except HCN clouds on a ethane-dominated lakes.

In the future, we would like to look for observational evidences for floating HCN particles on the surface of Titan's lakes.

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