Determining physical properties of Titan's empty lake basins through radar backscatter modeling.

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Abstract: We use repeat SAR observations to study the scattering properties of Titan's paleo-lake basins. The best-fit coefficients to standard quasi-specular plus diffuse backscatter models show that the bright basin floors have a higher dielectric constant, but similar RMS surface roughness, to surrounding terrain. This suggests that floor deposits are compositionally distinct to their surroundings, consistent with the interpretation that these basins are partially filled with evaporitic deposits, as previously suggested by their relative brightness at mid-infrared wavelengths**.** The basin floor deposits also express a larger diffuse component to their backscatter, suggesting variations in subsurface structure causing increased volume scattering.

Background: Surface conditions on Titan occur over a temperature and pressure range near the triple-point of methane, potentially allowing solid, gaseous, and liquid phases to co-exist. On Titan, methane and ethane act like water on Earth; raining out of the atmosphere, carving channels, and forming lakes in polar basins [1]. Observed lacustrine features on Titan are found in varying states of liquid fill (Figure 1) [2]. The dark features are interpreted as lakes and/or seas of liquid methane and ethane. Bright features of similar plan-view morphologic expression to the filled lakes, which are found to be hundreds of meter deep depressions and compositionally distinct from surrounding terrain, are interpreted as empty paleo-lake basins that are potentially filled with evaporitic deposits [2,3]. Lacustrine features of intermediate brightness, which are above the noise floor of the Cassini RADAR instrument but still dark relative to their surroundings, are interpreted as either shallow lakes that are penetrable by radar or saturated regolith.

While the larger Mare (Ligeia, Kraken and Punga) have fluvial networks flowing into them, the smaller lakes are not associated with any obvious surface drainage at the ~300 m resolution of Synthetic Aperture Radar (SAR) images [2]. In the absence of surface drainage, these lakes either interact directly with the atmosphere or have sub-surface drainage networks linked to an underground alkinofer [2]. If lacustrine features exhibit significant exchange of liquids either through surface run-off, evaporation or sub-surface infiltration, then their evolution may be observable and leave traces behind such as evaporitic or sedimentary deposits. Furthermore, if the liquid inputs of a lake are in disequilibrium with its outputs, we can expect the lake to evolve over time. The interpretation of intermediate brightness lakes as shallow and bright lakes as evaporated lake depressions suggests that the shallow lakes may be a transitional morphology as dark lakes evolve into empty lakes and vise-versa. Analysis of SAR backscatter curves of south polar lakes has supported the conclusion that observed differences in some small southern lake features are consistent with temporal variability of the liquid level [4]. Observations of the north polar region, however, have so far shown no unambiguous changes in lake level [4]. Systematic variability (as a function of observational geometry) in the backscatter of lacustrine features in both hemispheres, however, have suggested compositional and/or structural differences between the lake basins and their surrounding terrain [1,4]. These differences are the focus of this work.

Methods: The Cassini Mission's entrance into its second extended mission has resulted in repeat SAR coverage of several areas of Titan's north polar region, which in some locations have been observed up to seven times. In addition to providing temporal coverage, these observations represent an opportunity to analyze the scattering properties of lacustrine features at varying incidence angles. The T86 swath for example, which was acquired on 09/27/12, contains partial overlap with swaths T28 (04/10/07) and T29 (04/26/07) and was acquired as significantly larger incidence (~50° in T86 vs. ~20° in T28/T29). The overlap of these three swaths is particularly interesting because it contains an area of concentrated partially-filled and empty lakes. The SAR returns of the lacustrine features in T86 are remarkably different from those of T28 and T29. These differences can be used to discern the relative variation in the physical properties of lacustrine features as compared to their surrounding terrain.

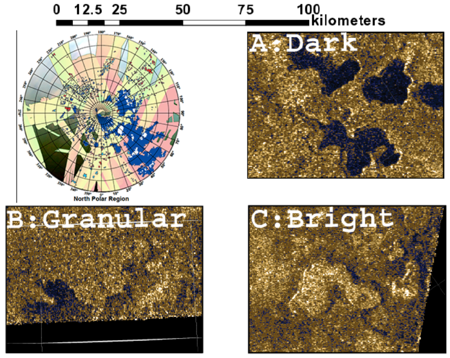
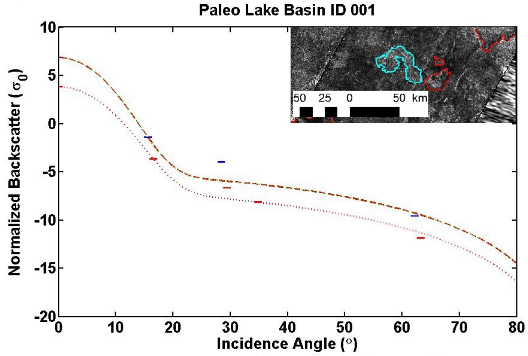


Figure 1: Examples of the three lake classes observed on Titan. A: Dark features are interpreted as liquid-hydrocarbon filled lakes. B: Granular features, are interpreted as a continuum between saturated regolith and partially-filled lakes. C: Bright lakes are interpreted as empty basins. Adapted from [2].

Herein we take advantage of the repeat RADAR coverage of Titan's polar terrain to study the backscatter properties of the bright empty paleo-lake basins. SAR images have the highest resolution of all operational modes (up to ~250 m/pixel). However, SAR imaging is typically restricted to a fairly narrow range of incidence angles [5]. By combining SAR with HiSAR and closest-approach altimetry, a wide range of viewing geometries can be investigated (scattering angles of ~0°-50°) for specific lacustrine features at spatial scales of a few km.

The bright paleo-lake basins have the highest backscatter returns of all lacustrine features and are interpreted as 200-300 m depressions consistent with previously filled lakes [1]. The bright returns from the floor deposits in these features are interpreted by [3] as evaporite based on their relative brightness at 5 um. Additionally, it was recently shown that while the relative depths of empty lake basins vary over a range of several hundred meters, the absolute floor elevations of north polar empty lakes are clustered around the elevation of Mare shorelines [6]. While prior investigations have pointed out the unique scattering properties of empty lake basins by comparing off-axis SAR to nadir-pointed altimetry [1] for one empty lakes feature, we expand upon previous work by investigating multiple features with multiple overlapping datasets, permitting quantitative assessment of their scattering properties.

The Cassini RADAR's ability to infer physical and compositional properties of observed features on Titan is dependent upon knowledge of different scattering models frequently employed in radar and planetary science. For solid surfaces, RADAR backscatter is typically modeled using a quasi-specular facet model, which models the surface as a series of planar facets oriented at varying angles with respect to the normal of a perfectly smooth surface. Each facet produces a coherent reflection, and these reflections sum to the specific radar cross section (σ_0, defined as the area of an isotropic scatter normal to incidence required to yield the observed RADAR echo intensity, normalized by the actual surface area of the region of interest) [9],[10]. Quasi-specular models relating σ_0 to the angle of incidence, θ, have been successfully used to infer the surface properties of terrestrial planets (Mercury, Venus, Earth, Mars, and the Moon) [see, for example, 10]. On Titan, the transparent properties of water-ice and hydrocarbon solids necessitate the addition of a diffuse term to allow for subsurface volume scattering [9]. In this study, we have fit observed backscatter to quasi-specular plus diffuse models that use Hagfors, Gaussian, and Exponential quasi-specular terms and a $\cos^n$ diffuse term as in [9]. Our models are dependent upon the surface dielectric constant, surface RMS facet angle (i.e., roughness), and amplitude of the diffuse term. We use a Levenberg-Marquadt least squares minimization to find the best-fit model coefficients for the bright paleo-lake basins and their immediate surrounding terrain (Figure 2).



Gaussian
Dielectric Constant=4.8693,
error=3.0956-6.6431
Surface RMS Angle=10.0132,
error=8.0079-12.0185
A=0.29929,
error=0.1891-0.4095

Gaussian of Surroundings
Dielectric Constant=3.2543,
error=
2.8972-3.6114
Surface RMS Angle=10.909,
error=9.9930-11.8250
A=0.19461,
error=0.1694-0.2198

Figure 2: Example scattering curves and best-fit model coefficients for empty lake feature 001 and its surroundings. The Gaussian, Hagfors, and Exponential models all predict a higher dielectric constant and diffuse term for the feature with respect to its surroundings, and comparable RMS angles.

Results: Results from modeling 7 features suggest that the empty lake basins have a higher dielectric constant than their surroundings, but a similar RMS angle to within error (68% CI). This is true regardless of which quasi-specular model (Hagfors, Gaussian, or Exponential) is used to fit the observations. Additionally, all three models predict a higher diffuse amplitude for the basins than the surroundings, suggesting either an increased subsurface volume scattering component or increased small-scale roughness (wavelength-scale as opposed the facet-scale). Future work will focus on spreading the above-mentioned methods to all paleo-lake basins that have been imaged with SAR sufficiently to allow the derivation of model coefficients. These results will help to constrain the physical properties and formation mechanisms of the paleo-lake basins, and provide insight into their role in Titan's surface processes.

References: [1] Stofan et al. (2007), *Nature*, 445. [2] Hayes A. G. et. al. (2008) *GRL, 35.* [3] Barnes J. W. et. al. (2011) *Icarus, 216.* [4] Hayes A. G. et al. (2011) *Icarus, 211.* [5] Elachi et al. (2004) *Space Sci. Rev., 115* [6] Hayes A. G. et al. (2013) EPSC. [7] Hagfors T. (1964), *JGR* 69. [8] Elachi C, (2006) Introduction to the Physics and Techniques of Remote Sensing. [9] Wye L. C. (2007) *Icarus,* 188. [10] Pettengill (1978), *Annual Reviews* Vol. 16.