Titan's empty lake basins: constraining surface physical properties by investigating radar backscatter behavior at multiple incidence angles.

R. J. Michaelides[1], A. G. Hayes[1], M Mastrogiuseppe[1], H. A. Zebker[2], T. G. Farr[3], M. J. Malaska[3], and V. Poggiali[4], [1]Cornell University, Ithaca NY, rjm342@cornell.edu; [2]Stanford University, Palo Alto, CA; [3]Jet Propulsion Laboratory, Pasadena, CA; [4]Università La Sapienza, Italy.

Abstract: We present a detailed investigation of the radar scattering behavior of Titan's north polar empty lake basins at nadir and off-axis viewing geometries. By combining quasi-specular backscatter modeling of off-axis SAR images with analysis of nadir radar altimetry passes, we can characterize the scattering behavior of Titan's empty lake basins over a range of incidence angles, and place constraints on the surface physical properties of these geologic features.

Background: Empty lakes, defined by their high backscatter returns (relative to their surroudings) and plan-view lacustrine morphology, are present at both of Titan's poles and typically found in the vicinity of filled lakes [1]. Based on their plan-view lacustrine morphology, topographic profiles, and geopgraphic association with filled lake basins, Titan's empty lakes have ben interpreted as either remnant or proto-filled lakes that currently lack liquid fill due to local variations in evaporation, surface runoff, and/or "communication" (infiltration/discharge) with a subsurface alkinofer table [1,2,3]. A dynamic hydrology , suggesting that these features have been filled in the past and may well be filled in the future, is consistent with observed temporal variations of south polar lake basins [4,5,6]. Investigations of empty lake features with Cassini's VIMS instrument have noted that many of them are 5-micron bright, which has been interpreted as potential evidence for evaporite depsoits, analgous to terrestrial evaporitic lake playas [7].

Previous investigations into the radar backscatter characteristics of Titan's empty lake basins have suggested that, quantitatively, these features are both compositionally and structurally distinct from their surroundings, and have surface dielectric constants consistent with solid hydrocarbons [3]. We expand upon previous work, combining quasi-specular backscatter modeling of overlapping off-axis SAR data with the analysis of several radar altimetry transects to characterize the scattering behavior of Titan's empty lake basins across a range of incidence angles in order to place constraints on their surface and near-surface physical properties.

Methods: Quasi-specular backscatter modeling relies on multiple observations of a target over a range of incidence angles. Variations in radar backscatter are interpreted as changes in wavelength-scale surface roughness, surface/near-subsurface dielectric properties, variations in near-subsurface structure, and/or pixel-scale changes in the orientation of surface scattering facets [8].

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 normalized radar cross section σ_0. Quasi-specular models relating σ_0 to the angle of incidence, φ, have been successfully used to infer the surface properties of terrestrial planetary surfaces [3,9]. On Titan, the transparent properties of water-ice and hydrocarbon solids necessitate the addition of a diffuse term to allow for subsurface volume scattering [10].

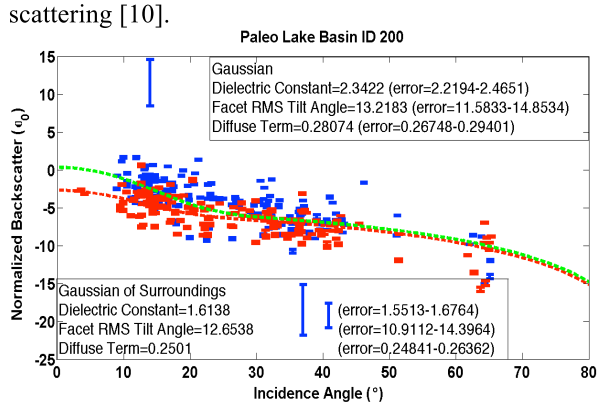

Figure 1: Quasi-specular backscatter behavior of all north polar empty lake basins averaged together. This model illustrates the model-predicted charcteristics of Titan's empty lake basins: they are brighter than their surroundings, have a similar facet-scale surface roughness, and have higher dielectric constants and diffuse term amplitudes.

Our models are dependent upon the effective surface dielectric constant, surface RMS facet tilt 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 empty lake basins and their immediate surrounding terrain.

By applying the observed SAR data to Gaussian, Hagfors, and Exponential quasi-specular backscatter models and inverting the fitted models, constraints on the effective physical properties of surface features can be placed, and the relative variation in the physical properties between surface features and their surrounding terrain can be quantified.

In order to complement the off-axis scattering behavior of empty lake basins characterized by quasi-specular backscatter modeling, we observe the scattering behavior of empty lake basins during the T30, T91, and T104 radar altimetry transects. After applying the processing techniques described in [11], we can quantitatively compare the scattering behavior of empty lake basins and their surrounding terrain at nadir.

Results: Model inversion of off-axis SAR data suggests that, within error, relative to their surroundings, empty lake basins have a higher dielectric constant and diffuse term amplitude, but similar pixel-scale surface roughness. Because backscatter is dominated by surface roughness and dielectric constant, and our model predicts no appreciable difference in surface roughness between empty lake basins and their surroundings at off-axis viewing geometries, we suggest that this difference in off-axis backscatter return is due primarily to a combination of differences in dielectric constant (compositional differences) and near-subsurface volume scattering (structural differences).

The uncalibrated altimetry echo returns at nadir are higher from empty lake basins than from their surroundings. Returned power is a factor primarily of surface dielectric constant and surface roughness, although at nadir viewing geometries surface roughness has a more pronounced effect on returned power than in off-nadir viewing geometries [8]. Echo pulse width, which can be used to constrain surface roughness, reveals that the roughness of empty lake basins is comparable to that of their surroundings. This result suggests that differences in nadir returned power, which are a function of both dielectric constant and surface roughness, may be primarily attributable to differences in dielectric constant, and thus surface composition. These results are consistent with our off-axis backscatter modeling, and further suggest that Titan's polar empty lake basins are compositionally distinct from their surroundings. Future work will use coordinate nadir and off-nadir returned power to determine the dielectric constant of the empty lake basins, relative to their surroundings, in order to further constrain the nature of the observed compositional change.

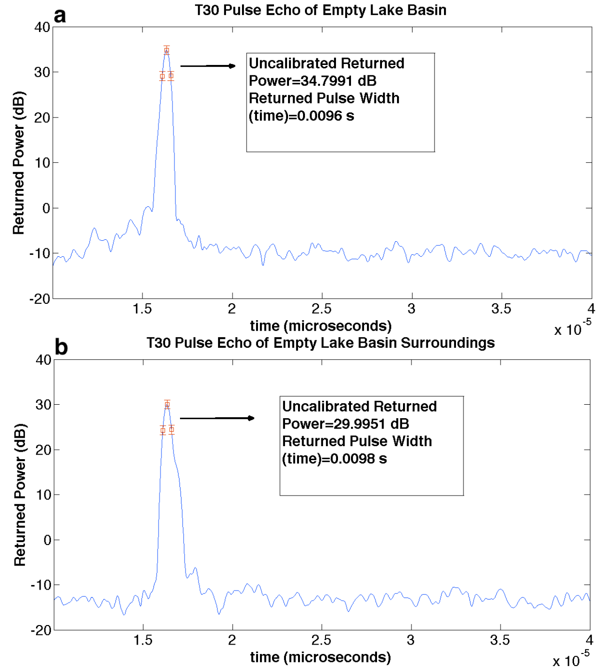

Figure 2: Individual altimetry pulse echoes from the T30 altimetry transect. 2a corresponds to a pulse within the empty lake basin, while 2b corresponds to a pulse over the surrounding terrain of the basin. The two pulses have similar pulse widths, which are a proxy for surface roughness, but the echo over the empty lake basin has a higher returned power than the echo over the surrounding terrain, which is indicative of an increase in surface dielectric constant. Returned power (dB) along the y-axis, time (microseconds) along the x-axis.

References: [1] Hayes A. G. et. al. (2008) *GRL, 35.* [2] Hayes A. G. et al. (2011) *Icarus, 211*. [3] Michaelides R. J. et al. (2014) *LPS XLV,* Abstract #1321. [4] Hayes A. G. et al. (2011) *Icarus, 211*. [5] Hofgartner J. D. et al. (2014) *Nature Geoscience, 7.* [6] Barnes J. W. et al. (2014) *Planetary Science, 3.* [7] Barnes J. W. et. al. (2011) *Icarus, 216.* [8] Campbell B. A. (2007) *GRL, 34.* [9] Pettengill (1978), *Annual Reviews* Vol. 16. [10] Wye L. C. (2007) *Icarus,* 188. [11] Mastrogiuseppe M. et al (2014) *GRL, 41.*