ARE TITAN'S LAKES LIQUID-FILLED? K. L. Mitchell[1], P. Paillou[2], B. W. Stiles[1], H. Zebker[3], G. Mitri[1], J. I. Lunine[4], S. D. Wall[1], R. D. Lorenz[5], R. M. C. Lopes[1], S. Hensley[1], E. R. Stofan[6], R. L. Kirk[7], S. J. Ostro[1], F. Paganelli[1] and the Cassini RADAR Team, [1]Jet Propulsion Laboratory, California Institute of Technology, MS 183-601, 4800 Oak Grove Dr., Pasadena, CA 91109-8099, USA, *Karl.L.Mitchell@jpl.nasa.gov*, [2]OASU, UMR 5804, 2 rue de l'Observatoire, 33270 Floirac, France, [3]Stanford University, Dept. of Electrical Engineering, Stanford, CA, [4]Univ. of Arizona, Lunar and Planetary Lab, Tucson, AZ, [5]Johns Hopkins University Applied Physics Lab, Space Dept., Laurel, MD, [6]Proxemy Research Inc., Laystonsville, MD, USA, [7]USGS Flagstaff, Flagstaff, AZ.

Introduction: SAR imagery obtained during Cassini's T16 Titan fly-by revealed numerous radar-dark features at > ~70° N, interpreted to be lakes [1] on the basis of their low radar reflectivity, morphology and consistency with predictions [2]. Later fly-bys revealed more lakes, and also overlapped with previous scenes, facilitating multi-angle, multi-temporal studies, with several more such opportunities over the coming months. Here we introduce our efforts to understand the nature of the lakes using such studies, focusing on one anomalous lake in particular, and address the issue of whether the observed lakes are liquid-filled or dry.

Observations: To date we have catalogued 156 radar-dark lakes, based on T16, T18 and T19 SAR imagery, observing a trend from broader lakes with more complex margins at higher latitudes, to smaller, more circular lakes with apparently steeper rims at lower latitudes. We also see many morphologically similar but radar-bright features, interpreted to be drained lakes [1] or cryovolcanic calderas [3]. These are primarily, though not exclusively, at the lower lakeland latitudes, and certainly significantly outnumber radar-dark lakes in these locations.

Overlapping T16 and T19 SAR imagery permits multi-look analysis of ~20 lakes. Within this region they have opposite look directions and a large contrast in incidence angles: 25-31° for T16 and 13-19° for T19. A visual comparison reveals no signs of change that cannot be accounted for by parallax effects due to topography or radar artifacts, with one exception.

"Lake 20" (Fig. 1) exhibits an exceptionally strong brightening of the left-most portion of the lake from T16 to T19, but within this region retains some of the same apparent internal structure. Also, the contrast at the lake boundary is different: for T16 there is a sharp contrast (roughly 6 to 8 dB) all around the lake, whereas for T19 there is only a sharp contrast on the top side of the lake, with a much more gradual change on the bottom side, giving it an appearance of being much less differentiated from the surrounding region.

Analysis: 4 large lakes in the overlap region were compared using thermal/quantization noise-subtracted pixel-averaged backscatter data. The contrast was also stretched to correct for a contrast reduction effect inherent in the compression. Pixels were averaged used a 5×5 pixel box filter to reduce speckle noise.

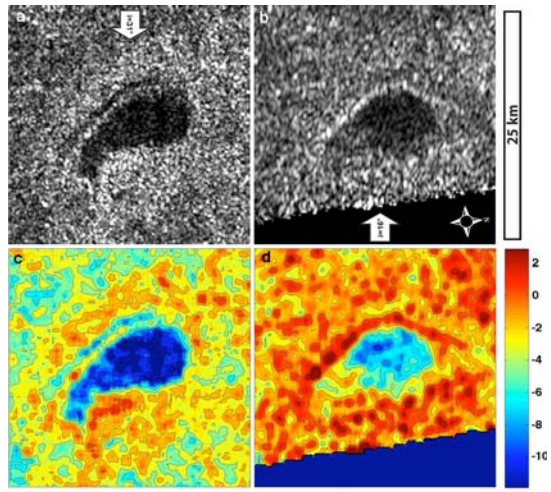

Figure 1. Noise-substracted SAR images of Lake 20 (at 78.3° N × 113° W). (a) T16 fly-by, illuminated from the bottom at 31.0° incidence angle. (b) T19 fly-by, illuminated from the top at 16.4° incidence angle. (c) As (a), pixel-averaged and shown in pseudocolour, with contour lines plotted at 2 dB backscatter intervals. (d) As (b), processed as (c).

We explore various hypotheses about the nature of the lakes, including their incidence-angle-dependent behavior, by fitting the backscatter data to a multi-layer scattering model [4] using several candidate materials (liquid methane, water-ice, water-ice-ammonia, tholins) in both 1- and 2-layer configurations, including: (i) a solid surface; (ii) a pure liquid reservoir; and (iii) a liquid reservoir over a solid surface.

First, it is necessary to explain the extremely low radar backscatter. Liquid methane and ethane have been predicted to be abundant at these latitudes, and their interaction with 2.2-cm microwave is known to be weak. Hence they should be largely transparent to Cassini SAR, although a deep enough reservoir should appear radar dark, similar to the Earth's oceans when viewed from space in visible light. Unfortunately, the loss tangent is not well constrained, and so the correlation of signal with depth is diffcult to estimate. If a dry lake is considered, a dielectric constant of < 3 is necessary, inconsistent with most solid materials proposed on the surface of Titan. However, tholins - radar dark materials (~2.2-0.01j dielectric constant [5]) that are widely predicted to have rained out over much of the planet - may be consistent with observations.

Second, the observations should be consistent with multiple incidence angle data. Using the current limited dataset, all configurations that involve a liquid methane or ethane layer and/or a solid tholin layer are consistent with the observations. Data to be acquired over the coming months, including some 3-look opportunities, should help us to constrain this further.

"Lake 20" analysis: As noted previously, Lake 20 presents us with an anomaly. We explore two hypotheses, both sub-sets of previous ones: (a) the lake is static between scenes, with a stronger dependence on incidence angle for the bright portion of the lake than for the surrounding terrain; and (b) the lake changes between scenes in its extent and/or depth.

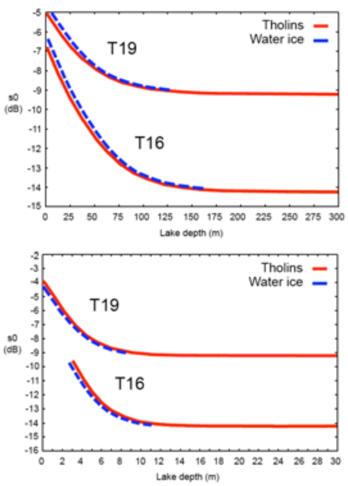

Figure 2. Two-layer modelling of Lake 20 at 31° (T16) and 16° (T19) incidence angles, assuming liquid methane covering a tholin or ice substrate. (a) The difference between T16 and T19 curves is due only to incidence angle change (b) As above, but with a higher loss tangent for liquid methane, and a lake level decrease from T16-T19 of 3 m, starting at ~3 m at the left part of the lake, and >25 m at the right part.

Static explanations. The backscatter observed in Lake 20 is only consistent with models that involve either: (1) an extremely low dielectric constant solid, with rather constant roughness (surface height standard deviation, σ=0.5cm, and surface correlation length, L=2.4cm), but a volume scattering component that decreases from left (albedo = 0.2) to right (albedo = 0.0) due to structural heterogeneity; or (2) a smooth (σ=0.35cm and L=2.5cm) liquid layer (here, we assume methane with a dielectric constant taken to 1.8-0.00007j) covering a rougher (σ=2.5cm and L=7.0cm) lake bottom – modeled as either tholins (dielectric constant 2.2-0.01j, volume scattering with albedo=0.2) or water-ice (dielectric constant 3.1-0.000006j, volume scattering with albedo=0.1) – with lake depth varying from either very shallow or exposed (left part) to > 200m (right part) (Fig. 2a).

Dynamic explanations. If Titan's lakes are liquid-filled, then we should expect the lake levels to change over time due to evaporative cooling/heating, advective heating/cooling and solar insolation and re-radiation, as previously modelled [2] for methane-ethane mixtures, as well as possible precipitation and drainage. Brightening of Lake 20 between T16 and T19 is slightly inconsistent with our model for incidence-angle dependence of methane, implying that if the lake is liquid methane then some sort of change has taken place. A plausibly high loss tangent of 0.0005 is consistent with a change as small as 3 m, with lower loss tangents corresponding to higher lake level decreases. Such a change can be accommodated within the model of [2]. The evaporation model is sensitive to local topography and, over the 79-day interval between T16 and T19, would necessitate very shallow local elevations, consistent with shallow lake basins. If the lake was richer in methane (35% methane, 65% ethane was considered by [2]), more rapid evaporation would be possible. A significantly lower loss tangent would imply greater lake elevation change, in which case some sort of drainage would be needed.

The localized brightening can also modeled by such a change in lake level (Fig. 2b), but compared with the static case we require both a higher volume scattering component in the bottom layer (albedo of 0.4) and a higher (still acceptable) loss tangent for the covering liquid layer (dielectric constant 1.8-0.001j).

Discussion: Our preferred interpretation, on the basis that it involves the least assumptions, is that the lakes are liquid hydrocarbons and that the brightening in Lake 20 can be explained by incidence angle effects given a variable lake depth (static hypothesis 2). We cannot completely rule out the possibility that we are looking at very low dielectric constant solid, which, for Lake 20, would require a spatially varying degree of volume scattering, consistent with an evaporitic or sedimentary tholin (or similar) residue of varying porosity. However, we find this unlikely, on the grounds that the few very dark spots in topographic lows at lower latitudes are both less radar-dark and less copious, despite predictions that tholins should rain out there also. In addition, if we accept the interpretations that radar-bright depressions are drained lakes [1], the implication being that the depressions are largely shaped by the interaction of the lake liquids and the substrate (consistent with karst or thermokarst lakes [6]) then, without the presence of liquid it is difficult to explain the dichotomy of both radar dark and radar bright lakes. Alternatively, if the lake depressions are cryovolcanic calderas [3], then the tendency of increasing apparent abundances at lower latitudes within the lake region (>~65° N), relative lack of similar forms elsewhere on the planet, and dynamics of caldera formation of Titan, must be addressed.

References: [1] Stofan E. R. et al. (2007) *Nature 445,* doi:10.1038/nature05438. [2] Mitri G. et al. (2007) *Icarus*, in press. [3] Wood C. A. et al. (2007) *LPS XXXVIII*, Abstract #1454. [4] Paillou P. et al. (2006) *JGR 111*, E11011. [5] Rodriguez S. et al. (2003) *Icarus 164*, 213-217. [6] Mitchell K. L. et al. (2007) *LPS XXXVIII*, Abstract #2064.

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