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Karl L. Mitchell, J.I. Lunine, Martin B. Barmatz, C. S. Jamieson, Michael J. Malaska, et al.. Towards an End-to-End Model Relating Microwave Observations to Bulk Chemistry of Titan's Lakes and Seas . 47th Lunar and Planetary Science Conference, Mar 2016, The Woodlands, Texas, United States. insu-01283776

HAL Id: insu-01283776

<https://insu.hal.science/insu-01283776>

Submitted on 6 Mar 2016

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TOWARDS AN END-TO-END MODEL RELATING MICROWAVE OBSERVATIONS TO BULK CHEMISTRY OF TITAN'S LAKES AND SEAS. K. L. Mitchell¹, J. I. Lunine², M. B. Barmatz¹, C. S. Jamieson¹, M. J. Malaska¹, R. D. Lorenz³, M. Mastrogiuseppe², A. G. Hayes², A. Le Gall⁴, J. M. Soderblom⁵, and the Cassini RADAR Team, ¹Jet Propulsion Laboratory, Mail Stop 183-601, 4800 Oak Grove Dr., Pasadena, CA 91109-8099 (Karl.L.Mitchell@jpl.nasa.gov), ²Cornell Univ., Ithaca, NY, ³Johns Hopkins Univ. Applied Physics Lab., Laurel, MD, ⁴LATMOS-UVSQ, IPSL, Paris, France, ⁵M.I.T., Cambridge, MA.

Introduction: Constraining the bulk chemistry of Titan's lakes and seas is critical for resolving between different models of Titan's hydrological and environmental state and its evolution over time [1]. Infrared spectroscopy is able to detect the presence of some chemical species at the lake surfaces [2], but quantifying bulk abundances is limited to the top layer of the liquid because of the short optical path-length, and is complicated by obfuscating methane and haze in the atmosphere. Microwave observations overcome some of these difficulties because the seas are, in places, sufficiently transparent to allow detectable sea floor returns. Several different methods have been employed to determine microwave properties of Titan's lakes [3-6], with varying degrees of certainty and model-dependence, and to constrain the real dielectric constant and/or the loss tangent (a derivative of the complex dielectric constant). This means that, at most, two quantitative constraints can be provided for the bulk properties. In this paper, we discuss the use and potential for modeling bulk chemistry of Titan's seas.

Chemical mixture modeling: Laboratory data and chemical models predict predominantly methane-ethane-nitrogen chemistry [e.g. 7,8]. However, there remains disagreement within this ternary system as to how much nitrogen should be dissolved in differing methane:ethane mixtures as a function of pressure and temperature. The chemical mixture model we implement for this study is that of Hollyday et al. [9], which is based on a Henry's Law fit to lab measurements [10]. It should be noted, however, that those efforts [10] reveal that a Henry's Law approach is insufficient, and preliminary interpretations suggest that it overestimates nitrogen solution for mixtures. By combining ongoing lab efforts [10,11] with a more complex solution model [e.g. 7] we anticipate less uncertainty.

Other components of the mixture are also being considered, but these are thought to be present in sufficiently small quantities that they are less likely to impact dielectric properties with any significance. However, their presence and volumes are highly speculative, and so it's plausible that they may play an important role, especially if they exhibit extremely high loss tangents, in which case they could behave in a manner akin to squid ink in water.

Dielectric modeling: If the methane-ethane-nitrogen paradigm is assumed to be true, then the die-

lectric properties can be used to provide constraints on the composition within their frameworks. Our laboratory studies are an attempt to provide the critical "missing piece": a precise model for determining the dielectric properties of these mixed compositions at appropriate temperatures. Preliminary findings [12] are that there is a unique complex dielectric constant as a function of methane:ethane ratio (which determines nitrogen fraction). Precision in dielectric constant determination is limited by the experimental procedure which results in an error of $\sim 10^{-5}$ in loss tangent, equivalent to ~ 0.1 in ethane molar fraction. At present, we derive the mixture complex dielectric constant from end-member components using a Lorentz-Lorenz mixture model, which is appropriate for these non-polar molecules but remains unverified for this particular mixture. Furthermore, we have no direct measurement of dissolved nitrogen at appropriate temperatures (~ 90 K), and so have extrapolated based on liquid nitrogen measurements at < 77 K. The cumulative effect on our results of the lack of mixture model verification and extrapolation of the Nitrogen end-member on error are unknown, but are thought to be less than experimental error at least for methane-dominated systems. In the future we will directly measure these mixtures.

Dielectric constants from Cassini: Mastrogiuseppe et al.'s [6] method is arguably the most precise and accurate method for determining bulk sea dielectric properties from Cassini observation. The interpretation of these results, however, is limited by our uncertainty in loss tangent, resulting in uncertainties of $\sim \pm 0.1$ in ethane molar fraction. A limitation of this method is that, currently it is only possible to apply to nadir RADAR altimetry passes, which are rare on Cassini, and so only of limited utility in determining temporal and spatial trends. Loss tangents have been determined [6,13], with the latest revisions of $\tan \delta = 4.4 \pm 0.9 \times 10^{-5}$ for Ligeia Mare and $\tan \delta = 7 \pm 3.0 \times 10^{-5}$ for Ontario Lacus.

At present, other methods place constraints on the real dielectric constant, but these are more model dependent, utilizing assumptions that result in great uncertainty in comparison with the likely chemical domain. They can be refined by using the altimetric results [13] to inform radiometrically-derived n-layer models [e.g. 14]. Further, the method and results here can also be applied to the interpretation of RSS bistatic

observations, which have the potential to add greatly to our results. In the meantime, our focus is on improving chemical and dielectric models.

Results: We use the preliminary chemical mixture treatment of Hollyday et al. [9] combined with our dielectric measurements and mixture model [12] to place chemical constraints based on altimetry-derived loss tangents [6], with additional real dielectric constraints where possible [e.g. 4] (fig. 1). Note that temperatures of Titan's seas may vary by a few Kelvin. The cumulative effect of errors in the y-axes are equivalent to at least 2×10^{-5} in loss tangent and 0.02 in real dielectric constant, possibly greater. Finally, because of uncertainties in the presence and dielectric properties of minor compounds, our ethane fractions are upper limits, although they are likely to be reasonable first order fits. Our best fits suggest a methane-ethane-nitrogen molar ratio of 71:8:21 for Ligeia Mare and 64:22:14 for Ontario Lacus.

Discussion: Even with the large uncertainties discussed, it is difficult to account for ethane molar fractions of >18-25% in Ligeia, and >42-53% in Ontario, and so these results support with moderate confidence the interpretation that Titan's seas are methane dominated. Until additional measurements are obtained and current uncertainties are reduced, however, we do not resolve between leading hypotheses about controls on the composition of Titan's seas [e.g. 1,8].

This analysis demonstrates the utility and potential of dielectric analyses of Titan's seas, but more work is required in order to realize their full potential. Ongoing efforts to determine solubilities and dielectric properties of the various constituents in the laboratory are considered a priority, as well as continued refinement

and application of the various methods for determining dielectric constants over multiple bodies as precisely as possible.

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Additional Information: This research was carried out at the California Institute of Technology Jet Propulsion Laboratory under a contract with NASA. We acknowledge support from the Outer Planets Research Program (09-OPR09-0023), Cassini Data Analysis and Participating Scientists Program (12-CDAPS12/2-0016) and the Cassini RADAR Team.

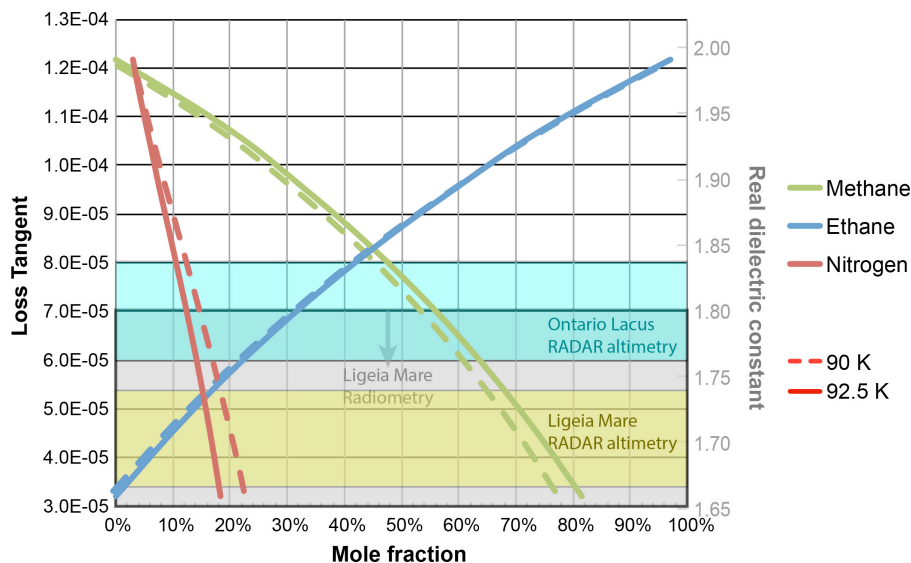


Figure 1: The relationship between composition and observed dielectric properties at 90.0 and 92.5 K using a chemical mixture model [9] and our dielectric data and mixture model [11]. Real dielectric constant, given on the R.H.S. y-axis, is approximate and applicable at 92.5 K only, shifting at different temperatures. In addition, curves have uncertainties of at least 10^{-5} in loss tangent and 0.02 in real dielectric constant. Shaded boxes represent recent altimetry [13] and radiometry [14] results.