Earth and Planetary Science Letters 474 (2017) 20–24

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Surface roughness of Titan's hydrocarbon seas

Cyril Grima[a,*], Marco Mastrogiuseppe[b], Alexander G. Hayes[b], Stephen D. Wall[c], Ralph D. Lorenz[d], Jason D. Hofgartner[c], Bryan Stiles[c], Charles Elachi[c], The Cassini RADAR Team

[a] Institute for Geophysics, University of Texas at Austin, TX 78758, United States
[b] Cornell University, Ithaca, NY 14853, United States
[c] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, United States
[d] The Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, United States

ARTICLE INFO

Article history:
Received 1 September 2016
Accepted 3 June 2017
Available online xxxx
Editor: C. Sotin

Keywords:
Titan
radar
roughness
waves

ABSTRACT

We derive fields of solutions for the surface properties (roughness and permittivity) of the liquid hydrocarbon bodies Ligeia, Kraken and Punga Mare on Titan by applying the Radar Statistical Reconnaissance (RSR) technique to the Cassini RADAR observations in altimeter mode during the northern early summer. At the time of observation, Kraken and Ligeia were confined within root-mean-square heights of 1.5–2.5 mm (similar to wave heights of 6–10 mm), correlation lengths of 45–115 mm, and corresponding to effective slopes of 1.1–2.4°. The latter extends up to 3.6–4.9° if the rougher Punga is included. The lower bound of those ranges has to be considered if the composition of the seas is methane-dominant. These are the first measurements to simultaneously constrain both the vertical and horizontal roughness parameters of Titan's seas from the same observations. Our results are representative for the global properties of the sea-scaled portion of the studied tracks and suggest that quiet surfaces are a dominant trend over the seas during the northern early summer. Fields of rougher textures, if existent, might develop mainly over local patches and/or might not be sustained over significant periods of time.

© 2017 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

Titan's surface bodies are similar to those on Earth, shaped by aeolian, pluvial, fluvial, lacustrine, tectonic, impact and possibly cryovolcanic processes (e.g. Aharonson et al., 2014; Poggiali et al., 2016). In that respect, investigating the properties of Titan's surface is a key to better understanding surface-atmosphere exchanges and climate dynamics. Of particular interest is dimensioning the waves (i.e. roughness when observed with signals of higher wavelength) rippling the hydrocarbon liquid bodies of the Saturnian moon. Waves can be, for example, wind-driven, ruffled by tidal flows, rain, or debris, so that their characterization can be used as a discriminator for the possible processes disturbing liquid surfaces. Ghafoor et al. (2000), Lorenz et al. (2005, 2010), Lorenz and Hayes (2012), Hayes et al. (2013). In addition, knowledge of liquid bodies' roughness is critical to the prediction of post-impact behavior for safe deployment of automatic probes (Ghafoor et al., 2000; Lorenz and Hayes, 2012).

The roughness of Titan liquid bodies have been assessed from the Cassini RADAR altimetry mode (normal incidence observations) using a classic specular model (Wye et al., 2009; Zebker et al., 2014). In this approach, the expected reflection coefficient in power for a liquid methane–ethane surface is weakened by $exp[-(4\pi\sigma_h/\lambda)^2]$, where σ_h and λ are the surface's root mean square (RMS) height (σ_h) and the signal wavelength, respectively (Bennett and Porteus, 1961). To apply this model, the effective value for the received surface echo power is implicitly considered as around-the-mean of a set of observations, of which randomness adds uncertainty to the derived surface properties. Thus, Wye et al. (2009) bounded $\sigma_h < 3$ mm from the T49 Cassini flyby over Ontario Lacus, while Zebker et al. (2014) estimated σ_h ranges from 0.5 to 1.5 mm over Ligeia Mare (T91). Non-simultaneous to radar measurements was the 0.05° upper limit for the surface slopes as derived from the specular reflection observed at 5 µm over Jingpo Lacus (T58) by the Visual and Infrared Mapping Spectrometer (VIMS) (Stephan et al., 2010; Barnes et al., 2011). Those values are consistent with a very smooth, quasi-undisturbed, surface. VIMS observations of diffused light over a localized patch within the boundaries of Punga Mare (T85) would correspond to surface slopes of 6° that could accommodate a slightly rougher liquid surface (Barnes et al., 2014). Also, The imager mode of the Cassini RADAR detected what could be local and transient rough patches at the surface of Ligeia Mare (Hofgartner et al., 2014, 2016).

* Corresponding author.
E-mail address: cyril.grima@gmail.com (C. Grima).

http://dx.doi.org/10.1016/j.epsl.2017.06.007
0012-821X/© 2017 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

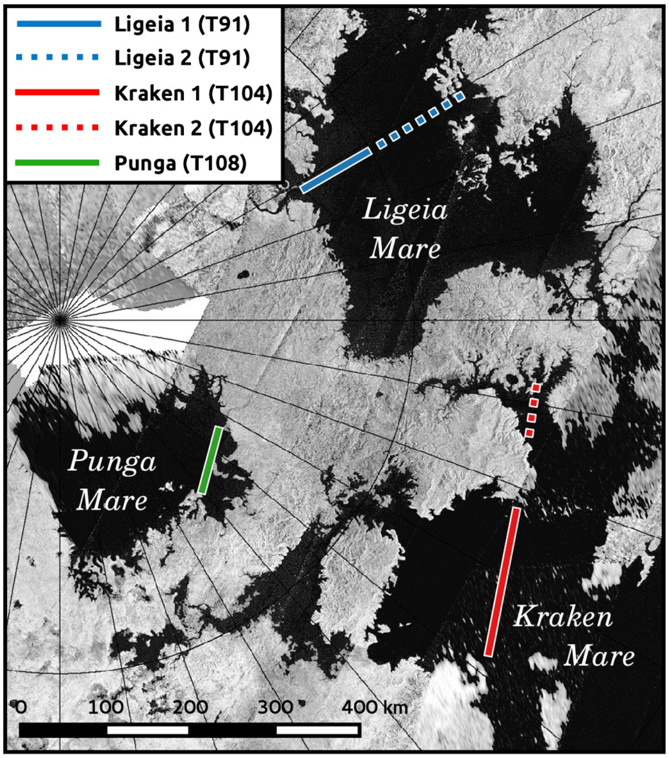

Fig. 1. Contextual map locating our regions of interest in the northern hemisphere of Titan. The background map is a Synthetic Aperture Radar mosaic of the surface from the Cassini RADAR.

The specular approach as applied by Wye et al. (2009) and Zebker et al. (2014) is valid for a coherent signal, i.e. with a deterministic phase. However, surface roughness birth and growth also causes the transfer of some coherent energy (P_c) into incoherent/random energy (P_n), the sum of both being the total received signal ($P = P_c + P_n$) (e.g. Ogilvy, 1991; Ulaby and Long, 2014). In case of the highly specular Titan's lakes, P_c is dominant by several orders of magnitude over P_n, and neglecting the latter does not have a severe impact on the derived σ_h estimates. Yet, P_n is highly sensitive to extra information regarding the roughness (Grima et al., 2014b) and its consideration, together with P_c, is an opportunity to better describes and constrains the surface properties.

In this study we apply the Radar Statistical Reconnaissance (RSR) technique (Grima et al., 2012, 2014b) to the altimetry observations from the Cassini RADAR over Ligeia (T91), Kraken (T104), and Punga (T108) seas, the three largest liquid bodies in the Northern hemisphere (Fig. 1). These observations span the first half of the Cassini Solstice mission (Northern early summer) at solar longitudes (L_S) of 45.22° (Ligeia), 59.38° (Kraken), and 63.78° (Punga). The RSR augments the classic specular model by considering the signal randomness behavior as a signature for the coherent–incoherent energy balance within the total received signal. The RSR product is a range of possible solutions for ϵ, σ_h, and the surface correlation length (l_c). We first present the dataset used along with a description of the RSR methodology and its application to the Cassini RADAR data. Then, we present the obtained surface roughness properties for the considered seas. Finally, we highlight some specifics of radar backscattering for a better understanding of the results and we discuss the implications in terms of wave generation and spatial/seasonal occurrence.

2. Data and method

The Cassini RADAR is an active 13.8 GHz ($\lambda =$ 2.2 cm) multiple-beam instrument with observation angles arranged across-track (Elachi et al., 2004; West et al., 2009). It is a part of the science payload for the NASA's Cassini spacecraft touring the Saturnian system and its moons since 2004 (Matson et al., 2002). The Cassini RADAR can operate sequentially in several modes: Radiometer (Receive-only), scatterometer (off-nadir transmission/reception), altimeter (nadir transmission/reception), and imager (synthetic aperture radar). The transmission sequence of the altimeter mode is a packet (a.k.a. burst) of ∼21 consecutive chirps at fixed rate, while about 15 of them are received back and recorded after reflection. The burst repetition frequency is adjustable to adapt to various targets and observation configurations. We used observations from the Cassini flybys where the signal is not saturated. In our analysis of these observations, we did not consider the overlapping of the burst's footprints with surrounded lands/islands. The relative short pulse width insures that the sea bottom reflection do not contribute to the surface echo power (Mastrogiuseppe et al., 2014).

The RSR technique constrains surface properties from the stochastic behavior of the amplitude for the surface echo peaks. The technique's principles have been firstly introduced with the Shallow Radar (SHARAD, 20-MHz central frequency, 10-MHz bandwidth) data onboard the Mars Reconnaissance Orbiter (Grima et al., 2012). Then, the RSR has been fully described and demonstrated with the High Capability Radar Sounder (HiCARS, 60-MHz central frequency, 15-MHz bandwidth) airborne radar in Antarctica (Grima et al., 2014a, 2014b, 2016).

In a first step, the signal components P_c and P_n are quantitatively extracted from the surface signal by best-fitting the amplitude (A) distribution of surface echoes for a given region with an Homodyne K-envelope (HK). HK statistics are derived by modeling the scattering with a random walk of negative-binomial statistics (leading to a K-noise) and in which a deterministic (a.k.a. homodyning) component is added (Jakeman and Tough, 1987; Dutt and Greenleaf, 1994). Analytically, the HK distribution is related to the product of a Rice (P_{Ri}) and a gamma (P_Γ) distribution (Jakeman and Tough, 1987):

$$P_{HK}(A|a, s^2, \mu) = \int_0^\infty P_{Ri}(A|a, s^2 w) P_\Gamma(w|\mu, 1) dw \quad (1)$$

where the coherent and incoherent powers are $P_c = a^2$ and $P_n = 2s^2$, respectively, and μ is the scatterer clustering parameter. The HK distribution appears to be the only model for which the parameters keep their physical meaning in the limiting case (Destrempes and Cloutier, 2010). It is a flexible model that does not require the condition of large scatterer number to be fulfilled and allows the scatterers to be clustered (non-stationarity) within the radar footprint. The bin width for an amplitude histogram is determined with the rule from Freedman and Diaconis (1981) that estimates the scale of the distribution from its interquartile range.

In a second step, once P_c and P_n have been deduced from the fit, they are introduced in a backscattering model to assess the surface properties. If the signal can be considered absolutely calibrated (i.e. a perfectly flat conductor would have a fully coherent surface echo amplitude of unity) we have (Grima et al., 2012):

$$P_c = \left| \frac{1-\sqrt{\varepsilon}}{1+\sqrt{\varepsilon}} \right|^2 e^{-(4\pi\sigma_h/\lambda)^2} \quad (2)$$

$$P_n = \frac{2}{h^2} \int_0^r G^2 \sigma^\circ x dx \Leftrightarrow P_n = 2 \int_0^\vartheta \frac{tan^{-1}(\theta)}{\theta^2+1} G^2 \sigma^\circ d\theta \quad (3)$$

where h is the range to the surface, $r = 2\sqrt{hc/B}$ is the radius of the circular pulse-limited footprint from where reflectors could contribute to the scattered part of the received signal and where $B =$

Download English Version:

https://daneshyari.com/en/article/5779714

Download Persian Version:

https://daneshyari.com/article/5779714

Daneshyari.com