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Cassini radar observation of Punga Mare and environs: Bathymetry and composition

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ABSTRACT

In January 2015 (fly-by T108), the Cassini radar observed Punga Mare, Titan's northernmost and third-largest sea, in altimetry mode during closest approach. The ground track intercepted a section of the mare and a system of channels and flooded areas connecting Punga to Kraken Mare. We use a processing technique, successfully adopted for Ligeia Mare and Ontario Lacus, for detecting echoes from the sea floor and constraining the depth and composition of these liquid bodies. We find that, along the radar transect, Punga Mare has a maximum measured depth of 110 m. The relative reduction in backscatter of the seafloor, as a function of increasing depth, suggests a liquid loss tangent of $3 \pm 1 \times 10^{-5}$. While this value is within the formal uncertainty of the loss tangent derived for Ligeia Mare, the best-fit solution is lower and is consistent with a nearly pure binary methane-nitrogen liquid with little to no ethane or higher order components. The indication of very low amounts of ethane toward the pole suggests that atmospheric processes are controlling the surface liquid composition of Titan's seas.

1. Introduction

Titan's surface has been widely mapped by the Cassini RADAR (2004–2017), a microwave remote sensing instrument able to penetrate the dense atmosphere of the moon at 2.17 cm wavelength. The Cassini radar was a multimode instrument capable to operate in active mode as a Synthetic Aperture Radar (SAR) for surface imaging, as a radar altimeter for topography measurements, as a scatterometer for surface composition and, in passive mode, as a radiometer for brightness temperature (Elachi et al., 2004). The instrument modes were activated sequentially during each fly-by to Titan, from an altitude of 100,000 km down to a 1,000 km at the closest approach, pointing the antenna in a convenient way to accomplish the targeted measurements. A detailed description of sequence planning and instrument performance is reported in West et al. (2009). A total number of 53 fly-bys dedicated to the radar observations, allowed Cassini to cover ∼50% of Titan surface at <1 km resolution in SAR mode, as well as to acquire 40 topographic profiles in altimetry mode. This dataset enabled the identification and characterization of a series of geomorphologic features, including hundred meters high dunes (Mastrogiuseppe et al., 2014b), fluvial network of channels and canyons (Poggiali et al., 2016), mountains (Radebaugh et al., 2007; Mitri et al., 2010), craters (Wood et al., 2010), possible cryovolcanic features (Lopes et al., 2013) and large deposits of liquid hydrocarbons in lakes and seas. A detailed description and mapping of the Titan's polar terrains is reported in Birch et al. (2017).

The presence of standing hydrocarbons liquid bodies on Titan was revealed by Cassini on July 22nd, 2006, during the fly-by T16, when the radar mapped a collection of 10–100 km diameter lakes present in the Northern hemisphere (Stofan et al., 2007). Later observations revealed the existence of three northern seas, or maria: Kraken Mare, Ligeia Mare and Punga Mare (Hayes et al., 2008).

The altimetric observation acquired in May 2013 (flyby T91) over Ligeia Mare demonstrated that the Cassini RADAR can also operate as a sounder, capable of probing Titan's seas down to ∼200 m, depending mainly on liquid composition (Mastrogiuseppe et al., 2014a). This was possible because of the very low microwave absorptivity of liquid hydrocarbon (methane and ethane), which has a microwave loss tangent (defined as the ratio between the imaginary and real components of the dielectric constant) that is approximately five orders of magnitude lower than seawater. This successful experiment suggested a re-design of the final targeted

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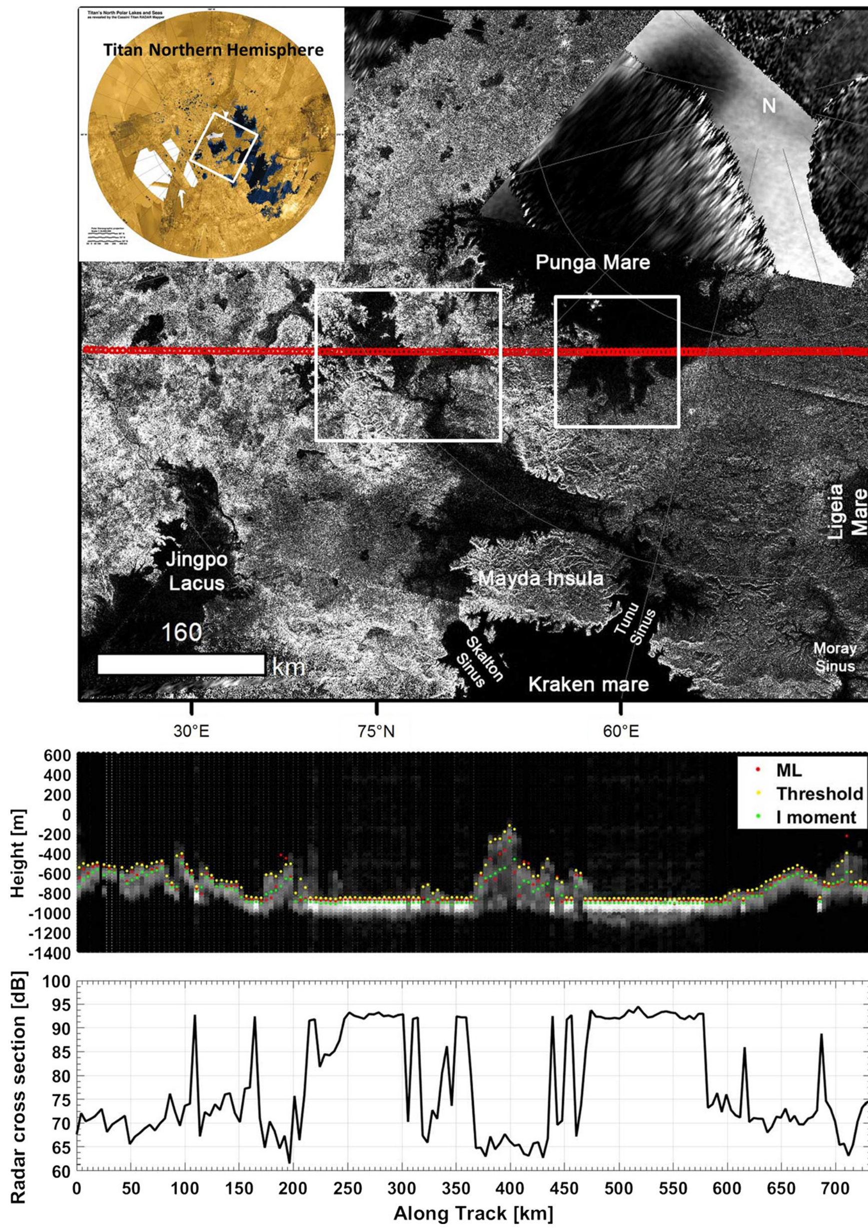

Fig. 1. (Upper panel) SAR mosaic and relative outbound altimetric 700-km-long track of flyby T108 with red circles indicating half power footprints and, in white, the two selected regions shown in Fig. 2. (Middle panel) Radargram and relative altimetry obtained using different tracking methods. (Lower panel) Radar cross section obtained from altimetry. Note that the abrupt changes to very high values of radar cross section indicate the presence of exposed liquid intercepted by the radar. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

observations of Titan aimed at acquiring similar altimetry datasets over Titan's other seas in order to investigate their depth and composition. Herein, we discuss the January 11th, 2015 observation (flyby T108) of the Cassini RADAR, that acquired data over a ∼100 km long transect through Punga Mare and a portion of the flooded terrain connecting Punga and Kraken Mare during the spacecraft's closest approach to Titan, with a favorable geometry for sounding (Fig. 1 and Supplementary material).

Punga Mare has been repeatedly observed by the Cassini RADAR in its high-resolution SAR mode, notably in October 2006 (T19), April 2007 (T29) and December 2009 (T64). It is the third largest (6.1×104 km^2, Hayes, 2016) and most poleward sea on Titan (85°N, 342°W). At the time of the T108 altimetry observation, Punga Mare's surface was very smooth at the Cassini radar wavelength ($\lambda = 2.17$ cm). Investigation of the surface roughness from T108 altimetry resulted in an estimated effective σ_h (standard deviation of the surface height) ranging between 2.3 and 2.5 mm (Grima et al., 2017), consistent with a lack of wind-waves (Hayes et al., 2013). In July 2012 (T85), the Cassini Visual Infrared Mapping Spectrometer (VIMS) observed offset sun glints that were characterized as isolated patches of increased roughness consistent with wind-waves (Barnes et al., 2014). In order to produce the observed glint magnitudes, the wind-waves would have required "Significant Wave Heights" ($\mathrm{SWH} = 4\sigma_h$) of 2^{+2}_{-1} cm (Barnes et al., 2014), consistent with wave fields generated by light winds of 0.4–0.7 m/s near the threshold for wave generation (Hayes et al., 2013).

In this paper, we adopt the dedicated radar processing technique described in Mastrogiuseppe et al. (2016) to quantitatively investigate the seafloor topography and composition of the liquid basins observed during fly-by T108. This technique has been successfully used to characterize the depth and composition of Ligeia Mare (Mastrogiuseppe et al., 2014a, 2016) and Ontario Lacus (Mastrogiuseppe et al., 2018) as reported in Table 1. A similar anal-