Composition, seasonal change and bathymetry of Ligeia Mare, Titan, derived from its 2.2-cm thermal emission

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Abstract

Ligeia Mare is the second largest sea of Saturn's moon Titan. It is also the first extraterritorial sea for which a bathymetry profile was obtained. In this paper, we analyze all data acquired up to July 2013 in the passive mode of the RADAR (i.e., radiometry mode) on board the Cassini probe in order to constrain its composition, seasonal change and bathymetry.

1. Introduction

Titan is the only planetary body besides Earth whose surface presently exhibits significant accumulations of liquids in the forms of lakes and seas. Among these bodies of standing liquid, three are large enough to deserve to be called 'seas': Kraken Mare, Ligeia Mare and Punga Mare. This paper is dedicated to Ligeia Mare.

Though the Titan's polar seas and lakes are thought to be composed of liquid methane and ethane, little is known about the ratio of these hydrocarbons in the lakes. Knowing the composition as well as the volume of liquid they contain would greatly help to improve our understanding of the lake formation and dynamics and therefore provide insights into the carbon cycle on Titan.

Towards that effort, passive microwave radiometry can be a powerful complement to radar backscatter measurements or remote sensing at smaller wavelengths, bringing independent constraints on both the composition and bathymetry of the lakes and searching for signs of evaporative cooling [1]. For the last 10 years, the radiometer incorporated in the Cassini RADAR instrument has been observing the 2.2-cm wavelength thermal microwave emission from Titan's surface. The radiometry global mosaic has been recently updated to include all data accumulated through Feb. 2014 and its calibration has been refined to an unprecedented accuracy of ~1% [2,3]. This paper aims at extracting all scientific information on Ligeia Mare from this dataset.

2. A two-layer model for the seas

The brightness temperatures measured above a Titan's sea consists of two contributions: the thermal emission from the liquid layer and that from the seafloor.

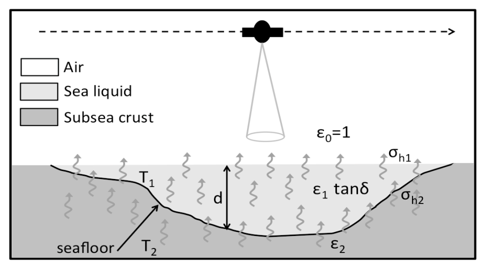

Fig. 1: Two-layer model for modeling the microwave thermal emission from Titan's seas.

Because the seafloor is *a priori* less emissive than the liquid layer, the net emissivity measured over Titan's lacustrine features is expected to increase as the depth of the sea increases i.e., as the contribution from the bottom diminishes. Furthermore, since the expected dielectric contrast between the liquid and the bottom is small (1.6-2 versus 2-3), the emissivity is expected to vary across Titan's seas by less than 1%. Lastly, the smaller the loss tangent of the liquid, the larger the penetration depth of the 2.2-cm emission and therefore the longer (in depth) it takes for the emissivity to reach saturation. Saturation is eventually reached once the sea bottom is deep enough so that its microwave thermal emission does not arise at the surface anymore.

3. Cassini high-spatial resolution radiometry observations of Ligeia Mare, Titan

During the first 9 years of the mission, from October 2004 to July 2013, Ligeia Mare was observed with high-spatial resolution (5-50 km) on 7 occasions (Fig. 2). All these observations were made in the SAR mode of operation of the Cassini RADAR except for one that occurred on 23 May 2013 during the 91th flyby of the moon as the instrument was operating as a nadir-looking altimeter. From that observation a bathymetry profile was obtained [4] that showed a maximum depth of 160 m. As anticipated, the T91 emissivity profile is correlated with the depth profile, with the most emissive areas being the deepest.

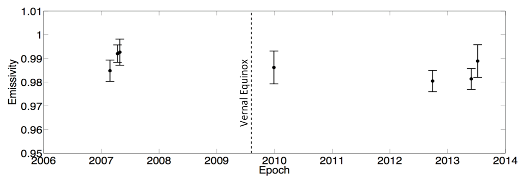

Fig. 2: Mean emissivity (corrected to normal incidence) of Ligeia Mare over the course of the Cassini mission through July 2013.

4. Results

The results briefly given below will be discussed during the paper.

4.1 Seasonal change

The flatness of the curve shown Fig. 2 suggests that Ligeia Mare has not experienced significant evaporative cooling from February 2007 to July 2013. This may change soon or have changed already due to an increasing amount of sunlight heating the northern polar terrains since Titan passed through the vernal equinox in August 2009.

4.2 Composition

Ligeia Mare appears as a radiometrically warm expanse (with an average emissivity of 0.988±0.010) while it is dark on the RADAR mosaic. This is consistent with the low dielectric constant of liquid hydrocarbons and also implies that the surface of the sea is smooth at the wavelength scale with little or no scattering in the liquid volume. The analysis of the data collected during T91 with the help of a two-layer model (see section 2) allowed us to derive the dielectric constant and loss tangent of the liquid. Overall, these results point to a methane-dominated composition. The dielectric constant of the seafloor was also inferred and is consistent with the presence of a depositional organic sludge layer at the bottom of Ligeia Mare, this layer being more compacted and/or more nitrile-rich that on that on the shores.

4.3 Bathymetry

Using the two-layer model with the inferred values the electrical properties of both the liquid layer and seafloor, the emissivity map of Ligeia Mare can be converted into the low-resolution bathymetry map that will be presented in this paper.

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