Clues to Titan Hydrology from Enhanced SAR Image Processing

Antoine Lucas[1], Oded Aharonson[1], Alexander Hayes[2], Charles Deledalle[3], Lauren Wye[4], Randolph Kirk[5], Elpitha Howington-Kraus[5], and The Cassini Radar Science Team, [1]Division of Geological and Planetary Sciences, Caltech, Pasadena, CA, USA (alucas@caltech.edu), [2] UC Berkeley, CA, USA, [3] Telecom, ParisTech, CNRS LTCI, Paris, France,[4] Stanford Univ., Geophysics Dept., Stanford, CA, USA, [5] USGS, Astrogeology branch, Flagstaff, AZ, USA

Introduction

As on Earth and ancient Mars, Titan is known to possess an active hydrologic cycle, including lacustrine/marine, fluvial and pluvial processes [1, 2, 3]. Whereas isolated small lakes may be fed by atmospheric volatiles and subsurface flow, larger seas with associated channel networks require surface runoff, and thus offer analogues to terrestrial drainage systems. The Cassini RADAR operating in SAR mode imaged fluvial networks with tributaries merging and draining into lakes and seas. In order to quantify the interactions of fluvial/lacustrine/marine processes with the topography we present new insights based on an adapted algorithm for de-noising images using an appropriate multiplicative noise model [4]. The data reveals details of the valleys incised into the terrain, shoreline morphology, and contrast variations in the dark, liquid covered areas, previously difficult to detect. The latter are suggestive of submerged valleys and gradients in the bathymetry.

Technique

Non-local (NL) approaches have been proposed to denoise images suffering additive white Gaussian noise [5]. While local filters lead to biases and resolution loss, non-local techniques are known to efficiently reduce noise and preserve structures. Instead of combining neighboring pixels, the technique averages non-neighboring similar pixels. An extension of the approach for SAR imagery has been recently proposed in [6] and adapted to Cassini SAR images by [4], showing that even small structures (*e.g.* channels of 2 pixels width) are well preserved after de-noising.

Results and Discussion

Along with stereo topography, we employ de-noised images (NLDSAR) in order to extract bathymetry based on a two-layer model proposed by [7] accounting for the reflection and transmission of radar energy. The advantage of NLDSAR over SAR is the ability to obtain a full resolution bathymetry map of large seas with the noise opitmally removed, and no local averaging. This preserves the structures in the presence of a liquid cover. Our results suggest the presence of submerged valleys beneath a shallow hydrocarbons layer (thickness ∼1-2 meter). Portions of valleys currently submerged exhibit similar widths and netowrk morphology to portions exposed, arguing the submerged valley formed prior to flooding (Figure 1).

We consider the bathymetic gradients near the shore. Significant differences in slope exist between profiles in region A and region B, where $S_A = 1 \times 10^{-4}$, $S_B = 8\times 10^{-4}$, and a transverse profile in B has a slope $S_{B^T} = 1.6 \times 10^{-3}$ at the valley wall. The shallow slopes in region A and C allowed the lake to flood over a large lateral extent (∼14 km) (Figure 1). Valleys incised at angles acute relative to the present shore further hint at temporal evolution. In addition benches in bathymetry are observed in region A and C at -1.5 m and -2.5 m elevation, respectively. The bottom depth of the valley in region C is also near ∼2.5 meters, suggesting that these valleys are equilibrated with the deeper marine bench. Assuming the latter is the base-level of the lake during the formation of the valley provides an upper bound on $\delta h/h \sim 0.25$ (where h is the maximum depth of the lake, here ∼8 meters in agreement with [8]). Note, the relative volumetric change may be larger, since for example for a constant shore slope $\delta v/v$ scales as $3\delta h/h$.

These liquid level increases may be compared with lake recession observed in the South. Ontario Lacus was seen to change over several years of observations, from ISS/SAR comparison [9, 10] at a rate of several tens of cm/year. Potential past high stands of the lake were also mapped by [11] using VIMS images. Overall, the observed changes correspond to a lake recession comparable in elevation magnitude and areal extent to the increases deduced here in the North.

The liquid level increases in the north evident in the morpology and bathymetry may be due to changes on seasonal or longer timescales. Several meters of change are predicted from GCMs to occurr due to seasonal cycles [12]; larger changes, or order 10's of meters, are expected from orbital oscillations on timescale of 10's – 100's kyr [13, 14].

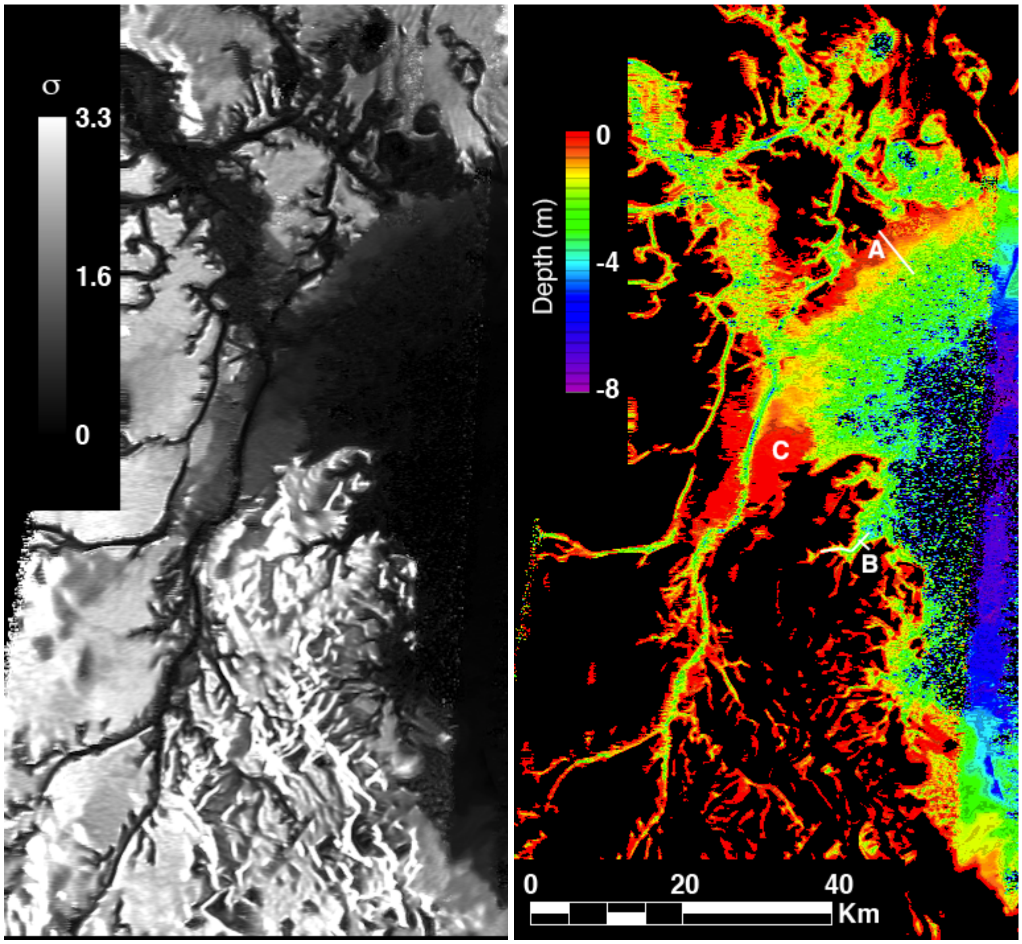

Figure 1: (left) NLDSAR image of Ligeia Mare shore from Cassini Titan pass T28; (right) Bathymetry extracted from NLDSAR following [7].

References

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