EPSC Abstracts
Vol. 11, EPSC2017-543, 2017
European Planetary Science Congress 2017

Dissolution on Titan: A Landscape Evolution Model

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Abstract

Landforms seen in Cassini/RADAR images of Titan, as well as thermodynamics models of solid-liquid equilibrium between organics and liquid methane, indicate that dissolution can be a very active process at high latitudes. We develop a Landscape Evolution Model incorporating dissolution in the context of Titan to simulate the evolution of the surface over time. We compute synthetic radar SAR images from the synthetic landscapes that we can compare with actual Cassini/RADAR images of Titan.

1. Introduction

Saturn's major moon Titan is an Earth-like world in many aspects. Its photochemically active N_2-CH_4-rich atmosphere allows the existence of liquid hydrocarbon lakes and seas at polar latitudes [1], sometimes connected to fluvial valleys and channels at polar to tropical latitudes [2], and large dune fields close to the equator [3]. Despite many morphological similarities with the Earth landscapes, the chemistry implied in the geological processes, however, is strikingly different. Titan's cold environment (T = 90 - 94 K) only allows water to exist under the form of an icy "bedrock". The presence of methane as the second major atmospheric constituent in these cold conditions allows sustaining a hydrocarbon cycle similar to the terrestrial hydrological cycle. Finally, a plethora of organic solids, more or less soluble in liquid hydrocarbons [4], are produced in the atmosphere and fall down onto the surface over geological timescales.

Based on comparisons with terrestrial analogues, dissolution and crystallization have been suggested in various instances to take part in the landscape development on Titan [5-8]. Dissolution has been invoked, for instance, for the development of the so-called "labyrinth terrain", located at high latitudes and resembling terrestrial cockpit or polygonal karst terrain [7] (Figure 1). Here we aim at testing this hypothesis by comparing the natural landscapes visible in the Cassini/RADAR SAR images, with the results of a 3D Landscape Evolution Model (LEM) that includes dissolution as the major geological process [9].

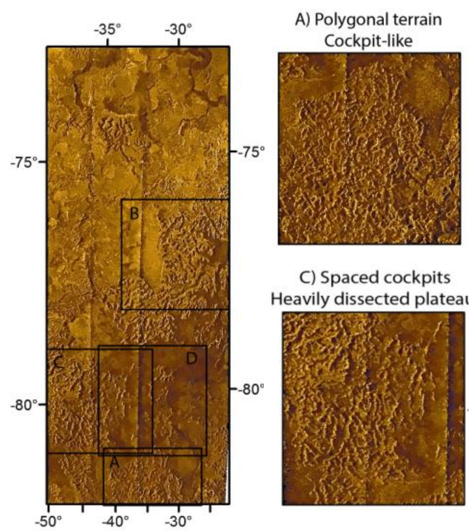

Figure 1: The Sikun Labyrinthus area on Titan seen at T39 by the Cassini/RADAR.

2. Methods

We use of the Channel-Hillslope Integrated Landscape Development (CHILD) model [10] as modified by Fleurant et al. [9] to include dissolution. Here, only dissolution and solute transport along the steepest gradient alter the initial mesh, set as a planar surface covered by a 100.0 ±0.1 m organic layer with a 50 m spatial resolution over a 25×25 km area. Four factors are tested: the dissolution rate, the diffusion rate for solute transport, and an initial "sink spatial density" designed to simulate pre-existing fractures of the layer. Using this LEM, we are able to follow the terrain elevation over millions of years.

Cassini/RADAR SAR images are the only high resolution imagery data available, where cockpit-like landforms can be distinguished (Figure 1). To compare these SAR images of Titan's surface with the model results, we compute synthetic SAR images from the Digital Elevation Models generated with the LEM. This step is ensured by following the procedure described in Paillou et al. [11], which takes into account surface reflections of microwaves. The method is validated on natural landscapes on Jamaica where cockpits are seen in SRTM elevation data and SAR Sentinel1 data.

3. Preliminary Results

We take into account the dissolution rate of a surface organic layer whose bulk composition is given by the relative abundance of organic solids produced by photochemistry in the atmosphere [12] and accumulated at the surface, as computed in Cornet et al. [4]. These deposits are exposed to methane precipitation rates given by Schneider et al. [13] at high latitudes (*P* ~ 8 m/Tyr), which leads to a dissolution rate on the order of $DR = 10^{-4}$ m/Tyr [4], converted into a dimensionless dissolution rate $K_X = DR/P \sim 10^{-5}$. The incidence angle for the SAR image simulation is that of the T39 SAR swath, where Sikun Labyrinthus has been observed. The dielectric constant of the ground corresponds to that of tholins [14].

We first studied the influence of the LEM parameters. Dissolution triggers the erosion of the landscape. Hillslope diffusion spreads the deformation and has a strong influence on the shape of the remnant hills. Both terms (especially dissolution), have a strong influence on the total time to erode the landscape. The number of sinks has no influence on the final landscapes. Figure 2 shows an example output after 8 Myr of erosion of a quasi-flat surface and the SAR image derived from the modelled topography. Despite a lack of preferred orientation of radar reflectors in our SAR simulated images, some similarities can be seen between the synthetic and actual SAR images in the areas of the polygonal terrain to residual hills (Figure 1), especially if the landscape has been exposed to several millions of years of chemical erosion (> 5 Myr in our simulations). This allows the facets to be spaced by a few km, such as for the polygonal and isolated ridges on Figure 1.

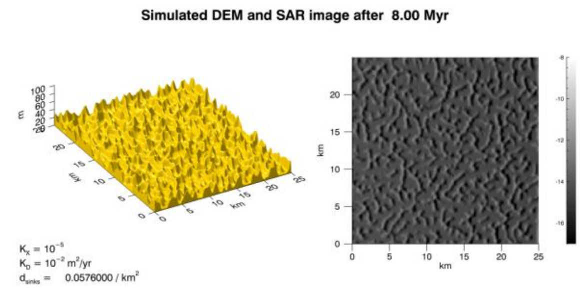

Figure 2: Snapshot of the landscape evolution by dissolution and solute transport taken after 8 Myr with a dissolution rate of 10^{-5} and a diffusion coefficient of 10^{-2} m^2/s. **Left:** Digital Elevation Model from the LEM. **Right:** synthetic SAR images generated from the DEM (illumination from the left).

4. Summary and Conclusions

We are able to produce landscapes formed by dissolution under Titan’s surface conditions. These DEMs are used to produce synthetic SAR images of the surface in order to compare the modelled landscapes with the actual Cassini/RADAR SAR images of Titan. Similarities are seen between simulated and actual SAR images, which suggests that the landscapes generated could explain the patterns observed in Cassini data. Further work will include the statistical analysis of the modelled landscapes in order to infer possible quantitative information about Titan’s high latitude terrain.

Acknowledgements

TC is funded by the CNES Research Fellowship programme. The authors also acknowledge financial support by the LabEx UnivEarthS.

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