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Evolution of Titan's labyrinths through chemical erosion and hillslope transport

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Introduction

- First detected in the Cassini RADAR Synthetic Aperture Radar (SAR) T39 data of the Sikun-Tupile-Ecaz Labyrinths area acquired in 2007 (Figure 1).
- Labyrinth terrain on Titan are dissected terrain formed by complex valleys networks ranging from polygonal to linear features [1], and are high altitude / high latitude areas [2].
- Titan's labyrinths present morphological similarities with terrestrial karst landforms [1], where the chemical erosion (dissolution) of fractured carbonates drives the landscape evolution [3].
- Theoretical predictions of the dissolution rates of some of Titan's expected solid organics in liquid methane are high, comparable to carbonates in water [4].
- In this work, using a Landscape Evolution Model (LEM), we study the influence of two main geomorphological processes on the development of eroded landscapes on Titan: a dissolution-driven erosion, and the hillslope transport.
- Using the simulated landscapes, we produce artificial radar SAR images that can be compared to the Titan Cassini Radar SAR data.

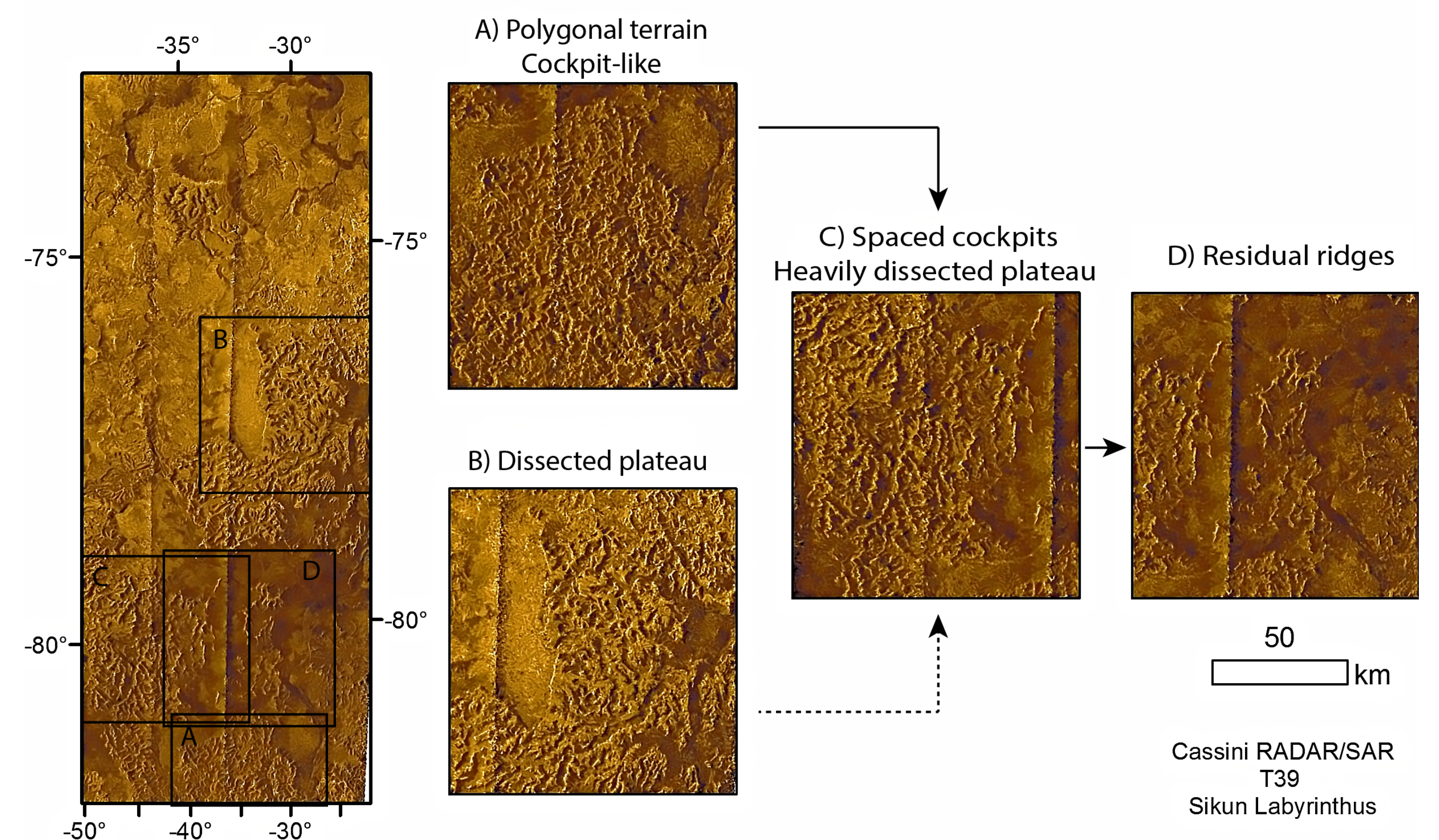


Figure 1: The Sikun (B) - Ecaz (A) -Tupile (D) labyrinth area seen at the high southern latitudes on Titan. Cassini Radar NLDSAR data [5].

Methods: Landscape simulation

- We use the Channel-Hillslope Integrated Landscape Development (CHILD) model [6], modified to include the rock dissolution process (epikarst zone theory) to model the Jamaican cockpit karst of Cockpit Country [7].
- We study the influence of the erosion via bulk dissolution (insoluble to soluble substrate), hillslope transport (linear diffusion), and fracturation (variable number of "sinks" as proxy for crossing fracture planes).
- Initial CHILD mesh setup (Figure 2):
 - 40 x 40 km regular hexagonal mesh, with a 100 m horizontal resolution.
 - Flat ($\Delta h = 10$ cm) or gently sloped surface, with an initial elevation h_{ini} (100m, 200m).
 - Titan climate net precipitation at relevant latitude taken from [8].
 - Run over 10 millions of Titan years.

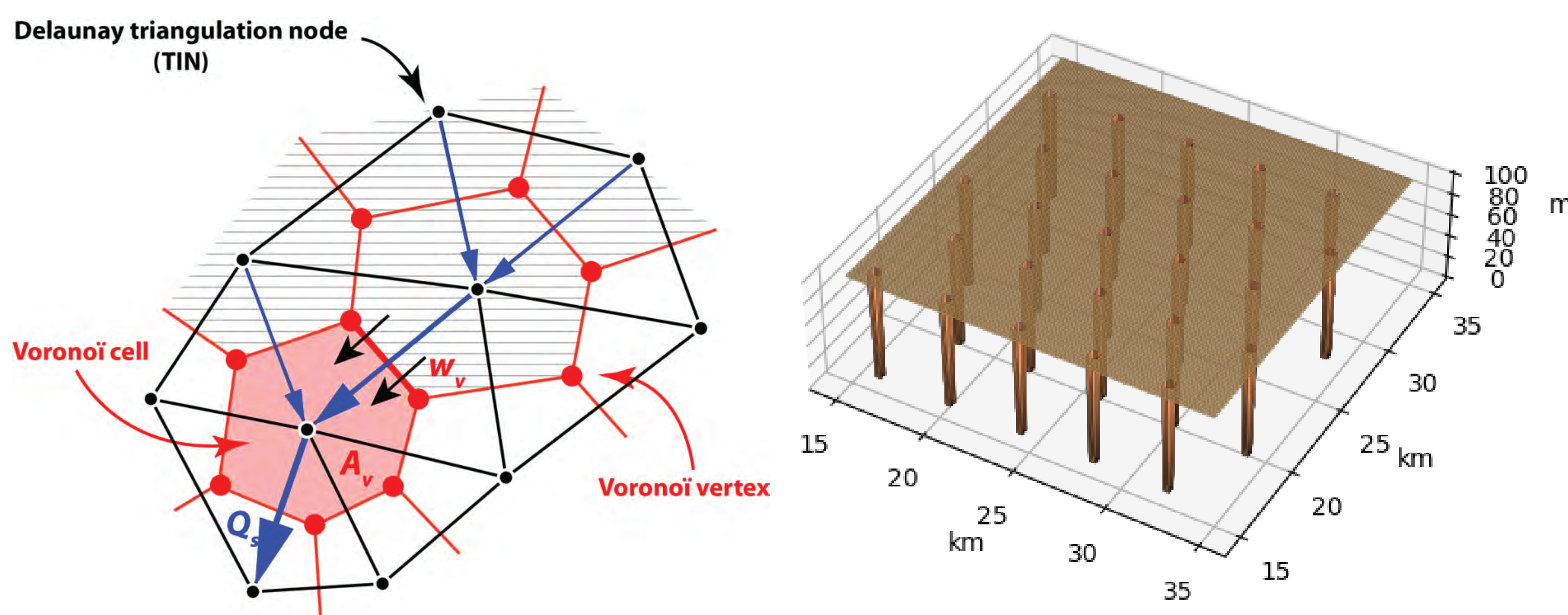


Figure 2: Initial CHILD mesh for a flat surface, and concept to track elevation changes. Changes in elevation and discharge (Q_s) are tracked from one node to the next downslope, each node being associated to a Voronoi cell with a given collecting area (A_v).

Methods: SAR images simulation

- Cassini observed Titan with the Radar in SAR mode in Ku-band ($f=13.7$ GHz, $\lambda=2.17$ cm).
- The measured microwave backscattering (σ^0) is primarily a combination of surface and sub-surface (volume) contributions depending on topography, roughness (via the correlation length L and RMS surface height σ), and composition (albedo a , dielectric constant ϵ) [9].
- We use surface and volume scattering models [9] to generate artificial SAR images from simulated topography.
- We validate the approach on the Cockpit Country area in Jamaica, test area of the CHILD modified model [7], using Sentinel 1A data (Figure 3). We adapt the radar and substrate properties to this terrestrial case to successfully reproduce radar SAR images of the area.

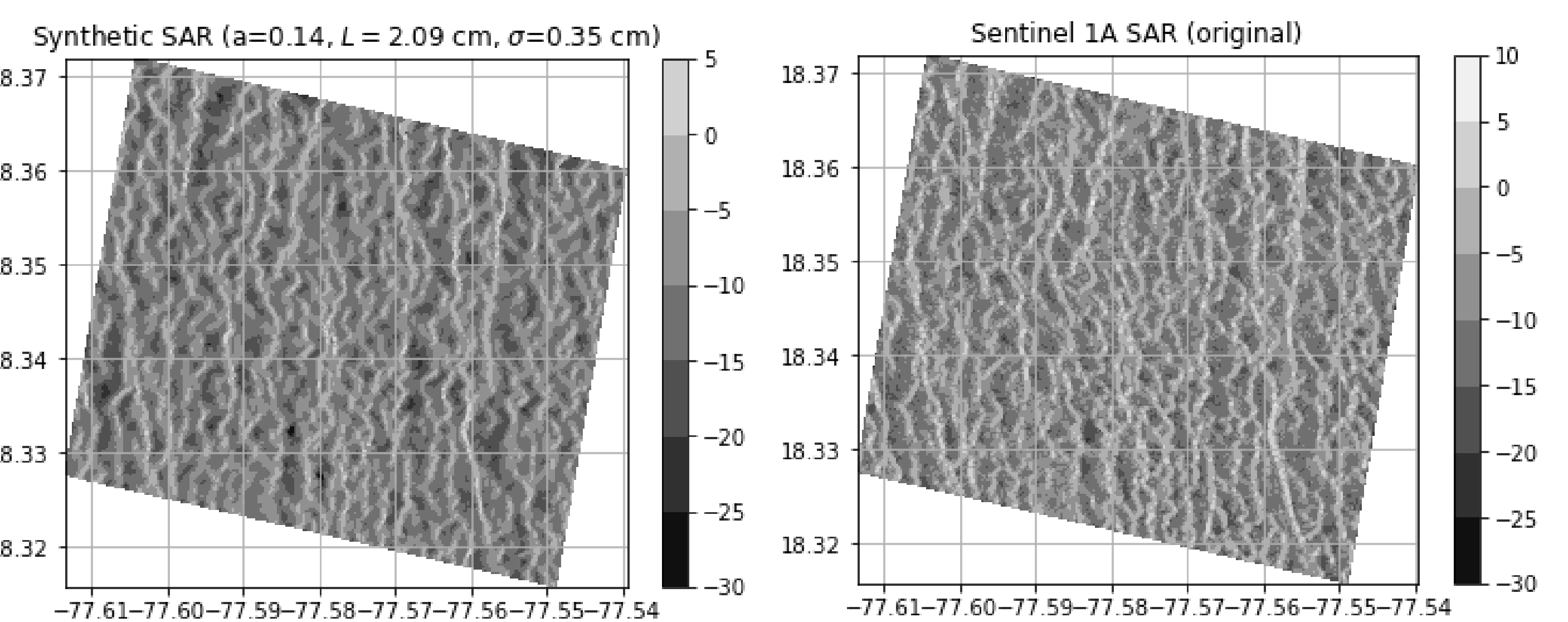


Figure 3: Radar SAR image of the Cockpit Country (Jamaica) reconstructed using the characteristics of real Sentinel 1A SAR data (C-band, look angle, altitude), SRTM topography, and limestone dielectric properties. Roughness parameters (σ , L) and albedo (a) inferred by fitting the backscatter distribution of the original S1A image. Colour scale in dB.

Results

Comparison of landscapes in Figure 4 shows:

- (A/C) Higher initial elevation favours the development higher residual hills.
- (A/B) Contrary to flat surfaces, slopes lead to the development of linear ridges.
- (C/D) For a set of geomorphological parameters (h_{ini} , K_D , and K_X), the number of sinks (\sim degree of fracturation) has little influence on the final landscapes.
- (C/E) Higher hillslope transport diffusion coefficients lead to the spread/smoothing of the topography, when coupled with another erosion mechanism (here dissolution).
- (E/F) Higher erosion rates (bulk dissolution) drastically increase the denudation speed of the landscape.

Future work

Future work will complete this parameters space study by expanding the range of values tested.

Quantitative comparisons with Titan labyrinths Cassini SAR images will be performed.

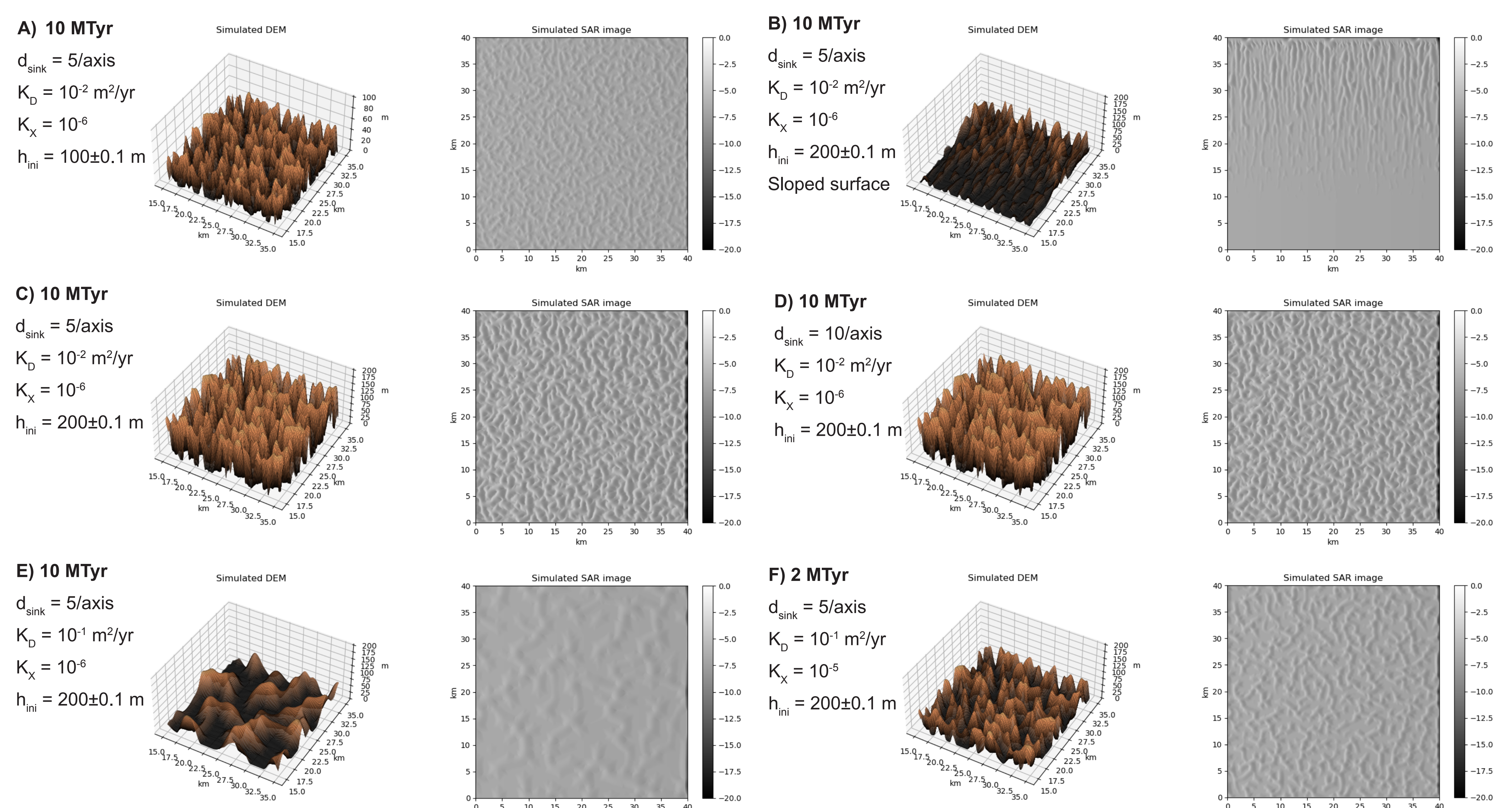


Figure 4: Contribution of the erosion rate via bulk dissolution (K_X), hillslope transport (K_D), fracturation (d_{sink}), initial elevation (h_{ini}), and slope on the resulting topography and simulated Titan SAR images (colourbar in dB).