SIMULATING THE EVOLUTION OF TITAN'S SURFACE THROUGH FLUVIAL & DISSOLUTION EROSION: I. THE BIG PICTURE. O.M. Umurhan[1,2], S.P.D. Birch[2], A.G. Hayes[2], M.J. Malaska[3]. [1]SETI Institute at NASA-ARC, MS 245-3, Moffett Field, CA, 94035 (orkan.m.umurhan@nasa.gov), [2]Cornell Center for Astrophysics and Planetary Science, Cornell University, Ithaca NY, [3]Jet Propulsion Laboratory, Pasadena, CA.

Introduction: Cassini SAR imaging of Titan's surface exhibits several landforms that appear to be shaped by fluvial erosion and alluvial/sediment transport. These landscapes include: vast river networks feeding Titan's many lakes and seas, their associated deltas, and alluvial fans. There are also places where sedimentary structures are expected, but not observed (e.g., terminus of channels entering northern seas). The coincidence of common sea-levels across several separated lacustrine landforms is suggestive of subsurface groundwater networks [1]. Most mysterious, are Titan's labyrinth terrain (e.g., Fig. 1A) which appear to have either been fluvially incised or surface-etched by dissolution and erosion, analogous in morphology to terrestrial landforms resulting from carbonate dissolution and sediment transport from flowing liquid H_2O that forms terrestrial karst (e.g., Pamukkale) [2]. The materials driving dissolution of Titan's labyrinth terrain are not exactly known but could conceivably include any solid organics that can be dissolved in ethane/methane liquid mixtures. Candidate organic materials, including their known degree of solubility and their estimated abundances on Titan, are: C_2H_2 (highly-soluble/very-abundant), tholins (nearly-insoluble/very-abundant), HCN (nearly-insoluble/abundant), C_2H_4 (highly-soluble/uncertain-abundance), and C_6H_6 (weakly-soluble except in n-butanes/moderate-abundance) [3].

Aims/Goals: Identifying and quantifying the relative importance of the primary array of physical processes responsible for shaping these varied landscapes -- *given Titan's observed precipitation pattern* [4] -- is central toward understanding how, to what degree, and with what efficiency organic materials are transported across its surface. In other words: how much organic transport occurs over Titan's surface over Milankovitch timescales [1] and what kind of broad implications will this have for the evolution of surface features and viability of biotic life on the moon?

Confronting this overarching question necessarily involves developing an evolution model that: (i) supports several possible parameter controlled physical processes, (ii) treats evolutionary scenarios on a Milankovitch timescale to include statistically variable amounts of yearly rainfall, and (iii) whose model output (e.g., degree of landform modification) can be statistically tested against Cassini SAR imagery of the landscapes of interest.

Methods: We have recently completed construction of a landform evolution model, based on the MARSSIM framework [5].Details of our model may be found in a parallel study presented at this meeting [6]. However, a summary of the suite of processes are the following: (i) a new and improved, highly efficient flow-routing routine simultaneously tracks several Lagrangian varying quantities contained in the fluid, including suspended load and dissolved species, (ii) a model for fluvial and slope erosion including bedrock weathering, nonlinear slope erosion via mass-wasting, and fluvial erosion and deposition involving the saltation of pebbles and boulders and the production and delivery of finer sediment loads, (iii) dissolution erosion by one or two chemically volatile materials with parameterized solubility and dissolution rates, (iv) groundwater flow through a multi-layered subsurface aquifer characterized by a certain amount of dissolution driven variable porosity and permeability. The evolutionary scenario involves invoking a probability distribution function of seasonal rainfall/evaporation rates based on the observationally validated output of the Titan Atmospheric Model [4] – also see [6].

Preliminary Numerical Experiments: We consider the surface evolution of a synthetically generated landscape (Fig. 1B) subjected to a fixed amount of precipitation from [4]. We consider the concurrent operation of mass-wasting, fluvial erosion and sediment transport, and dissolution erosion – the latter two of varying relative amounts. Our purpose here is to take the output eroded landscapes and degrade their appearance according to how it would be witnessed in Cassini's SAR image data (e.g., Fig. 1C). Fig 1D shows a perspective view of a model run with mixed amount of dissolution and fluvial erosion. Sediment builds up at local topographic lows and landscape etching by dissolution erosion, while pronounced, is relatively muted (Fig. 1E). Fig 1F shows the appearance of a model run with pure dissolution where the dissolved chemical species automatically goes underground once the flow reaches a topographic low. The landscape is deeply etched with high standing edifices emerging from chemical dissolution. Based solely on a qualitative evaluation, the resulting synthetic SAR image of this landscape (Fig. 1G) more closely resembles the labyrinth terrain shown in Fig. 1A.

Discussion and Directions: The results of the current evolution modeling are promising. Before performing long-term production simulations, we must constrain plausible input rates for dissolution and fluvial erosion. To this end we will implement a systematic test to quantitatively evaluate the resulting output landforms against imaging using an array of Chi-squared and Bayesian statistical analyses of slope, altitude and curvature distributions, to be discussed in an upcoming publication.

Acknowledgments: This research was supported by the NASA Astrobiology Institute through its JPL-led project entitled Habitability of Hydrocarbon Worlds: Titan and Beyond. We also thank Alan Howard for freely sharing with us his wisdom.

References: [1] Hayes, A.G., AREPS 44, 57-83, 2016. [2] Malaska et al., Icarus, submitted. [3] Cornet T. et al., JGR 120, 1044–1074, 2015. [4] Faulk, S.P., et al., Nature Astronomy, 2019. [5] Howard, A. D., Geomorphology 91, 332-63, 2007. [6] Birch, S.P.D. et al., LPSC 51, (this meeting) Abstract #xxx, 2020.

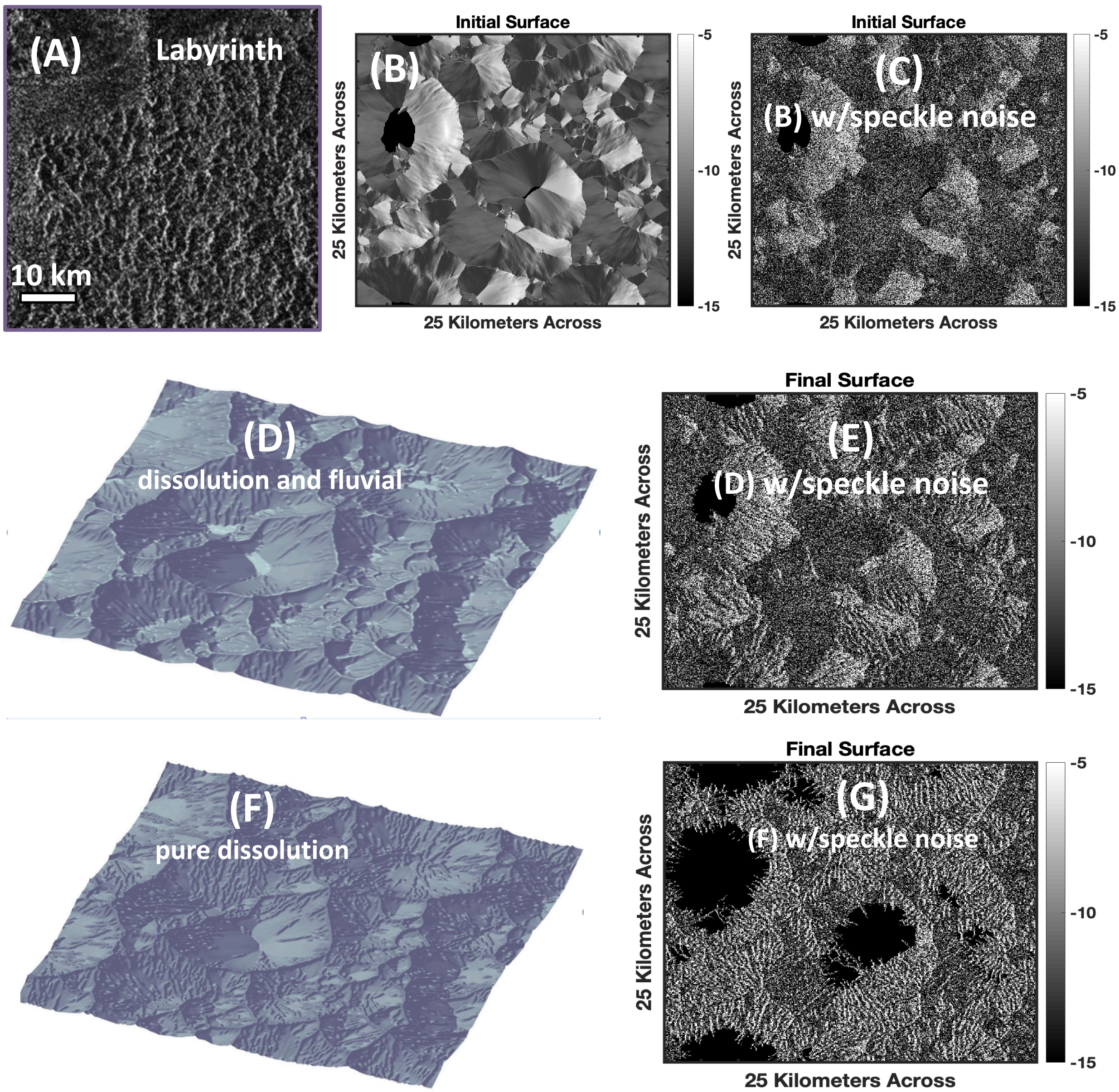

Figure 1. (A) SAR image of a section of Titan's labyrinth terrain. (B) A top down view of a sample synthetic terrain used in our modeling. An arbitrary sea-level has been placed. (C) Landscape in (B) degraded by speckle noise simulating as it would appear to SAR. (D) A perspective view of the result of a landscape model run with equal amounts of fluvial erosion and dissolution. (E) Top-down view of landscape of (D) degraded by speckle noise. (F) A perspective view of the result of a landscape model run with pure dissolution only. (G) Top-down view of landscape (F) degraded by speckle noise.