QUANTIFYING UNCERTAINTY IN INTERPRETATION OF TITAN'S FLUVIAL FEATURES.

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Introduction: Cassini's Synthetic Aperture Radar (SAR) imaged narrow, sinuous features on the surface of Saturn's moon Titan that are interpreted as hydrocarbon river channels or valleys (Figure 1). In many cases, the widths of these features are near the spatial resolution of Cassini SAR, complicating analysis of feature geometry and backscatter characteristics. These challenges can limit geomorphic interpretations and estimates for fluid transport on Titan's surface.

We use a two-part analysis to better quantify uncertainties in identification of fluvial features on Titan. In part 1, we build on an existing database [1] by adding measurements of feature geometry and associated radar backscatter data. In part 2, we use a terrestrial analogue study to test how spatial resolution and noise in radar data impact measurement accuracy.

Methods: A sample of 10 Titan fluvial features was selected for preliminary analysis, spanning polar (>60°N, <60°S) and equatorial regions, and with average feature widths less than one kilometer. We remapped these features and developed a software pipeline to systematically analyze feature width, continuity, and relative radar backscatter, and to compile this information in a database alongside the orientation and polarization of the associated radar pulse. Cassini SAR images can have significant speckle noise, so each measurement of radar backscatter was collected from a local average of pixel brightness. For features covered by multiple swaths of SAR data, we repeated the analysis for each SAR swath to enable comparison of feature characteristics as measured from different viewing geometries. We computed several statistics for each feature, including sinuosity and various SAR backscatter profiles (Figure 2).

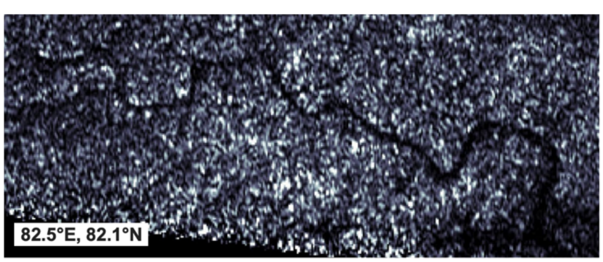

Figure 1. A Synthetic Aperture Radar (SAR) image of a fluvial feature on Titan, which has low radar backscatter compared to the surroundings.

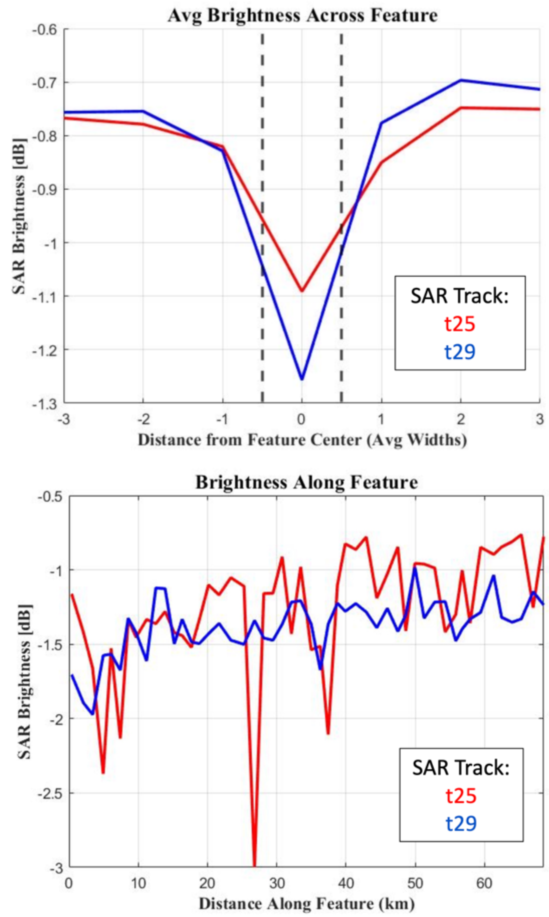

Figure 2. (top) Average profile of radar backscatter across the feature from two different SAR swaths. (bottom) Radar backscatter along the feature from two different SAR swaths.

To obtain an independent estimate of the error associated with resolving elongated features in Titan SAR imagery, we ran a complementary analysis on a set of terrestrial analogue sites. We used SAR observations of Earth across northern Alaska, northern Quebec, and northwestern Australia, which have limited vegetation and contain fluvial features with widths similar in scale as those on Titan. To mimic the characteristics of Titan SAR for the observations of terrestrial analogues, after [1] we degraded the data by both downsampling from 30 m/pixel to 350 m/pixel and introducing synthetic speckle noise (Figure 3). We then measured feature widths at evenly distributed sample locations, and quantified how well features were resolved by comparison to actual feature width measured from the undegraded imagery. By measuring features with widths that span values both smaller than and larger than the spatial resolution of the Cassini SAR dataset, we can identify the minimum width of a feature that is consistently resolvable and the corresponding uncertainty in feature geometry.

Results: Despite measurement noise, fluvial features on Titan show systematic differences in average radar brightness compared to their surroundings that are consistent across SAR swaths and with different viewing geometries (Figure 2). This consistency suggests that the radar backscatter trends can be reliably used to interpret landforms.

The terrestrial analogue analysis suggests that the widths of features narrower than 500 meters are overestimated, while features >500 meters wide are consistently resolvable to <5% error (Figure 4). All Titan features studied exceeded this threshold width and therefore, should enable robust measurements of feature geometry, continuity, and backscatter contrast.

Lacking detailed topographic data for Titan, we interpret Titan feature geomorphology using sinuosity. A sinuosity >1.5 cannot be explained by the random deviations in river path associated with irregular topography [2], but rather suggests active feature migration through meandering. Of this preliminary sample of Titan features, the majority have sinuosity values exceeding 1.5, and therefore are consistent with the channels of meandering rivers.

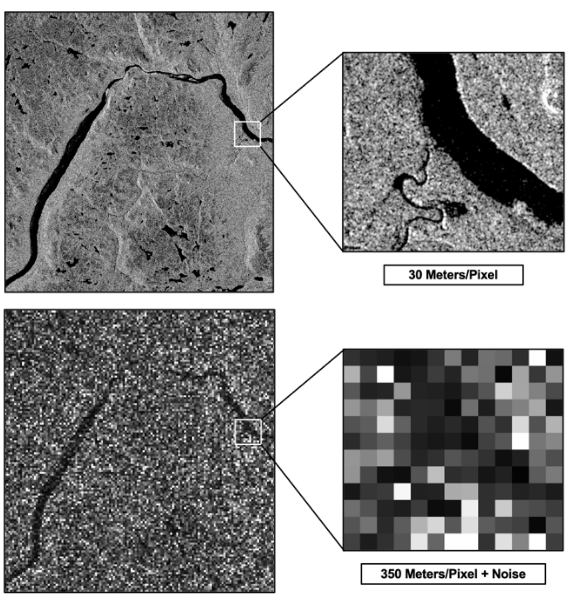

Figure 3. (top) A full-resolution SAR image of a terrestrial river in northern Quebec. (bottom) A degraded version of the image generated by reducing resolution and adding speckle noise, mimicking the characteristics of the Titan SAR dataset from Cassini.

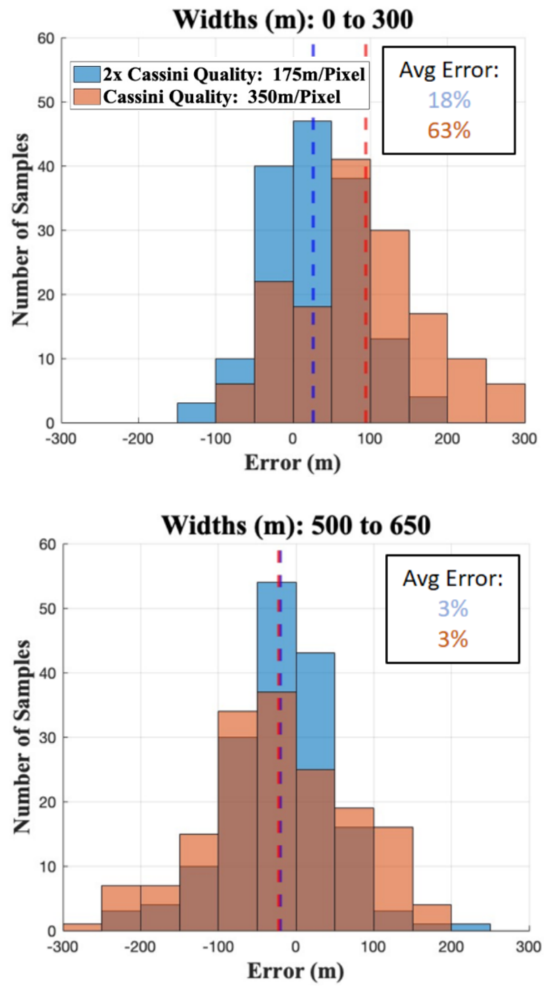

Figure 4. Distribution of measured feature widths using two degraded radar datasets with different resolutions. (top) Error is substantial and feature width is systematically overestimated for features less than 300 meters wide. (bottom) Measurement accuracy improves substantially for features at least 500 meters wide.

Discussion and Future Work: Most Titan surface features in this initial sample have the continuity, radar contrast, and sinuosity expected of rivers or dry riverbeds. The study of terrestrial Cassini analogue data suggests that these features are resolvable above a consistent scale of approximately 500 meters width. We will use this criterion to clarify the proportion of Titan fluvial features that can be confidently identified and compared to fluvial features on Earth and Mars.

Acknowledgments: This work is supported by NASA Solar System Workings Program (grant 80NSSC22K1380).

References: [1] Miller, J. W. et al. (2021), *Planet. Sci. J.*, *2*, 1-22. [2] Limaye, A. B. et al. (2021), *Geology*, 49, 1506–1510.