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DUNE SAND MIXING IN THE HUYGENS AND DRAGONFLY LANDING SITES REGION, TITAN.

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Introduction: As part of a largereffort to map and interpret the geological history of the greater Huygens Landing Site region (HSL) on Titan, which includes the planned Dragonfly mission landing site (Fig. 1A), we developed a method to model 0.93 μm reflectance (from the Cassini Imaging Science Subsystem (ISS)) and microwave emissivity (measured by the Cassini RADAR instrument) using radar-mapped terrains. This enabled a better understanding of the significant influence of aeolian deposition of dune material on non-dune Titan terrains.

Mapping: Our mapping technique starts with careful manual alignment of individual Cassini Synthetic Aperture Radar (SAR) swaths using the Huygens touchdown point in the T8 SAR swath as the reference point (Fig. 1A). We find that terrain contacts are held throughout the resulting SAR stack within 1 km error.

Next, we identified contacts and assigned terrain units as previously described for other Titan regions [1-4] at a working scale of 1:200,000 (Fig 1B) (The northern section of the greater HLS region was previously mapped in [1]). In order of spatial importance, the terrain unit classes are: dunes, plains, mountains/hummocky, and crater units. Each of these terrain classes were further subdivided as described in [1-4]. In the mapping at this large scale, lakes and labyrinth terrains were not identified.

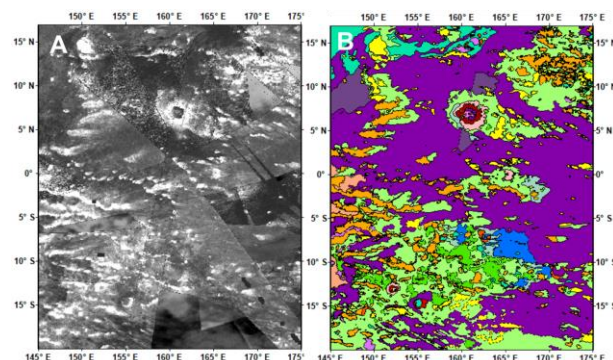


Fig. 1. A: Aligned SAR stack over the Huygens/Dragonfly landing site region. The white circular feature at image center is Selk crater. B: Mapped terrain units. Red/pink are craters, yellow/orange are mountain/hummocky, green/blue are plains, purple tones are dunes.

Terrain characterization: Following terrain unit identification, we extracted bulk-averaged infrared reflectance at 0.93 microns data and microwave emissivity values for each unit across the mapped region.

On comparing the bulk-averaged ISS and emissivity responses to the observed characteristics, we noted that the residual differences had a strong spatial correlation (Fig. 2A). In particular, the same terrain units had different measured responses based on whether they were situated in sand seas or in bright terrains; this spatial dependency was noted for all the terrain units examined. We successfully created an improved model using a combination of the material flux vector map [5], the location of terrain units with respect to dune class terrains, and empirical look-up values for the specific terrain units (Fig. 2B). The initial values for units in a given depositional zone were derived from area-averaged values from representative radar-defined terrain units.

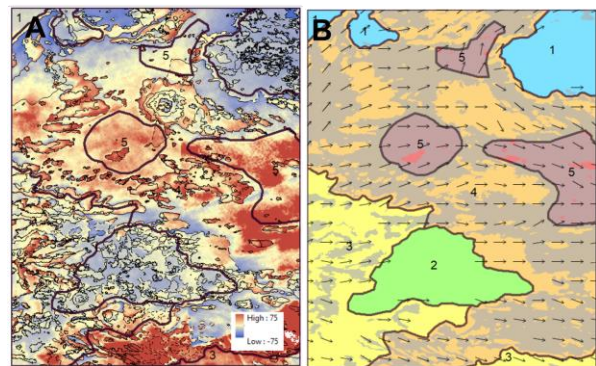


Fig. 2. A: Residual % difference between bulk averaged values and observed values in each terrain class. Terrain contacts are shown as fine lines. Depositional environments shown as thick lines. Note that the extensive sand seas unit residual varies across the span of the unit. B: Environment classification based on flux vector (arrows) and dune terrain class units (gray shade.) Numbers as described in text.

Terrain modeled characteristics: We identified five depositional environments for terrain units > 50 km² area in the greater Huygens/Dragonfly landing region (ref. Fig. 2B).

1. Higher latitude bright terrains with upwind divergent flux vectors (interpreted as exposure to the least amount of sand material).

2. Equatorially-situated bright terrains with upwind divergent flux vectors (minimal, but not zero dune materials passing through).

3. Equatorial bright regions with parallel flux vectors through the terrain (interpreted as medium amounts of dune materials passing through terrains).

4. Equatorial sand seas with parallel flux vectors (interpreted as high amounts of dune materials mixing with all terrains),

5. Equatorial sand seas with convergent flux vectors (interpreted as the highest amount of dune materials mixing with the terrains.).

Terrains that were less than 50 km^2 were placed into two classes, those in or directly adjacent to dune class terrains, and those in plains or mountain areas. The size limitation on these units characteristics is likely a factor of measurement resolution rather than actual mixing.

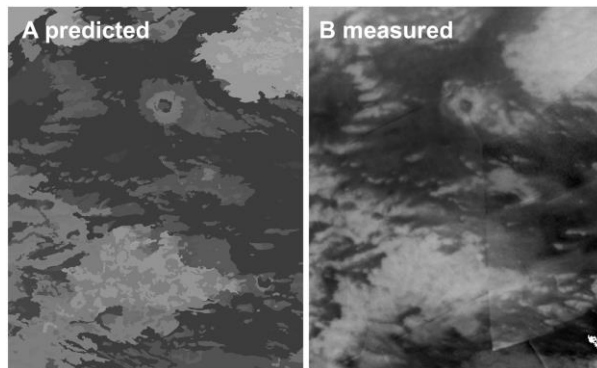


Fig. 3. Modeled (A) ISS response compared to (B) measured ISS response. Scale of pixel brightness in both images is 0 to 255. Mosaic from PIA9658: (<https://photojournal.jpl.nasa.gov/catalog/PIA19658>, credit: NASA/JPL-Caltech/Space Science Institute). Note mosaic artifacts at lower right.

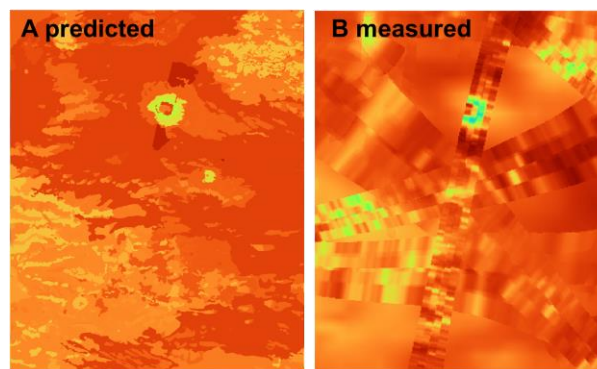


Fig 4. Modeled (A) microwave emissivity vs (B) measured emissivity at the same color scale of low (cold tones) to high (warmer tones). Selk crater (Dragonfly target) is the low-emissivity greenish circular feature above image center. Note artifacts in B from SAR swath outlines.

The resulting characteristics and maps from this improved model are shown in Fig. 3 and 4. By using only bulk average values across the scene, our predictions for the ISS response had a root mean square error (RMSE) of 38 (from pixel values of 0-255) and 0.019 of emissivity E. With the inclusion of environment zone, our improved predictions had an RMSE of 26 for ISS response and 0.015 units of emissivity E. (These calculated RMSE values are not weight-averaged and include terrains $<50 \text{ km}^2$).

For most terrains, there is a significant darkening in ISS response in going from environment zone 1 to 5. There is also a significant increase in overall microwave emissivity in going from environment 1 to 5. Both effects are consistent with increasing amounts of dune materials being mixed in all terrain units.

Conclusions and Implications: Our model and comparison with observations suggests that the observed ISS response and emissivity of a terrain unit in this region of Titan are strongly correlated to SAR backscatter and results from the intrinsic properties of that terrain unit coupled with the amount of dune material mixing in the local environment. This is predictable in advance with knowledge of the locations of dune terrains and inferred flux vectors. We find that the “purest” mountain and plains terrains are in the bright terrains located away from the dune seas with blocked or divergent flow on the windward side. The “dirtiest” mountain, plains, and crater units are located in the sand seas in locations with convergent fluxes into that environmental zone. This suggests that aeolian deposition is a major driver of the infrared and emissivity characteristics of terrains on Titan.

When interpreting the spectral and emissivity evolution of Titan terrains, the environment (and sand material delivery) may be a key contributing factor.

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References: [1] Malaska et al., *Icarus* 270 (2016), 130-161. [2] Lopes et al., *Nature Astronomy* 4 (2020), 228-233. [3] Schoenfeld et al., *Icarus* 366 (2021), 114516. [4] Schoenfeld et al., *JGR: Planets*, 128 (2023), e2022JE007499. [5] Malaska et al., *Icarus* 334 (2020), 113764.