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Stabilized Dunes on Titan as Indicators of Climate Change

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Abstract

Dune-like landforms (DLLs) have been detected at Titan's mid-to-high latitudes (which we define as the latitude band 40°-60°), similar in morphology to equatorial radar-dark features generally assumed to be dunes. DLLs have radar backscatter similar to that of surrounding materials, and we propose they are dunes that were once active but are now immobilized by moisture or cementation. Orientations (from 0° N) of these features are consistent across hemispheres, 100°-130° in the north and 25°-70° in the south. If the landforms are stabilized dunes, they provide new values for atmospheric modelers and give evidence of changing wind or humidity conditions across Titan.

1. Introduction

The Cassini spacecraft has imaged over 16,000 dunes on Titan with the Radar SAR instrument [1,2]. The dunes are linear in form with dimensions similar to those in Earth's large sand seas, such as in Egypt and Namibia [3]. Dune sands on Titan are dark to Cassini's 2.17 cm Radar because the dune surface is smooth, has a low dielectric constant and the sand is absorbing to radar at that wavelength, as is true for dunes in active dune regions on Earth (see Paillou and Bernard, this meeting). Often, the substrate beneath dunes does not carry the same radar characteristics so the dark dunes contrast strongly with the typically brighter interdunes [1,4] (Figure 1). Interdunes can also be relatively radar-dark, and in those cases it is assumed the interdune is covered in sand [1,4,5].

Dunes on Titan are found in a nearly continuous equatorial band from -30° to +30°, and rarely above those latitudes (Radar SAR coverage is widely distributed, and is close to 50%). Dunes appear to overly other morphological features, are considered to be among the youngest features present, and may have actively moving sands [5]. Their morphologies and interactions with topographic obstacles have shown that globally averaged winds at the tropics deviate slightly from W-E parallel to the equator [2,6]. The dearth of dunes at higher latitudes indicates winds here may not be sufficient for saltation, sand-sized particles may not be available in abundance, few stable collection areas exist (e.g., the onset of filled and unfilled lakes at higher latitudes indicate active hydrologic processes), or sands may have been stabilized against movement.

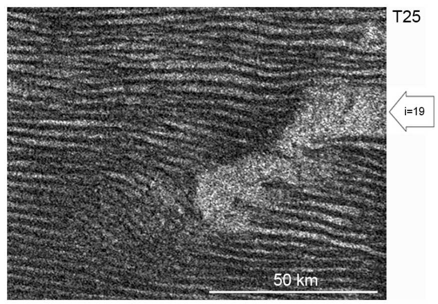

Figure 1: Radar-dark dune sands sit atop Radar-bright substrate in an equatorial region on Titan.

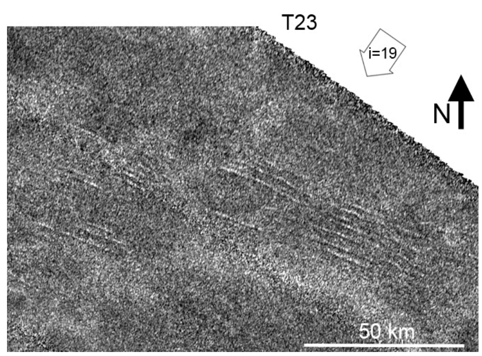

Figure 2: Potential stabilized dunes seen at 53 N, 43 W on Titan. Aside from illuminated slopes, the landforms have similar radar signal to surrounding materials.

2. Data

A small but significant number (Figure 2) of dune-like landforms can be found at mid-to-high latitudes on Titan, between 40° and 60°. These are similar in size and morphology to radar-dark dunes at low latitudes, yet they are not radar-dark; in fact, they have little to no contrast with surroundings. In many cases they are visible because the Cassini Radar SAR has illuminated a Cassini-facing slope, indicating the features are topographically elevated to heights similar to dunes at low latitudes. We measured the lengths and orientations of 169 features found in eight different locations at mid-to-high northern and southern latitudes to compare them with low-latitude dunes.

3. Results

Dune-like landforms are visible at mid-to-high latitudes in the Ta (51° N, 79° W), T18 (48° N, 352° W), T21 (40° N, 247° W), T23 (53° N, 43° W), T30 (59° N, 240° W), T50 (48° S, 342° W), T56 (59° S, 189° W), and T64 (42° N, 214° W) regions. The features have varying appearances and relationships with surrounding materials, and they all have widths of 1-2 km (appearing narrower than those at low latitudes, with no systematic measurements yet) and spacings of 2-4 km, like dunes on Titan. The average length of all 169 features is 31 km. DLLs in a sample low-latitude region with high-contrasting substrate have an average (all statistics are for 5x5 pixel samples) radar cross section σ_0=0.04, SD=0.06 while the interdunes have σ_0=0.83, SD=0.31. The dune-like landforms in Figure 2, at 53° N, have σ_0=0.26, SD=0.12, close to the average backscatter of bland, mid-latitude materials found nearby, with σ_0=0.19, SD=0.07. The mean orientations (from 0° N) of the dune-like landforms at mid-to-high northern latitudes is consistently 100°-130° and at mid-to-high southern latitudes is 25°-70°.

4. Discussion

The general morphology (length, width, spacing, height) of DLLs is similar to that of radar-dark dunes at the tropics. Additionally, the consistency of the orientations of DLLs in each hemisphere across a variety of latitudes strengthens the interpretation that these are dunes. No other landform is so broadly consistent in orientation on Titan, a factor that is related to the robustness of the global wind pattern. The mid-high latitude DLLs deviate more from E-W than the equatorial dunes, suggesting differences in the wind pattern at high latitudes. Incidentally, atmospheric circulation patterns are predicted to converge from high latitudes to low [6].

DLLs differ from equatorial dunes primarily in their radar backscatter, which is higher overall than that of low-latitude dunes and has negligible contrast to surroundings. Three main hypotheses for DLLs have emerged: the DLLs are composed of rough or porous materials (in contrast to smooth, absorbing organic dune sands), DLLs have thin sands, up to several meters, that allow the radar signal to penetrate through to the rough substrate, or DLLs are made of dune sands that have been stabilized by methane liquids or organic cements.

The first hypothesis could have been achieved by constructing DLLs with materials other than organics, such as water ice. This composition of sand would have a higher backscatter than organic sand, but there is still a lack of contrast with surrounding materials that is difficult to explain in terms of typical dune-forming processes. Sands should be organized into dunes and mainly not found in interdunes and surrounding terrains, yet the radar backscatter indicates similar materials across the DLL regions. Perhaps the DLLs formed by typical dune-forming processes and were then coated with atmospherically-derived organic materials that solidify with a higher surface roughness or dielectric constant. This coating would likely have to be meters thick or the radar signal would detect the underlying organic sands. The second hypothesis, that the DLLs are made of thin sands, is possible if the DLLs are currently in a sand-starved state, so that sand is actively being removed. If they are actively forming, dunes will grow to their limit, which at their width and spacing is to heights of about 100 m, as they have done across Titan [7].

We assert the final hypothesis, that DLLs formed of organic sands that were subsequently stabilized, is the strongest. Methane fluids could enter loose dune sands and thereby increase the density and thus the radar backscatter, as happens with wet sand on Earth, and thereby inhibit saltation. Methane could also carry dissolved organics and nitriles that precipitate within the dunes, creating cements and solidifying the dune forms, a process similar to the one that created the massive, dune-derived, bedrock layers of the Colorado Plateau.

Stabilized dunes are created when wind, humidity, or climate patterns have changed, leading to conditions no longer favourable for the active transport of sands [8]. Relative methane humidity is thought to increase toward polar regions, especially toward the north [9]. Dunes have a decreasing dune/interdune ratio toward higher northern latitudes, perhaps a result of increased humidity, which may anchor sands against movement [4], and/or introduce cements, causing the dunes to have similar radar backscatter to surrounding terrains. Given the long timescales for linear dune formation and evolution (tens of thousands of years on Earth), it is likely whatever process has stabilized the mid-to-high latitude dunes has persisted for longer than a single Titan season.

The possible presence of stabilized dunes on Titan indicates dune-forming processes are not exclusively equatorial. More recently, climatic or wind conditions may have changed at the mid-high latitudes, making this area less favourable to dune formation and evolution. Orientations of stabilized dunes provide atmospheric modelers with more data for wind directions at untapped latitudes, even if they are possibly winds from the past.

Acknowledgements

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