DETERMINING TIMESCALES OF THE DUNE FORMING WINDS ON TITAN.

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Abstract: Titan's linear dunes are a unique and robust record of past and present climatic conditions. The timescales (seasonal vs. milankovich) and direction of the surface winds that generated the dunes are two important components of climate. This work addresses challenges and outstanding questions pertaining to these climate components. We use Cassini Synthetic Aperture Radar (SAR) data to examine the interactions between the dunes and their environment in order to test the hypothesis that dune on Titan maybe in equilibrium with longer term (Milankovich) cyclic variations in the wind regime.

It is difficult to **not** form a line in the sand when a fluid moves loose granular particles of any composition. This statement reflects the paradigm of nearly the last 30 years of aeolian research on the formation of laboratory-to-landscape scale bedforms, indicating that patterns will emerge from grain interactions and self-organization regardless of differences in the fundamental variables affecting sediment transport such as gravity, fluid density and particle composition (Anderson, 1990; Werner, 1999; Kocurek et al., 2010). What is surprising, however, is that the individual patterns characteristics (e.g., length and spacing) are also independent of these environmental parameters. Building off the work of Ewing and Kocurek (2010), our initial analysis shows that the fundamental pattern parameters of dune fields found on Earth, Mars, and Titan are remarkably self-similar over a wide range of scales (Figure 1). Furthermore, dune fields that are not in equilibrium with respect to wind regime, sediment supply and sediment availability have pattern variables that are distinct from those that are in equilibrium, providing a method of discovery of degraded dune patterns. These observations provide a basis for applying established pattern analysis methods and models from Earth-based studies (Werner and Kocurek, 1997; 1999; Ewing et al., 2006; Ewing and Kocurek, 2010) to studies of Titan.

Previous work on Titan's dunes has established that the dunes are well-organized with regularly spaced crestlines at ~2 km, crestline lengths of 50+ km, approximate east -west orientations and crest heights reaching ~100 m (Lorenz et al, 2006; Radebaugh et al, 2010). Global variability in dune width and spacing are correlated with both latitude and elevation (Savage, 2010; LeGall et al., 2011; 2012). Variation in dune morphology is apparent from barchanoid forms that coincide with a decrease in sediment availability (Radebaugh et al, 2010). Despite the large amount of geomorphic

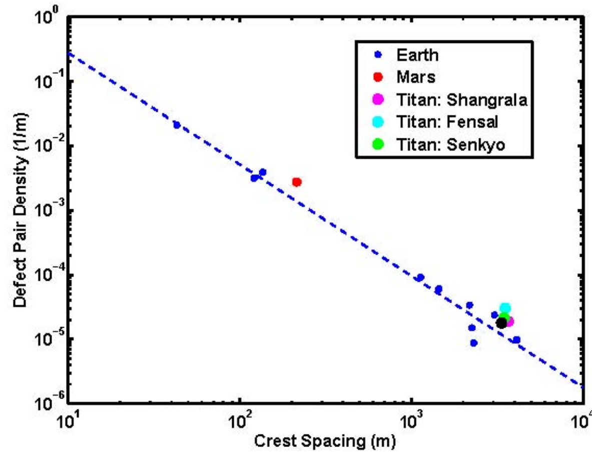

Figure 1: : Logarithmic plot of dune pattern vairables crest spacing vs. defect density on Earth, Mars and Titan. Defect density is the inverse of the average dune crest length. Note that the data points follow a similar power law relationship, irrespective of environmental conditions.

mapping done on Titan's dunes and the many successful contributions that have resulted from this work (e.g., Lorenz, 2006; Radebaugh, 2008; 2010), a mechanistically consistent explanation of the winds that generated dune field patterns is still missing. To date, interpretations of the dune forming surface winds on Titan have varied widely from unidirectional to obtuse bimodal (see review in Rubin and Hesp, 2009) and importantly, these cycling of these winds has been assumed to be seasonal. GCM studies find that seasonally varying westerly winds are meteorologically difficult to generate and the leading GCM-based hypothesis for the dune forming winds is that a tri-model wind regime, which has not yet been observed to generate linear bedforms (Rubin and Hunter 1987), may be responsible for the formation of Titan's dunes (Tokano et al. 2010). In summary, the current state of knowledge of the dune forming winds on Titan does not consider the possibility that Titan's dunes maybe in equilibrium with longer-term (Milankovich) cyclic variations in the wind regime.

In this work, we apply the crestline re-orientation model developed by Werner and Kocurek [Geology, 1997] to the equatorial dune fields of Titan. We use Cassini SAR images processed through a de-noising algorithm recently developed by Lucas et al. [LPSC, 2012] to measure variations in pattern parameters (crest spacing, crest length and defect density, which is the number of defect pairs per total crest length) both within and between Titan's dune fields to describe pattern maturity and identify areas where changes in dune orientation are likely to occur (or may already be occurring). Measured defect densities are similar to Earth's largest linear dune fields, such as the Namib Sand Sea and the Simpson Desert. We use measured defect densities in the Werner and Kocurek model to estimate crestline reorientation rates. We find reorientation timescales varying from ten to a hundred thousand times the average migration timescale (time to migrate a bedform one meter, ~1 Titan year according to Tokano 2010)). Well-organized patterns have the longest reorientation time scales (~10^5 migration timescales), while the topographically or spatially isolated patches of dunes show the shortest reorientation times (~10^3 migration timescales).

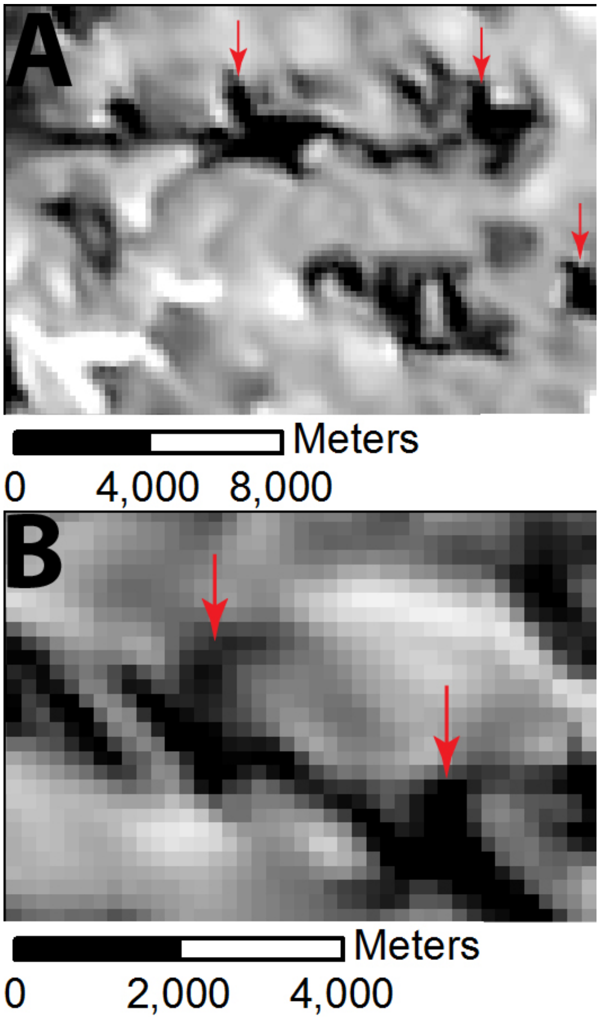

Figure 2: De-noised SAR image showing evidence for two distinct crestlines, incdicating a star dune morphology. Images have been de-noised by A. Lucas using the de-noising algorithm of Deladalle et al. 2009.

Morphologically, we find that barchanoid and star dunes occur in areas of the dune fields where the primary linear dune pattern is degraded (Fig 2. A and B) and that reoriented portions of the linear dune crestlines are found in both degraded and non-degraded areas. The most likely explanations for crestline reorientation are a change in wind regime or a reorientation resulting from the cycling of one component of a bimodal wind regime. Coupled to the results of the reorientation modeling, which suggested timescales of tens to hudreds of thousands of Titan years, this suggests that Titan's dunes may develop under bimodal winds that have a duty cycle greater than seasonal (e.g. 1 Titan season = 29 Earth years), an idea that is fundamentally distinct from current dune formation hypothesis.

Summary: Our preliminary results suggest that Titan's dunes may react to gross bedform transport over orbital timescales, relaxing the requirement that a single modern wind regime is necessary to produce the observed well-organized dune patterns. We find signals of environmental change within the smallest patterns suggesting that the dunes may be recently reoriented or are reorienting to one component of a longer timescale wind regime with a duty cycle that persists over many seasonal cycles.

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