DUNES ON TITAN: WIND DIRECTIONS, BEHAVIOR, AND EVOLUTION FROM STATISTICAL AND MORPHOLOGICAL STUDIES. J. Radebaugh[1], C.J. Savage[1], R.D. Lorenz[2], N. Lancaster[3], S.D. Wall[4], E.R. Stofan[5], J.I. Lunine[6], R.L. Kirk[7], A. Le Gall[4], T.G. Farr[4], [1]Brigham Young University, Department of Geological Sciences, Provo, UT 84602, *jani.radebaugh@byu.edu,* [2]JHU Applied Physics Lab, Laurel, MD, [3]Desert Research Institute, Reno, NV, [4]Jet Propulsion Laboratory, Pasadena, CA, [5]Proxemy Research Inc., Laystonsville, MD, [6]Lunar and Planetary Laboratory, Univ. of Arizona, Tucson, AZ, [7]US Geol. Survey Astrobiology Institute, Flagstaff, AZ.

Introduction: The tens of thousands of linear dunes organized into dune fields and sand seas on Titan imaged by the Cassini RADAR are emerging as a dominant landform [1,2] (covering an estimated 15% of the satellite [3]) and an indicator of perhaps active geological processes on this body. Statistical analyses of dune morphologies have proven fruitful in helping determine global and regional wind directions [4] and characterizing the current conditions and history of the dunes [5]. We study terrestrial dune analogues to pursue a solution to the puzzling discord between mean wind directions inferred from sand transport indicated by dune/topography interactions (W to E, or westerly [6]), and winds predicted by Global Circulation Models (GCMs) and from basic physics of angular momentum conservation (easterly [7]).

Wind Directions from Dune Morphologies: We rely on dune morphologies to determine wind directions, since there is only one short-lived set of in situ measurements from the Huygens probe. Linear dune long axes are modeled as aligned with the time-averaged dominant wind direction [2]. Long axes of 16,000 dune segments from the Cassini Prime Mission were mapped globally, with directionality determined from dune interactions with topographic obstacles [6]. The global dune long axis map (Fig. 1) shows most dunes are confined within 30° of the equator, and have orientations dominantly eastwards, with local and regional deviations of up to about 40° [4]. These results are anticorrelated with current GCM model wind directions [7].

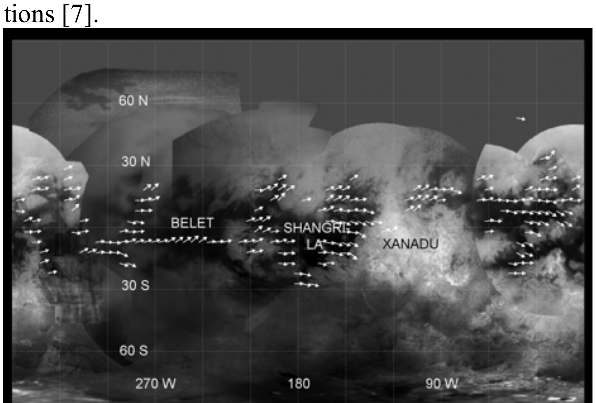

Fig. 1. Dune long axes from >16,000 measurements, binned into 5° intervals. Arrow heads come from analyses of dune interactions with topography. Global winds from these studies are eastwards, with regional deviations, such as that caused by Xanadu. From [4].

Dune Condition and History from Pattern Analysis: Using pattern analysis of dune field parameters, including crest-to-crest spacing and width, as has been done in terrestrial dune studies [8], it is possible to make preliminary inferences about the history of Titan's dunes. Parameter analysis reveals different dune populations, number of dune forming events, relative duration of stable dune building conditions and approximate age [8]. There is a general increasing trend between spacing and width of dunes on Titan from thousands of measurements in the equatorial leading hemisphere (RADAR swaths T21, T23, T25; Fig. 2). This correlates strongly with similar measurements of dunes from around the Earth [e.g., 9], and strengthens the idea that Earth's dunes may be used as a proxy for study of Titan's dunes [5].

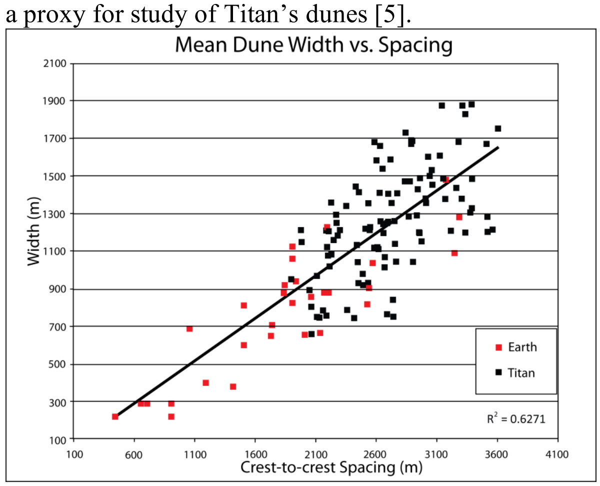

Fig. 2. Width and spacing of dunes from regions on Titan and Earth. Fit to a linear relationship with slope 0.5 for data for Earth and Titan together has an R^2 of 0.63, but is better for Earth alone (R^2 of 0.95) than for Titan (R^2 of 0.4)[5,9].

A study of crest-to-crest spacing of dunes on Earth reveals different populations within some dune regions, such as in the Namib Sand Sea, expressed as changes in slope on cumulative probability curves. These different populations may represent different periods of dune building, changes in wind strength or direction, or variations in sediment supply. No such inflections are observed in similar plots for Titan's dunes, which may indicate there is a single population of linear dunes on the satellite. Perhaps on Titan there are relatively uniform conditions over long time frames, or the most recent episode of dune building has erased evidence of previous conditions [5].

Wind Directions from Terrestrial Analogues: Several terrestrial dune regions with known wind data are robust morphological analogues to features observed on Titan. Studies of these regions should help more clearly determine wind directions on Titan from dune-topography interactions.

Dunes in the Saharan desert have a variety of forms, but are dominantly linear and are parallel to sand transport pathways, which, for the Saharan desert, are controlled by trade winds. Given these are stable over long time scales, dune forms in the Sahara are likely to be in equilibrium with current trade wind patterns [10].

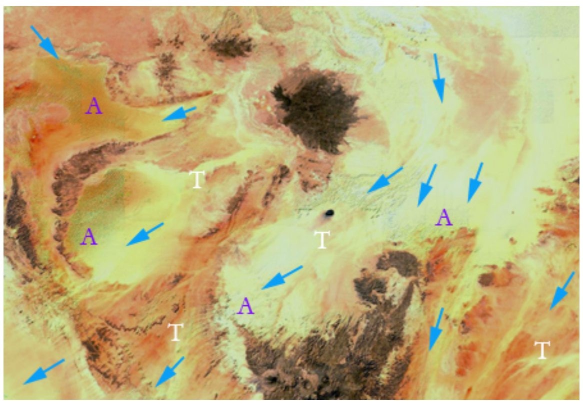

Fig. 3. Sand transport pathways for the Libyan Sahara (from [11]). Sand is yellow. Letters T indicate where transport dominates and A where accumulation is occurring. MODIS image from NASA.

Known current sand transport pathways, correlated with trade wind patterns [10], are shown for the Libyan Sahara in Figure 2. These pathways illustrate the transport of sand from northern mountains and rivers to the central and southern Saharan desert [11]. Here, sediment bypassing occurs over flat regions or through fluvial systems. However, locally, sand collects upwind of topographic obstacles, where winds decrease in strength and saltation is diminished [12]. Once sand begins to collect ahead of obstacles, the process feeds back and leads to upwind migration of the wind velocity minimum [11,12]. Thus, a local sand sink upwind of a topographic obstacle is established. The disruption of wind and collection of sand upwind of obstacles leads to a dearth of sand immediately downwind of obstacles and gradual regeneration of duneforms farther downwind. Results of these processes on landform morphologies – sand-rich vs. sand-sparse areas, obstacle-diverted dunes, and streaks indicating recent sand transport, can be seen clearly in a MODIS regional image (Fig. 3, marked A for accumulation areas) and ASTER close-up image (Fig. 4.a) [6].

These relationships are also seen on Titan, albeit at lower resolutions. In regions away from sand seas, dunes are clearly separated from interdunes, and sands appear to be primarily undergoing transport (Fig. 4b). Morphological comparisons of these dune regions with those in Libya indicate the sand transport direction and related winds are uniformly from the west to the east. These results are correlated with previous studies of wind directions based on dune morphologies [2,6] but are anticorrelated with current GCM model wind directions [7].

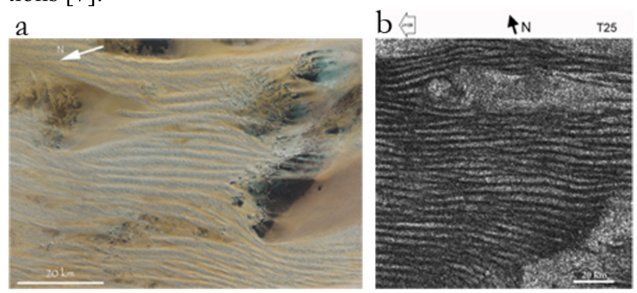

Fig. 4a. Closeup of dune forms in Libya seen in Fig.3. Sand transport is from left to right. 4.b. Similar morphologies in a Cassini radar image of dune forms in T25 region of Titan indicate sand transport direction is to the east (left to right).

Conclusions: The resolution and coverage of Cassini RADAR images have allowed us to pursue detailed pattern analyses of dunes on Titan and morphological comparisions with analogues on Earth. We are finding we can apply many of the methods that have been used for understanding the condition and evolution of dunes on Earth to Titan. It is likely we will find that Titan's dunes will help us approach a better understanding of linear dunes on Earth, their formation, and interaction with other geological features.

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