THE DUNES OF TITAN: A GLOBAL TRACING COMPENDIUM REVEALS LENGTHS, ORIENTATIONS AND CONTROLS. Jani Radebaugh[1], Madeleine Wright[1], Delaney Rose[1], Eric Christiansen[1], Jason W. Barnes[2], Elizabeth P. Turtle[3]. [1]Department of Geological Sciences, Brigham Young University, Provo, UT (janirad@byu.edu), [2]University of Idaho, Moscow, ID, [5]Johns Hopkins University Applied Physics Laboratory, Laurel, MD.

Introduction: Saturn's moon Titan contains vast fields of sand dunes, dominantly located at the equator between 30° N and 30° S latitudes [1, 2, 3]. Together with sandy areas, they cover up to 18% of Titan's surface area [4]. The dune and sand regions are organized into sand seas, drawing from the Earth tradition of categorizing the vast sand and dune deposits of the northern Sahara, Arabia and south Africa [5]. Titan's sand seas are divided almost equally by longitude, revealing the continuity of sand and dunes across the equator [6], punctuated by the paucity of sand at regional land masses such as Xanadu [7] (Plate 1). Upon closer examination, the distribution of sand and dunes across Titan is more sparse than rich, more shepherded and tendril-like than continuous (dark equatorial regions in Plate 1). We examine a global compendium of traces down Titan's dune long axes at the end of the *Cassini* mission to understand the dynamics of movement and collection within the sand seas.

Titan Dune Traces: Individual dunes are visible in *Cassini* Synthetic Aperture Radar (SAR) images, which cover ~50% of the surface in the sand seas. The resolution is close to the limit of dune observation, and several regions covered by SAR and hiSAR (high altitude, lower resolution SAR imagery) have images that seem to contain dunes but that are difficult or impossible to measure. Several other works have measured some portion of Titan's dunes, as end-to-end measurements of dune lengths [8], widths and spacings [9, 10, 11] or as representative summaries of dune orientations regionally [12]. Malaska et al. [13] measured dunes in ArcGIS for a global map and analysis. We also undertook measurements in ArcGIS Pro, with the specific aim of tracing dune long axes with as much precision as possible (Fig. 1), in all regions possible. The measurements were done by BYU undergraduate students Delaney Rose (now BYU MS student) and Madeleine Wright, with preliminary results in [14, 15]. At the time of writing, the Senkyo sand sea and several other small regions remain, making up ~10% of measurable dunes.

Dune Traces Reveal Patterns: Viewing dune traces is revealing for patterns, detail, and differences. While at first glance Titan's dunes appear extremely regular, parallel, long and straight, there are very few areas without interruptions or deviations to this order. Dunes in the Selk crater region of the Shangri-La sand sea, the landing site location for the *Dragonfly* spacecraft (Fig. 1), are highly parallel and straight to the SW, but they abruptly change direction south of the crater and become shorter and more discontinuous. Note that the dune traces are cut off by lack of SAR data on the west and middle of Fig. 1. Topography seems to control dune continuity and orientation [7]; the NW-SE trending mountain chain at image bottom abruptly stops dune passage and diverts them towards the north; additionally, Selk crater halts and steers the passage of dunes.

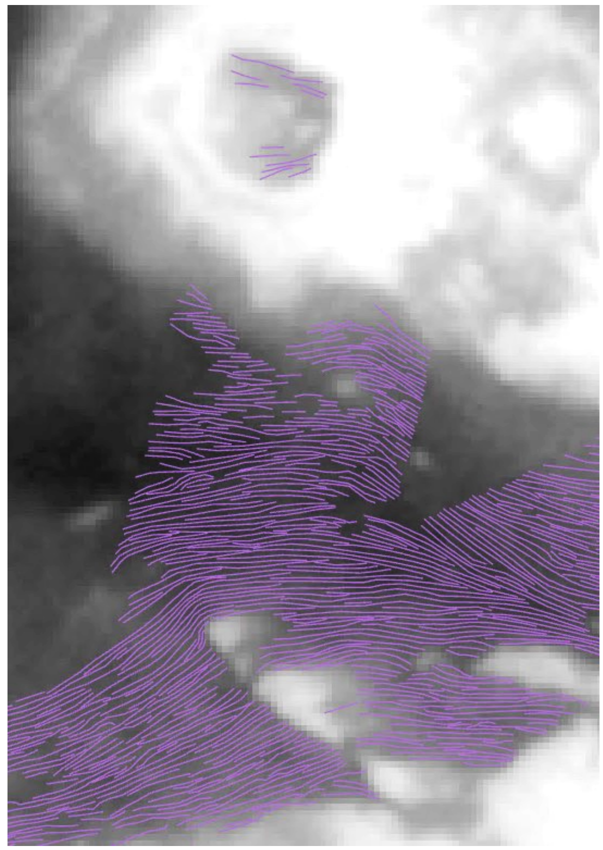
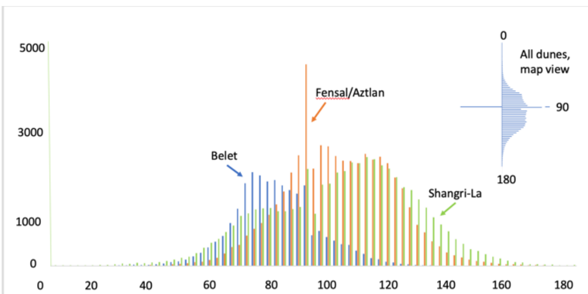


Fig 1. Dune trace detail from the Selk Crater region of Shangri-La. *Dragonfly* will land near image center. Elevated topography is bright in *Cassini* ISS image.

Dune Trace Statistics: Just over 25,000 undivided individual dunes have been measured across Titan, with most occurring in Shangri-La (11,717), then Fensal/Aztlan (8,758) and Belet (4,646) [15]. We estimate the measured dunes cover ~1/3 of the region containing dunes and sands. *Thus, we estimate there may number as many as 75,000 individual dunes on Titan.* The longest measured dune is 402 km in Shangri-La, though the challenge of measuring a single dune over a continuous SAR swath is high, so lengths are underestimated [15]. Lengths of Titan's dunes are high for this type of dune (linear or longitudinal [5]), perhaps indicating the freedom of ability of sand to be transported on Titan.

Orientation, or azimuth, is related to sand transport, in that dune orientation reflects wind orientation [8, 16, 12]. The dunes are considered to be the result of long-term sand transport down the dune long axis [12, 17, 18]. Titan dune orientation is dominantly E-W, though each sand sea has a median orientation slightly off E-W, as seen in Fig. 2. The dunes of Fensal/Aztlan are most E-W, while those of Belet skew towards the NE and those of Shangri-La to the SE (Fig. 2). The spread in azimuth reveals there are several changes to these orientations across each sand sea.



In fact, there appears to be a large-scale pattern to the dune orientations that crosses sand sea boundaries, perhaps related to global topography or wind patterns. Plate 1 shows all the dune measurements on Titan to date in green, purple and turquoise. Traced atop are regional scale patterns based on the orientations, shown as light green curves (deriving the patterns in Senkyo from images to be measured). Previous studies noted some of these trends, especially those towards the poles [13]. These new measurements additionally reveal equatorward transport and undulatory patterns on a global scale. These undulations could perhaps be controlled by gentle global elevation changes observed to occur on a similar scale; in general, Titan's dune long axes globally point towards the direction of low elevation, a process known as topographic steering and described previously for some locations on Titan [19]. Other, local-scale phenomena, such as mountain chains or impact craters may initiate deviations to dune orientations that persist over tens of degrees of longitude (Plate 1). Perhaps, also, there are atmospheric controls on wind movement that are not defined by landscapes. These dune maps and associated regional patterns could help feed into atmospheric models [12].

Titan Dunes – the Future: The completed dune long axis tracing compendium will be compared with *Cassini* remote sensing and topographic data and wind models, and Earth analogues – to solve the puzzle of how sand moves and collects across Titan.

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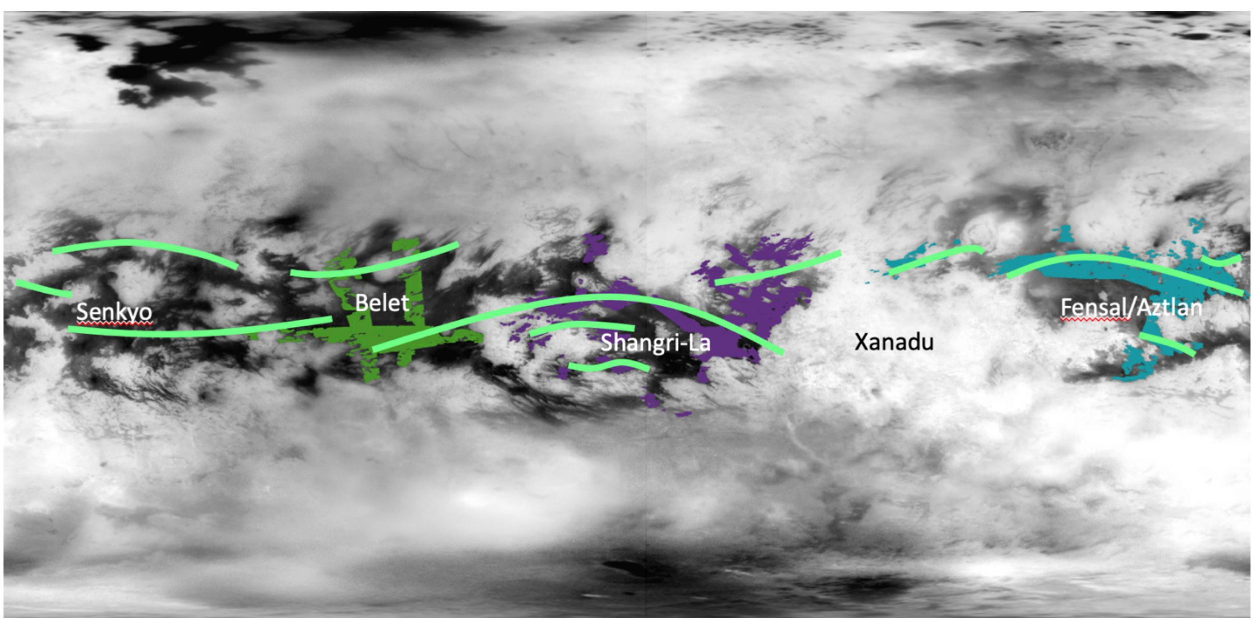

Plate 1. All dune measurements on Titan in green, purple and turquoise. Sand seas are labeled, as is Xanadu landmass. Light green lines indicate regional dune orientation trends. Basemap is ISS visible/near-IR from *Cassini*.