LONGITUDINAL DUNES ON TITAN AS INDICATORS OF GLOBAL CLIMATE. J. Radebaugh[1], R. Lorenz[2], J. Lunine[3], S. Wall[4], G. Boubin[3], E. Reffet[5], R. Kirk[6], R. Lopes[4], E. Stofan[7], L. Soderblom[6], M. Allison[8], P. Callahan[4] and the Cassini Radar Team,[1]Brigham Young University, Department of Geological Sciences, Provo, UT 84602 *jani.radebaugh@byu.edu* [2]Johns Hopkins University Applied Physics Lab, Laurel, MD [3]Lunar and Planetary Laboratory, Univ. of Arizona, Tucson, AZ 85721. [4]Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena, CA 91109 [5]LESIA-Paris Observatory, Meudon, 92195 France [6]US Geol. Survey Astrobiology Institute, Flagstaff, AZ [7]Proxemy Research Inc., Laystonsville, MD [8]Goddard Institute for Space Studies, New York, NY.

Introduction: The Cassini Titan Radar Mapper has uncovered thousands of longitudinal dunes on Titan's surface [1,2,3]. These features are themselves an indication of unique geologic conditions necessary for their formation and persistence. Additionally, dunes on Titan can be used to help us ascertain global wind patterns and Titan's climate, as we do on Earth and even Mars. Titan's unique possession, among the outer planet satellites, of a dense atmosphere makes it possible for Titan to have the dune-forming process in common with other atmosphere-bound solid bodies. We describe observations thus far of the dunes on Titan and their implications for wind directions and global climate.

Longitudinal dunes on Titan: Dunes on Titan, of the dominant form longitudinal or linar, are dark to both radar and optical instruments, such as VIMS and ISS [4,5], are 1-2 km wide, 1-3 km apart, ~100 m high, and 10 - >100 km in length [2-3, 5-8]. In this respect, they are similar in size to longitudinal (linear) dunes in the African Namib and Saharan deserts [9-11]. They are likely comprised of particulates of hydrocarbons and/or water ice and are found mostly near equatorial regions [2,3,5,12]. They show variations in lengths and spacings due to relative sand supply; more sand appears to be found in vast "sand seas" near the equator than at higher latitudes (Fig. 1). Titan's dunes also show evidence of diversion around topographic highs (Fig. 1) [2,3].

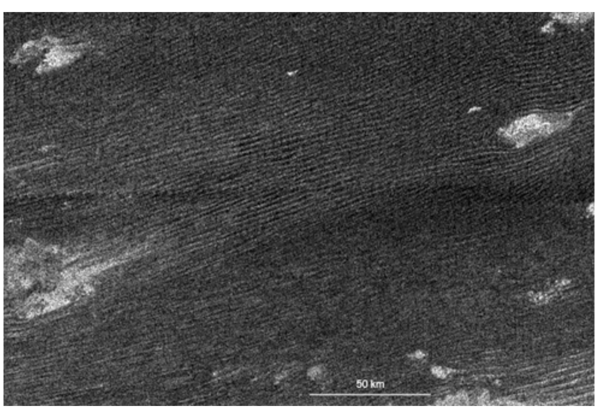

Fig. 1. A portion of the Belet sand sea, which extends nearly 2000 km. Dunes densely cover the underlying basement here, yet still divert around topographic highs. Image obtained during T8 (10/05), ~ 5° S, 250° W, ~175 m px^{-1}, radar illumination from the top (N).

Dune Orientations and Wind Direction: Longitudinal dunes form in Earth's deserts when winds are steady along a single direction parallel to the long axis of the dunes, with minor off-axis wind components that act to "shepherd" the dune particles [11,13-14]. Orientations of dune long axes thus correlate with local, surface wind directions. Orientations obtained for nearly 10,000 dunes on Titan have a mean azimuth (measured clockwise from N) of nearly 90° (Fig. 2), with slight variations by region, likely due to topographic interferences with wind directions. With the exception of these local variations, the generally 90° dune orientations and indicators from topographic interactions are likely direct reflections of the long-term mean wind direction of generally eastwards, extending from at least 30° N to 30° S latitudes.

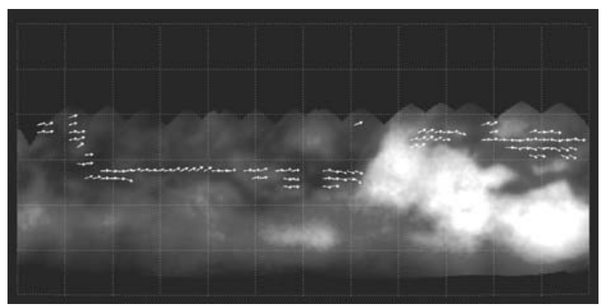

Fig. 2. Mean dune orientation vectors in 5°x5° boxes for all dunes seen on Titan through T19 (10/06). Dunes indicate a general W-E wind direction, but also show evidence of diverging around topographic features.

Titan's Global Climate: We seek to understand how the dunes on Titan can inform our understanding of Titan's climate. Dunes typically form on Earth in deserts, defined by their lack of a threshold yearly precipitation level. Thus, it is tempting to relate the presence of dunes on Titan to conditions of low precipitation. Direct measurements obtained at the Huygens landing site, however, which was near the equator and was in view of some dunes, revealed ambient methane humidity levels of 50% [15,16] and the GCMS measured evaporation of methane and ethane liquids [17]. This seeming paradox of dunes present in conditions of moderate humidity is considered in the context of terrestrial desert distributions and cyclical processes. Deserts on Earth are usually found near 30° N or S, due to the intersection of the dry, downwelling branch of the Hadley cell with the Earth's surface. On Titan, however, an asymmetric circulation regime has been modeled, in which there is upwelling at the summer pole and downwelling elsewhere [18]. Thus, low latitudes are generally dry, except when seasons change and polar summer shifts, bringing a temporary symmetric circulation regime and rainfall to the equator. A more recent zonally-averaged model of Titan's climate [19] explicitly shows that sporadic rainfall can occur at low latitudes, yet the ground there generally becomes dessicated. The frequency of rainfall and the latitude band that becomes dessicated depends on the total methane inventory in the climate system.

Evidence of the viability of this model of generally dry conditions at the equator exists in the myriad dry riverbeds populating Titan's equatorial regions [17], similar to river basins in the US desert southwest that are generally dry except during brief summer storms. In addition, recent general circulation models [20] predict low humidities at low latitudes and damp conditions near the poles. This is consistent with recent observations of lakes at Titan's north polar regions [21,22].

The importance of relative humidity is overshadowed by the dominant factors in dune formation: sufficient wind and adequate sediment supply. Given that some lakes at Titan's polar regions appear to be fed by channels [21,22], we assume that fluids also carry sediments in channels to be deposited into lake basins. In contrast, generally dry regions near the equator are free of sediment-trapping lakes. Instead, it appears that broad, perhaps locally low-elevation regions near the equator collect sediments that are subsequently reworked into dunes.

Thus, the major factors of generally low humidity, adequate sediment supply, sufficient winds, and absence of sediment trapping (in the form of rivers washing away sediments, or basins containing fluids) must be considered together to explain the presence or absence of dunes on Titan. Based on observations of dunes at Titan's equatorial regions and lakes at the north pole, a global picture of Titan's climate is beginning to emerge. It appears that methane rainfall occurs at Titan's winter pole [21], while generally dry conditions prevail at the equator. Local variations on this theme, such as the humidity observations at the Huygens landing site and some dry lakebeds at the north polar regions [22], highlight the Earth-like complexity of Titan's surface and atmospheric processes.

References: [1] Elachi, C. et al., 2006, *Nature* 441, 709-713. [2] Lorenz, R. D. et al., 2006, *Science* 312, 724-727. [3] Radebaugh, J. et al., *Icarus* submitted. [4] Porco, C. et al., 2005, *Science* 434, 159-168. [5] Soderblom et al., 2007, *PSS*. [6] Kirk, R. D. et al., 2005, *LPSC XXXVI*, Abst #2227. [7] Boubin, G. M. et al., 2005, *AAS DPS 37*, Abst #46.04. [8] Callahan, P., et al., 2006, *AGU FM* Abst #P13A-0165. [9] Spencer, C. et al., this conference. [10] McKee, E. D., 1982, USGS Spec. Pap. 188. [11] Lancaster, N., 1981, *Sedimentology* 1,1-8. [12] Radebaugh, J., et al., 2006, *AGU FM* Abst #P12A-03. [13] Fryberger, S. G. and G. Dean, 1979, *USGS Spec. Pap.* 1052. [14] Lancaster, N., 1995. [15] Tomasko, M. G., e.a., 2005, *Nature* 438, 765-778. [16] Niemann, H. B., et al., 2005, *Nature* 438, 779-784. [17] Lorenz, R. D., et al., 2007, *PSS*, in rev. [18] Hourdin, et al., 1995, *Icarus* 117, 358-374. [19] Mitchell, J. L. and R. D. Lorenz, EGU Conference, April 2007. [20] Rannou, P., et al., 2006, *Science* 311, 201-205. [21] Stofan, E. R., et al., 2007, *Nature* 445, 61-64. [22] Mitchell et al. in prep.