OUT OF AFRICA: RADARCLINOMETRY OF THE SAND SEAS OF NAMIBIA AND TITAN. C. D. Neish[1], R. D. Lorenz[2], and R. L. Kirk[3], [1]Lunar and Planetary Laboratory, University of Arizona, 1629 E University Blvd., Tucson, AZ 85721, cdneish@lpl.arizona.edu, [2]Applied Physics Laboratory, Johns Hopkins University, Laurel, MD 20723, ralph.lorenz@jhuapl.edu, [3]United States Geological Survey, 2255 N Gemini Drive, Flagstaff, AZ 86001, rkirk@usgs.gov.

Introduction: Recent observations by the Cassini spacecraft show widespread regions of longitudinal dunes on Saturn's moon Titan [1]. The exact composition of the dunes is not known, but its radar and infrared return suggest an organic component [2]. Given the broad extent of the dunes (they cover 40% of Titan's equatorial areas), they constitute an important portion of Titan's overall organic inventory.

To determine the exact volume of dune sands on Titan, it is necessary to estimate their heights over large areas. The height and spacing of dunes also provides information about the depositional environment in which the dunes were formed [3]. Given the paucity of altimetry data available on Titan, the best constraint on the height of the dunes comes from backscatter variations visible in high resolution SAR (synthetic radar aperture) images taken by the Cassini spacecraft.

Radar images of planetary surfaces provide a wealth of information about the surface being imaged, since radar backscatter depends on three surface properties – topography, roughness, and composition. Because of the dependence of radar backscatter on local incidence angle, an individual SAR image can reveal topography by radarclinometry, or "shape-from-shading" [4]. This technique is limited in the sense that radar backscatter does not depend exclusively on topography, but also on roughness and composition.

Sand seas (with sand-covered interdune areas) make excellent targets for radarclinometry, since they are essentially uniform in composition, and somewhat uniform in roughness. This makes topography the only changing variable, so differences in radar backscatter can be interpreted as differences in local incidence angle with some confidence. Radarclinometry has been performed on the longitudinal dunes observed on Titan, yielding slopes of 6 to 10 degrees, and heights of 100-150 m [1].

Nonetheless, given the assumptions and approximations inherent in radarclinometry, it is instructive to validate the technique using independent sources of topography, where such sources are available. This gives us an understanding of how robust the technique is when applying it to planets where independent sources of topography are limited or unavailable, such as Titan. The spacing and height of the dunes on Titan appear to be similar to the dunes observed in the Namib desert of western Africa. This region has been imaged by both Spaceborne Imaging Radar (SIR-C)

and the Shuttle Radar Topography Mission (SRTM), providing independent SAR and topography data.

In this work, we perform radarclinometric analysis of the SIR-C images of the Namib sand sea, and compare the resultant height profiles to topography data from the same region. We then use this technique to estimate the height of dunes on Titan. In this way, we judge the reliability of radarclinometry in determining the topography of sand dunes.

Method: To carry out any form of radarclinometry, a functional relationship between surface slopes and image signals is required. These scattering models describe the radar backscatter function, σ_0, as a function of local incidence angle, i. For the Namib desert, we used the scattering model given for smooth, gently sloping, dry desert sand in Ruck et al. [5], scaled to the observed changes in backscatter over the SIR-C radar image. For Titan, we used a scattering model developed by Wye et al. [6], fit to scatterometry data from dune areas on Titan (Equation 1).

$$\sigma_0(i) = \frac{\rho_1 C_1}{\cos^4(i)} \exp\left(C_1 \tan^2(i)\right) + \frac{3\rho_2 C_2}{\cos^4(i)} \exp\left(-\sqrt{6C_2} \tan(i)\right) + A\cos^n(i) \quad (1)$$

Once a suitable scattering model was obtained, the observed backscatter profiles across the dune fields were inverted to obtain the associated incidence angles from the backscatter law. A topographic profile was then constructed from the set of calculated angles. An example radarclinometric dune profile from the Namib desert is shown in Figure 1, with the corresponding topographic profile for comparison.
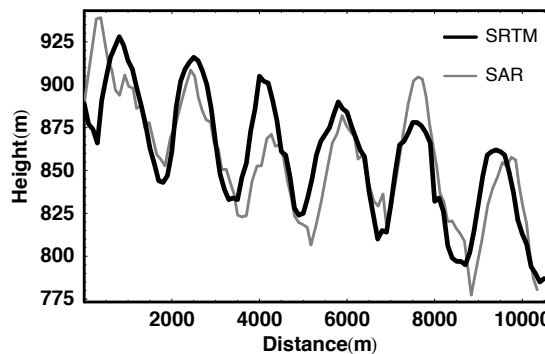

Figure 1: Radarclinometric profile from a region in the Namib desert (PR44422S), with corresponding SRTM data for reference.

Results: We completed radarclinometric analysis of four separate regions in the Namib desert (Figure 2), and one region on Titan (Figure 3). The regions in Namibia represent two areas with continuous sand cover and both SIR-C and SRTM coverage (PR44419N and PR44422S), one area with variable sand cover and both SIR-C and SRTM coverage (PR44422N), and one area with continuous sand cover but no SRTM coverage (PR44419S). In some areas, the Namib dunes are too dark to provide meaningful radar interferometry. This latter case is analogous to the situation on Titan, where no independent topography data is available.
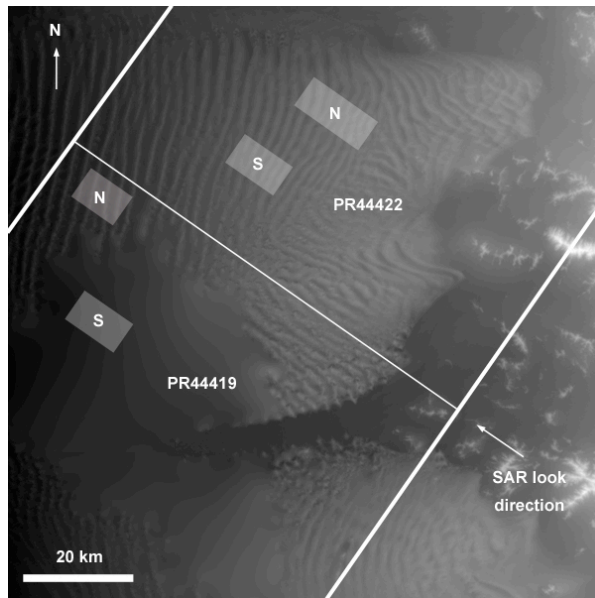

Figure 2: SRTM image of the Namib sand sea, showing the location of the two overlapping radar strips (PR44419 and PR44422), and the four regions of study.
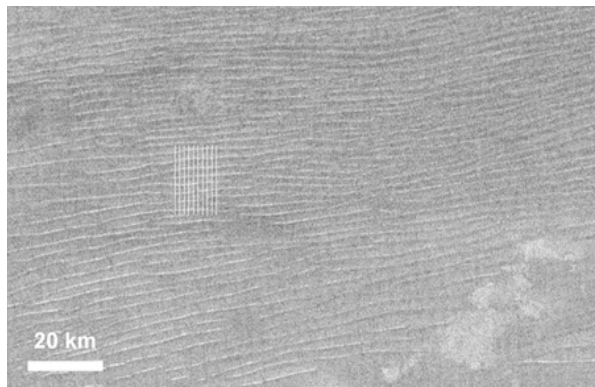

Figure 3: Portion of the Cassini T8 RADAR strip, showing the location of the ten radar profiles considered in this work.

For each region in the Namib desert, we conducted radarclinometry at three separate resolutions – 25 m/pix (the native SAR resolution), 100 m/pix (the SRTM resolution), and 350 m/pix (the Cassini RADAR resolution). For those areas with corresponding topography data, we found there was a significant decrease in least square residuals between radarclinometry and topography data when resolution was increased from 350 m/pix to 100 m/pix, but limited or no decrease when resolution was increased from 100 m/pix to 25 m/pix. Additional noise may be introduced at higher resolution, or the size of the dunes may not require resolutions lower than 100 m/pix to provide meaningful topography. Regardless, it seems that resolutions less than 100 m/pix are not required to obtain reliable topography of Titan's sand seas.

We also determined average height and dune spacing for the dune fields, using either topography provided by SRTM, or topography determined from the SAR images. The results are given in Table 1. They are compared to the range of dune heights and spacings for complex linear dunes encountered in the Namib desert [4].

Dune Region	Data Set	Dune Spacing (km)	Dune Height (m)
PR44419S	SAR	2.5	86
PR44419N	SAR	2.5	79
	SRTM	2.5	115
PR44422S	SAR	1.6	67
	SRTM	1.6	67
PR44422N	SAR	1.8	57
	SRTM	1.8	67
Titan T8	SAR	2.3	152
Namib Complex Linear Dunes	Direct measure	1.6 - 2.8	80 - 120

Table 1: Average dune spacings and heights determined for several regions in the Namib desert and on Titan by radarclinometry (SAR) and topography (SRTM) measurements.

Height estimations by radarclinometry are representative of, but may underestimate by as much as 30%, the true height. This error may be due to slope-dependent roughness effects, or penetration through the interdune sand cover. Alternatively, the finite resolution of the images may lead to underestimation of dune height [7]. If similar effects prevail on Titan, the height of the Belet (T8) dunes may exceed the 150 m reported previously.

References: [1] Lorenz R. D. et al. (2006) *Science, 312,* 724-727. [2] Lorenz R. D. et al. (2008) *GRL, 35,* L02206. [3] Lancaster N. (1989) *The Namib Sand Sea,* A.A.Balkema Publishers, Brookfield, VT. [4] Wildey R. (1986) *Earth, Moon, and Planets, 36,* 217-241. [5] Ruck G. T. et al. (1970) *Radar Cross Section Handbook*, Plenum Press, New York, NY. [6] Wye L. et al. (2009) *Icarus*, in preparation. [7] Kirk R. L. and Radebaugh J. (2007) *ISPRS Working Group IV/7 Workshop*.