A New Approach to Sand Volume Estimates on Titan from Cassini SAR and ISS

K. Arnold[1], J. Radebaugh[1], and E. H Christiansen[1]

[1]Brigham Young University, Department of Geological Sciences, Provo, UT 84602, *karlarnold17@gmail.com*

Summary

Dunes are a dominant landform on Saturn's Earth-like moon, Titan, covering as much as 15 – 20% of its surface. Data collected since the Cassini spacecraft arrival in 2004 indicate that dunes are linear in morphology and represent the results of major, global atmospheric and surface processes, similar to dunes in Earth's Namib, Saharan, and Saudi Arabian deserts [1,2,3].

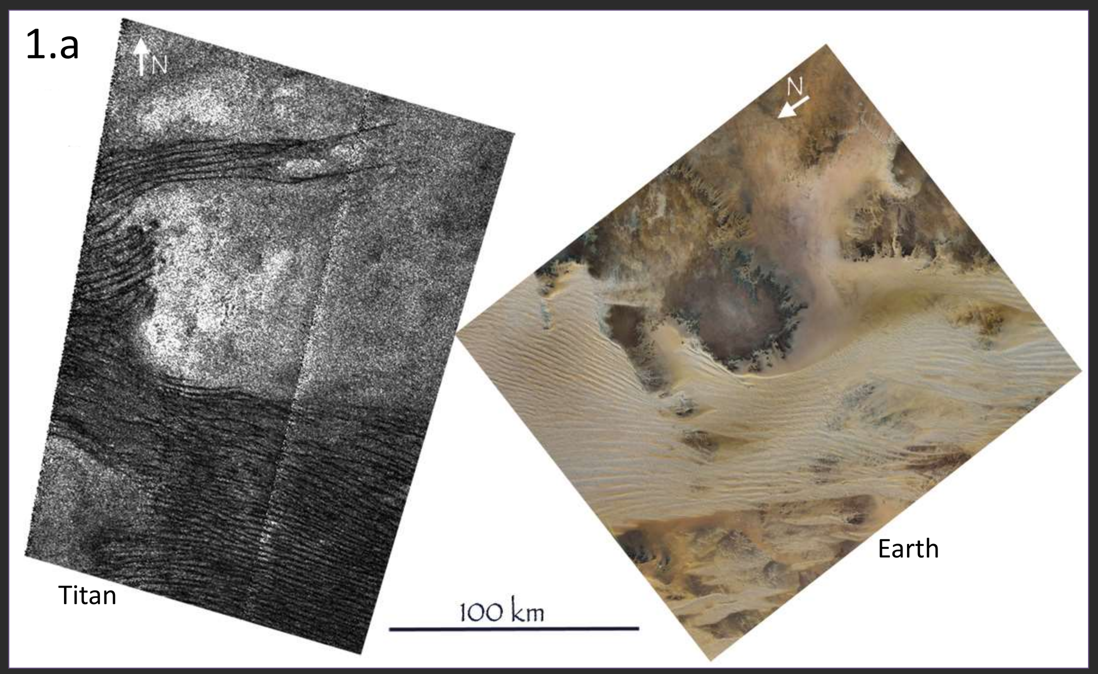
In this study, we produce the first direct measurements of the coverage of sand seas on Titan using both Cassini Synthetic Aperture RADAR (SAR) and Imaging Science Subsystem (ISS) data. Geomorphic characteristics in Cassini SAR images are used with Cassini ISS spectral data to interpret global dune field coverage. Additionally, a new volumetric model is described that includes dune characteristics measured by other researchers, such as dune height [2,4], width and spacing [6]. This new model will allow us to observe volume changes in each of Titan's 5 sand seas and sediment transport pathways across Titan's equatorial regions.

Importance

- Studying dune morphology will help us to better understand atmospheric processes on Titan.
- Estimating dune volume increases our understanding of the production of organics on Titan and Titan's methane cycle.
- Morphologies and relationships between dunes and interdunes will lead to an understanding of the movement of liquids on Titan's surface and near-subsurface.
- Studying Titan's major surface features will help us understand how processes under different conditions lead to Earth-like morphologies.

Dunes on Titan

- Similar in size, radar reflectivity, and morphology to dunes on Earth.
- Equatorially bounded by +/- 30 latitude
- Radar dark and linear in morphology in Cassini SAR (Fig 1.a)
- Dark in Cassini ISS global mosaic (Fig 1.b)
- Key to understanding active and past atmospheric and surface processes



(Radebaugh et al., 2010)

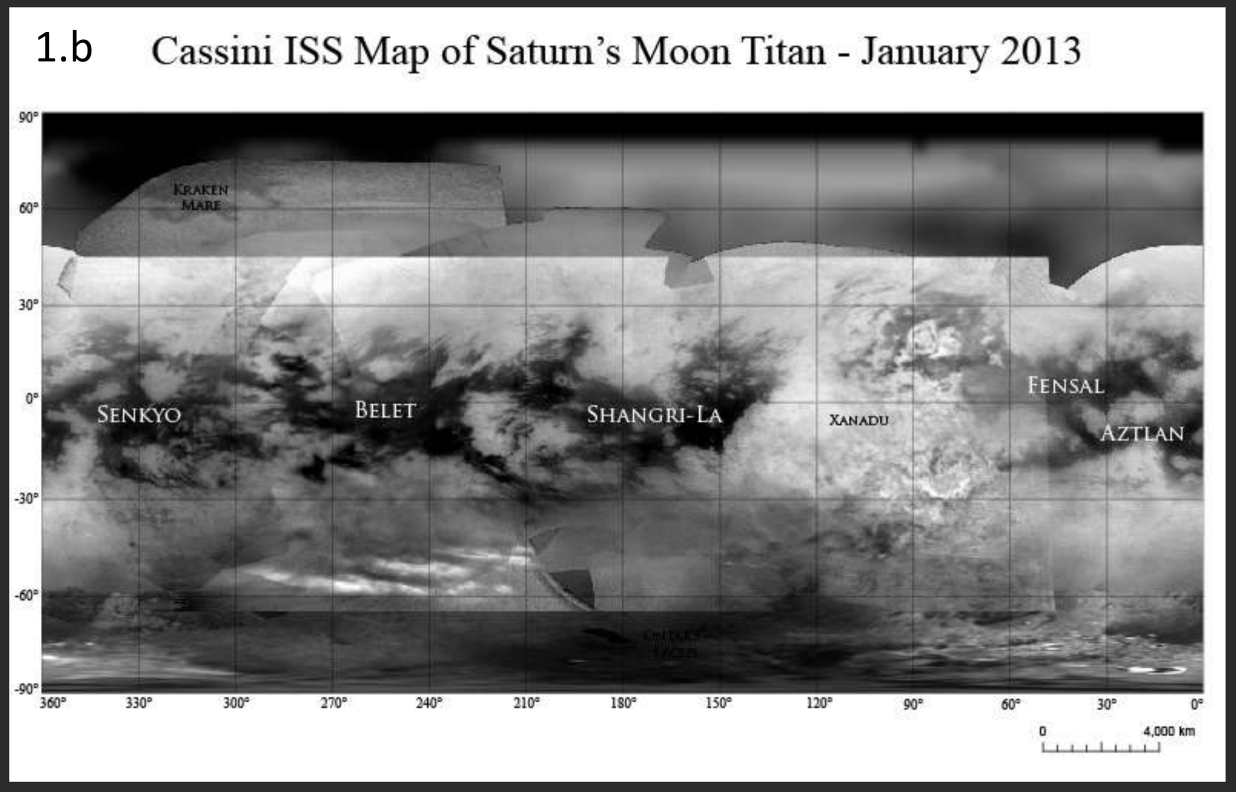


Fig 1. (a) Cassini SAR (Synthetic Aperture Radar) image (top left) showing similar morphology to dunes in Earth's Egyptian sand sea (top right). ***(b)*** *Cassini ISS (Imaging Science subsystem) visible/near-IR spectra global mosaic with arbitrary grayscale (lower).*

Methods

Area from SAR

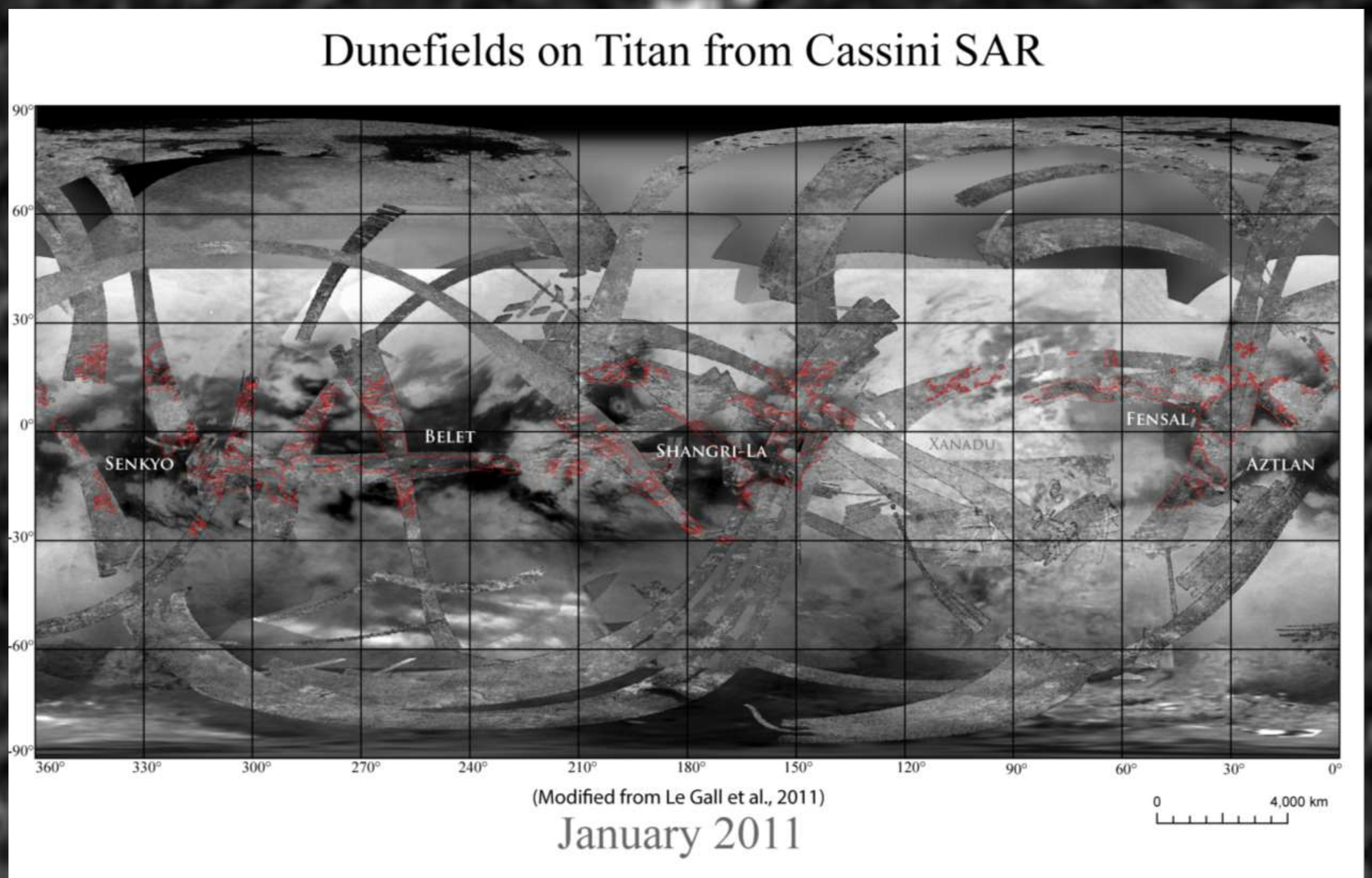


Fig 2. *Cassini ISS/SAR image of Titan showing dunefields mapped by Le Gall et al., (2011) using Cassini SAR data.*

Area from SAR and ISS

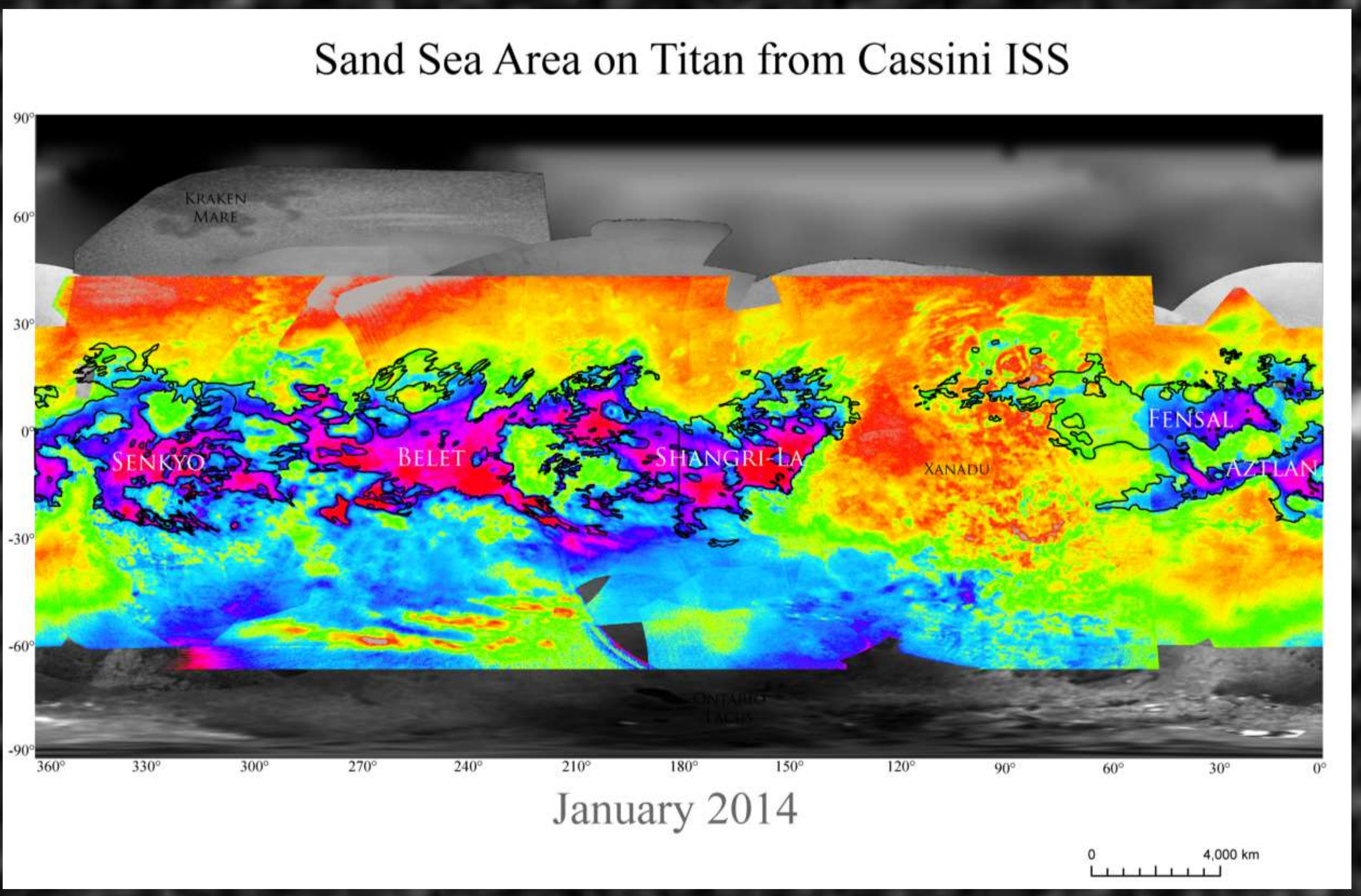


Fig 3. *Fasle color Cassini ISS image of Titan showing dunefields from Cassini SAR and ISS data.* Dune material is represented by arbitrary ISS data values ~115 and lower (range of 0 to 255). Perimeters for Fensal, Aztlan, Belet, Shangrila, and Senkyo Sand seas are outlined in black.

Area from SAR and ISS

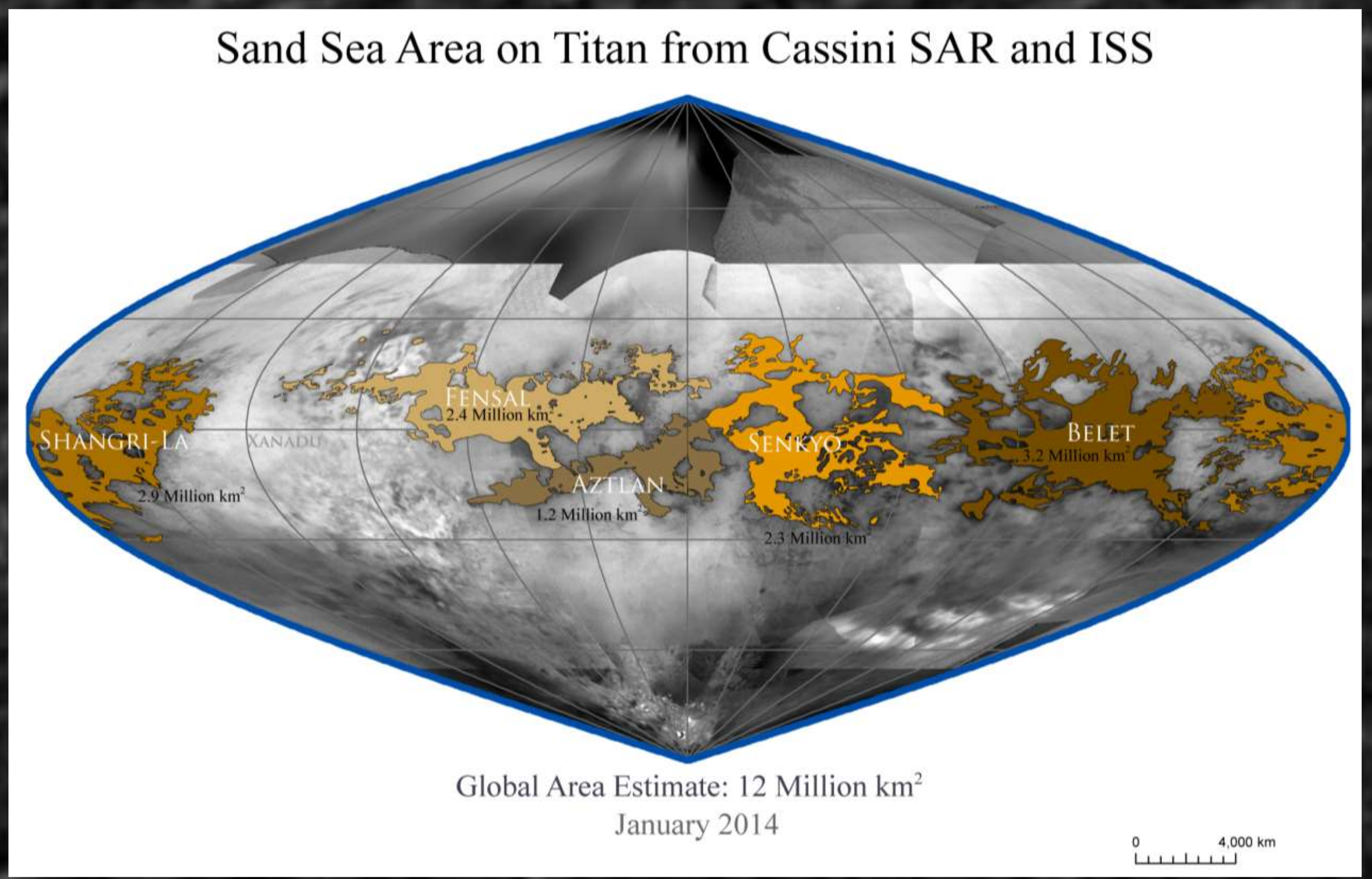
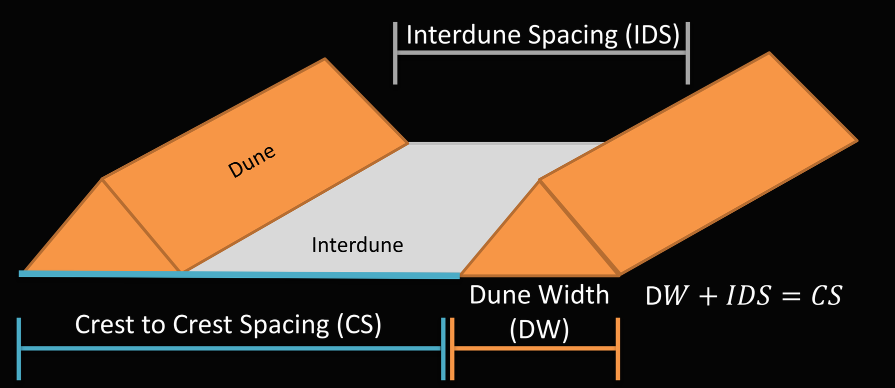


Fig 4. Equal area projection of Titan's surface showing the relative area of sand seas. *Cassini ISS image from USGS, 2013.* Perimeters for Fensal, Aztlan, Belet, Shangrila, and Senkyo Sand seas are outlined in black.

Dune Width and Spacing Analysis

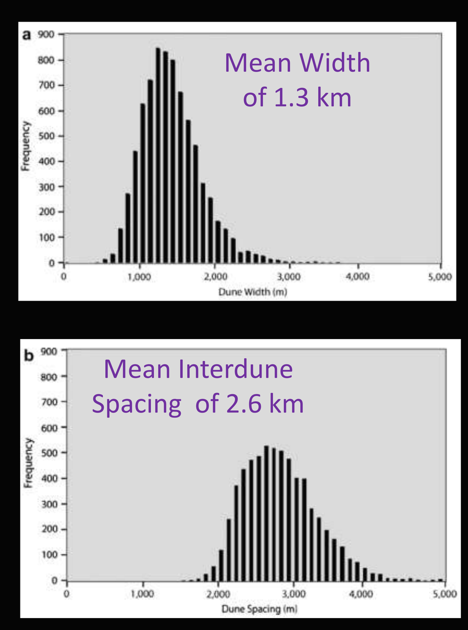


Dune Width (Savage, 2013; Williams, 2014)

	Shangri-La	Fensal	Aztlan	Senkyo	Belet
n=	-	3213	1849	344	540
Mean (km)	-	1.57	1.35	1.8	1.15
Median (km)	-	1.42	1.27	1.7	1.11

Interdune Spacing (Savage, 2013)

	Shangri-La	Fensal	Aztlan	Senkyo	Belet
n=	2021	2213	3465	439	1235
Mean (km)	1.38	1.40	1.14	1.43	1.08
Median (km)	1.35	1.31	1.02	1.47	1.05



Modified from Savage et al., (2013)

Fig 5. Dune width and spacing measurements from Savage et al., (2013). We use values for the average width and spacing within each sand sea for our analysis of dune coverage.

Volumetric Approach

Step 1 – We calculate the area of each sand sea.

	Shangri-La	Fensal	Aztlan	Senkyo	Belet	Global total
Area (Million km²)	2.9	2.4	1.2	2.3	3.2	12

Step 2 – We form our equation for volume after Le Gall et al., (2011).

$$Volume_{Sand} = A * h * C * S$$

Parameters	Range
Total Dune Field Area* (A)	Estimated to be 11.2-12 million km²
Dune Height (h)	100 m average, based on range of 30-180 m (Lorenz et al., 2005; Neish et al., 2010; Barnes et al., 2008)
Dune Coverage Ratio (C)	Calculated from Savage et al., (2013) measurements for dune with and spacing (See step 3)
Prismatic Shape (S)	Directly measure in the Namib Sand Sea August, 2013 (See step 4).

Parameters used in our equation for organic volume of dunes on Titan (based on A. Le Gall et al., 2010).

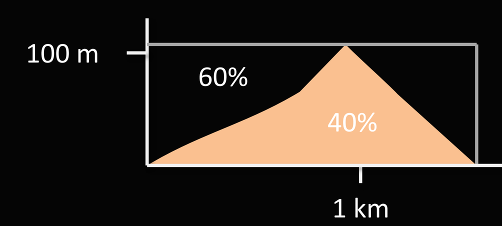
Step 3 – We determine the dune coverage fraction for each sand sea.

$$Dune\ Fraction = \left(\frac{Dune\ Width}{Crest\ Spacing}\right)$$

	Shangri-La	Fensal	Aztlan	Senkyo	Belet
Crest to Crest spacing (km)	2.41 (Williams, 2014)	2.97	2.49	3.23	2.23
Fraction of Dune Coverage (km)	.57	.47	.46	.44	.48

For an explanation of how crest to crest spacing is determined see figure 5.

Step 4 – We use a directly measured linear dune profile from the Namib Sand Sea to estimate the volume under each linear dune profile.



*Ratios calculated from a linear dune GPR transect in the Namib Desert near the Gobabeb Research Center

Step 5 – We calculate the total volume of organic sediment in each sand sea.

$$Volume_{Sand} = A * h * C * S$$

	Shangri-La	Fensal	Aztlan	Senkyo	Belet	Global total
Volume (km³)	67,000	45,000	30,000	41,000	62,000	245,000

Step 5a – To understand the significance of interdune material we calculate the total volume of organic sediment in each sand sea and assume a global interdune coverage of 5 meters.

$$Volume_{Interdune} = A * .005\ km$$

$$Volume_{Interdune} = 60{,}000 km^3$$

Organic Inventory Results

Our estimate of the total dune sand, and thus organic inventory, from dunes based on Cassini SAR and ISS data is **305,000 km³**. This is similar to global totals of 200,000-800,000 km³ from Lorenz et al. [7] who assumed a 40% dune coverage within Titan's equatorial region and 250,000 km³ from Le Gall et al. [4] who estimated 12.5% global dune coverage and a total area of 10 million km² based on SAR/HiSAR [4].

In this example, our model varies from those used previously in that we account for variations in dune material coverage by sand sea. We also assume a non-prismatic shape for dune forms on Titan. These changes have reduced our volume estimates relative to estimates by other authors [4,7]. The volume of interdune sand, in this example, when assumed to be only 5 meters thick accounts for a large portion of the total volume estimate, indicating the significance of interdune sands in future estimates [3,6].

Looking forward, our model will account for latitudinal and longitudinal changes in dune field characteristics as contour maps are overlain and volumes are calculated for individual grid cells and sand seas. This data will help us to identify sediment transport pathways and potentially support the conclusion that dunes are presently active on Titan.

References: [1] Radebaugh J. (2010) *Geomorphology* 121, 122-132. [2] Lorenz R. D. et al. (2006) *Science* 312, 724-727. [3] Radebaugh J. et al. (2008) *Icarus* 194, 690-703. [4] Le Gall et al. *Icarus* 213, 608-624. [5] Turtle et al. (2009) *GRL* 37. [6] Savage C. J. (2011) *Thesis, BYU*. [7] Lorenz, R.D. et al. (2008) *GRL* 35. [8] Garcia A. et al. (2013) *LPSC Abstract*. [9] Neish et al. (2010) *Icarus 208*, 385-394. [10] Barnes J.W. et al. (2008) *Icarus 195*, 400-414. [11] Savage et al. (2013) *Icarus* in review.