TOTAL SAND VOLUME ESTIMATES ON TITAN FROM CASSINI SAR, HISAR, AND ISS.
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Introduction: Observations of characteristics of sand seas on Saturn’s moon, Titan, confirm similarities with Earth’s deserts [1]. A careful study of details of these characteristics, such as sand sea areas, sand volumes, dune and inselberg morphologies, and sediment sources and transport will help to unveil the evolutionary history of Titan’s surface and climate. Nearly all dunes on Titan are linear in form [1,2] and are concentrated within the equatorial region [1,2,3,4]. On Titan, dunes are similar in size, radar reflectivity, and morphology to those imaged in Earth’s Namib, Saharan, and Saudi Arabian deserts [1,2]. This similarity of morphology suggests that there must be, or have been, sufficient wind, sediment supply, and collection area for the dunes to form.

Dunes and sand seas on Titan represent the results of major, global atmospheric and surface processes [1,2,3]. Understanding these regions is key to discovering the evolutionary history of the surface and atmosphere of Titan, and to better understanding similar landforms and processes on Earth.

This project is focused on inferring the mode and time frame of sand sea sediment accumulation by quantifying the area and estimating the volume of dune fields across Titan. This is the first detailed study of sand sea areas using images from Cassini’s Imaging Science Subsystem (ISS) in conjunction with Cassini SAR images. Unlike SAR images, ISS images have 100% coverage of the sand sea latitudes but at lower resolution [5]. Precise calculations of the areas of sand seas, along with dune spacing and heights [6], will allow accurate estimates of total sand volume and will help to further refine the organic inventory from dunes [7,4]. Presented here are the preliminary results from a detailed study of areas of all dunes on Titan from SAR/HiSAR, areas of Titan’s Fensal and Aztlan sand seas using Cassini SAR and ISS and an estimate for the total organic inventory from dunes on Titan.

Dune Areas from SAR/HiSAR: We identified where dunes are located within SAR and HiSAR images to calculate the areal extent of all dune areas imaged by Cassini SAR/HiSAR on Titan. Calculating the areas of sand seas is challenging, given the global coverage of moderate-resolution (350 m) SAR images of only ~40%. With the added use of slightly poorer-resolution HiSAR images global coverage increases to ~50%. Within SAR-imaged areas, dune sands and non-dune bedrock are clearly distinguished, so our estimate of areal coverage in SAR-imaged areas is probably good [3]. We classified dune material as being SAR dark and linear in morphology and excluded SAR-bright mountains and substrate and other non-dune, SAR-dark features, similar to [4] (Fig. 1a).

Each dune field was outlined in ESRI’s ArcMap 10

![Fig 1. Dune Fields Mapped on Titan using Cassini SAR, HiSAR and ISS data. (a) Fensal and Aztlan dune fields are to the east outlined in red. The red perimeter indicates estimated dune field extent based on ISS characteristics. All other polygons indicate dune fields mapped using SAR and HiSAR swath data. This data will be used in correlation with Cassini ISS data to estimate total dune coverage on Titan. (b) Altered ISS image shows dune characteristics more clearly. (Cassini ISS and SAR image of Titan’s equatorial region between +30° and -30° latitude)](image)
on Cassini SAR image swaths. We found a few slight inconsistencies in dune field boundaries where swaths overlapped in coverage. However, given sizes of the dunes and calculated wind speeds, dune migration during the elapsed time between flybys is unlikely. Rather, the inconsistency is attributed to variations in illumination angle and resolution. Image resolution decreases towards swath edges, so we used middle swath imagery where there is overlap. To calculate the area of dune regions in SAR and HiSAR we used a geodesic calculation tool from the USGS Astrogeology division that mathematically takes into account the curvature and size of Titan to accurately represent distances and areas on the surface. In addition, we merged locations where there was overlap before calculating areas.

The total area of dunes on Titan measured in SAR and HiSAR images alone (Oct 2004 to June 2011) is ~12 million km² or ~14%. This is close to values from [4] of 10 million km² or 12.5%. Given SAR/HiSAR coverage is about 50% globally, total dune coverage is likely to be >20% [see also 8].

Dune areas from ISS: For our analysis using ISS data, we found a reasonably clear correlation between dune regions seen in SAR and regions dark to ISS at 938 nm. Thus, we can map dune areas in ISS images away from SAR images with reasonable accuracy. The initial region of study is the Fensal/Aztlan sand sea east of Xanadu, following the study of [4]. Fensal is north of the equator while Aztlan lies almost directly below, both centered on about 50° W longitude (Fig 1b). Both sand seas are dark in Cassini ISS images [5].

Careful correlation of SAR to ISS data led us to pick ISS data values 115 and lower to represent dunes (from a range of 0 to 255). This value is represented where yellow transitions to deep-yellow-orange in a 20-interval color table from yellow to purple (yellow representing low data values). Utilization of the color table facilitated mapping and results in a map product with boundaries that are comparatively easily identifiable (Fig 1b).

Tests of the chosen threshold value in different regions yielded a fairly good correlation between dunes seen in SAR images and those in ISS images, increasing our confidence in this method. Dune areas are slightly overestimated in ISS images near Sinlap, Ching-tu (Fig. 1b), and in portions of the exposed substrate between the sand seas. It is possible the SAR is penetrating below thin sands observed by ISS in those regions [1,4,7].

To calculate the area of dune regions in ISS data for the Fensal/Aztlan sand sea we used the same geodesic calculation tool from the USGS Astrogeology division and the same data for dune heights from [9,10]. Total dune area in Fensal/Aztlan, based on the use of SAR/HiSAR and ISS data, is ~2.3 million km², similar to the combined areas of the Libyan and Egyptian sand seas, and about 1/5 the total estimated sand sea area on Titan based on SAR/HiSAR alone [4].

Sand Volumes and Organic Inventory: Sand volumes were calculated after Le Gall et al. [4]; similarly, we assume no sand cover in interdune areas. We assume an average dune height h=100 m based on values of 30-180 m [9,10]. We assume an average interdune width equal to dune width (decreasing sand coverage by ½) and a prismatic shape (introducing another factor of ½) to obtain a simple relationship for sand volume of V=Ah/4 where A=area of the sand sea.

Our estimate of the total dune sand, and thus organic inventory, from dunes is 150,000-300,000 km³, compared with 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].

The total volume of sand in Fensal/Aztlan from our calculations using SAR/HiSAR and ISS data is 30,000-60,000 km³. Looking forward we plan to refine these volume calculations by better estimating height variations across sand seas, creating a model to accurately infer interdune sediment thickness, and incorporating interdune/dune values, which range between 25 and 50% [3,6].

Conclusions: We have new estimates of dune areas and sediment volumes using SAR/HiSAR and ISS images. We plan to make similar ISS measurements in other sand seas across Titan, including Belet, Shangri-La, and Senkyo and to compare our studies with ongoing work using VIMS data [9]. These volume estimates will help us better understand the atmospheric processes that have led to the production of organics (approximately 4x10²⁶ mm/yr. globally according to our estimates assuming organic production began 4.5 Gya.) on Titan’s surface and to understand the controls on sand sea morphology and evolution.