COMPARISON OF TITAN'S NORTH POLAR LAKES WITH TERRESTRIAL ANALOGS THROUGH FRACTAL ANALYSIS.

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Introduction: Putative lacustrine features imaged by the Cassini RADAR instrument at the North Pole of Titan [1], were recently confirmed to be liquid-filled depressions. Conclusive evidence for the presence of liquid in these features was provided in the form of ethane detection in the south polar Ontario Lacus by the Cassini VIMS instrument [2] and also the specular reflection observed in the VIMS dataset corresponding to the north polar Kraken Mare [3].

Our previous study of Titan's north polar shorelines has revealed them to be closely approximated by fractal shapes, a property also demonstrated by terrestrial lake shorelines [4] i.e. measured lengths of these shorelines increases, as the measuring scale decreases, because smaller measuring scales are sensitive to smaller features of the shoreline. The measured perimeter can be related to the measuring scale by a specific fractal dimension (D), which varies from one shoreline to another ($P \alpha L^{(1-D)}$; where P: perimeter, L: measuring scale, D: fractal dimension). The fractal dimension D is a parameter used for evaluating the complexity/intricacy of a curve. It gives us a quantitative measure of how rough a shoreline is. Such a fractal analysis of shorelines can be used to extract a statistical characterization of Titan's topography [5].

The purpose of our current research is to follow-up on our previous study and perform a similar fractal analysis on terrestrial lake shorelines. In order to interpret the fractal dimensions of Titan's shorelines in terms of the surficial processes at work, it is necessary to characterize the fractal dimensions of terrestrial lakes formed by different processes.

Data: For this study, we use data from the Shuttle Radar Topography Mission (SRTM), which flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000 [6]. This mission mapped ~80% of the Earth's surface (60°N-56°S) at radar wavelengths. The STRM consisted of two separate radar instruments, SIR-C (C-band, wavelength 5.66cm) and X-SAR (X-band, wavelength 3.1cm), both of which produced backscatter data. The addition of a second detector at the end of a 60m boom allowed for elevation determination through interferometry (the main goal of the mission).

Version 2 of the C-band elevation data (publicly available for free) includes a vector database (SWBD: SRTM Water Body Database) of the outlines of water bodies (e.g. Fig. 1). This database has provided us with terrestrial lake outlines for comparison with Titan's lakes. The resolution of the C-band data is either 1 or 3 arc seconds (~30m or ~90m) for products covering US or non-US regions respectively. Apart from the vector database of lake outlines, we also utilize the C-band backscatter and elevation data for our research.

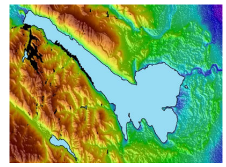

Fig. 1. Lake Garda is a 51km long glacially formed lake in northern Italy. The light-blue polygon is taken from the SRTM water body vector database. The background topography is derived from the C-band SRTM data.

Approach:

Classification and selection of terrestrial analogs. Terrestrial lakes can broadly be classified into eight different types on the basis of their formation mechanisms. Lakes on Earth can form as a result of glacial erosion/deposition, impacts, volcanism (caldera lakes), tectonic uplift/subsidence, fluvial processes (oxbow lakes), aeolian processes (interdune lakes), dissolution of limestone (karst), and periglacial processes (i.e. thermokarst) [7,8]. Fig. 2 shows SWBD shapefiles and corresponding Google Earth images of example terrestrial lakes corresponding to each process type (excluding thermokarst lakes since SRTM did not cover the high latitudes where these lakes are located).

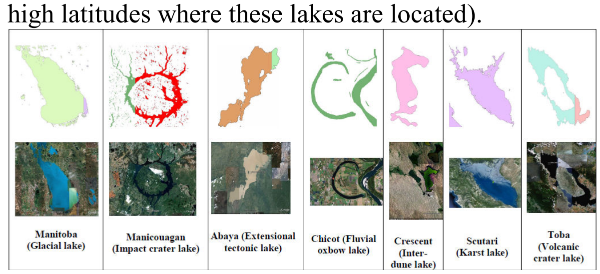

Fig. 2. Examples of terrestrial lakes formed by different processes.

Since the formation mechanism of lakes on Titan is currently not well understood (although a number of hypotheses have been proposed, e.g. in [9]), we chose to use surface area as the criterion for selecting terrestrial analogs for this study. We used lakes having surface area in the range of ~ (10-5000) km^2, the same as the surface area range of the lakes on Titan. We currently have a database of 35 terrestrial shorelines, which includes 5 lakes of each process type (excluding thermokarst lakes).

Statistical analysis of terrestrial analogs. We downloaded the SWBD shapefiles corresponding to all the terrestrial lakes in our database. To calculate the fractal dimension of these shorelines, we used the same two methods that we had earlier used to calculate the fractal dimension of Titanian shorelines: the ruler/divider method and the box-counting method (for details on the mechanics of these methods, please refer to [5]). Fig. 3 compares the calculated ruler and box-counting dimensions for the terrestrial analogs. From the figure, we observe that the ruler dimensions are spread over a large range of values (1.03-1.45), as would be expected for features formed by different processes, but the box-counting dimensions occupy a very short range (1.03-1.23). This implies that the ruler method does a better job at picking out the details of the shorelines and estimating their dimensions. One of the reasons for the poor performance of the box-counting method might be that we are employing an easier to implement version of the method called the grid method. This difference between the ruler and box-counting results reinforces one of the conclusions of our previous study [5], that overall, the ruler method is more reliable and accurate than the box counting method.

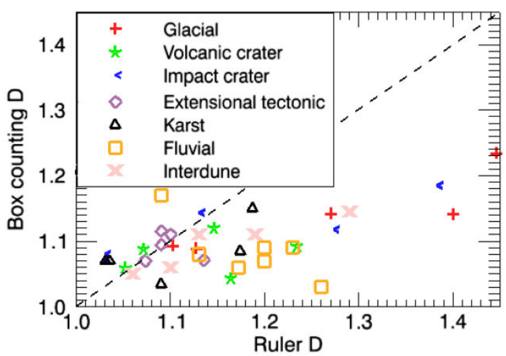

Fig. 3. Comparison of ruler and box-counting dimensions of terrestrial shorelines.

Comparison with Titan's north polar lake shorelines. The terrestrial ruler dimensions from Fig. 3 have been re-plotted in Fig. 4 for comparison with Titan's average shoreline fractal dimension (with the mean ruler dimension for Titan's shorelines and the corresponding 1σ range of values, taken from our previous study (1.27±0.1) [5]). Given the small number of terrestrial shorelines in our current database, it is hard to come to any conclusions on the basis of these preliminary results. However, we do observe that the same process can form lakes with shorelines with widely varying dimensions, e.g. in Fig. 4, we observe that glacial processes can form shorelines with dimensions ranging from as low as 1.1 to as high as 1.45. Another point to be noted is that we observe some overlap of dimensions between Titan's shorelines and the dimensions of terrestrial karst and volcanic lakes, both of which have been proposed to be possible processes responsible for forming the lakes on Titan.

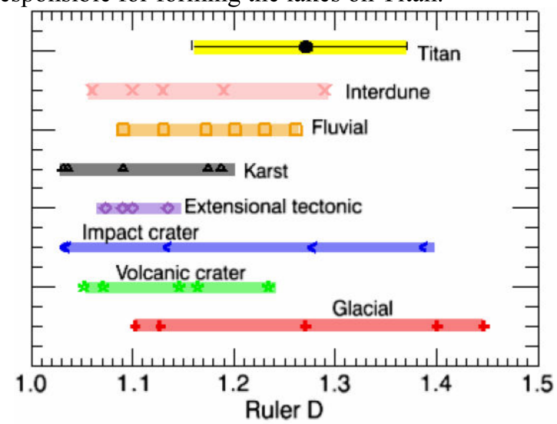

Fig. 4. Preliminary comparison of terrestrial and Titanian lake shorelines.

Future work: We intend to extend this study by including a larger number of terrestrial lakes in our database. We will also include larger terrestrial lakes (e.g. the Great Lakes in USA/Canada) in our study for comparison with some of Titan's larger seas like the Kraken Mare. We plan to employ datasets from sources other than the SRTM for calculating dimensions of high latitude thermokarst lakes. We will also utilize the SRTM backscatter data and manually digitize the outlines of some terrestrial shorelines for a direct comparison of manual mapping versus automated mapping techniques. We plan to make use of the SRTM high resolution elevation dataset to deduce the slope of the topographic power spectrum of the landscape surrounding the terrestrial lakes and compare this with shoreline complexity. We also seek to identify additional statistical signatures of geomorphic processes on Earth that can be used, in addition to shoreline fractal dimension, to constrain surface processes on Titan, e.g. shoreline development index [7,8], frequency-size distribution, spatial clustering [10], variation in widths of river valleys [11].

References: [1]Stofan E.R. et al. (2007) *Nature, 445, 7123,* 61-64. [2]Brown R.H. et al. (2008) *Nature,454,7204,* 607-610. [3]Stephan K. et al. (2010) *GRL, 37,* L07104. [4]Mandelbrot B. (1967) *Science, 156, 3775*, 636-638. [5]Sharma P. and Byrne S. (2010) *Icarus, 209, 2,* 723-737. [6]Farr T.G. et al. (2007) *Rev. of Geophys., 45,* RG2004. [7] Hutchinson G. E. (1957) *John Wiley & Sons, Inc.,* 1015 [8]Cole G.A. (1975) *Textbook of Limnology, 1st Ed.,* 283. [9] Mitchell K.L. et al. (2007) *LPSC XXXVIII,* Abstract# 1338. [10] Pelletier J.D. (2008) *Cambridge Univ. Press.* 304. [11] Gangodagamage C. et al. (2007) *Geomorphology,91,*198-215.