A novel use of fractal analysis to constrain Titan's topography

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Saturn's moon Titan has been shown to be able to thermodynamically sustain a liquid methane—ethane ocean (Lunine, Stevenson, & Young 1983), but it was not until the Cassini—Huygens mission that evidence of liquid of Titan's surface was presented. Stofan et al. (2007) used the images from the Radio Detection and Ranging Instrument (RADAR) to identify radar—dark patches around Titan's North Pole, which appear to be lakes given their low radar reflectivity along with morphological similarities. More recently, observations from the Visual and Infrared Mapping Spectrometer (VIMS) provided conclusive evidence of liquid by detecting ethane in one of the radar—dark regions (Brown et al. 2008). The surface features of Titan are as diverse as the Earth's, including mountain ridges and ranges (Barnes et al. 2007) and extensive dune fields across the equator (Lorenz et al. 2006). The images, both visible and radar, from Cassini and the Huygens probe provide evidence that Titan's terrain has been modified by numerous surface processes including fluvial and lacustrine (from rivers and lakes), aeolian (wind), tectonics, impact cratering, and mantling processes. The processes that create the landscape on Titan are analogous to those that create the landscape on Earth, but the surface materials are very different. What effect does having bedrock of water ice rather than silicates and having methane—ethane surface fluids instead of liquid water have on the evolution of the landscape?

Topographical information is needed to characterize the surface landscape of Titan and to test models of surface evolution. Currently, there is no absolute topographic data for Titan; however, using shorelines around the radar—dark lakes can provide relative contours of the topography. Sharma & Byrne (2010) have implemented the use of fractal analysis of the shorelines of the radar—dark lakes on Titan in order to determine the surface roughness and gain insight into the surface topography. Fractal analysis applies to natural features like shorelines because they are statistically self-similar: they display the same level of detail regardless of magnification. Mandelbrot (1967) and Richardson (1961) were the first to use fractal analysis to characterize a landscape by measuring the length of coastlines using straight line segments of different lengths G in order to find the "exponent of similarity", D such that $L(G) = MG^{1-D}$, where M is a positive constant. Higher values of D indicate more detail or roughness in the curve, and can be used to characterize the landscape, i.e. rugged landscapes would produce a complex shoreline with a high value of D. The work by Sharma & Byrne (2010) uses both the ruler method and the box—counting method to determine the "exponent of similarity" or fractal dimension D. The box—counting method overlays a grid on the image of the lake and counts the number of boxes that cover the shoreline at different grid resolutions, whereas the ruler method uses line segments of different lengths to measure the total perimeter. By measuring the fractal dimensions of the contours produced by the lakes on Titan, the power spectrum of Titan's topography can be deduced.

Sharma & Byrne (2010) measured D for 190 out of the 290 shorelines of lakes due to restrictions from the resolution of the RADAR dataset. They report the calculated mean fractal dimensions of Titan's shorelines as 1.32 ± 0.1 using box—counting and 1.27 ± 0.1 using the ruler method, which is comparable to the results Mandelbrot (1967) found for the coastline of Britain (1.25). The inferred power—spectrum exponent of Titan's topography is found to be ≤ 2. Relative to the power spectrum indices of Earth and Venus, which are higher, Titan's landscape tends to be rougher at shorter wavelengths relative to longer wavelengths, although, this may be attributable to the lower surface gravity on Titan.

The data were also investigated for different trends beyond the global averages that might distinguish between surface modification processes. Multi—fractal behavior, or changes in the value of D for a shoreline, was found in 21 lakes using the ruler method. This statistical change between different size scales indicates that different surface modification processes are becoming dominant at different spatial scales (Chase 1992); in general, higher D values indicate erosive processes, whereas lower values would be associated with depositional processes. Overall, there does not appear to be any definite spatial variation in D across latitude or longitude on Titan. When using the ruler method distribution of measurements, the D values are found to be anisotropic with the East to West D values being statistically different from the North to South values. Such directional topography could be an indication of tectonics or "aeolian scour." Combining all of these results leads to better constraints that could be used on models of the evolution of the titanian landscape, as well as a better understanding of how Titan's evolution differs from that of Earth's.

References

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