Classification and Degradation State of Mountainous Terrains on Titan from Cassini RADAR. D. E. Lalich and A. G. Hayes, Cornell Center for Astrophysics and Space Science (dllalich@astro.cornell.edu)

Introduction: While the Cassini orbiter is no longer actively collecting data, advanced processing techniques are enabling new information to be gained from existing observations. In particular, the recent development of delay-doppler processing [1] for altimetric data taken by Cassini’s RADAR instrument [2] allows us to investigate the topography of Titan at higher spatial resolution than previously possible [3]. This is particularly useful when paired with existing SAR images, which allow us to investigate the backscatter properties of features identified in altimetry.

By combining data sets in this manner, it is possible to gain new insights into the physical properties of Titan’s diverse surface features, including topographic structure, small-scale texture, and material composition. Toward that end, mountains and hummocks on Titan represent intriguing first targets for this newly developed data. Previous analyses of these features were based on morphological evidence from SAR images and low resolution topography [4][5][6]. Re-examining these features using delay-doppler altimetry may allow us to more accurately describe their construction and evolution, as well as how they are connected to ongoing surface processes.

Delay-Doppler Processing: In contrast to traditional radar altimetry, where returns simply represent the average backscatter within one whole footprint, delay-doppler processing leverages the doppler shift created by the motion of the spacecraft to increase along-track resolution [1]. Because the spacecraft is moving along track, returns from in front of or behind it will be shifted in frequency according to its velocity. Using these doppler shifts, it is possible to identify precisely where on the surface the reflected power originated, even within a single footprint. In effect, each footprint can be divided into doppler “bins” and each of these bins can then be treated as a separate observation, thus increasing the total number and resolution of observations along track.

For more detail on this technique, its limitations, and its implementation for the Cassini RADAR altimeter in particular, please see [3]. The result of applying delay-doppler processing was an enhancement in along-track resolution of 3-10 times with respect to traditional processing.

Results: Initial results from delay-doppler altimetry suggest that previously established terrain type classifications may not tell the whole story of mountainous morphologies on Titan. Delay-doppler RADAR altimetry shows little difference in either height or waveform shape for terrains previously identified as mountains or hummocks. Instead both terrains are typically characterized by a section of diffuse, low power reflection above a higher powered “base level” reflection, which is equal in elevation to surrounding plains (Figure 1). This suggests that mountains and hummocks are not separate features, and instead hummocks may simply be more highly eroded mountains.

![Figure 1: Section of flyby T98 showing typical altimetric radar return over mountainous/hummocky terrain.](image)

The presence of the base reflection itself bears examination. If mountainous regions are uniformly higher elevation than the surrounding plains, then no such reflection should be present. The fact that such a reflection is almost always visible instead indicates that mountainous terrains on Titan are heavily eroded, down to the basin level in most areas. Conversely, this could mean that the few areas without such a basal reflection (Figure 2) are relatively young and less eroded.

![Figure 2: Section of flyby T77 showing mountains that lack a strong “base level” reflection.](image)

Another interesting result is the lack of power received at higher time delays than that of the base layer. In regions of high relief, one might expect off-nadir surface topography or double-bounces to contribute backscattered power at time delays greater than that of the nadir surface itself. However, this is not observed in Cassini altimeter radarograms over mountains and hummocks. Instead, the lack of off-nadir quasi-specular returns indicates that the radar return may be dominated by diffuse volume scattering. An examination of SAR
backscatter vs. incidence angle for a mountainous region supports this hypothesis (Figure 3). The relatively slow decline in backscatter power at large incidence angles is consistent with enhanced volume scattering, though a specular component may still be present. Volume scattering could be caused by fresh or low density snow, ice with high impurity content, or a highly fractured surface.

![Figure 3: Plot of mean backscatter vs. incidence angle for SAR observations of a mountainous region centered near 43°N -25°E.](image1)

In addition to mountains and hummocks, we also analyzed a radargram over a circular feature with relief comparable to the tallest mountains. Geomorphologically, this feature was identified as “labyrinth” terrain due to its highly dissected morphology. However, it is very similar in appearance to a nearby feature informally nicknamed the “Hot Cross Bun,” initially identified by Lopes et al. [7] as a candidate cryovolcanic feature. Unlike the mountainous terrain, which shows evidence for multiple peaks and valleys within each altimetry footprint, the circular feature appears as a single dome in the delay-doppler altimetry (Figure 4). The lack of any sort of base layer reflection or identifiable peaks supports the hypothesis that this feature is fundamentally different in origin than other high-elevation features such as mountains. Instead, its resemblance and close proximity to the Hot Cross Bun suggest a cryovolcanic origin.

**Future Work:** The initial results from delay-doppler altimetry over mountains and hummocks on Titan are promising. In the future, further integration of other data sets such as SAR imagery, emissivity, or spectroscopic data may allow us to place tighter constraints on material composition, erosional state, or dominant scattering mechanisms. Of particular interest is the prospect of using differences in altimetric radar returns between mountains or mountain ranges to assign relative ages to separate features, allowing us to construct a more detailed geologic history of Titan and better understand material transport across the surface.

More generally, analysis of delay-doppler radar observations over other terrain types could lead to similar advances. Integrating the under-utilized radar altimetry data into studies of features such as the labyrinth terrain, dune fields, or potential cryovolcanic features will allow us to better understand the various geologic processes acting on Titan today and during the recent past.

![Figure 4: Top: SAR image of circular dome/labyrinth terrain centered near 39°N 145°E. Bottom: Section of flyby T91 altimetry crossing the dome from north to south.](image2)