Introduction: The multi-beam nature of the Cassini RADAR instrument makes possible the application of the SAR Monopulse Amplitude Comparison method (Chen & Hensley, 2005). This technique estimates surface heights by comparing the calibration of overlapping Titan SAR imagery obtained from different antenna feeds (beams) of the RADAR instrument onboard the Cassini spacecraft. The result has been the development of the SARTopo product (Stiles et al., 2009), which supplements the scant altimetric coverage of Titan with data that are conveniently located with SAR footprints.

The present incarnation of the SARTopo algorithms smooths the noisy data by 51 pixels, giving data that are ~9 km in horizontal resolution with a height uncertainty of ~75 m. However, this arbitrary degree of smoothing does not consider the actual signal strength, and so is excessive in areas of good radar return where topography varies within the measurement width, and insufficient in areas of low radar backscatter (e.g. the polar lakes and seas). This is particularly problematic around the lakes, the rims of which appear to exhibit considerable slopes.

This paper investigates alternative methods to the previous height uncertainty reduction strategy in an attempt to more accurately measure lake shorelines.

Overview of the technique: Cassini RADAR employs a burst-mode timing scheme in which bursts of typically 30–60 chirped pulses are transmitted followed by a planned gap (400–800 pulse intervals) in transmission which includes the time in which the echo is received. Five different antenna feeds (beams) are cycled in this process in order to obtain a wide swath on the ground, in effect producing 5 different SAR footprints which overlap substantially. In the regions where two beams overlap, given sufficiently accurate knowledge of spacecraft pointing and ephemeris and the antenna beam patterns, one can calculate the height of the surface from the apparent backscatter differences between the two single beam images when they are processed using the nominal 2575.0 km Titan reference sphere.

In the SARTopo implementation, we vary the estimate of the local Titan radius used to process the images and select the local radius that minimizes the amplitude mismatch between the two beams. Fig. 1 demonstrates the technique using an example image. The height estimates obtained in this manner yield 1–3 profiles in each SAR pass that are 10 km wide by 1000s of km long, extending along the entire long dimension of the SAR image strips, thus greatly expanding on topography gained from altimetry which is not colocated with imagery except in some limited areas.

The resultant data product gives height registered to pixel co-ordinated in the SAR image. These are bundle adjusted simultaneously over the entire planet, using topographic data gathered by the RADAR instrument in its altimetric mode as “truth”.

Height uncertainties due to random signal error are reported in the SARTopo product. For the unsmoothed data, median height uncertainty is typically ~300 m, but is strongly dependent on the magnitude of the radar backscatter, \( \sigma_0 \), and so may vary greatly. Other sources of error include biases due to antenna pattern error, of a few tens of meters, and long wavelength spacecraft ephemerides error, which is largely but not completely corrected by the bundle adjustment (Stiles et al., 2009).

Height uncertainty reduction strategies: In order to minimize height uncertainties, smoothing of the data in the along-track direction has been performed. By averaging over 51 pixels, Stiles et al. (2009) reduced uncertainty by a factor of ~7, increasing the along-track measurement width ~9 km, and reducing the height uncertainty to the same order as biases due to antenna pattern error. However, such precision is
only valuable in terrain that is smooth and regularly sloping.

There are locations on Titan’s surface where it would be valuable to see finer details in the along-track direction, particularly over rough terrain. Lakes, for example, are often surrounded by steep-sided rims over only a few SAR pixels in width. By averaging into the lake the uncertainty may even be increased, as poor returns from low backscatter liquid alkanes, sometimes below the noise floor, increases height uncertainty considerably.

Alternative strategy. Uncertainty in height in the SARTopo method has normal noise characteristics, and therefore vertical precision can be improved by √n, where n is the number of samples smoothed. The strategy demonstrated here takes an unsmoothed SAR-Topo dataset, and then box-filters it using an adaptive algorithm which increases the box-filter until vertical precision is less than a user-defined threshold. This allows for much smaller observation widths at the expense of vertical precision.

Results: The results of our adaptive filtering strategy are shown in figure 2 (top) for 100 m target vertical precision and a maximum along-track observation window of 5 km, above data (bottom) smoothed by 51-pixels (8.93 km along-track). Note that across-track precision is not accurately estimated by the circular footprints (a more precise way of doing this is being developed), and so the areal extent of the tracks shown is misrepresentative. Independent of the smoothing method used, across-track observation width is variable, averaging 3.3 km for the data shown.

Visually, the finer scale of the footprints makes topographic details crisper where elevation is variable for the adaptive smoothing version. It does so without significantly sacrificing surface coverage. Along-track observation widths average 1.4 km for the area shown, compared with a fixed 8.9 km for the 51-pixel version. The trade-off is a vertical precision of 100 m, compared with a mean of ~37 m for the 51-pixel version.

Conclusions: Considerable improvement in the utility of SARTopo data for local studies can be gained using different smoothing strategies. We find that adaptive smoothing, at times down to the 5-pixel level, although more commonly at around the 9- to 11-pixel level, results in a much finer detail along-track profile whilst maintaining reasonable (<100 m) uncertainties for lake shore studies. Our results reveal details in the morphology around polar lakes that were only previously possible to determine using radarcliometry, which is strongly backscatter model dependent, and stereo techniques, which requires SAR image overlap. Strategies for noise reduction in future local studies should be developed with careful consideration of the nature of the terrain, and will require unsmoothed input data.


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