EPSC Abstracts
Vol. 6, EPSC-DPS2011-1313, 2011
EPSC-DPS Joint Meeting 2011

Kilometer–Scale Titan Topography

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Abstract

Radar altimeter data from Cassini-Titan encounters have been frequency filtered to increase the along-track radar resolution, achieving a 5–10-fold improvement without sacrificing vertical accuracy. The highest resolution thus far achieved is 550 m in the periapsis region of the T30 fly-by, which had already been imaged by the SAR on the T28 fly-by. Many SAR features are found to have a topographic expression of tens to hundreds of meters, while many featureless regions appear flat to ±5 m over tens of km.

1. Introduction

The Cassini radar has operated in its altimetric mode during 24 Titan fly-bys[1], but mostly at altitudes greater than 5000 km, where the large footprint size has provided information on long-wavelength surface topography[2]. Only two passes, T30 and T49, took altimetric measurements with antenna footprints below 10 km in diameter. The $0.35°$ antenna beam restricts the range of scattering angles, making it impossible to deduce surface roughness from the altimeter alone, or to test quasi-specular scattering models[6], although a combination of altimeter- and scatterometer-mode data has been used to derive surface characteristics at low resolution[3].

The current analysis[4] uses Doppler-filtering of the altimeter signal to increase the along-track resolution of the instrument by a factor of 5–10, while retaining the $0.35°$ cross-track beamwidth. This corresponds to uncorrelated footprints of 0.55×5.5 km at periapse with a vertical resolution of better than 5 m. An independent SARtopo technique[5] derives relative topography from overlapping SAR antenna patterns to achieve a best vertical resolutions of 75 m over 10 km horizontal regions. It's advantage over altimetry is that its measurements are made within existing areas of SAR coverage.

2. Method

Before examining the data, the spacecraft ephemeris is used to allocate footprints along the Cassini nadir track, spaced along-track by the instantaneous frequency resolution. The raw altimeter bursts are then processed one at a time. The relative velocity between the spacecraft and the boresite intercept point (BIP) is computed, and the nearest footprint is found. The burst samples are converted to an array of complex numbers and multiplied by a phasor $\exp[-i2m\nu\tau]$ where ν is the frequency shift between the spacecraft and the center of the footprint, m is the sample index, and τ is the sampling interval (0.2μs). This is correlated with the range-tapered transmit waveform using FFT convolution. This process is repeated for the 7 footprints either side of the center footprint, a total of 15 footprints from each burst.

The center of the *physical* footprint, which seldom lies precisely along the nadir track, is located by minimizing the function $(\nu - \nu_{\delta x,\delta y})^2 + \delta x^2 + \delta y^2$ where $\nu_{\delta x,\delta y}$ is the Doppler shift to a point that is offset from the BIP by δx along-track and δy across-track. An areal weight A for each frequency component is defined as the area of the footprint, convolved with the normalized two-way antenna response – approximated by a 2-D azimuthally-symmetric Gaussian of width $w \sim 0.186^o$ (3.25 mrad.) If the distance from the BIP to the pair of *isodops* that enclose the footprint are x_1 and x_2, assuming nadir pointing and neglecting surface curvature, the weight is

$$A(x_1, x_2) = \int_{-\infty}^{+\infty} dy \int_{x_1}^{x_2} \exp\left(-\frac{x^2+y^2}{r^2w^2}\right) dx$$
$$= \frac{\pi}{2} r^2 w^2 \left[\mathrm{erf}\left(\frac{x_2}{rw}\right) - \mathrm{erf}\left(\frac{x_1}{rw}\right)\right] \quad (1)$$

where erf() is the Gauss error function, r is the distance from the spacecraft to the BIP, and $x_2 - x_1 = \Delta x/n$, the width of the footprint along the nadir track. If A is less than 0.1% of the full area of the antenna pattern, $A(-\infty,\infty) = \pi r^2 w^2$, this Doppler component is ignored. With the physical footprint located, the excess distance between spacecraft-to-nadir and spacecraft-to-footprint-center is calculated, and the range profile is resampled to compensate for the excess delay.

The resampled echo profile is converted to power, and thence to the scattering cross-section σ_0 using the radar equation. Profiles are summed element-by-element into a footprint range array, indexed so that its first element corresponds to an echo from a surface with a radius of 2590 km, with each subsequent element decreasing in radius by 30 m.

The range profile of each footprint is normalized by the sum of the weights of the contributing frequency elements. A noise baseline c_0 is calculated from the average of 100 samples starting at the 200'th sample prior to the peak value. The profile is then fitted to a pair of half-Gaussian functions, *i.e.*, $f_\alpha(t) = c_0 + c_1 \exp -[(t-t_0)/s_\alpha]^2$, where $\alpha = 1$ when $t \leq t_0$, and $\alpha = 2$ when $t > t_0$. Formal errors in the parameters are derived from the covariance of the fit.

Finally, the location, area, range dispersion, and σ_0 of each footprint is calculated from the weighted average of the individual frequency components.

3 Results

In the 7 instances of passes in which altimetry tracks overlapped – all at ranges greater than 5000 km – the RMS discrepancy between the interpolated cross-over altitudes was 35 m. The RMS height fluctuation for the single profile over the surface of Ontario Lacus was less than 3 m, even though the echoes saturated the receiver by a large factor.

The profile of the $1.0 \pm 0.2 \times 10^{-3}$ slope to the west of Ontario Lacus shows that the shoreline descends in a series of flat steps, hinting at cycles of erosion and/or deposition on longer time scales than the seasonal filling and evaporation described by Hayes *et al.*[7]

No instance has yet been found in which the altimeter has resolved the topography of a dune field: either the range was too large and the resolution too poor, or the altimeter footprints were not sufficiently aligned along the length of the dunes.

As expected, the most extreme topographic slopes were found in the two low-altitude passes, where the altimeter footprint is smallest. Along-track slopes of 10° or more are common in the T30 and T49 profiles, as illustrated in Fig. 1.

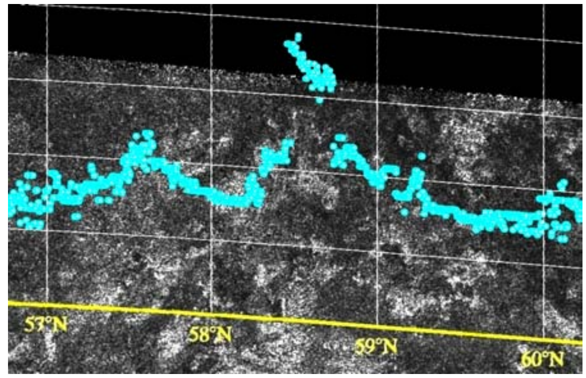

Figure 1: Topographic profile (blue) from pass T30 showing surface height as a displacement along the y-axis (250 m grid) relative to the nadir track (yellow) superimposed on a SAR image from pass T28.

Acknowledgements

The author wishes to express his thanks to L. Wye and H. Zebker for their assistance in calibrating the altimeter data, and to the Cassini RADAR team for numerous discussions.

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