TITAN ELECTROMAGNETIC RESPONSE AND SURFACE ROUGHNESS IMAGED BY CASSINI RADAR

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Introduction: Cassini RADAR SAR data from the Titan flyby on 15 February 2005 (T3) have been used to estimate the electromagnetic response and surface roughness as Root Mean Square (RMS). The estimates are derived using the inverted form of an empirical model developed using scatterometry data from Earth survey observations and previously tested and applied to both spaceborne (SIR-C) and airborne (AIRSAR) data. The model has been modified to suit the Cassini RADAR SAR data and has been used to estimate surface roughness to aid surface mapping.

Cassini SAR: The Cassini Titan Radar Mapper [1, 2] is a K_u-band (wavelength = 2.17 cm) instrument operating over a wide range of geometries in four modes. The synthetic aperture radar (SAR) mode produces image data with best resolution of 300 m/pixel. Titan's surface is somewhat challenging as it appears to be composed of organic compounds mainly identified as tholins, a mix of various hydrocarbons, and water-ice as suggested by the analysis of Cassini RADAR radiometry and scatterometry data acquired during the T3 flyby [3], with dielectric constant ranging from 2 to 4.5 (hydrocarbons ε = 2.0; water-ice ε = 3.1; water-ammonia ice ε = 4.5). These results, although highly model dependent, provided a good starting point and reference values for the dielectric constant used in the applied empirical model.

SAR modeling: Active microwave data have been shown to depend on several surface parameters such as dielectric constant and surface roughness [4]. Theoretical models like the Small Perturbation model (SPM), the Physical Optics model (PO) and the Geometrical model (GO) predict the trend of radar backscatter in response to change in roughness or soil moisture (dielectric constant) well. However, they can rarely be used to invert data measured from natural surfaces, mainly because of the restrictive assumptions made when deriving them. The model introduced by Dubois [5], bypasses the difficulties in applying theoretical models to data measured from natural surfaces [6], and was developed to infer soil moisture and surface roughness from radar data. The algorithm derived using ground-based scatterometer data from the LCX POLARSCAT [5], and the RASAM [5] systems, gave consistent results over data from different instruments when tested using AIRSAR and SIR-C data at C-, L- and P-bands. The hh- and vv- polarized backscattering cross-sections σ^0_{hh} and σ^0_{vv} were empirically found to follow these equations:

$$\sigma^0_{hh} = 10^{-2.75} \frac{\cos^{1.5}\theta}{\sin^5\theta} 10^{0.028\varepsilon\tan\theta} \left(kh\sin\theta\right)^{1.4} \lambda^{0.7} \quad (1)$$

and

$$\sigma^0_{vv} = 10^{-2.35} \frac{\cos^3\theta}{\sin^3\theta} 10^{0.046\varepsilon\tan\theta} \left(kh\sin\theta\right)^{1.1} \lambda^{0.7} \quad (2)$$

where θ is the incidence angle, ε is the real part of the dielectric constant, h is the RMS height of the surface, λ is the wavelength in cm, and k is the wave number ($2\pi/\lambda$).

Cassini SAR data comparability with POLARSCAT-RASAM data and model: Four homogeneous radar units representative of the surface brightness variability observed in the data were selected from the T3 swath. Areas with clear evidence of slope or topographic effects were excluded in order to estimate the radar return as a function of local surface roughness and dielectric constant. In this process, we took into account the incidence angle effect on the estimated radar cross-section and therefore limit the selection of representative units to similar incidence angle to allow cross-comparison. Also, areas fully contained within a single radar beam were preferred to avoid noise introduced by beam transitions [7, 8]. As the incidence angle is an integral part of the model, radar cross-section σ^0 noise subtracted and incidence angle uncorrected data were used. Furthermore, a 9x9 median filter was applied to the data to further reduce noise. The noise subtracted and uncorrected data were found to reduce the effect of beam transitions observed in the Cassini SAR data. It has to be noted that the Cassini SAR is better represented as a weighted linear expression of σ^0_{hh} and σ^0_{vv} in which a weight is introduced to compensate for the real polarization of SAR data, whose returns are co-polarized not hh or vv [9]. In the Cassini data the linear combination of hh- and vv- polarized backscatter with weighted contribution for the hh- and vv- polarized components is as follow:

$$\sigma^0 = \sin^2\theta_p * \sigma^0_{vv} + \cos^2\theta_p * \sigma^0_{hh} \quad (3)$$

where θ_p is the polarization angle, 0 or 180 for hh, and 90 or 270 for vv, with respect to the plane of incidence, thus resulting in the following:

$$\sigma^0_{hh} = \frac{1}{\cos^2\theta_p}\left[\ 10^{-2.75}\frac{\cos^{1.5}\theta}{\sin^5\theta}10^{0.028\varepsilon\tan\theta}\left(kh\sin\theta\right)^{1.4}\lambda^{0.7}\ \right] \quad (4)$$

and

$$\sigma^0_{vv} = \frac{1}{\sin^2\theta_p}\left[\ 10^{-2.35}\frac{\cos^3\theta}{\sin^3\theta}10^{0.046\varepsilon\tan\theta}\left(kh\sin\theta\right)^{1.1}\lambda^{0.7}\ \right] \quad (5)$$

In the selected areas the σ^0_{vv} component was found to be negligible and therefore the analysis was restricted to the σ^0_{hh} component by using equation 1. The mean value of the four homogeneous surface units, shown in Figure 1, were as follows: Σ^0_{hh}= -9 dB (dark unit: du), Σ^0_{hh}= -4.5 dB (medium unit: mu), Σ^0_{hh}= -0.5 dB (bright unit: bu), Σ^0_{hh}= 2 dB (verybright unit: vbu).

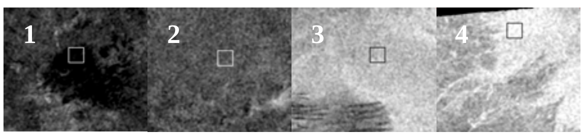

Figure 1. Units: du (1), mu (2), bu (3), vbu (4). Unit areas are 60x60 pixels covering ~110 km^2.

The σ^0_{hh} of each unit is plotted in Figure 2 alongside the backscattering models obtained for ε = 2.0 and variable height RMS surface roughness, suggesting the applicability of the model to the Cassini data.

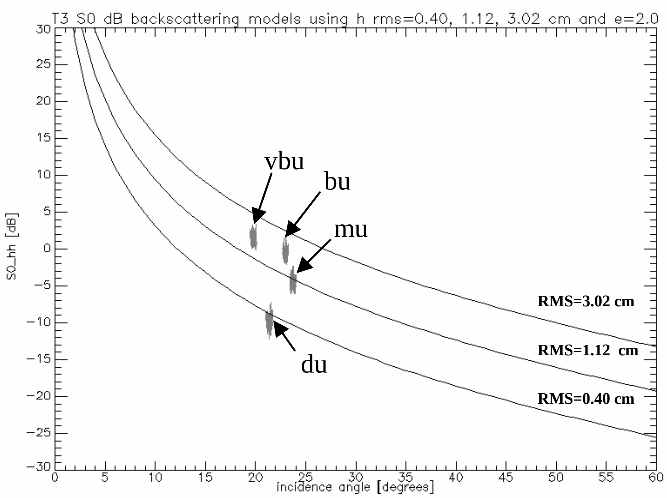

Figure 2. Cassini SAR σ^0_{hh} of selected units and empirical models for ε = 2.0 and variable surface RMS height.

Solving for h, with Cassini RADAR wavelength (λ=2.17 cm) and dielectric constant set at 2.0 (hydrocarbons), we derive that the dark unit is defined by RMS height of ~0.3 cm, the medium unit by RMS height of ~1.0 cm, and the bright unit and very bright unit by RMS height less than 2.5 cm as shown in the two sample plots in Figure 3. The models also suggested negligible variation when using 3.1 (water-ice) or 4.5 (water-ammonia ice) dielectric constant.

Considerations: The empirical model applied in this paper suggests that it can provide reasonable results in the estimate of Σ^0_{hh} radar cross-section and RMS height surface variability of Titan data. The dielectric constant variation from 2 (hydrocarbons), 3.1 (water-ice), and 4.5 (water-ammonia ice), turns out to be negligible with respect to the surface return variability, which suggests that the principal effects on the radar return are surface roughness and topography. However, the applied empirical model does not account for a volume scattering component as it takes into account only the surface intrinsic physical properties in terms of dielectric constant and RMS height of a simple homogeneous one-layer surface. In presence of local slopes or topographic effects, volume scattering should be considered as an intrinsic factor in interpreting the radar return. Furthermore, volume scattering can derive from a combination of surface and subsurface effects, as discussed in Paillou [10] using examples of one and two layer models to estimate the effect of volume scattering.

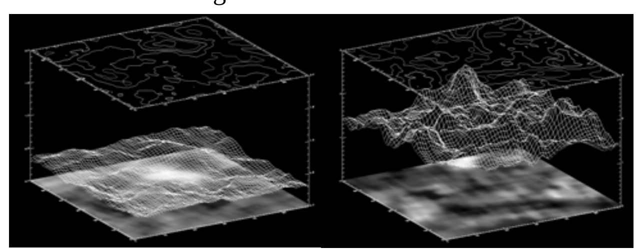

Figure 3. RMS surface roughness at cm scale estimated for dark unit (left panel) and very bright unit (right panel).

References:

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