Introduction to Titan and Cassini Radar

Titan, Saturn’s largest moon with a radius of 2575 km, is difficult to visualize by normal infrared and spectroscopic methods because of its thick, absorbing atmosphere. Thus, the Cassini-Huygens mission uses the microwave RADAR instrument (2.17-m wavelength) to minimize atmospheric effects. The Huygens probe entered Titan’s atmosphere and landed on the surface in January 2005. The Cassini orbiter, halfway through its nine-year mission, supplies us with two key measurement: 1) high-resolution scatterometer data across a wide range of incidence angles, which will attain near-global coverage, and 2) high-resolution Synthetic Aperture Radar (SAR) images acquired at a fixed incidence angle, to cover about 50% of Titan’s surface (Hulot et al., 2005a). Cassini has thus far returned SAR images of the region outlined below, labeled by orbital number, with TA occurring first. We view and study the swaths with our program distio to see images like Figure B. These radar reflectivity (normalized radar cross-section, or $\sigma_0$) images, as well as their latitude and longitude, are stored in Base Image Data Record (BID) files. The radar reflectivity imaged in Figure B varies with surface slope, roughness, and composition. Brighter regions signify higher reflectivity $\sigma_0$. Classification of Titan’s Features

Features assume many different shapes and sizes, and the radar images from its surroundings coded by a feature. Dunes are the most common features in the regions mapped thus far, but lakes recently detected in T16. Some features have not been officially identified; for example, the discolored rings could be eroded craters but cannot yet be catalogued as such. Collectively, the features exhibit possible cryovolcanism, impact craters, fluvial processes, nodular activity, and possible machine cycle activity Objective: Compiling a Catalog of Features & Surfaces

The Cassini Team has analyzed data from both the SAR and scatterometer modes, each with its own advantage. The SAR’s high-resolution images have allowed scientists to identify specific types of features, such as dunes, craters, lakes, and flows, and their location on the surface; meanwhile, scatterometer data, with its wide range of incidence angles, reveals the reflectivity vs.-angle relationships, which can be fit with backscatter curves to calculate surface properties.

My research has focused on classifying features and radar reflectivity seen in SAR images. While the Cassini RADAR Team has already identified features, I have been devising ways to categorize them systematically in a database of text files. By grouping features of similar types and listing their latitude, longitude, and average normalized radar cross-section in test files, the catalog can distinguish precise locations of features and surface terrain, providing a systematic way of studying them in unison and modeling their trends in the scatterometer data, where specific locations are not readily apparent.

Methodology and Measurement Procedure

1. Download and compress noise-subtracted SAR image files to a viewable size.

   BIRD files consume hundreds of megalobytes; the file is over-magnified, so we compress the image stored in the $\sigma_0$-BIRD file by replacing 4x4 sections of pixels with their average value to see more of the surface at once without losing too much feature detail.

2. Discern and catalog detailed features resembling one of several identified types.

   Dune fields are most prevalent across imaged regions, but craters, lakes, flows, and vestiges of features also appear. In separate files, we also cataloged unidentified features, such as lines, rings, dots, and peculiar markings. We tagged each feature with its type and the $\langle \theta \rangle$ coordinates of its bounding polygon’s vertices (as shown in Figure D), entering groups into their respective files.

3. Smoothen the compressed image with an averaging filter.

   Less-pass filtering blurs the image and allows us to distinguish large regions with similar radar cross-section or reflectivity $\sigma_0$.

4. Discern and catalog surface regions that share a similar $\sigma_0$ value.

   Regions sharing a backscatter coefficient could comprise similar material (observing at similar incidence angles removes the angular dependence of $\sigma_0$), so we catalog them together.

5. Extract the latitude and longitude of features and regions based on their $\langle \theta \rangle$ coordinates.

   Latitude and longitude values have their own BIRD files, corresponding pixed for each with the image file. We annotate the extraction procedure to produce text files and MatLab data vectors for plotting.

6. Systematically compute the average $\sigma_0$ value for each region.

   A program operating similarly to MatLab’s inpolygon averages $\sigma_0$ values within a specified boundary.

7. Determine logical bin cutoff values to separate regions of different types in test files.

   Each range of values denotes a different surface type, and categorization expedites access to each type.

Normalized Radar Cross-Section (Backscatter Coefficient)

The normalized radar cross-section, also known as the backscatter coefficient, or reflectivity, measures the reflectivity of a distributed radar target. It is the radar cross-section per unit area on the surface ground. We can compute values obtained by Cassini RADAR by solving the Radar Equation for $\sigma_0$:

$$\sigma_0 = \frac{G^2 P R}{\lambda^2 4 \pi^2 A}$$

where $G$ = gain of antenna, $P$ = power transmitted by radar, $R$ = range to target, $\lambda$ = wavelength, $A$ = effective area of receiver, and $\alpha$ = differential area element. Classification of Titan’s Surface Regions by Reflectivity

Different average $\sigma_0$ values separate surface regions of different types. The reflectivity of a type is closely related to the surface material and slope. Brighter regions signify higher $\sigma_0$ values. The inpolygon-based averaging algorithm computes average $\sigma_0$ for regions given perpendicular vertices. We then choose bin ranges so we can group regions of a similar type. Application of the Catalog to Analysis

We can fit backscatter model curves to the Average $\sigma_0$ vs.-Incidence Angle data from the scatterometer to determine the mean dielectric constant and surface slope of several large regions on Titan (Wye, 2006).

The features catalog and surface reflectivity database could permit more precise analysis by using $\sigma_0$ values from smaller but stronger similar areas, we can determine properties like the dielectric constant and slope for craters, craters, lakes, bright regions, dark regions, and other groups. We would know exactly where to find them in the scatterometer data since it follows the same latitude-longitude system as the observed SAR data.

Please see the text for additional details and references.