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Titan's Icy Scar

C.A. Griffith (1), P. F. Penteado (2), J.D.Turner (3), C.D. Neish (4), G. Mitri (5), M. J. Montiel (1), A. Schoenfeld(6), R.M.C. Lopes (2)
(1) Department of Planetary Sciences, LPL, University of Arizona, Tucson, AZ, 85721; grifith@lpl.arizona.edu (2) JPL, California Institute of Technology, Pasadena, CA 91109, USA (3) Department of Astronomy, University of Virginia, Charlottesville, VA 22904, USA (4) Dept. Physics & Space Sciences, Florida Inst. of Tech., Melbourne, Florida, USA (5) Universite de Nantes, Nantes, 44322 NANTES Cedex 3 - FRANCE (6) Department of Earth & Planetary Sciences, UCLA, Los Angeles, CA, 90095

Abstract

Here we conduct a Principal Components Analysis (PCA) of Cassini/VIMS [1] infrared spectral windows to identify and quantify weak surface features, with no assumptions on the haze and surface characteristics. This study maps the organic sediments, supplied by past atmospheres, as well as ice-rich regions that constitute Titan's bedrock.

1. Introduction

Titan's surface is composed of two compositionally distinct components, the icy bedrock and the atmosphere-derived organic sediments, which can be studied in the 8 wavelengths (0.93, 1.1, 1.3, 1.6, 2.0, 2.7, 2.8, and 5.0 μm) between optically thick CH_4 and CO bands in Titan's atmosphere. Within these "windows" candidate surface components exhibit different absorption features; e.g., NH_3 ice and C_2H_6 liquid absorb at 2.0 μm, while the complex organic material may absorb at 0.93 and 1.08 μm, e.g., However, water ice is the most straightforward constituent to identify, because 3 of its strong bands lie within the 1.6, 2.0 and 2.8 μm windows [2].

Recent advances in our understanding of Titan's surface composition at near-IR wavelengths stem from the analyses of Cassini's Visual and Infrared Mapping Spectrometer (VIMS). Detailed radiative transfer (RT) studies of Titan's surface that treat the effects of overlying atmosphere [3-9] target local regions of interest. Global studies of Titan's surface have either not treated the effects of the haze or used heuristic approaches to constrain the haze. While prior studies identified some major compositional tendencies, and revealed the compositional information of morphologically unique terrain, the question arises as to how to treat the effects of Titan's variable haze, how to extract weakest spectral features, and how to determine the spectral information content of the VIMS data.

1.1. The PCA analysis

Here we present an investigation of Titan's surface spectra order to determine the composition of Titan's surface on a global scale and to identify and map the surfaces where water ice "bedrock" is exposed, despite the ongoing sedimentation of organic material from the atmosphere. This work is accomplished by a Principal Components Analysis (PCA) of the 4 wavelengths that most clearly view Titan's surface (1.1, 1.3, 1.6, and 2.0 μm). In contrast to previous analyses, this study identifies and deconstructs the major spectral components of the surface on a global scale, without prior assumptions regarding the surface composition and atmospheric scattering and absorption, as assumed from radiative transfer analyses. In addition, this approach by virtue of sampling the correlations among the 4096 spectra that make up a cube can identify subtle spectral features that would not be apparent in a single spectrum.

The PCA analysis is conducted on over 130,000 spectra contained in 37 VIMS data cubes to determine the spectral trends that define the greatest spectral variance (the principal component) as well as successively lesser orthogonal correlations between the I/F values at each wavelength. Each VIMS cube, which contains M$\sim$4096 spectra, is analyzed separately to account for the different viewing conditions and signal-to-noise ratio. The orthogonal spectral trends are derived by calculating the eigenvalues and eigenvectors of the covariance matrix, defined by the I/F values at the 4 window wavelengths of each cube and their deviations from their mean values.. The eigenvector associated with the highest eigenvalue defines the principal component, with successively smaller eigenvalues defining lesser correlations between the variables. Spectroscopically distinct terrains are identified by determining which spectra fit the principal component to within 1-σ, and which of the remaining spectra require the 2^{nd}, and then 3^{rd} components to fit the data to within 1-σ.

For all cubes, we find that the principal component consists of the average spectral features modulated by the surface brightness, the main source of variance. This component contains 87%–99% of the variance, depending on the cube. It captures the effects of Titan's atmosphere, principally CH_4 absorption and haze scattering, which establishes the average spectrum. The primary component also carries the average surface spectrum, which based on Titan's dielectric constant measured by Cassini/Radar [10] and prior near-IR studies, e.g. [11-14] is dominated by organic sediments. In contrast, absorption features at 1.6 and 2.0 μm, characteristic of water ice, dominate the 2^{nd} component and explain 0.4%–13%. Ice features observed at zenith viewing indicate have the 2.8 μm water absorption. Thus the main spectral signatures of Titan's tropical surface are established by the presence or lack of water features.

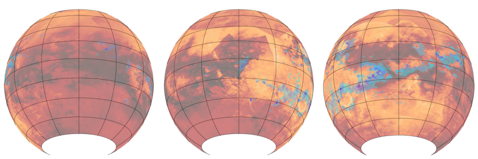

Figure 1: Titan's ice-rich terrain wraps around 40% of Titan's surface as a great circle.

The spectral trends of ice-rich and ice-poor terrains determined from the PCA analysis agree with microwave emissivity measurements [10]. The PCA-derived terrains agree in detail with prior RT analyses of local regions, e.g. [5,9,15]. The PCA analysis is consistent with much of the the composite maps. The detailed match of the RT and PCA techniques both justify RT analyses despite the required assumptions, and substantiate this PCA study of the surface composition on a large scale.

2. Summary and Conclusions

We find that the predominant spectral features of Titan's surface match 3 water ice bands of half of Titan's surface. The indicated strongest water ice absorptions concentrate in a linear feature, which extends, in a great circle, across 40% of Titan's globe. Otherwise ice is exposed only in local regions excavated by craters, particularly Titan's largest crater, Menrva, or exposed by erosion, thereby suggesting that cryovolcanism, if active, is currently not widespread. Titan's linear ice-rich feature appears to follow ridges, and based on its global nature is likely tectonic, although its origin and evolution remain obscure. In contrast, Titan's organic sediments indicate significant spectral diversity, correlated with large scale terrains. Whether this diversity is a result of a vibrant but slow organic chemistry on Titan's surface, or the interaction of sediment with the subsurface methane, or simply physical changes in the sediments, can be explored with a more extensive spectral studies of Titan's surface.

Acknowledgements

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