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Initial Correction for Atmospheric Scattering on Titan

G. Vixie (1), J. W. Barnes (1) and B. Jackson (2)
(1) Department of Physics, University of Idaho, Moscow, ID, USA, (2) Goddard Space Flight Center, Maryland, USA
(gvixie@vandals.uidaho.edu)

Abstract

We are using *Cassini*'s Visual and Infrared Mapping Spectrometer (VIMS) and RADAR to correct atmospheric scattering on Titan to first order using the single scattering approximation with a reflective bottom boundary. Titan can scatter signal in many ways, however we have only implemented the most important. More scattering modes exist, but are beyond the scope of this model. The goal here is to empirically fit a full atmospheric transfer function for Titan using as much of the current data as possible. This function will then be used to find absolute surface reflectivities (albedos) that can be used to constrain composition.

1. Introduction

Titan's atmosphere obscures the surface for the majority of wavelengths *Cassini* observes. At those methane windows where surface features are visible, scattering can distort the signal and lower the signal-to-noise ratio. Approximating a full atmospheric transfer function would allow correction of past, present, and future flyby data.

2. Scattering

We define I/F to be the total measured upward intensity divided by the solar flux. We make two major assumptions. First, that contribution from photons scattered by the atmosphere multiple times is negligible. Second, that multiple reflections from the surface contribute non-negligibly, but only two reflections are consistent with the first assumption. The contributions to I/F we consider are:

1. Reflection from surface, wholly unscathed on the way down or way up.
2. Scattering solely from the atmosphere.
3. Scattering from the atmosphere, subsequently scattered from the surface.
4. Reflection from the surface, subsequently scattered on the way up.
5. Reflection from the surface, subsequently scattered back into the surface, then reflected from the surface and unscattered thereafter.

We have only implemented the first three items so far and hope to incorporate items four and five later on in the project.

3. Method

We create masks over surface features on Titan we assume to have the same albedos. We assume three different mask types. First is dark albedo, which is as close to zero albedo as we see and covers lakes and select dune fields. Although the dune fields are known to not be the darkest albedo, there is much VIMS coverage of these areas. Second is bright albedo, which is as close to an albedo of 1 as we see. These masks cover VIMS (equatorially) bright areas close to the same area as the dark masks. Third is masks covering other lake areas lacking multiple flybys. Two sample masks are shown in the T66 flyby in Figure 1.

The goal is to look at the effective I/F in each mask over a variety of phase angles to fit a curve for our analytical radiative transfer model. The effective I/F is calculated using the equations in the following section.

4. Model

Our corrections and model are as follows, with each equation number corresponding to each item number in Section 2.

$$\frac{I}{F} = \frac{A\Phi_s(i,e,\varphi)e^{-\tau_0(\mu(i)+\mu(e))}}{2\pi} \quad (1)$$

$$+\frac{\tilde{\omega}_0 p(\hat{\Omega}_0,\hat{\Omega})}{4}\frac{\mu(e)}{\mu(i)+\mu(e)}(1-e^{-\tau_0(\mu(i)+\mu(e))}) \quad (2)$$

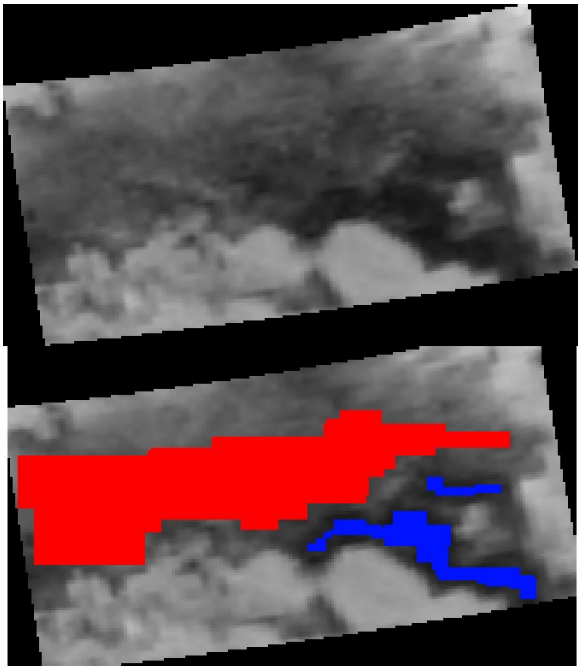

Figure 1: This is a single CUB mapped and calibrated showing a target region for a mask. The masks are created manually by drawing boxes over desired regions. The larger mask in the bottom figure represents a dark mask while the smaller two masks represent potential lake masks. The bright mask for this flyby is located on a different CUB covering the surface features beginning on the eastern edge of this map.

$$+ \frac{\tilde{\omega}_0 A e^{-\tau_0 \mu(e)}}{8\pi^2} \int_{\hat{\Omega}'=\mathrm{down}} \frac{\mu(e)}{\mu(e)-\mu(\theta')} p(\hat{\Omega}', \hat{\Omega}) (e^{-\tau_0\mu(\theta')} - e^{-\tau_0\mu(i)}) \mathrm{d}\Omega' \quad (3)$$

$$+ \frac{\tilde{\omega}_0 A e^{-\tau_0 \mu(i)}}{8\pi^2} \int_{\hat{\Omega}''=\mathrm{up}} \frac{\mu(e)}{\mu(e)-\mu(\theta'')} p(\hat{\Omega}'', \hat{\Omega}) (e^{-\tau_0\mu(\theta'')} - e^{-\tau_0\mu(e)}) \mathrm{d}\Omega'' \quad (4)$$

$$+ \frac{\tilde{\omega}_0 A^2 e^{-\tau_0 \mu(i)}}{64\pi^4} \int_{\hat{\Omega}'=\mathrm{down}} \int_{\hat{\Omega}''=\mathrm{up}} \frac{\mu(\theta')}{\mu(\theta')+\mu(\theta'')} p(\hat{\Omega}'', \hat{\Omega}')(1-e^{-\tau_0(\mu(\theta')+\mu(\theta''))}) \, \mathrm{d}\Omega'' \, \mathrm{d}\Omega' \quad (5)$$

Where:

- A = Surface albedo.
- τ_0 = Total atmospheric extinction optical depth, scattering + absorption.
- $\mu(i)$ = 1 / cosine of the solar incident angle for the plane parallel case. Otherwise this is the number of atmospheres traversed by the signal on the way down.
- $\mu(e)$ = 1 / cosine of the solar emission angle for the plane parallel case. Otherwise this is the number of atmospheres traversed by the signal on the way out.
- $\tilde{\omega}_0$ = Average single scattering albedo of atmosphere, given $\tilde{\omega}_0 = \frac{\int \tilde{\omega}_0 \mathrm{dz}}{\int \mathrm{dz}}$.
- p($\hat{\Omega}_0, \hat{\Omega}$) = Average haze phase function for scattering from direction $\hat{\Omega}_0$ into $\hat{\Omega}$, defined as above.
- dΩ = Solid angle in direction $\hat{\Omega}$, given by $cos(\theta)\mathrm{d}\phi\mathrm{d}\theta$.
- $\Phi_s(i, e, \varphi)$ = Average surface phase function in terms of incidence, emission, and phase angles.

5. Summary and Conclusions

The overall goal of this project is to help in the progression of correcting for signal scattering on Titan. We plan to achieve this goal by calculating the effective I/F on different albedo surfaces over a variety of phase angles to approximate the atmospheric transfer function. The resulting function will be an asset for current corrections, though not completely correct. Future flybys will result in a larger data set, allowing for a more precise fit.

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