ANALYZING CLOUD LOCATIONS AND CHARACTERISTICS ON TITAN WITH THE CASSINI VIMS.

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Summary: We analyze VIMS image cubes in order to complement previous cloud identification efforts and explore morphological characteristics of clouds on Titan.

Introduction: Titan is characterized by a complex methane cycle analogous to the Earth's hydrological cycle [1,2]. In 1995, this concept was strengthened by the first observational evidence of methane condensation clouds in the form of albedo increases in specific spectral windows [3]. Today, using data collected by the Visible and Infrared Mapping Spectrometer (VIMS) on board the Cassini spacecraft, we are able to produce high spatial-resolution images which can be used to visually inspect for tropospheric clouds on Titan. We have executed a manual search throughout the entirety of the VIMS dataset (>20,000 applicable cubes) to document cloud occurrence and morphology, providing an opportunity to analyze the global distribution, physical size, duration, and temporal variability of cloud location and geometry.

Methods: In order to identify clouds, we generate a set of three images for each VIMS cube: an RGB image and its grayscale counterpart as well as a stratospherically corrected tropospheric image. In order to produce the RGB images, we classified specific wavelength channels based on their observational sensitivity to either surface, tropospheric, or stratospheric features. After acknowledging the disadvantageous signal-to-noise ratio (SNR) of the five-micron window, we reduced our channel set to those classified in [4]. By assigning green to surface, blue to tropospheric, and red to stratospheric, we created RGB images in which tropospheric features appear as bright blue due to their relatively significant brightening along the wings of the methane windows (the common location of said channels, see Fig. 1) [3]. Using this color scheme, we created stratospherically-corrected tropospheric images simply by subtracting the red image from the blue image.

After processing all VIMS cubes, we designed a graphical user interface (GUI) in order to simultaneously analyze the images produced for each observation. This provides greater confidence throughout the cloud selection process, as the GUI allows for both multiple method verification and reference to previous identification efforts [3-6]. In addition to the displayed images, the software contains a spectral plotting tool which allows the user to compare the albedo spectra of Titan's surface and a candidate tropospheric feature (see Fig. 1). This tool provides for the distinction between true clouds and artifacts associated with low phase angle observations of bright surface features or a consistent difference in albedo caused by proximity to the terminator. Furthermore, our stratospherically corrected images mitigate the problems of hiding and blurring linked to high phase angle observations.

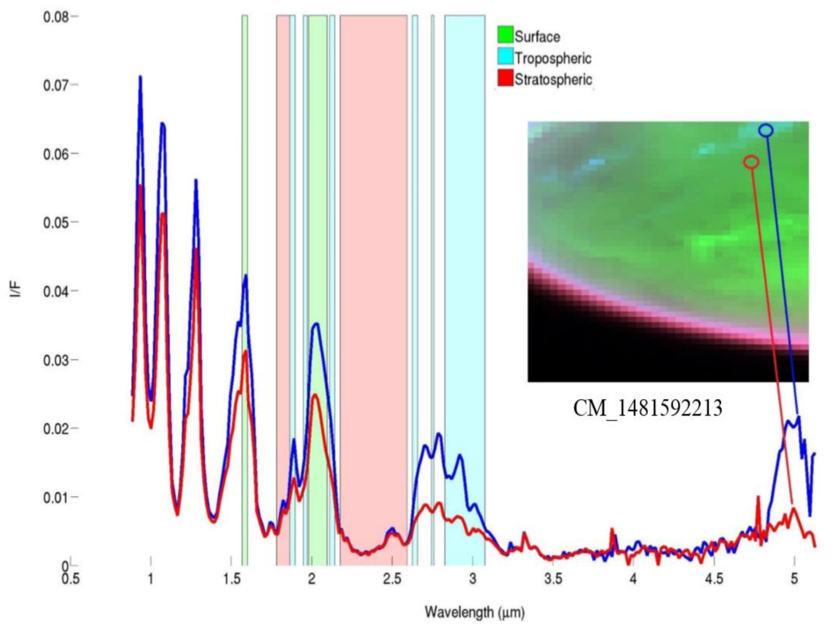

Fig. 1: Albedo as a function of wavelength for pixels corresponding to an observed cloud feature (blue) as well as Titan's surface (red). The cloud spectrum exhibits significant brightening in the tropospheric channels which manifests as a noticeable feature in the RGB image. The utilized wavelengths are labeled in accordance with the wavelength channel color scheme detailed in the methods section.

Results and Discussion: Our analysis spans all VIMS observations between flybys T0-T104 (October 2004 to August 2014). Within this dataset, we have identified and characterized tropospheric cloud features in more than 1500 cubes representing hundreds of unique clouds. We observe notable groupings of clouds throughout the southern hemisphere as well as scattered mid-latitude clouds in the northern hemisphere and a high-frequency north polar hood spanning all longitudes (see Fig. 2) Furthermore, our observations catalogue a significant density of clouds throughout the south polar region followed by a post-equinox (August 2009) transition to low frequency northern mid-latitude clouds and dense coverage in the

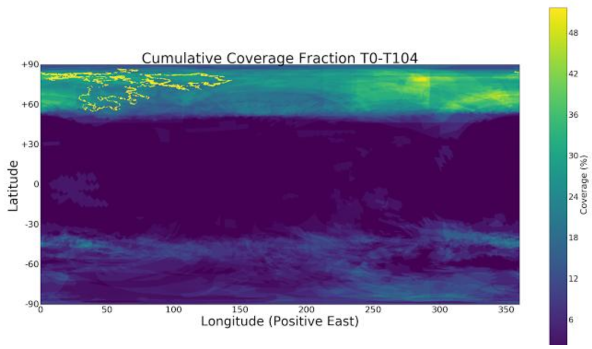

Fig. 2: A fractional coverage map of all clouds observed throughout flybys T0-T104 on an equirectangular projection of Titan. Fractional coverage is calculated by dividing cloud identification frequency by observation frequency for all projected locations. The outlines of Titan's hydrocarbon seas [2] are provided for reference.

north polar region. These distributions both support and further constrain predictions made by current global circulation models (GCMs) of Titan [7,8].

Selecting the complete expanse of every cloud visible in the VIMS dataset regardless of prior observation generates information from which properties can be derived. Applying connectivity matrices allows for the distinction between multiple features within a single image cube, and extracting the spatial resolution corresponding to selected pixels lets us calculate the total observable area (in km^2) of each individual cloud. In Fig. 3, we present a histogram of sizes for features measured to be less than 5E5 km^2 (to exclude polar hood observations), and we witness an exponential decrease in relative frequency with respect to increasing area. Furthermore, our repeated selection of clouds imaged in multiple cubes provides for the analysis of morphological evolution and motion, and we apply our knowledge of the observational timeline to derive cloud duration and the rates at which these developments are occurring in order to further constrain previous wind speed estimates [9]. We

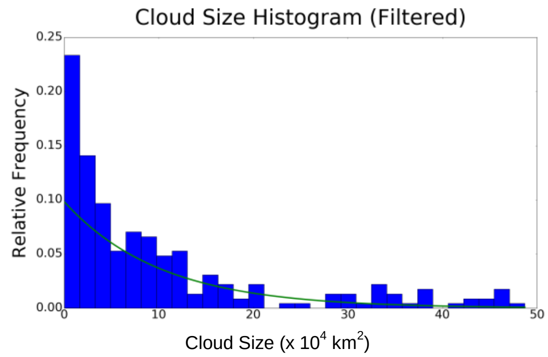

Fig. 3: A histogram displaying the relative frequencies of cloud size derived from the spatial resolution of selected pixels. Included are all unique clouds spanning measured areas less than 5E5 km^2 in order to exclude observations of the north polar hood.

documented repeat observations for over 73 percent of unique tropospheric features, about 41 percent of which exhibit a significant (>10%) change in viewable coverage area over collection timespans ranging from seconds to days. For example, in a sequence spanning 10.7 hours, we witness a geometric center displacement of 150 km through image cubes characterized by pixel resolutions of ~16-35 km, corresponding to a speed of roughly 4 m/s which agrees with current models [9]. Although our ability to measure these characteristics is limited by partial or incomplete observations, the magnitude of the VIMS library provides for a sufficient sample of desirable data, and the incorporation of imaging science subsystem (ISS) data will contribute to a better understanding of the connection between viewing geometries and problematic or discrepant measurements [10].

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