ANALYZING THE DYNAMIC AND MORPHOLOGICAL CHARACTERISTICS OF CLOUDS ON TITAN USING THE CASSINI VIMS. J. Kelland[*1], P. Corlies[1], A. G. Hayes[1], S. Rodriguez[2], and E. P. Turtle[3], [1]Department of Astronomy, Cornell University, Ithaca NY, [2]Institut de Physique du Globe de Paris (IPGP), CNRS-UMR 7154, Université Paris-Diderot, USPC, Paris, France, [3]Johns Hopkins Applied Physics Laboratory, Laurel MD, [*]Email: jak374@cornell.edu

Summary: We analyze VIMS image cubes in order to develop a cloud observation database while exploring dynamic and 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 clouds inferred from 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] (see Fig. 1). By assigning green to surface, blue to tropospheric, and red to stratospheric, 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

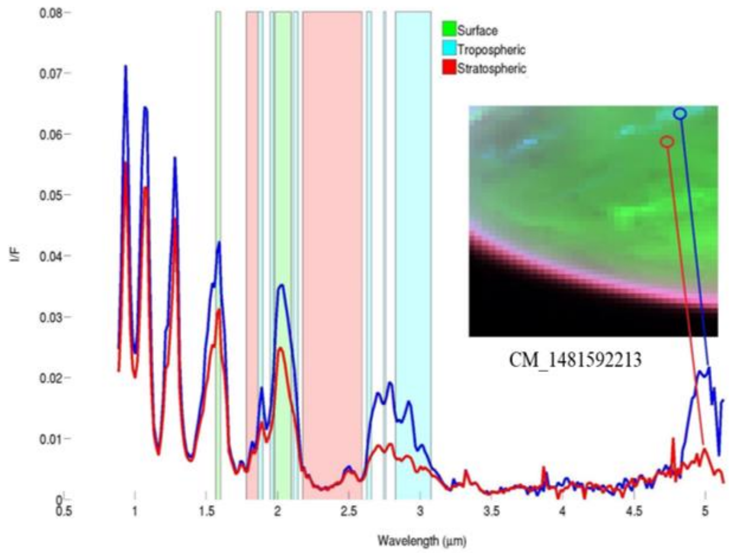

Fig. 1: Albedo as a function of wavelength for pixels corresponding to an observed cloud feature (blue) as well as Titan's surface (red). The cloud spectrum exhibits significant brightening in the tropospheric channels which manifests as a noticeable feature in the RGB image. The utilized wavelengths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

tropospheric feature (see Fig. 1) as well as a five-micron toggle which allows users to view cubes in the generally excluded long wavelength channels. These tools provide for the distinction between true clouds and artifacts associated with 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 limb-proximal cloud observations.

Results and Discussion: Our analysis spans all VIMS observations from flybys T-A through T-126 (October 2004 to April 2017). Within this dataset, we have identified and characterized tropospheric cloud features in more than 2000 cubes representing hundreds of unique clouds. We observe notable groupings of

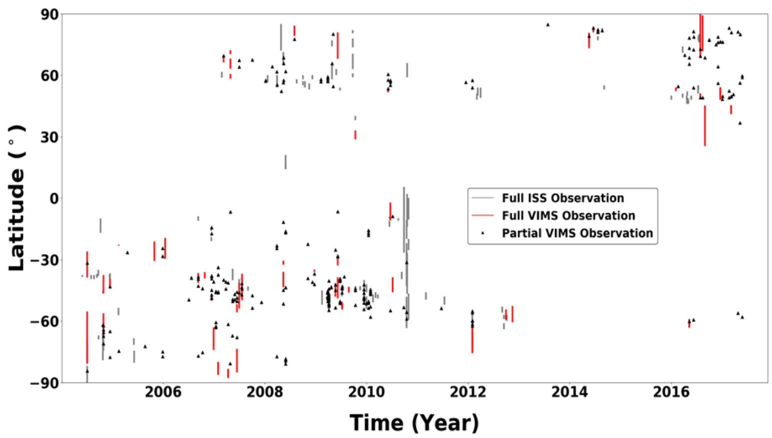

Fig. 2: Latitudes for all cloud observations are reported as a function of time. The distribution was compiled using data from both VIMS and the Cassini Imaging Science Subsystem (ISS). For clouds whose entire spatial extents were observed, vertical lines are utilized to represent their latitudinal ranges.

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. Furthermore, our observations catalogue a significant density of clouds throughout the south polar region alongside scattered clouds in the northern mid-latitudes followed by a delayed transition to dense coverage in the north polar region (see Fig. 2). 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. The GUI employs selection indices which allow 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. We witness an exponential decrease in relative frequency with respect to increasing area. Furthermore, our repeated selection of clouds imaged in multiple cubes provides two benefits: first, it allows for an analysis of the morphologic evolution of the cloud, which can inform on formation mechanisms, and second, it allows for tracking of cloud speed through repeat observations (provided significant spatial resolution) to further constrain wind speed estimates [10]. Using radiative transfer (RT) modelling of Titan's atmosphere, we can also obtain the altitudes of certain observations. By reporting cloud altitude as a function of displacement speed, we can construct altitudinal wind speed profiles which contribute to understanding the complex dynamics of Titan's atmosphere (see Fig. 3) [11]. Although our ability to measure cloud velocity is limited to observations in which a feature's displacement is resolved, the incorporation of ISS data allows for the determination of slower speeds due to a higher global resolution. We report velocities ranging from 1.5 to 23 m/s over the entire extent of the RT model's operable altitudes, 1.5 to ~48 km. Our cloud speed data does not display a strongly discernable trend, but decomposing the values into meridional subsets will allow for the analysis of wind speeds across the entirety of Titan.

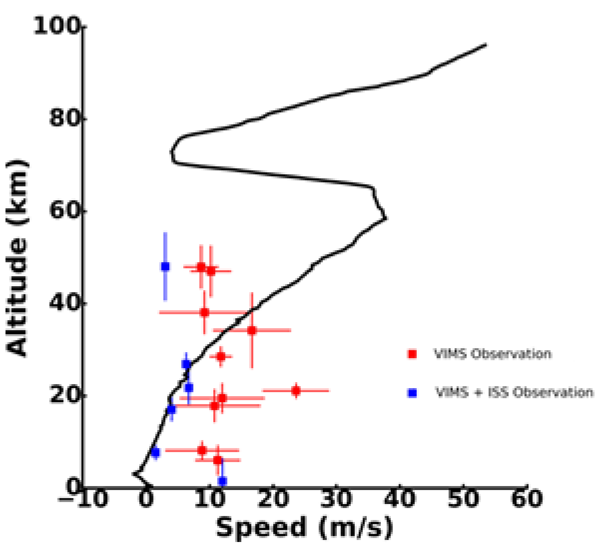

Fig. 3: Cloud altitudes are reported as a function of calculated displacement speeds. The data contains both VIMS and ISS observations and is plotted over the wind speed profile measured by the Huygens landing probe [9].

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