TITAN INSIGHTS DURING THE FINAL YEAR OF THE CASSINI MISSION. E. P. Turtle[1], J. E. Perry[2], J. M. Barbara[3], A. D. Del Genio[3], C. Sotin[4], S. Rodriguez[5], J. M. Lora[6], S. Faulk[6], R. A. West[4], E. Karkoschka[2], A. S. McEwen[2], M. Mastrogiuseppe[7], J. D. Hofgartner[4], P. Corlies[8], J. Kelland[8], A. G. Hayes[8], J. Pitesky[4], T. L. Ray[4], [1]Johns Hopkins Applied Physics Laboratory, Laurel, MD (Elizabeth.Turtle@jhuapl.edu), [2]University of Arizona, Tucson, AZ, [3]NASA Goddard Institute for Space Studies, New York, NY, [4]Jet Propulsion Laboratory, Pasadena, CA, [5]Université Paris Diderot, Paris, France, [6]University of California, Los Angeles, CA, [7]Sapienza University of Rome, Italy, [8]Cornell University, Ithaca, NY.

Introduction: Titan observations during the final year of the *Cassini* mission continued to inform and surprise us about this enigmatic moon. Although there were only two close Titan flybys during *Cassini's* F-Ring and Proximal Orbits, there were also observations during 16 distant encounters, which typically extended 24–40 hours with closest approach altitudes as low as 118,000 km. Indeed, with encounters almost every 2 weeks as well as interspersed Titan Meteorological Campaign observations, this part of the mission was ideal for monitoring Titan. Here we highlight atmosphere and surface observations and results during the final year of the *Cassini* mission.

Clouds and seasonal weather patterns: *Cassini's* Imaging Science Subsystem (ISS) and Visual and Infrared Mapping Spectrometer (VIMS) have documented changes in cloud distributions, morphologies, behavior, and altitudes over Titan's seasons from southern summer as *Cassini* approached the Saturnian system in 2004 through early northern summer in 2017 [*e.g.,* 1-4]. Based on atmospheric circulation models, storm activity was expected to increase at high northern latitudes as northern summer approached, similar to activity observed at high southern latitudes upon *Cassini's* arrival. Elongated streaks of clouds around ~55°N had begun to appear frequently in 2016, and with the summer solstice in May 2017, observations during *Cassini's* final year were highly anticipated. Activity at mid-northern latitudes became more common and widespread (*e.g.,* Figs. 1,2). Some small clouds appeared ~15-40°N, consistent with, but a few years later than model predictions.

However, in contrast to predictions of extensive north-polar cloud activity and precipitation occurring perhaps as early as ~2010 [*e.g.*, 5,6], ISS and VIMS only observed small isolated cells near Titan's North Pole through the end of the mission in September 2017. This stronger preference for clouds at mid- rather than high-northern latitudes is consistent with recent models: intriguingly, this weather pattern occurs for the case of polar "wetland" methane reservoirs, rather than being concentrated in the observed maria [7-9]. This comparison suggests that although liquids are only observed to cover parts of the surface at high latitudes, and primarily in the north, there may be a broader subsurface methane table that is accessible to the atmosphere in the polar regions.

A surprise during flybys in summer 2016 was VIMS detection of apparent north-polar clouds that were not visible at shorter wavelengths where ISS typically detects clouds. Figure 2 shows a later example (July 2017), with VIMS images at three different wavelengths. One of the VIMS channels used for cloud detection (2.1 µm) not only shows elongated streaks of clouds at ~60° N – also seen in ISS images from the same encounter (Fig. 1, right) – but it also shows a large bright cloud patch over Kraken Mare. However, this feature is not observed (or cannot be discerned from the surface) by VIMS at 2.0 or 5.0 µm or ISS at 0.94 µm, whereas the clouds at 60° N are visible at all wavelengths (Fig. 2). Thus the spectral characteristics of this feature differ from those of typical clouds. Potential hypotheses include high-altitude cirrus that is optically thicker than Titan's atmospheric haze at longer wavelengths but cannot be distinguished from the haze at shorter wavelengths [10], or low-altitude fog with very small droplets, but the spectral dependence of these features is currently unexplained pending radiative transfer modeling.

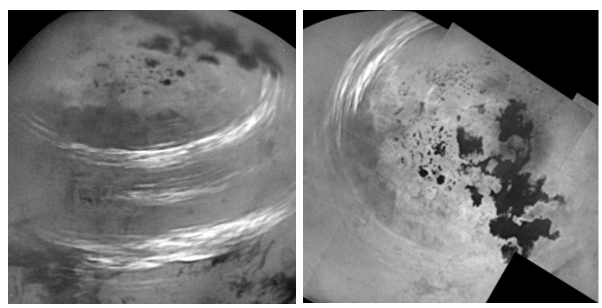


Figure 1: ISS observations at 0.938 µm showing extensive clouds at mid-northern latitudes on (left) 8 May 2017 during Rev 273, and (right) 10 July 2017, Rev 283.

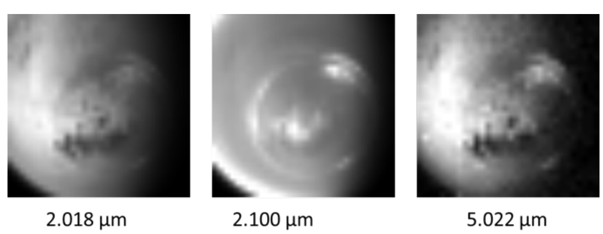


Figure 2: VIMS images at three wavelengths from an observation on 10 July 2017 (Rev 283) showing elongated clouds around 60° N, similar to the ISS observation made during the same encounter (Fig. 1, right).

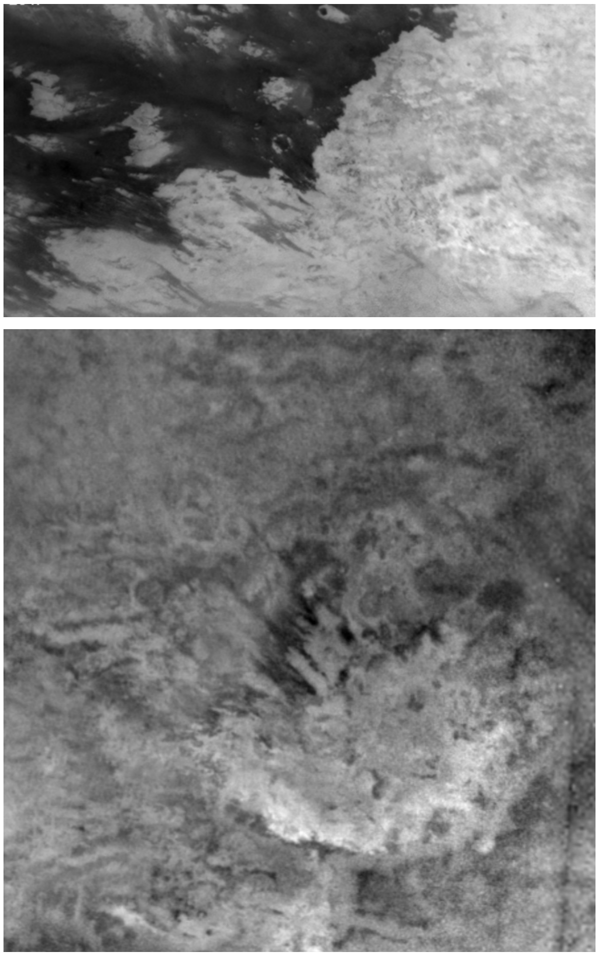
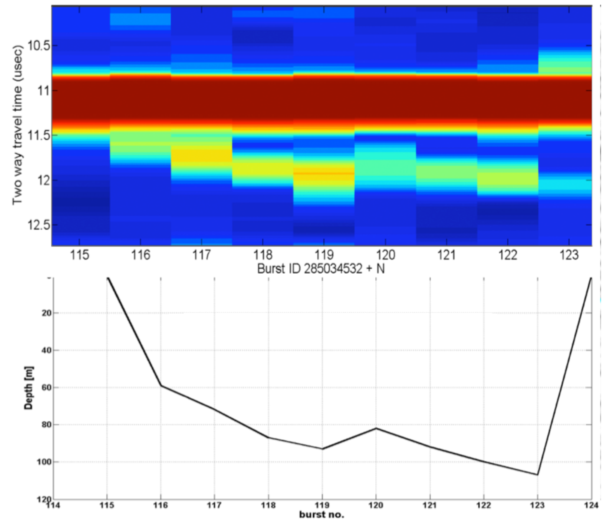


Figure 3: Portions of ISS map: (top) Shangri-La and Xanadu; (bottom) Hotei Arcus. Albedos, calibrated to DISR [11], range from 0.25 in the dunes to 0.9 at Hotei.

Surface observations: The last year of the *Cassini* mission also brought important developments regarding Titan's surface. The ISS map of the surface is now complete and photometric analysis of the entire ISS equatorial (±30°) dataset (Fig. 3) has improved the signal-to-noise ratio by a factor of 4-5 and the effective resolution, and produces calibrated surface albedos [11].

VIMS also completed a global-scale hyperspectral mosaic of Titan's surface [12], which is empirically corrected for atmospheric contribution and improves the coverage and resolution of the northern lake district.

RADAR observations of high northern latitudes on *Cassini's* final close flyby of Titan, T126 in April 2017, did not detect the transient "magic islands" that had been observed in Ligeia Mare previously, leaving the most likely explanations for this phenomenon to be waves, bubbles, or floating or suspended solids [13]. T126 observations also provided altimetry and bathymetric measurements of Titan's lakes (Fig. 4), constraining depths to be >100 m [14] and demonstrating that lakes are hydrologically connected but perched hundreds of meters higher than the equipotential surface of the maria [15].



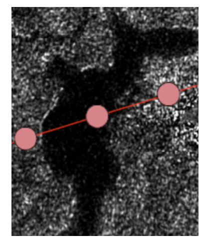


Figure 4: RADAR altimetry measurements revealed bathymetry of some of Titan's lakes. (Top) Radargram of a lake, showing the reflection from the lake floor beneath the red surface reflection. (Bottom) Corresponding bathymetry, with depths in excess of 100 m. (Right) SAR image with T126 altimetry track overlain.

Questions unanswered: Our view of Titan has been completely revolutionized by *Cassini-Huygens*, which revealed Titan's surface and atmosphere in detail, along with changes that occurred over nearly half a Titan year, and we now have an understanding of how Titan functions as a system. Nevertheless, as always, many questions also remain unanswered, and these have been summarized by Nixon *et al.* [16].

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