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Titan's seasonal weather patterns, associated surface modification, and geological implications

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Abstract

Model predictions [e.g., 1-3] and observations [e.g., 4, 5] illustrate changes in Titan's weather patterns related to the seasons (Fig. 1). In two cases, surface changes were documented following large cloud outbursts (Figs. 2, 3): the first in Arrakis Planitia at high southern latitudes in Fall 2004, during Titan's late southern summer [6]; and the second at low southern latitudes in Concordia and Hetpet Regiones, Yalaing Terra (Fig. 3), and Adiri, in Fall 2010, just over a year after Titan's northern vernal equinox [4, 7, 8]. Not only do these storms demonstrate Titan's atmospheric conditions and processes, they also have important implications for Titan's surface process, its methane cycle, and its geologic history.

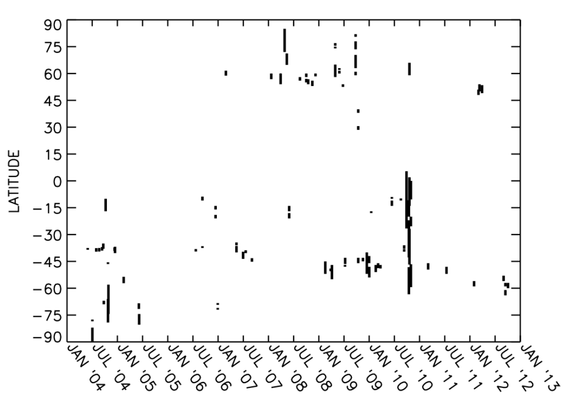

Figure 1: Latitudes of clouds observed by Cassini ISS through January 2013.

1. Surface changes & interpretation

The darkening observed after both storms (Figs. 2, 3) is attributed to wetting by methane rain and in places perhaps ponding of liquid methane on the surface [7]. Observations by Cassini ISS since the 2010 low-latitude storm revealed that, while most of the changes were short-lived, a few darkened patches persisted for up to a year. The variations in the rates at which the surface reverted to its original brightness (Fig. 3) suggest different areas drained (by overland flow or infiltration) or dried at different rates. In an unsaturated permeable medium, infiltration rates can exceed 20 mm/week [9], so persistence of surface liquids suggests a shallow impermeable layer or a shallow methane table. Evaporation rates >1 mm/week are predicted in equatorial regions [3] and rates ≤10 mm/week have been predicted [3] and are consistent with observations [10] at Titan's south pole. Therefore, areas where darkening persisted for several months could have had liquid ponded to depths of 2.5-25 cm on the surface.

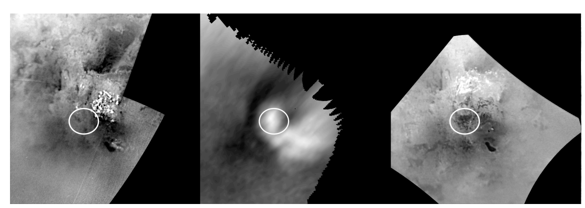

Figure 2: ISS images of Titan's south pole: before (July 2004, left), during (Oct. 2004, middle), and after (June 2005, right) the Fall 2004 outburst. Circle indicates area of change at Arrakis Planitia.

In addition to the rain darkening, several smaller areas brightened relative to their original appearance (Fig. 3) [7, 8]. In general, areas of brightening followed and persisted longer than the darkening, but have also reverted to their original appearance (e.g., Fig. 3). Although not well understood, the best explanation for the brightening is evaporative cooling of the wetted surface resulting in accumulation of methane and/or ethane frost, which then sublimes [8].

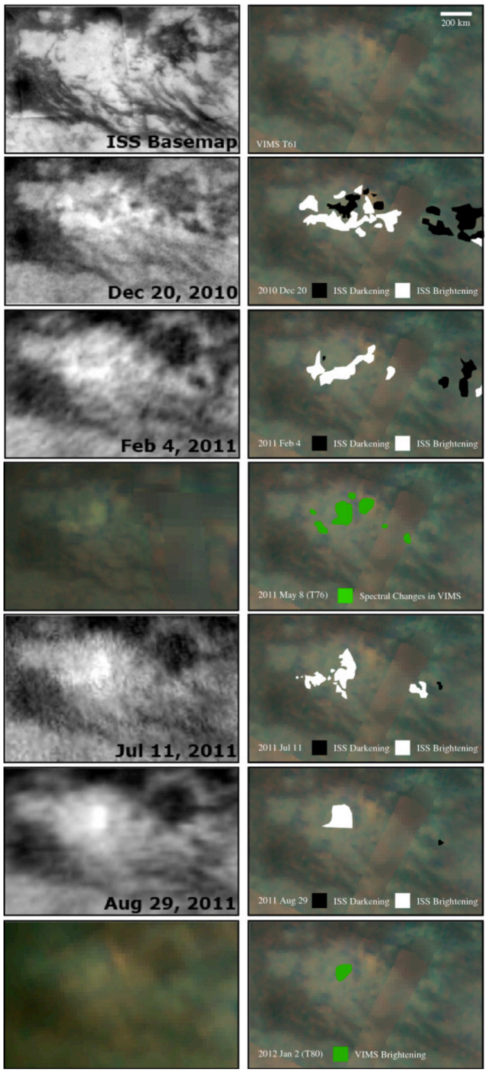

Figure 3: ISS and VIMS image sequence (left) of Yalaing Terra for ~1 yr after the Fall 2010 storm, and (right) highlighting the observed changes: ISS darkening (black) and brightening (white); VIMS spectral changes (green), these spectra do not match other surface units [8]. [After 8, Fig. 8]

2. Implications for Titan's surface

The frequency and amount of precipitation from storms at low latitudes have important implications for Titan's methane cycle, atmospheric circulation, and rates of geologic modification. The observation that darkening persisted for several months implies an impermeable layer or saturated ground at the level of a methane table, which would be consistent with observations, including detection of methane, by the Hugyens Probe after it landed on Titan's surface at ~10° S [11-13]. Furthermore, in places, liquid may have ponded up to several cm or a few tens of cm deep. Cassini observations demonstrate that liquids primarily exist on Titan's surface at high latitudes, and, although fluvial channels are observed globally, equatorial areas of long-lived longitudinal dunes indicate low latitudes are pre-dominantly arid [14]. Nonetheless, as in deserts on Earth, infrequent, but intense, rainstorms, like the one in Fall 2010 may be sufficient to form the observed channels.

3. Implications for weather patterns

Cassini and Earth-based observers monitor Titan frequently (typically at least a few times per month). However, clouds have been rare since the 2010 outburst (Fig. 1), suggesting that enough methane was removed from the atmosphere and the lapse rate sufficiently stabilized to decrease cloud activity. A similar, although shorter, lapse followed the 2004 south-polar storm (Fig. 1) [15, 4]. As a result, clouds may not pick up until the onset of convection at mid-northern latitudes anticipated in late northern spring. Although most models had predicted that this increase would occur well before 2013 [e.g., 1-3].

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