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Evidence of diurnal variations of Titan's near-surface temperature and of a cooling effect of the northern seas from the Cassini radar/radiometer

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At first order, the physical temperature of Titan's surface can be regarded as nearly constant and predictable. Due to the low incident solar flux reaching its surface (1/1000 of what Earth receives) and the high thermal inertia of its atmosphere, diurnal, seasonal (including latitudinal) and altitudinal variations of temperature are limited as well as the effect of surface albedo (Lorenz et al., 1999). Voyager 1 radio-occultation measurements indeed show no diurnal effect and point to lapse rates in the lower atmosphere smaller than 1.5 K/km (McKay et al 1997). Voyager infrared observations indicate a pole-to-equator temperature contrast of 2-3 K (Flasar et al., 1981; 1998).

The Cassini mission (2004-2017) somewhat confirmed these predictions and first measurements. On board the Cassini spacecraft, two instruments were able to measure the physical temperature of Titan's surface: the Cassini's Composite IR Spectrometer (CIRS) through a spectral window of low opacity in the thermal IR and the Cassini radar used as a microwave radiometer. Both instruments monitored the surface brightness temperature at their respective wavelengths (19 microns and 2.2 cm, respectively) during the almost two Titan's seasons of the Cassini mission. Interestingly, these two instruments probe different depths; the very surface for CIRS and at least several decimeters in the lands for the microwave radiometer (Janssen et al., 2016), much more in the lakes (Mastrogiuseppe et al., 2014). Combining these datasets thus provides insights into the vertical variations of the thermal and physical properties of the surface.

From the analysis of CIRS dataset, Cottini et al. (2012) report a diurnal signal of 1-1.5 K indicative of a thermal inertia of 300-600 MKS while Jennings et al. (2009; 2016) investigate seasonal changes confirming a constant maximum temperature of 93.65 +/- 0.15 K (as measured by the Huygens probe at 10.3°S latitude, Fluchignoni et al., 2005) and a variation of the latitude at which this maximum occurs following the sub-solar latitude (which moved from 24°S to 23°N between 2004 and 2017). Jennings et al. (2016) also found a 2-4 K equator-to-pole difference and note a delay in the northern warming at the end of the mission, as summer was on its way. This later was interpreted as a cooling effect of both the lakes and the surrounding moist lands as CIRS observations show no difference in the thermal behavior of these two types of terrains (within measurement uncertainty of about 0.5 K).

From the radiometry dataset, Janssen et. (2016) find latitude-dependent seasonal temperature variations smaller than those measured by CIRS by a factor of 0.87 +/- 0.05 in relative amplitude which is consistent with a penetration depth of 40 cm-1 m in organic sands. The difference with CIRS observations is slightly more pronounced in the northern hemisphere likely owing to the presence of lakes and seas in which microwaves penetrate deeper than in dry lands. In the North pole, Le Gall et al. (2016) also report the hint of a slower than expected rise in temperature in the second largest sea of Titan, Ligeia Mare, toward the end of the mission. Any diurnal effect was neglected considering that the radiometer would probe much deeper depths than the diurnal skin depth (Lorenz et al., 2003).

In this work, in order to investigate further the seasonal variations of Titan’s temperature, we present the analysis of the high-resolution radiometry observations recorded in the northern pole from 2007 to 2017. This analysis demonstrates that the seas warm more slowly than their surrounding lands and are therefore responsible for the global lag in summer warming observed in Titan’s high northern latitudes both by CIRS and the Cassini radiometer. This cooling effect could be due to the high thermal inertia of liquid hydrocarbons, their high transparency (which leads microwaves to sense the coldness buried from last winter, Le Gall et al., 2016) and/or methane evaporation (Mitri et al., 2007).

In addition, we present for the first time the analysis of the 118 distant observations of Titan collected during the course of the Cassini mission. These observations were designed for the computation of the disk-integrated brightness temperature of Titan. Though unresolved, they provide clues on the seasonal and longitudinal variations of Titan’s surface thermal emission. In particular, they clearly show Xanadu, a large-scale low emissivity/radar-bright feature on the leading side of the satellite. The analysis of this dataset reveals a possible diurnal component of amplitude 0.6 K and peaking at 4 pm in Titan’s radar-dark terrains and of amplitude 0.8 K and peaking at 2 pm in Xanadu. Unfortunately, such a signal cannot be isolated in high resolution observations because of the way data are calibrated (Janssen et al., 2016). If confirmed, this detection would bring a further argument for a smaller than expected electrical skin depth (i.e., a more absorptive subsurface) in most of Titan’s equatorial lands and/or a larger diurnal thermal skin depth (i.e. a higher thermal inertia), especially in Titan’s radar-dark dune terrains.

To conclude, monitoring surface temperature brings key insights into the surface properties and its coupling with the atmosphere. Cassini findings provide a global context for the future observations of DraGMet, the geophysics and meteorology package on board the Dragonfly quadcopter (Lorenz et al., 2018) which will investigate the ground thermal properties and record temperature variations in parallel with the atmosphere humidity, the ground moisture and wind speed.