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Retrieving Titan's surface temperatures from Cassini – CIRS observations

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Abstract

We retrieve Titan's surface temperatures by studying the moon's outgoing radiance through a spectral window in the thermal infrared at 19 μm (530 cm^{-1}) characterized by low opacity. We begin by modeling Cassini Composite Infrared Spectrometer (CIRS) spectra from nadir observations using a radiative transfer forward model combined with a non-linear optimal estimate inversion method. By zonally averaged results, we find a latitudinal decrease from the equator to the poles, ~2 K toward the South Pole and ~3 K toward the North Pole, and we are in agreement with the HASI near-surface temperature of about 94 K at 10 deg S (Fulchignoni, M., et al. 2005) and with a previous analysis of CIRS data (Jennings, D.E., et al., 2009). We also searched for diurnal variations by binning temperatures near the equator in hours of local time and find a trend of slowly increasing temperature towards the late afternoon with a magnitude of 1.5 K. We can obtain information on surface properties by correlating the retrieved surface temperature with Titan surface albedo maps. We find a decrease of about 1 K in the high-albedo Xanadu region and a generally similar increase in the darker region Belet (from the ISS visible map at 938 nanometers). We hope to use this data to derive the thermal inertia of the different terrains from the diurnal surface temperature variations, which may help to constrain the composition of the surface.

1. Introduction

The surface is a source of the radiation observed in the thermal infrared spectral range and its temperature changes may cause interactions between the surface and the atmosphere. The surface temperature derives in part from insolation and it is related to the exchange of heat and volatiles between the surface and atmosphere; these reasons attribute to the surface temperature an important role for understanding planetary atmospheres. At 19 μm, Titan's atmospheric opacity due to the gases and the thick haze layers that surround the moon presents a minimum and the emerging radiation field has 70-80% of its contribution from the surface. Therefore at this wavelength we can study the surface (Flasar et al., 1981; Hanel, R. A., et al., 1981; Samuelson, R. E., et al., 1981).

Voyager observed in the infrared an equator-to-pole gradient of surface temperature during the northern spring of about 2–3 K, and there was no other information on Titan's surface temperatures before the Cassini mission started to observe the moon in its northern winter in October 2004. In January 2005 the Huygens Atmospheric Structure Instrument (HASI) on the Huygens descent probe measured the near surface temperature (Fulchignoni, M., et al. 2005) at its landing site (10°S), assigning it a value of 93.65 ± 0.25 K.

During Cassini's first four years of observations of Saturn and its satellites the Composite Infrared Spectrometer (CIRS; Flasar, F. M., et al. 2004) has measured the radiation coming from a large part of Titan (Sadino, J., et al., 2006) and the surface brightness temperature has been detected from CIRS spectra using the 19 μm window (Jennings, D.E., et al., 2009). The inferred values are consistent with the HASI measurement near the equator and decrease by 2K and 3K towards the South and North Poles.

With an increased number of CIRS observations of Titan we are now able to cover a larger range of longitude and latitude and different local conditions; this together with the use of models (radiative transfer of the atmosphere) to fit the spectra gives us an opportunity to improve our knowledge of Titan's surface temperature.

2. Data and method

The Composite Infrared Spectrometer (CIRS) data in the far infrared range (400 – 600 cm^{-1}) are used for the task of surface temperature retrieval. We analyze the spectra detected by the Focal Plane 1 detector (FP1) with a spectral resolution of 15.5 cm^{-1} and a field of view of 3.9 mrad. Among Titan CIRS-FP1 data we selected those with (i) the entire FOV on the planet and also (ii) acquired from a distance less than 160,000 km and (iii) with an emission angle at the observed spot less than 70°. We also selected consecutive observations in which the FOV on the planet was moving by a maximum of 0.02% during the spectral scan. These selection criteria were applied in order to keep a small projected FOV on the surface. To be able to study the continuum level in this spectral range we averaged data in groups of about 100 close observations to decrease the noise background. To avoid biased results for possible seasonal changes of the surface temperature we also subdivided the available database in 3 different periods of data acquisition.
In order to obtain information on the surface temperature from the FP1 spectral continuum we applied a quantitative model developed at Oxford University (Irwin, P.G.J., et al**.**, 2008) to compute the spectral radiances which are to be compared with the measurements. For this purpose we used a combination of forward model and retrieval scheme based on the method of optimal estimation (Rodgers, C. D., et al., 2000) to determine the best estimates for the physical parameters in the model (surface temperature and atmospheric aerosol profile). The input atmospheric and surface model take into account the methane abundance, the haze, the aerosol spectral dependence of opacity, the collision induced absorption of the main atmospheric molecules, the surface brightness temperature for unit emissivity and the observation geometry.

3. Results and Conclusions

We found for the surface temperature a value around 94 K near the equator, in good agreement with the HASI ones (93.6 K at -10º of latitude) and with previous results of Jennings et al. 2009. The retrieved values for all the observations fall in the range 89.5 – 94.5 K, with decreasing trends towards the South and North Poles of 2-3 K, also in agreement with previous results, but for higher latitudes, a small increase, still to be investigated, has been observed.
The error on the temperature is variable for each retrieval depending on the instrument error, the a priori error for the retrieval and the standard deviation of the averaged spectra; the result is a retrieval error ranging from about 0.5 to 1 K for single retrievals and values always lower than 0.5 K when data are averaged in bins of latitude or local time.
An increase of the surface temperature as a function of the local time has been detected of about 1 K from the morning to the late afternoon, adding new and important information on Titan diurnal variations of the surface temperature.

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