Monitoring the Martian atmosphere from TIRVIM on board ExoMars/TGO: preliminary results on the temperature profiles and dust integrated content

Sandrine Guerlet (1), N. Ignatiev (2), T. Fouchet (3), F. Forget (1), E. Millour (1), R.M.B. Young (1), L. Montabone (1,4), A. V. Grigoriev (2) A. Trokhimovskiy (2) F. Montmessin (5) and O. Korablev (2).
(1) Laboratoire de Météorologie Dynamique, Paris, France (2) Space Research Institute (IKI), Moscow, Russia (3) LESIA, Observatoire de Paris, Meudon, France (4) Space Science Institute, Boulder, CO, USA (5) LATMOS, Guyancourt, France. (sandrine.guerlet@lmd.jussieu.fr)

Introduction: The ExoMars Trace Gas Orbiter (TGO), a mission by ESA and Roscosmos, was launched in March 2016. After a long aerobraking phase, it reached its final, near-circular 400 km orbit in February, 2018 then started its operational scientific phase in March, 2018. On board TGO, the ACS-TIRVIM instrument has the capability to map the thermal structure of the Martian atmosphere and its aerosol load at a great variety of local times. In this abstract, we describe our retrieval algorithm used to analyse TIRVIM data. We discuss synthetic retrievals performed for a great variety of scenes to fine-tune and evaluate the performance of our algorithm, then present results obtained from the first orbits of TGO. In a second step (not covered), the climatology dataset obtained from TIRVIM will be assimilated into the LMD Mars General Circulation Model to improve our understanding of the Martian atmospheric system.

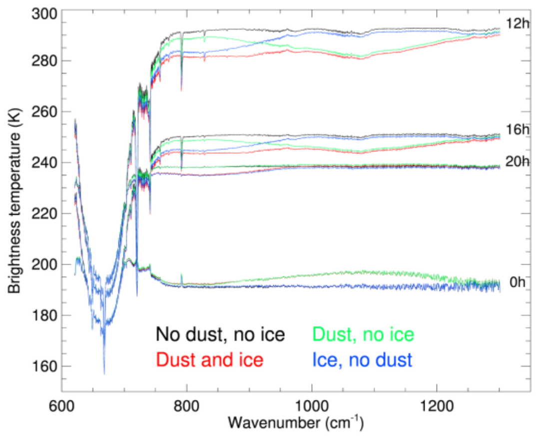
The ACS-TIRVIM instrument: The Atmospheric Chemistry Suite (ACS) is a set of three spectrometers including a thermal-infrared channel, TIRVIM [2]. It is primary dedicated to monitoring the thermal structure and aerosol content in the Martian atmosphere by acquiring spectra in nadir geometry. ACS-TIRVIM is a Fourier-transform spectrometer covering the spectral range 600–6000 cm^{-1} (1.7–17µm) with a spectral resolution of 1.2 cm^{-1}. This spectral range encompasses absorption by CO_2 (centered at 667 cm^{-1}), water ice clouds (centered at 820 cm^{-1}) and dust (centered at 1100 cm^{-1}). It is similar to the Thermal Emission Spectrometer (TES) on board Mars Global Surveyor or the Planetary Fourier Spectrometer (PFS) on board Mars Express, also operating in nadir geometry. The advantage of the TIRVIM data set over previous instruments comes from the TGO orbit, which was designed to sample a complete daily cycle every two months. Hence, TIRVIM has the capacity to uniquely study both the daily and the seasonal variability of the thermal structure, dust and ice cloud opacity, while previous instruments mainly sample the atmosphere at ~midday and ~midnight.

Retrieval algorithm: We have developed a line-by-line radiative transfer model coupled to a bayesian retrieval algorithm to retrieve vertical profiles of the temperature from ~5 to ~45 km, surface temperature, and integrated optical depth of dust and water ice clouds. Following the method of [1], a priori temperature profiles are built from the TIRVIM spectra themselves. At high altitudes, these a priori profiles relax towards a climatology profile constructed from MCS profiles. As nadir-viewing spectra cannot constrain the dust vertical profile, we currently assume that it is well mixed and retrieve a scaling factor to an a priori profile, but other options are investigated. Surface emissivity is taken from previously-derived TES emissivity maps. This algorithm will be described in more detail in a future publication.

Synthetic Retrievals: In order to evaluate the performance of our algorithm and identify challenging cases, we performed synthetic retrievals for a great diversity of scenes. To start with, we extracted the surface and atmospheric state of the Martian atmosphere from the Mars Climate Database (MCD) for various locations (sampling different elevations), seasons, local times and aerosol scenarios. For each of these scenes, we computed a synthetic TIRVIM spectrum and added realistic noise. We then run our retrieval algorithm, starting from the aforementioned a priori profiles that are independent of the MCD.
Overall, the retrieved temperature profiles are close to the “true” profiles used to compute synthetic spectra, with a typical error of 2-3 K. The main challenges lie in the retrieval of the temperature in the first scale height above the surface and close to the uppermost level probed by the core of the CO_2 band at 667 cm^{-1} (near the 1-Pa level). In these altitude ranges, the contribution functions are quite broad, leading to significant degeneracy of the inverse problem. As a consequence, we are able to retrieve the mean temperature in these altitude ranges, but not the slope of the temperature profile.

Regarding dust and water ice clouds, our algorithm performs well in retrieving their integrated opacity during daytime (~9am - ~5pm), even if the assumed vertical distribution of aerosols is very different from the “true” profiles used to generate synthetic spectra. However, there are special cases for which the TIRVIM nadir spectra are insensitive to changes in the aerosol load. This occurs when the temperature contrast between the surface and the atmospheric layer with strong aerosol opacity is low (typically in the morning and evening). Examples of synthetic spectra at different local times and aerosol content are shown in Figure 1 to illustrate this issue. Hence, although the strength of the TGO is to perform measurements throughout the day, the dust and ice retrievals will not be reliable at all local times. These cases need to be identified and not be taken into account within a data assimilation scheme.

Figure 1: Examples of synthetic TIRVIM spectra computed at different local times, as labeled, with or without aerosol. We highlight two special cases, for a given season and location: an example of a spectrum insensitive to cloud opacity (here at midnight) and an example of spectrum not sensitive to dust opacity (here at 20h).



Application to ACS-TIRVIM: We have applied our algorithm to the TIRVIM data acquired during the two Mars Capture Orbits in November, 2016 and March, 2017. To validate the retrieved temperature profiles, we searched for co-located measurements by the Mars Climate Sounder (MCS) on board Mars Reconnaissance Orbiter. This instrument operates in limb viewing geometry such that it measures the temperature with a much greater vertical resolution. It is however on a sun-synchronous orbit and acquires spectra only near 3am and 3pm. For these first TGO orbits, 6 ACS-TIRVIM data were colocated with MCS data, and the retrieved temperature profiles agreed well (typically within ~5K) except in one case (systematic difference of 10K). This work will be continued soon with the TIRVIM data acquired during the operational orbits, still being calibrated at IKI.

Summary and conclusions: We have developed a retrieval algorithm to analyse ACS-TIRVIM spectra acquired in nadir-viewing geometry. It is used to measure surface and atmospheric temperature (~5-45 km) as well as the integrated opacity of dust and water ice clouds. We have performed synthetic retrievals to evaluate its performance, identify challenging scenes and have applied it to TIRVIM data acquired during the Mars Capture Orbits. We validated the results using co-located MCS data. At the time of the workshop, we expect to have analyzed TIRVIM data acquired during the first few months of its operational phase and will discuss the results especially in term of the diurnal cycle of the temperature, aerosols (including the ongoing dust storm), and comparisons with predictions from the LMD Mars GCM. Future efforts will focus on error characterization, a crucial aspect for upcoming data assimilation. A companion abstract will present the work being done to assimilate the temperature profiles derived from ACS.

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