Spatial distribution and temporal evolution of Methane in the Martian atmosphere

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Introduction: After the definition of an upper limit for methane in the Martian atmosphere [1] [2], in the last few years several authors reported the detection of a very small amount of methane [3], [4], [5], [6]. Such a claim gave rise to a wide debate also because of the possible implications of such a discovery. In fact, due to the relatively short lifetime of the methane molecule in the Martian environment (about 350 years, [7]), its presence means that it is probably currently produced on the planet and hence it would be necessary to understand its production process. Suggested hypotheses are basically linked either to geothermal or biological activities [8], [9], [10], [11], [12] and, in both cases, our perspective of the planet evolution would require a major revision [13]. It is worthwhile to note that all the reported observations have been made in the spectral region of the strongest methane feature (at 3018 cm^{-1}), while the only observation made of the second strongest methane band (at 1306 cm^{-1}) yielded the upper limit given by Maguire [1]. Obviously the confidence about the presence of methane in the atmosphere of Mars will be greatly increased, if it could be detected using also measurements made in this spectral region.

Method of Analysis: We report the results of an analysis performed using the infrared spectra collected by the Thermal Emission Spectrometer (TES) on board of Mars Global Surveyor (MGS), operating in the thermal infrared [14]. In principle, its spectral resolution (6.25 or 12.5 cm^{-1}), should not be sufficient for the detection of such a narrow feature, but we have verified, through an experimental and a computational approach, that the 1306 cm^{-1} methane band is detectable by this spectrometer, averaging a few thousand spectra. We have selected about 3,000,000 TES spectra covering the region between 60° S and 60° N in latitude. Temporally they are centred at each equinox and solstice for each of the three Martian Years (MY) considered. In addition they have been collected during the warmest part of the Martian day and in nadir configuration. During MY24/25 and 26/27 MGS/TES operated mainly in the low resolution mode (12.5 cm^{-1}) while in MY25/26 in high resolution mode (6.25 cm^{-1}). This selection should provide 12 spatial/temporal slices, but the amount of usable spectra selected in Summer (Solar Longitude, Ls 90°) of MY26 was too low for considering this slice statistically reliable and we performed our analysis only on 11 slices. The number of averaged spectra is ranging between 14,000 and 43,000 for the resolution of 6.25 cm^{-1} and between 28,000 and 213,000 for 12.5 cm^{-1}. In order to deal efficiently with such a large quantity of data, we have explored each spatial/temporal slice by means of the cluster analysis approach by Marzo et al. [15], [16], which allowed us to selectively average tens of thousand of spectra and to group them on the base of the presence of the methane feature at 1306 cm^{-1}.

Results: The methane abundances for each temporal slice have been evaluated, taking into account both the number of spectra grouped into the cluster associated with the methane band and the depth of such band in the corresponding average spectrum. A quantitative comparison between our findings and the results of other authors [3], [4], [5], [6] reveals a strong consistency, even if the temporal and the spatial scales are quite different. In addition, due to the full spatial coverage of Mars, provided by TES over a time span longer than three MY, we have been able to trace with good accuracy the spatial distribution and the temporal evolution of methane in the Martian atmosphere. The spatial distribution of methane is far from uniform with some regions of higher concentration and, at the same time, locations where the concentration of methane is very low, if not zero. In particular, there are three broad regions where the methane amount is systematically higher: Tharsis, Arabia Terrae, and Elysium. On the other hand, the temporal evolution of the methane abundance, shows large variations not only in the global amount but also in the spatial distribution. Such variations seem to follow a seasonal cycle and are different from one year to the other. The main issue is that the observed annual cycle suggests a methane lifetime of ∼0.6 years [6], much shorter than previously suggested based on photochemical processes (∼350 years) [4], [7], posing questions not only concerning the possible methane sources but also about its sinks.

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