EPSC Abstracts
Vol. 13, EPSC-DPS2019-606-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

A diurnal cycle in near-surface methane concentration from micro-seepage as constrained by TLS and TGO

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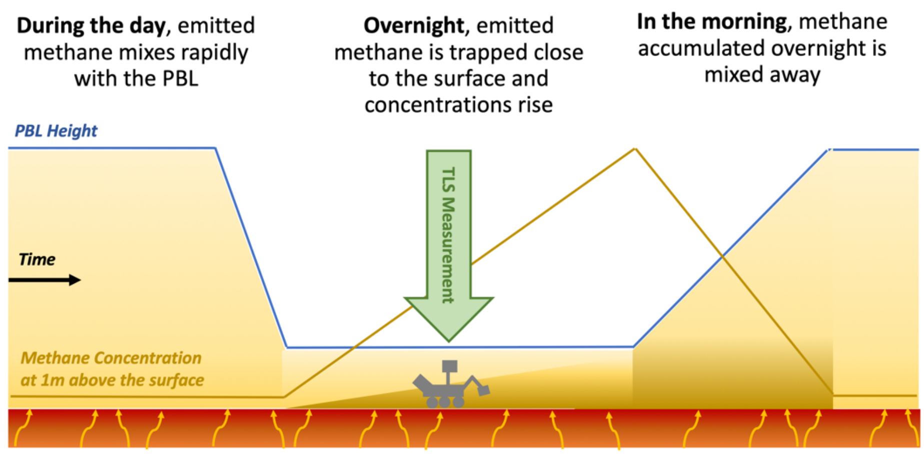
Abstract

The constraint on the methane content of the bulk martian atmosphere provided by TGO allows the expected variation in near-surface methane content to be quantified for constant micro-seepage. Under these circumstances, fluxes may be derived directly from MSL-TLS measured near-surface methane concentrations and are consistent with the low upper limit on methane derived in the middle and upper atmosphere by TGO.



The atmosphere should show a diurnal pattern to constant methane microseepage if background concentrations are near Zero

1. Introduction

Methane is a trace gas of intense interest on Mars. On the Earth, methane is produced primarily through biological processes. However, on Mars, there are several abiotic production mechanisms including water rock reactions, subsurface thermal decomposition [1] and UV-photolysis of exogenous organic carbon [2] which can be important due to the relatively small quantity of seeping into the atmosphere through the subsurface [3,4]. Small amounts of seasonally-varying methane have been observed near the surface [3] throughout the year but this varying background is not seen in the middle and upper atmosphere [5] suggesting a significant gradient.

Ultimately, if the concentrations of methane measured near the surface are representative of daytime values, this gradient is inconsistent with the known photochemistry and dynamics of the Martian atmosphere [5,6] which finds that methane should have an atmospheric lifetime of approximately 300 years and should mix thoroughly within months. Indeed, under reasonable assumptions for daytime mixing described by [5], emission from Gale required to produce a daily average of 410 pptv [3] in the several km thick [6] daytime planetary boundary layer (PBL) would produce a visible signal to TGO [5] in the upper atmosphere within a few decades.

However, the measurements of methane concentration near the martian surface are not acquired during the day, but in the middle of the night [3] when atmospheric conditions are stable and mixing is suppressed by several orders of magnitude giving rise to a PBL only a few m thick. As such, if methane concentrations exhibit a strong diurnal variation near the surface, fluxes into the upper atmosphere may be significantly smaller than anticipated since very little absolute methane must be released at night in order to generate relatively large concentrations (see Figure 1) in the near-surface air.

Indeed, if methane is emitted into the martian atmosphere through micro-seepage, as anticipated [1] and as well modelled [4], it would naturally create a variation like that shown in Figure 1 with concentrations building up in a small layer near the surface overnight and then mixed and diluted in the morning with several km of air down to a concentration of only a few pptv.

2. Methods, Results and Discussion

In this context, the TGO results [5] impose a powerful constraint. By indicating that methane is absent from the bulk of the martian atmosphere at most times and in most places, it becomes possible to use the TLS measurements of overnight methane concentration [3] to derive fluxes of this gas out of the subsurface. These are calculated to vary by season [8] from 5.2 x 10^{-11} kg m^{-2} sol^{-1} (1.8 x 10^{-5} tonnes km^{-2} $year^{-1}$) to 16 x 10^{-11} kg m^{-2} sol^{-1} (5.7x10^{-5} tonnes km^{-2} $year^{-1}$), similar to the values derived by [4]. These values are over an order of magnitude smaller than those calculated by [5] using the typical day-time mixing timescale of 1 sol [e.g. 9].

The lower limit of 50 pptv established by TGO on the bulk atmosphere [5] may be expressed as a maximum input into the martian atmosphere of ~2.4 kg sol^{-1} assuming a lifetime of 300 years. Taking the average of the derived flux values of ~1x10^{-10} kg m^{-2} sol^{-1}, a total surface area of 2.4 x 10^{10} m^2 or 2.4 x 10^4 km^2 may be emitting methane at rates comparable to the environment in which MSL has been operating. All of Gale need not emit methane as the same lack of mixing which prevents vertical dispersal of methane during the day would also prevent horizontal dilution.

If a fast destruction mechanism exists, especially one in the lower atmosphere involving dust, such as the sequestration mechanism proposed by [10] it would be amplified by the diurnal process. During the day, our calculations show that the eddy diffusivity is sufficiently high such that each gas molecule will encounter a dust grain on the order of once per second. Overnight, diffusivity may fall as low as the molecular diffusion limit, resulting in typical encounter timescales of weeks, suggesting only a few percent of gas molecules will have even a single encounter with a grain during the night.

As such, if gas-solid interactions with dust, such as [10] are important, these will happen much more frequently during the day, resulting in not only a dilution, but also a more rapid sequestration/destruction of this material. Overnight, the sequestration/destruction would be slowed by orders of magnitude, allowing the methane seepage to be observed by a near-surface detector (i.e. TLS on Curiosity). The net effect of this amplification, outside of the plumes, would make a larger micro-seepage flux from the subsurface mimic the same atmospheric concentrations as the currently observed small fluxes. This would help explain why martian subsurface fluxes appear to be exceptionally small compared to terrestrial seepage rates [1].

No upcoming surface spacecraft on Mars have plans to observe methane with the same (or better) sensitivity as the TLS instrument onboard MSL. However, the difference between the TGO and TLS results indicate that significant interesting chemistry may occur near the surface with methane being both diluted and sequested/destroyed as it rises, challenging orbital measurements. As such, to understand what is happening, more measurements near the surface are needed.

Yet, understanding the geographic distribution and temporal variation in methane producing regions remains key to understand what locations on Mars host underground processes which create and release methane. It would appear that such measurements can only be effectively observed by spacecraft able to sample the lower few meters of the martian atmosphere during the stable overnight period.

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