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Martian winds could drive seasonal methane variations observed by MSL-SAM: implications for TGO observations

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Abstract

The MSL-SAM team recently presented in situ measurements of the background methane levels in Gale Crater that exhibits a strong, repeatable seasonal variability with a mean value of 0.4 ppbv [1]. The Mars Regional Atmospheric Modeling System (hereafter MRAMS, [2]) is ideally suited to study the role of local atmospheric transport and mixing in the evolution of methane from potential source locations using instantaneous and steady-state (Figure 1) in time tracers, and to investigate whether methane releases inside or outside of Gale crater are consistent with TLS-SAM observations. Clathrate hydrates could be a possible source of episodic methane releases on Mars, and are used to estimate atmospheric abundances based on reasonable surface flux rates.

1. Experiment configuration

The model was run for twelve sols. Although the circulation patterns are highly repeatable from sol to sol beginning within a few hours of initialization, the first sol may be regarded as ‘‘spin-up’’. All simulations were started, at or slightly before local sunrise. In order to characterize seasonal mixing changes throughout the Martian year, simulations were conducted at Ls 270º (the wholesale inundation and flushing season of the crater reported in [3, 4]) and Ls 90º (as a representative of the rest of the year) and Ls 155º (the highest methane values in [5, Mumma]). Using the above model configurations, [3] demonstrate that the model was able to reproduce the meteorological observations obtained by the MSL Curiosity rover REMS instrument [6] in Gale crater.

2. Results

In our simulations, mixing of the crater air with external air is found to be high during all the martian year, being slightly more rapid at Ls 225-315 compared to other seasons. This result is in contrast to prior work, and we find that the crater is not isolated at any period of the year. The mixing time scale is ~1 sol or less. The model simulations further suggest that there must be a continuous release of methane to counteract atmospheric mixing, because the timescale of mixing is much shorter than the observed span of elevated methane levels. The model also indicates that the timing of MSL-SAM sample ingestion is very important, because the modeled methane abundance varies by one order of magnitude over a diurnal cycle (Figure 2). The crater atmospheric circulation is strongly 3-D, not just 1-D or 2-D, and any scenario describing the transport of methane must recognize this dimensionality [7].

3. Conclusions

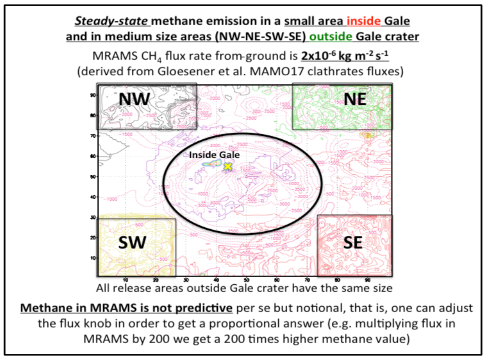
Presumably, ground temperature controls the release of methane trapped in clathrates on seasonal timescales. The methane flux should be higher during warmer seasons, implying a seasonal hemispheric difference in methane background values if we assume ubiquitous release sources over the planet. During Ls 225-315, the strong northwesterly air flowing down the crater rims during nighttime originates from deep within the northern hemisphere, whereas at other seasons the origin of that external air is from locations closer to the crater or from more tropical regions. The consequence of this is that although the local methane emission in the crater may be highest during the warm Ls 225-315 season, those emissions are rapidly transported away and replaced by methane-poor air emanating from the cold northern hemisphere (red circle in Figure 3). In contrast, the methane flux in the crater at other seasons is similar to the flux for the source air location (blue circle in Figure 3). In this scenario, mixing has little effect on the overall methane concentration and the concentration should be better correlated with the local ground temperature.

Based on the mean meridional circulation, surface winds would be expected to converge and confine in the equatorial zone as the rising branch transits through the equatorial region from one hemisphere into the other as it migrates to its solstitial location (green circles in Figure 3), containing and circulating methane-rich air in the equatorial zone.

Synergy of our modeling results with TGO observations could help to answer next intriguing questions: Where are the methane release locations? How spatially extensive are the releases? For how long is methane released?

4. Figures

Figure 1. Steady state methane release scenarios aerial view. Gale crater encircled. The yellow cross represent the MSL Curiosity rover location. Four independent methane release sources were located outside the crater ~100 km NW, NE, SW and SE of the rover landing site, each with an area of ~6,400 km^2 and another one located inside of the crater ~1 grid point west from the rover with an area of ~149 km^2:



Steady-state **methane emission in a small area inside Gale and in medium size areas (NW-NE-SW-SE) outside Gale crater**

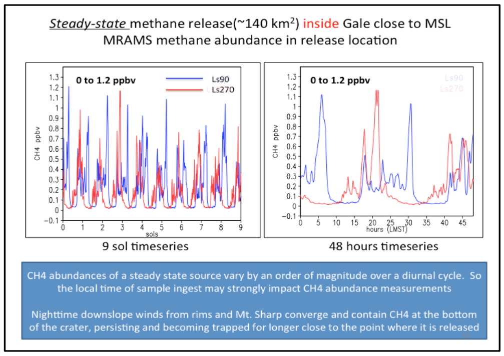
MRAMS CH_4 flux rate from ground is **$2x10^{-6}$ kg m^{-2} s^{-1}**

(derived from Gloesener et al. MAMO17 clathrates fluxes)

All release areas outside Gale crater have the same size

Methane in MRAMS is not predictive per se but notional, that is, one can adjust the flux knob in order to get a proportional answer (e.g. multiplying flux in MRAMS by 200 we get a 200 times higher methane value)

Figure 2. Nine-sols timeseries (left) and two-sols timeseries (right) of MRAMS methane abundances sampled ~14.5 m high at release site which is located inside of Gale crater ~1 grid point west from the rover with an area of ~149 km2. The release emission is steady state. Only nine of the twelve sols simulated were included into the figure:



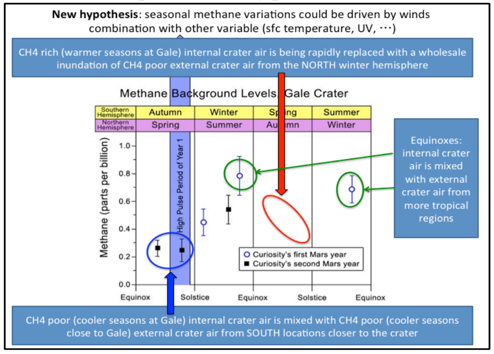
Steady-state methane release(~140 km^2) inside Gale close to MSL

MRAMS methane abundance in release location

CH4 abundances of a steady state source vary by an order of magnitude over a diurnal cycle. So the local time of sample ingest may strongly impact CH4 abundance measurements

Nighttime downslope winds from rims and Mt. Sharp converge and contain CH4 at the bottom of the crater, persisting and becoming trapped for longer close to the point where it is released

Figure 3. SAM methane background levels at Gale crater vs atmospheric mixing periods:



New hypothesis: seasonal methane variations could be driven by winds combination with other variable (sfc temperature, UV, ···)

CH4 rich (warmer seasons at Gale) internal crater air is being rapidly replaced with a wholesale inundation of CH4 poor external crater air from the NORTH winter hemisphere

Equinoxes: internal crater air is mixed with external crater air from more tropical regions

CH4 poor (cooler seasons at Gale) internal crater air is mixed with CH4 poor (cooler seasons close to Gale) external crater air from SOUTH locations closer to the crater

Aknowledgements

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References

[1] Webster et al, AGU 2017 P33F-07. [2] Rafkin et al, Icarus 2001. [3] Pla-Garcia et al, Icarus 2016. [4] Rafkin et al., Icarus, 2016 [5] Mumma et al, Science 2009. [6] Gómez-Elvira et al, Space Sci. Rev. 2012. [7] Pla-García et al, EGU 2018.