

Tracking the MSL-SAM methane detection source location Through Mars Regional Atmospheric Modeling System (MRAMS)

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1. Introduction:

The putative in situ detection of methane by Sample Analysis at Mars (SAM) instrument suite on Curiosity at Gale crater has garnered significant attention because of the potential implications for the presence of geological methane sources or indigenous Martian organisms [1, 2]. SAM reported detection of back-ground levels of atmospheric methane of mean value 0.69 ± 0.25 parts per billion by volume (ppbv) at the 95% confidence interval (CI). Additionally, in four sequential measurements spanning a 60-sol period, SAM observed elevated levels of methane of 7.2 ± 2.1 ppbv (95% CI), implying that Mars is episodically producing methane from an additional unknown source.

There are many major unresolved questions regarding this detection: 1) What are the potential sources of the methane release? 2) What causes the rapid decrease in concentration? and 3) Where is the re-lease location? 4) How spatially extensive is the re-lease? 5) For how long is CH₄ released?

Regarding the first question, the source of methane, is so far not identified. It could be related with geological process like methane release from clathrates [3], serpentinisation [4] and volcanism [5]; or due to biological activity from methanogenesis [6].

To answer the second question, the rapid decrease in concentration, it is important to note that the photo-chemical lifetime of methane is of order 100 years, much longer than the atmospheric mixing time scale, and thus the gas should tend to be well mixed except near a source or shortly after an episodic release. The observed spike of 7 ppb from the background of <1 ppb, and then the rapid return to the background level could be due to a sink (destruction) or due to atmospheric mixing. A wind mediated erosion process of ordinary quartz crystals was proposed to produce activated quartz grains, which sequester methane by forming covalent Si-C bonds. If this process is operational on Mars today, which some recent preliminary studies on olivine indicate could be the case, then it might explain the observed fast destruction of methane [7].

In an effort to better address the potential mixing and remaining questions, atmospheric circulation studies of Gale Crater were performed with the Mars Regional Atmospheric Modeling System (MRAMS). The model was focused on rover locations using nested grids with a spacing of 330 meters on the innermost grid that is centered over the landing [8, 9]. MRAMS is ideally suited for this investigation; the model is explicitly designed to simulate Mars' atmospheric circulations at the mesoscale and smaller with realistic, high-resolution surface properties [10, 11].

In order to characterize seasonal mixing changes throughout the Martian year, simulations were conducted at Ls 0, 90, 180 and 270. Two additional simulations at Ls 225 and 315 were explored to better understand the unique meteorological setting centered around Ls 270. Ls 270 was shown to be an anomalous season when air within and outside the crater was well mixed by strong, flushing, northerly flow and large amplitude breaking mountain waves: air flowing downslope at night is cold enough to penetrate all the way to the surface. At other seasons, the air in the crater is more isolated –but not completely– from the surrounding environment: mesoscale simulations indicate that the air flowing down the crater rims does not easily make it to the crater floor. Instead, the air encounters very cold and stable air pooled in the bottom of the crater, which forces the air to glide right over the colder, more dense air below. Thus, the mixing of near-surface crater air with the external environment is potentially more limited than around Ls 270.

2. Tracking methane source location

The rise in concentration was reported to start around sol 300 (~Ls 336), peaked shortly after sol 520 (~Ls 82), and then dropped to background values prior to sol 575 (~Ls 103).

Two scenarios are considered in the context of the circulations predicted by MRAMS. The first scenario is the release of methane from somewhere outside the crater. The second is a release of methane within the crater. In both cases, the release is assumed to take place near the season when the rise of concentration was first noted (~Ls 336). This is a transitional time at Gale Crater, when the flushing winds are giving way to the more isolated crater scenario:

In the situation where the release was outside the crater, the experiment assumes a uniform, elevated abundance of CH₄ outside the crater, and mixing should be sufficient to bring the crater methane abundance to something close to the larger-scale environmental value. As the crater becomes more isolated with time, the methane abundance in the crater will begin to lag whatever the value is outside the crater. If the release was far from the crater, the external ~7 ppbv value might be expected to slowly decrease as the methane becomes increasingly well-mixed on a global scale, and as some of that air mixes slowly into the crater. For the elevated methane levels in the crater to drop rapidly back to background levels, at least two things would need to happen. First, the external crater environment would have to drop at least as rapidly to the background levels. This seems possible only if there is very deep mixing that spreads the release through a very large volume of atmosphere, or if a rapid destruction mechanism is invoked. The second thing that would have to happen is that the crater air would have to mix nearly completely with the external crater air. The model results at Ls 90, which bounds the period between the observed peak and the return to the background levels, may be supportive of this idea. However, while mixing seems limited, it may still be possible that the mixing degree and time scale is sufficient to affect the necessary change.

In the second scenario, the release is assumed to be within the crater. In this case, some mixing of this air with external crater air at background values can be assumed. Depending on the rate of mixing, it is possible that the value could decay to the background levels in the given time. Thus, from a mixing stand-point, the second scenario seems at least plausible. Some preliminary work, including tracer gases into the model, is being performed to establish the amount of mixing during the limited mixing epochs. Preliminary results may support the idea that during periods of limited mixing, there could be enough time for methane to bind to activated mineral surfaces through wind erosion. More work is needed to establish the amount of mixing and to determine which scenario is more likely.

References:

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