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Evaluation of NASA Curiosity rover-SAM martian methane detections with the Mars Regional Atmospheric Modeling System (MRAMS)

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The in situ detection of methane at Gale crater by the SAM instrument suite on the NASA MSL Curiosity rover has garnered significant attention because of the implications for the potential of indigenous Martian organisms [1]. In the absence of a yet-to-be-confirmed rapid destruction mechanism, the photochemical lifetime of methane is on the order of several centuries. This is much longer than the atmospheric mixing time scale), and thus the gas should tend to be well mixed except when near a source or shortly after an episodic release. The observed spike of 7.2 ppbv from the background of <1 ppbv, and then the return to the putative background level in 47 sols is, therefore, curious. The Mars Regional Atmospheric Modeling System (MRAMS) [2] was used to study the transport and mixing of methane from specified source locations using tracers, and to investigate whether methane releases inside or outside of Gale crater are consistent with SAM observations.

MRAMS simulation configuration

Methodology

The simulation is configured with 5 grids. The innermost grid has a horizontal grid spacing of 2.96km. The model is run for 9 sols. Initialization and boundary condition data are taken from a NASA Ames GCM [3] simulation with column dust opacity driven by zonally-averaged TES retrievals. Vertical dust distribution is given by a Conrath-v parameterization that varies with season and latitude.

Vertical Grid Spacing

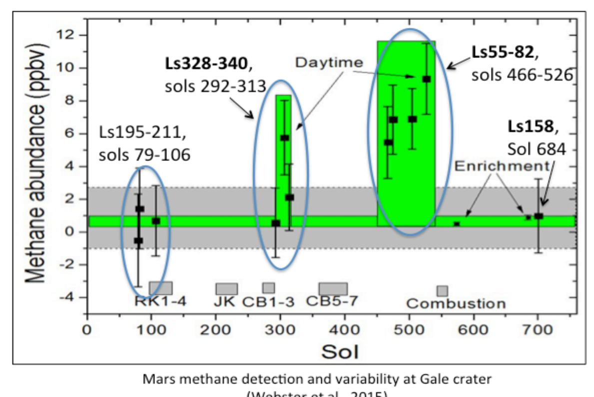
14.54m: First atmospheric layer
30m: Initial vertical grid spacing
1.12: Geometric stretch factor
2500m: Maximum grid spacing
50: Number of vertical grid points
51 km: Model top

Subsurface model and physics

11 soil levels; 1mm initial layer depth; 1.5m bottom layer depth; Initialized from GCM; Subgrid-scale level 2.5 TKE parameterization; NASA Ames two-stream, correlated-k radiation; Topo shadowing and slope radiation effects; Monin-Obukhov surface layer; Water microphysics not active; CO2 ice statically placed from GCM; Conductive regolith model

Tracers in the model

Can be placed anywhere, and may be released instantaneously or at a user-specified, time-dependent rate. Tracers are not radiatively active and do not contribute to the tendency of any model prognostic variables.

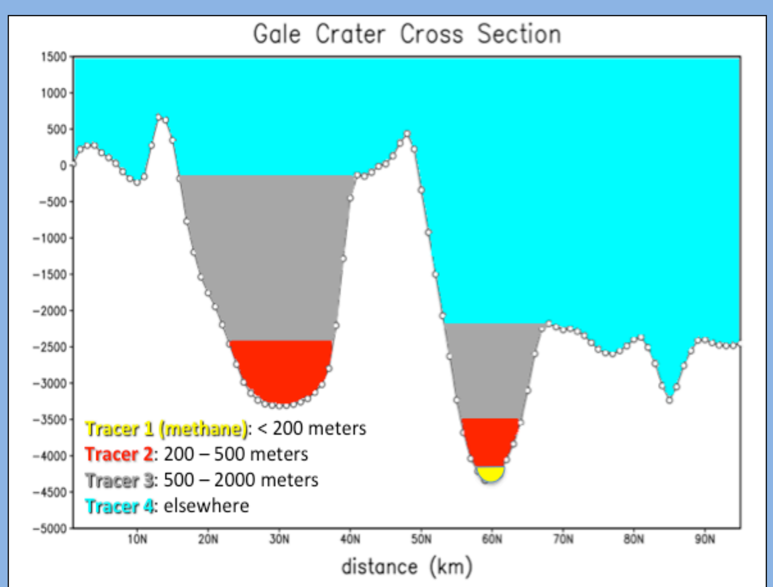


Mars methane detection and variability at Gale crater (Webster et al., 2015)

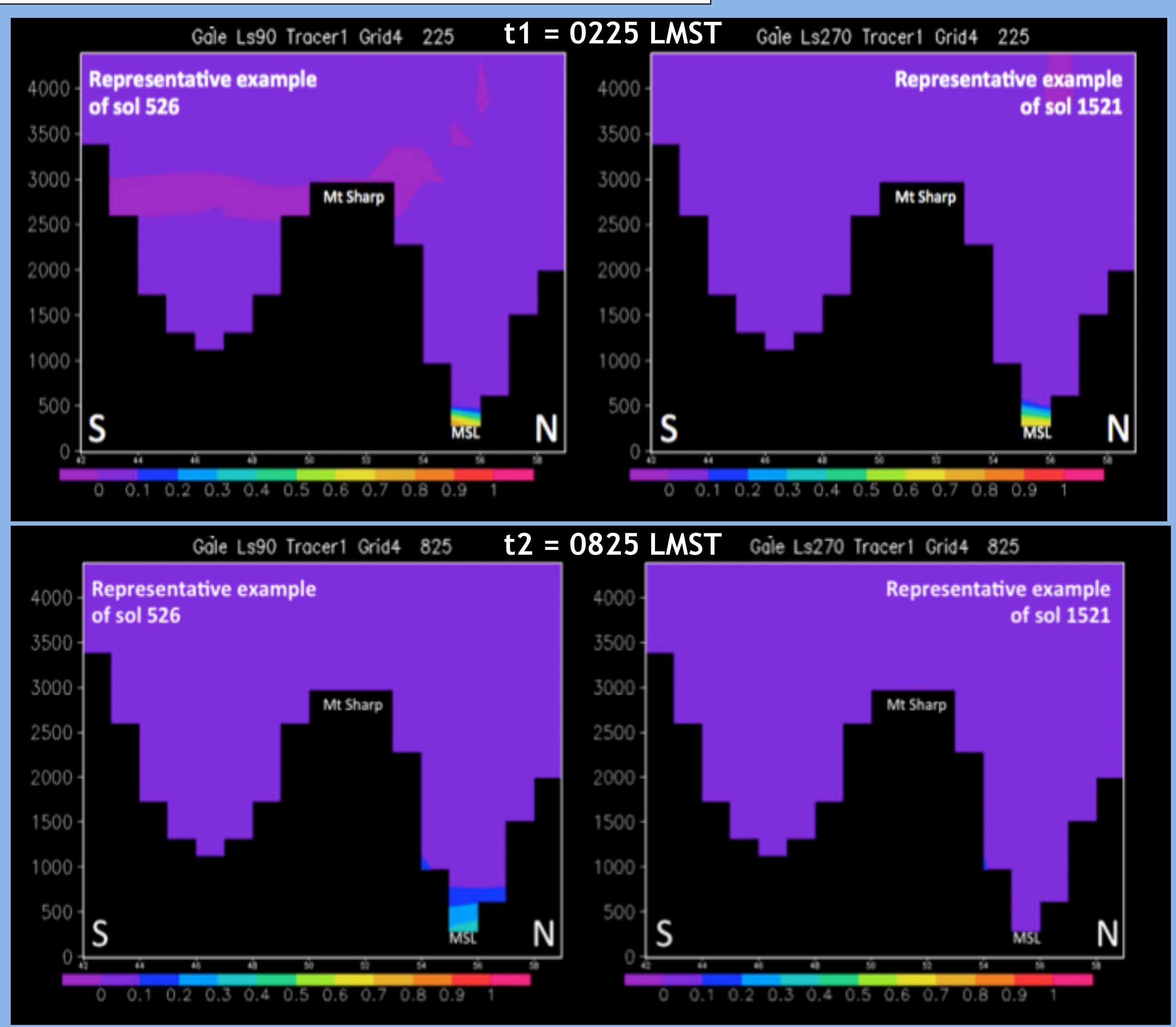
Punctual methane release scenarios

The fraction of a given tracer compared to the total tracers over time is studied. By comparing the fraction of other tracers at the same location, the amount of mixing from different air masses can be determined.

Methane release **inside** Gale scenario

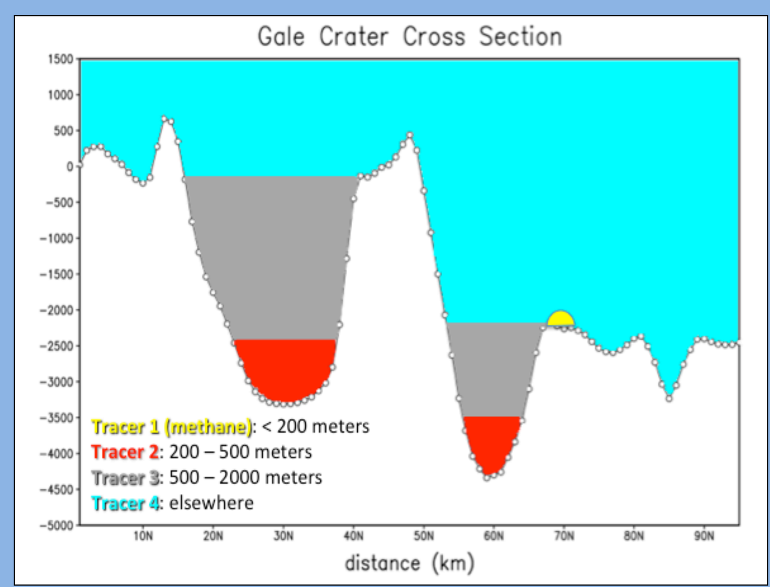


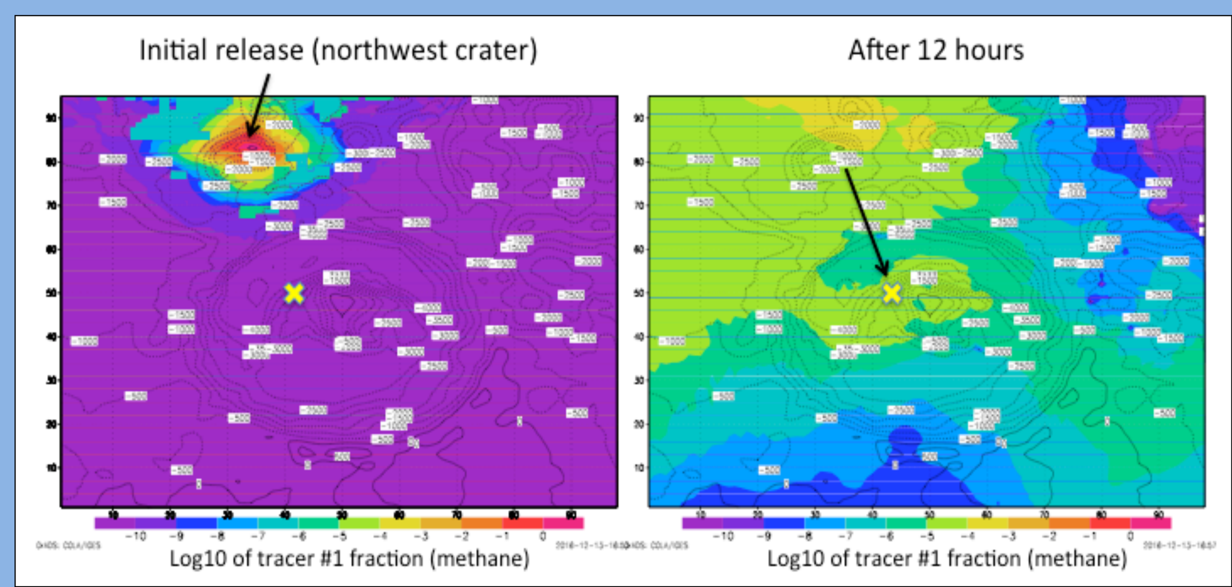
In this experiment four tracers were injected into the model: Tracer #1 mimics CH4 release and the other tracers are placed in different elevations. Tracer #2 is placed from 200 to 500 meters high inside Gale, tracer #3 from 500 to 2,000 meters high inside Gale and tracer #4 elsewhere.



Tracer #1 inside the crater is diluted to a few percent just 6 hours after the release @Ls270. In contrast, 50% of the tracer #1 in the crater @Ls90 remains after 6 hours. The mixing of the crater air with the external air outside of Ls270 is reduced, but the timescale it is still rapid. Regardless of the season, the air mass of the northern crater is evacuated and mixed away in 1 sol or less.

Methane release **outside** Gale scenario



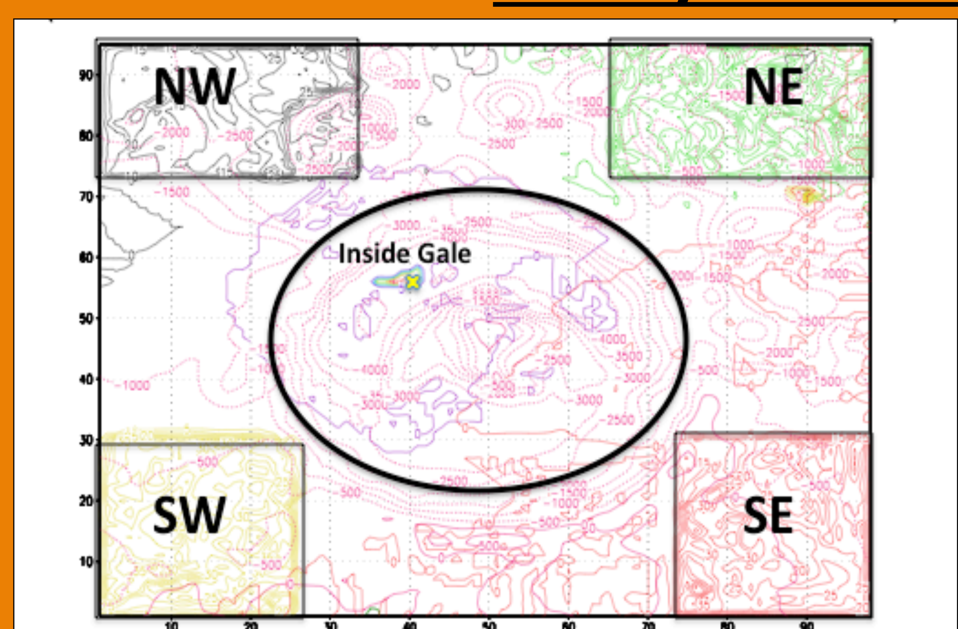


This scenario was configured as the CH_4 release inside Gale scenario but placing tracer #1 outside Gale to the NW (roughly upwind) with a medium size area (~6,400km²) emission. Results show that only 12 hours after release, the CH_4 that makes it to the MSL location is diluted by six orders of magnitude from the initial release concentration regardless of the season. Although the air in the crater is being rapidly replaced by outside air, there is a large amount of mixing and dispersion of the source air. To achieve a value of 1 ppbv, a release of CH_4 on the order of parts per thousand would be required, which is likely unreasonable.

Punctual methane release conclusions

Duration of CH4 peak detected by SAM is 100 sols (assuming no high frequency variations). So then the model simulations indicate that there must be a steady-state release inside the crater to counteract atmospheric mixing, because the timescales of mixing in the crater is ~1 sol during all seasons, which is much faster than previously estimated [4, 5].

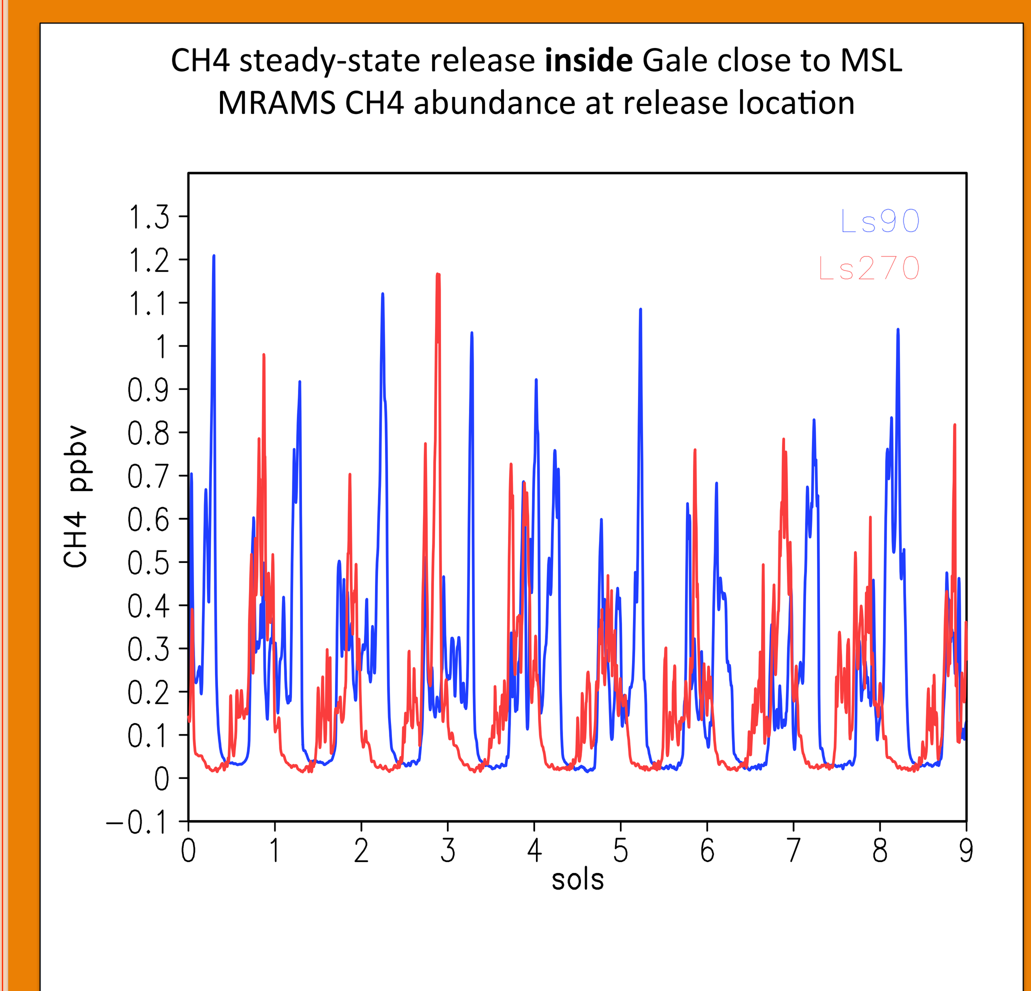
Steady-state methane release scenarios

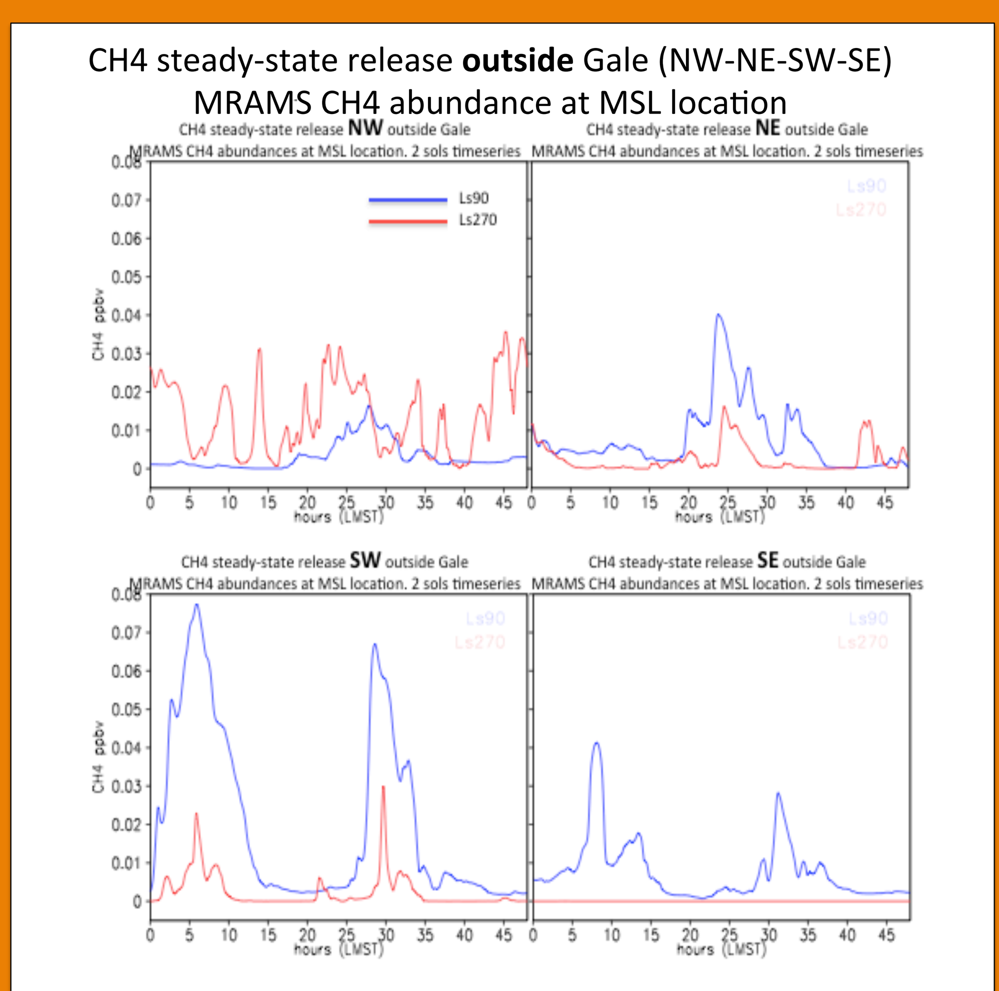


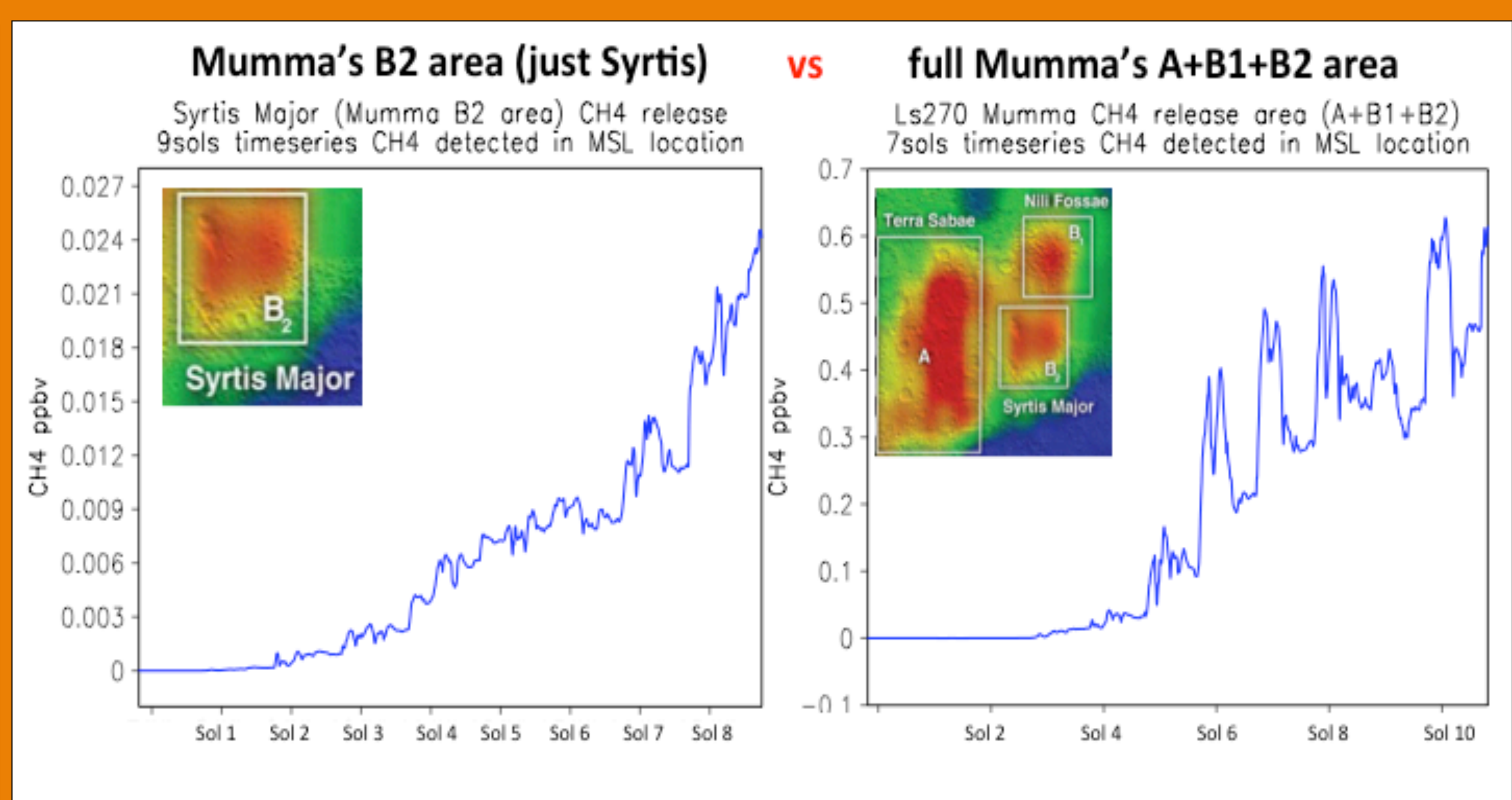
All release areas outside Gale crater have the same size

These scenarios include **five** independent methane continuous release sources located at NW, NE, SW and SE outside Gale crater with an area of ~6,400 km² each and a continuous release source inside Gale closed to MSL with an area of is ~149 km². Tracers do not interact with each other, so their behavior can be studied independently in the same simulation.

In these scenarios, the methane release is steady-state (continuous outgassing event from ground) with a prescribed flux of $\mathbf{2.3x10^{-6}\ kg\ m^{-2}\ s^{-1}}$ (derived from [6] clathrates fluxes subsurface model) during a period of ~9 sols. 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)







And additional simulation was conducted in order to mimick Mumma et al. 2009 [7] methane detections. In the figure only Ls270 is shown in 2 different release scenarios: full and limited Mumma et al. 2009 detection areas in order to study the impact of the different release sizes.

Steady-state methane release conclusions

* Predicted methane 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 methane abundance measurements.
* It is difficult to reconcile the SAM measurements with the transport and mixing predicted by MRAMS.
* The only plausible scenario is an intermittent local release close to the rover with the restriction that such releases must be globally rare or there must be a unknown rapid methane destruction mechanism.
* But, if we multiply flux, increase release area or move it closer to rover (or all of previous), we would get methane values that SAM should be capable to detect doesn't matter where it comes from.
* SW release at Ls90 and NW release at Ls270 outside Gale are the higher values due to global circulation.
* Ls90 (SAM's high-CH4 abundance period) seems to have higher methane values than Ls270. Release inside or close to Gale show very localized methane in contrast with Mumma et al. 2009 detection.
* In the mimicking Mumma release area scenario, CH4 is building up around MSL just 3 sols after being released >3,000 km away! With a smaller release area (just B2 area) we get 30 times lower CH4 levels at MSL
* Although Ls155 is the season of the peak methane observation by Mumma, the highest CH4 value in our experiment is reached in Ls270 (one order of magnitude higher than Ls155).
* The circulation in and around Gale Crater is extremely complex and varies seasonally. The circulation is strongly 3-D, not just 2-D, and any scenario describing the transport of CH4 must recognize this dimensionality

Aknowledgements: the authors would like to explicitly thank the MSL science team for their efforts. Additionally, this work benefited greatly from comments and discussions provided by Alberto G. Fairén (Cornell/CAB), Timothy Michaels (SETI), Lorie Bruhwiler (NOAA) and Cesar Menor-Salván (Georgia Tech/CAB). [1] Webster, C.R. et al. Science, 2015; [2] Rafkin S.C.R. et al. Icarus, 2001; [3] Kahre et al. JGR, 2006; [4] Pla-Garcia et al. Icarus, 2016; [5] Rafkin et al. Icarus, 2016; [6] Gloesener et al. 6th MAMO conference, 2017; [7] Mumma et al. Science, 2009