European Geosciences Union EGU
14-19 April 2024, Vienna, Austria

MSL TLS-SAM measurements consistent with localized methane containment and transport by 3-D atmospheric circulation in Gale crater

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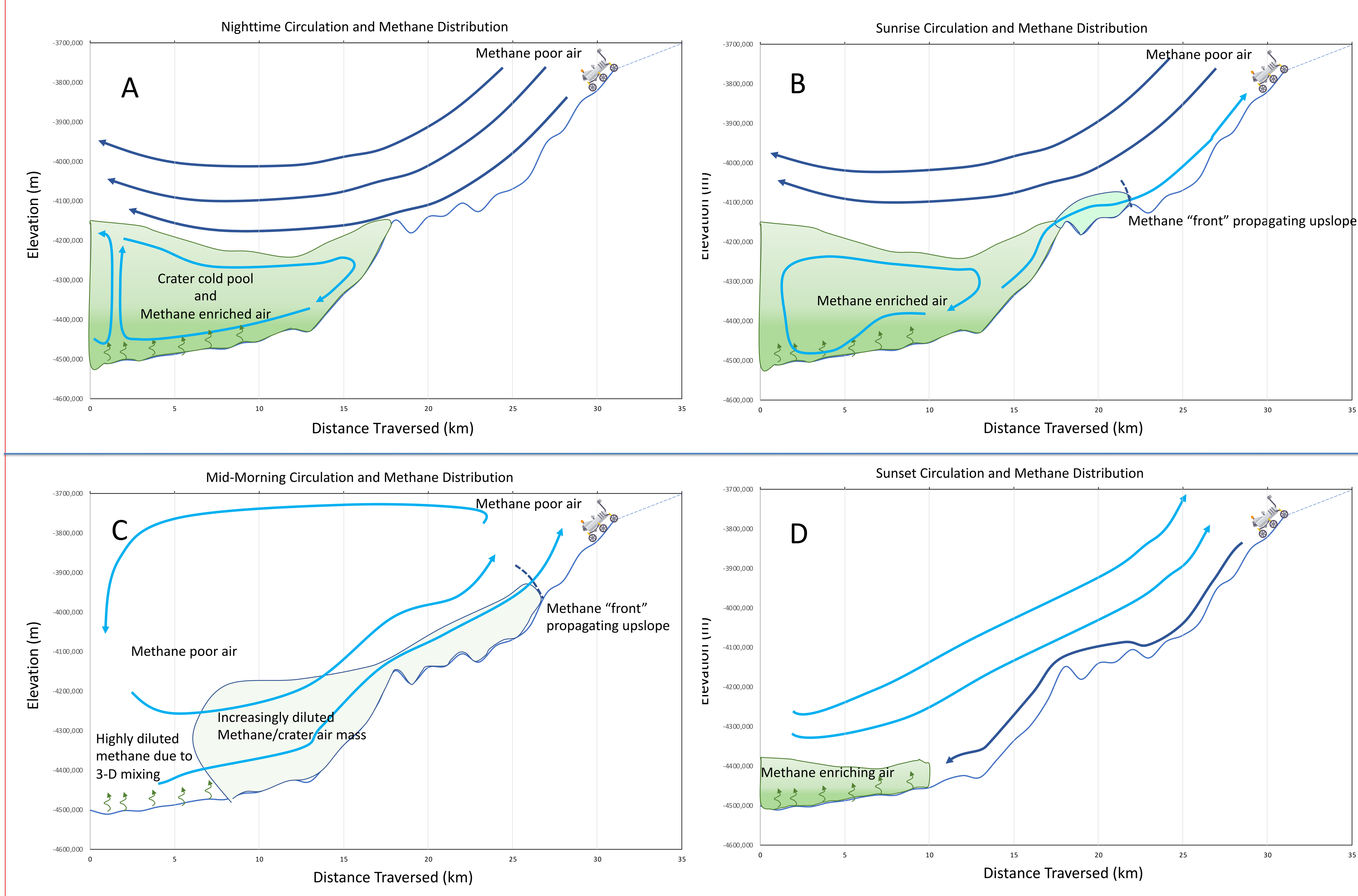
The Curiosity rover has moved ~31 km from the landing site climbing ~800 m into the Mnt. Sharp foothills over more than five Martian years. Modeling and observations suggest that the rover has ascended to elevations above a cold-air pool (hereafter CAP) at the bottom of the crater [1, *in preparation*]. Downslope winds originating from both Mnt. Sharp and crater rims converge at the very bottom of the crater floor [2; 3]. This flow would prevent the nighttime accumulation of methane (CH4) released along the slopes above the CAP and facilitate the quick transport downslope, convergence and accumulation of CH4 in the bottom of the crater.

3-D transport hypothesis: CAPs favor the accumulation of methane-enriched air close to the crater floor at night



Nighttime: CH4 could be released at bottom of crater (Panel A). The horizontal convergence is capped by PBL and there are downslope winds circulating along surface of Mnt. Sharp foothills that cannot scout the crater floor due to the colder air below, where the CAP is, so the CH4 is confined to bottom of crater.

At **dawn** the air masses begin to rise up through the sloped surface of Mnt. Sharp due to solar heating (buoyancy) and the confining horizontal convergence begins to breakdown as PBL starts to expand up, so consequently CH4 enriched air begins to advect upslope (Panel B).

CH4 enriched air inside the CAP start to dilute due to 3-D atmospheric mixing at this time. At **mid-morning** (Panel C), upslope circulation along surface rims is fully developed and there is a horizontal divergence at bottom of crater where CH4 is highly diluted due to 3-D atmospheric mixing and increasingly advected upslope and mixed out of crater by 3-D circulation.

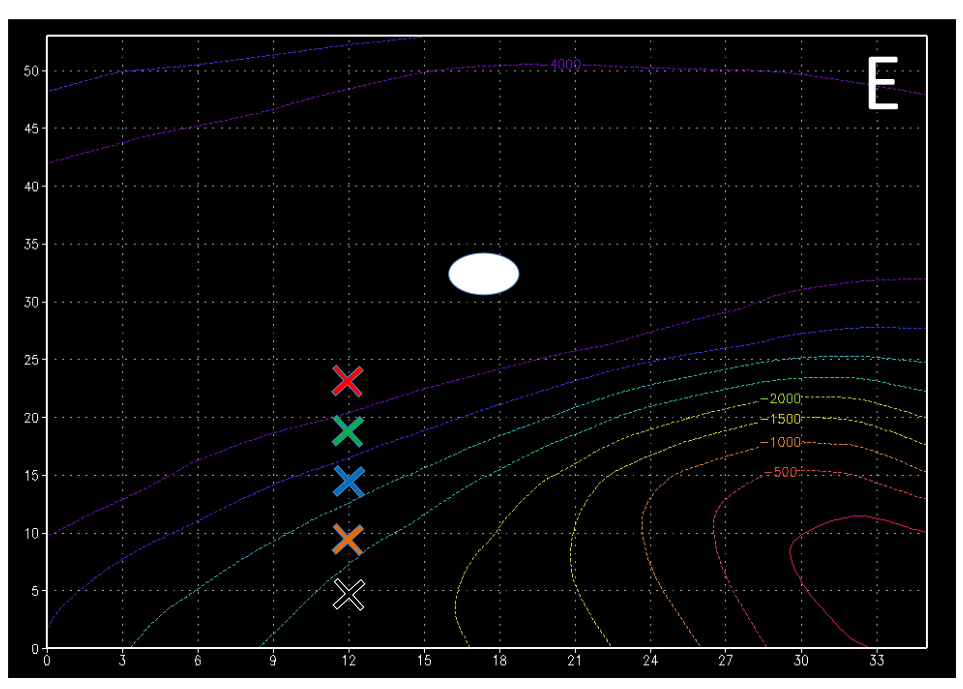
At **dusk**, downslope winds starts to develop through sloped surfaces of Mnt. Sharp, as well as the CAP of at the bottom of the crater, which begins to trap CH4 released from the ground to start the cycle again (Panel D).

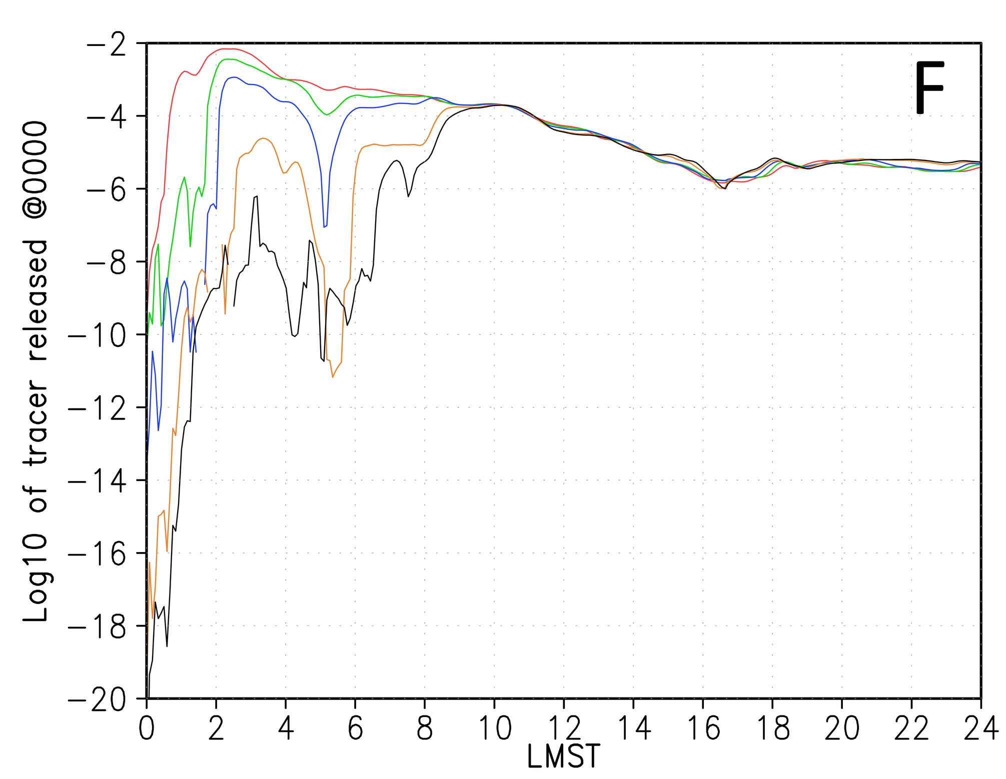
Panel E shows a topography elevation map with colored crosses marking different height locations at Mnt Sharp (Gale crater) with an instantaneous CH4 source (white oval) released for L_s 90.

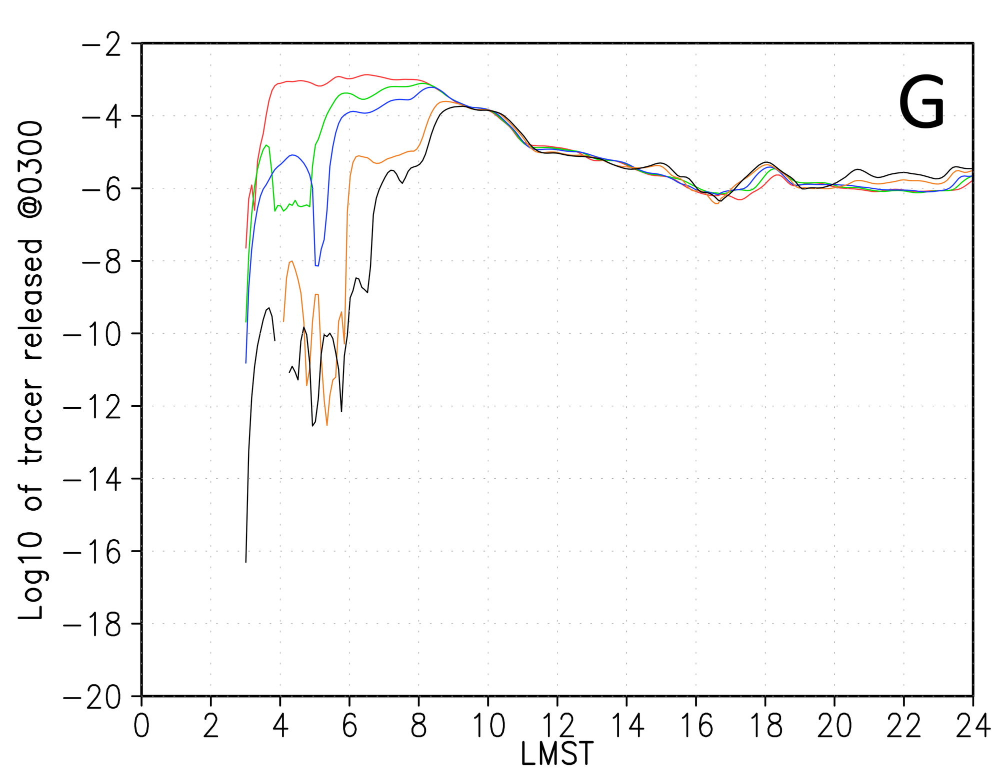
Panel F show log-10 time series of MRAMS CH4 released at 00:00 LMST and sampled at different heights marked with colors defined in Panel E. Panel G and H are the same than F but with CH4 released at 03:00 and 06:00 LMST respectively. Peak methane values are found at increasingly later times after sunrise, supporting CH4 front hypothesis (e.g., peak CH4 at -2,250m elevation (black cross location) occurs after ~0900 LMST).

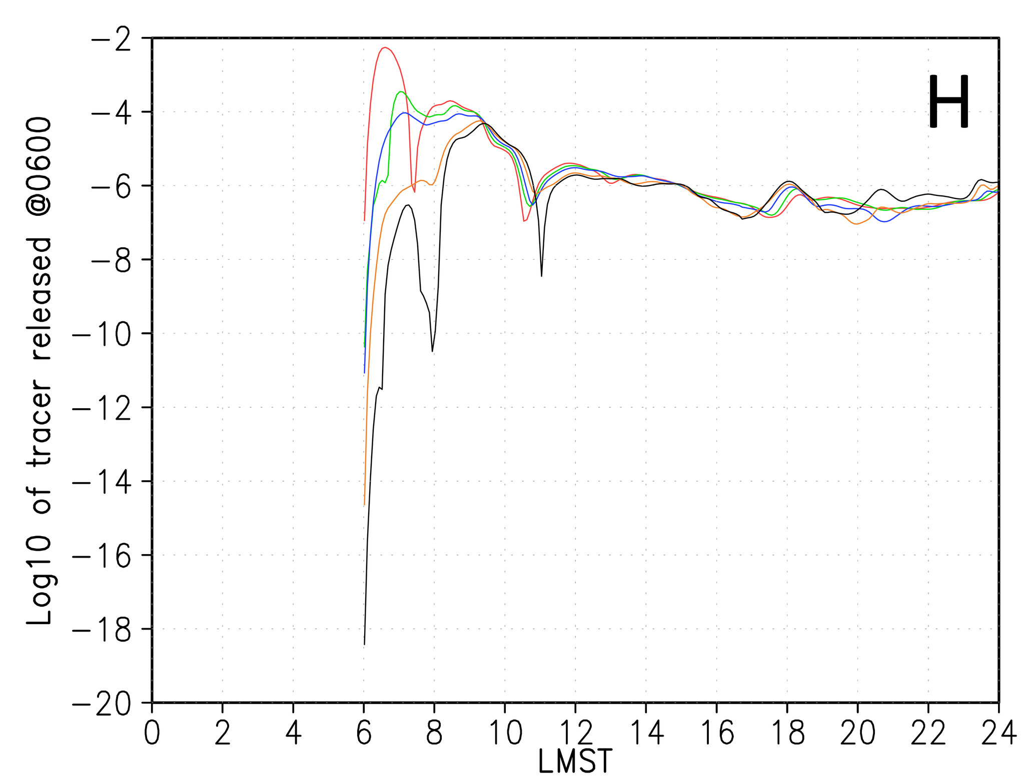
The current rover location (black cross) is too high for front to reach location early in the morning. MRAMS model predicts a CH4 front of peak values to pass higher elevations at increasingly later times after sunrise, moreover later in the morning (~09:00 LMST), but usually with highly diluted with time methane values (up to 4-5 orders of magnitude lower as shown in panels F-H.

MRAMS model tracers results









Conclusions

- **3-D distribution and evolution** of CH4 at Gale crater is extremely complex. Consistent with [Pla-García et al. 2019] the **3-D crater circulation** supplemented by the growth and collapse of the PBL is necessary to explain the TLS-SAM methane observations.
- CH4 could be concentrated at night by the horizontal downslope flow near the surface and a shallow nocturnal CAP. Even though the PBL is shallow along the slopes of the crater, horizontal (slope) winds can rapidly transport emitted methane into the bottom of the crater. Regardless of the PBL's behavior, horizontal transport of methane cannot be neglected.
- Regardless of the shallow nocturnal PBL, CH4 could not accumulate at current rover location with higher elevation to levels that were observed earlier in the mission at lower elevations.
- Assuming that CH4 is released only in bottom of crater, we could have a propagation of increasingly diluted methane "front" as a function of time and altitude (panels F-H).
- Future measurements are likely to show low CH4 abundance if methane is released only in the crater floor.

[1] Ruíz-Pérez et al. 2024 TBS [2] Rafkin et al. 2016 [3] Pla-García et al. 2019. Supported by Grant RTI2018-098728-B-C31 and PN2021- PID2021-126719OB-C41 by the Spanish Ministry of Science and Innovation/State Agency of Research MCIN/ AEI/10.13039/501100011033.