Mars Methane Plume Tracer

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Abstract: Ground-based detections of methane on Mars at the 10's of ppb level, and similar observations by orbiting assets such as PFS and TES have sparked renewed interest, within the past decade, in the possibility that Mars may be 'alive'; however, recent observations by MSL have found much lower levels of methane, consistent with a null detection. Here, we show how numerical climate models may assist in the localization and characterization of surface plume of methane, and address the limits inherent in orbital observations.

Plume Tracing Goals:

- Plumes are very likely small-scale surface features that cannot be isolated by orbital assets to any better than 10's of km.
- This is marginally sufficient to direct a rover.
- Can we better characterize plume behavior at Mars with numerical modeling approaches?
- Try to understand trades in detectability and localization, e.g., more frequent coverage may be at expense of sensitivity, and vice versa.

Modeling Plumes Numerically:

- Traditionally, general circulation models (GCMs) are built in an Eulerian framework, tracking model fields on a regular grid (e.g., Figure 1a).
- With this approach, numerical diffusion results in an 'artificial' distribution of the plume over time, making GCMs, alone, a relatively poor method for tracking (or backtracking) plumes to their source regions.
- We have combined MarsWRF GCM output with SCIPUFF, a state-of-the-art terrestrial operational/scientific Lagrangian plume dispersal model to create realistic plume shapes driven by meteorology of the GCM (e.g., Figure 1b), without the problems of a purely Eulerian framework.
- We need to consider duration of emission, magnitude of emission and spatial extent of emission, all of which modify the evolving plume in different ways.

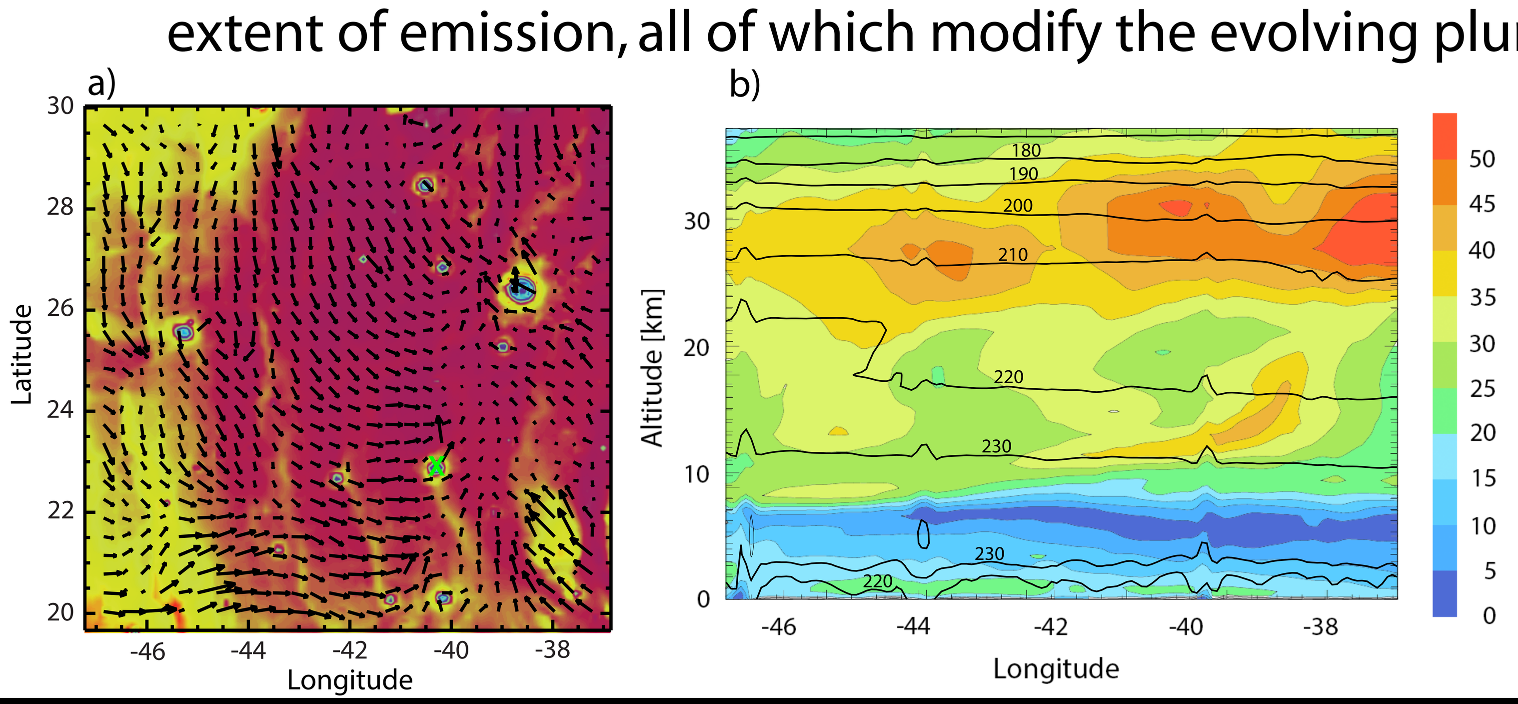

Figure 1: a) Map view of Chryse region of Mars showing horizontal wind directions at 00Z (~9 pm local time). Release point is a small crater indicated by a green 'X'. Winds derived from MarsWRF GCM. b) Vertical, E/W slice through release point shows contours of wind speed and temperature as a function of height. During nighttime, boundary layer is low to the ground, with weak winds.

Discussion:

- Even with 'perfect' representation of plume behavior from a model, we are limited by the capabilities of our observing spacecraft, e.g:
  - *Limb spectroscopy* has high sensitivity (ppt level), but large 'surface' footprint $\mathcal{O}$(100 km).
  - *Reflectance spectroscopy* is nadir pointed has a much smaller surface footprint $\mathcal{O}$(1 km) but lower sensitivity and less frequent coverage of any given location
- Figure 2a shows a representative plume from SCIPUFF after 12 hours, driven by MarsWRF winds. This fixed plume is detected by a reflectance spectrometer with 3x3 km footprint for 100 sols (Figure 2b) and a limb-sounding spectrometer with footprint 3x200 km for 100 sols (Figure 2c), both in realistic orbits.
  - In the former case, we can visualize the shape well, but at the expense of coverage. In the latter, we get full coverage of the region, but the 'true' plume is poorly discerned in both shape and magnitude.
- As in Mischna et al. (2012), a local plume source should be expected to globally mix in <30 sols, meaning localization will be much more difficult than demonstrated here.
  - Plume can shear out to 100s of km size in a single sol
  - Additionally, a plume will have diurnally varying 3-D extent.
- For all but the most steady-state plumes, we may only have a handful of measurements, over multiple days, to attempt to isolate a local methane source.

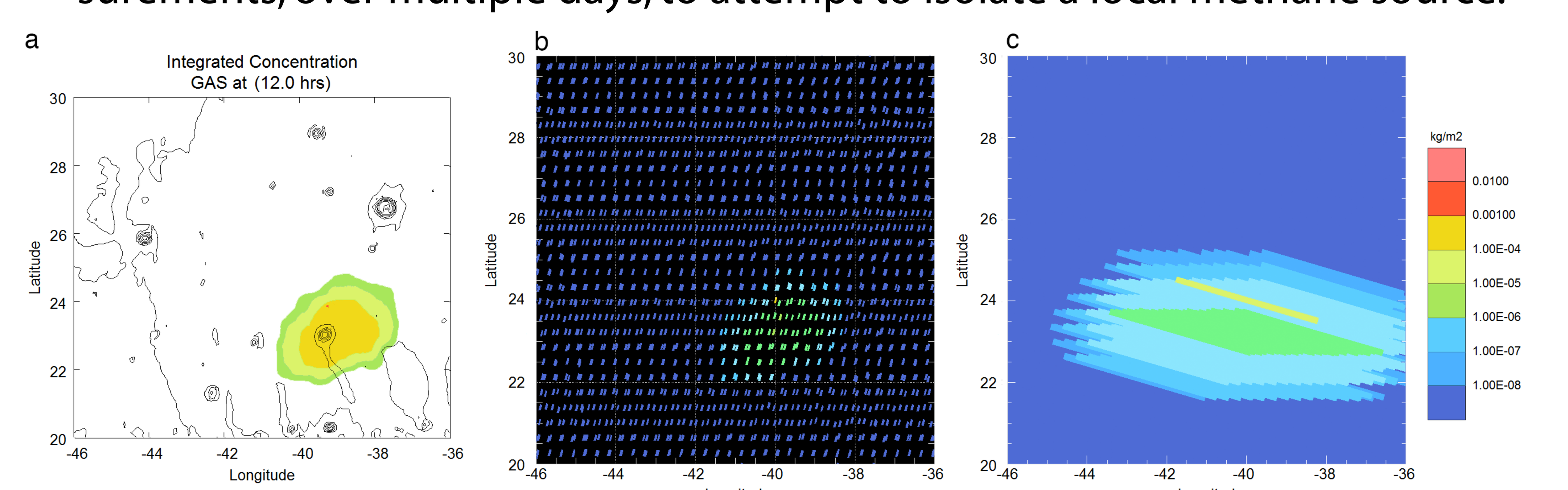

Figure 2: a) Shape of a trace gas plume after 12 hours, emitted from Chryse Planitia, near the Viking 1 landing site, as modeled by SCIPUFF using MarsWRF winds. b) What a nadir-pointed reflectance spectrometer would 'see' of such a distribution after 100 sols of typical coverage. Black represents area that have not been observed by the spectrometer, making observations every 6 seconds. Overall shape is well represented, but at the expense of total coverage. c) What a limb sounding spectrometer would 'see' of such a distribution after 100 sols of continuous coverage. Each 'noodle' represents one observation. Coverage of this region is complete, but at the expense of fidelity in plume shape and magnitude. The yellow 'noodle' footprint has overlapped the true plume center (red dot in panel a, but total signal is weakened by adjacent areas of lower abundance. In b and c, orbital inclination of 73 degrees is assumed.

Conclusions: It will be extremely difficult to isolate plume sources from orbit, considering the rapid evolution of the typical plume, it's assumed small source region, and the infrequent nature of orbital coverage. The consequence is that, for the near future, we may be unable to more precisely target source locations from orbit than 100's of km.