Localizing Putative Methane Sources on Mars from Back-Trajectory Modeling Techniques

Yangcheng Luo[1], Michael A. Mischna[2], Yuk L. Yung[1], Armin Kleinböhl[2], and Pin Chen[2]

[1]California Institute of Technology
[2]Jet Propulsion Laboratory, California Institute of Technology

November 24, 2022

Abstract

A variety of measurements of methane in the Martian atmosphere have been made over the past 15 years, showing wildly varying indications of methane abundance, location and lifetime in the Martian atmosphere. Attempts have been made to use numerical tools such as general circulation models (GCMs) to identify source locations and timing of methane releases, but these remain inconclusive under the current approach of forward-trajectory plume modeling. Here we present results using a novel, complementary method of localizing methane surface sources by modeling passive tracer trajectories backwards in time from the locations where observations of atmospheric methane have been made. Such back-trajectory modeling employs both GCM modeled winds and a Lagrangian particle dispersion model to isolate potential upwind sources of the observed signals. This approach avoids many of the pitfalls inherent in forward-trajectory modeling approaches such as numerical diffusion and subgrid-scale motion which cannot be captured in the Eulerian framework of a GCM. We have chosen to focus on localization of the detection of methane by the Planetary Fourier Spectrometer near Gale crater around Ls=336° in MY 31. This observation is consistent with a near-coincident enhanced methane 'spike' observed by the Mars Science Laboratory TLS instrument. We have chosen to use the Stochastic Time-Inverted Lagrangian Transport (STILT) particle dispersion model in conjunction with the Mars Weather Research and Forecasting (MarsWRF) GCM for our back-trajectory modeling. To date, we have combined MarsWRF output with a more basic trajectory model, which advects particles based on bulk winds, and have found areas of enhanced tracer density to the north of Gale crater at prior times. Incorporation of turbulent processes in the planetary boundary layer will subject these preliminary results into test. And geological context will also be used to constrain the likelihood of these methane source locations.

P41B-3419

Localizing Putative Methane Sources on Mars from Back-Trajectory Modeling Techniques

Yangcheng Luo[1], Michael A. Mischna[2], Yuk L. Yung[1,2], Armin Kleinboehl[2], Pin Chen[2]

[1]California Institute of Technology, Pasadena, CA [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

Introduction: After a number of observations that claimed to have found methane in the Martian atmosphere, the Tunable Laser Spectrometer (TLS) on *Curiosity* detected methane in Gale crater [1, 2]. The presence of methane raises a fundamental question about the possibility of Martian life, as nearly all known methane sources on the Earth are biogenic. On the top of a baseline level of ~0.4 ppb with seasonal variations, six greatly enhanced methane spikes with concentrations up to 21 ppb were detected. These spikes are considered as the outcome of near-field influence, indicative of some localized sources nearby. In this project, we aim to back out possible methane source locations on the Martian surface near Gale crater by doing back-trajectory analysis. We trace methane-rich air plumes back to their surface origins based on simulated winds. Our results will guide the landing site selection for future missions in order to to directly probe the methane sources, and shed light on the identification of methane production mechanisms, either biogenic or abiogenic.

Approach: Unlike previous work that used forward-modeling methods, in which methane-rich air parcels are transported forward in time from a large number of possible surface origins by bulk wind, we adopt a back-trajectory approach, in which air parcels are transported backwards in time from the detector, e.g., the *Curiosity* rover. Then the source locations are determined by marking the places where the air parcels travel through the near-surface mixed layer, in which methane is assumed to be instantaneously well mixed after being released from the surface.

MarsWRF GCM output in different resolutions, tuned to the season and conditions of the individual observations, is used to provide meteorological information to seed a Lagrangian (particle-following) transport model STILT [3, 4]. Turbulent dispersion is taken into consideration in addition to the advection by bulk wind. An ensemble of simulations are performed to smooth out weather variability.

The likelihood of each source location is determined by comparing the projected methane concentrations at the detector from an ensemble of time series of emission flux from that source location with the TLS-detected methane concentrations.

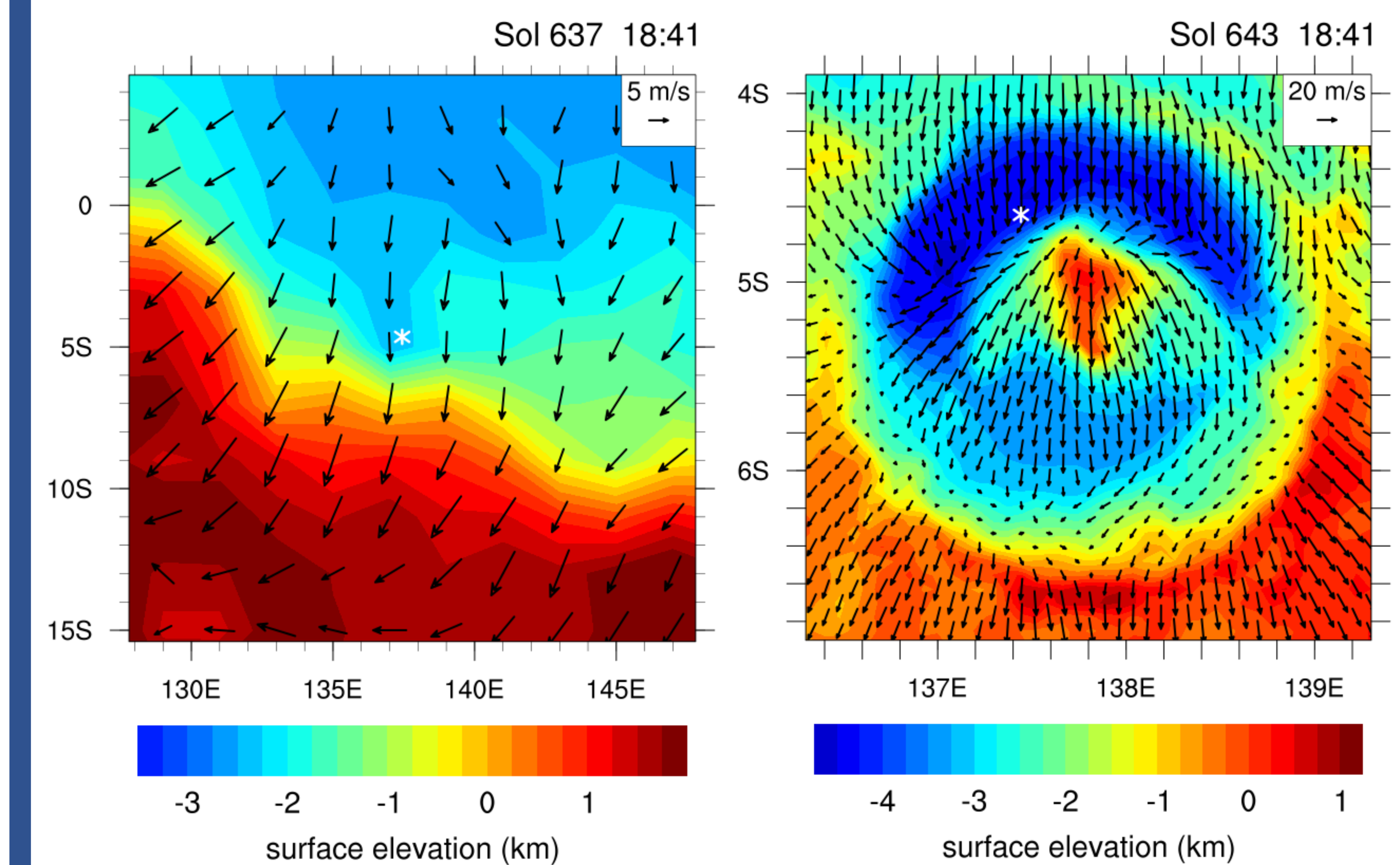
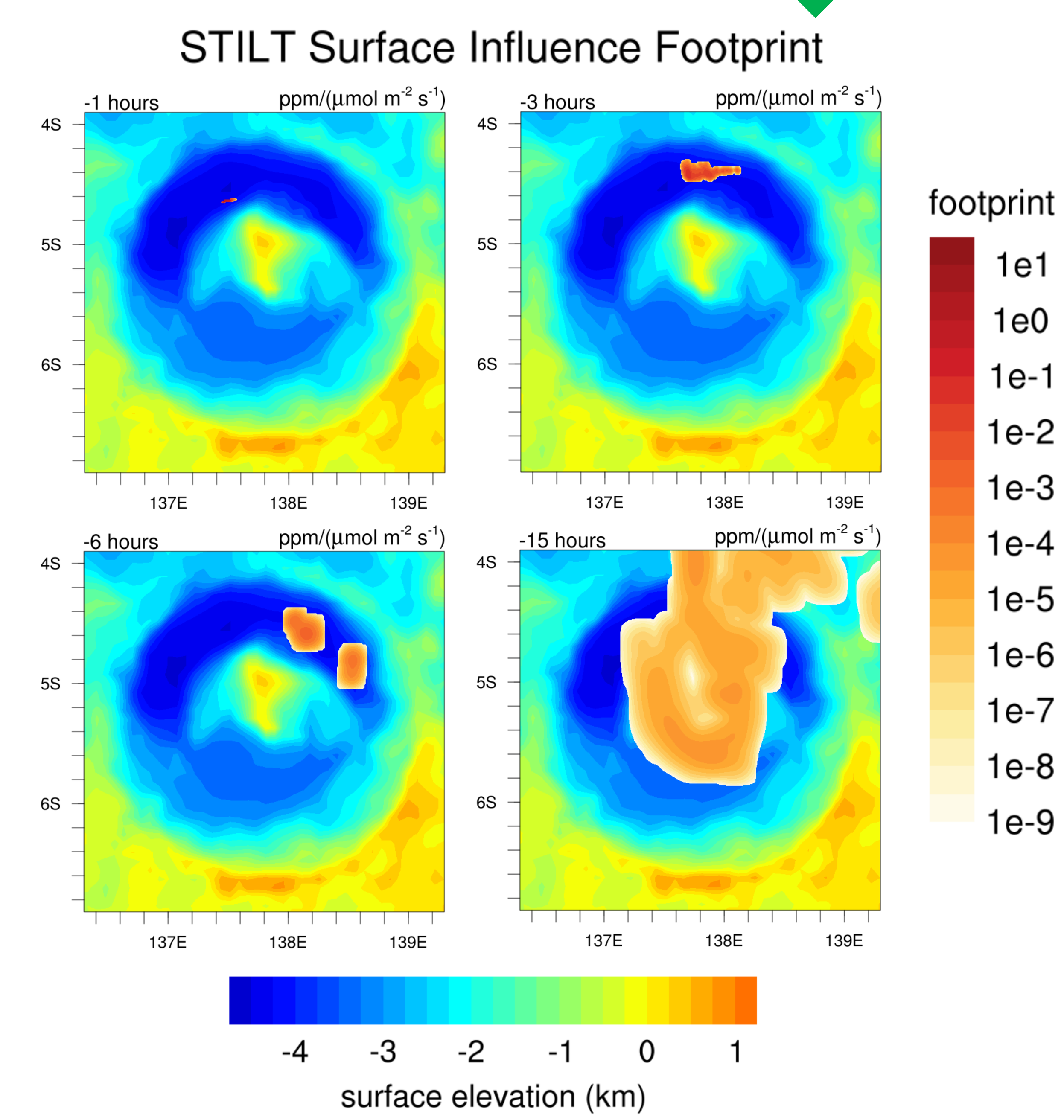


Figure 1: Simulated surface wind around/in Gale crater at local time 18:41. (Left) Large-scale wind with 120-km grid resolution. (Right) Mesoscale wind with 4.4-km grid resolution.

Figure 2: Demonstration of the use of STILT to back out surface source locations. Footprint shows the magnitude of influence of emission flux on the detected methane signal. Moving backwards in time, footprint spreads in space and decays in magnitude.



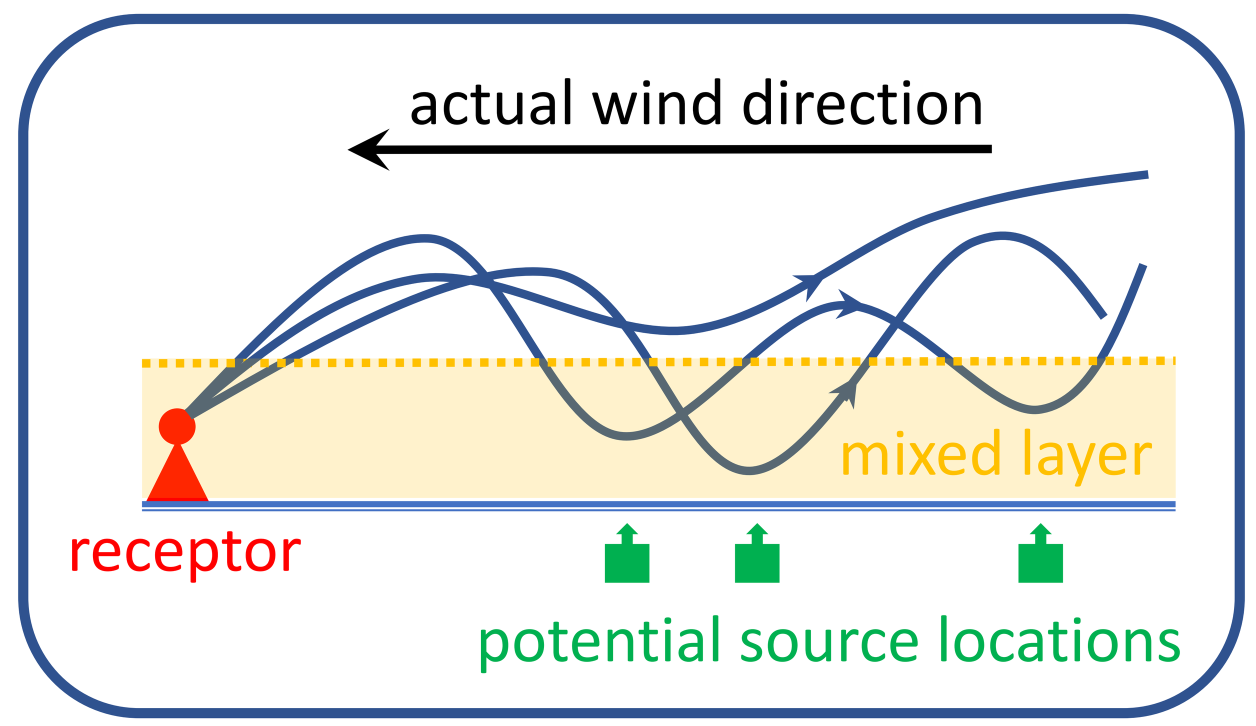


Figure 3: Illustration of the back-trajectory approach. Air parcels are advected backwards in time from the detector. Source locations are marked where the trajectories intersect the mixed layer.

References: **[1]** Webster, C. R. et al. (2015) *Science*, 347, 415-417. **[2]** Webster, C. R. et al. (2018) *Science*, 360(6393), 1093-1096. **[3]** Lin, J. C. et al. (2003) *Journal of Geophysical Research: Atmospheres*, 108(D16). **[4]** Nehrkorn, T. et al. (2010). *Meteorology and Atmospheric Physics*, 107(1-2), 51-64.