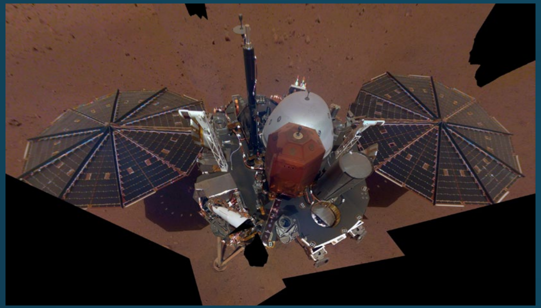
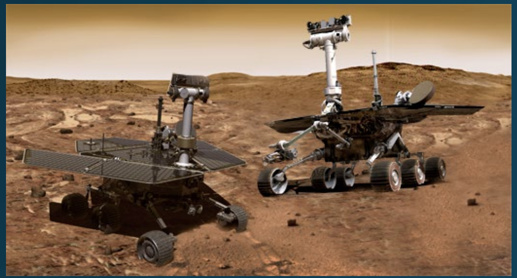
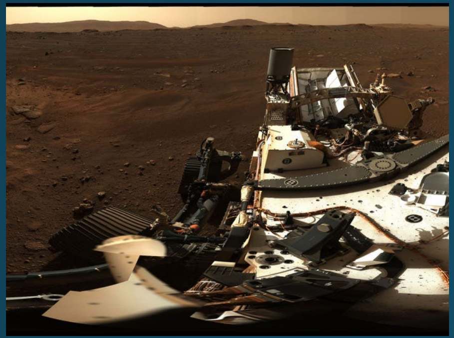
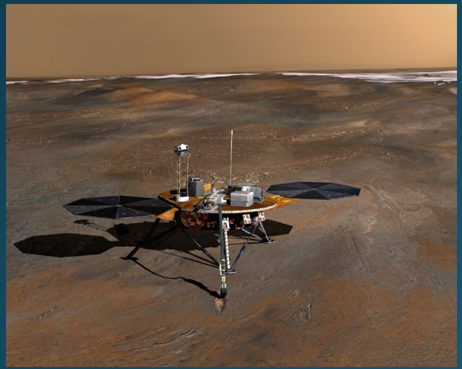
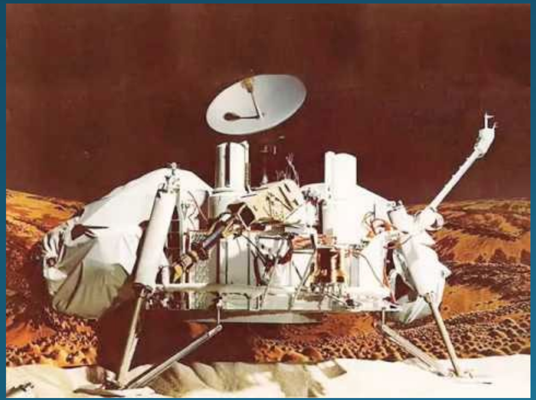
Atmospheric Transport of Contaminants and Microbes on Mars











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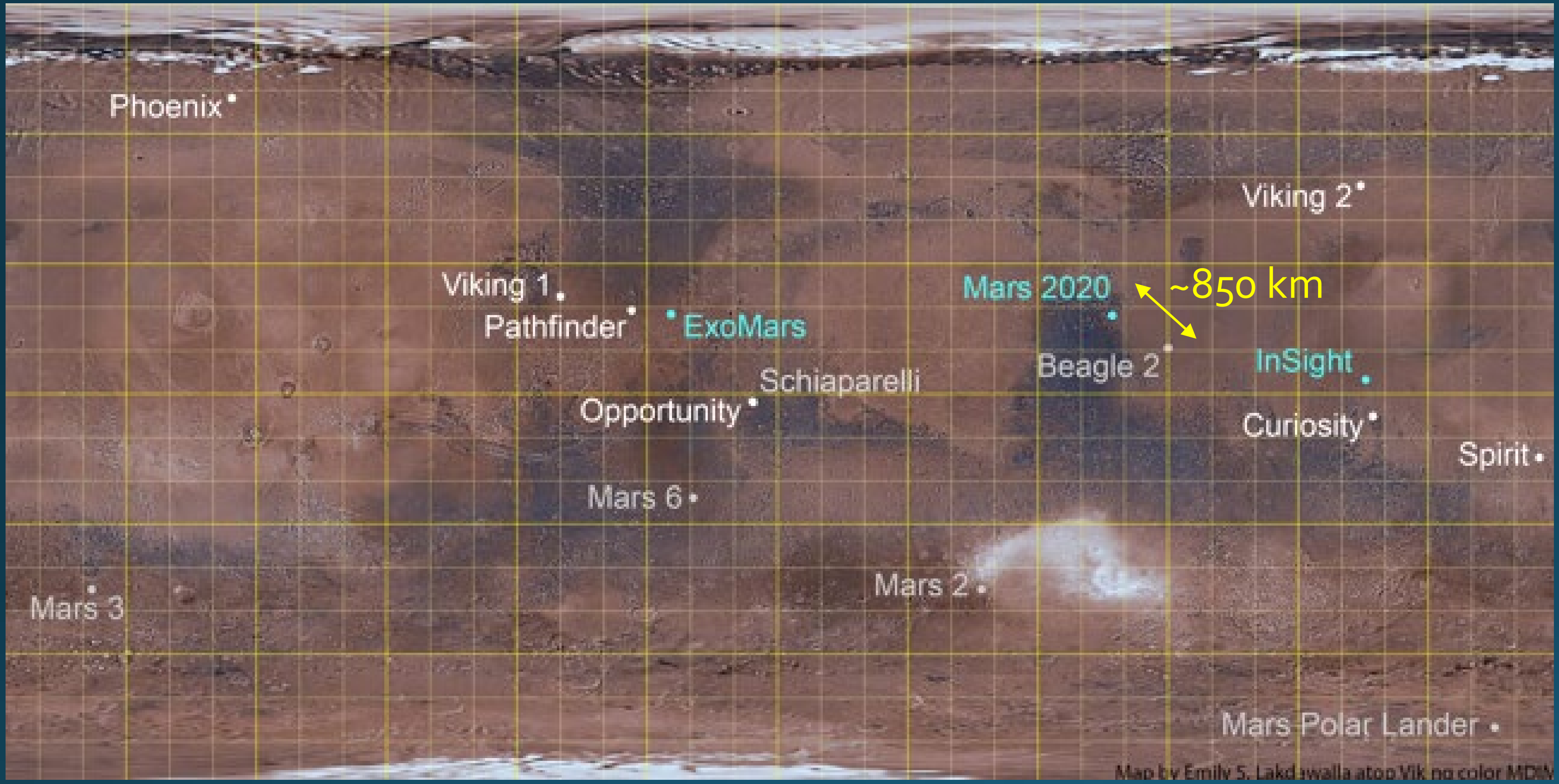
Science and Planetary Protection In Advance of Human Missions Seminar

Over a Dozen Forward Contamination Events



Thought Experiment: If I tossed a handful of very fine dust into the atmosphere from the steps of the Lincoln Memorial, Washington D.C., what is the probability that a single particle would land in a small sampling area on the Rockefeller Plaza ice rink in NYC?

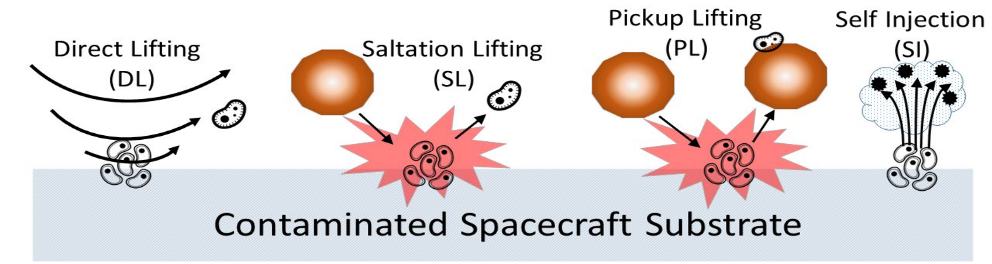
What is the potential for contamination transport from one location to another?

Has Mars already been hopelessly contaminated by prior missions?

How will future human "bag of bugs" contaminate Mars?

Transport Considerations

- Source Function
  - Total contaminant reservoir
  - Viable reservoir fraction
  - Mobilization processes and transport vector
- Transport
  - Wind
  - Turbulence
  - Sedimentation
  - Aerosol and microphysical interactions
- Sinks/Destruction Mechanisms
  - Ionizing radiation
  - UV spectrum
  - Chemistry
  - Temperature
  - Humidity/Water activity
  - Electrodynamics
  - Others?



Rafkin, PPRP proposal, 2018

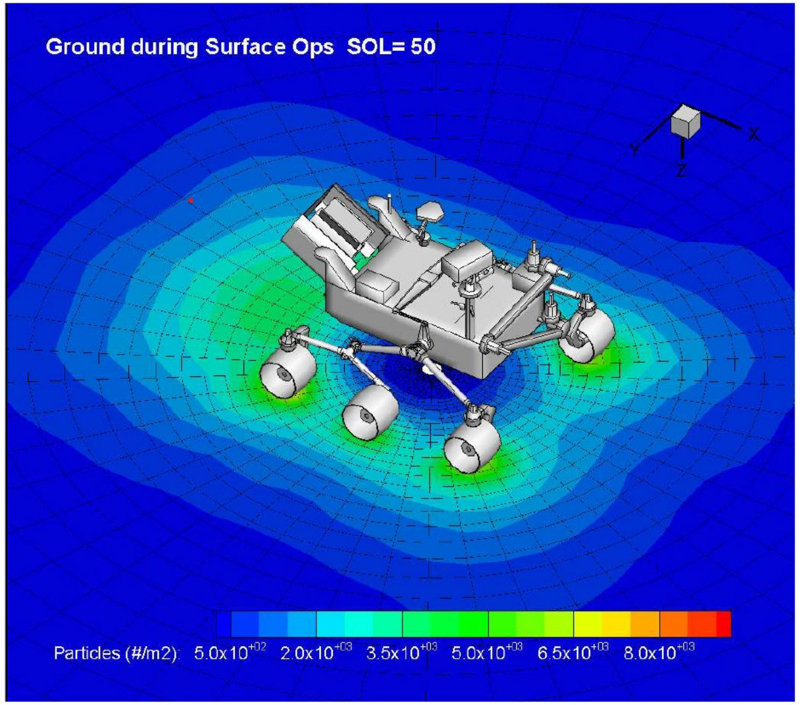


Fig. 4. Illustration of particle resuspension and transport for the Mars 2020 rover on the surface of Mars

Soares et al., 68th IAC, 2017

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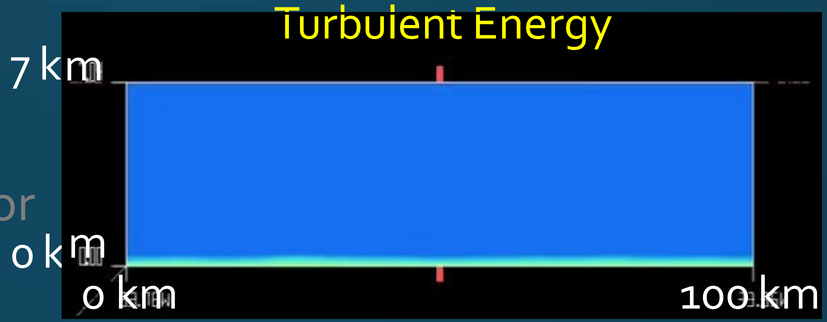
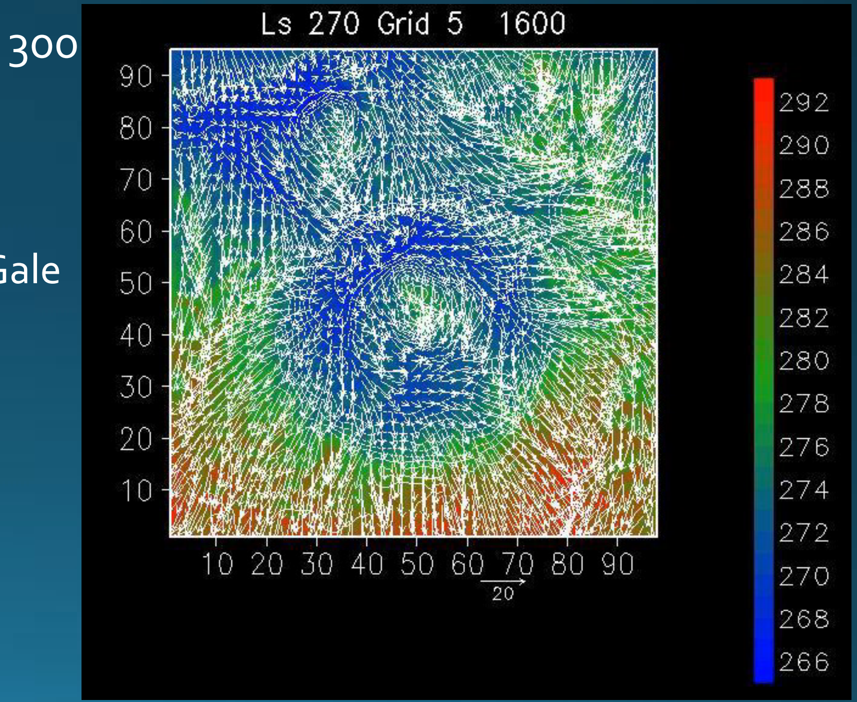


Large Eddy Simulation of Afternoon Turbulence



Near-Surface Winds in the Gale Crater Area. (Rafkin et al., Icarus, 2016)

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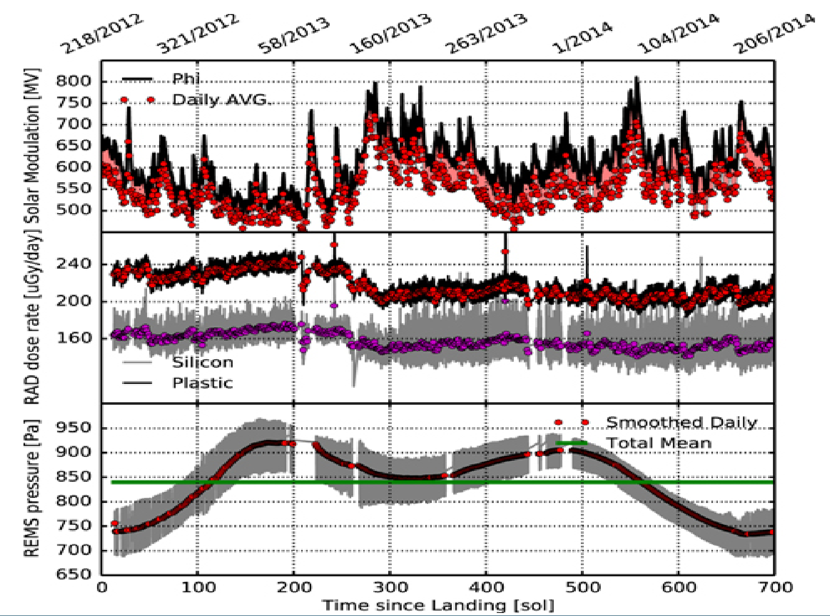
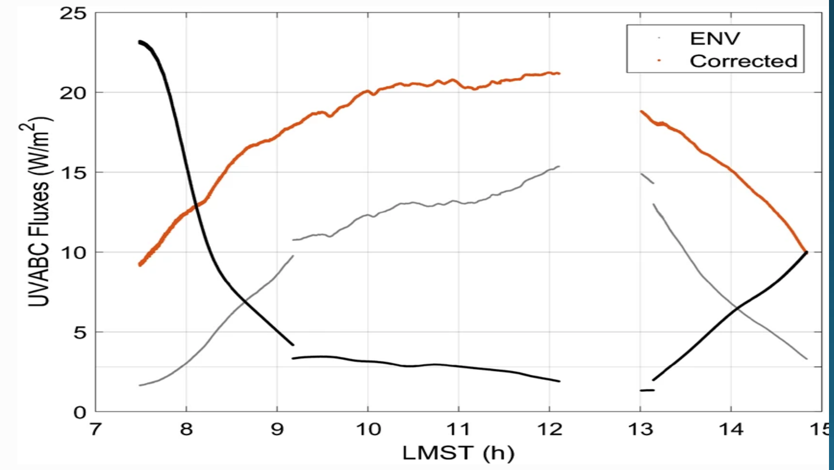


Measurements for the Mars Science Laboratory RAD and REMS Investigation (Guo et al., 2015)



UVABC flux from MSL REMS (Vicente-Retortillo et al.,Space Sci. Rev., 2020)

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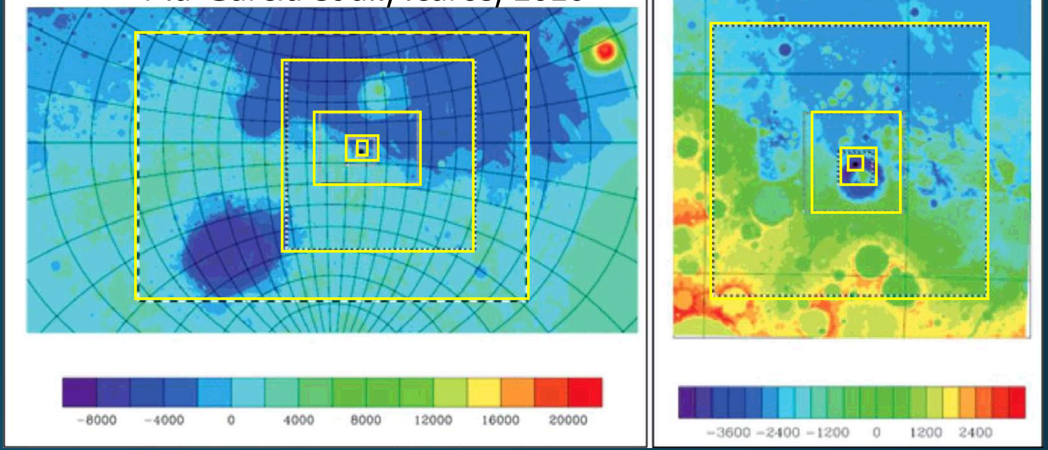
- This is a highly interdisciplinary problem.
- Many of the elements are poorly understood, poorly constrained, or highly uncertain.
- Parametric studies and simplifications can bound the problem.
- This study:
  - Ignore source function.
  - Ignore sedimentation and microphysics.
  - Ignore destruction.
  - Results in something close to an upper bound on contamination.
- Future Work will incrementally add complexity to encompass additional source, transport, and destruction mechanisms.

Modeling Transport at MSL: Tracers and Trajectories in the Mars Regional Atmospheric Modeling System

MRAMS Computational Grids

Pla-Garcia et al., Icarus, 2016



The Mars Regional Atmospheric Modeling System (MRAMS)

- A dynamic atmospheric model that calculates the time-varying atmospheric properties (Rafkin et al., 2013, 2021).
- Nestable: high-resolution coverage over limited domains and coarser resolution over larger domains.

Tracers

- Initialize a passive tracer at MSL.
- At t=0, tracer=1 fills lowest level model grid box: this means substantial dilution has already occurred. E.g., 1 m^3->10^8 m^3.
- Model winds and parameterized turbulence transport and mix tracer.
- Provides quantitative measure of dispersion and contamination probability.

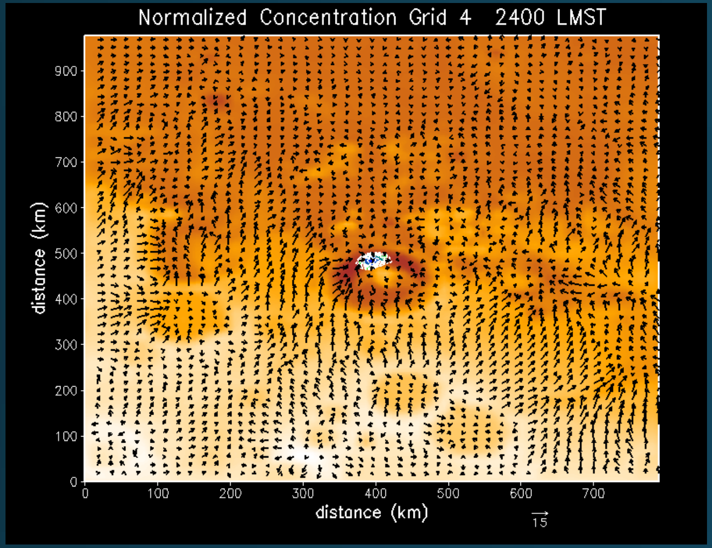
Trajectory

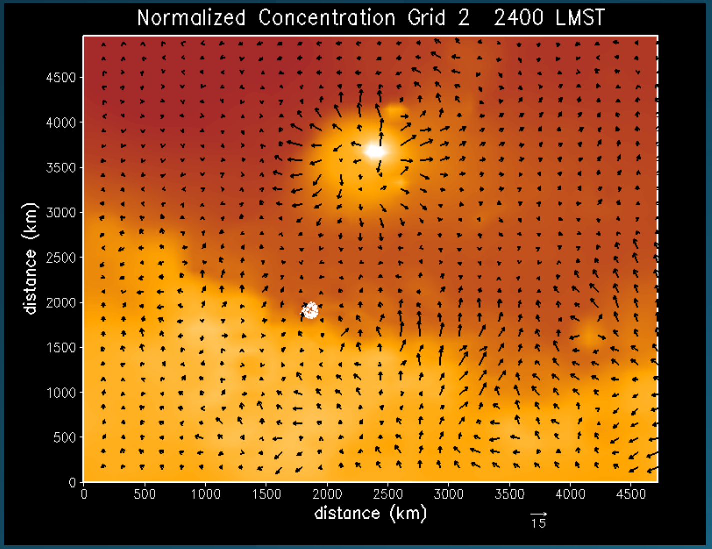
- Calculate the transport of a single particle by the model wind.
- Provides quantitative information on actual particle trajectories and histories.
- Can determine environmental properties along trajectory.
- Ensemble/Monte Carlo simulations quantify atmospheric transport chaos and chaotic attractors.

Example Tracer Experiment

Grid 4: 8.8 km grid spacing
Grid 2: 80 km grid spacing

Ls 90



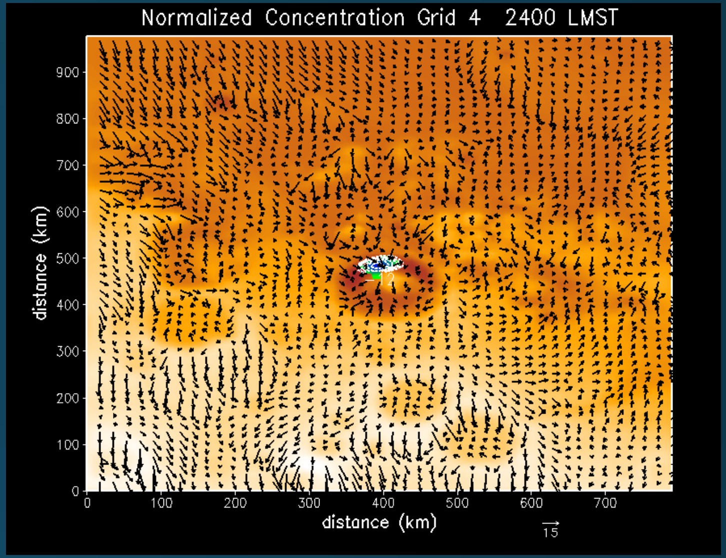


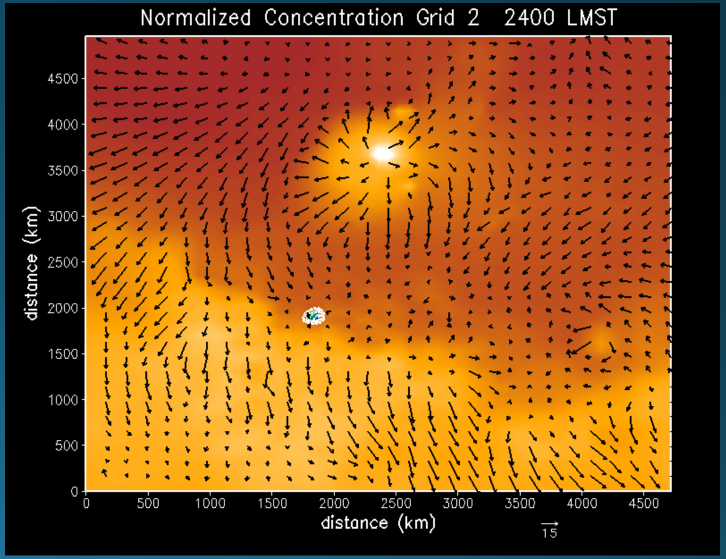
Log10 of normalized surface concentration at MSL in Gale Crater

Contour range is -3 to -12.

Remember that an additional dilution factor of ~10^8 must be applied to account for size of release location grid box compared to actual release

Ls 270



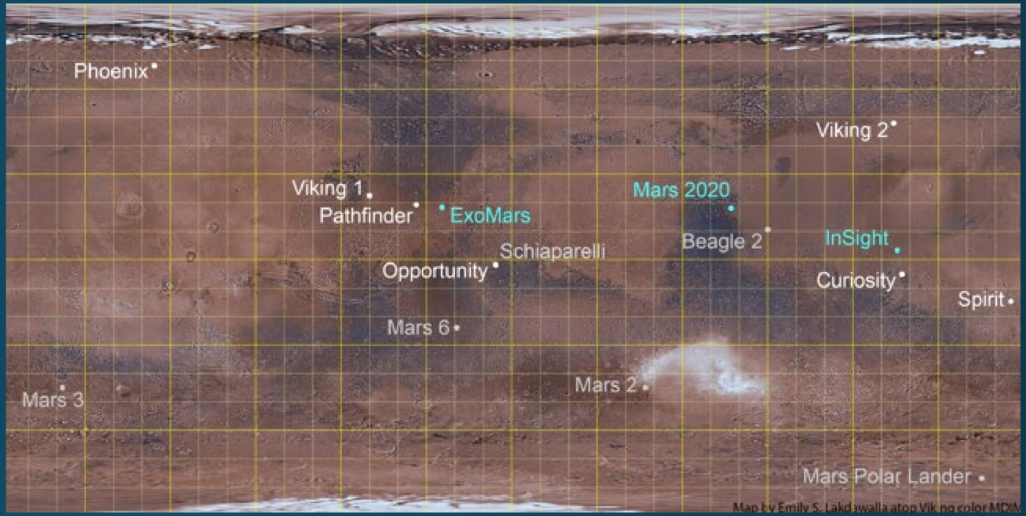


Rough Calculations (1/2)

- Assume source of 1 particle per m^3 in a 3 km x 3 km box 14 m high.
  - Almost certainly an absurd assumption, but it's convenient math.
  - A 6 m^2 spacecraft fluxing 100 particles/sec fills this volume in ~2.5 sols.
- Tracer experiments indicate a dilution of at least 9 orders of magnitude a few hundred km away.
  - 1 particle per 7×10^7 m^2 in lowest 14 m
- In 100 Mars years ~27,000 particles would accumulate in that area.
  - 2600 m^2 per particle after 100 years. That's ~5 football fields for each particle.
  - This is before factoring in the initial dilution in the grid box, which is approximately another 8 orders of magnitude!

Rough Calculations (2/2)

- M2020 surface sample size is order 1×10^{-4} m².
- Probability of collecting 1 particle is 10^{-4} m² ÷ 2.6×10^{3} m²/particle= 3.8×10^{-8}.
  - Probability of royal flush: 1.5×10^{-6}.
  - Probability of getting struck by lightning (in U.S.) in a lifetime: 6.5×10^{-5}.
  - Probability of getting killed by meteorite (est.): 4×10^{-6}.
- Simple transport considerations *generally* indicate contamination is, at best, only a local/regional issue.
- Rough calculations will be refined with ongoing modeling, including back trajectory calculations, time varying source functions, and sink processes.



- Closest contamination site to M2020 is Beagle 2 @ ~800 km.
- 17 years ago, not 100 years.
- Likely not continuously fluxing 100 particles/sec.
- Beagle not continuously upwind of M2020.
- Degradation of organics not factored in.
- Not all particles in lowest layer will settle to surface.

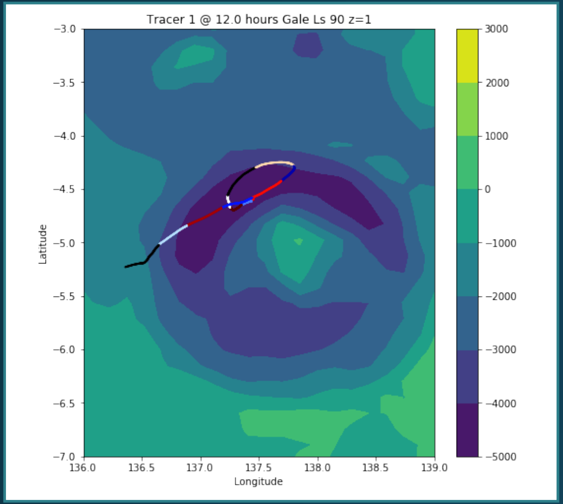
Tracer Dilution Interpretation

- Dilution by a billion (or a zillion) is meaningful if there are billions (or zillions) of particles.
- Dilution by factors much greater than the number of particles implies there will be either a particle or not.
- Trajectories are the deterministic complement to the diffusive tracer experiments.
- Particles on trajectories do land in an actual location, but the overwhelming majority of locations have no contamination at all.

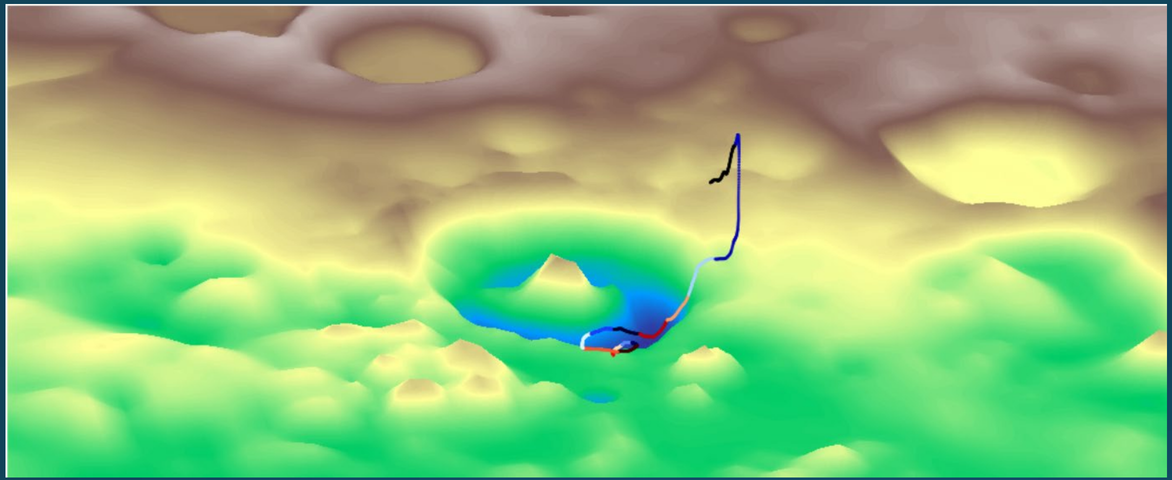
Example Trajectory Experiments Ls 90 with 12 Hour Integration

Morning Release

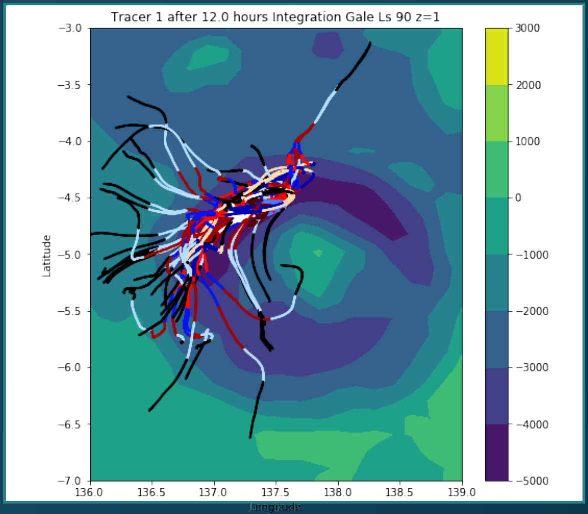
Single Trajectory



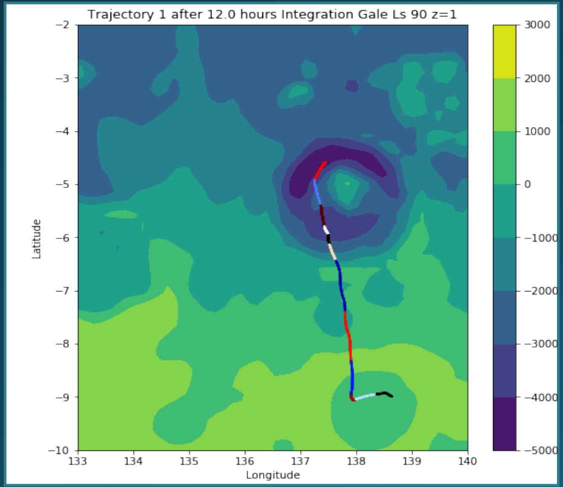
3-D Single Trajectory

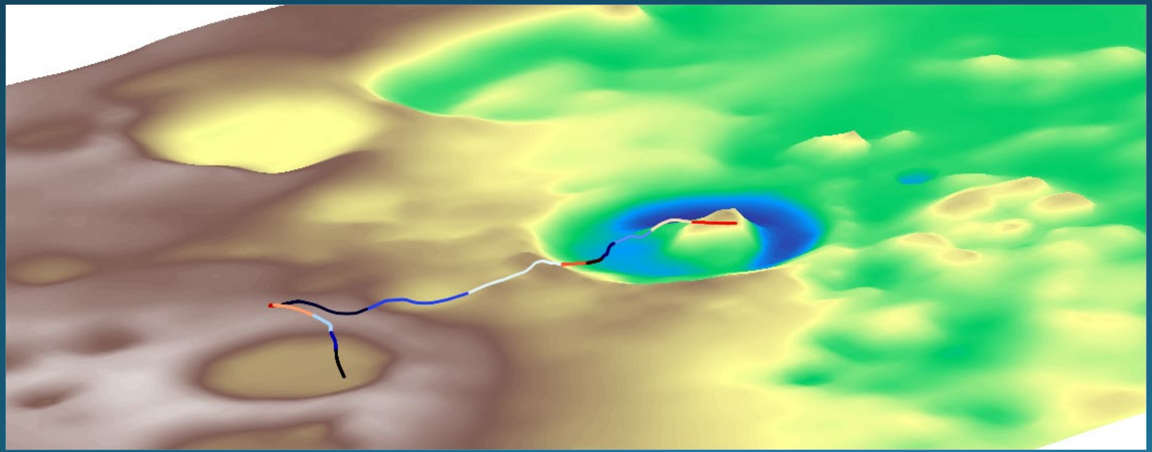


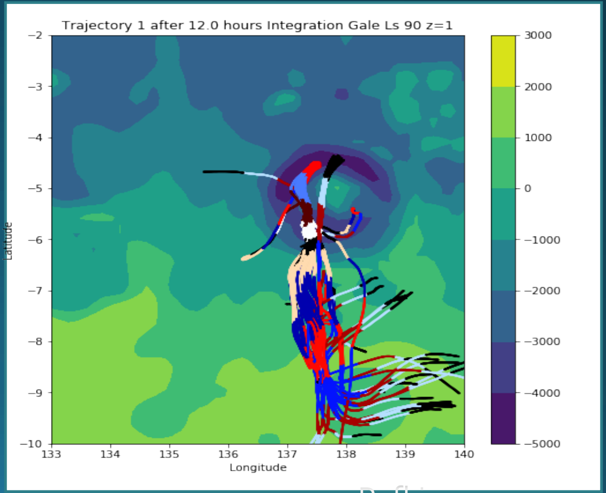
Ensemble of 48

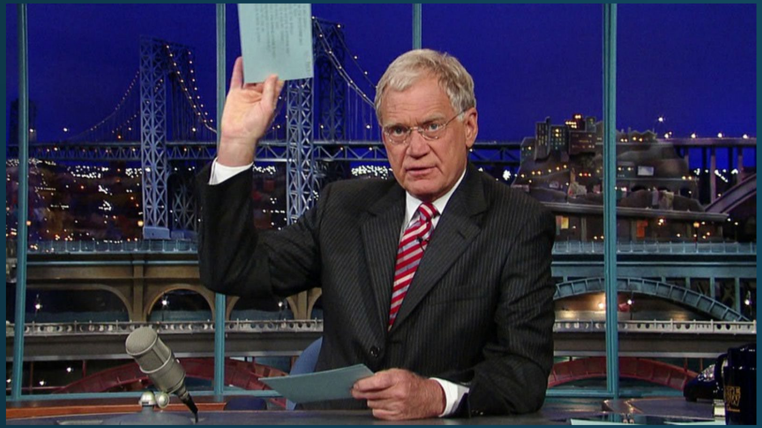


Afternoon Release









Top 5 Lessons from MRAMS Transport Experiments

5. Transport circulations are complex and vary strongly in space and time (minutes to seasonal).

4. Transport is location specific.

3. Mars transport *tends* to be highly dispersive.

2. Contamination *typically* drops by many orders of magnitude (e.g., 10^{12}) outside of immediate source region and continues to fall with distance.

1. The probability of transporting a single particle into a small sampling area hundreds of km away, sampling exactly that area, and finding exactly that particle is excruciatingly, tortiously small. Reality is absurdly smaller in probability.