Seismic noise on Mars and subsurface structure

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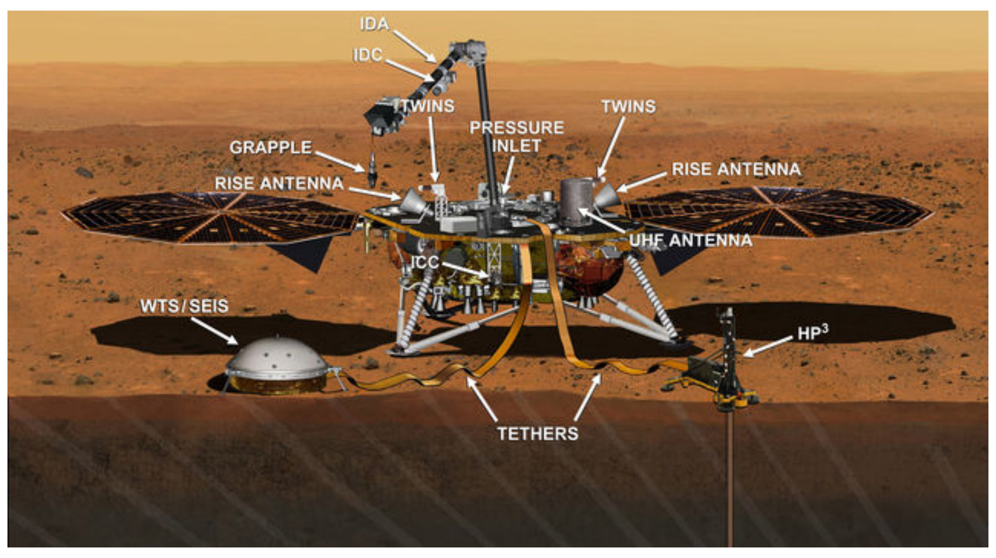


InSight lander and experiments deployed. Credits NASA/JPL.

Abstract

The 2016 InSight mission to Mars will depose a Very Broad Band seismometer (VBB – realized at IPGP) at the surface of the red planet, for the first time after the Viking attempts in the '70. On Mars, seismic noise is essentialy due to atmospheric circulation and turbulence, as well as to localized episodes, mainly dust devils. For this reason, a careful modeling needs to be prepared and similar terrestrial phenomena have to be analyzed. We propose estimates of the long-period noise based on atmospheric simulations and we put in evidence the ground tilt signature of dust devils, effectively detected by a recent terrestrial field experiment. The sensitivity of the ground displacement to the subsurface structure will permit us to determine the elastic properties of the shallow subsurface and the simultaneous analysis of the high-frequency seismic noise produced by dust devils, or more generally by wind, will lead to the inversion of the near surface structure. The principal interest is to apply these techniques to investigate the main geological structures at the landing site, and more precisely to determine regolith thickness and properties, subsurface layering and corresponding seismic velocities, presence and depth of lava flows.

The InSight Mission to Mars

- A geophysical observatory at the surface of the red planet
- Expected launch: March 4, 2016 from Vanderberg Air Force Base - USA
- Landing: September 28, 2016 in Western Elysium Planitia
- Main scientific payload: SEIS, Very Broad Band seismic measures
  HP3, Surface heat flux, thermal properties
  RISE, Geodesy
  TWINS, Meteorological station
- Main scientific goal: explore the interior of Mars and study the evolution of terrestrial planets

Seismic Sources on Mars

- Marsquakes (unknown)
- Meteor impacts
- HP3 experiment
- Phobos tides
- Large-scale atmospheric circulation
- Local winds and atmospheric turbulence

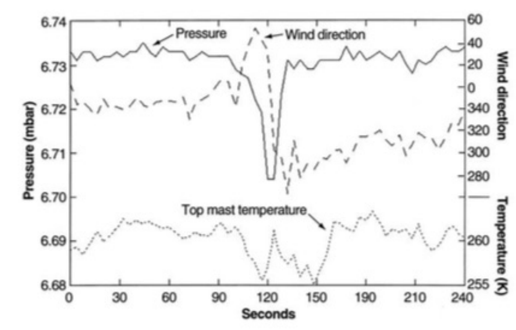
Atmospheric Seismic Noise

- Wind-related continuous background excitation
- Long-period ground tilt induced by pressure fluctuations
- Signature of more intense atmospheric phenomena, mainly atmospheric vortices and dust devils
- Atmospheric modeling provides estimations of the expected noise level on Mars
- Terrestrial data and field experiments validate the approaches and direct/inverse modeling strategies

Dust devils and atmospheric simulations

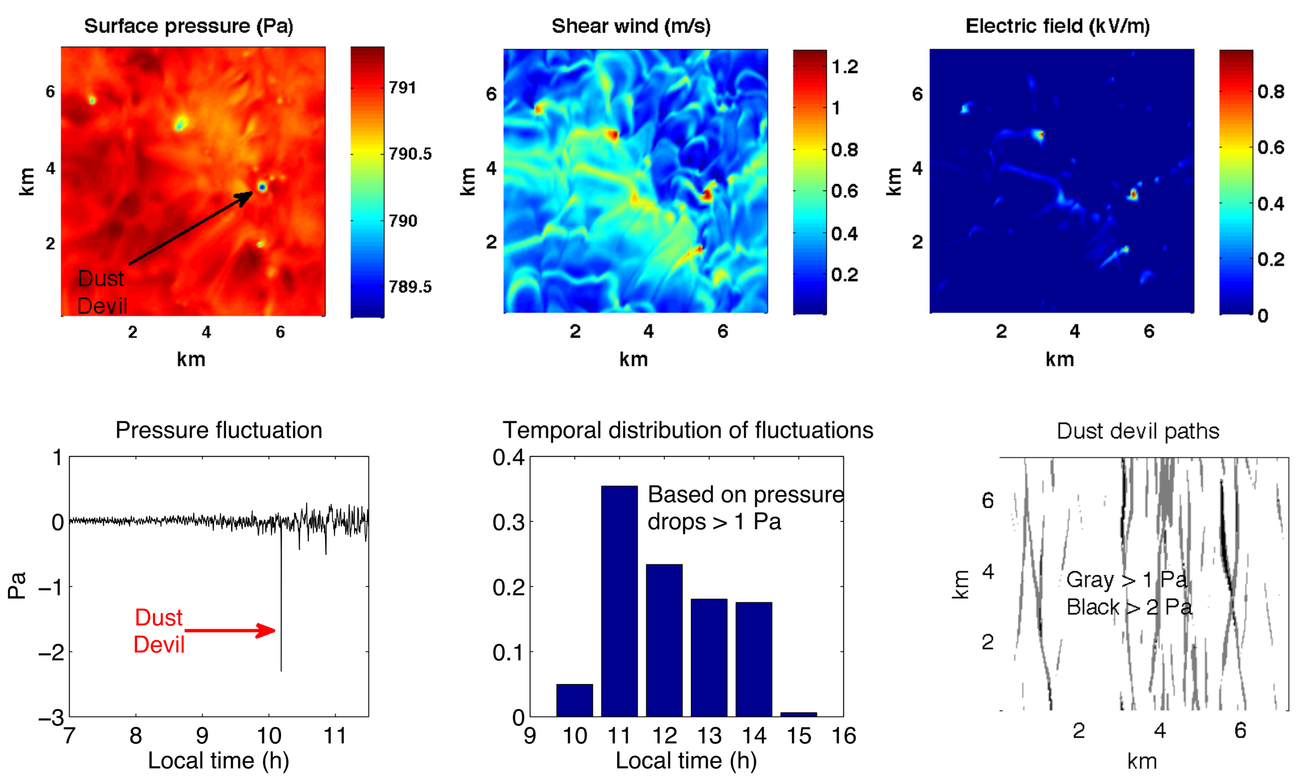
Martian dust devils are convective vortices characterized by
- Lifting of small size particules
- Low-pressure, warm core (fluctuations ~ 1-5 Pa, a few K)
- Quasi-electrostatic field (contact and mass stratification)
- Diameter 10-500 m, heigth up to 10 km

A dust devil as captured by HiRISE – MRO. Credits NASA/JPL/Univ. of Arizona.



Meteorological signature of a dust devil passing over the Pathfinder lander. From Ferri et al., 2006.

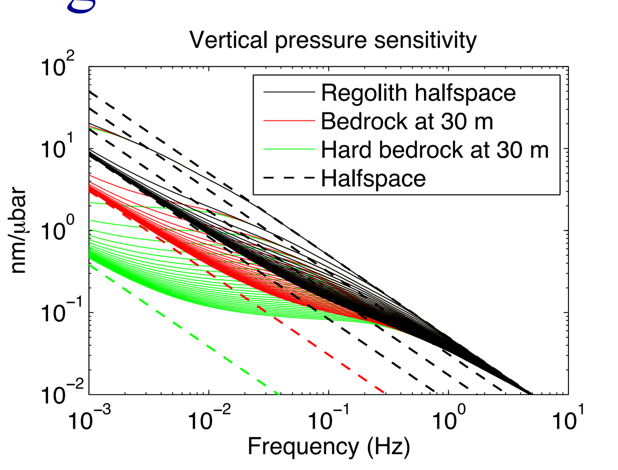
Large Eddy Simulations (LES) performed by the LMD of UPMC – Paris 6 (*Spiga et al.*, 2010) provide our atmospherical models. In these simulations, dust devil-like vortices can be identified by fluctuations in several atmospheric parameters. For seismological purposes, the main interesting parameter is the surface pressure fluctuation: the occurrence and the intensity of dust devil episodes can thus be estimated and they provide crucial information about the level of the seismic noise generated by atmospheric turbulence.



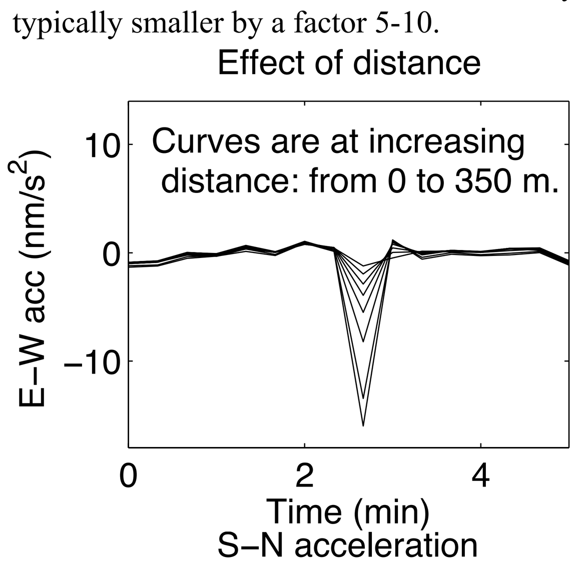
Numerical modeling

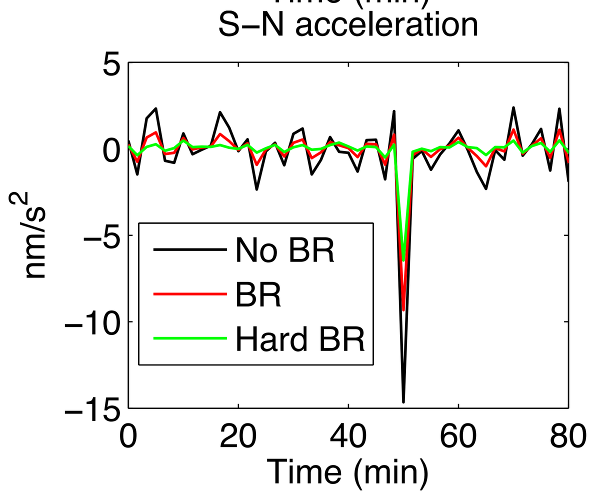
The long-period seismic noise is computed in several steps:
1. Take a subsurface model and compute the sensitivity to static loading
2. Take a LES simulation of the 2D time dependent surface pressure field
3. Compute the convolution of pressure field and ground response function
4. Correct for tilt effects

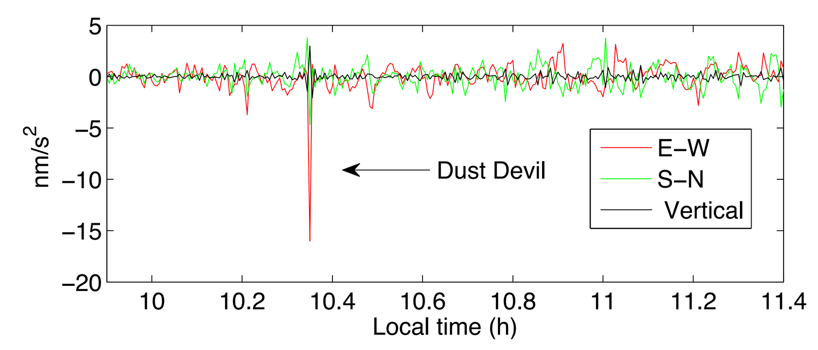
The results of the numerical simulations show:
1. The main effect will be ground tilt on the horizontal components
2. Dust devils will be detected by the VBB seismometer up to a distance of 300-500 m
3. Simultaneous analysis of seismic and metereological data results in determining the ground elastic properties
4. Waveform analysis of tilt acceleration gives the azimuth of the dust devil



Ground sensitivity to static loading is computed for increasing ambient wind from 0.5 m/s to 25 m/s. Horizontal sensitivity is typically smaller by a factor 5-10.





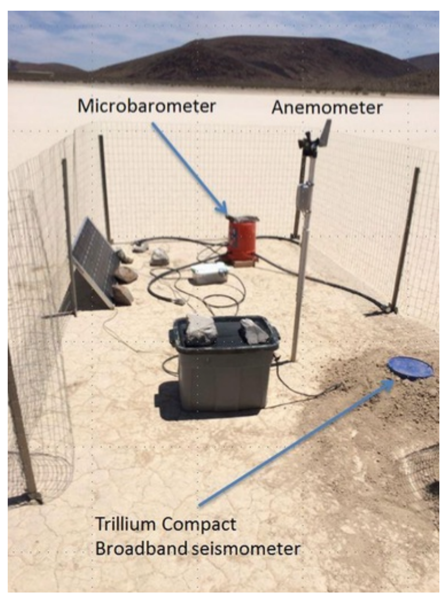


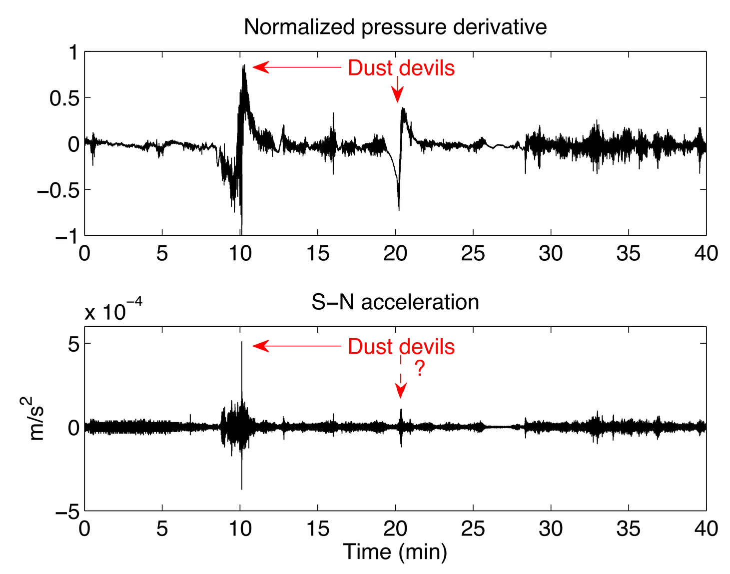
The vertical displacement field generates ground tilt and this is the effect measured on the horizontal components of the seismometer: Dust devils will thus be most likely detected on these components.

Terrestrial data

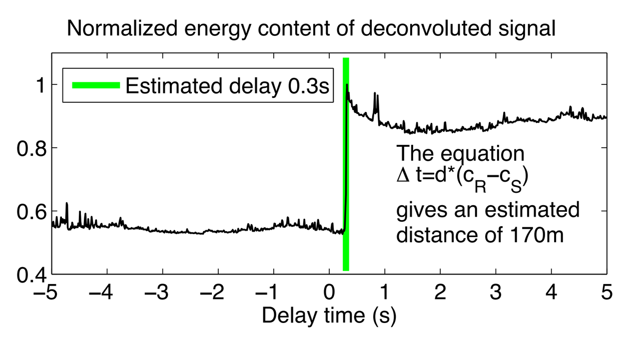
A recent field experiment conducted on an ancient lakebed at the Goldstone site (California, USA) resulted in the first detection of dust devils by ground tilt. This confirms the theoretical results and the possibilities offered by the study of martian dust devils: the good agreement between field data and synthetics is promising.

The Goldstone experimental setup included a broadband seismometer and meteorological instruments to simulate what will be measured by the InSight experiments. Image and terrestrial data from Lorenz et al., 2015.

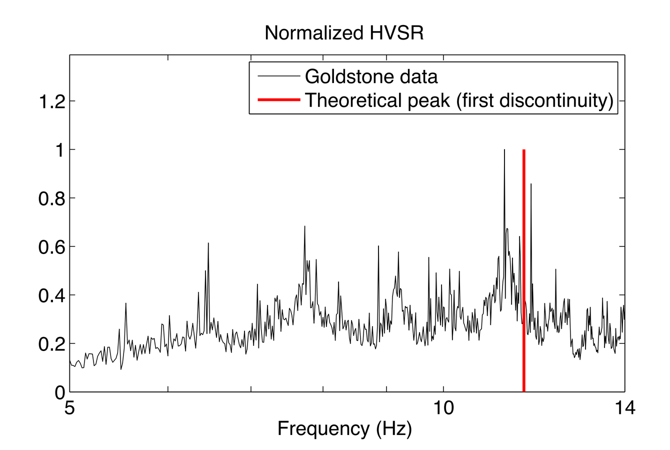


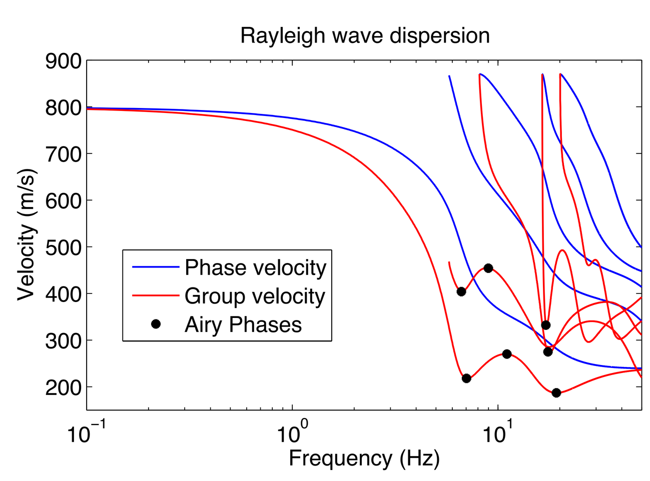


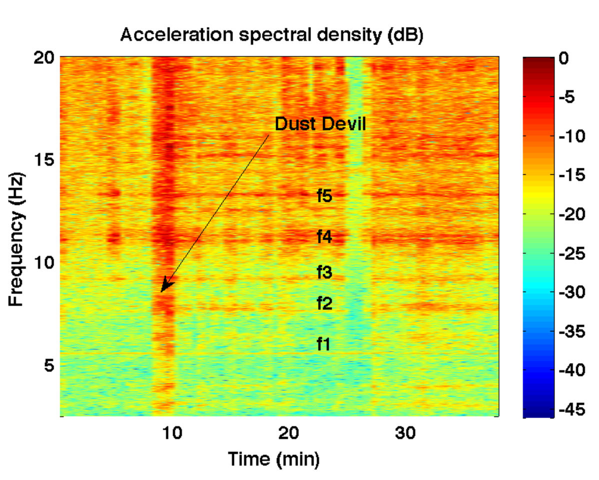
Dust devils, or more generally atmospheric turbulence, generate also high-frequency noise. Several techniques can be used in this analysis, and our work is focused on:
1. Delay of the acoustic wave to estimate the surface wave velocity
2. Horizontal to vertical spectral ratio to estimate the bedrock depth
3. Non-dispersive Airy's phases to invert for seismic velocities



The delay of the acoustic wave with respect to the surface wave is computed by deconvolution of the two signals with a sliding window method.







The good agreement between computed Airy's phases and high energetic noise frequencies makes an inversion attempt possible.

Future Work

Future efforts include an improvement of the direct modeling, especially of the high-frequency signal, and of other possible signatures of dust devils, mainly the magnetic one. The most interesting aspect to develop, however, regards the inversion strategies: after testing them on the already disponible Earth data, they will permit us to investigate with geophysical methods the martian subsurface starting from October 2016!

References: *J. F. Kok*, An improved parametrization of wind-blown sand flux on Mars that includes the effect of hysteresis. Geophysical Research Letters, 37, 2010. *R. D. Lorenz, S. Kedar, N. Murdoch, P. Lognonne, D. Mimoun, T. Kawamura and B. Banerdt*, Seismometer Detection of Dust Devil Vortices by Ground Tilt on Earth and Mars. Bulletin of the Seismological Society of America, submitted, 2015. *G. G. Sorrells*, A Preliminary Investigation into the Relationship between Long-Period Seismic Noise and Local Fluctuations in the Atmospheric Pressure Field. Geophysical Journal of the Royal Astronomical Society, 26, 1971. *A. Spiga, F. Forget, S. R. Lewis and D. P. Hinson*, Structure and Dynamics of the Convective Boundary Layer on Mars as inferred from Large-Eddy Simulations and Remote-Sensing Measurements. Quarterly Journalof the Royal Meteorological Society, 136, 2010.