Exploring Mars' Planetary Boundary Layer with InSight

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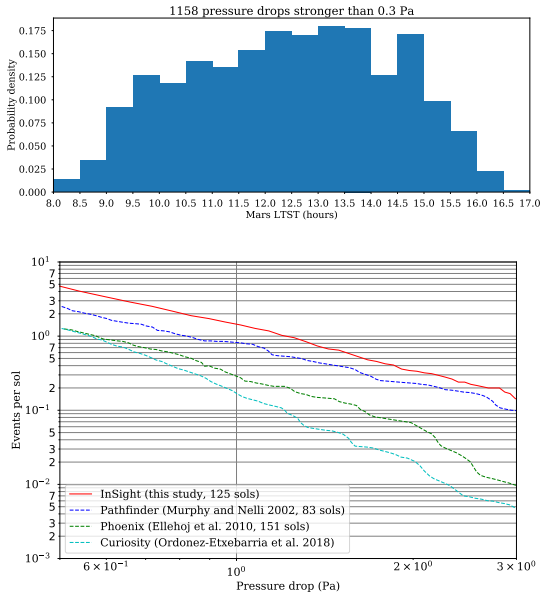

Figure 1: *[Top] Diurnal distribution of dust-devil-like pressure drops detected by InSight in the first 150 sols. [Bottom] Comparative statistics for Mars' landing missions.*

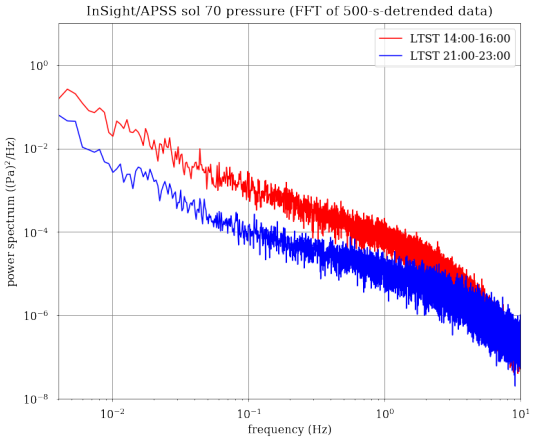

Figure 2: *Power spectral density of pressure observed by InSight in daytime vs. nighttime conditions.*

Motivation To fulfill its major geophysical goals, and in particular to decorrelate the atmosphere-induced seismic noise, the InSight lander is equipped with a complete weather station (pressure, wind, temperature) operating continuously at high frequency at the surface of Mars [1,2], complemented by color cameras and a surface radiometer (Mueller, this conf.). This makes InSight perfectly suited to explore the dynamics in the Planetary Boundary Layer [PBL] of Mars, dominated by atmospheric fluctuations on timescales shorter than an hour. Furthermore, the SEIS seismometer [3] can be used to study ambient and turbulent wind, acoustic and gravity waves, and vortex-induced seismic signatures [4] (Murdoch, this conf.).

Daytime PBL convection Pressure fluctuations of 0.5 Pa peak-to-peak and temperature fluctuations of 10 K peak-to-peak over 200-500-s timescales detected by the InSight sensors correspond to the advection of Rayleigh-Bénard-like polygonal convective cells. More than a thousand pressure drop events corresponding to dust-devil-like vortices have been detected in the first 150 sols of InSight operations (Figure 1). Similarly to terrestrial deserts [5], the distribution of pressure drops follow a power-law with a 2.6 exponent. Pressure drops occur from LTST 0800 to 1700, with maximal activity between 1200 and 1500, except a notable drop of activity in the interval 1400-1430. On sol 65, InSight recorded the strongest pressure drop caused by a dust-devil-like vortex on Mars (9 Pa). The strongest wind gust recorded by InSight (28 m/s) is associated with a ~ 4 Pa pressure drop on sol 26. InSight appears as the most active site visited thus far: $2\times$ as many pressure drops (≥ 0.5 Pa) per sol as Pathfinder and $5\times$ as Phoenix and Curiosity. Dust-devil-like vortices are causing ground deformation detected by InSight SEIS and could be used to probe the first meters below the surface. Yet, despite this intense vortex activity, and the dust devil tracks detected from orbit, not a single dust devil was imaged by the lander cameras in the first 150 sols of the InSight mission.

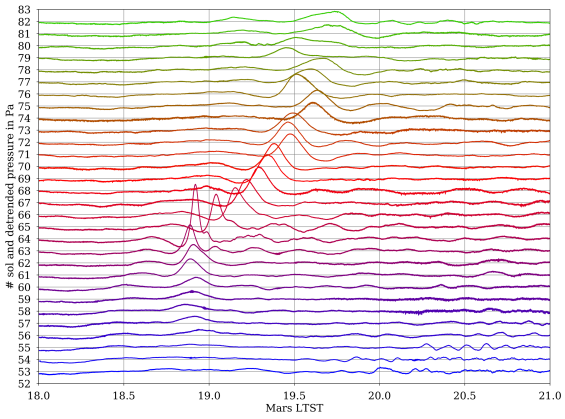

Figure 3: *Detrended evening InSight pressure for several sols showing bores and gravity waves.*

Spectral analysis Nighttime turbulence has much less energy than daytime turbulence (Figure 2) and near-surface shear conditions are causing it to vary with local time. In daytime conditions experienced by InSight, an expected $-5/3$ slope in pressure spectral density is observed below 0.1 Hz frequencies but a slope closer to -1 is observed in the range 0.1-2 Hz. The lander deck might affect high-frequency small eddies, but the reason could be more fundamental. With stable stratification and high Reynolds number (the near-surface Martian conditions), a transition zone might appear between the buoyancy subrange at low frequencies and the isotropic inertial subrange at high frequencies (Dougherty-Ozmidov scale) which both follow -5/3 power-law scaling. The transition region could exhibit a variety of slopes depending on wind and stability conditions[6].

Nighttime PBL mesoscale activity The InSight mission shows that the 300-800-s gravity-wave fluctuations first detected by Curiosity[7] are ubiquitous from the early evening to the late night. Some clear-cut events reaching 2 Pa peak-to-peak amplitude are detected. This demonstrates that gravity waves can be found far from topographical obstacles (thanks to an efficient near-surface waveguide) or even would originate from other sources than topography (jet acceleration, convection). During the late MY34 regional dust storm, the InSight pressure sensor also detected pressure jumps of a couple Pascals, occurring every sol in early evening, which became pressure bumps in the decaying phase of the regional storm (Figure 3). The pressure bumps reached a maximum of 4 Pa, occurred later and later every sol before disappearing at the end of the dust storm disturbance. Followed by gravity-wave-like fluctuations, as well as ambient wind change of speed and direction, those pressure bumps are reminiscent of bores and solitary waves – or, undular bores – caused by the propagation of a cold front and leading to "Morning Glory" elongated clouds on Earth[8] and Mars[9]. Undular bores are also observed by InSight in the morning.

Infrasound? The pressure sensor on board InSight detected coherent oscillations that are candidate for infrasound. The first kind of candidate infrasound is 80-s-period pressure and wind oscillations embedded within the above-mentioned 300-500-s gravity wave signal. The second kind of candidate infrasound could only be detected by the pressure sensor: oscillations of pressure with a period of 0.7-0.9 s can be noticed within the pressure minimum of dust-devil-like vortices. Studying infrasound is useful since their propagation provide indirect hints on the thermal structure and stability conditions in the Martian PBL.

Perspectives The weather station on board InSight is providing a new view of the Martian atmosphere through a reasonable upgrade of the instrumentation and a continuous time coverage. This is an excellent basis for validation of mesoscale models and large-eddy simulations, for future exploration of Mars and probably a milestone precursor of a future meteorological network on Mars.

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