PREDICTING THE METEOROLOGICAL AND SEISMIC SIGNALS OF MARTIAN DUST-DEVIL VORTICES AS OBSERVED ON THE INSIGHT LANDER. N. Murdoch[1], R. Lorenz[2], A. Spiga[3], R. F. Garcia[1], D. Mimoun[1], T. Warren[4], W. T. Pike[5], J.B., McClean[5], A. Stott[5], C. Charalambous[5], R. Widmer-Schnidrig[6], S. Kedar[7], B. Kenda[8], T. Kawamura[8], P. Lognonné[8], Perrin, C.[8], Jacob, A.[8], Lucas, A.[8], Rodriguez, S.[8], C. Newman[9], and W.B. Bannert[7]. [1]ISAE-SUPAERO, Toulouse, France (naomi.murdoch@isae.fr), [2]JHU-APL, Maryland, USA, [3]LMD, Paris, France, [4]University of Oxford, UK, [5]Imperial College London, UK, [6]Black Forest Observatory, Germany, [7]JPL, Pasadena, USA, [8]IPGP, Paris, France, [9]Aeolis Research, Pasadena, CA, USA.

Introduction: In November 2018 the InSight mission landed on Mars. Over the next two years this mission will perform the first comprehensive surface-based geophysical investigation of Mars [1].

Prior to landing, there were extensive efforts to understand the atmospheric contributions to the seismic signal on Mars [2-6]. Pressure fluctuations in the atmosphere induce an elastic response in the ground that can be detected as a ground tilt by seismic stations installed on, or close to, the surface. This effect has been known for a long time [7-9], and is one of the reasons that terrestrial seismic stations are typically installed deep underground vaults. However, given the absence of microseism-producing oceans on Mars, the atmosphere directly dominates the background seismic noise [10].

One atmospheric signal that is predicted to be visible on the InSight seismometers is caused by convective vortices (named dust devils when the vortex transport dust particles). The negative load of a dust-devil vortex pulls up the ground as it passes, causing the ground and seismometer to tilt away from the dust-devil vortex. This first identification of the isolated seismic signature of a dust-devil vortex on Earth [11] demonstrated that a seismometer appears to be capable of tracking close encounters with dust-devil vortices and, in addition, that seismometers may be more effective than in-situ meteorological instruments at detecting dust-devil vortices at long-range.

Dust-devil vortex observations on Mars: Convective vortices, which may or may not be dust-laden are detectable as a sharp (typically 10-100s long) dip in local pressure in the time series. The typical pressure distribution around a vortex can be seen in Fig. 1. The variation of the tangential wind speed and pressure with distance from the center of the vortex has been presented in multiple previous studies [e.g., 12,13]. The tangential to vertical wind velocity scaling for a convective vortex is less well defined, but is likely to be between 0.1 and 0.3.

As for the corresponding seismic signal: the surface will tilt away from the vortex. In the case of a straight-line path directly across the seismometer, the tilt will rise from zero to some maximum value, which then switches sign as the load crosses the instrument and then declines back to zero. In the case of a near-miss, the component of tilt along the direction of motion follows the same functional form, but is muted by the smoother distance history. The component of tilt orthogonal to the direction of motion rises to a maximum value at close approach and declines (but is always of the same sign).

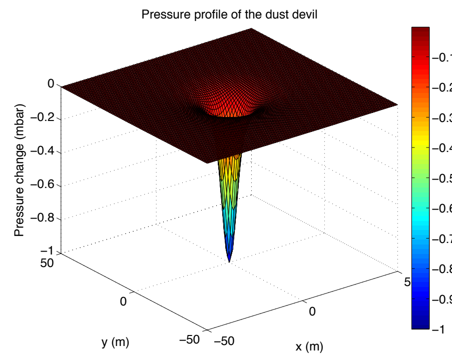

Figure 1: The pressure profile of an example dust-devil vortex. The colour bar indicates the pressure change in mbar.

Modelling dust-devil vortices:

Ground deformation model: The simplest model of a dust-devil vortex encounter is the straight-line constant-speed migration of a negative point load on an elastic half-space, as described in [11]. Although the negative load of a dust-devil vortex is actually a distributed pressure field (Fig. 1), this matters only within a diameter or so of the vortex center. The point load method is, therefore, suitable for small and/or distant dust-devil vortices. However, for large and close dust-devils vortices, the pressure distribution must also be taken into account (Fig. 2). This is done using a Greens' function grid approach, as described and validated in [3]. The ground deformation results in a mean displacement of the lander and also a tilt signal due to the differential vertical displacement of the lander feet.

Lander aerodynamic model: To fully understand the effects of a dust-devil vortex on the seismic data recorded on the lander deck, the lander aerodynamics should also be taken into account. We use the same approach as described in [2, 14] to calculate the lift and drag forces acting on the lander body, and the resulting motion of the lander.

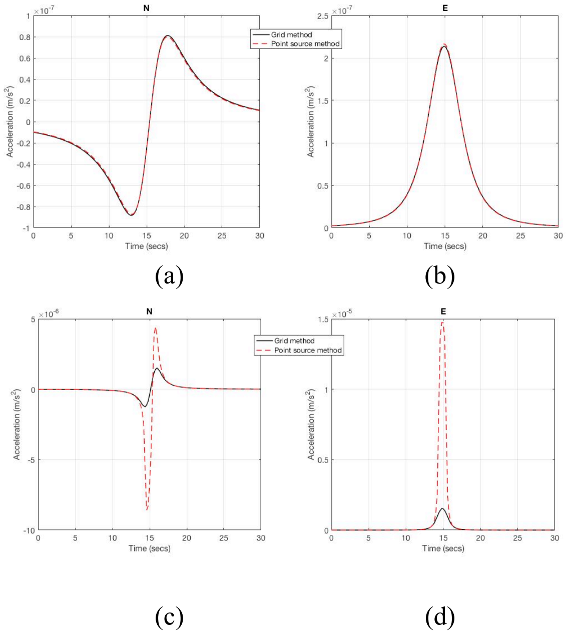

Figure 2: Tilt calculations for the point source vs. grid method for the passage of a dust-devil vortex with the following a parameters: D = 4 m, ΔP_o = -4 Pa, advection speed = 3 m/s. (a) and (b) compare the calculated N and E tilt signatures when the closest approach (center of lander – center of the vortex) is 7 m, (c) and (d) compare the calculated N and E tit signatures when the closest approach is 1 m.

Results: We present modelling results that predict how dust-devil vortices may be observed by the meteorological (pressure and wind) and seismic instruments (the Short Period sensors [15]) on the InSight lander deck, before the deployment of SEIS onto the surface of Mars. This model takes into account both the ground deformation due to the dust-devil vortex passage, and the lift and drag forces acting on the lander (Fig. 3). We find that the aerodynamic forces can lead to signals similar in amplitude to the ground deformation at close (i.e., within one dust-devil vortex diameter) approaches (Fig. 4). Using techniques similar to those applied in [11,16], it will be possible to use this model, in combination with observed meteorological (pressure, wind speed, wind direction acquired by InSight APSS) and seismic data (acquired by InSight SEIS) to place constraints on convective vortex parameters (size, core pressure drop, advection speed) and their trajectories.

References: [1] Lognonné et al., 2018; [2] Murdoch et al., 2017a; [3] Murdoch et al., 2017b; [4] Mimoun et al., 2017; [5] Kenda et al., 2017, [6] Spiga et al., 2018; [7] Crary and Ewing, 1952; [8] Sorrels, 1971; [9] Sorrels et al, 1971; [10] Lognonné and Mosser, 1993; [11] Lorenz et al., 2015; [12] Vasistas et al., 1991; [13] Kurgansky et al., 2016; [14] Murdoch et al., 2018, [15] Warren et al., LPSC 2019; [16] Lorenz et al., 2016.

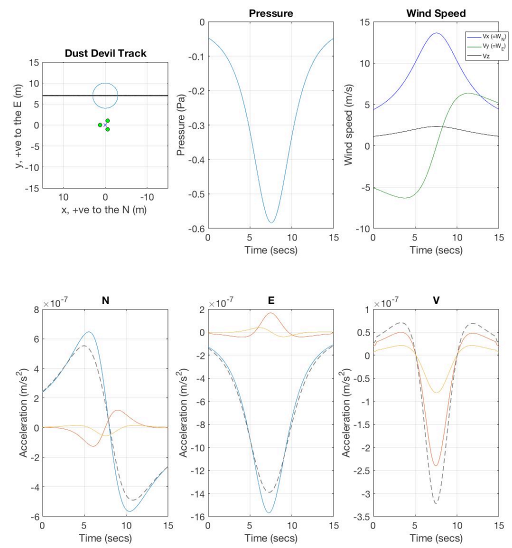

Figure 3: Predicted meteorological and seismic observations during a 'distant' dust-devil vortex passage. Dust-devil vortex parameters: D = 6 m, ΔPo = -8 Pa, advection speed = 2 m/s, closest approach = 7 m. The upper left figures show the dust-devil vortex trajectory with respect to the lander feet (green circles), and the pressure and wind speed at the lander. In the lower figures blue and red lines indicate the ground deformation signals (tilt and mean motion, respectively), orange indicates the acceleration from aerodynamic forces, and the grey dashed line indicates the total observed seismic signal.

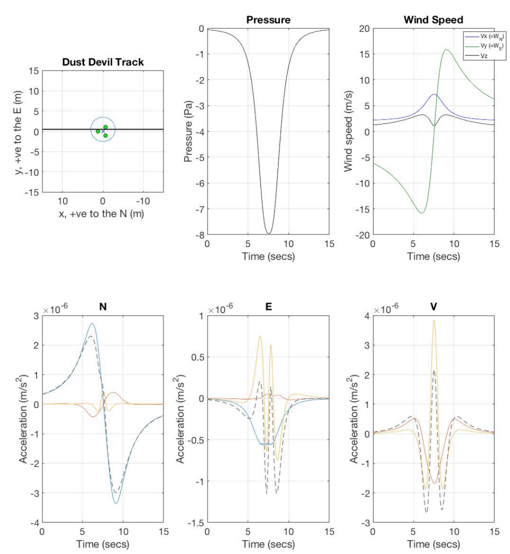

Figure 4. Predicted meteorological and seismic observations during a 'close' dust-devil vortex passage. Dust-devil vortex parameters: D = 6 m, ΔPo = -8 Pa, advection speed = 2 m/s, closest approach = 1 m. The legend for the figures is the same as Fig. 3.