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Constraining Martian dust devil vortex and regolith parameters from combined seismic and meteorological measurements

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Abstract

Prior to landing on Mars it was predicted that the seismic signal generated by dust devil vortices would be visible on the InSight seismometers. Here we present a method for modelling dust devil vortices, and we demonstrate how this model can be used in combination with InSight observations of dust devil encounters, to determine the vortex trajectory azimuths while simultaneously providing constraints on the Martian ground properties and key dust devil parameters.

1. 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, atmospheric pressure fluctuations dominate the seismic background on Mars [10].

2. Seismic Observations of Dust Devil Vortices

One atmospheric signal that was predicted to be visible on the InSight seismometers is caused by convective vortices (named dust devils when the vortex transports dust particles). Convective vortices are detectable as a sharp (typically 10-100s long) dip in local pressure in the time series. The pressure drop in the vortex pulls the elastic ground up leading to two types of seismic signal: 1. The surface tilts away from the vortex leading to a tilt signature on the horizontal axes (dominates the horizontal axes), 2. There is a mean upwards ground displacement resulting in a negative vertical peak in acceleration (dominates the vertical axis). The isolated seismic signature of a convective vortex was first detected on Earth in 2015 [11], and has since been detected on Mars with SEIS.

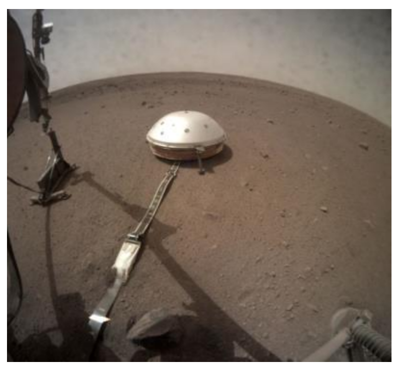

Figure 1: The InSight Seismometer SEIS deployed on the surface of Mars under the Wind and Thermal Shield.

3. Modelling dust devil vortices

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. 2), 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. This is done using a Greens' function grid approach again assuming an elastic half-space, as described and validated in [3]; the vortex-induced variation of the vertical force exerted on the ground in each section of the grid is calculated and the displacement of the ground is the sum of the displacements caused by each section of the grid.

By combining this model with InSight observations of dust devil encounters, we can determine the vortex trajectory azimuth while providing constraints on the Martian ground properties and key dust devil parameters (advection speed, S, core pressure drop, ΔP_o, diameter, D, closest approach distance, d_{min}).

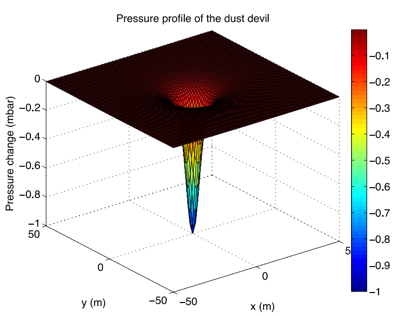

Figure 2: The pressure profile of an example dust-devil vortex. The colour bar indicates the pressure change in mbar (hPa).

4. Properties of Martian regolith and the dust devil vortex parameters

The elastic properties of the Martian regolith have an important influence on the seismic wave-field and travel times as recorded by the SEIS instrument. In addition, the geotechnical properties of the regolith have implications for material strength, future robotic exploration of Mars, and the geological evolution of the InSight landing site.

We solve a series of homogeneous equations to find solutions for the dust devil parameters (S, ΔP_o, D, d_{min}) matching both the pressure and seismic tilt data. As there are only a range of possible values of ground properties (Young's modulus, E) that provide a solution simultaneously for the seismic tilt data and for the pressure data (see example in Fig. 3) this places a constraint on the elastic ground properties.

We can then use the dust devil parameters to determine the dust devil trajectory by fitting the form of the seismic tilt data. This provides the most probable vortex trajectory azimuth, assuming a linear trajectory. This rapid technique provides interesting information for statistics, and for comparison with tracks observed from orbit [12] and the InSight wind observations.

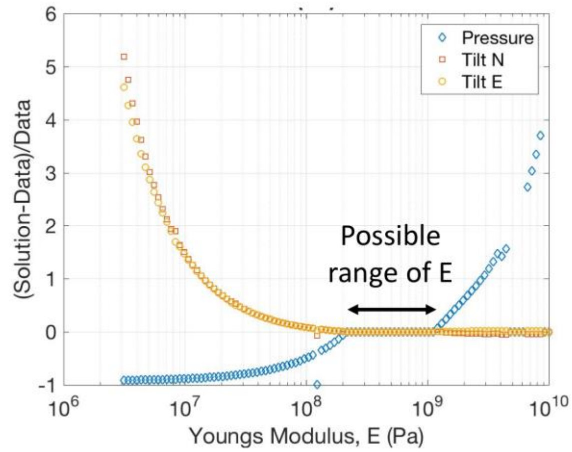

Figure 3: The range of Young's modulus (E) that provides solutions matching both the seismic tilt data and the pressure data during one dust devil encounter.

5. Conclusions

Prior to the InSight landing we developed models to study the seismic signals of dust devils and constrain the dust devil parameters [3,11]. We have since developed a method to rapidly constrain the Martian ground properties and trajectory azimuth from each dust devil passage measured by SEIS, while also providing a range of possible solutions for the key dust devil parameters.

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