EXPLORING THE MISS-DISTANCE AS A POSSIBLE CAUSE OF NON-SIMULTANEITY IN PRESSURE AND SEISMIC SIGNALS OF MARTIAN DUST DEVILS. L. Wright1, N. Bowles1, T. Warren1, W. T. Pike2, A. Stott2, J. M. McClean2, C. Charalambous3, B. Kendal3, N. Murdoch3, R. Lorenz4, K. Perrin3, A. Spiga3, D. Banfield5, P. Lognonne3, Atmospheric, Oceanic and Planetary Physics, University of Oxford, (lucy.wright@oriel.ox.ac.uk), (tristram.warren@physicsox.ac.uk), (2) Imperial College London, UK, (3) IPGP, Paris, France (4) ISAE-SUPAERO, Toulouse, France (5) Johns Hopkins Applied Physics Lab, Laurel, MD, USA (6) Faculté des Sciences, Paris, France (7) Cornell University, Ithaca, NY, USA

Introduction: Sharp drops, of width around 2 seconds, in atmospheric pressure are associated with travelling vortices, which, if sufficiently strong, loft Martian particles forming ‘dust devils’. The vortex, whether dust-carrying or not, imposes a negative load on the planetary surface, causing deformation of the ground. This deformation can be measured in terms of vertical and horizontal displacements, which can be detected by a seismometer.

The Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission landed on Mars in November 2018. InSight was equipped with a seismometer package (SEIS), placed on the Martian surface subsequent to landing, and an Auxiliary Payload Sensor System (APSS). SEIS comprises of a Short-Period (SP) seismometer and a Very Broad Band (VBB) seismometer. Each seismometer has three components, enabling the detection of seismic signal in three dimensions. APSS comprises of atmospheric sensors, namely pressure (PS), temperature, magnetic field and wind. InSight landed in the Elysium Planum region, which was predicted before landing to encounter dust devils.

Dust devils produce distinct seismic and pressure signatures, which have been modelled by Sorrells [1] and Lorenz [2]. We identify these signatures in the data and look at the difference in arrival times of the SP and pressure signals of likely dust devils. We explore the possibility that the non-simultaneity of these signals is related to the miss-distance — the distance of closest approach to the detector — of the dust devil.

Should we find miss-distance well explains the offset when studying a larger number of encounters, we will present a catalogue of Martian dust devils that will allow a statistical comparison to be made to HiRISE images of the region and that will help characterise the environment around the InSight lander. The catalogue will contain estimations of miss-distance, core pressure drop and size of the largest ten identified dust devils.

Approach: Lorenz [2] notes that the pressure field, over relatively short ranges, for a dust devil follows a Lorentzian lineshape,

\[ \Delta p = \frac{\Delta p_0}{r^2 - 1} \]

with respect to a dimensionless radius \( r = 2d/D \). Where \( d \) is the distance between the detector and the dust devil, a function of time, and \( D \) is the diameter of the devil, defined by its column ‘wall’ — the boundary between the spinning gas and the outer, descending, cool gas, where the tangential velocity of spinning gas is at its maximum — and assumed to be constant.

Looking at the geometry of the problem shown by Figure 1, and making assumptions described below, we show that the pressure field of a dust devil follows a Lorentzian lineshape with respect to time also. A key assumption is a suggestion of [2], that in a simplified model, the migration velocity of the dust devil is approximated to be equal to the ambient wind velocity, measured a significant time before or after the dust devil occurrence. A least-squares fit is used to model a Lorentzian to a sharp drop in pressure time-series data from InSight, probably caused by a dust devil, on Sol 191 (see Figure 2). This has been chosen as an example because it is one of the largest pressure vortices in the available data, and therefore the pressure and seismic signals are distinct from the noise.

The motivation for fitting a model to pressure data is to determine the position of the centre of the signal in time, such that the delay of the pressure signal with respect to the seismic signal can be deduced. The offset is around 0.5 seconds for the devil on Sol 191, and is shown in Figure 2.

The expected seismic signal from a dust devil has two parts: horizontal tilt and vertical displacement of the seismometer. Horizontal tilt signatures in displacement resemble smooth heartbeat shapes, with asymmetry determined by the migration direction of the devil. Vertical displacement signatures are single peaks. A typical dust devil seismic signature is shown in Figure 3. In our approach, the arrival time of the signal is required, not the entire movement of the seismometer. Thus, only the vertical displacement is...
used to constrain the dust devil properties. We fit a Gaussian, using a least-squares fit, to the vertical displacement of the seismometer to obtain the time at which maximum displacement occurs. A Gaussian was chosen for mathematical convenience: it is useful for estimating the maxima position and in estimating uncertainty. Sorrells and Lorenz have produced accurate models of ground deformation caused by dust devils, however that level of sophistication is not required for finding the signal offset, because, again, the entire movement of the seismometer is not studied here.

Figure 2: Atmospheric pressure drop (top) and vertical displacement of the SP (bottom), due to a probable dust devil on Sol 191. Time-series pressure data points are marked by a + and a Lorentzian fit is presented by a solid line (top). Red dashed lines mark the arrival times of the seismic (left) and pressure (right) signals.

It is the pressure fluctuation which imposes the negative load on the surface, causing ground displacement. Therefore, at the site of the dust devil, the time at which the ground is at maximum displacement corresponds to the time at which the atmospheric pressure is at a minimum. Hence to compare offsets in pressure and seismic signal at the detector, the positions that must be compared are those of the centre of the vertical displacement and the centre of the pressure trough (shown by red lines in Figure 2).

Kenda [4] shows dust devils are a source of short-period Rayleigh waves, of typically 1-20Hz, so we assume the seismic signal travels along the surface at a typical Rayleigh wave velocity for Mars. We have used a value of \(v_{\text{seis}} = 750\text{m/s}\) to provide example results for this abstract. We assume the pressure signal travels through the atmosphere at sound velocity, \(v_{\text{pres}} = 244\text{m/s}\), as estimated by [5]. We use these values to estimate the miss-distance by

\[ d_{\text{min}} = \frac{\Delta t}{v_{\text{pres}} - v_{\text{seis}}} \]

where \(\Delta t\) is the offset in signal arrival times and \(v_{\text{pres}}\) and \(v_{\text{seis}}\) are the assumed velocities of the pressure and seismic signals, respectively.

We derive other best-fit parameters of the pressure Lorentzian in terms of dust devil attributes, namely core pressure drop, migration velocity, diameter and miss-distance. Knowledge of the parameters, which we gain from performing a least-squares fit, therefore constrain these attributes. Solving these equations gives a set of non-unique properties of the dust devil. ObsPy was utilised to process the raw data. The seismic data sets were corrected for instrument response using the sensors’ transfer function stored in the dateless file. Pressure and seismic data sets were band-pass filtered with cut-off frequencies (0.0125, 1)Hz and (0.03, 0.3)Hz respectively. Calculations of miss-distance, core pressure drop and diameter of the dust devil occurring on Sol 191 are presented in the table 1.

<table>
<thead>
<tr>
<th>Miss-distance (m)</th>
<th>Core pressure drop (Pa)</th>
<th>Diameter (m)</th>
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<tbody>
<tr>
<td>122.4 ± 31.5</td>
<td>87.9 ± 29.3</td>
<td>12.7 ± 2.8</td>
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Table 1: Estimates of properties of the dust devil on Sol 191, using the approach described in the main text.

These estimates are unrealistic since typical vortex pressure drops are a factor of 10 smaller. This points to the premise that the offset between the two signals is due to the miss-distance is incorrect and hence we will check other dust devils with larger offsets and also explore other possibilities.

Future Work: We will apply our approach, with an updated value for seismic signal velocity (provided by [6]), to many dust devil signatures, particularly those with larger offsets, and compare our results to those deduced by the models of Lorenz and Sorrells. We will apply our approach to the VBB data also. Comparison of results should lead us to verify or deny the possibility that the non-simultaneity of the signals is due to the dust devil’s miss-distance. We will also explore other possible causes such as the azimuthal asymmetry in the vortex structure and asymmetry in wind field [3].


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