Characterization of Martian convective vortices using InSight's seismic and meteorological data

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Introduction: From Nov. 2018 to Dec. 2022, NASA's InSight (Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport) was operated on Mars to conduct seismic and meteorological observations. InSight's long quasi-continuous and high-temporal sampling observations have significantly improved our understandings of the inner structure, seismicity, and meteorological phenomena of the red planet (e.g., [1]-[8]). Prominent among these are convective vortices or dust devils.

Martian convective vortices: From previous missions, it is known that the convective vortices are common meteorological events on Mars (e.g., [9]-[11]). They are closely related to the thermodynamical structure of the local atmosphere and often cause dust lifting. Therefore, understanding this phenomenon is important to know the local meteorological behaviors as well as how the dust particles are transported from the ground to the atmosphere.

In addition, since a convective vortex is a moving low-pressure system, it causes ground deformation (e.g., [12]-[14]). As shown in Figure 1, the ground acceleration responds to the temporal pressure drop, via air-solid coupling or compliance. The spectral ratio of the ground response against pressure perturbation allows us to infer the subsurface rigidity structure. Thus, this phenomenon can also contribute to the investigation of the subsurface structure.

Systematical catalog of Martian convective vortices: Until Sol 900, about 13000 vortices have been detected in InSight's pressure data [8]; most were observed during the convectively-active daytime (Figure 2). Details of larger events in that period were compiled in a previous catalog [15]. In this study, we are making a new systematic catalog of Martian convective vortices, using InSight's seismic as well as meteorological data, covering the full mission duration.

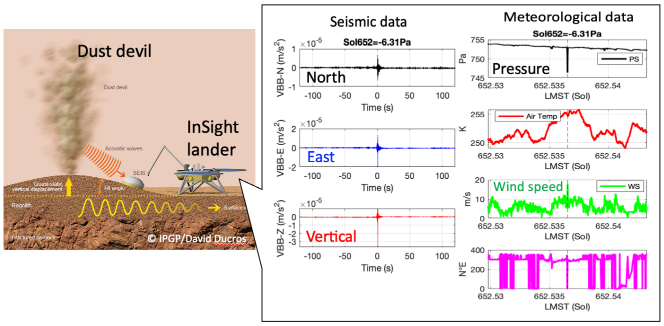

Figure 1. (Left) Schematic illustration of InSight's observation of a vortex (Note that no actual dust devils have been imaged by InSight [16]). (Right) Examples of the recorded seismic and meteorological data by InSight on Sol 652 (652 Martian days after landing). The north, east, and vertical components are presented from top to bottom for the seismic data. Pressure, air temperature, wind speed, and wind direction are shown from top to bottom for meteorological data. All time traces are centered at the maximum pressure deficit.

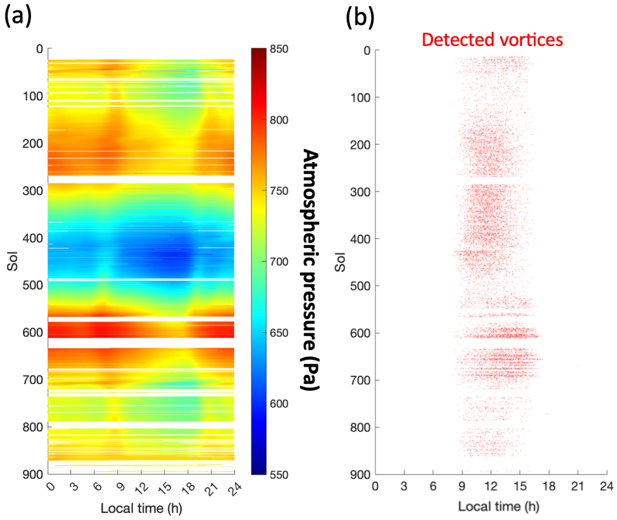

Figure 2. (a) Time evolution of the Martian atmospheric pressure over 900 sols. (b) Temporal distribution of the detected convective vortices by Spiga et al. [8].

Our catalog includes the following parameters besides the fundamental information already provided in [8,15], such as event time in UTC and/or local time, pressure drop value.

1) Signal to noise ratio (SNR) in various frequency ranges, which would be useful to select the high-quality events.
2) Ambient wind speed, wind direction, and air temperature, which can be used to check how much the local meteorological conditions varied due to the passage of vortices.
3) Asymmetricity of pressure drop profile, which could be a key parameter to illustrate the vortex wall structure.
4) Event duration, which is an important parameter for the classification of the vortex-related signals. As shown in Figure 3, we can observe different ground responses depending on the duration time of the pressure drop (i.e., event duration).
5) Cross-correlation coefficients between ground velocity and pressure signal in various frequency ranges, which are paramount parameters for performing compliance analysis to retrieve the subsurface rigidity structure. Depending on frequency, we can obtain the different depth information (i.e., higher frequency content is more sensitive to the shallower structure). For the analysis, we can only use the highly correlated events (i.e., those with better air-solid coupling). This parameter can help us determine which events can be used for the estimation of the subsurface rigidity structure.
6) Lag time between ground velocity and pressure signal in various frequency ranges. We almost always observe a time offset of the peak arrival between the ground response and pressure variation during the encounter of a vortex. However, the source of this time-lag remains an open issue. Therefore, quantification of this parameter would be a solid milestone to provide a reasonable explanation in the future.

Summary and future perspectives: Our new catalog describes seismological and meteorological features on each vortex event detected by InSight. These may help us better understand the vortex phenomenon itself as well as the local subsurface structure around the InSight landing site.

Furthermore, InSight's data complements other missions' observations. For example, Perseverance (Mars2020) carries a pressure sensor and microphone and observes the Martian convective vortices (or dust devils) from different aspect [17]. Thus, future collaboration between InSight and Perseverance data would be a possible option to study the convective vortices from multiple points of view.

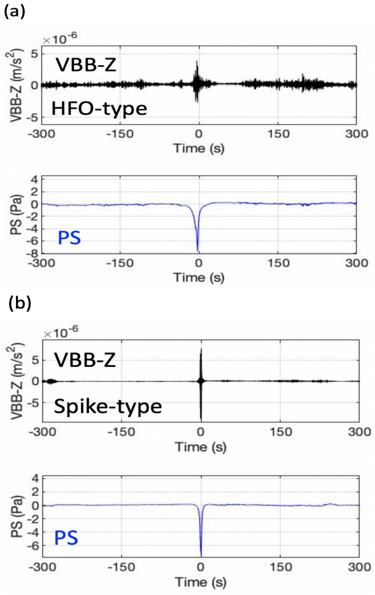

Figure 3. Comparison of two types of vortex-related signals (a: high frequency oscillation type and b: spike type). In each panel, the vertical ground velocity (VBB-Z) and the detrended pressure signals (PS) are displayed from top to bottom.

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