Overview of observed seismic signals on Mars

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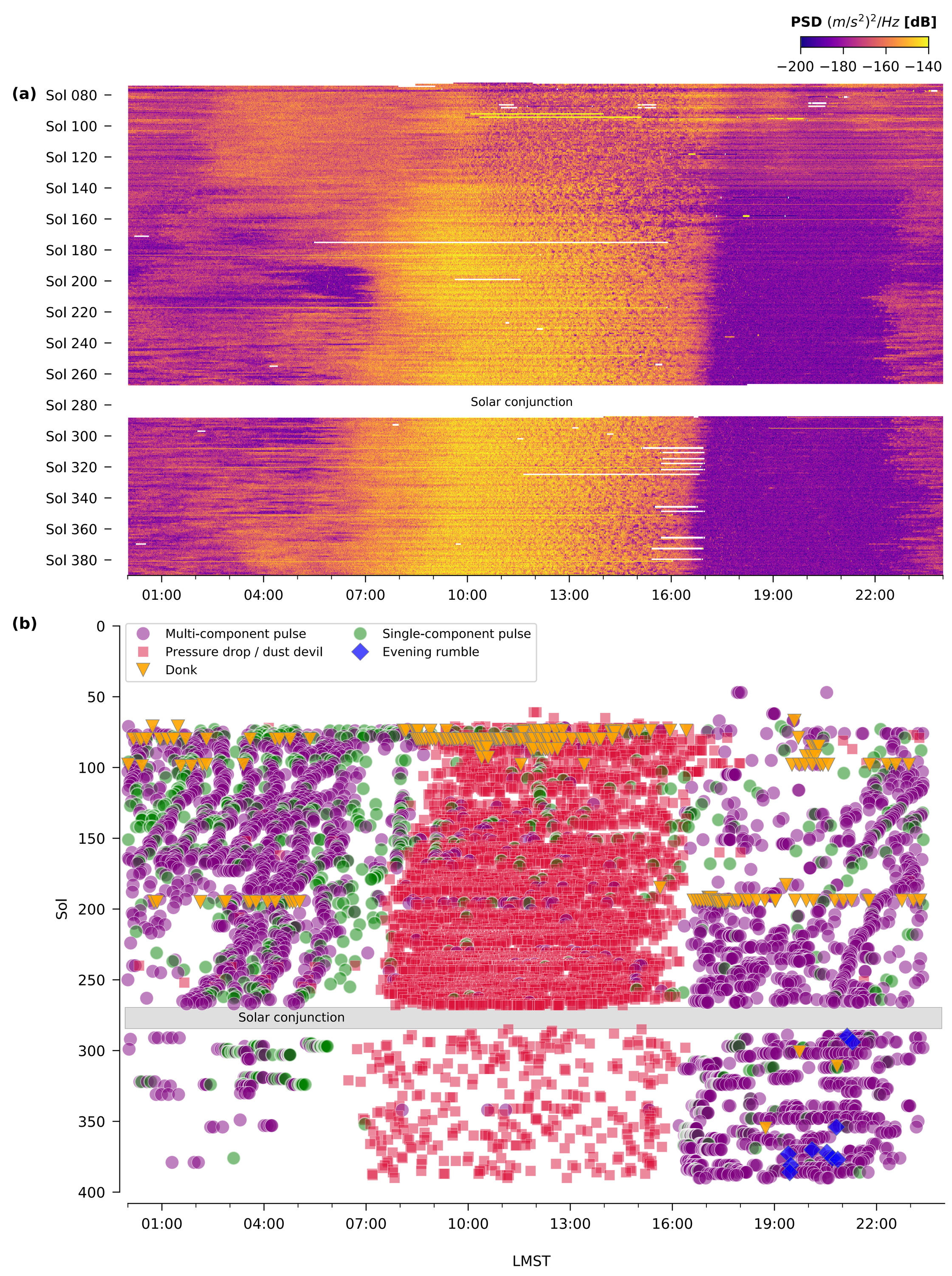
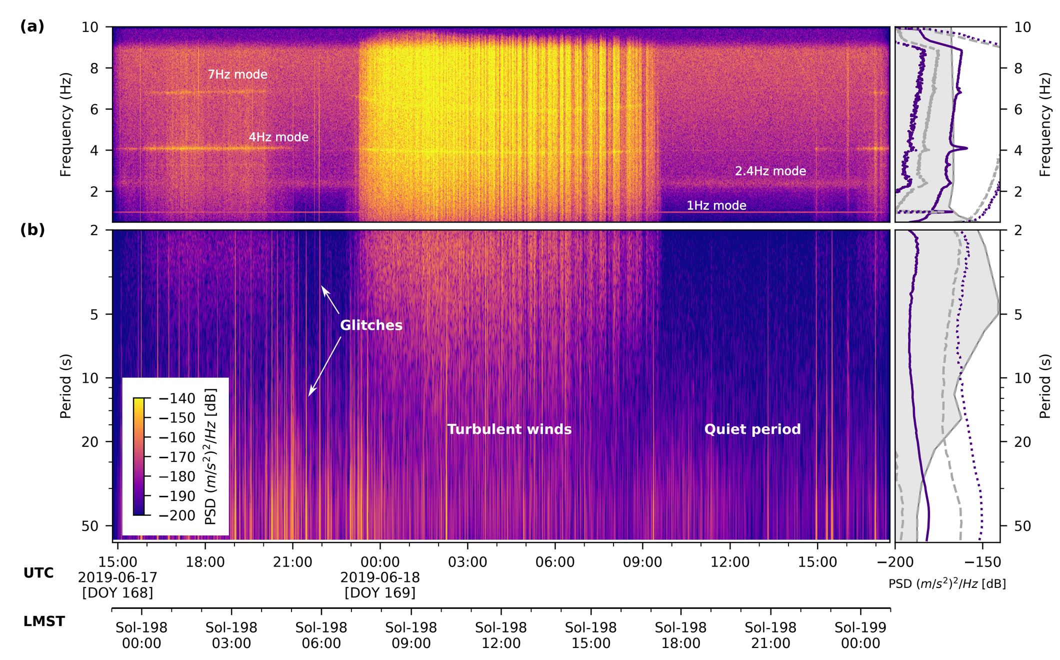
InSight landed on Mars in late November 2018, and the SEIS package, which consists of one short period and one very broadband sensor, was deployed on the surface shortly after. The data returned by the InSight is monitored in a timely manner by the Marsquake Service (MQS), a ground segment support group of InSight that has been set up to establish and maintain the seismicity catalogue. The MQS has at least one member on duty who routinely checks the data for any type of seismic signals. All suspicious signals are then communicated to the InSight team after evaluation.

To date, MQS has identified more than 365 events which are classified into two general families as high and low frequency, with each family having unique features in terms of their energy content. The most distinct quakes detected so far belong to the low frequency family that occurred on Sol 173 and 235, and have clear P and S-wave arrivals that reveal a distance around 30 degrees east of the lander, pointing the region in the vicinity of Cerberus Fossae. In addition to the signals of seismic origin, the SEIS data contain features that originate from other sources such as atmospheric effects or electronics. Part of these non-seismic observations may resemble quakes which may lead to wrong interpretations, and therefore require careful analysis.

Here, we show examples of signals of both seismic and non-seismic origins. We describe the characteristics of these observations in time and frequency domains in order to give an overview of martian data content.



Sol view

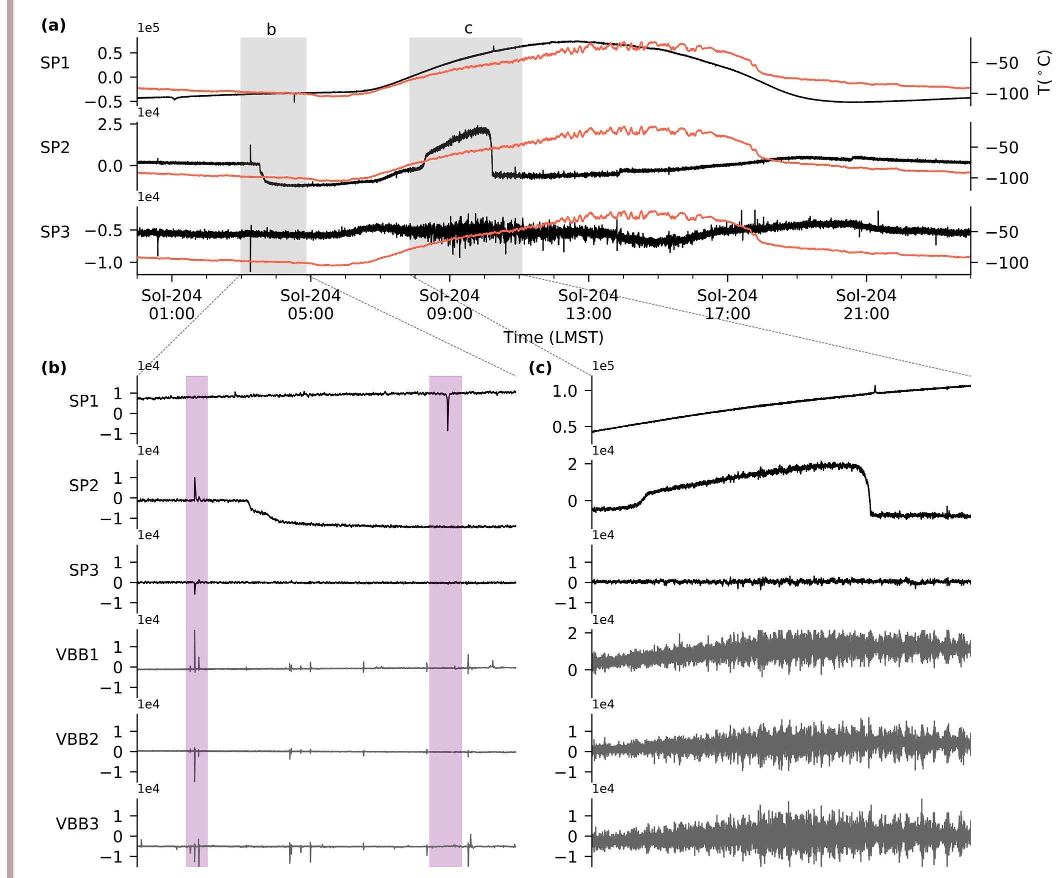


- Modes at 4Hz and 7Hz:
These modes are also called as the lander modes, and caused by the coupling between the lander and ground. The dominant frequencies of these modes decrease between the sunrise and sunset, indicating that they are temperature dependent.

- The mode at 2.4Hz:
The 2.4Hz mode is a natural ambient resonance that originates from the substructure beneath the lander. It is stronger in the vertical component than the horizontals with no apparent dependency on changes in the temperature or wind intensity.

- The mode at 1Hz:
This mode is caused by the EBOX when data acquisition system samples data in 1s intervals; therefore also called as the tick noise.

SP temperature pattern

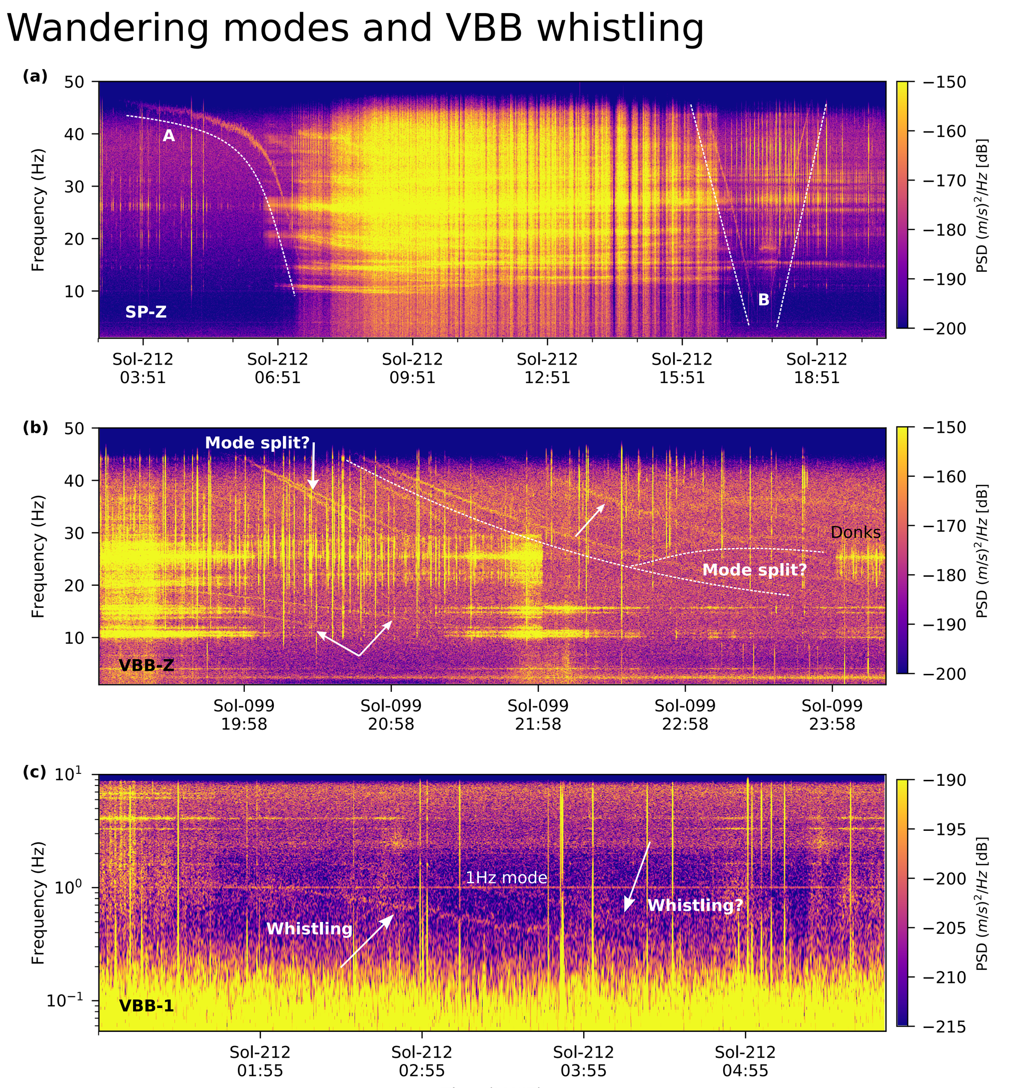


- SP1 follows a similar trend with the temperature.

- SP2 shows a sudden decrease in colder temperatures (b). The trend turns to positive slowly when the temperature starts increasing in the early morning hours, followed by a sudden jump after the sunrise (c).

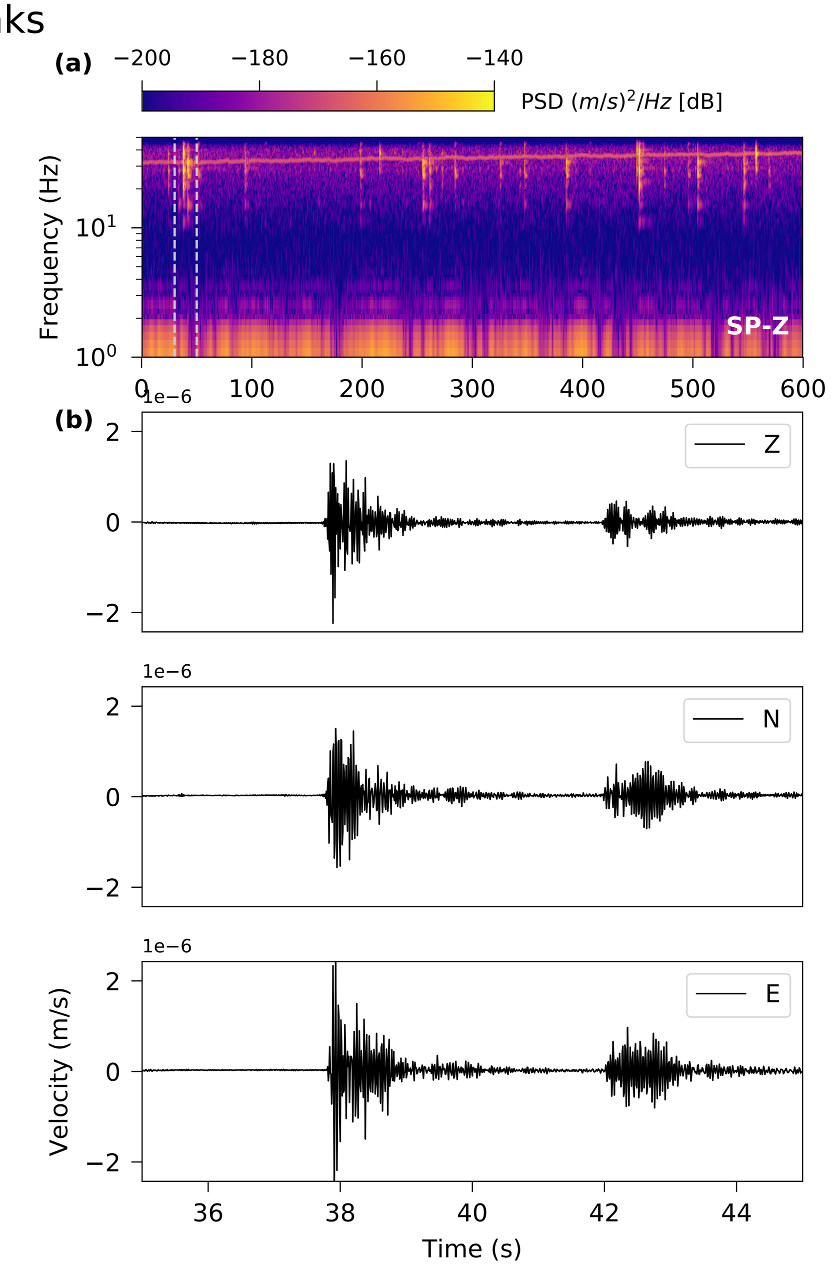
- There are temperature induced glitches on SP2 and SP3 at the beginning of the SP pattern's first stage, as well as on all VBB components (b). At the end of the decay temperature glitches occur on only SP1.

Wandering modes and VBB whistling



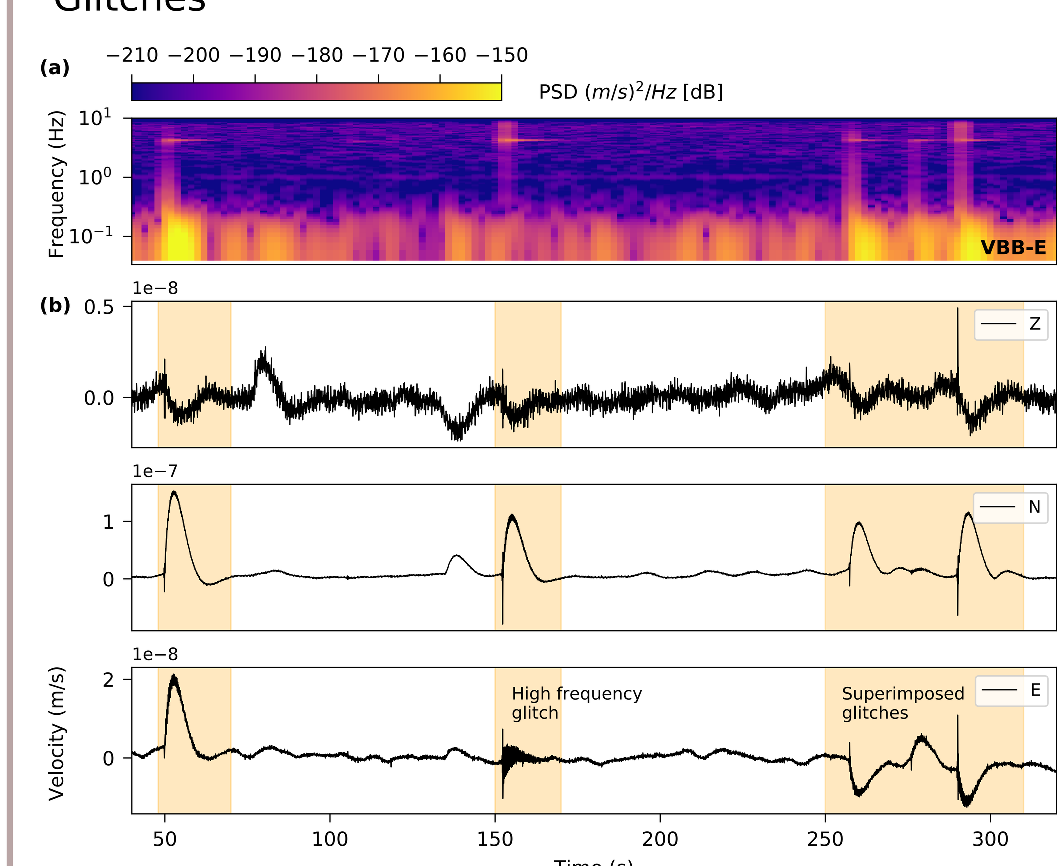
The SP modes appears across a wide range of frequencies (a). The VBB velocity spectrogram (b) shows multiple modes that leak from frequencies above the Nyquist. Some of these modes appear to be splitting.
There is one unique case where we also observe these strange modes leaking into frequencies lower than 1Hz (c). This mode is only seen on VBB1 in the early morning hours. It has a linearly decreasing pattern starting from ~2Hz down to 4s, with a duration of 60-90 minutes.

Donks



- Mono-chromatic anomalies that are observed on all three components of both seismometers at > 8Hz
- Occasionally may have tails injecting energy at frequencies lower than 8Hz.
- Short duration: at the order of a few seconds

Glitches



- One the most frequent anomalies predominantly observed on the VBB channels. The SP waveforms also contain some glitches in rare cases such as the sensor's response to daily temperature changes.

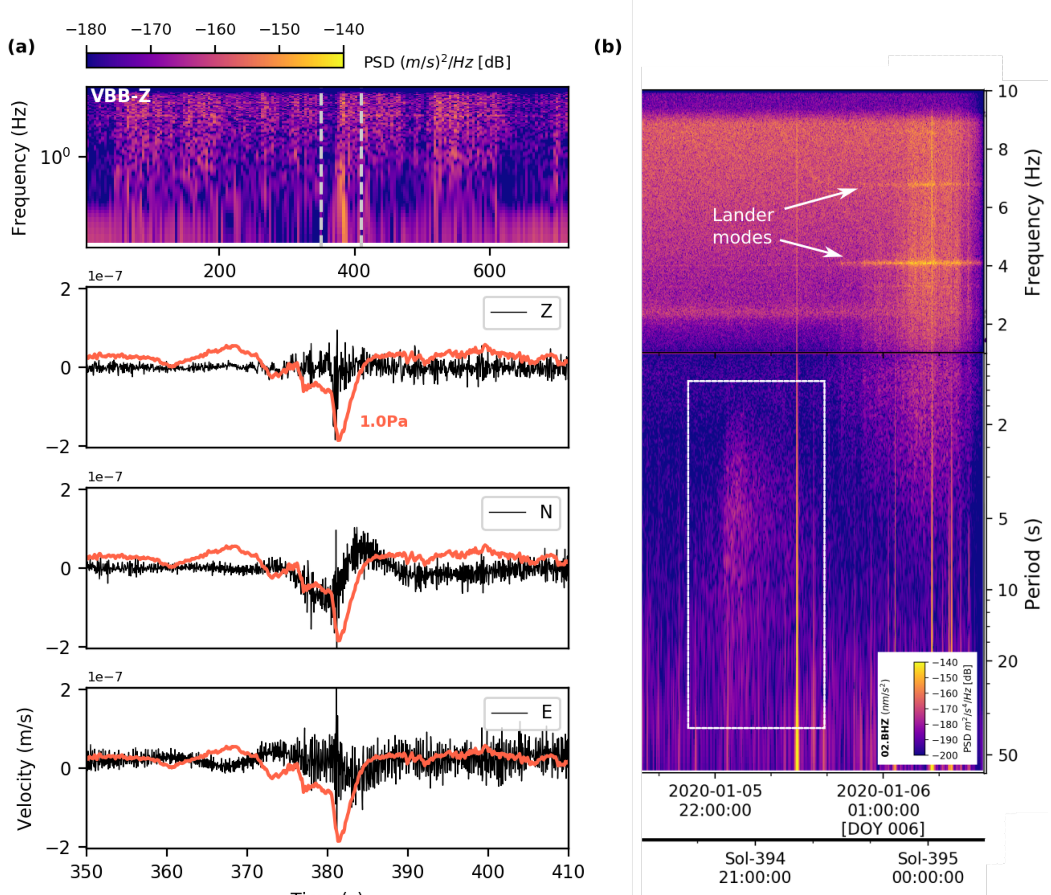
- Their shapes can be approximated to single-sided pulses.

- Generally evident as very broadband energy blocks in the spectral domain.

- Average duration of glitches is 30-35s.

- They can be seen on a single component as well as all three components.

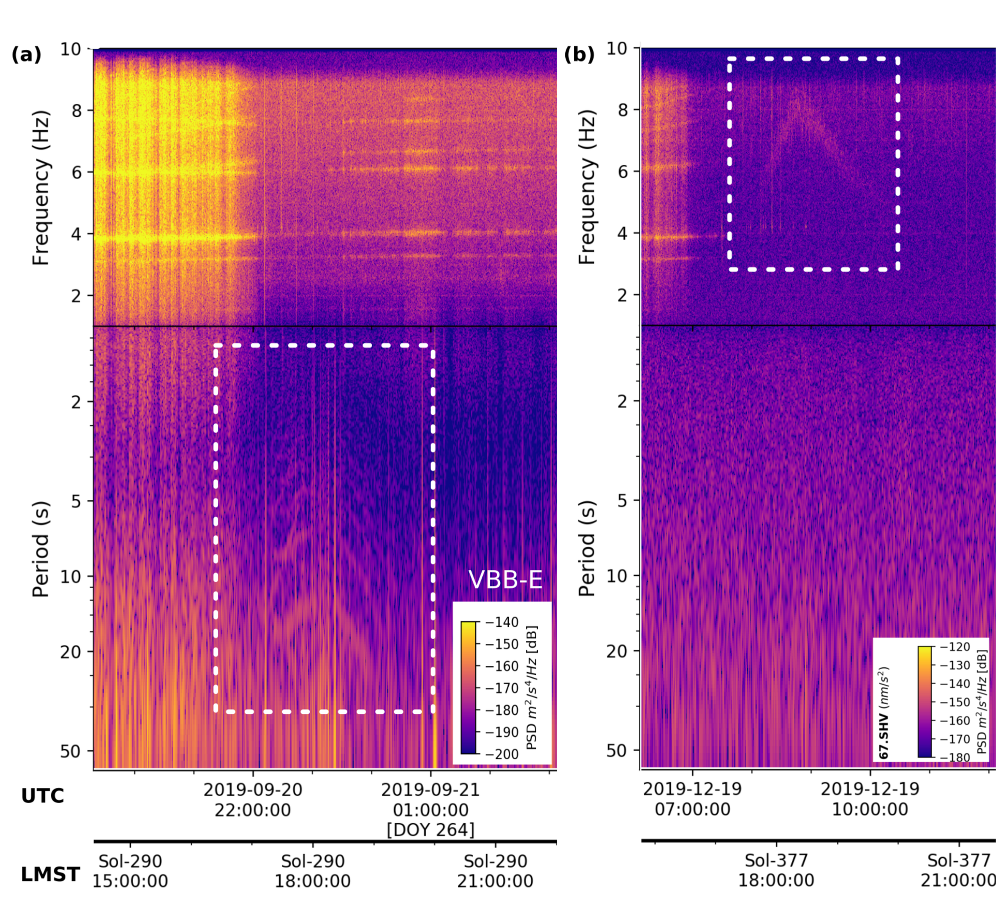
Wind, pressure drops, evening rumbles



Pressure drop/dust devils are vortexes in the martian atmosphere (a) that are often evident in the seismic recordings depending on their intensity and proximity to the SEIS. Pressure drops are very common during the turbulent periods when temperature is higher.

Evening rumbles are relatively long period (>2s), pressure induced signals on SEIS with a duration of 2-3 hours. Their signatures on the seismic time series are not very distinct. They are visible during the quiet periods in the evening, associated with the long period change in atmospheric pressure (b).

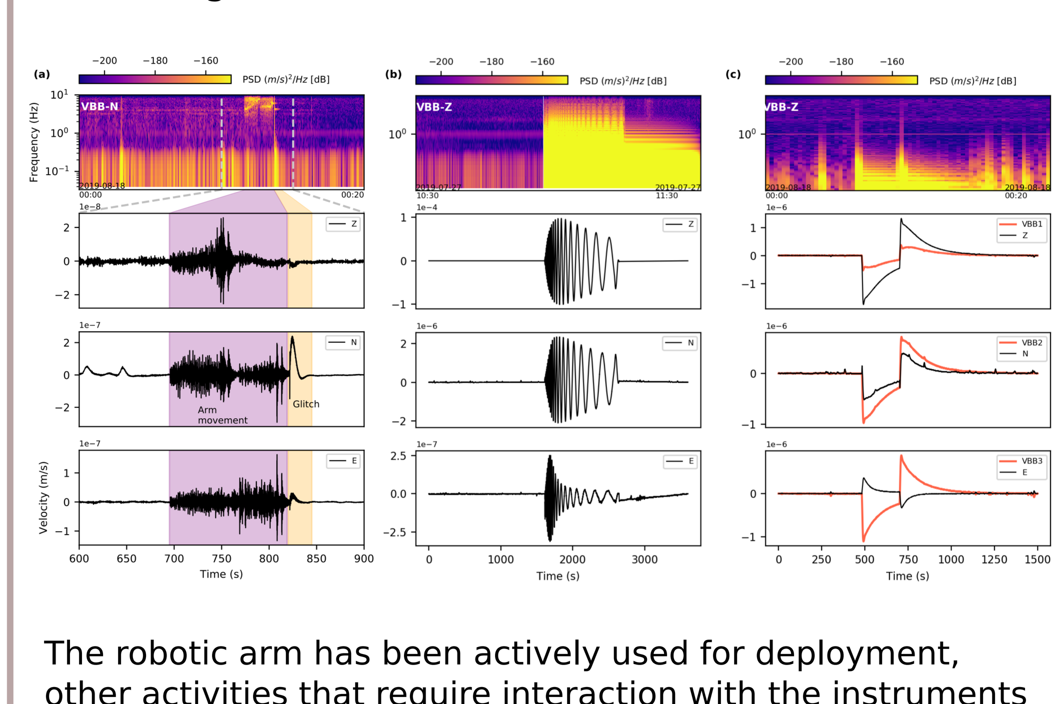
Sunset chirps, sandman



Sunset chirps are frequency domain features that occur in the evening hours after the windy period (a). They usually last for 30-60 minutes, with no apparent time-domain signature. They are commonly more noticeable on the east component of the VBB, at periods 4-35s.

The sunset chirps show a fishbone-like pattern on the acceleration spectrograms. The pattern has energy that looks like dispersive with several overtones, increasing in frequency over time.

Other signals



The robotic arm has been actively used for deployment, other activities that require interaction with the instruments on the ground, and imaging the surroundings. Arm motion is seen as a series of relatively high frequency (>4Hz) and dispersive signals on both VBB and SP (a). The characteristics change depending on the performed activity.

The SEIS sensors go through occasional sanity checks similar to the seismis stations on Earth for re-centering and sensor calibration. An example of how calibration looks on SEIS is shown in b. Calibration signals are visible on both sensors and all components.

SEIS has internal heaters in order to maintain the health of electronics and mechanical components. When the heaters are run, they cause impulses on the sensors which are damped over time, resembling a boxcar (c).