# Mars Seismic Catalogue, InSight Mission; V2 2020-04-01.

## Overview

This is the description of V2 of the Marsquake Catalogue for InSight, and includes the Martian seismic events as recorded by InSight up to December 31, 2019 / Sol 389 for the InSight mission. The catalogue is provided by InSight's Marsquake Service (MQS). The catalogue files are available at IPGP and IRIS.

The citation for the catalogue is:
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This catalogue is an update of V1 (InSight Marsquake Service, 2020a).

The catalogue is provided in 2 files. Both are in QuakeML format. One is in standard BED format and validates against the QuakeML 1.2 schema. The second includes a Mars-specific extension that includes basic information for single station locations and Mars catalogue management that is not available in the BED format. These include:

- Distance
- Back Azimuth
- Mars Event Type
- Mars Event Quality

The XML schema and documentation of the Mars-specific extension will be provided in a subsequent release.

A first description and interpretation of the marsquake catalogue is provided at Giardini et al, 2020, which also includes details of the routine MQS operations as well as marsquake identification and characterisation. More detailed descriptions of the catalogue, key event presentations, and MQS procedures, will be provided in forthcoming Insight team publications that are currently under preparation and review. A pre-landing description of the MQS is at Clinton et al, 2018.

The InSight seismic event catalogue is subject to revision in each version, as new events are collected and analysed, the velocity models are improved, and our understanding of the seismicity increases and MQS procedures evolve. Revised catalogues will be released alongside new waveform data releases. An overview of the major changes between V1 and V2 (this version) is at the end of this document; detailed changelogs for each of the 2 catalogue files are provided separately.

## MQS conventions

MQS assigns an event type and quality to seismic signals. The event type reflects the frequency content. The event quality is assigned based on the signal strength and ability to identify and interpret the phase arrivals.

### MQS Event Type

| | |
|---|---|
| **Low Frequency family of events: dominated by long period signals** | |
| Low frequency (LF) | energy in 3 components all below 2.4Hz |
| Broadband (BB) | energy in 3 components predominantly below 2.4Hz though also includes excitement at and possibly above 2.4Hz. |
| **High Frequency family of events: dominated by high frequency signals** | |
| High Frequency (HF) | energy in 3 components predominantly at 2.4Hz and above.<br>'Predominantly' indicates some leakage of energy below 2.4Hz is possible |
| 2.4Hz | energy in 3 components centered around 2.4Hz resonance, with very limited excitation above or below.<br>(It is likely these are small amplitude HF events.) |

| | |
|---|---|
| Very High Frequency (VF) | special case of high frequency events that show clear differences in energy between vertical and horizontal components. Horizontal energy is significantly larger the vertical energy at higher frequencies. Events tend to have shorter durations than HF events. |
| Super High Frequency (SF) | very short duration high frequency events that do not include energy at 2.4Hz or below. Energy is typically between 8-15Hz, and horizontal energy is significantly larger than vertical energy. |

**MQS Event Quality**

| Label | Quality summary | Key features |
|---|---|---|
| A | High | Multiple clear and identifiable phases / clear polarisation<br>(implies possibility of distance and BAZ => location) |
| B | Medium | Multiple clear and identifiable phases but no polarisation<br>(implies possibility of distance but no location) |
| C | Low | Signal is clearly observed but phase picking is challenging:<br>- (HF/2.4Hz/VF) Pg and Sg pickable, but speculative or large uncertainty or low SNR<br>- (LF/BB) no clear phases can be identified OR<br>- (LF/BB) only a single phase is clearly identifiable OR<br>- (LF/BB) multiple phases are identifiable, but no clear picks can be attributed to P and S phases |
| D | Suspicious | - Signal only weakly observed OR<br>- Signal is likely not attributable to a seismic event OR<br>- (HF/2.4/VF) impossible to pick both Pg and Sg OR<br>- All SF event types are automatically Quality D |

**MQS Event Names**

Events are labelled following the convention S[xxxx][z]; where [xxxx] indicates the InSight mission sol the event begins on (starting from sol 0, the sol InSight landed on Mars), and [z] is a letter that ensures unique names if multiple events occur on a single Sol.

**MQS Phase Picks**

When possible, MQS selects the first arrival times for distinct energy packets. Pick time uncertainties are on the order of seconds if made on the waveform in the time domain; and on the order of 10's of seconds if these are based on a distinctively new signal visible on a spectrogram. Typically, only 1 or 2 energy packets are identified, if any, and are labelled P and S for HF/BB event types, and Pg and Sg for HF, VH and 2.4Hz event types. SF events do not have phase assignments.

For each event, MQS also includes 'picks' for event start and end and start and end of noise windows with similar noise as observed during the event. Since there are often numerous glitches occurring within the event time window, we also include 'clean' P and S coda windows when possible. Depending on the event type, the time at which peak amplitudes occur with bandpassed signals are also indicated. MQS is tracking all significant glitches within the event start and end window, but these are not currently available.

Pick uncertainties are assigned for P/S/Pg/Sg, but not for any other pick type.

**Distances, Back Azimuth and Location**

*BB/LF events:* If multiple picks are assigned as P and S phases, a distance is estimated using a priori Martian velocity models. The back-azimuth can be estimated using the first phase arrival, assumed to be P, if polarization is present. A single station location estimate can be made by combining the distance and back-azimuths. This approach is outlined in Clinton et al, 2018 and Böse et al, 2017. Distance / back-azimuth / location uncertainties are included in the catalogue.

*HF, VF and 2.4Hz events*: If multiple picks are assigned as Pg and Sg phases a preliminary distance estimate is made using a simple crustal velocity model with Vs=2.3km/s, Vp/Vs=1.73. There are no back-azimuth estimates for any of these events. Location uncertainty is provided as +/-(0.75xDistance).

*SF events*: there is currently no distance or back-azimuth estimates for these events

Giardini et al. (2020) introduces a procedure that provides aligned epicentral distances for good quality events for most event types that is based on similarity of waveform envelopes. These aligned distances are currently not provided in this catalogue version.

***Only a handful of events in the catalogue include a computed latitude/longitude location. A location is required for a valid QuakeML origin, so by default all other events are assigned the location of the lander, at lat=4.5024, long=135.6234.***

**Depth**
Depths are not included in the V2 catalogue (like for V1).

**Magnitude**
Magnitude scales for Martian events are developed in Böse et al, 2018 and have been revised since landing. These are described in Giardini et al (2020). Magnitude scales using P and S ($m_{\mathrm{b}}^{\mathrm{Ma}}$ and $m_{\mathrm{b}S}^{\mathrm{Ma}}$) body phase amplitudes, 2.4Hz resonance ($M_{2.4\mathrm{Hz}}^{\mathrm{Ma}}$) amplitudes, and spectral fitting ($M_{\mathrm{FB}}^{\mathrm{Ma}}$) are included, when possible. The preferred magnitude is $M_{\mathrm{FB}}^{\mathrm{Ma}}$ when available.

Only events with distance estimates are assigned magnitudes. Magnitude uncertainty is currently not populated.

For a handful of LF and BB events, magnitudes are computed using 'aligned' epicentral distances (see Giardini et al, 2020) that are not included in the catalogue. The list of these events, with the aligned distances in degrees, are: S0167a (150°); S0254b (77.7°); S0167b (77°); S0152a (66.7°); S0234c (65°); S0183a (45°); S0320b (45°); S0205a (42°). In a future version of the catalogue, distances derived using both phases and alignments will be added, and magnitudes using both distance methods will be available, when available.

**Catalogue Completeness:**
MQS makes every effort to identify all events within the catalogue time period. The exception is the SF events. These have only recently been identified, and at this time, only a handful of events from June / July are included in the catalogue. We expect to provide a more complete event list for this type of event in the next catalogue release.

## Catalogue Overview

| | **Total** | A | B | C | D |
|---|---|---|---|---|---|
| **Total** | 383 | 2 | 68 | 141 | 172 |
| LF | 23 | 1 | 3 | 5 | 14 |
| BB | 11 | 1 | 4 | 2 | 4 |
| HF | 41 | - | 25 | 14 | 2 |
| 2.4Hz | 273 | - | 30 | 112 | 131 |
| VF | 18 | - | 6 | 8 | 4 |
| SF | 17 | - | - | - | 17 |

## Changelog

- The SF event type is added to the catalogue .
- Minor changes to the definition of the event type and quality (C,D) have been introduced.
- For location of *HF, VF and 2.4Hz* events, the Vp / VS have been modified, leading to minor changes in distances (and magnitude) for these events.
- Error in V1 catalogue fixed in V2: Uncertainties associated with P, S, Pg and Sg phase picks were missing in V1. They are now added.
- MQS periodically reviews the events in the catalogue to ensure consistency for event type and quality. Hence a handful of events may have differences between V1 and V2, with reassigned Event type, quality, picks and distances.

## References

Böse, M. et al. 2017. A probabilistic framework for single-station location of seismicity on Earth and Mars. Phys. Earth Planet. Inter. 262. doi:10.1016/j.pepi.2016.11.003

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