

Mars Seismic Catalogue, InSight Mission; V3 2020-07-01.

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Overview

This is the description of V3 of the Marsquake Catalogue for InSight, and includes the Martian seismic events as recorded by InSight up to March 31, 2020 / Sol 478 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*) and V2 (*InSight Marsquake Service, 2020b*).

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
- Marsquake Name

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

A detailed description of this V3 version of the catalogue, as well as key event presentations and MQS procedures, will be provided in *Clinton et al (in preparation)*. A first description and interpretation of the marsquake catalogue V1 is provided at *Giardini et al, 2020*, which also includes details of the routine MQS operations as well as marsquake identification and characterisation. 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 V2 and V3 (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: event energy generally at long period	
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: event energy generally at high frequency	
High Frequency (HF)	energy in 3 components predominantly at 2.4Hz and above. 'Predominantly' indicates some energy below 2.4-Hz is possible.

2.4Hz	energy in 3 components centered around 2.4Hz resonance, with very limited excitation above or below. (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.
Other Signals	
Super High Frequency (SF)	very short duration high frequency events that do not include energy at 2.4~Hz or below. Typically between 5-10Hz, 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 (implies possibility both distance and back azimuth are determined, and hence location)
B	Medium	Multiple clear and identifiable phases but no polarisation (implies possibility of distance but no location) OR polarisation, but not enough clear phase picks for a distance estimate
C	Low	Signal is clearly observed but phase picking is challenging: <ul style="list-style-type: none"> - (HF/2.4Hz/VF) Pg and Sg pickable, but speculative OR large uncertainty OR low SNR - (LF/BB) no clear phases can be identified OR only a single phase is clearly identifiable OR multiple phases are identifiable, but no clear picks can be attributed to P and S phases - (SF) peak signal amplitude of data with 7.9Hz filter is above 2×10^{-9} m/s
D	Suspicious	<ul style="list-style-type: none"> - Signal only weakly observed OR - Signal may not attributable to a seismic event OR - (HF/2.4/VF) impossible to pick both Pg and Sg OR - (SF) peak signal amplitude of data with 7.9Hz filter is below 2×10^{-9} m/s

MQS Event Names

Events belonging to the Low and High frequency families 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.

SF events are assigned the prefix letter T instead of S in order to clearly separate them from other events: T[xxxx][z].

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 distinct 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. In rare cases, when phases cannot be clearly attributed to P or S, they are labelled x1, x2, x3... 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/x? 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 $V_s=2.3\text{km/s}$, $V_p/V_s=1.73$. There are no back-azimuth estimates for any of these events. Location uncertainty is provided as $\pm(0.75 \times \text{Distance})$.

SF events: there are 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 LF/BB events for most event types that is based on similarity of waveform envelopes. These aligned distances are now provided in this catalogue version, and all new LF/BB events in V3 have been considered. 25 events have aligned distances, which are preferred when available. Double origins are available for 10 events, where both aligned and S-P distances are available (S0105a, S0173a, S0183a, S0185a, S0189a, S0235b, S0290b, S0325a, S0407a, S0409d). Aligned distances have a methodID attribute of *smi:insight.mqs/algorithms/distance/aligned* in their corresponding DistanceComputation element, whereas S-P distances have a methodID attribute of *smi:insight.mqs/algorithms/distance/S-P_phases*.

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 $\text{lat}=4.5024$, $\text{long}=135.6234$.

Depth

Depths are not included in the V3 catalogue (unchanged from V1/2).

Magnitude

Magnitude scales for Martian events are developed in **Böse et al (2018)**. These are described in **Giardini et al (2020)**, though they are revised in this catalogue version. The new relationships will be described in **Böse et al (in preparation)**. Magnitude scales using P and S (m_b^{Ma} and m_{bS}^{Ma}) body phase amplitudes, 2.4Hz resonance ($M_{2.4\text{Hz}}^{\text{Ma}}$) amplitudes, and spectral fitting ($M_{\text{FB}}^{\text{Ma}}$) are included, when possible. The preferred magnitude is $M_{\text{FB}}^{\text{Ma}}$ when available.

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

For the LF and BB events that have both multiple origins based on ‘aligned’ and S-P distance estimates, magnitudes are provided for each distance.

Catalogue Completeness:

MQS makes every effort to identify all events within the catalogue time period. SF events have been systematically added to the database since Sol 189 using an automated detection algorithm documented in **Dahmen et al, submitted**.

Catalogue Overview

Marsquake type events (events from Low and High Frequency Families)

	Total	A	B	C	D
Total	465	2	85	183	195
LF	28	1	6	11	10
BB	13	1	1	9	2
HF	52	-	31	18	3
2.4Hz	349	-	38	137	174
VF	23	-	9	8	6

Super high frequency events

	Total	A	B	C	D
SF	712	-	-	129	583

Overview of Major Changes from V2 to V3

- Beginning from Sol 189, a systematic approach has been applied to include all SF events to the catalogue, according to **Dahmen et al (submitted)**.
- Aligned distances following **Giardini et al (2020)** are added to the catalogue for LF/BB events. Aligned distances are now preferred.
- Separate major reviews of the Low Frequency and High Frequency event families have occurred in an effort to achieve consistency across the catalogue.

For the Low Frequency family, this included

- o Re-classification of 2 event types (S0133a and S0185a moved from LF to BB)
- o Re-classification of some event qualities.
- o For origins with S-P distances, ensuring all origin times are consistent with the estimated epicentral distance (fixing an error in previous catalogue versions)
- o Re-assignment of some phase time and uncertainties, including re-assigning phase names, removing and/or adding picks.

For the High Frequency family, this included

- o Systematic review of event type and quality, leading to some reassignments, according to **van Driel et al (submitted)**.
- o For origins with Sg-Pg distances, ensuring all origin times are consistent with the estimated epicentral distance (fixing an error in previous catalogue versions)
- Magnitude relations have been modified according to **Böse et al (in preparation)**.
- Minor changes to the definition of the event type and quality (C,D) have been introduced, chiefly for the SF event type.

References

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