Mars Seismic Catalogue, InSight Mission; V6 2021-04-01.

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Overview

This is the description of version 6 (V6) of the Marsquake Catalogue for InSight, which includes the Martian seismic events up to December 31, 2020 / Sol 746 as identified by the InSight Marsquake Service (MQS). The catalogue files are available at the IPGP (datacenter.ipgp.fr) and IRIS (ds.iris.edu) data centres. New versions of the catalogue are released in sync with updated waveform data releases.

The citation for the catalogue is:
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This catalogue is an update of the previous catalogue versions V1-5 (***InSight Marsquake Service, 2020a, b, c, d; 2021a***).

The catalogue is provided in two files, both in QuakeML format. One is in standard QuakeML 1.2 format, known as "basic event description" (BED). Thus, it validates against the QuakeML 1.2 schema. The second includes two Mars-specific extensions in separate XML namespaces. These include basic information for single station locations and Mars catalogue management, which is not available in the standard BED format. The additional information includes: distance, back azimuth, Mars event type, Mars event quality, and Marsquake name. The XML schema of the Mars-specific extension has been provided with the V4 release and is still valid for the current release. Documentation of the schema will be provided in a subsequent release.

A detailed description of the V3 version of the catalogue, as well as key event presentations and MQS procedures, is provided at ***Clinton et al (2021)***. All MQS conventions for this version, V6, are unchanged from this publication. Key details are also repeated here.

The previous catalogue release (V5) has been accompanied with a software release. This is the latest software release, and the same codes have been used to compile the current version (V6). The code of the basic GUI used by MQS, developed by ETH and gempa GmbH, is available at zenodo.org (doi:10.5281/zenodo.4033316). This software provides the framework for data review, Marsquake detection, identification and quantification. The code to compute distances of events, given P and S picks, is available at zenodo.org (doi:10.5281/zenodo.4302312). Alongside future catalogue releases, updates to this GUI, as well additional software critical for MQS operations, will continue to be released.

An overview of the major changes between V5 and V6 (this version) is at the end of this document; detailed changelogs for each of the two catalogue files are provided separately.

MQS conventions

MQS assigns an event type and quality to each seismic event. 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 2.4Hz 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 than vertical energy at higher frequencies.
Other Signals	
Super High Frequency (SF)	very short duration high frequency events that do not include energy at 2.4Hz 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: - (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 BP filter above $2x10^{-9}$m/s
D	Suspicious	- Signal only weakly observed OR - Signal may not be 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 $2x10^{-9}$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

A/ Onset 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, VF 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 currently not provided in the catalogue.

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

B/ Aligned Phase Picks

In V6, aligned phase picks based on ***Giardini et al. (2020)*** are available. There is no change from V5.

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 based on ***Böse et al., 2016***, and outlined in ***Clinton et al, 2021.*** 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) (van Driel et al, 2021)

SF events: there are currently no distance or back-azimuth estimates for these events (Dahmen et al, 2020).

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 provided in the catalogue since V3, and new events were added in V4. For this method, V6 is unchanged from V5 and V4 since only one quality D event of type LF was added. 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*.
Aligned distances are given as the preferred distance when they are available.

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 V6 catalogue (unchanged from previous catalogues).

Magnitude
V6 uses magnitude relations as described in ***Clinton et al. (2021)*** for V3. The preferred magnitude is M_{FB}^{Ma} when available. Magnitude scales using P and S (m_b^{Ma} and m_{bS}^{Ma}) body phase amplitudes, 2.4Hz resonance) amplitudes, and spectral fitting) are included, when possible.

Only events with distance estimates are assigned magnitudes. Magnitude uncertainty is currently not populated. For the Low Frequency family BB events that have both multiple origins based on 'aligned' and S-P distance estimates, magnitudes are provided for each distance estimate.

V6 Catalogue Overview

Marsquake type events (Number in brackets is the increase since V5)

	Total	A	B	C	D
Total	492 (+7)	2	89 (+1)	192 (+2)	209 (+4)
LF	30 (+1)	1	6	11	12 (+1)
BB	14	1	2	9	2
HF	56 (+2)	-	32	18	6 (+2)
2.4Hz	362 (+1)	-	38	141	183 (+1)
VF	30 (+3)	-	11 (+1)	13 (+2)	6

Super high frequency events

	Total	A	B	C	D
SF	794 (+5)	-	-	169 (+4)	625 (+1)

Overview of Major Changes from V5 to V6

In V5, the *preferredMagnitudeID* element was missing for events S0235c and S0474a. This has been fixed in V6.

References

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